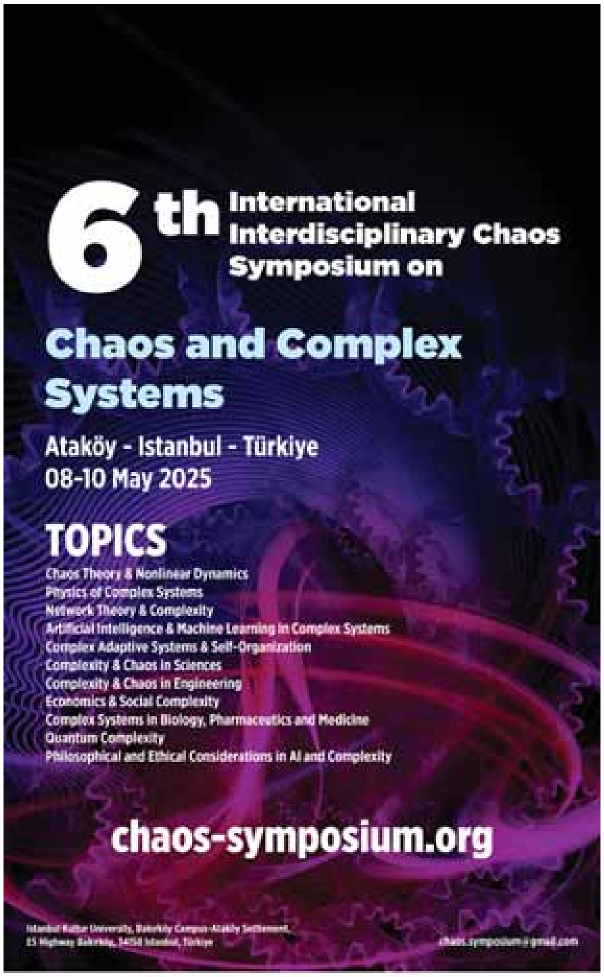

SCCS2025
PROGRAMME
AND
BOOK OF ABSTRACTS

Editors:
Gözde KUZU ULUÇAY
Kerem YÜCESAN
Erdem YÜCESAN

6th International Interdisciplinary Chaos Symposium on

CHAOS and COMPLEX SYSTEMS

İstanbul, Türkiye

May 08-10, 2025

International Interdisciplinary Chaos Symposium (6: 2025: İstanbul)

6th International Interdisciplinary Chaos Symposium on Chaos and Complex Systems: 8-10 May 2025, İstanbul

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I. Chaos; II. Complex

Invited Talks

Plenary Talks

- **Prof. Dr. Jürgen KURTHS**
  Institute of Physics, Humboldt-Universität zu Berlin, Berlin, Germany
  Editor of Chaos: An Interdisciplinary Journal of Nonlinear Science (AIP)
- **Prof. Dr. Klaus MAINZER**
  President of the European Academy of Sciences and Arts, Salzburg, Austria
  TUM Senior Excellence Faculty, Technische Universität München, Munich, Germany
  Carl Friedrich von Weizsäcker-Center, Eberhard-Karls-Universität Tübingen, Germany

Keynote Talks

- **Prof. Dr. Fernando CORINTO**
  Department of Electronics and Telecommunications, Politecnico di Torino, Torino, Italy
- **Prof. Dr. Costas DEMETZOS**
  Demetzos Lab, Department of Pharmaceutics, University of Athens, Athens, Greece
  Ordinary Member of the European Academy of Sciences and Arts, Salzburg, Austria
  President of the Hellenic Pharmaceutical Society
- **Prof. Dr. Claudio MIRASSO**
  Institute for Cross-Disciplinary Physics and Complex Systems-IFISC, Universitat de les Illes Balears, Palma de Mallorca, Spain

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SCCS2025
6th INTERNATIONAL INTERDISCIPLINARY CHAOS SYMPOSIUM ON CHAOS AND COMPLEX SYSTEMS

MAY 08 – 10, 2025

ISTANBUL KULTUR UNIVERSITY
BAKIRKOY CAMPUS – ATAKOY SETTLEMENT, ISTANBUL, TÜRKİYE

P R O G R A M M E

THURSDAY, MAY 08, 2025

08:00-14:00	***REGISTRATION***	
09:00-13:00	***WORKSHOP*** ***(Computer Lab.: 4C08101214)*** **AI-Driven Timeseries Forecasting Based on Nonlinear Dynamics** **Prof. Dr. Michael HANIAS** Democritus University of Thrace – Greece	
	MAIN SESSION ***(ONDER OZTUNALI CONFERENCE HALL)***	
14:00-14:15	***OPENING CEREMONY*** **Prof. Dr. Fadime ÜNEY YÜKSEKTEPE, Rector** Istanbul Kültür University – Türkiye **Prof. Dr. Tamer KOÇEL (E), Honorary Chair** Istanbul Kültür University – Türkiye **Prof. Dr. Stavros G. STAVRINIDES, Co-Chair** Democritus University of Thrace – Greece	
14:15-15:15	***PLENARY SPEAKER*** Chairperson: Stavros G. STAVRINIDES **Stability of Power Grids Concerning Strong Perturbations** **Prof. Dr. Jürgen KURTHS** Institute of Physics, Humboldt-Universität zu Berlin, Berlin, Germany Editor of Chaos: An Interdisciplinary Journal of Nonlinear Science (AIP)	
15:15-15:45	***To capture the memories of the symposium, we will be taking a group photo.*** ***We kindly ask all participants to join us and be present on time.*** ***COFFEE BREAK***	
	SESSION A ***(ONDER OZTUNALI CONFERENCE HALL)***	***SESSION B*** ***(ZA1 LECTURE HALL)***
PARALLEL SESSIONS *15:45-16:45*	Chairperson: Oğuz SÖNMEZOĞLU (15:45-16:05) (ID-35) **Locally Active Memristors Mimic Neuron Behavior** *A. Ascoli, A.S. Demirkol, I. Messaris, V. Ntinas, D. Prousalis, F. Corinto, M. Bonnin, M. Gilli, P.P. Civalleri, S. Slesazeck, T. Mikolajick, R. Tetzlaff, and L.O. Chua* (16:05-16:25) (ID-74) **Phase Transition in a Nonlinear Quantum Protocol** *T. Kiss, A. Portik and O. Kálmán* (16:25-16:45) (ID-27) **Finite-Time Synchronization of Complex Valued Fractional Order Memristive Neural Networks Via LMI Approach** *M. Otkel, S.Ganesan and A. Kashkynbayev*	Chairperson: Sawsan BAŞPINAR (15:45-16:05) (ID-72) **Measuring the Dynamic Complexity of Self-Organized Systems** *E. Brandao, R. Emoneta ,M. Sebban, and J.P. Colombier* (16:05-16:25) (ID-41) **Bounded Detection of Connectivity in Experimental Networks Under Chaotic Regimes, and Related Spectral Properties** *M. Cescato, A. Perinelli, R. Iuppa, L. Ricci* (16:25-16:45) (ID-90) **Complex Switching Dynamics in Pendula Networks** *P. Ebrahimzadeha, M. Schiek, Y. Maistrenko*
16:45-17:15	***COFFEE BREAK***	

	MAIN SESSION ***(ONDER OZTUNALI CONFERENCE HALL)***
17:15-18:15	***KEYNOTE SPEAKER*** Chairperson: Mehmet ÖZER **Energy-Efficient Edge Computing Systems: Advances in Devices, Networks, and Applications** **Prof. Dr. Fernando CORINTO** Department of Electronics and Telecommunications, Politecnico di Torino, Torino, Italy
18:15-20:30	***WELCOME COCKTAIL (B1 FLOOR)*** *The welcome cocktail will be held at the university, providing an opportunity to meet colleagues in a convivial atmosphere.*

FRIDAY, MAY 09, 2025		
	MAIN SESSION ***(ONDER OZTUNALI CONFERENCE HALL)***	
09:30-10:30	***PLENARY SPEAKER*** Chairperson: Stavros G. STAVRINIDES **From Complex Systems and Nonlinear Dynamics to AI** **Prof. Dr. Klaus MAINZER** President of the European Academy of Sciences and Arts, Salzburg, Austria TUM Senior Excellence Faculty, Technische Universität München, Munich, Germany Carl Friedrich von Weizsäcker-Center, Eberhard-Karls-Universität Tübingen, Germany	
10:30-11:00	***COFFEE BREAK***	
	SESSION A ***(ONDER OZTUNALI CONFERENCE HALL)***	***SPECIAL SESSION*** ***(ZA1 LECTURE HALL)***
PARALLEL SESSIONS *11:00-12:00*	Chairperson: Hacer Neyir TEKELİ (11:00-11:20) (ID-43) **Barred Galaxies as Complex Dynamical Systems - How Order and Chaos Shape Galactic Bars** *P.A. Patsis* (11:20-11:40) (ID-12) **Stability Analysis in the CR3BP with Albedo and Oblateness Effects** *Ashok Kumar Pala and Bhupendra Jangid* (11:40-12:00) (ID-25) **Examination of the Transportation Abilities of Mean Motion Resonances in the Main Asteroid Belt** *M. Kováčová*	Chairperson: Tolga ARUL (11:00-11:20) (ID-88) **An Examination of the Effects of Thermal Stress on the Complexity of Flash Pufs** *A. Babu, Z. Guan, T. Arul,b, N. Mexis, N. A. Anagnostopoulos* (11:20-11:40) (ID-65) **Logistic Map Compact Model for Image Encryption** *R. Cavazzana, J. Secco, A. Ascoli and F. Corinto* (11:40-12:00) (ID-55) **Complex Thermal Dynamics of Smart Cylindrical Shells with Nanoparticles** *Ahmad Farrokhian, Reza Kolahchi*
	MAIN SESSION ***(ONDER OZTUNALI CONFERENCE HALL)***	
12:00-13:00	***KEYNOTE SPEAKER*** Chairperson: Mehmet ÖZER **Dynamics, Synchronization, and Computation: Bridging Lasers and Neurons** **Prof. Dr. Claudio MIRASSO** Institute for Cross-Disciplinary Physics and Complex Systems-IFISC, Universitat de les Illes Balears, Palma de Mallorca, Spain	
13:00-14:00	***LUNCH (VIP Restaurant, please note that the lunch service will begin at 13:00. We kindly ask that you do not proceed to the restaurant before this time. Thank you for your understanding and cooperation.)***	

	SESSION A ***(ONDER OZTUNALI CONFERENCE HALL)***	***SPECIAL SESSION*** ***(ZA1 LECTURE HALL)***
PARALLEL SESSIONS *14:00-15:00*	Chairperson: Sadiye Oya IŞIKÇI (14:00-14:20) (ID-84) **Social Dynamics and Thermodynamics Mobility on Urban Networks** *F. Panichi, G. Turchetti* (14:20-14:40) (ID-58) **Chaotic Dynamics and Forecasting in Monthly Rate Employment Time Series: The Case of Australia, Colombia, Greece, Turkey and USA** *I. Malamou, S.G. Stavrinides, L. Magafas, M. Ozer, M.P. Hanias* (14:40-15:00)	Chairperson: Jamal Odysseas MAAITA (14:00-14:20) (ID-16) **Lagrangian Descriptors: A Powerful Method for Investigating the Behavior and Chaoticity of Dynamical Systems** *Ch. Skokos* (14:20-14:40) (ID-101X) **Comparing Different Chaotic Indices in Systems with Maximal Lyapunov Characteristic Exponent Very Close to Zero** *Jamal Odysseas Maaita* (14:40-15:00) (ID-89) **A Novel Mixing Method for 3D Tumbler Mixers** *M. S. Demirsoy, Y. El Naser, S. Mahmud, F. Mohammed, C. Freeman, M. Kutlu*
15:00-15:30	***COFFEE BREAK***	
PARALLEL SESSIONS *15:30-16:30*	Chairperson: Nur BUDAKLIER (15:30-15:50) (ID-24) **The Grand Strategy is Dead, Long Live the Grand Strategy! An AI-driven Framework for Grand Strategic Decision-Making** *Caesar Wu, Rajkumar Buyya, and Pascal Bouvry* (15:50-16:10) (ID-19) **Panel Data Analysis of the Relationship Between Renewable Energy Share and the Human Development Index** *E.Müge Çetiner and Kerem Yücesan* (16:10-16:30) (ID-102X) **Chaotic Dynamics in Gold Price Time Series: A Physics-Based Forecasting Approach** *I. Bacharnikos, E. Tsatsou, L. Magafas, M. Ozer, M.P. Hanias* *(16:30-16:50) (ID-75)* **High Energy of Recurrent Chaotic Trajectories in a Time-Dependent Potential Well Model** *M.S. Palmero, F.H. Graciano, E.D. Leonel, J.A. de Oliveira*	Chairperson: Jamal Odysseas MAAITA (15:30-15:50) (ID-22) **Hopf Bifurcation in a Van Der Pol Perturbation** *E. Meletlidou, Ch. Volos and G. Stouboulos* (15:50-16:10) (ID-28) **Chaos and Thermalization in Dipole Chains** *J. Pablo Salas and Manuel Iñarrea* (16:10-16:30) (ID-100X) **Novel Experiments on the Liesegang Phenomenon** *Joana Haidar and Rabih Sultan* (16:30-16:50) (ID-47) **Investigating Hallucinations in Artificial Intelligence-Based Forecasting of Chaotic Time Series** *Ergun Eray Akkaya*
16:50-18:00	***POSTER SESSION (B1 FLOOR)*** Chairperson: Tülay ÖLMEZ P01 (ID-6) **Modeling Women's Employment Rates in Turkey and BRICS Countries Using Fractal Analysis** *Erdem Yücesan and Ece Şen* P02 (ID-15) **Sentiment Analysis on Biblical Texts** *D. Oustadakis, I. Tsimperidis, K. Toparlakis and G.A. Papakostas* P03 (ID-17) **Exploring the Assessment of Student Attentıon and Engagement Through Computer Vision** *E. Kytidou, T. Tsikriki, E. Vrochidou, D. Oustadakis and G.A. Papakostas* P04 (ID-18) **Information–Theoretic Analysis of Visibility Graph Properties of seismic point processes** *Luciano Telesca* P05 (ID-21) **Modeling Student Behavior and Predicting Academic Performance Using LMS Data** *F. Kurtuluş and M.T. Bilişik* P06 (ID-29) **Mapping Competency Development Through Student Interaction Networks in a Web 3.0 Learning Environment** *A.G. Uluçay and M.T. Bilişik* P07 (ID-30) **Chaotic Coverage Path Planning Using Lorenz Chaotic Circuit** *Maria S. Papadopoulou* P08 (ID-33) **Optimizing the Recurrence Threshold for Time Series Analysis in Dynamical Systems** *Á. Herczeg and B. Sándor* P09 (ID-37) **Modeling Chaotic Behavior in the Lorenz System with Layered Polynomial Neural Networks** *David Garrido González, Nathaniel Saura, Peter Beyer and Sadruddin Benkadda* P10 (ID-40) **The Relationship Between the Logistics Performance Index and Economic Growth: A Panel Data-Based Analysis for the Period 2007–2023** *Erdem Yücesan and Esra Çimen Atlı*	

	P11 (ID-57) **Bridging Surface Complexity and Neural Network Loss Landscapes: A Unified Metrological Perspective** *A. Kondi, E.-M. Papia and V. Constantoudis* P12 (ID-61) **Evaluation of the Perspective of Hotel Managers in Crisis Management: An Application in Five Star Hotels in Istanbul** *H. Arslan and P. Tuna Arslan* P14 (ID-71) **Stochastic Geometry of Fibrous Networks: Connectivity and Spatial** *E.-M. Papia, A. Kondi, and V. Constantoudis* P15 (ID-76) **Competency Development of University Students Under Vuca Conditions: A Qualitative Study Based on the Complex Systems Approach** *G. Kuzu Uluçay and Ç. Kaya* P16 (ID-77) **Fractals and the Mandelbrot Set Via Iterated Quantum Protocols** *P. Téglás, O. Kálmán, A. Portik and T. Kiss* P17 (ID-79) **Unraveling the Chaotic Nature of U.S. River Streamflow: Complexity and Prediction Horizons** *D.T. Mihailović and S. Malinović-Milićević* P19 (ID-86) **Average Vector Field Method and Caputo Fractional Derivative Definition for Linear Space Fractional Differential Equations** *Neslihan Fatma Er* P20 (ID-87) **Quantum Artificial Intelligence: An Innovation within the Innovation** *P. Tzounakis, I. Antoniou, M.P. Hanias and S.G. Stavrinides* P21 (ID-95) **Organic Electrochemical Transistors with Memristive behavior for textile knitted circuits** *E.P. Louris, S.G. Stavrinides and D.H.Tassis* P22 (ID-103X) **Bounded Confidence Opinion Dynamics Based on the Independent Cascade Model on Signed Social Networks** *A. Tsakonas, I. Antoniou, S.G. Stavrinides* P23 (ID-104X) **Applying Social Network Analysis to the Eurovision Song Contest** *M. Kotrotsiou, I. Antoniou, S.G. Stavrinides, M.P. Hanias*
18:00-21:00	***OFFICIAL DINNER (B1 FLOOR)*** *The official dinner will take place at a university venue, offering an opportunity to network and enjoy a pleasant evening with colleagues.* ***(Please note that the official dinner is exclusively for registered guests.)***

SATURDAY, MAY 10, 2025	
	MAIN SESSION ***(ONDER OZTUNALI CONFERENCE HALL)***
09:30-10:30	***KEYNOTE SPEAKER*** Chairperson: Michael HANIAS **Complexity of Pharmaceutics** **Prof. Dr. Costas DEMETZOS** Demetzos Lab, Department of Pharmaceutics, University of Athens, Athens Greece Ordinary Member of the European Academy of Sciences and Arts, Salzburg, Austria President of the Hellenic Pharmaceutical Society
10:30-11:00	***COFFEE BREAK***

	ROUND TABLE ***(ONDER OZTUNALI CONFERENCE HALL)***	***SESSION B*** ***(ZA1 LECTURE HALL)***
PARALLEL SESSIONS *11:00-13:00*	Chairperson: Michael HANIAS (11:00-11:20) (ID-105X) **Network Analysis of Chaotic Dynamics and Stability of Liposomal Nanosystems** *Michael Hanias* (11:20-11:40) (ID-51) **Translating Mitochondrial Complexity into Drug Delivery Design** *Ioannis Tsichlis* (11:40-12:00) (ID-91) **Complexity in Industrial Scale of Innovative Medicines and Dietary Supplements** *Nikolaos Naziris* (12:00-12:20) (ID-50) **Application of Machine Learning in Drug Development Process** *Chrystalla Protopapa* (12:20-12:40) (ID-106X) **The European Regulation on Artificial Intelligence** *Katerina Demetzou* (12:40-13:00) **Sponsor's corporate presentation talk** *Nikolaos Naziris* **Brief Discussion**	Chairperson: Barış SAFRAN (11:00-11:20) (ID-59) **Semidefinite Programming Certificates for Synchronization of Kuramoto Oscillators on Arcs** *A. Gökçen, S. Şahin, M. Kudeyt, S. Tripathi, Ö. Karabacak* (11:20-11:40) (ID-20) **Solving the Hamiltonian Path Problem Using Transiently Chaotic Dynamical Systems** *L. Mihály, M. Ercsey-Ravasz, and B. Molnár* (11:40-12:00) (ID-69) **From Stability to Chaos: Fixed Points and Bifurcations in the Framework of Discrete Dynamical Systems** *D. Sekman and V. Karakaya* (12:00-12:20) (ID-83) **Chaos Detection in Dynamical Systems: Lyapunov and Reversibility Error Invariants** *G. Turchetti, G. Gradoni, C. E. Montanari, F. Panichi, J. Qrich* (12:20-12:40) (ID-68) **Picard-Type Hybrid Fixed Point Iterative Approaches for the Control of Chaos in Discrete Dynamical Systems** *D. Sekman* (12:40-13:00) (ID-36) **Modeling Nonlinear Dynamics of Burgers' Equation with an Interpretable Data-Driven Reduced Order Model** *Sadruddin Benkadda, David Garrido González, Nathaniel Saura and Peter Beyer*
13:00-14:00	***LUNCH (VIP Restaurant, please note that the lunch service will begin at 13:00. We kindly ask that you do not proceed to the restaurant before this time. Thank you for your understanding and cooperation.)***	
	SESSION A ***(ONDER OZTUNALI CONFERENCE HALL)***	***SESSION B*** ***(ZA1 LECTURE HALL)***
PARALLEL SESSIONS *14:00-15:00*	Chairperson: Mehmet ÖZER (14:00-14:20) (ID-34) **Reframing Biomedical Science: Toward a Top-Down, Complexity-Driven Model of Health and Disease** *Alejandro Espinosa Sosa* (14:20-14:40) (ID-64) **Colon Cancer Disease Diagnosis based on CNN and Machine Learning** *Fawzi Khalifa, Salim Khalifa, Levent Cuhacı, Javad Rahebi* (14:40-15:00) (ID-93) **Investigations of The Interactions of Glu-Glu-Arg, Glu-Pro-Arg and Pro-Arg-Pro Tripeptides That Have Anti-Cancer Properties, With Human Serum Albumin by Molecular Docking Studies** *Gozde Yilmaz, Sefa Celik, Aysen E. Ozel , Sevim Akyuz*	Chairperson: Kerem YÜCESAN (14:00-14:20) (ID-52) **Dual Lyapunov Based Synchronization Control of Rossler System** *A. Gökçen, S. Şahin, M. Kudeyt, S. Tripathi, Ö. Karabacak* (14:20-14:40) (ID-32) **Benchmarking Polynomial Chaos Techniques for Uncertainty Propagation in the Lorenz System: Intrusive vs Non-Intrusive Polynomial Chaos** *A. García Gutiérrez, C. Rubio, F. Parra and J.A Mayo* (14:40-15:00) (ID-73) **Which Strategy Configurations Enable Turkish Firms to Reach Peaks on the Fitness Landscape?** *A.Kadir Varoğlu, Yavuz Ercil and Berkay Tarım*
15:00-15:15	***CLOSING CEREMONY (ONDER OZTUNALI CONFERENCE HALL)*** **Prof. Dr. Mehmet ÖZER, Co-Chair** Istanbul Kültür University – Türkiye **Prof. Dr. Stavros G. STAVRINIDES, Co-Chair** Democritus University of Thrace – Greece	

CHAOTIC TRACES OF LIGHT

Photography Exhibition – “The Aesthetics of Chance”

Nesil TÜRKYILMAZ

“Chaotic Traces of Light” aims to reveal the hidden patterns embedded within nature. This selection of 20 photographs by Nesil Türkyılmaz, created using long exposure techniques, invites viewers into the dynamic realm of chaos, complexity, and chance.

Each photograph unveils how a small initial motion can evolve over time into unpredictable and mesmerizing patterns. These light traces serve as visual representations of an underlying order within disorder, of structure born out of randomness, and of a universe in constant flux.

The varying speeds and durations used to capture each image emphasize the role of chance in the creation of these luminous forms. Here, light is not merely a visual element—it is also a record of energy, motion, and the passage of a singular moment in time.

The works explore the nature of complex systems and the aesthetic dimensions of chaos theory, both physically and metaphorically.

The audience is invited to uncover the hidden systems behind seemingly random movements and to view the universal dynamics through the traces that light leaves behind in time.

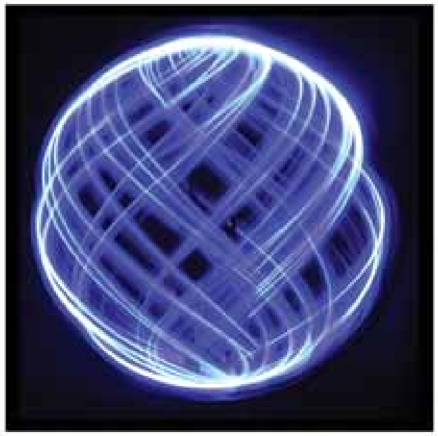
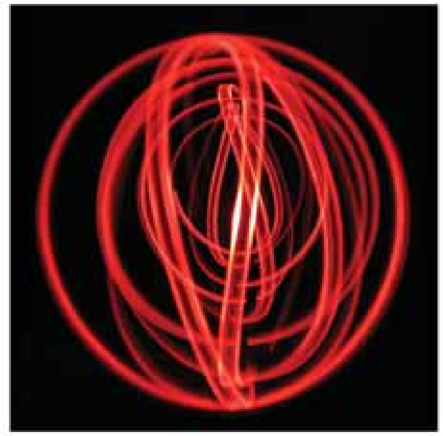
Number of Works: 20 Photographs

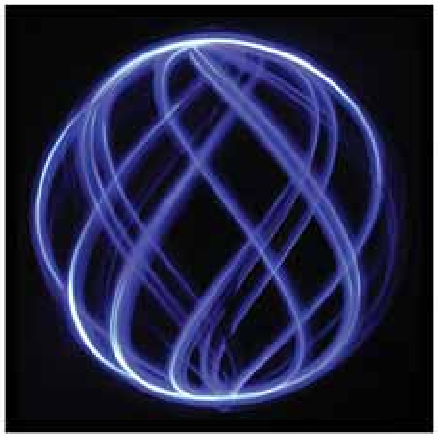
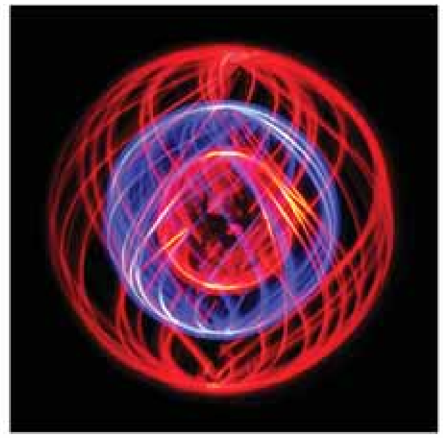
Artist: Nesil Türkyılmaz

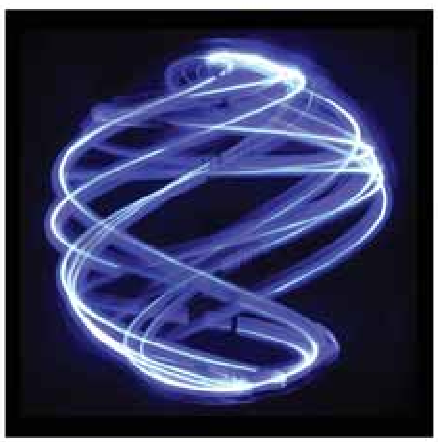
Venue: T.C. Istanbul Kültür University – Ataköy Campus

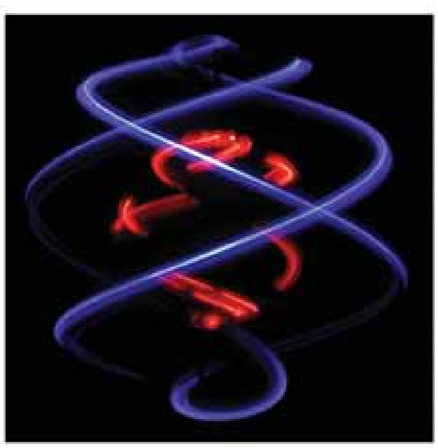
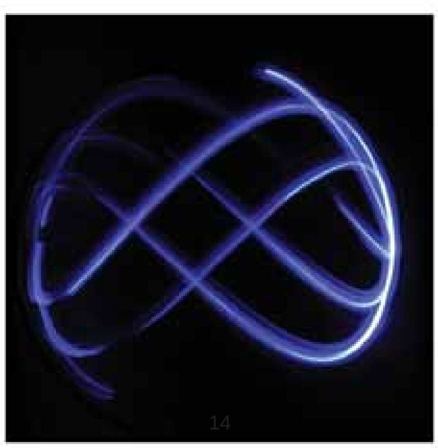
Dates: May 8–10, 2025

NESİL TÜRKYILMAZ
CHAOTIC TRACES OF LIGHT
Photography Exhibition – “The Aesthetics of Chance”




Exhibition

Chaos and Complex Systems: Dynamic Reflections of Art

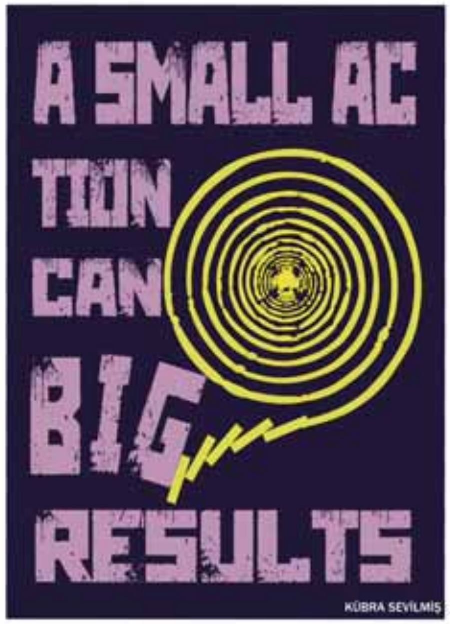
The chaos and complexity hidden in the depths of nature have long inspired not only scientists but also artists. This exhibition explores how art, as a mirror of the universe's intricate structures, transforms its aesthetic quest into a visual language that reflects the fundamental mechanisms of nature—capturing the shared vibrations of science and art.

Complex systems span a wide range—from fractal formations to non-linear dynamic processes. As in nature, the unique rhythm, unpredictable flow, and multi-layered structures of these systems are echoed in the artworks presented. Chaotic systems, which show how minute initial differences can lead to significant long-term effects, serve as both subject and method for the artists, who aim to make these delicate balances, surprising transformations, and hidden orders visible. Much like the endlessly repeating patterns of fractals, the referenced works reflect the universe from both macro and micro perspectives.

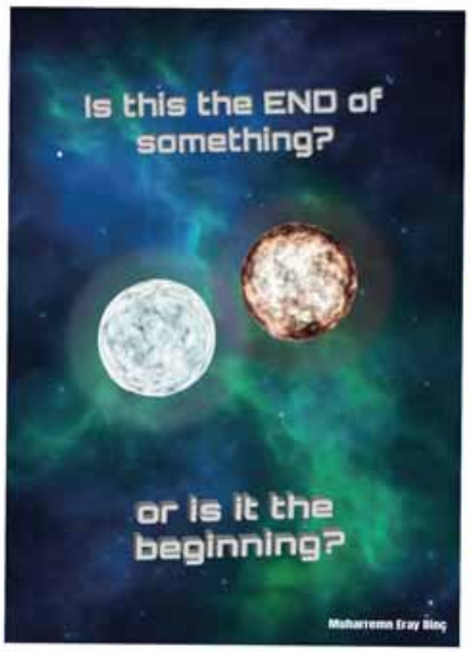
This exhibition reveals the hidden order within disorder, the intricate patterns emerging from simple rules, and the artistic expressions of dynamic systems through diverse approaches and techniques. It embodies the convergence of multidisciplinary structure and aesthetics.

Curated by **Asist. Prof. Dr. Emin Sansarcı** and **Lecturer Ilgın Özer**, the exhibition titled *Chaos and Complex Systems: Dynamic Reflections of Art* presents a selection of works that trace the visual language of chaos and complexity embedded in nature's deep structure. The exhibition features 20 digitally rendered print posters, 13 manually crafted poster works, and 5 motion teasers. It was held at Istanbul Kültür University Ataköy Campus on 9–10 May 2025 as part of the 6th International Symposium on Chaos and Complex Systems.


KAOS
her şeyin temeli
IRMAK KURTULUŞ


A SMALL AC
TION
CAN
BIG
RESULTS
KÜBRA SEVİLMİŞ

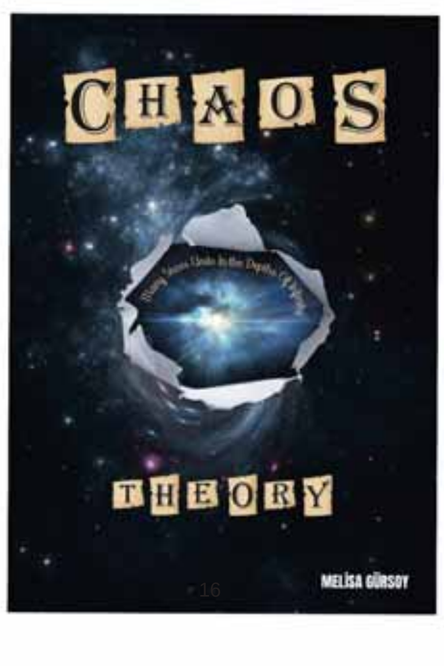

İREMSU KENÇ
Bir adım sonsuz kaos

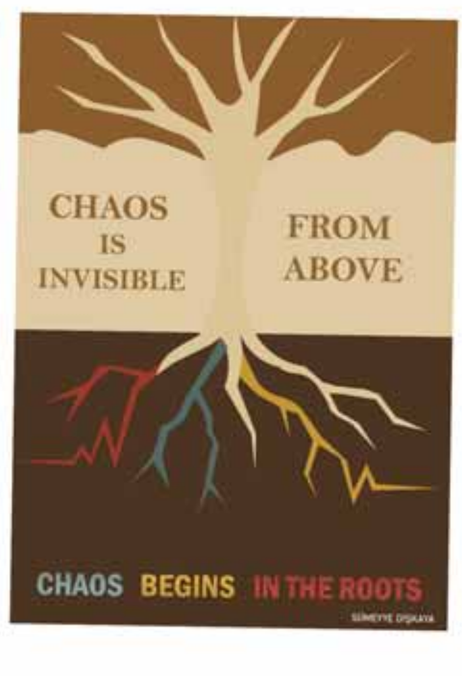

Is this the END of
something?
or is it the
beginning?
Muharrem Eray Binç


NOTHING IS A COINCIDENCE
METEHAN SEZEN


KAOS
EVRENİN GİZLİ DİLİ


THE QUIET
VIOLENCE OF
CHAOS


CHAOS
THEORY
MELİSA GÜRSOY


CHAOS
IS
INVISIBLE
FROM
ABOVE
CHAOS BEGINS IN THE ROOTS


Emre Acar

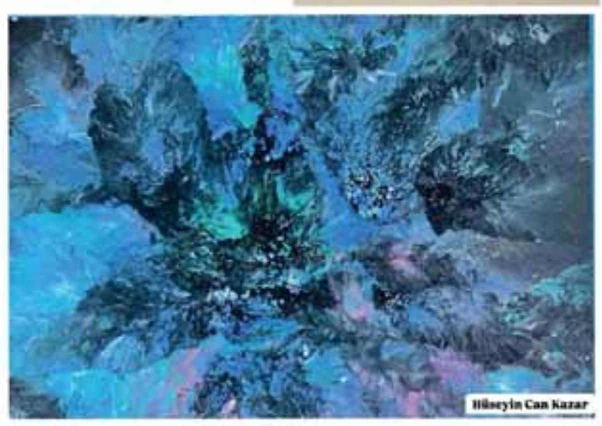

Sude Naz Atila


Emine Ravza Karamuk


Yağmur Şahinbaş


Hüseyin Can Kazar

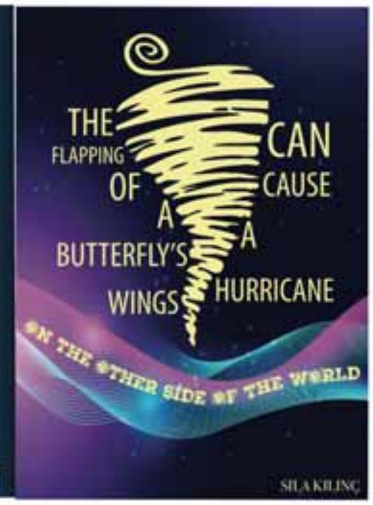

Hilal YASAK

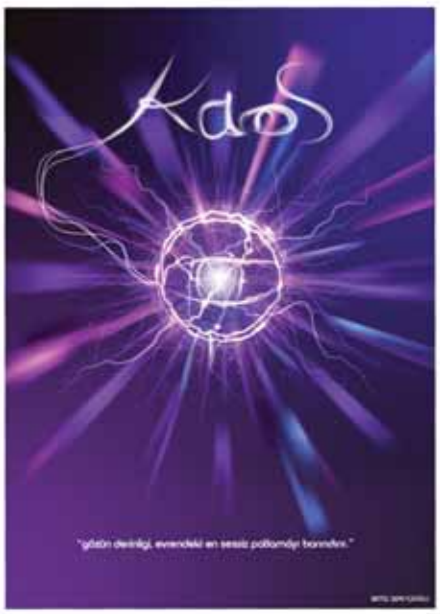

Hüseyin Can Kazar


DÜZENSİZLİKTEKİ
GİZLİ
DÜZEN

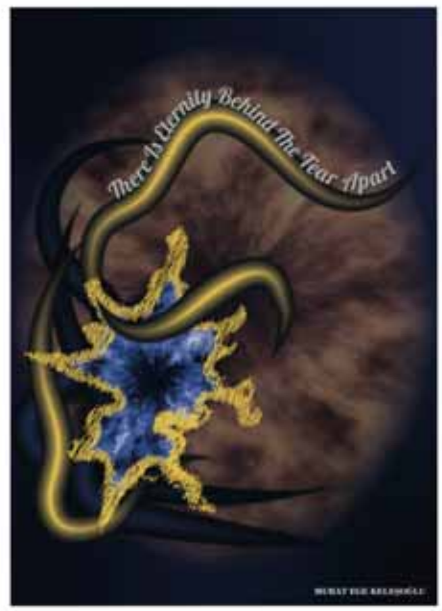

DÖNGÜ
TAMAMLANMADI.
ZAMAN
PARÇALANDI.
BİZ,
BELİRSİZLİĞİN İÇİNDE
KAYBOLDUK

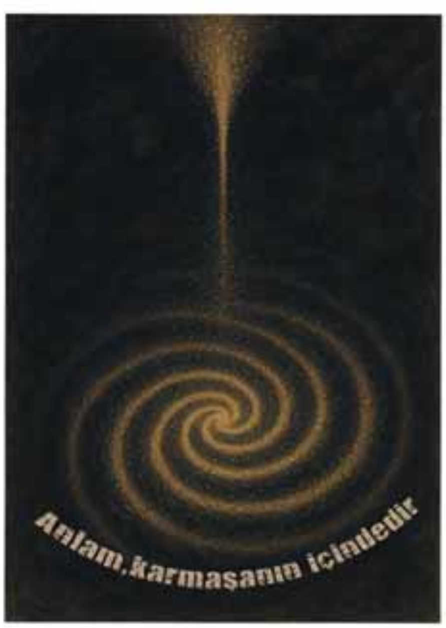

CHAOS IS THE BUILDING
BLOCK OF EVOLUTION
İREM ÜNSALAN


THE
FLAPPING
OF
A
BUTTERFLY'S
WINGS
CAN
CAUSE
A
HURRICANE
ON THE OTHER SIDE OF THE WORLD
SILA KILINÇ


Kaos


GERÇEK DENGE KAOSTAN DOĞAR
İKBAL ÇOLAK


There Is Eternity Behind The Tear Apart


Anlam, karmaşanın içindedir


EVRENSEL DÜZENIN
GÖRÜNMEYEN HALI


RİTİM
Zaman iniş
çıkışlarla ibarettir.

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KEYNOTE TALKS

High Energy of Recurrent Chaotic Trajectories in a Time-Dependent Potential Well Model

M.S. Palmero[a,b*], F.H. Graciano[c,d], E.D. Leonel[c], J.A. de Oliveira[c,e]
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[d]Instituto Federal do Sul de Minas Gerais (IFSULDEMINAS), Pouso Alegre, Brazil
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Chaos Detection in Dynamical Systems: Lyapunov and Reversibility Error Invariants

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[c]University of Surrey, UK

Social Dynamics and Thermodynamics Mobility on Urban Networks

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[b]Centro Systemi Complessi di Senigallia CSC

An Examınatıon of the Effects of Thermal Stress on the Complexıty of Flash Pufs

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POSTER PRESENTATIONS

Plenary Talk

Stability of Power Grids Concerning Strong Perturbations

Jürgen Kurths

Institute of Physics, Humboldt-Universität zu Berlin, Berlin, Germany
Editor of Chaos: An Interdisciplinary Journal of Nonlinear Science (AIP)

The infrastructure, in particular power grids, of our modern society is efficient but also sensitive concerning strong perturbations, as attacks on the cybersystem or extreme climate events. Power grids are strongly ongoing a transition to distributed renewable energy sources. The desynchronization of a few of those would likely result in a substantial blackout. Thus, the dynamical stability of the wanted synchronous state has become a leading topic in power grid research, in particular for rather strong perturbations where traditional linearization-based concepts are not appropriate. To treat this problem, we discuss the concept of basin stability covering strong perturbations and identify most vulnerable motifs in power grids. Considering the vulnerability of power grids against extreme wind loads and, consequently, increasing its robustness to withstand these events is of great importance. Here, we combine a detailed model of the climatic drivers of extreme events, and a cascadable model of the transmission network to provide a holistic co-evolution model to explore wind-induced failures of transmission lines in the Texan electrical network. The proposed modelling approach could be a tool so far missing to effectively strengthen power grids against future hurricane or typhoon risks even under limited knowledge.

Plenary Talk

From Complex Systems and Nonlinear Dynamics to AI

Klaus Mainzer

President of the European Academy of Sciences and Arts, Salzburg, Austria
TUM Senior Excellence Faculty, Technische Universität München, Munich, Germany
Carl Friedrich von Weizsäcker-Center, Eberhard-Karls-Universität Tübingen, Germany

According to several prominent authors, a main part of 21st century science will be on complexity research. The intuitive idea is that global patterns and structures emerge from locally interacting elements like atoms in laser beams, molecules in chemical reactions, proteins in cells, cells in organs, neurons in brains, etc. (Mainzer 2007). Complex pattern formation has been reported from many disciplines (e.g., physics, chemistry, biology, brain research). The causes of complex pattern formation have been analyzed from various perspectives such as, e.g., Schrödinger's order from disorder (1948), Prigogine's dissipative structure (1980), Haken's synergetics (1983), Langton's edge of chaos (1990), brain research (Hodgkin/Huxley 1952), and memristive cellular networks (Mainzer/Chua 2013).

Recently, these results of complexity research have become important for machine learning of AI systems. Instead of complex pattern formation in nature, complex pattern recognition of artificial neural networks (ANN) is considered which is modeled in statistical learning theory. But ANN-systems are only simulated on digital computers with von-Neumann architectures which run into severe problems of energy consumption (von-Neumann bottleneck) in the future - in contrast to the highly energetically efficient biological brains. Therefore, neuromorphic systems with more brain-orientated computing such as memristive and photonic networks should be considered also for hardware realization. The research target is not only sustainable computing and AI with respect to energy and environment, but also to overcome mathematical limits of digital computing (Mainzer 2024).

References: K. Mainzer, Thinking in Complexity, Springer: Berlin 5th edition 2007; K. Mainzer/L. Chua, Local Activity Principle. The Cause of Complexity, World Scientific Singapore 2013; K. Mainzer, Artificial Intelligence. When do Machines take over? Springer: Berlin 2nd edition 2019; K. Mainzer, Artificial Intelligence of Neuromorphic Systems. From Digital, Analogue, Quantum, and Brain-Orientated Computing to Hybrid AI, World Scientific Singapore 2024.

Keynote Talk

Energy-Efficient Edge Computing Systems: Advances in Devices, Networks, and Applications

Fernando Corinto

Department of Electronics and Telecommunications, Politecnico di Torino, Torino, Italy

The use of Artificial Intelligence (AI) is driving a significant shift in history. It is estimated that about 85 terawatt/hours of electricity -more than the annual consumption of most small nations - will be utilized by AI technology in 2027. As the need for computing power increases, so does the possible environmental impact. Conventional computing, including both hardware platforms and computer languages, seems to be close to its physical limits in terms of speed and data density. Among the recent disruptive technologies, two-terminal metal/insulator/metal device able to change their resistance upon electric stimulation, i.e. the memristor (memory-resistor), has attracted the researchers' attention as a fundamental nanoscale computation element. Networks of interconnected and interacting memristive units can develop cooperative and collective dynamics, and self-organizing spatio-temporal phenomena for alternative computing schemes overpassing the limits of conventional digital and Boolean computation.

The talk aims to provide an overview of a novel comprehensive framework to develop Edge Computing Systems based on memristor devices that exploit the device physics and the interaction functionality. These devices and systems will provide a foundational skeleton for unique exploration of nonlinear circuit theory, computing architectures, and energy-efficient artificial intelligence.

Keynote Talk

Dynamics, Synchronization, and Computation: Bridging Lasers and Neurons

Claudio Mirasso

Institute for Cross-Disciplinary Physics and Complex Systems-IFISC, Universitat de les Illes Balears, Palma de Mallorca, Spain

The exploration of complex systems frequently yields surprising findings. This arises from the inherent nature of these systems: their dynamics are shaped not solely by individual elements within the system, but predominantly by the interactions among these elements. These interactions can give rise to emergent phenomena that may manifest in systems initially perceived as disparate. In this presentation, I will deepen into the dynamic behavior of delay-coupled semiconductor laser systems and show how the gained insights can be extended to the examination of neural circuits within the brain, particularly shedding light on the feature binding problem.

Going back from neurons to photonics, I will explore how the fundamental properties of neurons with dendritic compartments can inspire innovative approaches to pattern recognition tasks. By using simple optical components, we can design systems that mimic neural computation, opening the door to more efficient and scalable solutions in areas such as machine learning, signal processing, and artificial intelligence. These insights exemplify the bidirectional exchange between neuroscience and photonics, highlighting their potential to mutually advance each other.

Keynote Talk

Complexity of Pharmaceutics

Costas Demetzos

Demetzos Lab, Department of Pharmaceutics, University of Athens, Athens Greece
Ordinary Member of the European Academy of Sciences and Arts, Salzburg, Austria
President of the Hellenic Pharmaceutical Society

Pharmaceutics involves the science of designing and developing drug formulations used to treat patient diseases. It includes the processes of drug absorption, distribution, metabolism, and excretion, collectively known as the ADME profile. Nanotechnology, which works at the atomic and molecular scale, plays a key role in developing nanocarriers defined as advanced excipients used to deliver drugs to target tissues. These nanocarriers are complex systems, and their behavior must be studied carefully, especially during batch-to-batch production of nanotherapeutics. The complexity of nanocarriers, due to their self-assembly and dynamic processes, creates challenges for both the pharmaceutical industry and academia.A sustainable regulatory system is needed to manage this complexity and support the approval process of innovative nanomedicines. Scientific efforts must address the non-linear and chaotic behaviors that arise during development, requiring advanced methods for accurate characterization. Additionally, principles of information and entropy are essential for understanding and controlling these complex systems. Artificial Intelligence (AI) can play a significant role in expanding the scientific and regulatory processes to evaluate the unique properties of nanoparticles, overcoming existing barriers in the approval process of nanomedicines.

Stability Analysis in the CR3BP with Albedo and Oblateness Effects

Ashok Kumar Pal[a*] and Bhupendra Jangid[a,]

[a]*Manipal University Jaipur, Department of Mathematics & Statistics, Jaipur, Rajasthan, India*
[*] *Corresponding author: ashokpalism@gmail.com;ashok.pal@jaipur.manipal.edu*

Abstract

This study investigates the effects of the radiation pressure, albedo effect, and oblateness in the circular restricted three-body problem (CR3BP). The equilibrium points are computed, and their stability is analyzed. The Zero-velocity curves are examined to determine regions of possible motion for an infinitesimal object. The results reveal that equilibrium points are more significantly influenced by radiation pressure than the albedo effect. Additionally, the linear stability of collinear equilibrium points is assessed using the radiation and albedo parameters. It is found that all collinear equilibrium points are unstable, whereas non-collinear equilibrium points remain stable.

Keywords: Circular restricted three-body problem (CR3BP); Radiation pressure; Albedo effect; Oblateness.

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LAGRANGIAN DESCRIPTORS: A POWERFUL METHOD FOR INVESTIGATING THE BEHAVIOR AND CHAOTICITY OF DYNAMICAL SYSTEMS

Ch. Skokos

Nonlinear Dynamics and Chaos Group, Department of Mathematics and Applied Mathematics,
University of Cape Town, Cape Town, South Africa
Email: haris.skokos@gmail.com and haris.skokos@uct.ac.za

Extended abstract

We discuss simple and efficient methods for estimating the chaoticity of orbits in conservative dynamical systems, specifically autonomous Hamiltonian systems and area-preserving symplectic maps. These methods are based on calculations of Lagrangian descriptors (LDs) [1, 2] over short time scales. In particular, we explore approaches that use the difference and ratio of LDs between neighboring orbits, as well as a quantity related to the finite-difference second spatial derivative of LDs [3, 4]. We apply these indices to analyze the chaotic or regular nature of orbits in several systems, including the prototypical two-degree-of-freedom Hénon–Heiles system, as well as the two- and four-dimensional standard maps. Our results show that these indicators correctly identify the chaotic or regular behavior of orbits with more than 90% agreement when compared to results from the Smaller Alignment Index (SALI) method of chaos detection [5, 6]. In addition to quantifying chaos, these indicators also provide insights into both the local and global phase space structure of the systems. Our findings demonstrate that LDs can efficiently identify chaos in conservative dynamical systems, without requiring the variational equations (tangent map) of continuous (discrete) time systems, which are necessary for traditional chaos detection methods. Additionally, we present some preliminary results on the application of LDs and related chaos indicators in studying the dynamics of a spacecraft under the influence of Earth's gravitational field, when the planet's oblateness and solar radiation pressure [7] are also considered.

Keywords: Lagrangian descriptors; Chaos; Smaller Alignment Index; Hamiltonian systems; maps.

Acknowledgments

Some of the presented results are based on the research supported in part by the National Research Foundation of South Africa (Ref. Number WABR240401211578).

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Panel Data Analysis of the Relationship Between Renewable Energy Share and the Human Development Index

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Extended Abstract

Climate change, sustainable development, and energy transition have become some of the most crucial policy areas in today's world. The increasing share of renewable energy sources in total energy production plays a critical role in environmental sustainability while also having a significant impact on the economic and social development of countries. This study examines the relationship between the share of renewable energy in total energy production and the Human Development Index (HDI) across multiple countries using panel data analysis.

Existing literature extensively discusses the effects of renewable energy on economic growth, environmental sustainability, and development. HDI serves as a comprehensive development indicator that goes beyond economic growth by incorporating education, health, and living standards. While renewable energy provides economic and environmental advantages, it is also considered a crucial factor in the long-term development processes of countries. However, empirical studies directly examining the relationship between these two variables using panel data techniques remain limited.

This analysis applies panel data analysis to investigate the relationship between the share of renewable energy and the Human Development Index (HDI) across multiple countries.

This study aims to test the hypothesis that the share of renewable energy in total energy production positively influences HDI. Increased use of renewable energy may positively impact human development by promoting environmental sustainability, economic growth, improved health conditions, and expanded educational opportunities. However, given the structural differences and policy variations among countries, the magnitude and direction of the effect may vary.

The findings of this study will provide valuable insights into how energy policies relate to social development. Investments in renewable energy are expected to support not only environmental sustainability but also human development by improving education, health, and living standards. For policymakers, this study is expected to offer important recommendations on how renewable energy policies can be integrated with economic and social development goals.

Keywords: *Human Development Index (HDI), Renewable Energy, Panel Data Analysis, Sustainable Development, Econometric Modeling, Fixed Effects, Random Effects, Generalized Method of Moments (GMM)*

SOLVING THE HAMILTONIAN PATH PROBLEM USING TRANSIENTLY CHAOTIC DYNAMICAL SYSTEMS

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The Hamiltonian path/cycle problem[1] is a classic challenge in graph theory asking whether a path exists within a given graph visiting each vertex exactly once. This seemingly simple question has profound implications across various fields, from network routing and logistics to computational biology and cryptography, due to its NP-completeness[2] and the inherent difficulty in efficiently finding solutions for large graphs. Being NP-complete also makes it possible to be transformed into a Boolean Satisfiability Problem (SAT) in polynomial time[3]. Recently, a novel analog, continuous-time dynamical systems (CTDS) SAT solver was developed, in the form of coupled ordinary differential equations (ODEs), running in continuous variables domain problems and with a one-to-one correspondence between the solutions of the SAT problem and the set of all the attractors of the CTDS[4].

The primary objective of this study was to introduce a metric for quantifying the complexity of such difficult problems like the Hamiltonian path/cycle problem, using the *escape rate*, an invariant of the transient chaos present in the CTDS.

The performance of the system, as well as the various encoding types used to transform the Hamiltonian path problem into SAT form were evaluated using a collection of randomly generated benchmark networks. Furthermore, a series of experiments were conducted to investigate various aspects of the chaotic behavior of the system. The complexity of the problem was studied in relation to the size and density of the benchmark networks.

We show that the *escape rate* shows the hardness of the problem and where the system exhibits a phase transition. We also investigate the change in phase transition and hardness in case of different network topologies, such as the simple Erdos-Renyi random graphs or Barabasi-Albert scale-free networks.

Keywords: Hamiltonian path, Boolean Satisfiability Problem, Continuous-Time Dynamical System, optimization, phase transition

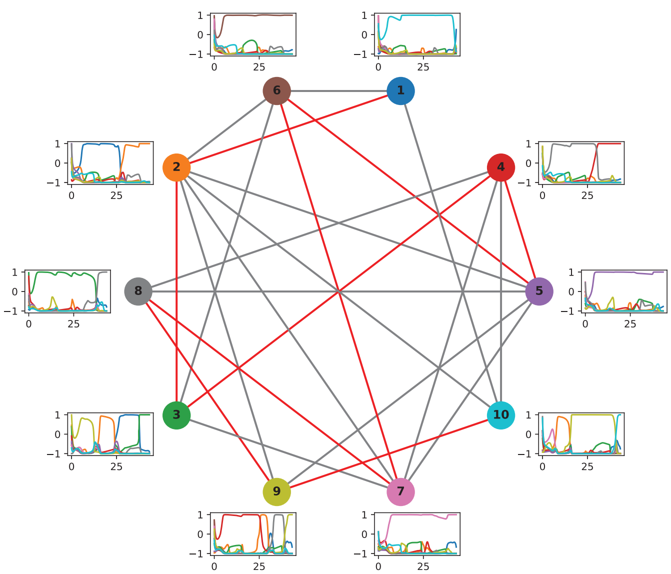

Figure 1. Hamiltonian path obtained in a randomly generated benchmark network with *N=10* nodes and *L=24* links, with a density of *53%*. The fill color of nodes corresponds to the color of the spin variable trajectory (see insets) and number within the nodes represents the sequence number of the node within the Hamiltonian path. The insets show the spin variable trajectories in function of the analog time. The red links represent the connections comprising the Hamiltonian path.

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HOPF BIFURCATION IN A VAN DER POL PERTURBATION

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Abstract

We find limit cycles in a system of two second order differential equations with a van der Pol perturbation. 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 limit cycles continued from the unperturbed system to the perturbed one through the implicit function theorem. This is accomplished with the help of elliptic functions of Jacobi. 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.

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The Grand Strategy is Dead, Long Live the Grand Strategy!

An AI-driven Framework for Grand Strategic Decision-Making

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Abstract

Contemporary grand strategists, political scientists, economists, and business analysts have formulated various theoretical models to interpret historical events and forecast future scenarios for strategic decision-makers (Freedman, 2013). However, many of these models remain predominantly qualitative and narrative led. While they provide some principles, they often lack empirical quantification, thereby limiting their applications for precise decision-making (Allison & Zelikow, 1999) over a long time. Traditional frameworks frequently struggle to adopt modern strategic environments characterized by interconnective, dynamic, nonlinear, and emergent properties (Axelrod & Cohen, 2000). To address this gap, we propose a hierarchical framework underpinning by seven decision layers (See Figure 1), which can be quantified by Artificial Intelligence (AI) and Machine Learning (ML) methods that integrate rule-based learning, deep learning, and reinforcement learning (RL) (Wu et al., 2023). This framework enables us to handle grand strategic challenges across dynamic, nonlinear, and complex issues. We argue that a grand strategy is an emergent phenomenon that emerges from multiple decision layers below and is driven by emotional value rewards from the top (See Figure 1) rather than being confined by three meanings: principle, plans, and behaviors (Silove 2018). Moreover, it transcends the way of balancing means with the end and context (Gaddis 2019). The grand strategy is human intelligence, which can be abstracted from the lower level of detail with tangible activities (Chollet 2019). Philosophically, a grand strategy is a determinism-chaos. Determinism implies that our time, resources, and capability are limited with bounded rationality (Simon, 1990). Chaos means a long-term consequence is unpredictable. Our goal is to create a hierarchical framework that can harness the complexity of the grand strategy through machine learning.

Key Innovations

To test this framework, we identify three variables, economic capacity (E), population (P) size, corporation's competitiveness (C), actuation μ, and a set of parameters $(\alpha, \beta, \gamma, \delta, \epsilon, \vartheta, \eta)$ to model the grand strategy of business development, which is defined by three ordinary differential equations (ODEs) to predict the unpredictable consequence based on the determinism-chaos assumptions. The generalized form of these ODE equations can be formulated as follows:

$$\frac{\partial x}{\partial t} = f(x, t,\ \mu; \beta)$$

Where "f" is dynamics (vector field), "x" is a state, "t" is time, μ is actuation (control), and β is a set of parameters. Subsequently, we generate the EPC strange attractor for an optimal grand strategy (See Figure 2). These ODEs are derived from a combination of Lorenz (Lorenz 1987), Rossler (Rossler 2006), and Chen-Lee (Chen et al. 2008) 's systems (strange attractors) that we can draw isomorphisms between multi-layers of abstraction and atmospheric convection. The goal of finding a strange attractor is to minimize the cost or maximize the reward.

The "x" can emerge from the lower level of state or historical data based on the layers of operations, tactics, tasks, and subtasks. The empirical experiment aims to tune a set of parameters and initial conditions to predict the future state within a strange attractor by ML or long-short term memory (LSTM) algorithm (Haluszczynski, 2021) by adjusting the μ variable. We can also use Hamilton-Jacobi Bellman (HJB) model to fine-tune the μ variable for the future state. Our primary contributions are threefold: 1.) **Integrate** the AI/ML method of a.) Deep Learning for time-series forecasting to model long-term trends and tipping points (Bengio et al., 2021), b.) Reinforcement learning to drive emotional rewards via the HJB value or belief function (Kahneman, 2011) that influences strategic decision (Sutton & Barto, 2018).; c.) Rule-based learning for logical deduction and scenario analysis ensuring coherence in decision pathways (Russell & Norvig, 2020); **2.) Articulate** an innovative hierarchical framework emerged from seven emergent layers (Refer to Figure 1), **3.) Highlight** the primary difference between grand strategy (emergent state) and strategy (state). Ultimately, the grand strategy is a blueprint regarding scale, scope, abstraction, interconnection, long-time horizons, and nonlinear dynamics (Liddell Hart, 1967; Freedman, 2013). Strategy, by contrast, focuses on a master plan within defined boundaries.

Methodological advancements:

The implication of this framework is to synthesize three analytic techniques (Refer to Figure 3): 1.) **Non-Rationality:** Probabilistic pattern recognition to assess the current decision state (Silver et al., 2018), 2.) **Irrationality**: Emotional rewards drive human-like prioritization and decision-making under uncertainty (Kahneman, 2011), 3.) **Rationality:** Logical deductions to ensure consistency, feasibility, and coherence in strategic planning (Russell & Norvig, 2020). We implement the model on high-performance computing (HPC) platform infrastructure to quantify unpredictability and test various scenarios in real-time. It bridges the gap between the qualitative principles and quantitative data by offering a new solution to solve dynamic, nonlinear, and complexity problems. The innovative methodology provides the empirical way for grand strategy and strategy analysis through ML (Goodfellow et al., 2016; Sutton & Barto, 2018).

Philosophical Implications

This research aims to "predict unpredictability" by operationalizing abstract strategic principles—including emergence, creativity, and emotional resonance—into measurable computational frameworks. By bridging these concepts with advancements in AI-driven analysis, this study offers adaptable and scalable solutions in a dynamic, nonlinear, and complex environment (Bostrom, 2014; Tegmark, 2017). The proposed framework amalgamates mindset, dataset, and rule-set. Our approach empowers strategic decision-makers to navigate uncertainty without compromising core values or long-term objectives, fostering resilience in the face of dynamic challenges.

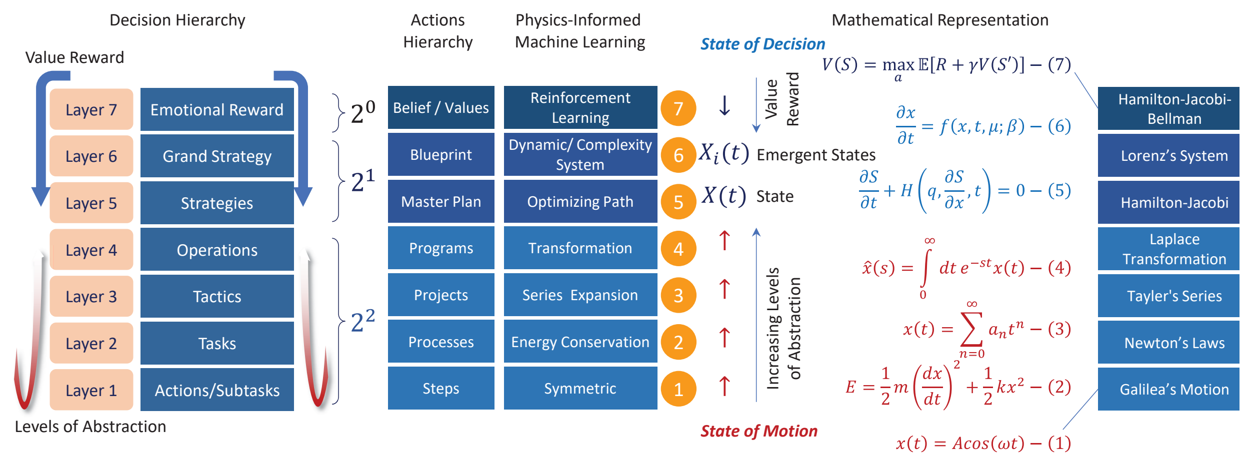

Figure 1: Seven Layers of Strategic Abstraction From an AI/ML Perspective

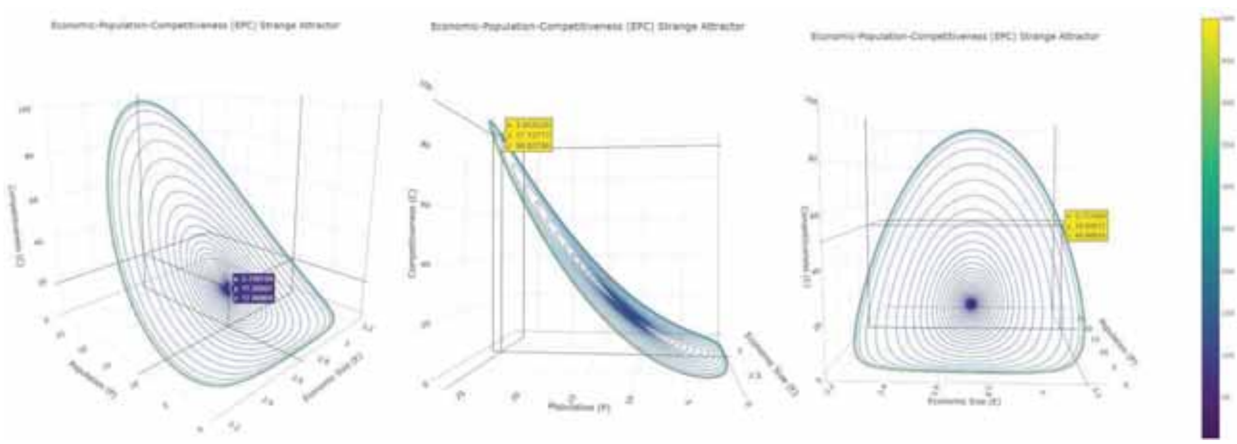

Figure 2: EPC Strange Attractor

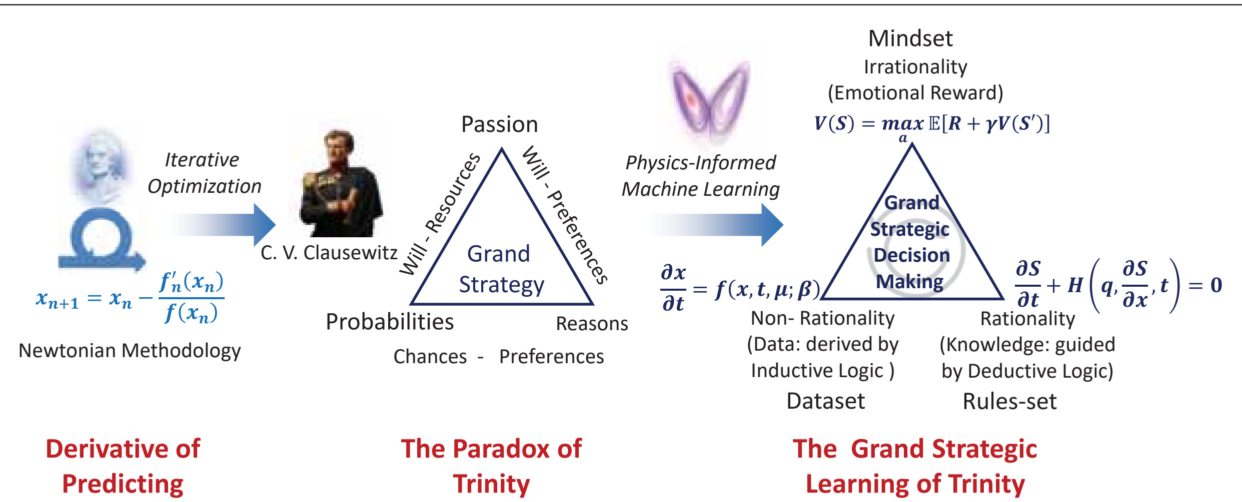

Figure 3: The Grand Strategic Learning of Trinity

Keywords: Grand Strategy, Strategic Decision-making, Computational, Hierarchical Framework, Chaos, Attractor, Complex Abstraction, Emergence, Artificial Intelligence, Physics-Informed Machine learning, Deep Learning, Reinforcement Learning

Acknowledgments

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EXAMINATION OF THE TRANSPORTATION ABILITIES OF MEAN MOTION RESONANCES IN THE MAIN ASTEROID BELT

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Extended abstract

Resonances in the main asteroid belt play a significant role in the dynamical evolution of small bodies. There are several types of resonances and they can be a source of long-term stability (e.g. the Hilda group and Trojan group of asteroids in 3:2 and 1:1 mean motion resonances (MMRs) with Jupiter), but also instability (e.g. missing asteroids in the distribution of asteroids in the main belt - so-called Kirkwood gaps, related to some chaotic MMRs with Jupiter) [1, 2]. These unstable resonances are capable of driving objects into various parts of the Solar System, including the region of near-Earth objects (NEOs).

So far, we have focused on the 5:2 and 3:1 MMRs with Jupiter.The 5:2 MMR is located in the outer part of the main belt and therefore it is believed to be not very efficient in delivering objects to the NEO region [3]. However, it has a non-negligible contribution to NEO population at larger sizes. On the other hand, 3:1 MMR and secular resonance ν_6 in the inner main belt are the largest contributors to the steady-state NEO population regardless of the size [4].

We examine the transportation abilities of these MMRs by tracking the dynamical evolution of test particles that were labeled as unstable based on computed FLI (Fast Lyapunov Indicator - chaos indicator) maps. In total, we selected 20160 particles from 2016 maps (see Fig. 1) and integrated them up to 10 Myr. We are interested in transportation to the NEO region, migration to the Sun, close encounters with the planets, final destinations of the test particles (see Fig. 2), potentially hazardous orbits, and confrontation with the lists of all known potentially hazardous asteroids and meteorites with pedigree.

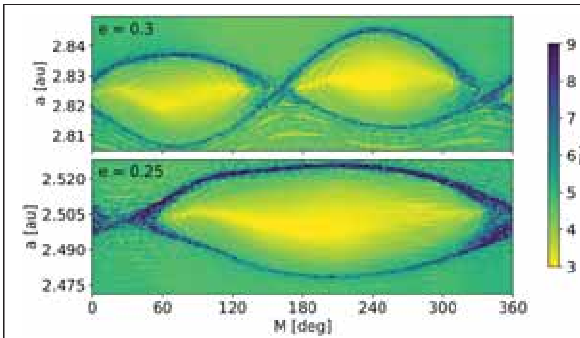

Figure 1: Two examples of our 2016 FLI maps. Top panel represents map of the 5:2 MMR for remaining orbital elements $(e, i, \omega, \Omega) = (0.3, 0°, 0°, 0°)$. Bottom panel is map of the 3:1 MMR for $(e, i, \omega, \Omega) = (0.25, 0°, 0°, 300°)$.

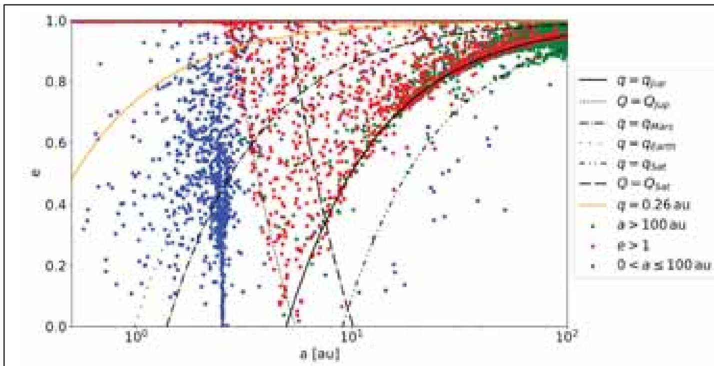

Figure 2: Final distribution of 10080 test particles (selected based on our FLI maps of 3:1 MMR with Jupiter) integrated up to 10 Myr. Red and green dots represent the positions from which the particles were ejected to hyperbolic orbits (red dots) and orbits with a > 100 au (green dots), whereas particles that survived whole simulation for 10 Myr are blue. Black lines represent the sets of (a, e) where a particle can be to have a perihelion (or aphelion) distance equal to the perihelion (or aphelion) distance of one of the planets.

During our simulation dedicated to 5:2 MMR, 99.45% of test particles became NEOs, over 27% of particles migrated to low perihelion distances, (q < 0.005 au), 92.8% of the particles entered the Hill sphere of the Earth and over 97% reached an orbit at which we would classify them as potentially hazardous if they were sufficiently large. More details can be found in our recent paper [5]. The outputs from the simulation dedicated to 3:1 MMR are still being processed. At SCCS 2025, we will compare the obtained results for both resonances.

Keywords: transportation abilities; MMRs; FLI; NEOs.

Acknowledgments

The examination of the 5:2 MMR was supported by the VEGA - the Slovak Grant Agency for Science, grant No. 2/0009/22. The examination of the 3:1 MMR and the opportunity to participate in SCCS 2025 were supported by PostdokGrant APD 0093.

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FINITE-TIME SYNCHRONIZATION OF COMPLEX VALUED FRACTIONAL ORDER MEMRISTIVE NEURAL NETWORKS VIA LMI APPROACH

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Extended abstract

This abstract is a study that investigates the finite-time synchronization of complex valued fractional order memristive neural networks (CVFOMNNs) with time-varying delays. By separating the model into real and imaginary parts, we design a unified sliding mode surface and construct a suitable sliding mode controller to synchronize the drive system and response system trajectories. We prove that the novel super-twisting sliding mode controller forces the error system to reach a sliding surface in a finite time and remain in that surface after reaching. Moreover, we observe that the mentioned super-twisting sliding mode controller significantly reduces the chattering effect which is common in traditional sliding mode controllers. Furthermore, the LMI conditions are formulated to guarantee the finite-time synchronization of the CVFOMNNs with time-varying delays by using a less conservative Lyapunov-Krasovskii functional. Finally, numerical simulations are presented to validate the effectiveness of the theoretical results.

Keywords: Fractional order neural networks; Sliding mode control; Synchronization of neural networks; Linear Matrix Inequality.

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CHAOS AND THERMALIZATION IN DIPOLE CHAINS

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Since the study of Fermi, Pasta, Ulam, and Tsingou (FPUT) in 1953 [1], the relationship between chaos, thermalization, and ergodicity in Hamiltonian Systems (HS) with many degrees of freedom remains a topic with intriguing open questions. Indeed, for an excited chain of nonlinear oscillators, FPUT found that the expected energy equipartition was not reached. Instead, they observed quasiperiodic energy recurrences that, today, we know where due to strong energy localization in the normal mode space (q-breathers) [3–5]. Therefore, the possibility that even in weakly nonlinear HS, thermalization might not occur or be extremely slow due to the spontaneous appearance of local fluctuations is a legitimate point of view.

The goal of this work is to provide more insight on the connection between chaos and thermalization. To this end, we use a linear chain of N identical rigid interacting dipoles. Starting from the ground state (GS), one dipole of the chain is excited with different energies ΔK. The ΔK values are measured in terms of a given energy gap Δ_s (see [3] for more details). The chaoticity of the system is studied with the finite time Lyapunov exponent $\lambda(t)$,

$$\lambda(t) = \frac{1}{t}\log\frac{\|w(t)\|}{\|w(0)\|}$$

where $w(0)$ and $w(t)$ are the deviation vectors of a given trajectory at $t=0$ and $t>0$. To follow the localization of the energy, we use the participation ratio $\Pi(t)$,

$$\Pi(t) = \frac{1}{N-1}\left[\frac{\Delta K^2}{\sum_{k=1}^{N} E_k(t)^2} - 1\right].$$

For each value of ΔK, $\lambda(t)$ and $\Pi(t)$ are determined by averaging over 20 different compatible initial conditions.

The behavior of the (averaged) $\lambda(t)$ can be observed in Fig.1. Indeed, it turns out that $\lambda(t)$ shows always the same behavior: Once the system is excited, there is a transient during which $\lambda(t)$ decreases in time. After the transient, there is a crossover to a plateau, and the corresponding (averaged) maximal Lyapunov exponent λ_1 is reached asymptotically. However, the value of ΔK dictates the strongly varying times scales of the behavior of $\lambda(t)$: A larger excess energy ΔK implies a shorter transient and a larger value of λ_1. This hierarchy indicates an increasingly chaotic dynamics for increasing values of ΔK. When the system is excited with small and medium ΔK values, the decay pattern of the $\lambda(t)$ closely follows the expected power law $\lambda(t) \sim t^{-1}$ of regular orbits. Then, at a given time, $\lambda(t)$ deviates from this regular behavior, and it tends to converge to the corresponding λ_1 value. For the largest excitation energies considered here, there is no trace of regular behavior in the decay of $\lambda(t)$ before the corresponding asymptotic value λ_1 is reached. See [3] for more details.

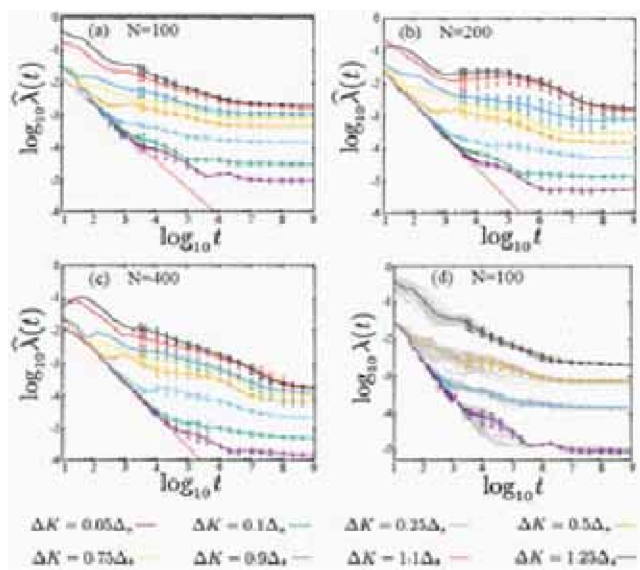

Fig.1

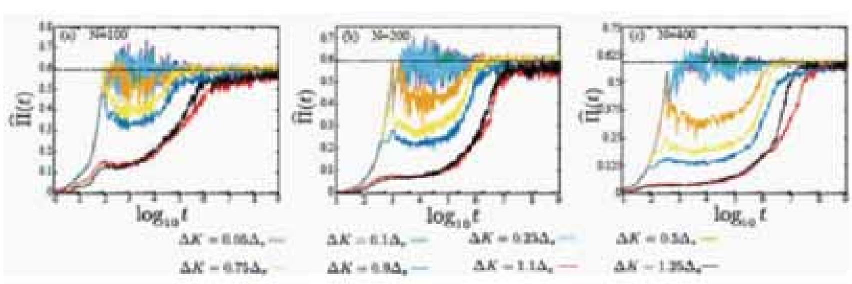

Fig.2

The behavior of the (averaged) $\Pi(t)$ can be observed in Fig.2. For small ΔK values, the (averaged) participation ratio $\Pi(t)$ shows a short transient with a fast spreading of the excitation. After that transient, $\Pi(t)$ fluctuates around a constant value which depends on N. For larger *ΔK* values, the fast initial transient for small *ΔK* values is replaced by a slow increase. Thence, for long times, *Π(t)* eventually reaches an asymptotic value. For the largest *ΔK* values, we find that the extremely long relaxation times of *Π(t)* in comparison with the values of the Lyapunov times $\tau=1/\lambda_1$ are due to chaotic breathers that keep the system far from equipartition. See [3] for more details.

The computed asymptotic values of *Π(t)* indicate a degree of thermalization well below the energy equipartition. Assuming the system is ergodic, we have determined the thermal equilibrium values $<\Pi>$ of *Π(t)* by means of the Boltzmann statistics. We find that the $<\Pi>$ values are in good agreement with the asymptotic values attained by *Π(t)*. Therefore, we can assert that the asymptotic values of *Π(t)* indicate that the system is in thermal equilibrium [3].

Keywords: Chaos, Hamiltonian Systems, Thermalization, Ergodicity.

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Benchmarking Polynomial Chaos Techniques for Uncertainty Propagation in the Lorenz System: Intrusive vs Non-Intrusive Polynomial Chaos

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Extended abstract

Uncertainty quantification (UQ) plays a critical role in the analysis of chaotic dynamical systems, where small perturbations in initial conditions can lead to significantly divergent outcomes. The Lorenz system, characterized by strong nonlinearities and extreme sensitivity to initial conditions, serves as a widely used benchmark for evaluating UQ methodologies [1]. Sampling-based approaches are among the most commonly employed techniques, leveraging random or structured samples to estimate the statistical properties of the system.

This study compares intrusive and non-intrusive Polynomial Chaos Expansion (PCE) with the Monte Carlo (MC) method to assess their effectiveness in propagating uncertainty in chaotic regimes. While Monte Carlo sampling provides an unbiased estimation of statistical moments, it requires an exceptionally large number of simulations to achieve convergence, particularly in high-dimensional settings. In contrast, PCE approximates the stochastic solution using an orthogonal polynomial basis, offering a computationally efficient alternative. The intrusive variant (I-PCE) directly modifies the governing equations to propagate uncertainty, whereas the non-intrusive approach (NI-PCE) relies on sampling, offering greater flexibility at the cost of increased computational expense.

Figure 1 illustrates the evolution of the Lorenz system under uncertainty in initial conditions using I-PCE. The trajectories of the three state variables—x (blue), y (orange), and z (green)—are plotted over time. The wider continuous line represents the mean trajectory predicted by I-PCE, while the finer dashed lines correspond to multiple realizations capturing the uncertainty-induced spread. The figure highlights the nonlinear amplification of initial perturbations, leading to divergence in state trajectories and demonstrating the capability of I-PCE to efficiently capture this behavior.

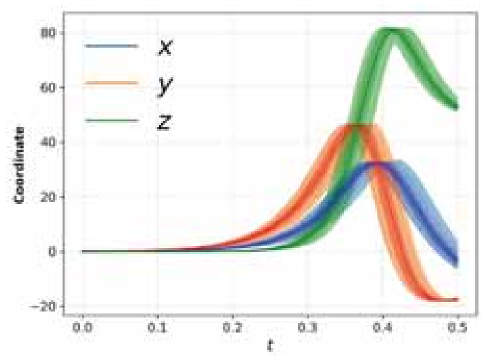

Figure 1 Uncertainty propagation in the Lorenz system using intrusive polynomial chaos

We evaluate these methods based on their ability to approximate key statistical moments (mean, variance, and skewness) and the Bhattacharyya Coefficient, which quantifies deviations from Gaussianity, as functions of time, initial conditions, and approximation order. Our analysis highlights three fundamental challenges [2]:

- Curse of dimensionality: as the number of uncertain parameters increases, NI-PCE and MC demand significantly greater computational resources, while I-PCE may become numerically stiff.
- High-order truncation error: higher-order PCE expansions improve accuracy but introduce numerical instabilities, particularly in chaotic systems where higher-order terms grow rapidly.
- Polynomial-order sensitivity: the accuracy and convergence of PCE methods depend on polynomial order selection, influencing their performance relative to MC simulations.

Our results demonstrate that PCE-based methods converge more rapidly than Monte Carlo but exhibit sensitivity to polynomial order and system nonlinearity. While I-PCE is computationally efficient, it necessitates equation reformulation, whereas NI-PCE offers greater flexibility at the expense of increased computational cost. These findings provide insight into the trade-offs between efficiency and accuracy in UQ for chaotic systems.

Keywords: Intrusive polynomial chaos; UQ; Lorenz system;

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Reframing Biomedical Science: Toward a Top-Down, Complexity-Driven Model of Health and Disease

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Abstract:

Modern biomedical science, while revolutionized by molecular and cellular biology, remains limited by its reductionist foundation. Though Systems Biology and Network Medicine have introduced tools from complexity science, they are often constrained by bottom-up logic that neglects the emergent and nonlinear dynamics of living systems. This work advocates for a paradigm shift: a Top-Down, goal-oriented framework rooted in Complexity Science. We conceptualize health and disease as dynamic attractor states within a high-dimensional physiological landscape, where disease emerges not from isolated molecular defects but from critical transitions in network stability.

We propose to integrate dynamical systems , normal mode analysis, and information theories, to show how system-wide perturbations shape physiological behavior more effectively than single-target interventions. We introduce the concept of Probiotherapeutics—an orderogenic, self-organization-based therapeutic model—and demonstrate its clinical potential through available experimental data in cancer, chronic inflammation, and cardiometabolic conditions. Additionally, we outline how N=1 medicine, informed by patient-specific networks and real-time multiscale data, redefines treatment as a dynamic control problem rather than static molecular targeting.This approach not only enables individualized therapies but also aligns with the inherent adaptability and feedback-driven nature of biological systems.

Keywords: complexity, personalized medicine, systems medicine,

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LOCALLY ACTIVE MEMRISTORS MIMIC NEURON BEHAVIOR

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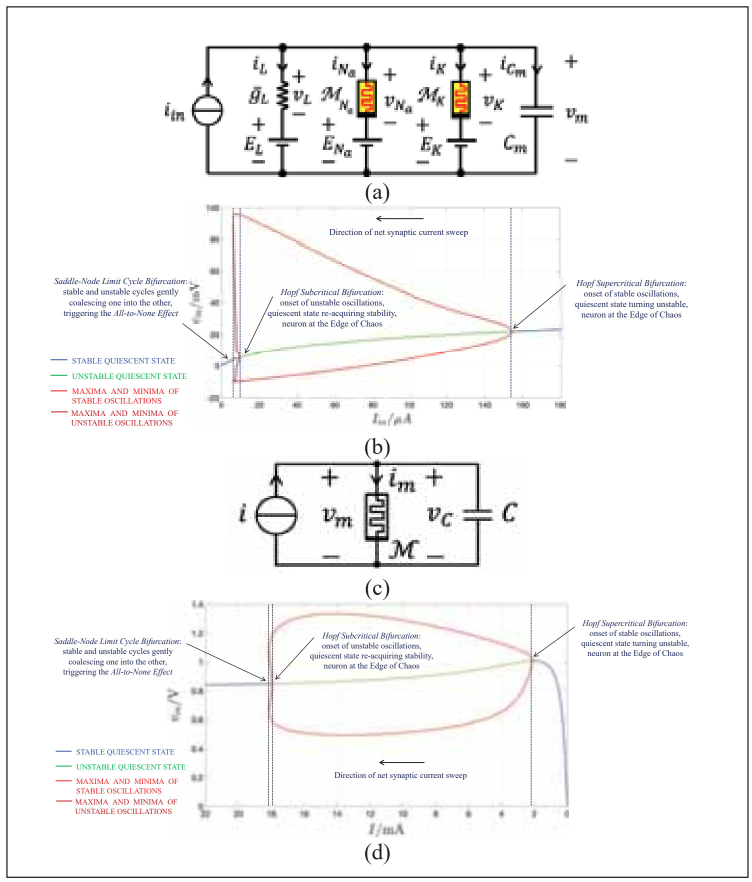
Extended abstract

In their seminal paper from 1952 Hodgkin and Huxley [1] developed a bio-plausible fourth-order circuit-theoretic model (see Fig. 1(a)) capturing the nonlinear dynamics of a biological neuronal axon membrane. Very importantly, under a monotonic decrease in the net synaptic current, exciting the neuronal cell, the interaction between the four dynamical states of the model, embodied in the membrane capacitance voltage, and in the three gating variables, one (two) of which controlling the behavior of the potassium (sodium) ion channel, determines the emergence of three fundamental bifurcations [2], which goven the entire life cycle, from birth to extinction, of a train of electrical voltage spikes, also referred to as *action potentials* in neuroscience. This is visualizable in the classical bifurcation diagram of Fig. 1(b), showing in a compact form all the possible stable and unstable steady-state behaviors for the membrane capacitance voltage for each net synaptic current value.



The first dramatic event, namely a *local Hopf supercritical bifurcation* [3], destabilizes a previously globally asymptotically stable quiescent state for the neuron, with the concurrent generation of infinitesimally-small globally asymptotically stable limit-cycle oscillations across the neuronal membrane.

As the current stimulus undergoes further reductions, both the amplitude and the degree of nonlinearity of the oscillations in the train of action potentials experience a progressive growth. Importantly, at some point the neuron experiences another *local Hopf bifurcation*, yet of subcritical type [3]. This second dramatic event recovers the stability of the quiescent state, yet in a local sense only, while triggering concurrently the birth of infinitesimally-small unstable oscillations around it in the four-dimensional state space. From this point, and for a while, the neuron exhibits an interesting form of *bi-stability*, approaching either of two attractors, the operating point or the large limit cycle, associated to the train of action potentials, depending upon the initial condition. Further monotonic changes in the net synaptic current result in a significant increase in both the amplitude and the degree of nonlinearity of the unstable oscillations, until the occurrence of a third dramatic *global* event, known as *saddle-node limit cycle bifurcation* [2], when the stable and unstable limit cycles gently coalesce one into the other, before disappearing together from the state space, which turns the operating point into a globally asymptotically stable attractor as was the case at the beginning of the input current forward sweep. The saddle-node limit cycle bifurcation determines therefore the well-known *All-to-None* phenomenon [4], inducing the sudden transition of the neuron from a phase, where, for suitable initial conditions, it supports a train of action potentials (the so-called *All effect*), to a phase, where it sits on a quiet state irrespective of the initial conditions (referred to as *None effect*), after transients vanish out.

In this oral talk we present the first and simplest ever-reported analogue electrical circuit [5], which supports all the three fundamental bifurcations, which, as discussed above, characterize the life cycle of a train of action potentials across neuronal cells, according to the predictions of the Hodgkin-Huxley model. Under this perspective, the proposed circuit is referred to as *Hodgkin-Huxley neuristor*. This nanoscale circuit is a bio-inspired second-order relaxation oscillator, consisting in its most elementary form of the parallel combination between a DC current source, a linear capacitor, and a niobium oxide volatile memristor [6] fabricated in house at NaMLab [7] (see Fig. 1(b)).

Importantly, leveraging the extremely-rich locally-active dynamics of the threshold switch [8] from NaMLab enables to reproduce the complex phenomena, appearing in the fourth-order Hodgkin-Huxley neuron model, through half the number of state variables, which, together with other studies [9]-[10] from our group, reveals the potential of a nanodevice of this kind to enable energy-efficient bio-mimetic circuit design.

Recurring to the Theory of Local Activity [11] allows to identify a suitable parameter setting, which, as the current stimulus is subject to a progressive monotonic increase, allows the second-order circuit to enter in and out of two excitability regimes of operation, known as *Edge of Chaos* domains, which are the *conditiones sine quibus non* for the emergence of the two local Hopf bifurcations, which crucially anticipate the global *All-to-None* phenomenon. Under suitable capacitance re-calibration, the three-element cell of Fig. 1(c) would be able to reproduce qualitatively the classical bifurcation diagram of the Hodgkin-Huxley neuron model, while sweeping monotonically the respective input current across some specific range, irrespective of the particular volatile locally-active memristor physical realization, as long as its DC current versus voltage locus admits a S shape [12].

Keywords: Negative Differential Resistance, Local Activity, Edge of Chaos, Neuron, Volatile Memristors

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MODELING NONLINEAR DYNAMICS OF BURGERS' EQUATION WITH AN INTERPRETABLE DATA-DRIVEN REDUCED ORDER MODEL

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Extended abstract

This work explores the application of a novel interpretable data-driven reduced order model for non-linear dynamics (AiPoG). In this study, AiPoG is applied to the Burgers' equation—a fundamental nonlinear partial differential equation that models the interaction between nonlinear advection and diffusion. Traditional projection-based ROMs, such as those constructed using Proper Orthogonal Decomposition (POD) with Galerkin projection, efficiently reduce the dimensionality of complex systems but often struggle to capture nonlinear dynamics and ensure stability. In many cases, this nonlinear behavior is well described by polynomials, which can be challenging to compute, especially in complex geometries. Some approaches leverage artificial intelligence to address this problem [2]. AiPoG overcomes these challenges by integrating machine learning techniques, specifically, our newly developed Layered Polynomial Neural Network (LPNN), to model the temporal evolution of reduced-order coefficients, offering improved generalization and robustness.

The hierarchical structure of LPNNs consists of sequential shallow neural networks designed to model polynomial terms of increasing degree. This layered design enhances the model's expressivity while maintaining interpretability by efficiently constructing polynomial combinations up to any desired degree. The architecture dynamically scales the number of parameters to match the complexity of the target system, avoiding underparameterization. LPNNs provide a scalable and adaptable solution capable of modeling systems with complex interactions and many degrees of freedom by progressively generating polynomial coefficients.

The methodology begins with the spatial discretization of the Burgers' equation and the application of POD to extract dominant spatial modes and their temporal coefficients through Singular Value Decomposition (SVD). In traditional approaches, these modes are used in a Galerkin projection to derive a system of reduced ordinary differential equations (ODEs). However, to address the limitations and improve the accuracy of traditional projection methods, we employ LPNN to compute the coefficients of the polynomials governing the ROM.

Results demonstrate AiPoG's superior performance in modeling Burgers' dynamics compared to traditional ROMs. AiPoG effectively captures both large-scale advection and small-scale diffusion, maintaining a low mean squared error (MSE) over time and accurately reproducing the system's behavior even with reduced modes. Both the linear diffusion term and the nonlinear advection term are learned from data, enabling AiPoG to balance energy transfer across modes.

The AiPoG framework does present some limitations, including increased computational complexity during training as the number of required modes grows and challenges in extending the model to systems with more complex boundary conditions or higher-dimensional domains. Future work will focus on integrating sparsity-promoting techniques to mitigate overfitting and expanding the framework to handle a broader range of nonlinear PDEs.

Keywords: Burgers' Equation; Reduced Order Models; Proper Orthogonal Decomposition; Neural Networks; Nonlinear Dynamics.

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Bounded detection of connectivity in experimental networks under chaotic regimes, and related spectral properties

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Extended abstract

The inference of links, and thus of network structures, in complex systems of interacting nodes is a fundamental issue in experimental science, routinely addressed via linear and nonlinear techniques that are applied to recorded time series [1, 2, 3]. The detection of a link, however, becomes challenging when the system's dynamics lacks well-defined spectral features, such as characteristic frequencies of periodic regimes, as is most notably the case in the presence of chaos [4].

To experimentally investigate in a controlled environment the issue of detecting links in chaotic systems, we used a novel, versatile platform based on electronic elementary units that are connected together to provide scalable networks with arbitrary topology. Each elementary unit relies on an electronic analog circuit aimed at the implementation of the Burridge–Knopoff model [5, 6]. The model, originally conceived to mimic an earthquake fault via an array of elastically-coupled massive blocks subject to nonlinear friction, consists of a network of stick-slip oscillators subject to strong diffusive coupling, and was proven to exhibit chaotic dynamics both numerically and experimentally [6].

In this contribution we present the investigation of the crucial issue of connectivity detection in the presence of chaos by leveraging the novel electronic platform, which is real-time controlled by a custom board based on a field-programmable gate array (FPGA). By assessing connectivity between oscillators in the time domain, connectivity strength was shown to decay exponentially as a function of the topological size of the network, a phenomenon interpreted in terms of a "topological unpredictability" [7]. Here we investigate how these observations are linked to the spectral properties of the dynamics: in the frequency domain, the decay of connectivity is paralleled by spectral broadening and flattening.

Our results show that the emergence of chaotic regimes hinders the detection of links in real-world systems, whereby strongly coupled nodes can misleadingly appear as being independent. Significant implications of these results concerning the identification of networks in many research fields, from Earth science to neuroscience, are finally addressed.

Keywords: networks; connectivity; chaotic systems; Burridge–Knopoff model; electronic analog.

Acknowledgments

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BARRED GALAXIES AS COMPLEX DYNAMICAL SYSTEMS - HOW ORDER AND CHAOS SHAPE GALACTIC BARS

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Abstract

Barred galaxies (Figure 1) are complex systems primarily composed of stars, with a significant amount of gas and a smaller fraction of dust. They are embedded within dark matter halos, which interact with luminous matter solely through gravitational forces. Stars form from gas, and throughout their evolution, they explode, enriching the interstellar medium with gas, which subsequently collapses to form new stars. Dust serves as a useful tracer in these processes.

Observations [1], numerical studies in analytic potentials [2], and N-body simulations [3] suggest that galactic bars consist of two distinct components. The first, known as the "thin part," extends to the end of the bar, while the central region contains the "thick part."

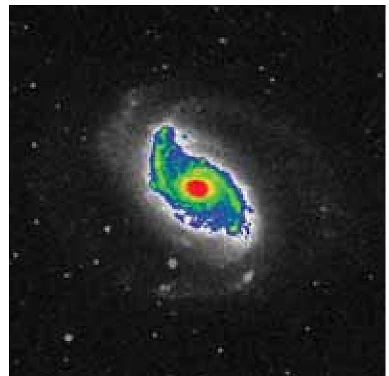

Figure 1: The barred-spiral galaxy NGC5248, observed with the ESO 2.2m telescope, La Silla, Chile, in B filter.

The stellar orbits within galactic bars provide crucial insights into the density distribution of these systems and the processes driving their formation. Understanding the orbital structure in both two-dimensional (2D) and three-dimensional (3D) Hamiltonian systems that describe rotating barred potentials is key to interpreting the observed morphologies of barred-spiral galaxies. Since bars (and spirals) are considered significant perturbations of axisymmetric disks, nonlinear dynamical effects and chaos play a major role in shaping their structure.

2D models are effective for studying the outer regions of bars (the "thin part") and the spiral arms that may extend beyond them. While chaotic orbits can contribute to the formation of spiral arms in certain barred-spiral galaxies, they may also support the outer parts of bars or even the bar itself in some cases [4].

3D models, on the other hand, are necessary for investigating how the thick part of bars is sustained and reinforced by stellar orbits. There is general consensus that the backbone of boxy and peanut-shaped structures ("b/p bulges") observed in the central regions of edge-on disk galaxies [5] consists of 3D families of periodic orbits. These orbits originate from the central x1 family through vertical resonances. However, in most cases, these families are "complex unstable" over a significant range of energy levels, requiring a detailed analysis of the surrounding phase-space structure to understand how they contribute to the reinforcement of boxiness beyond the equatorial plane [6].

This talk will examine the various dynamical mechanisms that support bars and spirals in disk galaxies, explore the role of "stickiness" in this process, and highlight the orbital families responsible for shaping the b/p bulges and the X-shaped features they exhibit.

Keywords: Galactic Dynamics; Hamiltonian Chaos; Structure formation

Acknowledgments

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INVESTIGATING HALLUCINATIONS IN ARTIFICIAL INTELLIGENCE-BASED FORECASTING OF CHAOTIC TIME SERIES

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Extended abstract

The forecasting of chaotic time series is a pivotal challenge across various scientific and engineering disciplines, given the inherent sensitivity of chaotic systems to initial conditions. Recent advancements have seen the integration of artificial intelligence (AI) methodologies, particularly deep learning models such as Long Short-Term Memory (LSTM) networks and Transformers, to enhance predictive accuracy in these complex systems. However, a notable concern in employing AI for chaotic time series forecasting is the phenomenon of "hallucinations," wherein models generate predictions that are not substantiated by the underlying data patterns. This paper presents a comprehensive literature review on applying AI techniques to chaotic time series forecasting, focusing on hallucination occurrences. We analyze the efficacy of various AI models, including Echo State Networks (ESNs) and hybrid approaches that combine chaos theory with deep learning, in mitigating hallucinations and improving forecast reliability. The review underscores the necessity for rigorous evaluation metrics and the development of robust methodologies to detect and reduce hallucinations in AI-driven forecasting of chaotic systems. Future research directions are proposed to address these challenges and enhance the credibility of AI-based predictions in complex, chaotic environments.

Keywords: Chaotic Time Series, Artificial Intelligence, Forecasting, Hallucinations, Deep Learning, Echo State Networks, LSTM, Transformers, Chaos Theory

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APPLICATION OF MACHINE LEARNING IN THE DRUG DEVELOPMENT PROCESS

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Extended abstract

The revenues of the global pharmaceutical industry totalled around $1.6 trillion in 2023 [1]. In the U.S., about 60% of adults aged 18 and over reported taking at least one prescription medication, with 36% claiming taking three or more. As a result, the time and money spent on the drug development process are crucial for the global health and economy [2]. This was clearly demonstrated during the COVID-19 pandemic, which revealed the importance of reducing time to market, ultimately saving lives and providing significant benefits to the global economy.

Figure 1: Application of AI in Pharma

Over the past decade, Artificial Intelligence (AI) has garnered significant global interest and has been rapidly adopted across nearly every industry to tackle challenges and drive economic growth [3]. Pharmaceutical industry could not stand aside and ignore the potential of this technology in its operations. AI can be applied to clinical trial design and monitoring, quality assurance and quality control, pharmaceutical product development, drug discovery, and product management. In healthcare, AI algorithms are used to enhance diagnostics, treatment, and medical decision-making [4]. The global AI growth rate in the pharmaceutical sector reaches 47% and its market is expected to reach $120.2 billion by 2028. Numerous studies suggest that AI can perform as well as, or even better, than humans in essential healthcare tasks.

Until recently, the Design of Experiments (DoE) was the most widely used modeling methodology in formulation development, primarily for quantifying the impact of preselected factors. However, DoE has several limitations: it is only effective for datasets with a small number of variables, requires prior knowledge of the manufacturing process, demands a large number of experiments to build a comprehensive model, and cannot incorporate information from previous experimental data [5]. Additionally, traditional experimental design studies are typically limited to offline analysis and are not well-suited for dynamic applications. The use of DoE often requires the preparation of drug formulations that experienced researchers would typically avoid. However, these preparations and inputs are necessary for the software to achieve the required statistical power and sensitivity. As a result, alternative data processing methods are needed to enhance our understanding of manufacturing processes and support the development of new drug-loaded formulations.

Machine learning (ML), which is part of AI, enables the identification of patterns within complex datasets. Various algorithms allow computers to process vast amounts of data, learning automatically and making real-time decisions and predictions about real-world events, often within seconds [6]. These algorithms can handle intricate, high-dimensional data commonly found in pharmaceutical research. The more high-quality data a model utilizes, the stronger and more reliable it becomes. It can replace time-consuming laborious processes with predictions generated in just 2 seconds. The main limitation of ML is that the effectiveness of models heavily depends on the availability and quality of the data used for training. Insufficient or poor-quality data can significantly limit the accuracy and reliability of the model's predictions.

Overall, it can be concluded that Artificial Intelligence has numerous and multifaceted applications in the pharmaceutical industry. Its integration is always guided by the goal of improving patient care, while ensuring compliance with regulatory standards that uphold the quality of the final pharmaceutical product.

Keywords: Artificial Intelligence; Machine Learning; drug development; pharmaceutics;

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TRANSLATING MITOCHONDRIAL COMPLEXITY INTO DRUG DELIVERY DESIGN

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Extended abstract

Mitochondria are vital organelles that regulate cellular energy metabolism, apoptosis, redox balance, and calcium signaling. Their function is driven by oxidative phosphorylation (OXPHOS), a process powered by the electron transport chain (ETC) embedded in the inner mitochondrial membrane (IMM). The IMM maintains a highly negative membrane potential ($\Delta\psi_m \approx -180$ mV), which is essential for ATP synthesis but also poses a major barrier for effective drug delivery. Mitochondria contain their own genome (mtDNA), which is maternally inherited and is particularly susceptible to mutations. Accumulation of mutant mtDNA (heteroplasmy) beyond a pathological threshold leads to mitochondrial dysfunction and contributes to a wide range of diseases, including Leigh syndrome, Leber's hereditary optic neuropathy (LHON), neurodegenerative diseases, cardiomyopathies, and metabolic disorders. Mitochondrial gene and drug delivery has emerged as a promising approach to restore mitochondria function [1].

Despite the growing recognition of mitochondria as a therapeutic target, efficient drug delivery to these organelles remains a major challenge, due to their complex structure. Mitochondrial targeting involves overcoming multiple barriers, including reduced cellular uptake, endosomal entrapment, poor mitochondrial specificity, and potential cytotoxicity. The complex and compartmentalized structure of mitochondria, and the selective permeability of the inner mitochondrial membrane, further complicates targeted strategies. To overcome these obstacles, there is a critical need to develop nanocarriers designed according to the physicochemical and electrochemical properties of mitochondria. Specifically, positively charged, lipophilic nanoparticles can accumulate in the mitochondrial matrix by utilizing the highly negatively charged mitochondrial membrane potential, as explained by the Nernst equation. However, effective targeting also depends on factors such as particle size, polydispersity index, ζ-potential, and the ability to escape from endosomal degradation [2].

Stimuli-responsive biomaterials, such as pH-, redox-, or thermo-sensitive polymers, combined with mitochondrial-targeting ligands or peptides (e.g., mitochondrial targeting sequences, triphenylphosphonium) offer promising strategies. The developed nanosystems are designed specifically to respond to the unique mitochondrial microenvironment, including the alkaline pH in the mitochondrial matrix, high ROS levels, and altered glutathione (GSH) concentrations, enabling site-specific release of therapeutic cargo with minimal off-target effects [3].

At present, limitations in mitochondrial targeting can result from an insufficient understanding of mitochondrial complexity. In the context of chaos and complexity, mitochondria represent an organelle where spatial organization, electrochemical gradients, and genetic heterogeneity converge to regulate essential life processes. A comprehensive understanding of mitochondrial function, as dynamic, compartmentalized, and electrochemically active organelles is essential for the rational design of drug delivery nanosystems that are both efficient and safe, and can facilitate the development of targeted therapies for mitochondrial diseases and other disorders associated with mitochondrial dysfunction.

Keywords: mitochondria; complexity; drug delivery; nanoparticles

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DUAL LYAPUNOV BASED SYNCHRONIZATION CONTROL of ROSSLER SYSTEM

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Extended abstract

This paper proposes a novel approach for the synchronization problem of nonlinear dynamical systems, integrating dual Lyapunov stability analysis with polynomial optimization. A comprehensive review of the relevant scientific literature on synchronization is conducted, with a particular focus on classical Lyapunov-based methods for chaotic systems, such as the Rössler system [1,2]. In this study, the Rossler system is synchronized by employing a dual Lyapunov-based closed-loop synchronization method which might be assumed as a model reference adaptive controller. This method uses semidefinite programming (SDP) and sum-of-squares (SOS) polynomials to compute a nonlinear state feedback which synchronize a chaotic system to a selected reference model. The paper discusses how new constraints should be employed and adapted to more complex systems. The approach of the study integrates the dual Lyapunov theorem with polynomial optimization techniques to ensure almost global stability for a broad class of systems. A key step involves formulating stability and feedback design conditions through SOS constraints, which can be solved by employing SDP. For a dynamical system modeled as $\dot{x} = f(x), f: \mathbb{R}^n \rightarrow \mathbb{R}^n$, a density function $\rho(x) = a(x)/b(x)$ is constructed to characterize the almost global stability of the closed-loop system. If a positive $\rho \in C^1(\mathbb{R}^n - \{0\}, \mathbb{R})$ is integrable on the set $\rho(x)f(x)/|x|$, $\{x \in \mathbb{R}^n : |x| > 1\}$ and satisfies the condition $[\nabla \cdot (\rho f)(x)] > 0$, then almost all sets of solutions of $f(x)$ converge to zero [3]. SDP re-expresses the constraints in linear matrix inequalities form and forces a non-negativity constraint $[\nabla \cdot (\rho f)(x)] > 0$ to be satisfied considering the closed-loop system and a rational density function. This closed-loop system is constructed by the system to be controlled/synchronized $\dot{x}$, reference dynamical system $\dot{x}_d$ and differential error $\dot{e} = \dot{x} - \dot{x}_d$ which represents the distance between the actual output and the reference output. A state feedback function is computed and used to minimize the error dynamics thus the reference tracking or synchronization problem is solved. In this paper, the Rossler system in the limit cycle is employed as the reference model. It is aimed that chaotic behavior is destroyed and, instead, a limit cycle becomes attracting by a state feedback function. SeDuMi solver is employed to compute state feedback function. Simulation studies are performed for randomly selected 100 different initial conditions to show that synchronization process is successfully performed (Figure 1). In light of the results obtained from the work, the stability analysis and synchronization of more complex systems will be considered in future studies. It becomes possible in principle to incorporate additional objective criteria into the design.

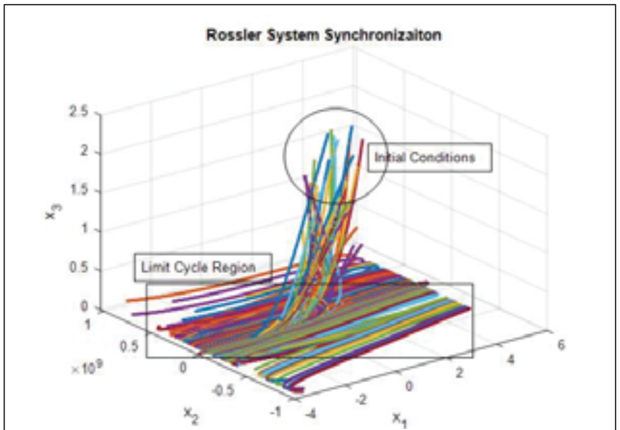

Figure 1: Phase plane for the synchronized system.

Keywords: Dual Lyapunov Theorem; Synchronization; Model Reference Adaptive Systems; Rossler Equation; Chaos.

Acknowledgments

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Complex Thermal Dynamics of Smart Cylindrical Shells with Nanoparticles

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Extended abstract

The authors examine vibration aspects of piezoelectric cylindrical shells reinforcement with embedded carbon nanotubes under uniform temperature conditions. The system obtains its control of vibration behavior from the voltage application that operates across its thickness direction. Mixture low helps determine the effective properties present in the nano-composite structure. The shell along with elastic medium constants exhibit material properties that depend on temperature changes. The model equations originated from Hamilton's principle. The frequency of smart structure can be computed through the deployment of differential quadrature (DQ) method. The analysis includes a comprehensive parametric investigation which demonstrates how temperature distribution patterns together with external voltage applications and CNT volume fractions as well as their distribution types impact the system frequency. The system achieves elevated frequencies when supplied with negative voltage according to numerical outputs.

Fig.1 depicts the CNT reinforced piezoelectric cylindrical shell with dimensions. L represents length and h represents the thickness value. The structural surroundings consist of Pasternak medium. This research utilizes one uniform CNT distribution together with three different forms of functionally graded CNT distributions. The concept of Rule of Mixture enables determining the equivalent material properties of this nano-composite structure. Based on FSDT shell theory [1], the final motion equation inn matrix form is $Kd+M\ddot{d}=0$, where K and M are stiffness and mass matrix, respectively.

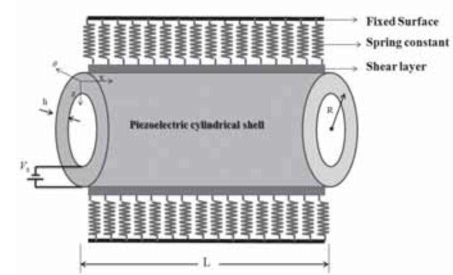

Fig. 1 A cylindrical shell in elastic medium reinforced by nanoparticles

To verify the research findings this work uses an analysis which dismisses CNT volume percentage, elastic medium and shell temperature effects to examine piezoelectric cylindrical shell vibrations. The authors derived the structure frequency based on FSDT and Navier's method which they compared to the work of Sheng and Wang [2] in Fig. 3. The current research findings demonstrate acceptable match with the results presented by Sheng and Wang [2] which verifies the accuracy of this present study.

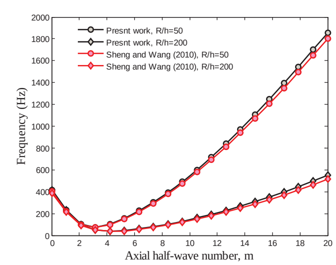

Fig. 2 Validation of present work with Sheng and Wang (2010)

A diagram in Fig. 3 shows how external applied voltage affects dimensionless frequency in the CNTRC shell across different CNT volume fractions. Dimensionless frequency of the CNTRC shell rises when external applied voltages receive negative values. An increase in CNT volume fraction leads to elevation of the dimensionless structure frequency. The structure becomes harder when CNT volume fraction rises. Using nanotechnology as an innovative method allows engineers to build systems that are more rigid and show better vibration performance.

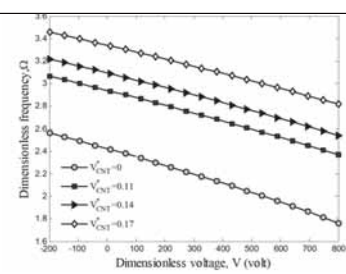

Fig. 3 Dimension frequency versus external applied voltage

In conclusion, this paper demonstrated how external applied voltage together with volume percent and distribution type of CNT in polymer and temperature distribution type influence the system frequency. A changing external applied voltage from negative to positive produces decreasing values of dimensionless frequency according to test results. The dimensionless frequency of structure becomes higher when the CNT volume fraction receives increased values. The research results match the data published by Sheng and Wang [2]. The authors expect that the findings in this work might assist designers in developing control procedures for NEMS/MEMS devices which include strain sensors and mass and pressure sensors.

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Chaotic Dynamics and Forecasting in Monthly Rate Employment Time Series: The Case of Australia, Colombia, Greece, Turkey and USA

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Extended abstract

Studying social systems from the point of view of complexity by utilizing established tools of nonlinear dynamics and chaos theory is gaining increasing attention in the field of sociophysics. Within this context, the analysis of phenomena relating society and economy are quite attractive for research and extremely interesting for the decision makers. The employment rate in a country is an important index quantifying (maybe) the most important social parameter that of labour market. The proper study of employment rate timeseries within the frame of nonlinear dynamics provides with a valuable opportunity to explore the existence of deterministic chaos in the apparently complex socioeconomic enviroment of a country.

This paper investigates possible emerging nonlinear dynamical patterns and behaviors in the study and analysis of the monthly employment rate data across five diverse economies: Australia, Colombia, Greece, Turkey, and the USA. The countries chosen come from four different continents, while in the case of Europe two countries with different characteristics (EU member-non EU member, small-large population, etc.) have been chosen, to further support the feature of diversity in our study. Additionally, the forcasting potential of employment rate in the above mentioned countries is explored, as indicatevely is presented in Figure 1.

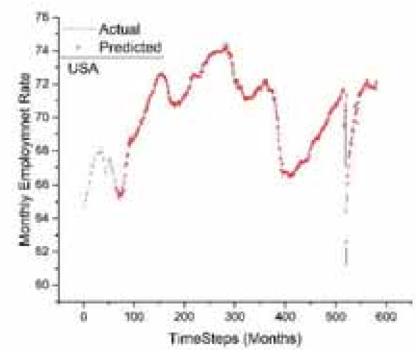

Figure 1: Successful forecasting of the employment (the rate is in %) for the case of the USA.

In specific, the primary objective of this research is to identify and quantify the existence of deterministic chaos in the complex socioeconomic enviroment of a country by analyzing the timeseries of employment rate employing nonlinear dynamics analysis. The methodology applied incorporates advanced nonlinear time series analysis techniques rooted in chaos theory, like:

- the estimation of invariant chaotic measures, such as the Lyapunov exponent spectrum, aiming to investigate and confirm the possibility if deterministic chaos existence, while determining the prediction horizon applied;
- determination of the minimum embedding dimension by properly applying the Method of the False Nearest Neihbours and Cao's Method, aiming to defining the essential parameters for further perform forecasting;
- reconstruction of the phase space of the underlying system determining the employment rate for properly forecasting it;
- exploitation of and artificial neural networks (ANNs) for forecasting employment, always within the limits imposed by the maximum Lyapunov exponent.

Finally, in this brief, we compare the reliability of the utilized forecasting methods and model, thereby contributing to improved predictability in labor market trends.

Keywords: Employment rate; Nonlinear time series analysis; Embedding dimension; Lyapunov exponents; Artificial Neural Networks, Sociophysics.

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Semidefinite Programming Certificates for Synchronization of Kuramoto Oscillators on Arcs

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Extended abstract

This paper studies a class of generalized Kuramoto model expressed as

$$\dot{\theta}_j = \omega + K \sum_{k=1}^{d} \left(\sum_{c=1}^{L} \alpha_c \sin\left(c\theta_k - c\theta_j + \beta_c\right) \right), \quad \theta_j = 1, \dots, d,$$

where $\alpha_c > 0$ and $|\beta_c| < \frac{\pi}{2}$ for $c = 1, \dots, L$. We propose a novel approach, using Semidefinite Programming (SDP), for certifying local phase synchronization in this model for all initial conditions lying on an arc of length a for some $0 < a < \frac{\pi}{2}$, or in other words, for initial conditions satisfying $\left\{ \left|\theta_k(0) - \theta_j(0)\right| : \ j, k = 1, \dots, d \right\} < a$. By virtue of phase-shift symmetry, phase synchronization of this model can be established by certifying local asymptotic stability (to the origin) of the phase-difference system with variables $\varphi_j = \theta_j - \theta_d$, for $j = 1, \dots, d-1$. We use trace parametrization property and Gram matrix representations of trigonometric polynomials along with Putinar Positivstellensatz [1] to obtain SDP certificates for local asymptotic stability of the phase-difference system. The work is based on our findings in [3, Theorem 2] where an SDP certificate for existence of a local Lyapunov function for systems having a trigonometric polynomial expansion was obtained. In this work, we adapt the results in [3, Theorem 2] to obtain an SDP certificate for existence of a local Lyapunov function for initial conditions on arc of length $a^* = \frac{\pi}{2r}$, given any $r \in \mathbb{N}$. Due to the structure of Kuramoto models assumed in this in this work, additionally, forward invariance on arc of length $a_* = \frac{2}{L}\left(\frac{\pi}{2} - \max_k |\beta_k|\right)$ can be analytically established, which allows us to conclude local stability for initial conditions on arcs of length $a = \min(a^*, a_*)$ if the SDP is feasible. The results are, however, general and can be extended to other systems of coupled oscillators where forward-invariance on arcs can be established. For solving the SDP program, we use our openly available SOS-t (Trigonometric Sum of Squares) solver [2] based on SeDuMi in MATLAB.

Keywords: synchronization, stability, Lyapunov function, semidefinite programming

Acknowledgements: This work is supported by TUBITAK under the project number 122E522.

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Colon Cancer Disease Diagnosis based on CNN and Machine Learning

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Abstract. Colon cancer is a leading cause of cancer-related mortality worldwide, underscoring the urgent need for effective and accurate diagnostic techniques. This study proposes a novel hybrid approach for colon cancer diagnosis using convolutional neural networks (CNNs) combined with the Bitterling Fish Optimization (BFO) algorithm for enhanced feature selection and classification. Utilizing a publicly available histopathological image dataset from Kaggle, the proposed method begins with extracting high-level features through pre-trained CNN models such as VGGNet, AlexNet, and SqueezeNet. These features are then refined using the BFO algorithm to select the most informative attributes. Multiple machine learning classifiers—including Support Vector Machine (SVM), Decision Tree, Ensemble methods, Naive Bayes, Logistic Regression, and K-Nearest Neighbors (KNN)—are employed for the final classification of images into cancerous and non-cancerous categories. The VGGNet-BFO model paired with the SVM classifier achieved the highest accuracy of 98.21%, demonstrating the model's robustness and efficiency. The findings highlight the potential of deep learning models integrated with bio-inspired optimization algorithms for reliable and automated colon cancer diagnosis.

Keywords: Colon Cancer, Convolutional Neural Networks, Machine Learning, Feature Selection.

LOGISTIC MAP COMPACT MODEL FOR IMAGE ENCRYPTION

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Extended abstract

Introduction. In this paper, a novel, compact and low-cost image encryption system based on chaos and DNA coding is proposed. To achieve this, a loop circuit capable of mimicking the dynamics of the logistic map, a well-known discrete chaotic system, has been designed. An Arduino Nano, equipped with an ATMEGA328P microcontroller, was employed to implement a signal acquisition and processing algorithm, which extracts signals from the loop chaotic circuit. The algorithm can process the chaotic signals to generate balanced binary codes (composed of '0s' and '1s') and performs an iterative search for orthogonal sequences, ultimately producing a set of balanced and mutually uncorrelated binary sequences. Unlike previous works, in this approach, the dynamics of the iterative map are physically reproduced through a loop circuit, overcoming the limitations associated with the use of numerical models. In fact, when using these models, the chaotic orbits generated are periodic due to the limited numerical precision of machines. Additionally, since they do not depend on natural variations of the system, identical logistic map algorithms generate identical orbits when the same initial conditions are provided. This inevitably compromises the security of any encryption system. In this work, the proposed method for binary and orthogonal sequences generation has been integrated into an image encryption pipeline. Specifically, the proposed algorithm leverages both binary chaotic sequences extracted from the designed system to perform permutation and diffusion processes. Moreover, DNA coding technique, inspired by the nucleotide bases adenine (A), guanine (G), cytosine (C) and thymine (T), has been combined for the image encoding.

Logistic map circuit. The logistic map [1] is an iterative mathematical model expressed as $x_{n+1} = rx_n(1 - x_n)$ that exhibits chaotic behavior under certain conditions. x_n represents the normalized population at time n, varying between 0 and 1, while r is a control parameter that determines the evolution of the system. For $3.56 \leq r \leq 4$ the system reaches the region of chaos, thus a non-convergent and non-periodic behavior. The dynamics of the logistic map for different values of the control parameter r can be visualized in a characteristic graph called bifurcation diagram.

System design. The loop circuit dynamics were characterized by testing the circuit for different values of the control parameter r, finally obtaining the characteristic bifurcation diagram of the logistic map. An Arduino Nano was integrated for the acquisition and processing of the chaotic sequences obtained from the implemented loop circuit. For the current work, the sequence length was set equal to the number of pixels N in the image to be encrypted, with a size of 200 x 410, resulting in N = 82.000, and the number of orthogonal sequences was set to M = 8. An image encryption algorithm was implemented using chaotic sequences obtained through the described method to perform permutation and diffusion operations. Additionally, the DNA coding technique was incorporated, leveraging predefined rules for encoding bits into 'A', 'T', 'C' and 'G', inspired by DNA nucleotide bases. The implemented chaotic system was tested and validated through the NIST SP800-22rev1a statistical test suite (Information Technology Laboratory, Computer Security Resource Center, Gaithersburg, MD, USA) [2]. Additionally, 6 tests were conducted to assess the security and robustness of the proposed image encryption algorithm.

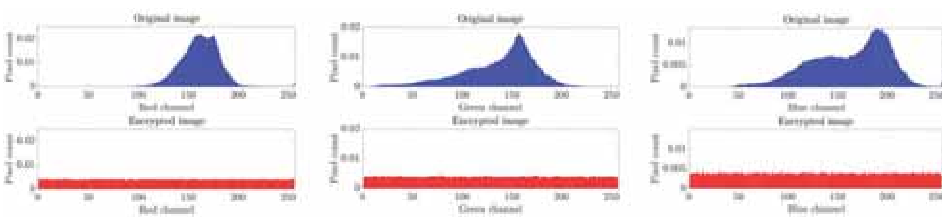

Figure 1. Pre and post image encryption histograms.

Results. The most relevant statistical tests of the NIST test suite were successfully passed, with a significance level α = 0.01, confirming the pseudo-randomness nature of the chaotic binary sequences and thus the validity of the implemented circuit. The security and robustness tests conducted on the encryption algorithm also yielded significant results, reducing pixels patterns and correlations. An example is shown in Fig. 1, illustrating how the proposed algorithm removes recognizable patterns of the plain image (in blue), resulting in a cipher image with completely flattened histogram (in red).

Conclusion. This work introduces a novel physical system based on the logistic map that overcomes the limitations of computer-based algorithms. The system is highly sensitive to initial conditions, ensuring unpredictable and non-reproducible sequences. This compact and cost-effective system is integrated into an image encryption pipeline, where a DNA-based algorithm performs encryption using chaotic sequences. Security and robustness tests validate the system, showing results comparable to existing methods, while making it difficult to decrypted the cipher image without replicating the chaotic system physically implemented.

Keywords: Logistic map circuit, chaotic sequence, orthogonality property, balance property, image encryption

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PICARD-TYPE HYBRID FIXED POINT ITERATIVE APPROACHES FOR THE CONTROL OF CHAOS IN DISCRETE DYNAMICAL SYSTEMS

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Extended abstract

Chaos theory has been extensively studied from various perspectives by numerous researchers over the years. With the advancement of computational technologies, a novel research field known as *chaos control* has emerged, introducing innovative approaches for managing chaotic behaviors observed in real-world systems. Particularly in the study of discrete chaotic dynamical systems-where unpredictability and complexity are dominant-there is an ongoing need for the development of new control strategies.
In the analysis of nonlinear dynamical systems, various feedback-based methods have been employed, which are inherently connected to the concepts of iteration and orbits. Fixed point theory, a powerful tool in the analysis of dynamical systems, offers iterative methods that have proven effective in controlling chaos within discrete systems. By adjusting the parameters of these iterative schemes, it becomes possible to regulate the growth that leads to chaotic dynamics.
This study introduces new chaos control mechanisms based on hybrid fixed point iteration methods of the Picard type, known for their rapid convergence in the literature. Through the proposed hybrid techniques, the unstable and chaotic structures of certain transformation classes are transformed into stable and convergent regions via a fixed point feedback approach. Furthermore, the theoretical results are demonstrated through an application involving a chaotic transformation class that models a real-life problem, thereby highlighting the practical relevance of the proposed control methods.

Keywords: Chaos control; Nonlinear discrete dynamical systems; Hybrid iteration methods; Feedback technique; Stability analysis.

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FROM STABILITY TO CHAOS: FIXED POINTS AND BIFURCATIONS IN THE FRAMEWORK OF DISCRETE DYNAMICAL SYSTEMS

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Extended abstract

This study explores exponential and logistic growth models within the context of discrete dynamical systems, with particular emphasis on the qualitative behavior of orbits, the nature of fixed points, and the emergence of chaotic regimes. Initially, population growth is modeled through deterministic difference equations, and the transition from unbounded exponential growth to constrained logistic dynamics is discussed in light of environmental limitations.
The logistic equation serves as the basis for analyzing system behavior under varying parameter values. The study investigates the stability of fixed and periodic points through derivative-based criteria, illustrating how system trajectories evolve over time. As the growth rate parameter increases, the system exhibits classical bifurcation phenomena-culminating in the onset of chaos.
Drawing upon Robert May's pioneering contributions to nonlinear population models, the work demonstrates how bifurcation diagrams reflect transitions from equilibrium to periodic and ultimately chaotic dynamics. The universality of chaotic behavior is addressed via Feigenbaum's constant, revealing the self-similar structure in the bifurcation cascade. Moreover, Lyapunov exponents are employed to quantitatively assess sensitivity to initial conditions, confirming the presence of chaos in cases where positive exponents are observed. The findings affirm that even simple nonlinear maps can give rise to highly complex and unpredictable behavior, underscoring the relevance of discrete dynamical systems in mathematical modeling across a range of scientific disciplines.

Keywords: Chaos; Bifurcation; Nonlinear discrete dynamical systems; Logistic growth; Lyapunov exponent.

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Measuring the dynamic complexity of self-organized systems

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Extended abstract

Most would agree that clouds and cats are complex systems. Crystals and nematodes, interesting as they may be, seem to be less so. Making this statement precise is no easy task: complexity is easier to recognize than it is to define. The literature offers a range of complexity measures to match the different perspectives — ranging from information-theoretic (e.g., *Shannon entropy* [1]) to computational (e.g., *Kolmogorov complexity* [2]), and beyond.

In practice, practitioners often sidestep this conceptual variety by using a standard measure of complexity specif to their field of study. When no such measure exists, one can sometimes still avoid conceptual ambiguities since different measures are often related. For example, Kolmogorov complexity, which measures how difficult it is for a universal computer to reconstruct an object via the length of the shortest program that generates it, is clearly related to *time complexity*, which measures how quickly that program runs. Crucially, while these quantities may be related, they are clearly not the same.

In this work, we are interested in *self-organization* [3], where ordered structures spontaneously form. Self-organization is everywhere in Nature, from the bands on the clouds of Jupiter to the spots on a leopard's fur, and even life itself [4]. Most would agree to call these systems complex. But are *all* self-organized systems complex? Identifying a measure of complexity that is able to characterize self-organized structures can shed light on the physical mechanism driving their formation. This, in turn, is crucial to understanding their remarkable properties.

We therefore focus on measures of *dynamical complexity*. *Lyapunov exponents* and *Kolmogorov-Sinai entropy* [5], for example, capture sensitivity to initial conditions, which is a hallmark of deterministic chaos. They are measures of diversity, which is important for characterizing structures formed by self-organization, but not sufficient. Diversity fails to characterize the uniformity that we observe in the midst of structural diversity and which we commonly call "patterns". An established approach, *LMC complexity* [6], is based on this insight. It defines complexity as the product of two quantities, entropy and disequilibrium. Its has seen numerous applications in different fields, but there is criticism regarding its theoretical foundations.

Here we propose a novel measure of complexity rooted in the dynamical behavior of self-organization. We define complexity as $\mathcal{D}\times(1-\mathcal{T}_{q^*})$, where $\mathcal{D}$ is a measure of dynamical diversity in the sense of *permutation entropy* [7] (which approximates Kolmogorov-Sinai entropy in the times-series case), and q^* is the *entropic index* of the *Tsallis entropy* $\mathcal{T}_{q^*}$ [8] which makes the system extensive.

As Bandt and Pompe's permutation entropy, our measure is straightforward to implement and efficient to compute, and applicable to systems at multiple scales, from nanometric self-organized patterns which are created from convective processes [9], to the large-scale structures of the Universe [10,11]. This demonstrates its versatility and intuitive applicability across disciplines.

Keywords: Complexity; Self-Organization; Permutation Entropy; Tsallis Entropy; Dynamical Systems.

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Which Strategy Configurations Enable Turkish Firms to Reach Peaks on the Fitness Landscape?

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Abstract. In increasingly complex and competitive industrial environments, firms must continuously adapt their strategic positions to sustain long-term performance. This study investigates how Turkish manufacturing firms achieve higher levels of performance by navigating the fitness landscape through specific configurations of strategic capabilities. Using the NK model—where N represents the number of strategic capabilities and K reflects the degree of interaction between them—the study models 256 binary-coded combinations based on eight identified capabilities: digitalization, R&D investment, internationalization, quality improvement, lean production, technology-driven supply chain, human capital development, and environmental sustainability. Each configuration's fitness value was calculated using normalized performance data from publicly available databases, including TÜİK, Eurostat, OECD, and KOSGEB. The results show that higher fitness peaks are not randomly distributed but tend to cluster around specific strategic bundles. Particularly, combinations including digitalization, lean production, and sustainability demonstrate consistent success across contexts. The research makes a methodological and theoretical contribution by applying the rugged fitness landscape and dynamic capabilities framework [5] to an emerging market setting. It also provides a scalable model that can inform strategic planning at the firm and policy levels.

Keywords: Fitness Landscape, NK Model, Strategic Capabilities, Turkish Manufacturing Firms, Dynamic Capabilities, Complexity Theory, Adaptive Strategy, Organizational Performance, Epistasis, Strategic Fit.

1 Theoretical Framework

1.1 Scope and Nature of the Study

This study analyzes the effects of strategic capability configurations on the success of firms operating in Turkey's manufacturing sector. Based on the complex systems perspective, the Fitness Landscape theory offers a powerful analytical framework to evaluate how firms optimize their strategic positions in rapidly changing environments [2]. The NK model employed in this study represents firms' strategic capabilities through binary encoding (0: absent, 1: present) and calculates performance (fitness) values across 256 possible strategy combinations.

1.2 Theoretical Framework

The research builds on the NK model [3], the concept of dynamic capabilities [5], the idea of epistasis (Levinthal, 1997), and the Red Queen effect [6]. In the NK model, N denotes the number of strategic capabilities, and K indicates the level of interdependence among them. As the degree of interaction increases, the number of paths to peak performance also rises, though so does the system's complexity [4].

The dynamic capabilities approach emphasizes firms' abilities to reconfigure internal and external competencies in response to environmental change—an essential factor for achieving long-term competitive advantage [5]. Additionally, the Red Queen hypothesis highlights the need for firms to evolve continuously in tandem with their external environments [6].

The modeling process was implemented using Python to compute fitness values across 256 combinations. These fitness scores were calculated using normalized performance indicators sourced from TÜİK, Eurostat, OECD, and KOSGEB, including productivity, export activity, digital transformation, and sustainability metrics. Each configuration was mapped within a high-dimensional hypercube to identify local and global fitness peaks [1]. The analysis revealed that the structure of interdependencies among capabilities (i.e., epistasis) plays a decisive role in achieving superior performance. This research provides an empirical application of the fitness landscape approach within the context of Turkish strategic management. It also introduces a replicable and scalable model based on publicly available data, which can be expanded to accommodate sectoral differences and guide both firm-level strategy and policy formulation.

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Phase transition in a nonlinear quantum protocol

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Extended abstract

Post-selective quantum operations can lead to nonlinear quantum evolution if applied on more initial systems in the same quantum state [1]. Iterated application of this type of protocols leads to chaotic quantum evolution equivalent to a complex dynamical system, characterized by the iteration of a rational complex function [2]. The emerging time-evolution can be exponentially sensitive to the initial pure quantum state for single qubit systems [3] as well as for qubit pairs [4]. In the latter case, chaoticity emerges also in the entanglement properties of the qubit pair. One can construct an operation for any complex *n*th order rational map [3].

Noisy initial states are characterized by a density matrix, described by three real variables for a qubit. The iterated nonlinear protocol thereby naturally extends complex dynamical systems on the the Riemann sphere (equivalent to the surface of the Bloch sphere in physics) to the internal volume of the sphere. Somewhat surprisingly, noise does not destroy the fractals belonging to the Julia set on the surface. Instead, a phase transition occurs at a critical noise level. Above the corresponding critical purity, the fractal dimension of the borders between convergence regions remains constant [6]. One can identify a repelling fixed point inside the sphere at the critical purity. Backward iterations of the dynamics starting from points close to the Julia set on the sphere will all converge to this fixed point. A similar phase transition is present in protocols corresponding to all higher order rational maps by applying the same construction [6].

We show that small coherent errors in the quantum gates do not affect substantially the characteristic features of the system [7]. The robustness of the discussed phenomenon suggests that it can be observed in physical realizations, e.g. in quantum computers.

Keywords: Iterated quantum protocols; Nonlinear quantum dynamics; Chaotic quantum evolution; Phase transition.

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High Energy of Recurrent Chaotic Trajectories in a Time-Dependent Potential Well Model

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Extended abstract

In this numerical study, we apply Recurrence Quantification Analysis (RQA) to chaotic trajectories, introducing a novel approach for detecting atypical dynamical behaviors. By defining an ensemble of Initial Conditions (ICs), evolving them until a specified maximum iteration time, and calculating the Recurrence Rate (RR) for each orbit, we identify trajectories that significantly deviate from the average dynamical behavior [1]. These special trajectories are pinpointed through a statistical distribution, where peak detection highlights the IC that leads to a highly recurrent orbit. We then use this method to examine the impact of these recurrent chaotic trajectories within a symplectic model of a time-dependent potential well [2]. The phase space, shown in Fig. 1, illustrates the system's characteristic dynamical configuration, highlighting a particularly recurrent chaotic trajectory that exhibits the stickiness phenomenon. Our results demonstrate that, for certain parameter values and initial conditions, the system can undergo rare transient states of high energy, driven by quasi-periodic dynamics that persist for sufficiently long periods.

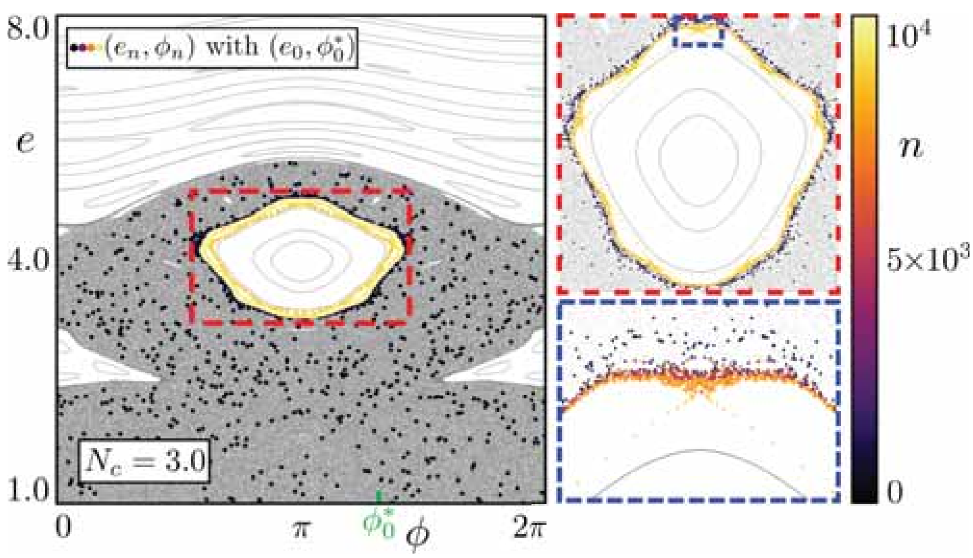

Figure 1: Phase space of the system along with the trajectory started from a specific IC that produces a highly recurrent chaotic trajectory.. Colour scale shows iteration time. Dashed boxes are subsequent amplifications.

Keywords: Chaotic Trajectories; Recurrence Quantification Analysis; Time-Dependent Potential; Symplectic Model.

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CHAOS DETECTION IN DYNAMICAL SYSTEMS: LYAPUNOV AND REVERSIBILITY ERROR INVARIANTS

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Extended abstract

The detection of chaos in dynamical systems is performed by computing the Lyapunov exponents. However, the time limit occurring in their definition is often hard to reach numerically. To this end the fast Lyapunov indicators (FLI) [1] was introduced in celestial mechanics. To any initial deviation $\varepsilon\boldsymbol{\eta}$ where $||\ \boldsymbol{\eta}\ || = 1$, one associates the normalized deviation at time *t* defined as $||\ S_t(\mathbf{x}+\varepsilon\boldsymbol{\eta}) - S_t(\mathbf{x})\ || / \varepsilon$ where $S_t(\mathbf{x})$ denotes the flow. This definition depends on the deviation amplitude ε and its direction $\boldsymbol{\eta}$. To avoid the dependence on ε, we consider the linear response defined by the limit: $\lim_{\varepsilon\to 0} \big(S_t(\mathbf{x}+\varepsilon\boldsymbol{\eta}) - S_t(\mathbf{x})\big) / \varepsilon = L(\mathbf{x},t)\boldsymbol{\eta}$ where $L(\mathbf{x},t)$ is the fundamental matrix of the linearized flow. Since the linear response $||\ L(\mathbf{x},t)\boldsymbol{\eta}\ ||$ depends on $\boldsymbol{\eta}$, we replace $\boldsymbol{\eta}$ with a random vector $\boldsymbol{\xi}$ having unit covariance matrix $<\boldsymbol{\xi}\,\boldsymbol{\xi}^T>=I$ and compute the covariance matrix $\Sigma^2_L(\mathbf{x},t)= L(\mathbf{x},t)\ L^T(\mathbf{x}, t)$. The eigenvalue matrix, we denote as $e^{2t\ \Lambda(\mathbf{x},t)}$ is such that $\Lambda(\mathbf{x})$, defined by the limit of $\Lambda(\mathbf{x}, t)$ for $t\to\infty$, exists according to the Oseledet theorem, whereas the limit of the eigenvectors matrix might not exist, unlikely the Lyapunov matrix $L^T(\mathbf{x},t)\ L(\mathbf{x}, t)$. Rather than the eigenvalues of $\Sigma^2_L(\mathbf{x},t)$ we compute its invariants. The first invariant is the trace, the last one the determinant: they correspond to the sum and the product of the eigenvalues respectively. In addition, we consider the linear response to an additive Gaussian noise $\varepsilon\ \boldsymbol{\xi}(t)$ specified by its covariance matrix. For a Wiener noise $\mathbf{w}(t)$, the covariance matrix of the white noise $d\mathbf{w}(t) = \boldsymbol{\xi}(t)\ dt$ is $<\boldsymbol{\xi}(t)\ \xi(t')>=I\ \delta(t'-t)$. Denoting $S^{\varepsilon}_t(\mathbf{x})$ the *noisy* flow, then the linear response and its covariance matrix are

$$\Xi_F(\mathbf{x},t) = \lim_{\varepsilon\to 0} (\ S_t^{\varepsilon}(\mathbf{x}) - S_t(\mathbf{x})\ )/\varepsilon \quad \text{and} \quad \Sigma_F^2(\mathbf{x},t) = <\Xi_F(\mathbf{x},t)\ \Xi^T_F(\mathbf{x},t)> \tag{1}$$

A simpler expression is obtained when the Forward evolution up to time *t* is followed by the Backward evolution from time *t* to *2t* (or vice versa). The covariance matrices of the corresponding linear responses are denoted by $\Xi_{BF}(\mathbf{x},t)$ and $\Xi_{FB}(\mathbf{x},t)$. In general they differ but, for autonomous Hamiltonian systems, they are equal and we denote them with

$\Xi_R(\mathbf{x},t)$. The explicit expression being $\Xi_R(\mathbf{x},t)= \int_0^t L(\mathbf{x},t')\ L^T(\mathbf{x},t')\ dt'$.

The Lyapunov error $e_L(\mathbf{x},t)$ and the Reversibility error $e_L(\mathbf{x},t)$ are given by

$$e_L^2(\mathbf{x},t) = \mathrm{Tr}\ (\ L(\mathbf{x},t)\ L^T(\mathbf{x},t)\ ) \quad \text{and} \quad e_R^2(\mathbf{x},t) = \int_0^t e^2_L(\mathbf{x},t')\ dt' \tag{3}$$

In numerical computations the flow $S_t(x)$ is replaced by an integrating map $M(\mathbf{x})$ such that for an integration scheme of order m with step Δt, we have $S_{t+\Delta t}(\mathbf{x})=S_t(\mathbf{x}) + \Delta t\ M(S_t(\mathbf{x})) + O\big((\Delta t)^{m+1}\big)$ for $t=n\Delta t$. In numerical computations the discrete flow generated by $M^{\circ\ n}(\mathbf{x})$ is affected by the numerical round-off whose amplitude we denote with ε^* [3,4]. Letting $M^{\circ n}_{\varepsilon*}(\mathbf{x})$ be the discretized time flow with round-off, then the corresponding reversibility error, REM (Reversibility Error Method), is defined by $\varepsilon_{REM}(\mathbf{x},t) = ||\ M^{\circ\ n}_{\varepsilon*}(\mathbf{x}) - M^{\circ\ n}(\mathbf{x})\ || / \varepsilon^*$. The round-off introduces a noise-like perturbation, whose amplitude ε^* is equal to 10^{-16} in the 8-bytes IEEE 754 standard representation of real numbers. Since just one realization of this pseudo-noise is available for $\varepsilon_{REM}(\mathbf{x},t)$ exhibits significant fluctuations, which can be smoothed by averaging over a disc with centre $\mathbf{x}$ and a small radius r. On the contrary, $e_R(\mathbf{x},t)$ Reversibility error, is the average over all possible realizations of a random noise [5]. The first error invariants $e_L(x,t)$, $e_R(\mathbf{x},t)$, $e_{REM}(\mathbf{x},t)$ have been analysed for various models [5,6]. The first and second error invariants $e_L^{(2)}(x,t)$, $e_R^{(2)}(\mathbf{x},t)$ are computed here for the coupled standard maps on $T^4([-1/2, 1/2])$ and the Hénon map on R^4, which describes the non-linear transverse motion in particle accelerators [5]. The possible use of our indicators for Hamiltonian systems with a weak damping and systems with strange attractors is outlined.

Keywords: Lyapunov indicators, reversibility error indicators, round off induced reversibility error (REM), invariance property

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SOCIAL DYNAMICS AND THERMODYNAMICS MOBILITY ON URBAN NETWORKS

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Extended abstract

We propose the following informal definition: "*complex systems are the living or artificial life systems.*" Even though highly informal, this definition has the advantage of being clear and unambiguous. In the Universe, there are two major discontinuities. The first discontinuity is the Big Bang, which gave rise to space, time, particles and radiation. The uniqueness of this event cannot be proved and rises the question: "*What did exist before the Big Bang?*" A way to avoid this open-ended question is to consider a periodic Universe in which the expansion after the Big Bang is followed by a contraction until a Big Crunch which, in turn, is followed by a new Big Bang and so on, indefinitely. The appearance of life is the second major discontinuity, a sort or phase transition, with emerging properties definitely different from the classical ones observed for the aggregation states of matter (e.g., plasma, gas, liquid, and solid).

The appearance of life might be far from being unique since the number of planets in the habitable zone just in our galaxy is estimated to be half a billion [1] not to speak about the billions of galaxies around the milky way. As a consequence, the chances that life has appeared at several places and at different times is high. We should remember that emergent properties or sensitivity to the initial conditions and to the environment are shared by many non-linear systems. According to our definition, it is natural to choose the Von Neumann cellular automaton [2] as the complex unit, we might also call it the *complex atom*. The automaton, virtual or real, has a body with sensors and actuators so that it can perceive the environment and move in it. In addition, it has a central processing unit with a memory on which the instructions to replicate itself are coded. The replication occurs by copying the automaton project on a universal constructor which has access to a reservoir of raw material or pre-built components. Modern computing technology and sophisticated 3D printer are about to close the gap between a simple existence theorem to a technologically mature and self-replicating *complex atom*, which could be used to create independent habitats for future space missions on near planets such a Mars, the major asteroids or the Jupiter and Saturn moons. Models of complex systems, based on an ensemble of interacting automata were considered with a special focus on urban mobility [3,4,5,6]. A toy model of complex system was proposed about 20 years ago and consisted of a system of N hard disks with a visual cone whose axis was aligned along the disk velocity vector. Two disks may attract at long distances and repel at short one. Thermodynamic properties were investigated, showing interesting patterns which depend on the social charge [7] . An application to the urban mobility was consider with *naïve* agents (virtual automata) moving in an urban network with the imposition to be compliant with the highway code [8]. A very significant progress occurred since then concerning the pedestrians motion in a square or in a network, the motion of cars in a highway or an urban network of streets. Also, the amount of data available has increased by several orders of magnitude so that the model can be refined in order to obtain an agreement with the observations. Governing the traffic on the basis of short-term predictions (nowcasting) is today possible by a real time semaphoric control of the action of most critical situations. Examples of pedestrians or vehicles mobility in urban networks are discussed including statistical laws on the velocity or travel time distributions [9,10].
The possibility of simulating swarms of dog-like humanoid robots [9] or drones in and on the sky of urban environments in order to compare simulations with real experiments is discussed.

Keywords: Artificial life, Von Neumann automata, complex networks, urban mobility, social thermodynamics

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AN EXAMINATION OF THE EFFECTS OF THERMAL STRESS ON THE COMPLEXITY OF FLASH PUFS

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Extended abstract

A Physical Unclonable Function (PUF) is the "fingerprint" of a physical object, the generation of which utilises minor manufacturing variations to produce a unique output[1], corresponding to a specific challenge, for a particular instance of the object under certain conditions [1]. Memory-based PUFs most often can provide cost-efficient, practical, lightweight, scalable, and flexible security solutions, because they usually form inherent components of the relevant computer systems they provide security applications for, their realisation and operation do not require significant resources, in terms of both software and hardware, and, due to their storage capacity, a single instance of such a PUF can generate multiple cryptographic tokens of varying lengths, e.g., even several 16,384-bit keys [1].

Our work considers the Flash-memory-based PUF proposed and preliminarily investigated in [1,2,3]. This PUF is based on the disturbances caused on certain NAND Flash memory pages by the rapidly repeated programming of their adjacent memory pages. Generally, each of these disturbed pages is considered as an individual PUF, with its content forming the relevant PUF response. More specifically, in this work, we examine the effects of thermal stress on the complexity of the responses of a PUF implemented on a Commercial Off-The-Shelf (COTS) NAND Flash memory module using programming disturbances, in a similar manner to [4] that considers Dynamic Random-Access Memory (DRAM) retention-based PUFs. In particular, we test a removable Flash memory module serving as a PUF, before and after it is exposed to thermal stress, as well as after a period of inactivity following the exposure of the Flash memory module to thermal stress. To determine the complexity of the recorded binary responses, we utilise well-known PUF metrics, such as their Hamming weight, binary Shannon entropy, intra-device and inter-device Hamming distances, and intra-device and inter-device Jaccard indices.

Four previously unused Samsung K9F1G08U0E NAND Flash memory boards have been tested, and a Weiss Technik LabEvent LC/64/70/3 climate chamber was used to induce the thermal stress. The experimental setup is similar to the one described in [1,2], as shown in Figure 1, while the overall system architecture is demonstrated in Figure 2. Moreover, two memory blocks, of 64 pages each, are considered, with the 32 odd-numbered pages forming the relevant PUFs and the 32 even-numbered pages utilised for the rapidly repeated programming that causes the characteristic disturbances forming the PUF responses of the odd-numbered Flash memory pages, i.e., of the PUF pages. The Flash memory boards have been exposed to a stable temperature of 80°C for a time period of two months, followed by a period of inactivity lasting one month. The responses of the relevant Flash memory PUFs have been recorded before the thermal stress was applied, after one month of constant exposure at the temperature of 80°C, after two months of exposure to 80°C, and after one month of module inactivity following the thermal stress application. All measurements have been performed at a stable temperature of 25°C, using the aforementioned climate chamber.

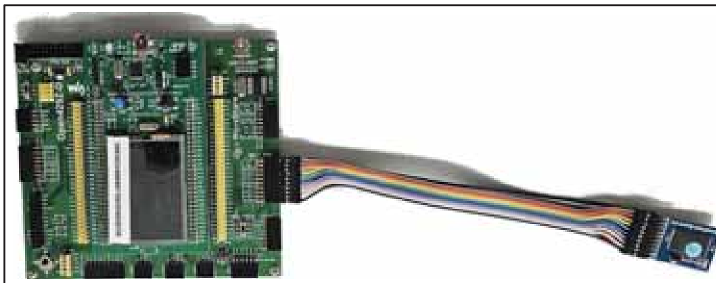

Figure 1: NAND Flash memory module connected to an STM32 board acting as the measurement system.

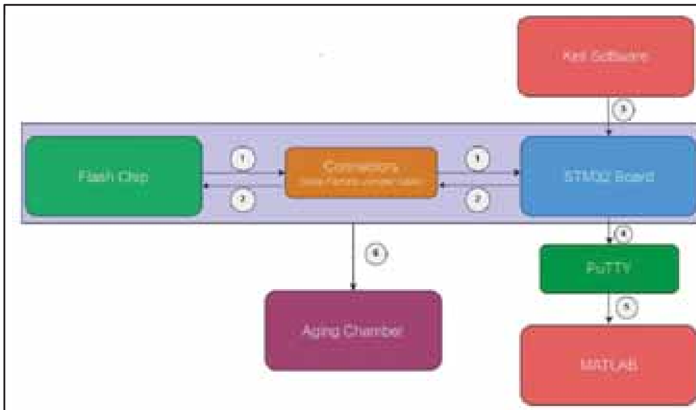

Figure 2: Block diagram of the system architecture.

Our results demonstrate a large variance in the quality characteristics of the PUF responses of the tested Samsung K9F1G08U0E NAND Flash memory in all experimental phases, even when the Flash memory chips are relatively "fresh". Nevertheless, the relevant values, in most cases, indicate a very high level of randomness, robustness, and

[1] Thus, the term "Physical Unique Function" can more accurately describe a PUF.

uniqueness, demonstrating responses of high quality and complexity. Additionally, we have also observed rather divergent effects caused by the thermal stress applied on the different memory chips tested, as the complexity of the PUF responses increases for certain Flash memory chips and decreases for others, while the relevant trends do not appear to be stable even for each individual chip.

Hence, in order to improve the quality of the responses of this type of PUF, and in this way increase their complexity, we have put into effect the two relevant methods suggested in [1,2]. More specifically, we have first excluded from consideration a particular set – the same for all Flash memory boards tested and memory blocks considered – of PUF pages that demonstrate particularly biased responses, i.e., ones that have a very low or a very high Hamming weight, then, in a separate attempt, we have considered all the pages of each Flash memory block as a single PUF instance (referring to the relevant sets of PUF pages of each memory block that form the corresponding individual PUF instances as superpages), and, finally, we have also considered the combination of the aforementioned two methods. However, the exhibited increase in the complexity of the responses and their quality is rather limited, and although the use of superpages as PUF instances leads to an average Hamming weight closer to 0.5 indicating less bias towards one of the two logical values, at the same time, it also leads to much worse values with regards to inter-device metrics, as the different superpages appear to be rather similar to each other, especially when individual pages of high bias are not excluded from their creation.

Quite unexpectedly, the results acquired after the boards have been left to rest for a month (after the two months that they had been under thermal stress) indicate rather good quality and high complexity in the responses of the examined Flash memory PUF, sometimes even better in comparison to the initial responses of the previously unused devices and/or the responses acquired at the end of the thermal stress period.

Thus, our work indicates that the responses of the PUF based on the tested Samsung K9F1G08U0E NAND Flash memory are inherently of high complexity and of good quality, while thermal stress tends to have rather divergent effects on these responses, in some cases improving their complexity and quality and in other cases deteriorating them. Nevertheless, when such thermal stress is followed by a long period of inactivity, the quality and complexity of the relevant responses seem to improve significantly, sometimes even surpassing the complexity and quality observed in the initial responses of the previously unused devices and/or the responses acquired at the end of the thermal stress period. In this way, thermal stress might actually lead to the enhancement of the properties of the examined PUF, including the complexity exhibited in its responses.

Keywords: Physical Unclonable Function (PUF); NAND Flash memory; thermal stress; complexity.

Acknowledgments

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A NOVEL MIXING METHOD FOR 3D TUMBLER MIXERS

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Extended abstract

This study explores the use of chaotic dynamics to enhance powder mixing efficiency in a tumbler mixer. Traditional constant-speed mixing methods often fail to achieve efficient homogeneity in powder mixtures and require extended operation times. In contrast, we hypothesize that chaotic speeds generated from nonlinear dynamical systems can produce more effective and uniform mixing. To test this, simulations of the Halvorsen, Newton-Leipnik, Hadley, and Sprott-A systems were performed, and their chaotic outputs were used to control the rotation of a 3D tumbler mixer via an Arduino Mega microcontroller. Experimental results indicated that the Hadley system achieved the best energy efficiency, while still delivering effective mixing. For instance, chaotic control modes significantly reduced energy usage compared to constant-speed operation, with velocity and acceleration plots demonstrating complex attractor behavior, confirming the presence of chaos [1,2].

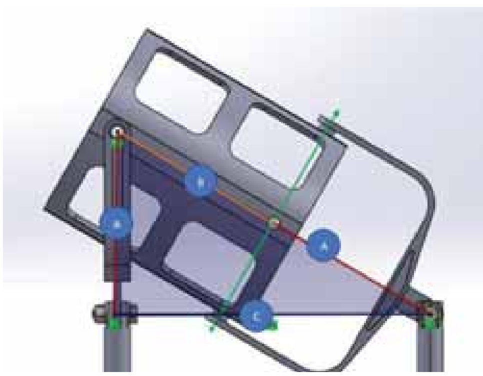

Figure 1: Tumbler mixer design

Figures from the study reveal that for all configurations, trajectory differences between chaotic and constant-speed inputs produced significant gains in mixing uniformity. The Hadley system exhibited a smoother yet dynamically rich profile, while Sprott-A introduced sharper, energetically favorable bursts of motion [2]. The improvements reported in this work align with similar studies, such as Yagmur et al's 3D chaotic mixing application for polymer production [3], and Kalaycı et al.'s delta robot-based chaotic mixer, both of which support the effectiveness of chaos in industrial processes [4].

In conclusion, the integration of chaotic control offers tangible benefits in homogeneity and energy efficiency, contributing to the broader adoption of chaos theory in practical engineering systems. Future work includes testing on diverse materials and exploring feedback-controlled chaotic modulation.

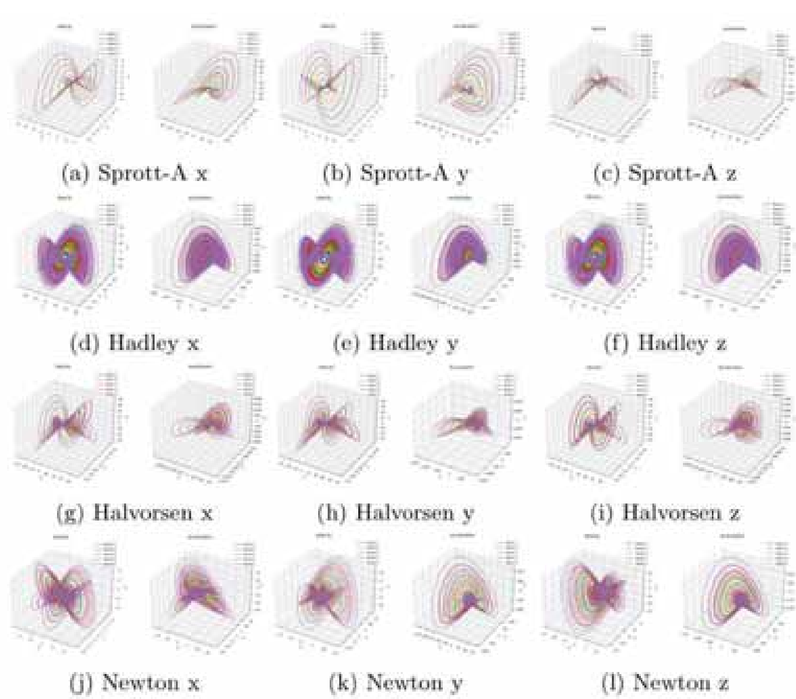

Figure 2: 3D Tumbler mixer velocity and acceleration profiles under chaotic actuation

Keywords: Chaotic systems; Mixing technology; Powder metallurgy; Energy efficiency; Nonlinear dynamics.

Acknowledgments

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Complex switching dynamics in pendula networks

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The collective behavior of coupled identical oscillators exhibits various dynamics ranging from simple phase-locked synchrony patterns to spatio-temporal chimera states and chaos. Chimera states, traditionally, refer to patterns in networks of non-locally coupled identical oscillators in which the network dynamics manifests as synchronization of a subgroup of oscillators and incoherent states of the other group. In pendula networks, however, the so-called *mixed-mode chimera states* are characterized by the coexistence of different synchronous clusters with zero and non-zero average frequencies [1]. The frequency clustering behavior follows the notion of weak chimera states with characteristic examples arising in the Kuramoto model with inertia where solitary chimeras are found in all types of network coupling from local to global.

We report different types of collective dynamics and chimeric phenomena for a network of N=100 all-to-all coupled pendula, followed by a detailed description of the minimal case of N=3. The existing regimes of different chimeras, fixed-point and chaotic attractors are obtained in the parameter plane (coupling strength and phase-shift). Large coexisting regions for these behaviors are found, where the system dynamics are multistable; the asymptotic behavior of the system trajectory then depends on the initial conditions.

We identify three scenarios for the transition to the spontaneous chaotic switching between the chaotic chimera states: 1) starting with a riddling bifurcation where an unstable periodic orbit inside the chaotic chimera becomes transversally unstable while the chaotic chimera itself on average remains transversely stable 2) a blow-out bifurcation, where the chaotic chimera becomes transversally unstable in average and 3) a chaotic chimera becomes a laminar chaotic saddle within a so-called turbulent attractor [2]. This kind switching behaviors cause an additional uncertainty in the limiting system behavior, which becomes even less predictable due to the possiblity of system trajectory escpaing to an stable equilibrium or limit cycle co-exising with the chaotic switching.

Keywords: Chaos; Chimera states; Chaotic Switching; Nonlinear dynamics; Pendula networks.

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Complexity in industrial scale of innovative medicines and dietary supplements

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Extended abstract

Chaos, or the exponential sensitivity to small perturbations, is ubiquitous in nature and many kinds of phenomena are considered chaotic. Complexity and chaos theory offers a universal framework for studying dynamical systems in an interdisciplinary manner.[1]

The industrial-scale production of innovative medicines and dietary supplements presents multifaceted challenges that stem from scientific, technological, regulatory, and economic complexities. As research in pharmaceutics and nutraceutics advances, to translate laboratory breakthroughs into mass-produced, market-ready products requires sophisticated approaches.[2] Especially, the complex and dynamic nature of the self-assembly process of biomaterials is of particular interest currently, in order to produce well-defined morphologies and biophysical properties in advanced healthcare products (Figure 1).

Herein, we explore the inherent complexities in scaling up such products, including their manufacturing processes, quality control, stability, bioavailability, and interaction with the evolving regulatory frameworks. Particular emphasis is placed on the integration of advanced technologies such as nanotechnology, and AI-driven systems. Additionally, the interplay between innovation, consumer demand, and regulatory scrutiny in both pharmaceutical and dietary supplement sectors is presented. Understanding these layers of complexity is essential for stakeholders aiming to achieve sustainable scalability while ensuring safety, efficacy, and economic viability in a competitive global market.

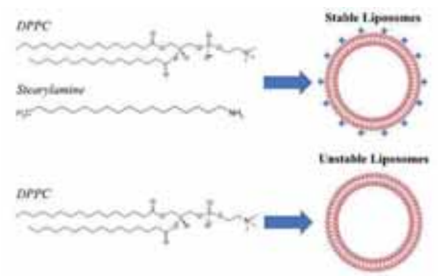

Figure 1: Two cases of nanoparticulate systems and their respective biomaterials[3]

New health technologies have become a cornerstone of the twenty-first century, playing a pivotal role in the advancement of knowledge, scientific discovery, and economic growth.[4] These technologies are not only crucial drivers of societal progress, but they also significantly contribute to shaping modern economies by creating new industries, job opportunities, and improving the quality of life for individuals worldwide. However, as these innovations rapidly evolve and become increasingly integrated into healthcare systems, they present complex and often daunting challenges. In this increasingly complex landscape, the concept of "complexity" gains importance as a framework for understanding the intricate nature of both living and artificial systems. These systems, by their very design, are inherently dynamic and multifaceted, evolving in response to both internal and external factors. As such, complexity is not just a feature of these technologies, but a critical perspective that helps us unravel their behavior, adaptability, and overall impact. It provides a lens through which we can better understand their evolution over time, assess their quality, and develop strategies to ensure their effectiveness and safety in health applications.

Keywords: Production process; Biomaterials; Analysis tools; Quality; Regulatory framework

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INVESTIGATIONS OF THE INTERACTIONS OF GLU-GLU-ARG, GLU-PRO-ARG AND PRO-ARG-PRO TRIPEPTIDES THAT HAVE ANTI CANCER PROPERTIES, WITH HUMAN SERUM ALBUMIN BY MOLECULAR DOCKING STUDIES

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Abstract

Human serum albumin (HSA) is the main blood plasma carrier protein that binds and transports several exogenous and endogenous substances. It also performs important roles in various biological systems and processes. Drugs distributed throughout the body via the bloodstream can bind to HSA extensively and reversibly. In pharmacology, interactions with proteins can affect the biological activity and toxicity of drugs. In our previous study we investigated the anticancer and antiviral properties of Glu-Glu-Arg, Glu-Pro-Arg and Pro-Arg-Pro tripeptides by molecular docking and molecular dynamics simulations [1]. It was shown that tripeptides have good anticancer properties. Moreover, in Silico Structure-Based anticancer and antibacterial predictions of the Glu-Glu-Arg, Glu-Pro-Arg and Pro-Arg-Pro tripeptides showed potential activity against various cell lines of chondrosarcoma and different bacteria stains [1]. Thus, the interactions of these tripeptides as anti-cancer and anti-viral agents with HSA were found to be interesting for to evaluate their pharmacokinetic and pharmacodynamics properties.

Molecular docking, a computer-assisted drug design method, is one of the targeted approaches that play an important role in pharmaceutical research. In this study the binding energies and binding modes of these tripeptides in Human Serum Albumin (HSA, PDB ID: 1AO6) were evaluated by molecular docking studies.

Keywords: HAS, tripeptides, anticancer, docking

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NOVEL EXPERIMENTS ON THE LIESEGANG PHENOMENON

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Extended abstract

We present some special aspects of periodic precipitation in reaction-diffusion systems. In a first project, carrageenan gel is texturized by a diffusing KCl solution, yielding microscopic stratification similar to Liesegang banding (Figure 1.a). Dynamical and structural studies are conducted to unravel the physico-chemical mechanism leading to such interesting topological rendering.

In a second study, a diffusion-precipitation reaction is coupled to a redox scenario initiated through an applied DC electric field to generate two-precipitate patterns. Water reduction by electrolysis can precipitate $Pb(OH)_2$ and couple to PbI_2 precipitation in a Liesegang setting (Figure 1.b). Similarly, electro-oxidation of Fe^{2+} to Fe^{3+} can co-precipitate $Fe(OH)_3$ in an original $Fe(OH)_2$ framework (Figure 1.c). The obtained bands are analyzed and identified using ion-selective electrodes, SEM, powder XRD and EDX methods. The pattern morphology is characterized, delineating between overlap or alternation of bands, or even completely separate, banded precipitation zones. The possibility of chaotic patterning inherent in the dynamics is investigated.

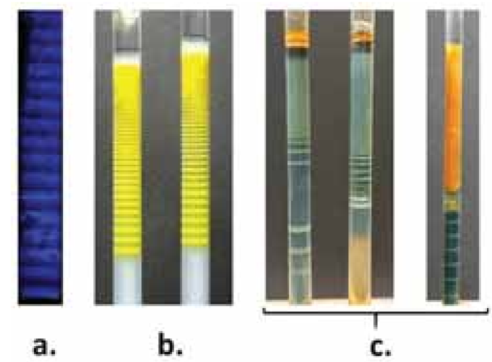

Figure 1: A mosaic of Liesegang patterns

Keywords: Liesegang; Periodic Precipitation; Carrageenan; Electrolysis; Keywords.

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Comparing different chaotic indices in systems with maximal Lyapunov Characteristic Exponent very close to zero

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Extended abstract

Determining a system as chaotic requires a more in-depth investigation using different numerical or analytical tools. The primary method that scientists use is the Lyapunov Characteristic Exponents, but it is not the only method. Several scientists have introduced different methods that utilize various properties of dynamical systems. This talk presents four different chaotic indicators based on the evolution of the deviation vectors: the maximal Lyapunov Exponent, the Lyapunov Characteristic Exponents, the Fast Lyapunov Index (FLI), and the Small Alignment Index. Also, we will use some of these indices to study the dynamic behavior of systems with a maximal Lyapunov Characteristic Exponent that is very close to zero.

Keywords: chaotic indices, maximal Lyapunov Exponent, Lyapunov Characteristic Exponents, SALI, FLI

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Chaotic Dynamics in Gold Price Time Series: A Physics-Based Forecasting Approach

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Extended abstract

The study presented hereby analyzes the evolution of the price of gold (in USD per ounce) from 1995 to 2025. The performed study utilizes established methods originating from nonlinear dynamics and chaos theory, extending previous work [1].
The time series is partitioned into four distinct segments to investigate and assess the persistence of chaotic behavior across temporal different regimes. Chaos is quantified through the calculation of the embedding dimension, the fractal dimension, and Lyapunov exponents [2], confirming an underlying deterministic nonlinearity in all segments [3].
The results indicate that gold prices exhibit low-dimensional chaos. Notably, the underlying dynamical structure remains stable despite significant shifts in the global financial environment, suggesting that the fundamental drivers of gold's price movements are governed by a consistent set of variables [4]. Based on these findings, we implement a forecasting model leveraging phase-space reconstruction to predict near-future price trends, demonstrating the practical applicability of chaos-theoretic approaches in commodity markets [5]. Our results advocate for the integration of nonlinear dynamical systems theory into financial risk management frameworks, particularly for assets exhibiting chaotic behavior.

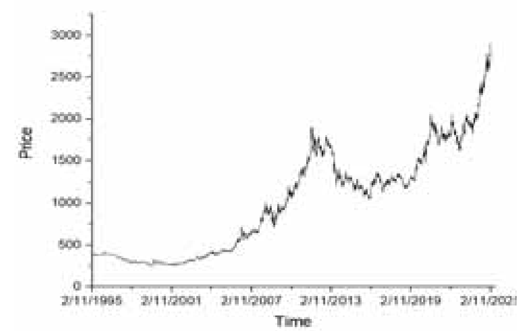

Figure 1: Gold price evolution for the period 1995-2025.

Keywords: Gold price dynamics; Chaos theory; Nonlinear time series analysis; Econophysics; Risk management.

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Network Analysis of Chaotic Dynamics and Stability of Liposomal Nanosystems

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Extended abstract

Liposomal nanosystems are critical in drug delivery due to their ability to encapsulate and release therapeutics efficiently [1]. These nanosystems consist of lipid bilayers forming spherical vesicles that can entrap active agents in their aqueous core or within the lipid bilayer [2]. However, their dynamics and stability are influenced by various factors leading to chaotic behavior, which complicates their practical applications [3]. The emerging complexity, due to the emerging chaotic dynamics, introduces unpredictability that can affect the stability and release profile of the encapsulated agents, thereby impacting the therapeutic efficacy and safety. This paper presents a network analysis approach to understand and characterize the dynamics and stability of liposomal nanosystems. In specific, we explore the interactions within liposomal structures and between the nanosystems and their environment using network theory. Our findings further lead to insights into the complex regimes of liposomal behavior and suggest strategies for stabilizing these systems for enhanced performance in biomedical applications. Two types of networks derived by two sets of experimental measurements on a stable and an unstable sample, are studied. The stable sample network reflects conditions where liposomal size and polydispersity are tightly regulated. Biological processes such as drug encapsulation or controlled release in pharmaceutical formulations often target such stable systems for predictable behavior. On the other hand, the network corresponding to the unstable sample represents dynamic and unstable conditions. Such instability can mimic biological processes like membrane fusion during vesicle trafficking or pathological destabilization of lipid structures in diseases.

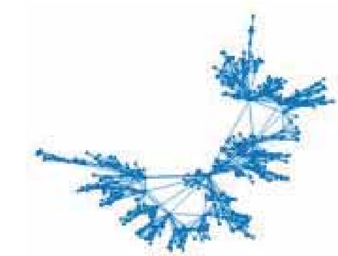

Figure 1: The visibility graph of the polydispersity (PDI) for a stable liposomal sample (DPPC:SA).

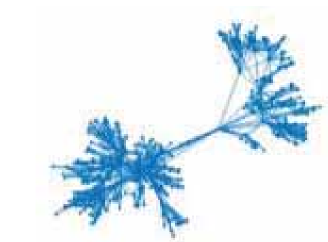

Figure 2: The visibility graph of the polydispersity (PDI) for a unstable liposomal sample (DPPC).

Network generation depicting the self-assembly process of phospholipids into membranes and liposomes, utilizing the visibility graph technique is presented in the case of a stable (Figure 1) and an unstable sample (Figure 2). An initial report on the corresponding network metrics is also presented [4]-[6].

Beyond reporting and analyzing relevant network metrics between the stable and the unstable case, future work should concentrate on providing interpretations of the estimated metrics and on looking for further insights of the impact of these two distinct behavioral cases in drug delivery and therapeutics efficiency.

Keywords: Complex Networks, Liposomes, Lipid nanoparticles, Artificial bio-networks, Bioinformatics

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The European Regulation on AI

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Extended abstract

In 2020, the European Commission published a White Paper entitled ‘White Paper on Artificial Intelligence: a European approach to excellence and trust’. Five years later, Europe has adopted its first law (the so called, EU AI Act) that regulates AI systems and is applicable to all EU Member States. Before anything else, one should understand the AI Act’s legislative journey; from the European Commission highlighting the need to have a common EU Law on AI, to proposing that law and finally adopting and enforcing it. Which are the key actors (european institutions and relevant stakeholders) involved in the EU legislative process and how long did that process last? In what way does the EU AIA form part of the wider EU Digital Strategy and how does it interract with laws such as the GDPR (General Data Protection Regulation)? After having placed the EU AIA into the broader EU legal structure, we shall dive deeper into the actual rules set by the Regulation. The EU AIA introduces rules for the placing on the market, the putting into service, and the use of AI systems in the Union, prohibitions of certain AI practices, specific requirements for high-risk AI systems and obligations for operators of such systems, harmonised transparency rules for certain AI systems. The Regulation also sets specific rules that apply to General-Purpose AI and it classifies AI systems into four distinct categories on the basis of the risk those systems present to the fundamental rights and freedoms, health and safety. The EU AIA endorses a risk-based approach in the sense that the higher the level of risk raised by an AI system, the stricter the obligations for providers and deployers (e.g. conformity assessment, fundamental rights impact assessment, compliance with specific requirements such as transparency / cybersecurity / human oversight, obligations among the various actors of the supply chain etc). It is also useful to explore the role that standards could play when developing AI systems, as well as the European governance around AI with the establishment of new bodies, as is the European Artificial Intelligence Board (EAIB). Next to Europe, other non-EU jurisdictions (e.g. Brazil, APAC, Canada etc) as well as organisations (e.g OECD, Council of Europe) have made important steps towards regulating AI systems. It is crucial to take note of the global state of play with regard to the regulation of AI, given that AI technology and its impact to the world is beyond Europe’s borders.

Keywords: Artificial Intelligence; EU AI Act; high-risk AI; prohibited practices; global AI.

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Modeling Women's Employment Rates in Turkey and BRICS Countries Using Fractal Analysis

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Extended abstract

Women's participation in the labor force is crucial for economic growth and sustainable development. However, female employment in the labor market is influenced by dynamic and unpredictable processes, shaped by factors such as economic crises, education levels, social norms, technological advancements, and political variables. This study examines the use of fractal analysis in modeling women's employment rates in Turkey and BRICS (Brazil, Russia, India, China, South Africa) countries.

Chaos theory helps understand the underlying order within complex and nonlinear systems. The variability of female employment rates in Turkey and BRICS countries over the years will be analyzed in conjunction with economic and social indicators to determine whether these trends exhibit chaotic structures. In this context, fractal analysis will be employed to examine past trends in women's labor force participation and forecast potential future scenarios.

The study will utilize employment data from Turkey and BRICS countries to develop machine learning-based models incorporating chaotic data sets. By examining how female employment rates respond to economic fluctuations, proactive policy strategies will be proposed for policymakers. These analyses will provide new perspectives on the nature of labor markets and contribute to the development of sustainable employment policies.

Ultimately, the study will demonstrate that fractal analysis is an effective tool for modeling women's labor force participation in Turkey and BRICS countries. This research will contribute to both industrial engineering and economics by offering new approaches to understanding employment dynamics.

Keywords: Fractal Analysis, Women's Employment, Machine Learning, Labor Market, BRICS Countries

SENTIMENT ANALYSIS ON BIBLICAL TEXTS

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Religion is an important component of human culture and is a complex of beliefs, ideas, rituals, hierarchy, and rules. It was, and still is, an important pillar in the development of culture. The reasons for the existence of religions are various and their influence on the human race is enormous, since they strengthened social cohesion, set conditions of behavior, caused wars, and helped discoveries and inventions. An important means of preserving and propagating a religion are religious texts, which contain narratives about Gods and important people, admonitions, and prophecies. The authors of these texts approached the topic from a different point of view, expressing, beyond the doctrine they followed, their personal point of view. This view, as well as the emotions that overwhelmed them while writing, is a matter of research, debate, and speculation.

Several historians have been interested in them and using various methodologies, they have come up with interesting opinions and useful conclusions. However, all of these methods involve the human factor, mainly in the form of the researcher's personal opinion, which results in questioning their objectivity. In contrast, natural language processing (NLP), which enables machines to understand, analyze, and produce human language, with the help of machine learning, is a tool that is not influenced by the personal point of view of the researcher and can shed light on unseen aspects of the character of the authors of religious texts.

In this work, sentiment analysis techniques are used to reveal the emotional state of authors of Biblical texts, as well as their point of view on the issues they deal with. Analyzing emotions in biblical texts can provide a new perspective for understanding the text. It can help to explore the feelings of the writers of the Biblical texts and the feelings expressed. This understanding can be useful in the study of history, religion, and literature.

The subject of this work is the analysis of a text from the Greek New Testament. After the collection of the necessary data and their pre-processing, the analysis of the emotional loading of the authors followed. Specifically, five algorithms were used, each of which uses models for sentiment analysis, emotion recognition, and semantic search.

After running the experiments, the extracted results showed that in Algorithm 1, 57.7% of the sentences were classified as positive and 42.3% as neutral, with no negative sentences, in Algorithm 2, 52.7% were positive, 47.3% were neutral, and none were negative, in Algorithm 3, 62.8% were classified as positive, 32.5% as negative, and 4.7% as neutral, in Algorithm 4, 51.9% were positive, 48.1% were neutral, and none were negative, and in Algorithm 5, 74.4% were positive, 25.5% were negative, and none were neutral.

To demonstrate the reliable operation of the algorithms used, their ability to sentiment analysis in different texts was tested. This text was of a similar size to those used in the present study, and its sentences were already labeled as “positive”, “neutral”, and “negative”. The results showed that the sentiment analysis was completely successful, which is a strong indication that the algorithms have reliable operation.

The main conclusion of this work is that the results were shown to be similar to those reached by scholars of the same text, which is an important finding and a strong indication that machine learning can work reliably in sentiment analysis of religious texts. This indication remains to be confirmed by similar research, and once done, machine learning can be used as a tool in the interpretation of such texts.

This research can be expanding in many ways. First, by extending the sample of texts, adding more biblical texts to the analysis. Second, by looking at different translations of biblical texts, as sentiment analysis can be affected by the words and language structure used in the translation. Finally, by combining emotional analysis with other parameters, such as language use and symbolic representation, to provide a more complete understanding of the emotional dimension of biblical texts in the context of religious and cultural communities.

EXPLORING THE ASSESSMENT OF STUDENT ATTENTION AND ENGAGEMENT THROUGH COMPUTER VISION

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Extended abstract

The assessment of students' attention and active participation levels can provide valuable insights for educators, helping them adjust their teaching strategies in real-time or in the short term according to the classroom's needs, with the goal of improving learning outcomes. Therefore, the assessment of students' attention and engagement is critical towards evaluating the impact of the learning process. Typical attention assessment tools include student questionnaires and surveys conducted within the classroom after a lecture or by the end of the semester [1]. However, even if such tools provide some insights, they fail to capture the real-time in-class engagement level of students. Therefore, additional assessment methods are being considered, such as direct observation and formative assessment to gain a more comprehensive understanding of the students' engagement. Even so, continuous observation and ongoing feedback would ideally require a human observer per student, or it could be conducted by teachers while teaching, administering, and analyzing the observations in real time, which is not feasible in practice.

Monitoring students with cameras and analyzing their attention through computer vision techniques allows for real-time monitoring and objective measurements through the analysis of specific visual cues. It is non-invasive and can provide a wide range of captured data from multiple students at the same time, including emotional and behavioral indicators [2]. Most importantly, computer vision is closely related to adaptive learning, capable of providing instant cues regarding students' engagement and thus enabling personalized learning experiences by reshaping the teaching mode in real-time to recapture students' attention and improve the dynamic of the lecture.

This research direction arises from gaps observed in the literature regarding the potential of computer vision for assessing students' attention and engagement, as well as the possibility of improving the educational process through these techniques. While similar studies have been reported [3,4]; which focus on the development of autonomous agents or teaching assistants providing information to students and teachers, there is no comprehensive review of the existing literature examining the aspects of computer vision and student engagement. Other works [5] focused on specific attention estimators coming from computer vision systems, related to emotions or behavior. Therefore, this work aims to fill these gaps and identify all the components of the complex process of monitoring students' engagement. The latter includes five main directions, guided by targeted research questions: (1) Computer vision methods for students' attention and participation analysis, (2) types of students' participation, (3) input devices for computer vision in educational processes, (4) information provided by computer vision regarding students' participation, and (5) factors affecting attention and participation analysis. To this end, this paper conducts a systematic review of the current literature, examining the impact of integrating computer vision in the analysis of student behavior, attention, and active participation within the educational framework. At the same time, it explores how computer vision techniques can contribute to enhancing the educational experience, highlighting both the prospects and challenges associated with this research field.

The findings indicate that, despite the potential of computer vision for personalizing learning, significant challenges remain, such as the need for more accurate algorithms, advanced technological infrastructure, and secure management of personal data. Furthermore, there has been an increased use of such techniques post-COVID-19, especially in the context of remote education. The study identifies key factors that influence the assessment of students' attention and suggests directions for future research, such as incorporating multimodal data for a more comprehensive analysis of learning behavior. These findings underscore the role of computer vision in improving the educational experience, while also highlighting challenges that require further investigation.

Keywords: Computer vision; learning analytics; engagement assessment; attention detection; education.

Acknowledgments

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Information–Theoretic Analysis of Visibility Graph Properties of seismic point processes

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Extended abstract

The field of complex network theory has expanded significantly with the introduction of methods for converting time series into networks, which have been successfully applied across various research fields. In the last decade, the visibility graph has gained popularity due to its straightforward implementation and effective performance on both natural and synthetic data [1].
Information Theory quantifiers, like the Fisher Information Measure and the Shannon entropy, have been used to extract information from networks generated by the visibility graph. While several studies have explored the informational properties of visibility graph networks derived from time-continuous series, such as fractional Brownian motion [2], none have focused on the informational properties of visibility graph networks from point processes.
In this study we focus on a particular case of point process: earthquake sequences. These can be represented as temporal point processes, where each event is marked by its magnitude. In this framework, p(t) describes the distribution of event occurrence times, while p(M) represents the distribution of earthquake magnitudes. p(M) represents the well-known Gutenberg-Richter law, $\log_{10}(p(M))=a-b(M-Mo)$, where b is a parameter that quantifies the relative proportion of small to large events and provides insights into the stress conditions of a seismic region, and Mo is the completeness magnitude, which corresponds to the minimum magnitude detectable by the seismic network. The function p(t), which describes the distribution of event occurrence times, can take various forms depending on the seismic process. In particular, we examine two extreme cases: the power-law distribution, which models a clustered seismic sequence, and the exponential distribution, which models a Poissonian seismic sequence.
In this study, we illustrate the different patterns in the relationship between the Fisher Information Measure and the Shannon entropy of the degree of networks generated by the visibility graph for seismic point processes, depending on the parameters of p(M) and p(t).
The results of this study can contribute to further explore the complexity of seismic sequences.

Keywords: Visibility graph; Fisher Information Measure; Shannon entropy; point processes; seismic sequences

Acknowledgments

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Modeling Student Behavior and Predicting Academic Performance Using LMS Data

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Extended abstract

Introduction. The COVID-19 pandemic has significantly accelerated the adoption of digital education platforms, particularly Learning Management Systems (LMS). Research indicates that student activity on these platforms increased during the pandemic, playing a critical role in sustaining educational processes (Fitriani, 2020). This shift underscores the need to analyze student behavior patterns and their impact on academic outcomes.

Objective. This study aims to develop a predictive model for academic performance by integrating process mining and machine learning (ML) techniques. The primary focus is to extract meaningful behavioral process models from LMS data and correlate them with academic success.

Methodology. The research utilizes event logs from a university LMS, comprising 105 students' interactions over one academic semester. Process mining techniques, including Inductive Miner (van der Aalst, 2016), are applied to model student learning pathways. Key features such as activity frequency, session duration, and process conformance scores are derived. Machine learning algorithms—Random Forest (RF), Support Vector Machines (SVM), and XGBoost (Chen & Guestrin, 2016)—are trained on a combined dataset of traditional LMS metrics and process mining outputs. Performance is evaluated using F1-score, AUC-ROC, and precision-recall metrics.

Results. The integration of process mining features contributed to a noticeable enhancement in ML model accuracy, with XGBoost demonstrating the strongest performance in terms of AUC. Key behavioral factors, such as timely assignment submission and consistent engagement with course materials, appeared to be significant indicators of academic success. Additionally, conformance checking suggested that students who followed structured learning paths generally achieved better outcomes.

Conclusion. This study demonstrates that process-oriented analysis enhances the predictive capability of academic performance models. The findings enable personalized educational interventions and optimize LMS efficiency. Future work will focus on testing the generalizability of the developed model by applying it to courses from different disciplines and evaluating its performance across various machine learning algorithms. Additionally, real-time adaptation of learning strategies using explainable AI (XAI) techniques will be explored.

Keywords: Educational Process Mining, Machine Learning, Learning Management Systems, Academic Performance Prediction, Student Behavior Analysis

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Mapping Competency Development Through Student Interaction Networks in a Web 3.0 Learning Environment

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Extended abstract

This study presents a novel approach to competency-based education through the visualization of student interaction networks in a Web 3.0-supported learning environment. It introduces the PUMA (Performance and Upskilling Management Application) mobile app as a platform that utilizes decentralized technologies, AI-driven personalization, and gamification to track and enhance students' learning processes.

Web 3.0 and Educational Transformation. Web 3.0 technologies—comprising semantic web structures, decentralization, artificial intelligence, and gamified experiences—offer significant potential for transforming traditional educational systems [1]. These tools allow for real-time interaction tracking, adaptive feedback mechanisms, and learner autonomy, creating dynamic and student-centered learning ecosystems.

Network Mapping and Competency Modeling. The core of the project involves capturing and analyzing student interaction data as a complex network. Nodes represent learners, while edges represent participation in academic events, peer collaborations, or system-driven tasks. These networks are used to construct visual competency maps [2] that reveal how learning behaviors and achievements evolve over time.

Methodology and Results. The PUMA mobile app was developed and deployed at the university level. Student activity data—including task completions, badge achievements, and social interactions—were collected and processed using network analysis tools. Findings show that students with denser interaction networks exhibit higher levels of competency development and engagement. Personalized feedback and visualized learning paths positively influenced self-regulation and academic motivation [3].

Conclusion. By integrating network theory with Web 3.0 infrastructure, the PUMA application transforms the traditional learner assessment approach into a dynamic, data-driven, and personalized experience. The findings offer strategic implications for designing scalable and adaptive educational technologies. This research provides a framework for future AI-enhanced systems that aim to support student success through intelligent, competency-based learning models.

Keywords: Web 3.0 Technologies; Student Interaction Networks; Competency Mapping; Gamification in Education; Personalized Learning.

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CHAOTIC COVERAGE PATH PLANNING USING LORENZ CHAOTIC CIRCUIT

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Extended abstract

Coverage Path Planning (CPP) is essential in robotics, particularly for tasks requiring systematic area coverage such as cleaning, inspection, and exploration. Techniques like spanning tree algorithms, neural networks, and recursive approaches are commonly utilized to enhance efficiency in terms of energy and time [1]. Spanning tree algorithms ensure comprehensive coverage without unnecessary repetition, neural networks adaptively optimize paths using environmental data, and recursive methods prioritize unvisited neighboring cells, making them effective for dynamic or grid-based scenarios.

An innovative approach to addressing CPP challenges involves leveraging chaotic systems. Emerging from chaos theory in the 1960s, these systems exhibit high sensitivity to initial conditions [2], which can be harnessed for adaptability and efficient exploration of unknown spaces. Unlike random walk methods, chaotic systems offer a strategic balance that is predictable for the robot itself but unpredictable to external observers [3]. This feature makes them ideal for tasks requiring thorough exploration, especially when sensory and computational resources are limited.

This study delves into how the Lorenz system can be applied to control robotic movement, with a focus on CPP. By exploiting the inherent unpredictability of chaotic circuits, robots can achieve superior coverage in environments where traditional algorithms might fall short [4].

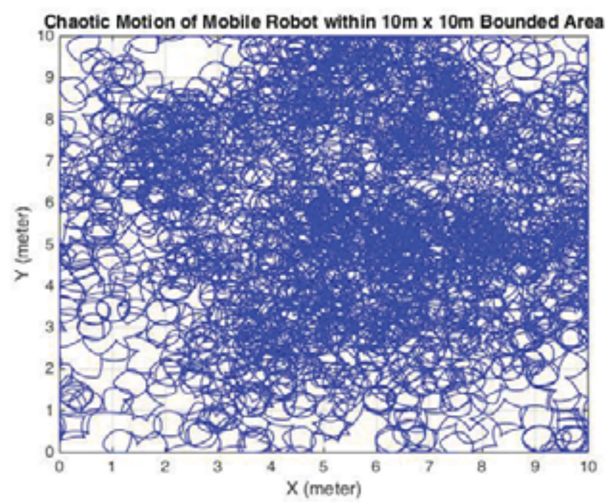

Figure 1: Coverage area 88.87%

Keywords: Non-linear circuits; Mobile robot; Coverage path planning; Chaotic behavior; Lorenz equations

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OPTIMIZING THE RECURRENCE THRESHOLD FOR TIME SERIES ANALYSIS IN DYNAMICAL SYSTEMS

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Extended abstract

Recurrence matrices serve as powerful tools for identifying phase-space recurrences in time series, capturing instances when the phase point revisits previously explored regions. The selection of an appropriate recurrence threshold is critical, as it defines the size of these regions and directly influences the informativeness of the recurrence matrix.

In this study, we propose a general framework for characterizing time series using recurrence-based metrics to classify underlying dynamical systems. Our approach determines the optimal recurrence threshold by analyzing the phase-space average velocity of the phase point, providing a data-driven criterion for threshold selection.

The proposed method is systematically compared to conventional approaches, including the commonly used fixed threshold at 5% of the data's standard deviation and a constant recurrence rate *[1, 2]*. Through evaluations on both theoretical models and real-world time series, our results demonstrate that our approach more accurately captures system dynamics and enhances classification performance based on recurrence matrix features.

By leveraging phase-space velocity analysis, we introduce an improved criterion for selecting the recurrence threshold, which offers superior performance compared to traditional methods. This advancement contributes to more reliable time series analysis and classification of dynamical systems.

Keywords: Recurrence analysis, time series, dynamical systems, phase-space velocity, threshold selection

Acknowledgments

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MODELING CHAOTIC BEHAVIOR IN THE LORENZ SYSTEM WITH LAYERED POLYNOMIAL NEURAL NETWORKS

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Extended abstract

Understanding the dynamics of complex systems governed by ordinary differential equations (ODEs) is a critical challenge across various scientific disciplines. Many of these systems are inherently polynomial in nature, yet traditional modeling approaches face significant challenges in accurately capturing their intricate behavior. Polynomial Neural Ordinary Differential Equations (PolyNODEs) [1, 2] have been developed to address these issues, but they suffer from underparameterization as the system's degrees of freedom and the polynomial degree increase. To overcome these limitations, we have developed a novel machine learning tool, the Layered Polynomial Neural Network (LPNN), specifically designed to accurately recover the governing equations of complex multivariate polynomial systems directly from raw data.

LPNNs feature a hierarchical structure composed of sequential shallow neural networks, each dedicated to modeling polynomial terms of increasing degree. This layered design enables the efficient construction of polynomial combinations up to any desired degree, enhancing the model's expressivity while maintaining interpretability. The architecture dynamically scales the number of parameters to match the complexity of the target system, effectively mitigating underparameterization. By incrementally generating polynomial coefficients, LPNNs offer a flexible and scalable solution capable of modeling systems with high degrees of freedom and complex interactions.

The effectiveness of LPNNs is demonstrated through their application to the Lorenz system [3], a canonical example of chaotic dynamics characterized by sensitive dependence on initial conditions. The Lorenz system, defined by a set of three coupled nonlinear differential equations, serves as a rigorous benchmark for evaluating the performance of dynamic system models. Our results show that LPNNs successfully capture the system's chaotic behavior, accurately reconstructing its governing equations and reproducing the iconic butterfly-shaped attractor. The model's predictions closely align with the true system dynamics, validating the approach's ability to handle complex, high-dimensional systems.

Training the LPNN involved optimizing a custom loss function that combines the Mean Squared Error (MSE) with sparsity-promoting regularization terms [4]. This approach ensures that the learned models are both accurate and interpretable. Hyperparameters were fine-tuned using the Optuna framework [5], enhancing model performance and stability. The Adam optimizer was employed for efficient gradient-based optimization, resulting in rapid convergence and high-fidelity modeling. Training data consisted of trajectories sampled from the Lorenz system, and validation was conducted on unseen trajectories to assess generalization.

Beyond the Lorenz system, LPNNs have the potential for broader applications in fields where polynomial dynamics are prevalent, including fluid dynamics, plasma physics, and biological systems. However, the scalability of LPNNs remains a challenge due to the combinatorial growth of polynomial terms, which exponentially increases the number of neural network parameters. This growth can result in significant computational costs for high-dimensional systems. Future work will focus on addressing this limitation by integrating sparsity-promoting techniques and exploring extensions to more complex dynamical systems.

Keywords: Layered Polynomial Neural Networks; Chaotic Systems; Neural ODEs; Symbolic Regression; Lorenz System.

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The Relationship Between the Logistics Performance Index and Economic Growth: A Panel Data-Based Analysis for the Period 2007–2023

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Extended abstract

The logistics sector plays a strategic role in ensuring the smooth operation of global trade and achieving the sustainable development goals of national economies. In this context, the LPI, periodically published by the World Bank—with occasional interruptions such as during the pandemic—serves as a key indicator for measuring the efficiency of countries' logistics systems. The LPI consists of six core components: the efficiency of customs clearance processes, the quality of trade and transport infrastructure, the ease of arranging international shipments, the competence and quality of logistics services, the timeliness of deliveries, and the effectiveness of tracking and tracing consignments.

This study aims to analyze the relationship between logistics performance and economic growth through a panel dataset constructed from LPI reports published between 2007 and 2023, along with per capita GDP growth rates obtained from the World Bank. The analysis focuses on the top 10 countries in the 2007 LPI ranking, along with Türkiye. To account for cross-country structural differences, both fixed effects and random effects models are estimated, and the Hausman test is applied to determine the more appropriate model.

The findings are expected to provide clearer insights into the impact of strategic investments in logistics infrastructure on economic growth and contribute to policy development in this field. In this regard, the study aims to offer both a contribution to the academic literature and data-driven guidance for decision-makers.

Keywords: Logistics Performance Index, Economic Growth, Panel Data Analysis, Fixed Effects, Random Effects, Hausman Test, GDP

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Bridging Surface Complexity and Neural Network Loss Landscapes: A Unified Metrological Perspective

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Extended abstract

Recent breakthroughs in both materials science and machine learning underscore the importance of understanding complex surfaces—whether they describe physical topographies of materials or high-dimensional neural network error functions. In the materials domain, metrology provides a robust toolkit for capturing surface complexity through metrics such as roughness parameters, fractal dimensions, and autocorrelation functions. These measures not only reveal intricate multiscale features of surfaces ranging from thin films to biological interfaces, but they also illuminate how small structural variations can significantly influence global properties like adhesion, mechanical stability, and transport phenomena.

A parallel development in machine learning focuses on the “loss landscape,” a high-dimensional “surface” depicting the error or cost associated with various configurations of model parameters. The geometry and topology of this landscape—its basins, saddle points, and overall ruggedness—play an essential role in determining how efficiently a network can be trained, whether it converges to globally optimal or merely good-enough solutions, and how well it can generalize to unseen data. Yet, formal tools for quantifying these properties remain an active area of research.

By unifying these two perspectives, this work outlines a framework in which established metrological techniques—such as height–height correlation functions, correlation length analysis, and fractal-based roughness indices—can directly inform the study of neural network loss landscapes. Specifically, these metrics can identify characteristic spatial scales and degrees of complexity in the parameter space, offering new ways to track the training process and pinpoint regime shifts in a model’s error surface. For example, understanding how correlation lengths change over the course of training may reveal the transitions of a model from exploring numerous shallow minima to settling into a narrower basin of attraction. Likewise, fractal measures could help quantify how finely or coarsely structured the overall loss surface is, yielding insights into why some network architectures are more resilient to noise or more prone to overfitting.

To further extend the available toolbox, we introduce two new complexity metrics: one grounded in the Arnold cat map—capturing the distance from the structured noise it generates—and another based on multiscale Shannon entropy, quantifying the landscape’s deviation from homogeneity. These additional measures aim to expose subtler aspects of high-dimensional surfaces, illuminating how both chaotic and entropic factors can drive or constrain system behavior—whether in controlling the functionality of engineered materials or in shaping training outcomes in deep learning networks.

Ultimately, this cross-disciplinary synthesis can facilitate more principled approaches to surface engineering and network optimization—extending beyond purely algorithmic heuristics toward a deeper, complexity-inspired comprehension of high-dimensional search spaces. Whether the goal is improving the robustness of a complex material interface or boosting the performance of a deep learning model, recognizing shared principles of surface complexity offers a powerful, unifying lens through which to tackle challenges in both materials and computational research.

Keywords: Complexity; Machine Learning; Loss Landscape; Surfaces

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EVALUATION OF THE PERSPECTIVE OF HOTEL MANAGERS IN CRISIS MANAGEMENT: AN APPLICATION IN FIVE STAR HOTELS IN ISTANBUL

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Extended Abstract

It is a known fact that the tourism sector is one of the economically and socially important sectors for countries. The tourism sector is also one of the most vulnerable sectors in terms of negative events (Berbekova et al., 2021). The tourism sector is among the sectors that feels the impact of extraordinary situations very quickly. The special characteristics of accommodation businesses make them much more vulnerable to crisis situations than other economic sectors. Therefore, the concept of crisis management is of great importance for hotel businesses. The expertise of hotel managers in crisis management is of great importance when various crisis periods are a source of great concern for hotel businesses. A hotel manager should have the necessary knowledge, tools and experience to manage crisis processes correctly. Otherwise, new problems may be generated if a crisis process is not carried out correctly (Jaaffar et al., 2023). Proper management of crisis periods creates a driving force for both the tourism sector and other sectors. This is because crisis periods trigger innovation and change. The tourism sector in Türkiye has faced many crises such as the 'Economic Crisis' in 2009, 'Gezi Events' in 2013, 'Terrorist Attack' and 'Türkiye-Russia Crisis' in 2016, the 'Türkiye-America Crisis' in 2018, and the 'Covid-19 Pandemic' in 2020. As a result of these crises, a very rapid decline in the number of tourists occurred with successive reservation cancellations in hotels. Despite the negative developments during these periods, hotel businesses were able to complete the process with minimal loss and recover very quickly after the crises. Such crises not only destroy tourism resources and attractions in local communities, but also threaten tourists and increase their fear in terms of travel restrictions (Kim and Pomirleanu, 2021). A study of the literature reveals that although there are many studies on crisis management in hotel businesses, the number of studies that examine the perspectives of hotel managers during crisis periods are limited (Tuna et al., 2019; Mesci et al., 2016). The aim of the research is to reveal whether hotel businesses take proactive measures for crisis periods, how they are affected by the process during the crisis, how they manage crisis periods and their outlooks on crisis periods in general. In line with this purpose, the interview method was chosen as the method of data collection because the findings obtained in qualitative research methods reveal a rich and detailed picture of the investigated phenomenon. The data to be obtained with semi-structured interview forms will be evaluated by establishing thematic codes through content analysis. Since the majority of five-star hotel establishments in Türkiye are located in Istanbul and it is the city with the highest tourism potential in terms of incoming tourist demand, the population of the study consists of five-star hotel establishments in Istanbul. The research aims to contribute to the measures to be taken by hotel managers in times of crisis, the paths to be followed, and the most effective evaluation of the economic process in terms of both internal and external stakeholders.

Keywords: Kriz Yönetimi, Otel İşletmeleri, Otel Yöneticileri, İstanbul

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Stochastic Geometry of Fibrous Networks: Connectivity and Spatial Organization

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Extended abstract

Fibrous materials, from nanowire networks in neuromorphic computing to electrospun membranes in filtration, exhibit an intricate topology governed by the random distribution of fibers. These networks can be viewed as complex systems whose emergent behavior arises from local interactions and global constraints [1]. In this work, we develop and apply a metrological framework to characterize spatial patterns within fibrous materials, focusing on two critical point patterns: (1) the intersections, or junctions, of fibers, pivotal in neuromorphic networks for signal routing and memory functions; and (2) the centroids of pores, vital for fluid transport properties in membrane applications [2].

Our approach utilizes stochastic geometry methods from point pattern analysis. We first investigate the distribution of nearest-neighbor distances to quantify deviations from complete spatial randomness. For junctions, we observe a pronounced clustering tendency caused by the fiber-overlap mechanism—intersections tend to occur in close proximity whenever multiple fibers converge. In contrast, pore centroids exhibit a mild ordering effect, reflecting how adjacent pores cannot overlap and thus appear more regularly spaced.

To capture local directional phenomena beyond standard global metrics, we introduce a novel Local ColLinearity (LCL) method. By connecting each point to its nearest neighbor in a unique path, we detect triads of collinear points. This enables the quantification of alignment or "local anisotropy," which remains undetected by conventional analyses. Our results reveal that intersection point patterns exhibit strong alignment—inherent to the linear geometry of fibers—while pore centroids show weaker but non-negligible collinearity.

Application to scanning electron microscopy images of nanofilament-coated membranes confirms the predictive power of our framework, bridging theory and experiment. These findings offer new insights into how local fiber geometry influences global connectivity, transport, and emergent network properties. By treating fibrous materials as complex systems, our methodology paves the way for designing and optimizing multifunctional networks in fields ranging from filtration and biomedical scaffolds to neuromorphic computing.

Keywords: fibrous networks, complex materials, spatial point patterns, anisotropy, local collinearity, stochastic geometry

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COMPETENCY DEVELOPMENT OF UNIVERSITY STUDENTS UNDER VUCA CONDITIONS: A QUALITATIVE STUDY BASED ON THE COMPLEX SYSTEMS APPROACH

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Extended abstract

Rapid transformations in global economic, technological, and social dynamics have increasingly rendered the environments in which individuals and institutions operate unpredictable, volatile, complex, and ambiguous. This context, commonly defined in the literature as VUCA (Volatility, Uncertainty, Complexity, Ambiguity), requires a critical reassessment of the cognitive, emotional, and behavioral competencies that individuals need to develop and sustain in such environments.

According to the 2025 Future of Jobs Report by the World Economic Forum, the most in-demand skills in the labor market over the next five years include: analytical thinking and innovation, active learning and learning strategies, complex problem-solving, critical thinking and analysis, creativity, originality and initiative, leadership and social influence, technology use, monitoring and control, technology design and programming, resilience, stress tolerance and flexibility, and reasoning, problem-solving and ideation. These competencies are considered essential for individuals to successfully adapt to the complexity and uncertainty embedded in VUCA environments.

In this context, the present study aims to explore how university students develop competencies under VUCA conditions and to conceptually interpret this developmental process within the framework of complex systems theory. The complex systems approach focuses on collective behavior patterns that emerge at the system level through the interaction of numerous independent elements, without a central controlling mechanism. Core concepts such as self-organization and emergence help explain how individual responses to unpredictable environmental stimuli evolve into structured systemic patterns over time. Consequently, learning and adaptation strategies gain transformative qualities not only at the individual level but also at the organizational and societal levels.

The study also seeks to examine the role of artificial intelligence-supported learning systems, which are increasingly used in digital learning environments, in facilitating students' adaptation to complex conditions. These technologies reinforce self-regulated learning by offering personalized experiences, reducing cognitive load, supporting decision-making processes, and diversifying learning strategies—thereby aligning with the decentralized and dynamic nature of complex systems.

This research is designed as a qualitative study. Data will be collected through semi-structured interviews with university students and analyzed using content analysis. The emerging thematic patterns will be interpreted through the lens of complex systems theory. The study aims to provide a theoretical contribution by revealing how individual learning strategies correspond with the key competencies identified by the World Economic Forum, and how these strategies evolve into systemic behavioral patterns over time.

Keywords: VUCA; Complex Systems Theory; Competency Development; Self-Regulated Learning; Adaptive Learning Strategies.

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Fractals and the Mandelbrot set via iterated quantum protocols

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Extended abstract

Iteration of a post-selective quantum operation acting on quantum systems in an identical state is ubiquitous in quantum entanglement distillation, where the quantum system consists of qubit pairs or more qubits [1]. The same type of iterated dynamics applied to single qubit systems can lead to nonlinear, chaotic dynamics [2]. Repeated steps of a unitary operation, a measurement on some of the qubits and then post-selection of the unmeasured qubits can generally be described as the iteration of a rational complex function. If two qubits are operated on in each step, then the function will be quadratic rational. Generalization to *n* qubits leads to an *n*th order rational function. One can construct a unitary operator corresponding to each quadratic (in general *n*th order) rational complex function [3]. In this way, the Mandelbrot set can be directly realized or, with other words, calculated in such an iterated quantum protocol.

The above considerations assumed a perfect, pure initial quantum state. In a realistic situation, the initial state will be affected by noise and, in general, it will be a mixed state. Mixedness of the initial state further complicates the dynamics. We cannot rely on iterated complex functions anymore. The dynamical equations will involve the three real parameters characterizing the density matrix. Our analysis of the dynamics related to a circuit consisting of a CNOT gate and a Hadamard gate shows that the fractals dividing the different convergence regions will be present for moderate initial noise, up to a critical purity. Moreover, the fractal dimension remains the same below the critical noise level but disappears abruptly when reaching the critical purity [4]. Similar behavior occurs for the same protocols for higher order dynamics [5].

The quantum circuit realizing the transformation related to the Mandelbrot set has been proposed to test quantum computers [6]. Here we examine how initial noise distorts the fractal nature of the set. We note that two steps of the iterated protocol leading to ergodic dynamics has been experimentally realized in a photonic arrangement [7].

Keywords: Iterated quantum protocols; Mandelbrot set; Nonlinear quantum dynamics; Chaotic quantum evolution.

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UNRAVELING THE CHAOTIC NATURE OF U.S. RIVER STREAMFLOW: COMPLEXITY AND PREDICTION HORIZONS

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Extended abstract

A streamflow time series encompasses a large amount of hidden information, and reliable prediction of its behavior in the future remains a challenge. It seems that the use of information measures can significantly contribute to determining the time horizon of rivers and improving predictability. Using the Kolmogorov complexity (KC) and Lyapunov exponent (LE), it has previously been shown that the degree of streamflow predictability depends on human activities, environmental factors, and natural characteristics. This paper applied the KC and LE measures to investigate the randomness and chaotic behavior of monthly streamflow of 1879 rivers from the United States for the period of 1950–2015 and evaluated their time horizons via the Lyapunov time (LT) [1].

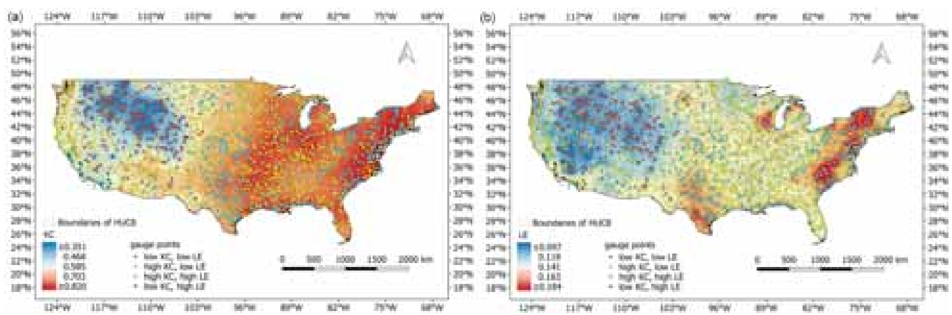

Figure 1: Spatial distribution of KC (left) and LE (right) of the U.S. river monthly streamflow for the period 1950-2015.

For the considered KC and LE domains of rivers, we used the following values for "borderlines": KC ≤ 0.520 (low complex - *k*); KC > 0.520 (high complex - *K*); LE ≤0.149 (low chaotic - *l*); and LE > 0.149 (high chaotic - *L*) (see Fig. 1) [2]. The Lyapunov time (LT), which represents the prediction horizon, varies significantly across U.S. regions. In the West and Southwest (Southwestern part), LT ranges from 10 to 13 months or more, indicating longer prediction horizons. Rest of the Southwest, Midwest, Southeast, and Northeast: LT falls between 5 and 9 months, reflecting shorter prediction windows.

Keywords: Kolmogorov complexity (KC); Lyapunov exponent (LE); Time horizon (LT); Streamflow; U.S. rivers.

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AVERAGE VECTOR FIELD METHOD AND CAPUTO FRACTIONAL DERIVATIVE DEFINITION FOR LINEAR SPACE FRACTIONAL DIFFERENTIAL EQUATIONS

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Extended abstract

In this study, the numerical solution of Linear Space Fractional Differential Equations is comprehensively investigated through the application of the Average Vector Field (AVF) method combined with the Caputo fractional derivative definition. The non-integer order derivative component of the equation is addressed by employing the Caputo formulation, which is widely recognized for its suitability in modeling initial value problems with memory and hereditary properties.

For the spatial discretization, a finite difference approach is utilized to approximate the integer-order derivatives, while a compact finite difference scheme is employed to enhance the accuracy and efficiency of the method along the spatial coordinate. These numerical schemes are carefully integrated into the overall solution strategy to ensure that both the fractional and integer components of the equation are handled with sufficient precision.

Moreover, to validate the numerical stability and accuracy of the proposed method, a detailed dispersion analysis is carried out. This analysis confirms the consistency and convergence of the numerical scheme, providing a solid theoretical foundation for its reliability.

The numerical experiments conducted as part of this research demonstrate that the proposed technique not only maintains theoretical accuracy but also approximates the exact solution with high fidelity. Therefore, the combination of the Average Vector Field method and the Caputo fractional derivative is shown to be a robust and effective approach for solving space fractional differential equations, making it a valuable tool in the broader field of fractional calculus and its applications in science and engineering.

Quantum Artificial Intelligence: An Innovation within the Innovation

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Extended abstract

In this brief, a summary of the almost seventy-year evolution of Artificial Intelligence [1] is initially provided. The new dimension that quantum information [2] introduces as an additional enabler to artificial intelligence is exhibited and the reinforcement of dynamics in the augmented new paradigm of processing information with quantum neural networks is documented.

Focus is placed on the mathematical aspects and the model of the artificial neuron, as a basic building block of all neural networks [3]. The classical neuron paradigm is juxtaposed with innovative, still evolving and competing proposals on the quantum version of the artificial neuron. Some key examples of how quantum computing may help AI by solving complex problems that are intractable for classical computers [4] are also presented. This way in the presented work the following domains are briefly highlighted:

a) specific application areas that may benefit from mutual assistance between quantum computing and artificial intelligence,
b) stages and/or operations and methods of artificial intelligence that are eligible to get a performance boost for quantum computing.

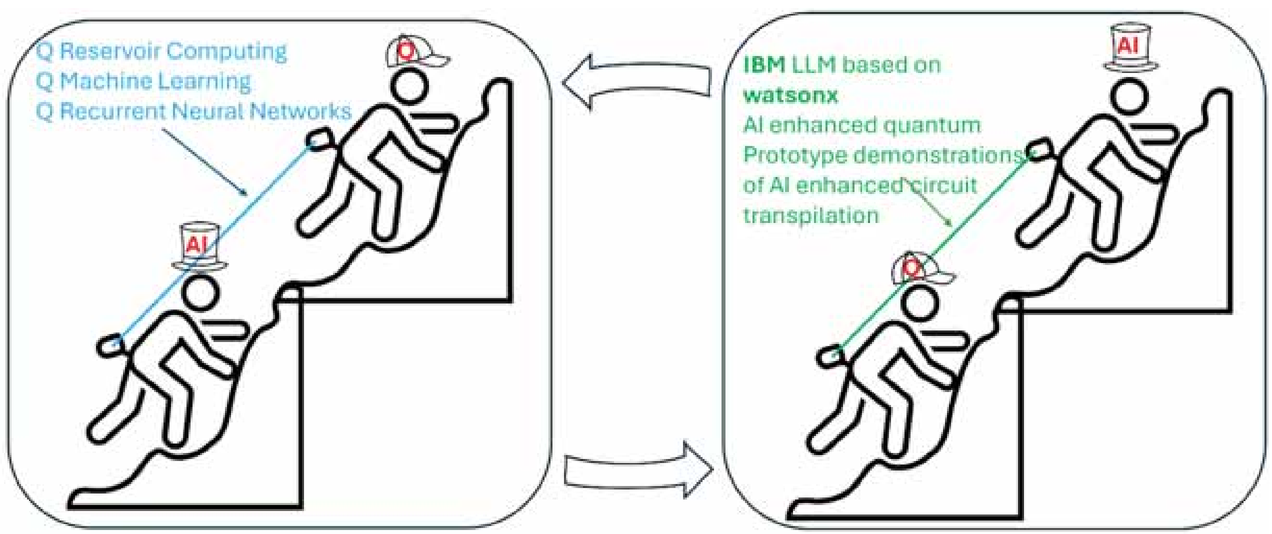

Figure 1: Quantum Computing and Artificial Intelligence entering a cycle of mutual improvements.

Challenges form the practical limitations imposed on quantum computing from current Noisy Intermediate-Scale Quantum (NISQ) [5] devices are discussed in view of the already emerging fault Tolerant Quantum Computing (FTQC) [6], due to recent quantum error correction breakthroughs.

Finally, future directions are sketched, while considering:

a) current trends of quantum computing towards standardization, interoperability and full-stack approaches, and
b) hybrid quantum-classical computing systems emergence with integration of Central Processing Units (CPU), Graphics Processing Units (GPU) and Artificial Processing Units (APU) with Quantum Processing Units (QPU).

Keywords: Artificial Intelligence; Quantum Information; Neural Networks; Machine Learning; Quantum Artificial Intelligence.

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Organic Electrochemical Transistors with Memristive behavior for textile knitted circuits

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Extended abstract

Although electronic textiles are still at an early technological readiness level (TRL), it should be expected their future transition into a next generation platform for human-IoT networking and interaction [1,2]. Textile structures can produce topologies suitable for the development of computational circuits [2,3], while textile substrates have been shown to be suitable for the development of organic electronic devices [4,5]. Compared with conventional electronics, organic electronics exhibit greater flexibility, simpler fabrication, and lower manufacturing costs [6], which increases the interest in the future mass production of fabric-based circuits. Among organic electronic devices, memristor devices are expected to play a central role in future computing applications. Since the first theoretical definition of memristors [7], research has progressed towards refining the original theory and implementing devices with memristive behavior for practical applications [8,9]. A memristor is a two-terminal device in which the application of external inputs changes its internal state, thereby causing a change in its resistance, which is then retained to some extent as an intrinsic memory effect. Previous research on organic electrochemical transistors (OECT) based on poly(3,4-ethylene-dioxythiophene):poly-styrene sulfonate (PEDOT:PSS) as the semiconductor channel material demonstrated the possibility of fabricating three-terminal devices with memristive characteristics for potential use in neuromorphic computing [10,11]. Fabric-based OECT fabrication has also been demonstrated with various implementations in the past [3-5]. However, most of these implementations require techniques that are difficult to adopt in the textile and apparel industry. In our research, we have constructed a knitted-fabric OECT based on conductive PEDOT:PSS treated yarns, and a solid electrolyte made of a poly-ethylene-glycol-diacrylate (PEGDA) polymer matrix, plasticized with propylene carbonate (PC), and lithium perchlorate ($LiClO_4$) as source of ionic charges. The device, which can be easily reproduced in conventional textile and garment manufacturing lines, exhibits long-term stability and significant current hysteresis loops on direct and reverse potential sweeps, indicating a clear memristive behaviour (Figure 1). From the textile manufacturing aspect, weaving technology produces mostly rectangular networks, while knitting technology offers higher flexibility, producing more complex networks with controllable positioning of yarn junctions -potential synapses- at precise locations within the fabric structure. Although converting a textile structure into a fully functional electronic circuit is still challenging, further research and optimization of knitted-OECTs and their memristive functionality will contribute the future development of textile-based computing devices.

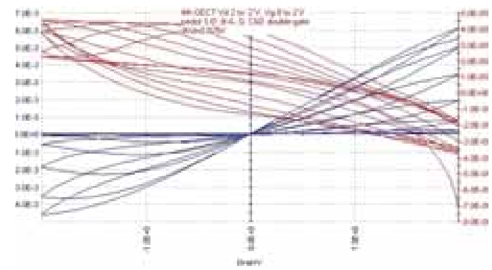

Figure 1: Output characteristics of OECT exhibiting strong hysteresis phenomena corresponding to memristive devices of Type I (crossing)

Keywords: memristive device; memristive transistor; fabric device, textile OECT; fiber-based OECT

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Bounded confidence Opinion Dynamics based on the Independent Cascade Model on Signed Social Networks

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Extended abstract

Within the study of the literature relevant to opinion dynamics on signed networks, there are works that assume that nodes express their opinion at each time instant [1]. Among them, there are models also considering the bounded confidence assumption on signed networks [2], [3]. On the contrary, other works assume that nodes express their opinion only when they become either infected or active, according to a typical epidemic or activation-spreading model on signed networks; without considering the bounded confidence assumption [4], [5].

In this work, we propose a novel opinion-spreading model on signed networks considering the combination of both the assumption that only the infected nodes express their opinion and the bounded confidence assumption (IC, BC). We compare our proposed model with three other opinion models on signed networks, as these are described below:

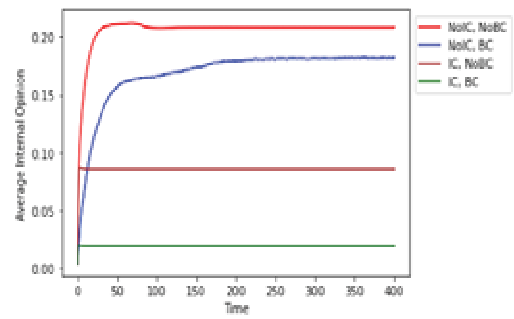

Figure 1: Comparing the average internal opinion metric as calculated for the proposed (IC, BC) model (in green) against the other three models (NoIC, NoBC in red), (NoIC, BC in blue), and (IC, NoBC in light brown).

a) a model that assumes repeated interactions between nodes considering the bounded confidence assumption (NoIC, NoBC),
b) a model that assumes repeated interactions between nodes without considering the bounded confidence assumption (NoIC, BC),
c) and a model that assumes that only infected nodes express their opinion without considering the bounded confidence assumption (IC, NoBC).

As metrics of a model's influence on the network, the average internal opinion and the average public domain opinion, are utilized. Simulation experiments on subgraphs of two signed online social networks, namely, Epinions and Slashdot, are performed. In all cases, the model proposed hereby demonstrates a significant percentage difference in all metrics as this is compared to the other three models, something depicted in Figure 1. Moreover, in our model there is a significant percentage difference between the average internal opinion and the average public domain opinion as depicted in Figure 2.

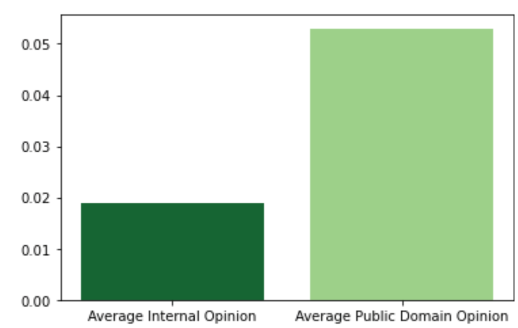

Figure 2: Comparison of the average internal opinion and average public domain opinion metrics, under our proposed model (IC, BC).

Finally, an outlook to our work is to create a node selection algorithm to solve the Influence Maximization Problem under our proposed opinion spreading model.

Keywords: Opinion Dynamics; Signed Networks; Independent Cascade Model; Bounded Confidence; Opinion Spreading

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Applying Social Network Analysis to the Eurovision Song Contest

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Extended abstract

This brief explores the application of Social Network Analysis (SNA) to the Eurovision Song Contest, analyzing voting behavior among participating countries. Eurovision Song Contest is a paradigm of a Europe-wide social network demonstrating dynamics expressed following specific, one may say unique, rules.

The contest is modeled as a directed, weighted network, with countries being the network nodes and the votes exchanged between them being the weighted edges. Using the R programming environment and the igraph library, the study investigates network density, centrality metrics, transitivity, small-world characteristics, mutual voting relationships, and the rich-club effect.

A focused analysis of the 2005 contest - when Greece won the contest - revealed that Greece ranked highest in multiple centrality measures (Authority, PageRank, In-Degree metrics), demonstrating its pivotal role in that year's voting network. Additionally, that year Moldova showed the highest betweenness centrality. The results clearly indicate a heterogeneous network structure, validated through a power-law and Poisson's distribution fitting.

Additionally, a community detection investigation was performed using various algorithms, namely the *cluster optimal*, the *cluster infomap* and the *cluster edge betweenness*. Out of this investigation, meaningful voting communities emerged, especially when focusing on countries exchanging the maximum 12 points. These communities often reflected geographic and cultural affinities, with Scandinavian countries consistently forming a distinct bloc. The study further identified ten long-term community clusters across Europe, influenced not only by music but also by geopolitical and cultural factors.

To conclude, this work offers new insights into how political, geographic, and social dynamics shape voting alliances in a popular international event and proposes directions for future research in network-based analysis of cultural phenomena.

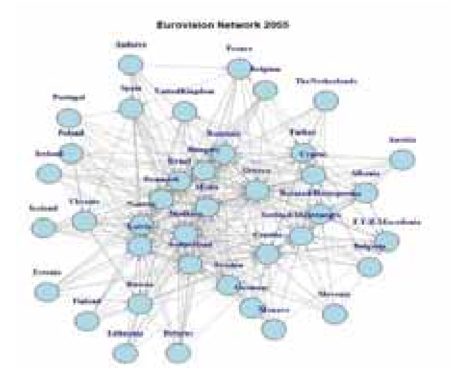

Figure 1: Representation of the Eurovision Song Contest network.

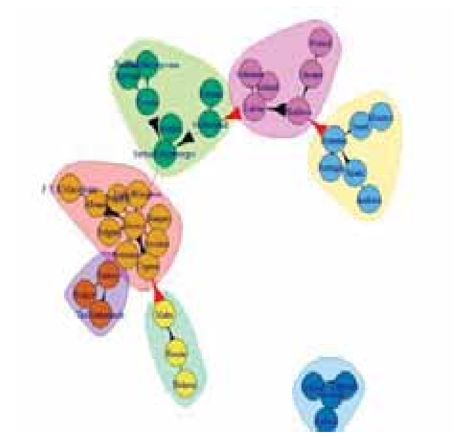

Figure 2: Illustration of the optimal Community Detection.

Keywords: Social Network Analysis; Eurovision; Graph Theory; Voting Behavior; Community Detection; Centralities Measures

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