IOCMA 2026 Conference

The 2nd International Online Conference on Mathematics and Applications

10–12 June 2026 | Online



Program and Abstract Book

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#IOCMA2026

The 2nd International Online Conference on Mathematics and Applications

10–12 June 2026 | Online

MDPI

Organizing Committee

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Prof. Dr. Ivanka Stamova
Prof. Dr. Tadashi Dohi

Session Chairs

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Prof. Dr. Michel Chipot
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Prof. Dr. Rodica Luca
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Welcome from the Chairs

It is a pleasure to announce **the 2nd International Online Conference on Mathematics and Applications**, following the first edition held in 2023. The conference is organized by MDPI and the scientific journal ***Mathematics*** and will be held from **10 to 12 June 2026**. It has been designed to closely align with the innovative new section structure of the journal. The main special sessions and their aims are as follows:

- **Algebra, Geometry, Topology, and Logic with Applications:** This session delves into the core areas of algebra, number theory, differential geometry, complex geometry, mathematical logic, cryptography, and topology, as well as their connections with other scientific and technological domains.

- **Mathematical Analysis:** This session encompasses research in real and complex analysis, differential equations (both ordinary and partial), evolution equations, dynamical systems, functional analysis, calculus of variations, and harmonic analysis with wavelet with applications in biology, finance, fluid mechanics, etc.

- **Statistics and Operational Research:** This session covers recent advances in the theory of probability and statistics, data analysis, operations research, and their applications in many disciplines. It is dedicated to the latest advancements in theoretical research and their various applications.

- **Applied Mathematics:** This session focuses on developing and applying computational techniques to solve complex scientific problems across multiple disciplines. This includes numerical linear algebra, numerical, numerical approximation, computational geometry, and numerical solutions of differential equations, integral equations, and inverse problems.

- **Control Theory and Mechanics:** Submissions reporting novel mathematical methods and computational techniques for control and mechanics issues are welcome for this session. Topics include, but are not limited to, robust control theory, predictive control, nonlinear control, adaptive control, optimal control theory in mechanical systems, stability analysis, mathematics of multibody dynamics, control-oriented parameter identification, multiscale mechanical systems, mechanical contact problems, topology optimization, etc.

- **Mathematics, Computer Science and Artificial Intelligence:** This session aims to showcase the latest research results in the evolving intersection of mathematics, computer science, and artificial intelligence (AI). It places a particular emphasis on the mathematical foundations of AI, such as neural network theory, optimization algorithms for AI, and probability theory in machine learning. Additionally, papers that describe the real-world applications of AI while highlighting the underlying mathematical principles are highly encouraged.

We sincerely invite all interested researchers and academics to participate in this event to exchange ideas, create fruitful collaborations, and make the new edition of this conference a success.



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mathematics

an Open Access Journal by MDPI

Mathematics (ISSN 2227-7390) is an international, open access journal which provides an advanced forum for studies related to mathematical sciences. It devotes exclusively to the publication of high-quality reviews, regular research papers and short communications in all areas of pure and applied mathematics. *Mathematics* also publishes timely and thorough survey articles on current trends, new theoretical techniques, novel ideas and new mathematical tools in different branches of mathematics. A submission must be well written and of interest to a substantial number of mathematicians and scientists.

Our aim is to encourage scientists to publish their experimental and theoretical results in as much detail as possible. There is no restriction on the maximum length of the papers. The full account of the research must be provided so that the results can be reproduced. Electronic files or software which provide the full details of the calculations, proofs and experimental procedures can be deposited as supplementary material (if unable to be published in a normal way).

Journal webpage: https://www.mdpi.com/journal/mathematics

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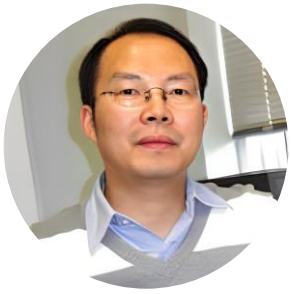
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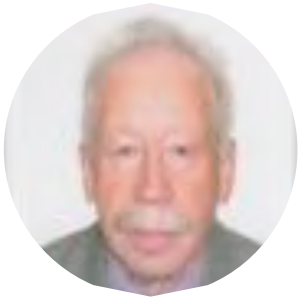
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Program at a Glance

	10 June	11 June	12 June
Morning— 09:00 AM CEST	**S2.** Mathematical Analysis	**S1.** Algebra, Geometry, Topology and Logic with Applications	**S5.** Control Theory and Mechanics **S4.** Applied Mathematics
Afternoon— 14:00 PM CEST	**S3.** Statistics and Operational Research	**S6.** Mathematics, Computer Science and Artificial Intelligence	**S4.** Applied Mathematics

IOCMA 2026 Program

Program Day 1

DAY 1 Morning

Opening Remark & S2. Mathematical Analysis

9:00-11:40 CEST, 10 June 2026

Session	CEST (Central European Summer Time)	Type	Speaker	Title
Opening Remark	9:00-9:15	Prof. Dr. Francisco Chiclana Prof. Dr. Ivanka Stamova Prof. Dr. Tadashi Dohi		Opening Remark from Event Chairs
S2. Mathematical Analysis	9:15-9:25	Prof. Dr. Michel Chipot		Welcome Speech from Session Chair
	9:25-9:45	Invited Speaker	Prof. Dr. Snezhana Hristova	Revisiting Boundary Value Problems for Differential Equations and Ulam type Stability
	9:45-10:05	Invited Speaker	Prof. Dr. Flavia Giannetti	Higher regularity of the symmetric gradient of solutions to Φ-Laplacian systems
	10:05-10:25	Invited Speaker	Prof. Dr. Songting Luo	Semiclassical Approximations for Fractional Quantum Mechanics
	10:25-10:40	Oral Speaker	Gioconda Moscariello	Quantitative and asymptotic estimates for parabolic obstacle problems with a drift term
	10:40-10:55	Oral Speaker	Sergey Shmarev	EXISTENCE AND REGULARITY RESULTS FOR A NEW CLASS OF DOUBLE-PHASE PARABOLIC EQUATIONS
	10:55-11:10	Oral Speaker	Aicha OUALI	Nonlinear Fractional Inclusions for Tumor Dynamics under Treatment
	11:10-11:25	Oral Speaker	Matieyendou Lamboni	Dimension-free approximations of gradients
	11:25-11:40	Oral Speaker	Assia Guezane Lakoud	Fixed Point Analysis of Variable-Order Fractional Problems with Nonlocal Conditions

DAY 1 Afternoon

S3. Statistics and Operational Research

14:00-16:25 CEST, 10 June 2026

Session	CEST (Central European Summer Time)	Type	Speaker	Title
S3. Statistics and Operational Research	14:00-14:10	Prof. Dr. Antonio Di Crescenzo		Welcome Speech from Session Chair
	14:10-14:30	Invited Speaker	Prof. Dr. Elvira Di Nardo	Efficient Computation of Complementary Set Partitions with Applications to Generalized Cumulants
	14:30-14:50	Invited Speaker	Prof. Dr. Felix Belzunce	Non parametric inference for joint stochastic orders
	14:50-15:10	Invited Speaker	Prof. Dr. Mauro Passacantando	Interday and Intraday Chemotherapy Appointment Scheduling: a Patient-Centered Approach
	15:10-15:25	Oral Speaker	Jingchi Wu	An Empirical Research for Likelihood-free Parameter Estimation Approach for NHPP-Based Software Reliability Models

15:25-15:40	Oral Speaker	**Priyantha Wijayatunga**	Sharp Null Hypothesis Testing and Jeffreys-Lindley Paradox
15:40-15:55	Oral Speaker	**Paolo Giudici**	Statistical methods for Safe Artificial Intelligence
15:55-16:10	Oral Speaker	**Pei Fun Lee**	Prediction of Stock Market Index in Malaysia with Neural Network
16:10-16:25	Oral Speaker	**Danyal Tazakori**	I-PASS: Interpretable Position-Aware Statistical-based Swap Operator

Program Day 2

DAY 2 Morning

S1. Algebra, Geometry, Topology and Logic with Applications

9:00-12:10 CEST, 11 June 2026

Session	CEST (Central European Summer Time)	Type	Speaker	Title
S1. Algebra, Geometry, Topology and Logic with Applications	9:00-9:10	Prof. Dr. Irina Cristea		Welcome Speech from Session Chair
	9:10-9:30	Invited Speaker	Prof. Dr. Irina Cristea	Challenging Problems in Hypercompositional Algebra
	9:30-9:50	Invited Speaker	Prof. Dr. Qingwen Wang	The general solutions to some matrix equations over dual quaternions with applications
	9:50-10:05	Oral Speaker	Enrico Talotti	Classification of Finite Preordered Semigroups via Group Action induced by Pushforward
	10:05-10:20	Oral Speaker	Bianca Bercea	Cyclic Codes as Ideals in Polynomial Rings: Algebraic Foundations and Applications
	10:20-10:35	Oral Speaker	Kyriaki Evangelia Aslani	Multivector Time Generator: A Novel Algebraic Framework for Temporal Symmetries
	10:35-10:50	Oral Speaker	Alejandro Fructuoso-Bonet	TOPOLOGICAL PRESERVATION BY QUASI-PSEUDOMETRIC AGGREGATION FUNCTIONS
	10:50-11:05	Oral Speaker	Zohreh Vaziry	Orderconvergence, a quasitopos for Bounded Topology (BT)
	11:05-11:20	Oral Speaker	Álvaro Antón-Sancho	A Monodromy-Theoretic Approach to Control Systems on Principal Bundles over Riemann Surfaces
	11:20-11:35	Oral Speaker	Danail Brezov	Refining Geodesy and Photogrammetry with Geometric Algebra
	11:35-11:50	Oral Speaker	Hristo Manev	Almost para-Ricci-like solitons with torse-forming vertical potential of constant length on para-Sasaki-like Riemannian Π-manifolds
	11:50-12:10	Invited Speaker	Prof. Dr. Graham Hall	Geometry and Physics

DAY 2 Afternoon

S6. Mathematics, Computer Science and Artificial Intelligence

14:00-16:25 CEST, 11 June 2026

Session	CEST (Central European Summer Time)	Type	Speaker	Title
S6. Mathematics, Computer Science and Artificial Intelligence	14:00-14:10	Prof. Dr. Marjan Mernik		Welcome Speech from Session Chair
	14:10-14:30	Invited Speaker	Prof. Dr. Darian M. Onchis	Feature Weighting for Unsupervised Clustering via SHAP Values
	14:30-14:50	Invited Speaker	Prof. Dr. George Anastassiou	Approximation by overactivated and spiked convolutions as Positive Linear Operators
	14:50-15:10	Invited Speaker	Prof. Dr. Tien Anh Tran	Least-square error model for measuring the fuel consumption level of marine diesel engines based on variable factors

	15:10-15:25	Oral Speaker	**Luigi Altieri**	Topology optimization of planar truss structures with Large Language Models
	15:25-15:40	Oral Speaker	**Gabriel Winter**	Analytical Surrogates for Incompressible Flow Dynamics via Physics-Based Optimization
	15:40-15:55	Oral Speaker	**Raziya Sabri**	Dynamics of Gradient Propagation inComplex-Valued Neural Networks with PlantedSingularities
	15:55-16:10	Oral Speaker	**Enrico Zanardo**	Scalable Approximate Inference in LIMEN-AI: Gradient-Guided Algorithms for the Neuralized Lukasiewicz Markov Engine
	16:10-16:25	Oral Speaker	**Jiacheng Bai**	A Note on Kernel Regression with Several Bandwidth Selection Methods in Software Reliability Prediction

Program Day 3

DAY 3 Morning

S5. Control Theory and Mechanics & S4. Applied Mathematics

9:00-11:30 CEST, 12 June 2026

Session	CEST (Central European Summer Time)	Type	Speaker	Title
S5. Control Theory and Mechanics	9:00-9:10	Prof. Dr. Paolo Mercorelli		Welcome Speech from Session Chair
	9:10-9:30	Invited Speaker	Dr. Fernando E. Serrano	Robust Control Lyapunov Functions for Fractional Order Uncertain Lagrangian and Hamiltonian Systems
	9:30-9:45	Oral Speaker	Francisco Javier Fernández	Koopman-Certified Safe Actor–Critic Reinforcement Learning via Robust Projection in Lifted Space
	9:45-10:00	Oral Speaker	Mario Spirito	Explicit Solutions for LTV Systems: A New Perspective on Stability Criteria
	10:00-10:15	Oral Speaker	Meriem Benaouad	Energy-Optimal Control of Singular Continuous-Time Linear Systems Using the Weierstrass–Kronecker Decomposition.
S4. Applied Mathematics	10:15-10:25	Prof. Dr. David Carfì		Welcome Speech from Session Chair
	10:25-10:45	Invited Speaker	Dr. Mariusz Białecki	On inverse power cluster-size distributions generated by the Random Domino Automaton
	10:45-11:00	Oral Speaker	Naseem Zoha Ansari	An Automated Persistent Topological Framework for Robust Multi-Scale Data Analysis
	11:00-11:15	Oral Speaker	Andreas Kalogeropoulos	On retrieving the electric fields of point-like scatterers in the presence of a large dielectric cylinder by means of the Foldy-Lax approximation
	11:15-11:30	Oral Speaker	Asmaa Lakhdar	Resolution of Maxwell's Equations in Atmospheric Electromagnetic Phenomena

DAY 3 Afternoon

S4. Applied Mathematics

14:00-16:40 CEST, 12 June 2026

Session	CEST (Central European Summer Time)	Type	Speaker	Title
S4. Applied Mathematics	14:00-14:20	Invited Speaker	Prof. Dr. Svetozar Margenov	Rational-Approximation-Based Numerical Methods for Fractional Diffusion–Reaction Equations
	14:20-14:40	Invited Speaker	Dr. Joseph Cabeza-Lainez	Solution of the fundamental integral equation in heat transfer and its repercussion for architecture, fire prevention and tunnelling
	14:40-14:55	Oral Speaker	Sabia Asghar	Mathematical models for the mechanics of soft tissues: from linear elasticity to morpho-poroelasticity

	14:55-15:10	Oral Speaker	**Paul Kehinde Imoukhedeme**	A DERIVATIVE-FREE OPTIMIZATION METHOD ON HADAMARD MANIFOLD FOR SOLVING NONLINEAR MONOTONE SYSTEMS WITH APPLICATION IN IMAGE DEBLURRING
	15:10-15:25	Oral Speaker	**Hisham Hussein**	Wave Solutions and Dynamical Behavior of the Ivancevic Option Pricing Model
	15:25-15:40	Oral Speaker	**Fernando Agustín Otero**	Reverse Rule-to-Model Inference with Physics-Guided Refinement: Application to the Three-Zone Scattering Model for Fractal Aggregates
	15:40-15:55	Oral Speaker	**Mohammed Osman Goni**	Invasion Dynamics and Therapeutic Effects in a Tumor–Immune Interaction Model
	15:55-16:10	Oral Speaker	**Carlos Jose Carvajal Ariza**	A Feynman–Kac Approach to Conditional Mean–Field Models with Markovian Switching and Poisson Jump
	16:10-16:25	Oral Speaker	**Eymard Hernandez-Lopez**	Bifurcation Analysis of a Two-Dimensional Cancer–Immune Model with Antigenicity and Strong Allee Effect

IOCMA 2026 Poster List

Submission ID	Authors	Title
sciforum-129055	Michael Banf	Curvature-guided Graph-to-Hypergraph Structural Lifting Alleviates Over-Squashing in Graph Learning
sciforum-135468	Halyna Yakivna Tuluchenko	Analytical Modeling of a Dynamic Probability Mixture via Sigmoidal Weighting for Heterogeneous System Degradation
sciforum-136345	Madeleine Al-Tahan	Bridging group theory and graph theory through commutativity degrees
sciforum-138731	Miltiadis Karazoupis	The Principle of Emergent Continuity: Proof of the Emergence of the Mathematical Continuum from the Arithmetic of Prime Numbers
sciforum-139558	Miltiadis Karazoupis	Fundamental Incompatibility of the Yang–Mills Mass Gap and Asymptotic Freedom within Continuum Quantum Field Theory
sciforum-144382	Gnouma Jerome Kadouno	Tabular Arithmetic and Deterministic Primality Testing via Multiplication Tables.
sciforum-145611	Guoqiang Dang	Study solutions to the coupled nonlinear fractional Drinfel'd–Sokolov–Wilson model
sciforum-145774	Ilhem Kadri	Bridging Analytical and Numerical Methods for Fractional 4D Chaotic Systems
sciforum-145977	Anne Kétri Pasquinelli da Fonseca, Edson Denis Leonel, Diego Oliveira	Scaling invariance for the diffusion coefficient in a billiard system
sciforum-155023	Arthur Nduwayo, Medard Bivuzeyezu	Predictive Modeling of Student Academic Performance Using Multivariate Statistical Techniques and Machine Learning Algorithms
sciforum-157078	Mohamed Mazloum Salem	A Unified Survey of Grand Challenges and Open Problems at the Intersection of Physics, Mathematics, and Computation
sciforum-157079	Mohamed Mazloum Salem	FireCast: A Hybrid Physics-Informed Diffusion Model for Nowcasting Wildfire Spread from Geostationary Satellite Data
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		Refuge, Cooperation, and Harvesting
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sciforum-173984	Spyridon C. Katsoudas, Panagiotis D. Linardopoulos, Anastasios A. Raptis, Konstantinos G. Moulakakis, John D. Kakisis, Konstantinos T. Spanos, Miltiadis I. Matsagkas, Athanasios D. Giannoukas, Christos G. Manopoulos, Efstratios E. Tzirtzilakis, Michalis A. Xenos	Mathematical Modeling and Surface-Based Quantification of Hemodynamics in Abdominal Aortic Aneurysms
sciforum-174043	Khadeejah James Audu, Rashidat Adedayo Oyewole, Yusuph Amuda Yahaya, Mubarak Femi Inuolaji, Faruq Adesina Olayiwola	Investigation of Third-Order Refinement Iterative Methods for Solving Linear Systems in Engineering Applications
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sciforum-174136	NIpun Prabashwara Jayasuriya, K.M.N.M. Chathuranga	Foliation from an Algebraic Perspective
sciforum-174139	Minakshi ., ANIL KUMAR	A parametric study on the effect of horizontal and vertical location parameters on surface deformation due to a buried tensile fault
sciforum-174151	benramdane amina	Finite-Time Blow-Up of Solutions to a Stochastic Quasilinear Viscoelastic Wave Equation withNonlinear Damping and Logarithmic Source
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sciforum-174209	Ilya Galaktionov, Mark Mesyatsev, Vladimir Toporovsky, Oleg Kolesnikov	Adaptive Wavefront Correction Algorithms for Enhancing Transmission Efficiency in Atmospheric Optical Communication Links
sciforum-174223	Ilya Galaktionov, Andrey Sharafislamov, Vladimir Toporovsky, Oleg Kolesnikov	Optimization of light distribution of lenses for Li-Fi luminaires: comparative study of models LIA and LIB with photometric calculations

sciforum-174286	Xiaohu Tian, Junjun Zheng, Hiroyuki Okamura, Tadashi Dohi	A Note on Reliability Analysis of Multi-Stage Manufacturing Systems with Controlled Capacity Release
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sciforum-174326	KOKI NAKAYAMA, Hiroyuki Okamura, Jingchi Wu, Junjun Zheng, Tadashi Dohi	Application of Phase-Type Distributions to Actuarial Lifetime Data under Left-Truncated and Right-Censored Observations
sciforum-174327	Tirthanath Doley, Samiran Das	Propagation of KdV-DIA and mKdV-DIA Solitons in an Unmagnetized Dusty Plasma with Kaniadakis Distributed Electrons
sciforum-174345	Anil Kumar, Dr. Minakshi	Fixed-Point and Common Fixed-Point Theorems for Rational and Almost Contractions in θR-Metric Space
sciforum-174380	Mrinmoy Bora, Rinku Dey	Some generalized sequence space defined by Musielak–Orlicz function
sciforum-174409	SAVITA .	Economic Analysis of Redundant System with Repair/Replacement Facility and Correlated Life Time
sciforum-174438	Mehdi Alimohammadi, Mohammad-R Akbarzadeh-T	A Hybrid Pole-Placement and Deadbeat Controller for Discrete-Time Systems
sciforum-174464	Ashini Madhuwanthi, K.K.K.R. Perera	Centrality-Driven Community Detection for Efficient Petroleum Distribution Planning
sciforum-174480	SABITA BERA, Mausumi Sen	Numerical Simulation of Variable-Order Fractional Advection–Diffusion Processes with Memory Effects
sciforum-174499	ALEXANDER N. RUDY	The characters of involutive automorphisms of simple Lie algebras
sciforum-174515	Mirna Rodic	New Insights into Hermite–Hadamard-Type Inequalities via Green Functions
sciforum-174545	Syeda Rafia Fatima, Waqar hussain shah	Persistent Homology and Fractal Dimension-Based Classification of Retinal Fundus Images

Session 1. Algebra, Geometry, Topology and Logic with Applications

sciforum-168657: (α, β)-Intuitionistic Fuzzy Ideals in BCK-Algebras: A New Approach

Anjaneyulu Naik Kalavath, Satyanarayana Bavanari

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This article introduces the concept of (α, β)-intuitionistic fuzzy positive implicative ideals in BCK-algebras, a novel extension of fuzzy set theory applied to algebraic structures. BCK-algebras are a class of algebraic structures that have been widely studied in the context of fuzzy logic and fuzzy set theory, with applications in information sciences, decision-making processes, and artificial intelligence. We utilize the relationships of belongs to (∈) and quasi-coincidence (q) between intuitionistic fuzzy points and intuitionistic fuzzy sets, where α and β can be any of {∈, q, ∈ ∨ q, ∈ ∧ q} except ∈ ∧ q. This approach allows for a more nuanced and flexible treatment of fuzzy ideals in BCK-algebras, encompassing various existing concepts as special cases. The proposed notion generalizes various existing concepts in fuzzy BCK-algebras, providing a unified framework for studying implicative ideals. Key properties of (α, β)-intuitionistic fuzzy positive implicative ideals are investigated, including characterization theorems and relationships with other types of fuzzy ideals in BCK-algebras. We establish several important results, including necessary and sufficient conditions for an intuitionistic fuzzy set to be an (α, β)-intuitionistic fuzzy positive implicative ideal, and examine the relationships between these ideals and other types of fuzzy ideals, such as fuzzy implicative ideals and fuzzy positive implicative ideals. Several examples are provided to illustrate the concepts and demonstrate their significance, highlighting the applicability and relevance of the proposed notion. This work aims to enrich the theory of fuzzy BCK-algebras and contribute to the broader field of fuzzy algebraic structures, with potential applications in information sciences and decision-making processes. The introduced concepts and results are expected to stimulate further research in this direction, providing new avenues for exploration and discovery in fuzzy mathematics and its applications.



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sciforum-162008: *-envelopping algebras from stochastic automata of topological subshifts: integrable dynamical system of newly weakened hyperbolocity

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*-envelopping algebras of the functionals of stochastic automata from topological subshifts are newly written as the restriction of all the functions of isometric isomorphism on the weak open set. The Margulis Theory is here applied to theweak open set: the sigma-algebra generated from the weak topology coincides when transforming a strong topology: the original functional is smooth (therefore, a homeomorphism in the weak topology is a diffeomorphism in strong topology). The Frechet operator is descended to ordinary differentials in finite-dimensional spaces, after which the measure from the functional is written based on the Radon-Nikodym derivative $d\mu/dv$: the transition probabilities are the derivatives of the functionals, which are density functions with respect to the measure v. The Frechet operator is a map that is used to define isomorphisms between Frechet spaces; after having constructed the isomorphism using the weak *-topology in a dual space, this map is used to transfer the isomorphism to a weak-topology-norm space. The isometric isomorphism is a specification of the Rokhlin aperiodic endomorphism. The non-empty compact space, the distance to it, and the functional constitute a triplet, which forms a Smale space. The newly found dynamical system is an integrable dynamical system of newly 'weakened' hyperbolicity; this dynamical system is compared with that of the Ruelle diffeomorphism [D. Ruelle, Non-commutative algebras for hyperbolic diffeomorphisms, Invent. Math. 93, 1-13(1988).] when the Sinai–Ruelle–Bowen measure is substituted with the new opportune uniform-entropy measure. The new corresponding Miatello–Wallach family of meromorphic functions is written: the variances are indicated to be calculated after application of generic potential theory. The star-algebras are proven to be reduced to envelopping algebras, to which the Tomita–Takesaki paradigm is proven to apply.



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sciforum-173160: On t-g-Radical Supplemented Modules

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This study investigates a specific class of modules in terms of supplemented module theory, defined as t-g-radical supplemented modules. An R-module M is called t-g-radical supplemented if every submodule of M possesses a g-radical supplement that is also a t-summand of M. This research aims to provide a comprehensive structural analysis of these modules and establish several characterization theorems regarding their algebraic properties.

First, we establish the relationship between t-g-radical supplemented modules and classical supplemented modules. It is proved that if M is a t-g-radical supplemented module such that $Rad_g(M)$ is a small submodule of M, then M is necessarily a supplemented module. For finitely generated R-modules, we show that being t-g-radical supplemented implies being t-g-supplemented. One of the central results of this paper is the behavior of these modules under sums. We prove that a finite sum of t-g-radical supplemented modules remains t-g-radical supplemented. Furthermore, the preservation of this property under factor modules and homomorphic images is examined. Specifically, it is shown that for a distributive t-g-radical supplemented module M, every quotient module and every homomorphic image of M inherits the t-g-radical supplemented property. Finally, we discuss the conditions under which every t-summand of M is t-g-radical supplemented, particularly focusing on modules satisfying the $(D3)$ property or the Summand Sum Property (SSP).



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sciforum-169253: Geometry and Physics

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This talk concerns the development and interrelations between geometry and physics since the development of Euclidean geometry. It briefly describes the ideas behind Euclid's work and moves quickly through to the groundbreaking work of Copernicus, Kepler, Galileo and Newton during which the foundations of classical (Newtonian) physics were laid down. These advances used the geometry of Euclid, as applied to 3-dimensional space, to act as the arena where the activities of physics took place and to measure and describe, for example, the motion of particles. In such a philosophy, the geometry was absolute and fixed (and Euclidean) and uninfluenced by the physics. Such ideas were developed in a different way by Lagrange, Hamilton, Routh and others who employed the use of "generalised" coordinates to shake off the idea of preferred inertial observers. However, Euclidean geometry still played the role of absolute background geometry. With the advent of Einstein's general relativity theory in the 20th century the sources of the physics (the matter and fields, etc) were now allowed to influence the geometry and, conveniently, the resulting (differential) geometry needed was then being developed by the Italian school. For Einstein the geometry was no longer background and Euclidean but rather a Riemannian-type geometry determined by the physics and, in this sense, dynamical and so there arose reciprocal actions of the geometry and the physics upon each other. This was the approach of Einstein and it led to his field equations which, given the physical situation, gave (somewhat complicated) field equations for determining the geometry and, from this, the physics. This is now the best available theory of gravitation and, when applied on a global scale, led naturally to the study of cosmology.



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sciforum-170033: A Novel Digital Signature Scheme Using a Non-Commutative Algebraic Structure

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Digital signature schemes are a cornerstone of modern public key cryptography, providing essential security services such as authentication, data integrity, and non-repudiation in open communication networks. Most classical digital signature constructions are based on commutative algebraic structures and rely on a single hard mathematical problem. In recent years, non-commutative algebraic frameworks have attracted increasing attention due to their potential to offer enhanced security and resistance to emerging cryptanalytic techniques. In this paper, we propose a novel digital signature scheme based on elliptic curves defined over a finite non-commutative ring. We first introduce a non-commutative ring R constructed from an elliptic curve over the finite ring $ \mathbb{F}_{q}[\varepsilon]$ where $\varepsilon^4=\varepsilon^3$ and $(char(\mathbb{F}_q)\neq 2,3)$ \cite{1}. The proposed construction combines two well-known computationally hard problems: the elliptic curve discrete logarithm problem and the conjugacy problem in non-commutative rings. The proposed digital signature algorithm is designed by exploiting the interaction between these two problems, resulting in a hybrid cryptographic scheme that strengthens security compared to classical approaches based on a single hardness assumption. The scheme ensures the fundamental security properties required for digital signatures, including authentication, message integrity, and non-repudiation. Furthermore, we present a comprehensive security analysis of the proposed scheme and evaluate its resistance against four common types of cryptographic attacks. The results demonstrate that the use of non-commutative algebraic structures provides a promising direction for the design of secure and efficient digital signature schemes.



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sciforum-171045: Approximation and Decomposition of Functions in L^2 via Fractal Structures

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This paper establishes a comprehensive theoretical framework for the approximation and decomposition of functions within the square-integrable space L^2([0,1]) by utilizing fractal structures. We focus on investigating the structural and approximation properties of functional spaces, denoted as V_n, which are generated through the translations and rescalings of a family of generating functions B over the elements of a fractal partition Gamma. Within this general setting, classical techniques such as Fourier series decomposition emerge naturally as special cases of our proposed decomposition scheme.

A central result of this study concerns the necessary conditions for universal approximation when the family consists of a single generator B. We prove a significant rigidity condition: the system constitutes a dense fractal system in L^2 if and only if B is constant almost everywhere. Furthermore, we derive explicit quantitative bounds for the speed of convergence when the approximation spaces are spanned by piecewise polynomials and trigonometric polynomials adapted to the fractal structure. By extending the classical theorems of Jackson and Bernstein–Walsh to the fractal domain, we demonstrate that the error decay depends on the regularity of the target function and the geometry of the structure. Specifically, for analytic functions, the error decays exponentially based on the scaling factor and structure level, while for differentiable functions, the error decays polynomially with respect to the degree and geometrically with the level. Finally, we discuss the representation of functions as series expansions and extend the fundamental density results to general metric spaces endowed with a finite Radon measure.



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sciforum-170778: Orderconvergence, a quasitopos for Bounded Topology (BT)

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Orderconvergence provides a unifying framework for the study of point convergence, boundedness, and filter merotopy, and plays a central role in both Convenient Topology and Bounded Topology. It offers a flexible approach to convergence phenomena that extends beyond the limitations of purely topological methods. In this paper, we investigate spaces equipped with order convergence from a categorical point of view and analyze the structural properties of the categories naturally associated with them.

It is well known that several classical categories arising in topology and convergence theory fail to satisfy desirable convenience properties, such as being Cartesian closed, extensional, or stable under the formation of quotients and products. In particular, the category **TOP** lacks these structural features, while the category **CHY** of Cauchy spaces, although Cartesian closed, does not form a quasitopos. Moreover, the full subcategory **EF-PROX** of **CHY**, consisting of Efremovič proximity spaces, also fails to possess the expected convenient properties.

To address these shortcomings, we introduce and study an appropriate supercategory of order convergence spaces together with suitable morphisms. We show that this category forms a strong topological universe in the sense of Convenient Topology, and in particular a quasitopos. As a consequence, quotients in this setting are stable under arbitrary products. This categorical framework enables a uniform treatment of bornological and Cauchy structures and provides a clearer understanding of their mutual relationships and categorical behavior. To exclude pathological cases, all underlying sets are assumed to be non-empty.



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sciforum-170851: Quadratic Extensions of Hyperfields and Local–Global Principles

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In this joint work with Pawel Gladki (University of Silesia, Poland) and Kaique M.A. Roberto (Faculty Einstein, Brazil), we develop a new approach to local–global principles in (non-reduced) algebraic theory of quadratic forms by employing instruments and techniques of hyper compositional algebra (a.k.a. multi-algebras).

We define quadratic extensions of special hyperfields (hyperfields that faithfully encode quadratic forms theory) as a particular type of Marshall quotients and investigate their basic properties. In particular we apply these constructions to develop new types of local–global principles in the algebraic theory of quadratic forms that we call n-th Pfister approximation properties (n-PAP) and analyze a few instances where they do—as well as do not—hold. This approach builds on Pfister's and Marshall's local–global principles that have been established in the realm of reduced theories of quadratic forms.

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sciforum-171614: The world is a Category of transformations

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Many of the properties and aspects of nature should be understood in an inherently dynamical context. Some of them as a product or producers of dynamism, while others are to be understood as the lack of some changes that are expected to happen, as patterns of resistance to change. For this, it is pivotal to have a formal understanding of the basic unity of change, i.e., transformations. We define a transformation as a duple $t = (K,s)$ of a set K of characteristics and a finite sequence s of entities with no constant steps, such that there is a characteristic $c \in K$ that remains constant in each step. The concept of composition of two transformations is defined as the duple formed by the union of the sets of characteristics and the concatenation of the sequences. If we label with V the space of transformations, a subspace of V is any set $S \subset V$ that is closed under composition of elements. Let $e>$ be the set of all the transformations that have e as the first element of the sequence; then, $e>$ is a subspace of V. It is proved that there is a category W whose set of objects is the space of entities. The set of morphisms $Mor(e_1,e_2)$ is the set of transformations of e_1 into e_2. For every triple of entities e_1, e_2, and e_3, a suitable restriction of the composition is the composition of morphisms between $Mor(e_1,e_2)$ and $Mor(e_2,e_3)$. Each identity morphism is a trivial transformation with only one step. Finally, we approach the subject of patterns of resistance to change in terms of this theory of transformations, thus refining our understanding of the wholeness and unity of nature.



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sciforum-173296: Time-Embedded Information Geometry: A Compatible Geometric Extension of the Fisher–Rao Framework

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Introduction

Classical information geometry provides a differential-geometric framework for statistical models based on structures such as statistical manifolds and the Fisher–Rao metric. However, time is typically treated as an external parameter, which limits the representation of evolving statistical systems and dynamic probabilistic structures.

Methods

We propose a conceptual extension called Time-Embedded Information Geometry (TEIG), in which temporal evolution is incorporated directly into the structure of the statistical model. Instead of treating time as an external variable, it is embedded as an additional coordinate within the model. This formulation enables a unified geometric representation that captures both parameter variation and temporal change, while preserving the underlying statistical structure.

Results

We show that this formulation remains compatible with the classical Fisher–Rao geometry and provides a consistent way to describe time-dependent statistical configurations. The proposed framework maintains structural coherence with existing theory while extending its expressive capability. In particular, when temporal effects are neglected, the framework reduces naturally to standard information geometry.

Conclusions

TEIG offers a geometrically consistent extension of Fisher–Rao-based models and provides a new perspective for analyzing time-dependent statistical systems. This approach may contribute to broader applications in mathematical modeling, dynamical systems, and computational science. Furthermore, it provides a flexible framework for integrating temporal dynamics into geometric modeling.



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sciforum-154513: A Monodromy-Theoretic Approach to Control Systems on Principal Bundles over Riemann Surfaces

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This work presents a novel geometric approach to control theory on curved surfaces by establishing a precise connection between isomonodromic deformations of logarithmic connections on principal bundles and control systems on Riemann surfaces. The key insight is that optimal trajectories in control systems can be understood as geodesics with respect to a metric determined by monodromy data. The framework begins by characterizing control systems in terms of logarithmic connections on principal bundles over Riemann surfaces, where the residues at singular points encode the control structure. We establish that controllability is equivalent to the residues generating the full Lie algebra of the structure group under commutator brackets, providing a geometric criterion that can be verified algebraically. The main result demonstrates that optimal control trajectories minimizing a quadratic cost functional correspond precisely to isomonodromic deformations, where the monodromy representation remains constant under parameter variation. This correspondence extends naturally to systems with non-holonomic constraints, where the eigenvalue structure of the residue matrices determines the growth vector of the constraint distribution. The symmetry algebra of the constrained system is shown to be isomorphic to the Lie algebra generated by the residues. We illustrate the theory through a detailed computational example involving principal bundles with special unitary structure group over a hyperbolic surface of genus two.



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sciforum-176968: Algebraic Polynomial Automorphisms and Their Minimal Polynomials

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Inspired by the Cayley–Hamilton theorem for linear operators, we introduce the notion of an algebraic polynomial automorphism. In this framework, a polynomial automorphism is called algebraic if it satisfies a nontrivial polynomial operator identity when regarded as an operator acting on the polynomial algebra; otherwise, it is called non-algebraic. This notion provides a new algebraic perspective on polynomial automorphisms, allowing them to be studied using ideas analogous to those appearing in the theory of algebraic linear operators and operator identities.

We investigate the algebraicity of several important classes of polynomial automorphisms. First, we prove that every elementary automorphism is algebraic. More generally, we show that any finite composition of commuting elementary automorphisms is algebraic as well. Moreover, we obtain explicit bounds for the degree of the corresponding minimal polynomial satisfied by these automorphisms. These results indicate that algebraicity naturally arises within a large and fundamental family of polynomial transformations.

On the other hand, algebraicity does not follow from tameness. To demonstrate this phenomenon, we construct a tame automorphism of k[x,y,z] which is non-algebraic. Finally, we study the classical Nagata automorphism together with a family of higher-dimensional Nagata-type automorphisms. We prove that they satisfy a cubic operator identity and hence are algebraic of degree three.



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sciforum-171218: Almost-para-Ricci-like solitons with torse-forming vertical potential of constant length on para-Sasaki-like Riemannian Π-manifolds

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In 1976, Sato introduced the concept of an almost paracontact structure. On such a manifold, two types of compatible metrics can be considered—the induced transformations, which are isometries, or the antiisometries on the paracontact distribution of the tangent space. The main difference between them lies in the type of associated tensor (0,2) of the metric on the structure. In compatible manifolds, it is a metric, while in metric manifolds, it is a 2-form.

Furthermore, different geometers contributed to the development of the study of the first case manifolds—Riemannian almost paracontact manifolds. In 1980, Sasaki introduced the notion of a Riemannian almost paracontact manifold of type (*p*,*q*). By *p* and *q* he meant the multiplicities of the eigenvalues +1 and -1 of the structural endomorphism φ.In addition to these eigenvalues, the tensor field φ also has a simple eigenvalue 0.

In the other possible case, i.e., the case of almost paracontact metric manifolds, the metric is pseudo-Riemannian with a signature (*n*+1, *n*). These geometric objects have been well studied by a number of authors.

An almost paracontact structure (φ, ξ, η) that possesses a traceless endomorphism φ plays the role of an almost paracomplex structure on the paracontact distribution of a (2*n*+1)-dimensional smooth manifold and is called a Π-structure. Such a manifold, equipped with a Π-structure, is called a Π-manifold, and when it is also equipped with a Riemannian metric *g*, it is called a Riemannian Π-manifold.

In this work, a generalization of para-Ricci-like solitons with torse-forming potential on para-Sasaki-like Riemannian Π-manifolds, which is constant multiple of the Reeb vector field, is investigated. Necessary and sufficient conditions are established for such solitons to be equivalent to almost-para-Einstein-like metrics. Further results are derived concerning parallel symmetric covariant tensors of second order. An explicit example in an arbitrary dimension is constructed to illustrate the obtained results.



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sciforum-173148: Annihilator Based Dependency Relations in Modules and Radical Characterizations

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This paper introduces two novel concepts in module theory based on the structural behavior of annihilator ideals and their radicals: totally annihilator-dependent modules and a radical dependency relation between modules. These notions aim to generalize classical submodule dependence—such as linear or essential dependence—by incorporating the radical behavior of annihilator ideals into the algebraic analysis of modules over commutative Noetherian rings. Within the framework of radical dependency, denoted by $N_{1} \triangleleft_{rad} N_{2}$, we establish that two submodules are radically dependent if and only if their radical annihilators satisfy a mutual containment relation, specifically that either $\sqrt{Ann(N_{1})} \subseteq \sqrt{Ann(N_{2})}$ or $\sqrt{Ann(N_{2})} \subseteq \sqrt{Ann(N_{1})}$. We further provide a comprehensive characterization theorem for totally annihilator-dependent modules, proving that a finitely generated module M satisfies this dependency condition if and only if its set of associated primes, $Ass(M)$, consists of a single prime ideal. Additionally, for finitely generated multiplication modules, we demonstrate that the radical of the annihilator of the sum of two nonzero submodules is equal to the sum of the radicals of their respective individual annihilators under the condition of a single associated prime. The study also explores the properties of radically supplemented modules and introduces the set $Z_{g}(M)$ to translate these dependency relations from submodules to module elements via annihilator radical equivalency classes. Several illustrative examples are provided to demonstrate the scope and limitations of these results, offering a new perspective for classifying modules through the lens of annihilator radicals and Krull dimension.



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sciforum-170931: Balancing numbers that are palindromic concatenations of two distinct repdigits

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Let $(B_n)_{n\geq 0}$ be the sequence of Balancing numbers defined by the recurrence relation $B_{n+2} = 6B_{n+1} - B_n$, $n \geq 0$, with initial terms $B_0 = 0$ and $B_1 = 1$. In this work, we determine all Balancing numbers that can be written as palindromic concatenations of two distinct repdigits. Our method combines the theory of linear forms in logarithms of algebraic numbers, together with Baker's reduction technique.

This sequence has been studied for its rich arithmetic and combinatorial properties, and its connection to balancing numbers, which solve the Diophantine equation: $1 + 2 + \cdots + (x - 1) = (x + 1) + \cdots + (x + r)$ for suitable integers x and r. The Balancing numbers also appear in applications to continued fractions and are related to certain classes of Diophantine tuples. The first few terms of the sequence are: 0, 1, 6, 35, 204, 1189, 6930, 40391, . . .

First, we obtain an upper bound for n by comparing the growth of B_n with the number of digits in the target palindrome. Next, we apply Matveev's theorem on linear forms in logarithms to derive explicit lower bounds. Finally, we employ the Baker–Davenport reduction method to restrict the problem to a finite set of cases, which are then checked computationally. This procedure yields the following result:

Theorem. There is no Balancing number which is a palindromic concatenation of two distinct repdigits.



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sciforum-136345: Bridging group theory and graph theory through commutativity degrees

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The interplay between algebraic structures and graph theory has emerged as a dynamic and fruitful area of research in modern mathematics. By establishing connections between graphs and groups, mathematicians have developed innovative approaches to visualize and analyze the intrinsic properties of groups using graph-theoretic tools. These connections enhance our understanding of group theory and provide new perspectives on how graph theory can be effectively applied within algebraic frameworks.

The origins of this interdisciplinary relationship can be traced back to the pioneering work of Arthur Cayley in 1878, who introduced what are now famously known as *Cayley graphs*. These graphs serve as visual representations of groups, where each vertex corresponds to a group element, and edges reflect the relationships defined by a generating set. Cayley's groundbreaking idea laid the foundation for a vast and ongoing exploration of the rich interactions between group theory and graph theory, which continues to inspire contemporary research across various mathematical domains.

In this study, we contribute to this line of research by investigating different notions of commutativity degrees in finite groups and exploring their algebraic properties. Building on these findings, we construct new classes of graphs associated with finite groups and examine their structural characteristics. We further illustrate our results by considering several examples of special types of groups, offering fresh insights into the mutual influence of algebraic and graph-theoretic perspectives.



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sciforum-162062: Classification of Central Modular Phases via Explicit Dirac–Spinor Constructions in Finite-Dimensional Tomita–Takesaki Theory

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This work presents a rigorous analysis of central modular phases in finite-dimensional Tomita–Takesaki theory and develops an explicit construction of the non-standard case in which the modular conjugation fails to be involutive. Focusing on the four-dimensional Dirac spinor algebra, we show through direct computation that the corresponding charge-conjugation operator squares to minus the identity rather than the conventional plus identity assumed in standard modular theory. Interpreting this operator as a modular conjugation demonstrates the existence of a modular structure whose square equals negative one, providing a concrete counterexample to the usual assumption that modular conjugations must be involutions.

We prove that this sign is a genuine algebraic invariant: modular conjugations with positive and negative square values cannot be related by any unitary similarity transformation, and therefore represent two fundamentally distinct modular phases. We further show that these two possibilities exhaust all central modular phases in finite-dimensional fermionic systems, yielding a complete binary classification. The construction is fully explicit, representation-independent, and formulated within the standard algebraic setting.

Finally, we extend the analysis to pseudo-Hermitian quantum systems by defining a twisted Tomita operator that respects closability and admits a well-defined polar decomposition. This establishes that non-standard modular phases persist in modified inner-product settings and remain compatible with the general modular framework. The results provide a mathematically controlled foundation for modular structures beyond the Hermitian paradigm and contribute new algebraic invariants relevant to modern mathematical physics.



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sciforum-174318: Classification of Finite Preordered Semigroups via Group Action induced by Pushforward

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We investigate finite semigroups equipped with a preorder relation that is compatible with the semigroup operation. We introduce the concept of a compatible preorder and define the associated structure of a preordered semigroup, which captures the interaction between the semigroup operation and order-theoretic properties. To classify such structures, we develop an enumeration methodology based on automorphism group actions. For a fixed finite semigroup S, the automorphism group Aut(S) acts naturally on the set Pre(S) of compatible preorders via pushforward, and the orbits of this action correspond exactly to isomorphism classes of preordered semigroups. To address anti-isomorphism, we incorporate the converse relation, which allows us to identify preorders equivalent up to inversion, effectively reducing the computational complexity. By considering the quotient of Pre(S) modulo, the converse relation, and extending the action via pushforward to the equivalence classes, we obtain a systematic approach to enumerate preordered semigroups up to both isomorphism and anti-isomorphism. Using known classifications of semigroups of a small order, together with exhaustive generation of compatible preorders, our method provides a complete enumeration of preordered semigroups up to an order of five. Finally, this framework opens a computational window toward the study of more complex algebraic systems, notably EL-hyperstructures arising in hypercompositional algebra, where preordered semigroups serve as a fundamental tool for their construction.



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sciforum-171330: Cyclic Codes as Ideals in Polynomial Rings: Algebraic Foundations and Applications

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Cyclic codes form a fundamental class of linear error-correcting codes widely used in digital communications and data storage systems due to their efficient algebraic structure. Despite their long-standing presence in coding theory, the exploration of cyclic codes through the lens of polynomial rings over finite fields continues to reveal new insights into their structural properties and practical applications.

In this study, cyclic codes are represented as ideals of the quotient ring $F_q[x]/(x^n-1)$, where F_q denotes a finite field of order q. Ring-theoretic methods are employed to analyze the relationship between codewords and generator polynomials. The factorization of x^n-1 is examined to determine the structure of all possible cyclic codes of a given length, and algebraic techniques are used to derive their dimension and minimum distance.

The theoretical analysis demonstrates a direct correspondence between ideals in the quotient ring and cyclic codes, highlighting how generator polynomials uniquely define each code. Several illustrative examples show how this algebraic framework enables systematic construction of cyclic codes with predictable parameters. The results confirm that the polynomial approach simplifies encoding procedures and provides a clear method for calculating essential code characteristics, such as code length, dimension, and error-correcting capability.

This study reinforces the effectiveness of polynomial rings as a unifying algebraic framework for cyclic codes. By connecting abstract ring-theoretic concepts with practical coding applications, the work bridges theory and implementation, offering a foundation for further explorations of advanced cyclic code structures and their applications in modern communications systems. The approach also opens avenues for designing new classes of codes with enhanced error-correcting properties.



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sciforum-174136: Foliation from an Algebraic Perspective

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Introduction: Foliations are geometric structures that decompose smooth manifolds into immersed submanifolds called leaves. While classical theory relies on differential-geometric methods and the Frobenius theorem, a purely algebraic characterization remains underexplored. This study develops an algebraic framework for foliations by translating their structure into the language of modules, derivations, and ring theory.

Methods: Building on the foundations of smooth manifolds and differential maps, three interconnected perspectives are developed. The classical approach examines integrable and involutive distributions via the Frobenius theorem. The Lie-theoretic viewpoint employs Lie algebras, Lie groups, and Hopf algebras to encode symmetries. The module-theoretic perspective uses the module of derivations Der(C-infinity(M, R)) to provide an algebraic description of tangent vector actions. Smooth Gelfand duality is employed as the categorical framework connecting geometric structures with their corresponding algebras of functions.

Results: The central result establishes that every foliation F on a manifold M determines a unique involutive projective submodule of Der(C-infinity(M, R)) that encodes the foliation's structure. Furthermore, an ideal–leaf correspondence is established: each closed leaf L corresponds to an ideal I(L) of functions vanishing on L, preserved under the foliation action. The foliation algebra A_F, consisting of functions constant along leaves, is shown to encode the leaf space structure even when the geometric quotient M/F is singular.

Conclusions: This work demonstrates that foliations can be fully characterized in algebraic terms, establishing a dictionary between differential geometry and algebra. Tangent distributions correspond to submodules of derivations, Lie brackets to commutators, and integrability to involutivity. These results open new pathways for applying categorical methods to the study, classification, and reconstruction of foliations on smooth manifolds.



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sciforum-171123: Homological Objects of the Proper Class Determined by Weakly D-Closed Modules

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This talk is devoted to the study of a distinguished class of modules characterized by the property that all crumbling submodules of their factor modules are trivial. This defining condition imposes strong internal constraints on the module structure and leads naturally to a coherent and well-organized framework within module theory and relative homological algebra. The motivation behind this investigation arises from the observation that such a restriction allows for a systematic treatment of both structural and homological properties, thereby enabling meaningful comparisons with classical module theory concepts. The primary objective of the talk is to analyze the fundamental structural properties of this class of modules and to examine the relative classes that are naturally induced by it. Within this framework, the proposed module class is positioned among several well-known and extensively studied classes of modules in the literature. The relationships between these classes are explored in a precise and systematic manner, with particular attention given to similarities, differences, and inclusion properties. In particular, the effects of radicals, direct products, and module homomorphisms on the defining properties of the class are examined in detail. This analysis provides insight into the stability of the class under common operations and clarifies the extent to which the defining condition is preserved. Moreover, it sheds light on how these modules interact with classical methods and techniques in module theory. Overall, the results presented in this talk contribute to a deeper understanding of the interplay between structural properties and homological considerations in module theory. By developing and refining the conceptual framework surrounding this module class, the study lays the groundwork for further investigations in relative homological algebra and highlights new directions for research based on the interaction between algebraic constructions and module theory.



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sciforum-162998: Mathematical Proof of the Existence of Intrinsic Spatial Mass: A Rigorous Framework Based on Discrete Groups and Complex Linear Spaces

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Existing studies mostly infer the existence of intrinsic spatial mass from physical intuition through a qualitative analysis of wave–particle duality (e.g., empirical application of the zero equation) but lack a proof process that meets mathematical rigor. The core contribution of this paper lies in constructing a strict "axiom–lemma–theorem" derivation system based on the discrete group Z_2 (describing the binary reciprocity of "particle nature–spatial nature") and the complex linear space M (representing mass states), combined with the kernel space theory of linear functionals and the positivity of Hermitian inner products.

Intrinsic spatial mass is a core concept in the mass mathematics system that connects abstract mathematical structures to the properties of physical spacetime. A rigorous proof of its existence is crucial for ensuring the theoretical consistency of this field. Using discrete group representation theory, complex linear space theory, and linear functional analysis as tools, this paper constructs a theoretical framework comprising four core axioms (Discrete Symmetry Group Axiom, Complex Mass Space Axiom, Zero equation Constraint Axiom, and Physical Observability Axiom). Through a three-level derivation chain—non-emptiness of the kernel of a linear functional–non-vanishing of intrinsic spatial mass–consistency of discrete group action—the existence of intrinsic spatial mass is strictly proven. This study shows that intrinsic spatial mass has three cases in the complex mass space M≅C2: m_is = im_rp; m_rs = −im_ip; and m_is = -m_ip (where m_p is the particle mass, m_s is spatial mass, r is the real number, and i is the imaginary number). It satisfies both physical observability (its squared norm is a non-negative real number) and discrete symmetry consistency (closure under Z_2 group action). This proof provides core support for the axiomatic construction of mass mathematics and offers a new perspective on the mathematical interpretation of wave–particle duality in quantum mechanics.



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sciforum-171240: Multivector Time Generator: A Novel Algebraic Framework for Temporal Symmetries

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In this presentation, a multivector time generator is introduced in which temporal evolution is represented as the action of a multivector on the phase plane, formulated within two-dimensional geometric (Clifford) algebra. Rather than extending time as an additional scalar or complex parameter, the proposed approach reinterprets the time derivative itself as a structured generator whose scalar, vector, and bivector components encode distinct temporal symmetries. Within this framework, bivector components generate symplectic, Hamiltonian evolution and correspond to reversible dynamics, while scalar components produce uniform contraction or expansion in the phase plane, providing a direct geometric characterization of irreversibility. Vector components generate reversible but anti-symplectic transformations, such as reflections, revealing temporal symmetries that lie outside the standard Hamiltonian and complex-time formalisms. This decomposition yields a natural classification of linear dynamical systems into elliptic, hyperbolic, and nilpotent regimes, corresponding to oscillatory, overdamped, and critically damped behavior. General solutions are expressed through multivector exponentials, allowing reversible and irreversible contributions to factorize transparently. The framework further clarifies the status of complex time, showing that it emerges only as a restricted case when vector components vanish and the generator reduces to an even subalgebra admitting a Wirtinger representation. Outside this regime, temporal evolution is intrinsically a multivector and cannot be described by a single complex parameter. By focusing on the algebraic structure of the time generator rather than on time as a primitive parameter, the proposed framework provides a unified geometric language for temporal symmetries in dynamical systems and offers new tools for analyzing reversible and irreversible evolution within a purely algebraic setting.



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sciforum-171182: On indices and monogenity of certain classes' number fields defined by quadrinomials

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Let K be an algebraic number field of degree n with ring of integers $\mathbb{Z}_K$.

The field K is called monogenic if $\mathbb{Z}_K=\mathbb{Z}[\theta]$ for some primitive element θ of Z_K.

Equivalently, $(1,\theta,\ldots,\theta^{n-1})$ forms a $\mathbb{Z}$-basis of $\mathbb{Z}_K$.

Such a basis is called a power integral basis of $\mathbb{Z}_K$.

If the ring $\mathbb{Z}_K$ does not admit any power integral basis, then K is said to be non-monogenic.

The monogeneity of number fields and the construction of power integral bases have been widely studied in both classical and recent research, and many interesting open problems related to these topics remain the subject of active investigation. One of the most important contributions to this problem was made by Gy\H{o}ry, who effectively proved that there exist only finitely many $\mathbb{Z}$-equivalence classes of elements θ, generating a power integral basis of $\mathbb{Z}_K$.

In this talk, for some fixed positive integers n, m, and s, we study the prime common divisors of the indices associated with certain infinite families of number fields defined by quadrinomials of the form $x^n + a x^m + b x^s + c$.

As an application of our results, we provide some explicit conditions on a, b, and c under which these number fields are not monogenic.

Our approach is based on Ore's classical theorem on the decomposition of primes in number fields, which is formulated using Newton polygon techniques.



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sciforum-170694: On symplectomorphisms of generalized Lie-Rinehart algebras

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Lie-Rinehart algebras provide an algebraic abstraction of Lie algebroids, encoding simultaneously a Lie algebra structure and a module structure over a commutative algebra, together with a compatible anchor map acting by derivations. Since their introduction by Herz, these structures have played a central role in the algebraic formulation of differential geometry, Poisson geometry, and deformation theory, serving as the natural algebraic setting for derivations, differential forms, and cohomology on commutative algebras. An analogous construction for a general Lie algebroid has been introduced by Iglesias and Marrero under the name of a generalized Lie algebroid. In parallel, Jacobi algebras generalize Poisson algebras by allowing the Leibniz rule to hold up to a derivation, capturing algebraically the geometry of contact and locally conformal symplectic manifolds. While Poisson algebras correspond to Lie algebroids via the cotangent bundle construction, Jacobi algebras require a more flexible framework that incorporates both a Lie bracket and a distinguished derivation.

In our talk, we describe generalized Lie-Rinehart algebras as an extension of Lie-Rinehart algebras and give some examples. These structures extend classical Lie-Rinehart algebras by allowing the anchor to take values in first-order differential operators. We characterize generalized symplectic manifolds and contact manifolds in terms of generalized symplectic Lie-Rinehart algebras and we show the existence of Jacobi structure induced by a generalized symplectic Lie-Rinehart algebra. We introduce the notion of symplectomorphisms of generalized Lie-Rinehart algebras and describe them particularly in the case of contact manifolds, generalized symplectic manifolds and in the case of non-degenerate Jacobi structures



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sciforum-171572: On the topology induced by fuzzy partial metric spaces

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In recent years, fuzzy metric spaces and fuzzy partial metric spaces have attracted considerable attention due to their ability to generalize classical metric structures and model uncertainty in a more flexible and nuanced manner. In particular, fuzzy partial metrics extend fuzzy metrics by allowing different self-distances for points. Considering that each point's self-distance may vary in fuzzy partial metric spaces, the concept of an open ball is defined accordingly, differing from its definition in classical fuzzy metric spaces. One of the central problems in this area is the construction and comparison of topologies induced by different notions of open balls. In the existing literature, there are two commonly used notions of open balls, and it has been shown that a topology can be induced using only one of these concepts. In this study, we introduce a new notion of open balls in fuzzy partial metric spaces and demonstrate that a topology can be constructed from a fuzzy partial metric via the proposed concept. We further compare this notion with other variants of open balls and examine the corresponding induced topologies. Additionally, we investigate fundamental properties of this topology, including completeness, metrizability, and compactness, providing insight into how classical topological properties extend to the fuzzy partial metric setting.



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sciforum-171216: On the Upper Embeddability of Johnson Graphs for n>k≥2

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Topological graph embeddings, particularly 2-cell embeddings, establish a fundamental link between graph theory and surface topology. For a connected graph G, the minimum genus $\gamma(G)$ and maximum genus $\gamma_M(G)$ are defined as the smallest and largest genera of orientable surfaces admitting a 2-cell embedding of G, respectively. It is known that an upper bound for the maximum genus of a graph G is

$\gamma_M(G) \leq \lfloor \beta(G)/2 \rfloor$, where $\beta(G)$ is the Betti number of G. A graph is said to be upper embeddable if this equality is achieved.

First, we introduce a lexicographic labeling of the vertices and edges of the Johnson graph J(n,k). Using this labeling, a spanning tree is constructed by sequentially adding edges while avoiding cycles. We prove that this spanning tree is a splitting tree, whose complement contains at most one component with an odd number of edges, and hence establish the upper embeddability of J(n,k) for all n>k≥2 through Jungerman's characterization. Finally, by applying the classical upper bound in terms of the Betti number, we obtain an explicit formula for the maximum genus of J(n,k).

We prove that the Johnson graph J(n,k) is upper embeddable for all n>k≥2 by explicitly constructing a splitting tree. As a consequence, the maximum genus of J(n,k) is obtained as $\gamma_M(J(n,k)) \leq \lfloor (k(n-k)-2)/(2k!) \prod_{i=1}^{k-1}(n-i) \rfloor$.

In this study, we establish the upper embeddability of the Johnson graph J(n,k) for all n>k≥2. Using an explicit splitting tree together with Jungerman's characterization, we show that the maximum genus of J(n,k) attains the theoretical upper bound given by its Betti number. This leads to an exact formula for $\gamma_M(J(n,k))$.

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sciforum-162140: Optimizing Emergency-Station Placement through Roman and Double Roman Domination in Zero-Divisor Graphs of Finite Rings

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Zero-divisor graphs provide a powerful bridge between commutative algebra and graph theory by encoding annihilation relationships among zero divisors of a finite ring. While parameters such as connectivity, chromatic number, and classical domination have been extensively explored, Roman domination and double Roman domination in zero-divisor graphs remain largely uncharacterized. These parameters model optimal resource allocation under different levels of protection and redundancy. This study aims to compute and analyze the Roman domination number and the double Roman domination number for key families of finite commutative rings and to establish structural relationships between algebraic properties of rings and optimal domination behavior.

Methods:

For each selected ring family, zero-divisor graphs are constructed from annihilation relations. Roman and double Roman domination are formulated as constrained optimization problems, supported by algebraic–graph theoretic lemmas, degree-based bounds, and annihilator structure analysis. Exact values are obtained using integer linear programming (ILP), while large graphs are studied using heuristic algorithms informed by neighborhood structures and annihilator classes.

Results:

Preliminary analyses reveal that vertices with maximal annihilator degree play a central role in optimal Roman and double Roman labelings. Structural features such as star-like patterns, complete subgraphs, and decompositions from the Chinese Remainder Theorem significantly reduce domination cost. Across ring families, distinct algebraic characteristics—particularly annihilator chains and idempotent behavior—strongly influence domination numbers.

Conclusion:

This work establishes new theoretical bounds, exact values, and structural characterizations of Roman and double Roman domination in zero-divisor graphs. These findings also support an application framework interpreting domination assignments as minimum-cost emergency-station placement strategies, demonstrating the practical relevance of the studied parameters.



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sciforum-173898: Refining Geodesy and Photogrammetry with Geometric Algebra

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Clifford's geometric algebras originally arise from theoretical physics, the most developed mathematically of the empirical sciences, where they provide a natural and elegant description of phenomena, such as classical mechanics and electrodynamics. Unfortunately, however, they are less well known to students nowadays, since already at the end of the 19th century they were replaced by the hollow formalism of vector analysis. Decades later Pauli and Dirac had to reinvent geometric algebras to write their famous equations, but the breakthrough that led to their triumphant return to the epicenter of active research came this time from technology: robotics, navigation, computer vision, animated simulations, etc. In view of these trends, a valuable opportunity opens up in many engineering sciences to upgrade and improve their mathematical description, optimize their algorithms, and significantly simplify the academic curricula. In this paper we approach some of the classical problems in geodesy and photogrammetry from the perspective of geometric algebras, which have proven rather effective in other engineering disciplines, such as robotics and computer vision. More precisely, we tackle problems like self-calibration and 3D reconstruction, trilateration, triangulation, and synchronization of reference frames, using dual quaternions, the Projective geometric algebra (PGA) and the more general Conformal geometric algebra (CGA). As expected, this approach provides a simpler and more elegant mathematical description, more suitable for both pedagogical reasons and algorithm efficiency. The results presented here are also meant to be used as a framework for future research targeting more advanced problems in those areas.



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sciforum-174380: Some generalized sequence space defined by Musielak–Orlicz function

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In this paper, we introduce and investigate new classes of sequence spaces defined by a Musielak–Orlicz function $\Pi = (\pi k)$ over a linear space (V, q), where q is a seminorm. By combining the structural flexibility of Musielak–Orlicz functions with generalized averaging techniques inspired by the classical M(ϕ)-space, we define the sequence spaces $\ell 1[\Pi, q]$, $\ell\infty[\Pi, q]$, and $M[\Pi, \phi, q]$. These spaces extend several well-known Orlicz-type and modulus-based sequence spaces and provide a unified framework for studying coordinate-wise variable modular growth conditions. The space $M[\Pi, \phi, q]$ is constructed as a natural generalization of the classical M(ϕ) sequence space by incorporating a Musielak–Orlicz modular structure. We investigate the fundamental algebraic and topological properties of these spaces, including linearity,solidity, symmetricity, monotonicity, and completeness. Suitable Luxemburg-type seminorms are introduced,and it is shown that these spaces become complete seminormed spaces whenever the underlying seminormed space (V, q) is complete. Furthermore, we establish several inclusion relations between the newly defined spaces under appropriate growth conditions on the sequence $\phi = (\phi s)$ and on Musielak–Orlicz functions satisfying the $\Delta 2$-condition. In particular, we prove that $\ell 1[\Pi, q] \subseteq M[\Pi, \phi, q] \subseteq \ell\infty[\Pi, q]$,and obtain additional inclusion results involving compositions and sums of Musielak–Orlicz functions. These results generalize earlier works on Orlicz sequence spaces and contribute to the further development of modular and generalized sequence space theory, opening new directions for the study of dual spaces, matrix transformations, and operator-theoretic properties in Musielak–Orlicz-type settings.



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sciforum-164728: Spectral Radius Thresholds and Higher Homotopy in Random Simplicial Complexes

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Introduction: We develop a spectral–topological framework linking the spectral radius of data matrices to the emergence of higher homotopy groups in associated simplicial complexes. Using a Hurewicz-type principle, we show that spectral growth governs both the birth and collapse of higher-order topological structure. The approach provides a computationally tractable alternative to persistent homology, with rigorous results for low dimensions and principled conjectures in general.

Methods: Given a sequence of symmetric matrices A_n, we constructed clique complexes X_n via thresholding. Spectral radius $\rho(A_n)$ was used as the governing control parameter. Algebraic-topological tools (Hurewicz theorem, homology–homotopy correspondence) and probabilistic asymptotics were combined to study limiting behavior as $n \to \infty$.

Results: Theorem 1 Spectral Threshold for π_2: There exist deterministic thresholds $0 \ \rho_2^- \ \rho_2^+$ such that $\pi_2(X_n)$ is nontrivial with high probability if and only if $\rho(A_n) \in (\rho_2^-, \rho_2^+)$. Full formal proof will be provided in the paper.

Theorem 2 Limiting Law for Homotopy Rank: For $k = 2$, $n^{-1}\text{rank}(\pi_2(X_n))$ converges in probability to a continuous function of $\rho(A_n)$. Full formal proof will be given in the paper.

Conjecture 1: Spectral thresholds (ρ_k^-, ρ_k^+) exist $\forall k \geq 2$.

Conjecture 2: A deterministic limiting law holds for $n^{-1}\text{rank}(\pi_k)$.

Conjecture 3: Centered homotopy ranks satisfy asymptotic normality.

Conclusion: The results establish spectral radius as a unifying scalar invariant governing higher-order topology. The framework connects spectral graph theory, Hurewicz-type arguments, and random topology, opening a path toward scalable inference of homotopy without full persistence. Related frontier work includes Kahle (random complexes), Linial–Meshulam models, and recent spectral-TDA (topological data analysis) connections in applied topology.



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sciforum-158342: Strictly Anti-Diagonally Dominant Matrices in Systems of Yang–Baxter Matrix Equations

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This study explores a system of Yang–Baxter-type matrix equations, XAX=BXB and XBX=AXA, which generalize the classical matrix Yang–Baxter equation. This work focuses on analyzing the existence of intertwining and commuting solutions using geometric and topological methods. To support this analysis, the notions of *anti-diagonally dominant matrices* (ADMs) and *strictly anti-diagonally dominant matrices* (SADMs) are introduced. It is shown that strictly anti-diagonally dominant matrices are nonsingular, ensuring stability and uniqueness in the associated linear systems. Furthermore, if the coefficient matrices of the system satisfy the SADM condition, then an intertwining solution X exists that fulfills both Yang–Baxter-type relations. When the matrices A and B are invertible, the corresponding solution X is proved to be a commuting one. These findings extend the algebraic framework of Yang–Baxter systems and provide new insights into the dominance properties that govern the solvability of matrix equations.

The equation was formally introduced by C. N. Yang in two landmark papers published in late 1967 on a one-dimensional quantum many-body problem. Yang established the form A(u)B(u+v)A(v) = B(u)A(u+v)B(v), where A(u) and B(v) are rational functions of the spectral parameters u and v. Later, in 1972, R. J. Baxter employed the same relation while solving the eight-vertex model in two-dimensional statistical mechanics.



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sciforum-164868: Structural Identities Determined by Prime Ideals through Generalized P-Derivations

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This paper focuses on the investigation of commutativity properties of the factor ring $\Re/P$, where P is assumed to be a prime ideal of an arbitrary ring $\Re$. The main objective is to determine sufficient algebraic conditions under which the quotient structure $\Re/P$ exhibits commutative behavior. To achieve this goal, the study employs the concept of generalized P-derivations δ and $\amalg$, which are constructed in association with the P-derivations χ and $\propto$, respectively. These generalized mappings are required to satisfy specific functional identities that create intrinsic links between the ring $\Re$ and its prime ideal P.

By analyzing these identities, we establish several results that reveal how the interaction between generalized P-derivations and the underlying ring structure influences the commutativity of $\Re/P$. The approach adopted in this work allows for a unified treatment of various derivation-like operators and highlights their effectiveness in deriving commutativity criteria in the presence of prime ideals. Furthermore, a number of related consequences and supplementary observations are discussed to place the main results within a broader algebraic context.

In order to emphasize the necessity of assuming the primeness of P, illustrative examples are presented showing that the obtained conclusions may no longer hold if this assumption is weakened or removed. These examples demonstrate that the primeness condition plays a crucial role in guaranteeing the validity of the established identities and the resulting commutativity of the factor ring. Overall, the results contribute to the ongoing study of derivations and generalized derivations in ring theory and provide further insight into their applications to factor rings determined by prime ideals.



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sciforum-169580: Structural Properties of Fuzzy β-Continuous and M-Fuzzy β-Continuous Mappings

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This paper establishes several results on fuzzy β-continuous and M-fuzzy β-continuous mappings between fuzzy topological spaces. Equivalent characterizations of fuzzy β-continuous maps are obtained. In particular, it is proved that a mapping is fuzzy β-continuous if and only if the inverse image of every fuzzy closed set is fuzzy β-closed. Additional characterizations are derived using β-closure operators, where necessary and sufficient conditions of the form $\beta cl(f^{-1}(V)) \leq f^{-1}(\beta cl(V))$ are established for arbitrary fuzzy sets. The central contribution of this work concerns the composition of fuzzy β-continuous mappings. It is shown that the composition of two fuzzy β-continuous mappings need not be fuzzy β-continuous in general; however, sufficient conditions are provided under which the composition becomes fuzzy β-continuous, particularly when one of the mappings satisfies stronger continuity conditions such as fuzzy pre-continuity or fuzzy semi-continuity. Several propositions formalize these results, and explicit examples illustrate that the corresponding converse statements fail. This theorem clarifies the structural behavior of fuzzy β-continuity under composition and provides useful criteria for analyzing the stability of such mappings in fuzzy topological spaces. The relationships between fuzzy β-continuous mappings and other classes of fuzzy mappings are also examined. It is proved that every fuzzy continuous, fuzzy pre-continuous, and fuzzy semi-continuous mapping is fuzzy β-continuous, while the reverse implications do not hold in general. The notion of M-fuzzy β-continuous mappings is studied, and it is shown that every M-fuzzy β-continuous map is fuzzy β-continuous, although the converse fails. Finally, for a bijective mapping between fuzzy topological spaces, it is proved that if $\beta int(A) \leq f^{-1}(int(f(A)))$ for any fuzzy set A, then $f(\beta cl(A)) \leq cl(f(A))$.



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sciforum-159291: The Alpha Group: Holonomic Structure and Dynamic Coupling of Dual Hopf Topologies in a Nontrivial Topological Space

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We define the Alpha Group as a four-dimensional real associative algebra A = spanR{1, i, μ, iμ}, with relations $i^2 = -1$, $\mu^2 = \mu$ (idempotent invariant), and $i\mu = -\mu i$ (noncommutative). Under the regular representation, elements of A act as 4×4 real matrices. Division is defined projectively via right multiplication by invertible elements of A.

The angular deformation operator M(θ) is the original 4×4 matrix introduced in the Alpha Group framework, whose entries depend analytically on θ and encode the coupling between the imaginary and μ-components of the algebra. This operator governs the deformation of basis directions and induces a θ-dependent metric structure on the associated orbit space.

To study the induced topology, we construct ε-graphs over point clouds generated by iterated application of M(θ). Vertices are connected whenever the induced metric satisfies $d(x,y) \leq \varepsilon$. The resulting filtration defines a Vietoris–Rips simplicial complex.

Persistent homology groups Hk for k = 0, 1, 2, 3 are computed along the filtration. For $0.4 \leq \varepsilon \leq 0.8$, the second homology group H^2 exhibits sustained growth, indicating stable 2-cycles generated by the θ-dependent deformation. The third homology group H^3 remains constant across the filtration, acting as a structural invariant.

A structural transition occurs near $\theta \approx \pi/2$, where the antisymmetric coupling encoded in M(θ) maximizes the generation of higher-order cycles. These results demonstrate that the algebraic structure of the Alpha Group induces a dynamically coupled topology with persistent higher-dimensional invariants, structurally distinct from classical Riemannian models.



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sciforum-172525: The Canonical Triple-Graph: A Structural Organization of the Positive Integers

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Introduction: The set of positive integers admits a latent hierarchical structure beyond the familiar linear ordering. We introduce the Canonical Triple-Graph (CTG), a fixed directed graph on the positive integers defined by an admissible associator on odd integers: n = (2^k m - 1)/3, where 2^k m ≡ 1 (mod 3). This relation is interpreted algebraically as defining edges that exist a priori within a predetermined structure, not as steps of an iterative or dynamical process.

Method: We analyze the structural properties of the admissible associator and its induced adjacencies. Every odd integer not divisible by 3 admits infinitely many admissible exponents forming blocks of associates. These blocks decompose uniquely into canonical triples of the affine form (n, 4n+1, 16n+5), which expose uniform self-similarity throughout the structure. Even integers integrate canonically via 2-adic factorization, forming deterministic vertical pillars above their odd parts.

Results: The CTG forms a directed graph (forest) on the positive integers. The distinguished root 1 generates Block(1), an infinite set of odd integers each serving as the root of its own infinite self-similar tree with identical local structure governed by canonical triples. We prove structural completeness via a block-closure principle: every block-closed component must contain an element of Block(1), ensuring all odd integers belong to trees rooted in Block(1). The structure is acyclic with unique parenthood within the CTG.

Conclusions: The CTG provides a purely structural framework comprising infinitely many self-similar trees, all rooted in Block(1), organizing positive integers independent of numerical magnitude or dynamical interpretation. This reframes classical iteration questions as structural position and component membership within an a priori fixed combinatorial forest.



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sciforum-174499: The characters of involutive automorphisms of simple Lie algebras

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The paper deals with the arbitrary finite-dimensional irreducible representations of simple complex Lie algebras g of types B2 and G2 and real forms so(1,4), so(3,2) and G of these algebras. Involutive automorphisms θ on Cartan subalgebras of these algebras are considered. Formulae for characters value $\chi(\theta)$ are obtained. This allows us to find the number of linearly independent space-like and time-like vectors in the representation space Consider a simple complex Lie algebra g and an irreducible finite-dimensional representation $\varphi : g \to sl(V)$. Denote by gr the real form of inner type for algebra g. Then $\varphi(gr) \subseteq su(p,q)$, where $p - q = \delta(gr)$ is the signature of the invariant Hermitian form on V. It is possible to find $\delta(gr)$ using Weyl character formula for the representation φ. In [1], F.I.Karpelevich derived formulae for δ in the case of classical Lie algebras. In [2], Lie algebras su(p,q) are considered convenient tables for δ in the case a small rank of g is found. In [3, 4], formulae for $|\delta|$ in the case of gr = G,FI,FII,so(p,q) were presented. Nevertheless, in applications, the exact tables including the sign of δ are necessary. We obtain in this paper the tables of δ in terms of the marks of the highest weight of representation φ. In addition, a similar table for any representation of exceptional Lie algebras of type G2 is derived. And it is not necessary to know the system of all weights of the representation φ.

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sciforum-171684: The geometry, topology, group theory and harmonics of Kaluza–Klein unification

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In my programme of covariant compactification, I seek to explain all the fundamental fields of physics as geometric quantities. This is based on the work of Kaluza and Klein to extend general relativity.

In this talk, I explore how the geometry of product spacetimes determines their diffeomorphism and covariance groups, and the general linear and (pseudo-)orthogonal actions these induce on tangent spaces. I show how tensors decompose and gauge fields arise when transformation groups are non-linearly realised.

I explain how the topology of factor spaces determines their harmonics, which are manifested as matter fields. With an appropriate choice of geometry, these can be identified with the known fermions, as each harmonic can be labelled by its quantum numbers.

Unlike most post-1960 Kaluza–Klein theories, unitary gauge transformations do not act directly on the additional dimensions. Instead, orthogonal diffeomorphisms on compact factor spaces have a 'dragging action' on fields defined on these spaces. The induced actions on multiplets of harmonics are unitary representations of the orthogonal groups. This includes spinor representations. This allows us to identify multiplets of harmonics with spinors, on which the unitary gauge transformations act.

And in contrast to perceived wisdom about modern Kaluza–Klein theories, symmetry restoration does not take place at high energies. Instead, it occurs at the zero-curvature 'decompactification limit', in which all dimensions appear on the same footing.



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sciforum-138731: The Principle of Emergent Continuity: Proof of the Emergence of the Mathematical Continuum from the Arithmetic of Prime Numbers

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This paper presents formal proof of the Emergent Continuum Hypothesis (ECH), a principle positing that the mathematical continuum is not a fundamental, axiomatic entity but a macroscopic phenomenon emerging from a discrete underlying reality. We demonstrate that a specific, non-trivial continuum is the necessary and unique limit of a system built from the set of prime numbers. The proof is constructed in four parts. First, we define a sequence of finite, directed metric spaces derived from the primes. The metric is determined by a novel, asymmetric weight function where the interaction between any two primes is mediated by the entire system; this interaction strength is based on the p-adic norms of the gap between the primes, evaluated against all primes in the system. Second, we prove that this sequence of spaces is a Cauchy sequence in the measured Gromov–Hausdorff metric, and therefore, converges to a complete, path-connected geodesic space, which we identify as the Emergent Continuum. Third, we prove that this convergence is critically dependent on the deep arithmetic nature of the rules, showing that simpler, non-arithmetic rules fail to produce a stable, non-trivial limit. Finally, we prove that the canonical Laplacian operator on this Emergent Continuum possesses a spectrum with eigenvalue spacing statistics that necessarily follow the Gaussian Unitary Ensemble (GUE). This is shown to be a direct consequence of the intrinsic asymmetry in our rules of assembly, which breaks time-reversal symmetry and induces the quantum chaotic behavior observed in number theory. This work establishes a rigorous mathematical bridge between discrete arithmetic and continuous analysis, offering a new paradigm for foundational questions in mathematics.



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sciforum-170601: TOPOLOGICAL PRESERVATION BY QUASI-PSEUDOMETRIC AGGREGATION FUNCTIONS

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Aggregation functions play a fundamental role in mathematics, particularly in the combination of multiple measurements into a single quantity. They also allow the construction of a single mathematical structure of the same type from a family of given structures. Early work in this area dates back to Boršík and Doboš, who studied the aggregation of metrics. Their results motivated further research on the aggregation of more general structures, including quasi-pseudometrics, fuzzy quasi-pseudometrics, and indistinguishability operators.

All these structures induce a topology on their underlying sets, which raises a natural question: does the aggregation process preserve the associated topological properties? In particular, one may ask whether the topology generated by an aggregated (quasi-)(pseudo)metric coincides with the product topology of the individual spaces. For metric aggregation functions on products, this problem was solved by Boršík and Doboš through the introduction and characterization of strongly metric aggregation functions.

In this work, we extend their approach to the broader setting of quasi-pseudometric aggregation functions on products. We introduce the notion of strongly (quasi-)(pseudo)metric aggregation functions on products and provide a complete characterization of this class. A function is said to be strongly aggregating if, for every family of (quasi-)(pseudo)metric spaces, the topology induced by the aggregated (quasi-)(pseudo)metric agrees with the corresponding product topology.

As a key illustration of our results, we prove that a (quasi-)metric aggregation function on products is strongly aggregating if and only if it is continuous at the zero vector. This condition yields a concise and transparent topological characterization.

In conclusion, our results generalize the classical theory of strongly metric aggregation functions to the quasi-pseudometric framework and establish explicit relationships between the different classes of strongly quasi-pseudometric aggregation functions on products.



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sciforum-172574: Topological Stability of Neural Operators: A Nonlinear Functional–Geometric Theory for Controlling Infinite-Dimensional Learning Systems

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This paper develops a rigorous mathematical framework for understanding modern neural networks as infinite-dimensional dynamical systems acting on function spaces rather than on finite vectors. Neural operators—networks designed to learn mappings between spaces of functions, such as those arising in fluid mechanics or material science—are typically analysed numerically but lack a coherent theoretical foundation that connects their stability, generalization, and controllability. This study proposes a synthesis of nonlinear functional analysis, differential topology, and control theory to address this gap.

By modeling neural operators as nonlinear semigroups on Banach and Hilbert manifolds, the paper defines learning as a topological flow evolving in an infinite-dimensional state space. Training, in this formulation, is not merely optimization but a process of steering trajectories through a geometrically constrained function landscape. Stability is shown to depend not only on loss minimization but on the topological structure of attractors induced by the network architecture and regularization scheme.

The paper introduces a notion of *topological generalization*, where the ability of a neural operator to extrapolate across unseen physical regimes is governed by the homotopy class of its learned solution manifold. Using tools from degree theory and nonlinear spectral analysis, the study demonstrates how certain architectural choices enforce global geometric constraints that prevent chaotic overfitting even in highly underdetermined learning problems.

The control-theoretic implications are substantial. Training algorithms can be reinterpreted as feedback control laws acting on infinite-dimensional learning dynamics, opening the possibility of stability-certified and robustly controllable AI systems. This framework provides a mathematically principled route toward trustworthy machine learning for complex physical systems governed by partial differential equations.

By embedding AI within the deep structure of geometry, topology, and functional analysis, the paper reframes learning not as a black-box procedure but as a controllable mathematical process.



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sciforum-171084: Uniform HX Rings

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The primary objective of this article is to extend the fundamental concepts of ring theory to the setting of uniform HX rings and elucidate the structural differences between classical rings and these newly defined algebraic systems. By positioning uniform HX rings within the broader framework of hyperalgebra, this study seeks to advance the generalization of algebraic structures characterized by multivalued operations and contribute to the theoretical expansion of the field. To achieve this aim, this paper introduces and systematically analyzes the notions of subalgebraic structures and the product of uniform HX rings. It investigates the conditions under which these constructions preserve uniformity and examines several algebraic properties that arise from their interaction. Particular emphasis is placed on HX ideals, the images and pre-images of which are characterized through homomorphisms defined between uniform HX rings. This approach not only clarifies the behavior of ideals under structure-preserving mappings but also provides a solid foundation for subsequent theoretical developments. A further objective of this study is to generalize the concept commonly studied as hyperrings in the hyperalgebraic literature. After formally presenting the definition of uniform HX rings, this article establishes their existence through carefully constructed examples, thereby demonstrating the mathematical viability of the proposed structure. Building on this foundation, key properties of uniform HX rings are identified, revealing both their parallels with and departures from classical ring theory. Moreover, HX ring homomorphisms are defined to support the formulation of algebraic structure theorems and illuminate the relationships among uniform HX rings. These mappings play a central role in understanding structural correspondences within the theory. This article culminates in the presentation of a fundamental theorem that ensures a one-to-one correspondence between specific algebraic objects, thereby reinforcing the theoretical framework and offering a basis for future research in hyperalgebra and related areas.



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sciforum-171828: Zero-Divisors in Commutative Rings: A Graph-Theoretic Perspective

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Introduction: Zero-divisors are essential for understanding the structural intricacies of commutative rings and their algebraic properties. A zero-divisor in a commutative ring R is a non-zero element a such that there exists b ≠ 0 with ab = 0. Beyond detecting non-reduced behavior, zero-divisors encode how ideals and annihilators interact, and they often reflect decomposition phenomena in residue rings such as Z_n.

Methods: We investigate zero-divisors using a graph-theoretic approach by constructing the zero-divisor graph $\Gamma(R)$. Vertices are the non-zero zero-divisors of R, and two distinct vertices are adjacent exactly when their product is zero. We examine how quotients and finite direct products affect adjacency, and we compare rings using standard graph invariants (connectivity, diameter, clique number, chromatic number, and girth). Equitable partitions and spectral information (adjacency and Laplacian eigenvalues) are used as complementary descriptors to compare graphs efficiently and to highlight regularities in zero-product relations for finite examples.

Results: The combined viewpoint reveals patterns that distinguish rings with similar zero-divisor sets but different multiplication. We discuss zero-divisors in Noetherian and Artinian rings, links to algebraic geometry via annihilators, and relevance to applications in cryptography and network optimization where zero-product constraints naturally arise. Representative examples from Z_n and polynomial quotients over Z_n illustrate how modular arithmetic governs adjacency and clustering, and how product decompositions lead to predictable changes in distances and colorings.

Conclusions: By bridging foundational theory with recent advances, this work highlights open problems and proposes practical methodologies for studying zero-divisors, supporting further developments in commutative algebra and its applications.



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Session 2. Mathematical Analysis

sciforum-174164: Critical Anisotropic Quasilinear Equations with External Potentials in IRn

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Anisotropic diffusion phenomena arise naturally in several physical models, including crystalline media, non-Newtonian fluids, and nonlinear optics, where the material properties depend directly on direction. In the current work, we investigate a wide class of nonlinear anisotropic quasilinear equations in the whole space IRn, which is driven by a convex Finsler structure and involves a critical Sobolev growth. The critical fact of nonlinearity generates a loss of compactness, which leads to a fundamental difficulty in domains that are unbounded, and it is also closely related to the concentration phenomena.

To be able to model confinement effects and to restore compactness, we introduce an external potential that is assumed to be continuous, strictly positive, and coercive at infinity. This potential can play a role widely analogous to trapping mechanisms in a nonlinear Schrödinger-type model. Within this framework, we develop a method using a variational approach and analyze the associated energy functional. By combining compact embedding arguments with a careful comparison between the Mountain Pass level and the optimal anisotropic Sobolev constant, we prove the existence of at least one positive weak solution.

Our results provide a rigorous analytical framework for anisotropic critical models with external potentials and contribute to the mathematical understanding of direction-dependent nonlinear phenomena in unbounded media.



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sciforum-170610: Equilibrium Problems in Fluid-Structure Interactions: The Eldrod and Adams Model.

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This paper investigates the dynamic behavior of a lubricated mechanical system in the incompressible fluid case. The main objective is to develop a rigorous mathematical model describing the motion of the upper surface subjected to lubrication effects. The model is based on the quasistationary Reynolds equation, which governs the pressure distribution within the lubricant film, coupled with Newton's second law to characterize the vertical displacement of the moving surface.

We establish theoretical results concerning the existence and uniqueness of solutions to the coupled differential system arising from this model. In addition, we identify conditions under which global solutions fail to exist, providing insight into possible mechanical instabilities or breakdown of the lubrication regime.

A detailed numerical analysis is performed to investigate the influence of key physical parameters, particularly the film thickness parameter a and the pressure field p, on the overall system dynamics. Various computational experiments are carried out to illustrate the evolution of these parameters and their interaction with the mechanical response of the system.

The obtained results contribute to a deeper understanding of lubricated contact mechanisms and highlight the critical role of fluid-structure interaction in determining system stability. These findings may support the design and optimization of engineering devices involving thin film lubrication and moving rigid surfaces.



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sciforum-162049: Nonlinear Fractional Inclusions for Tumor Dynamics under Treatment

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In this talk, we present a mathematical model describing the evolution of tumor density under treatment while accounting for a delayed effect. After a medical motivation, we introduce a conceptual scheme linking the observed biological mechanisms to the choice of model variables. The resulting system is formulated as a fractional differential inclusion with Caputo derivative and two maximal monotone operators, representing respectively the intrinsic tumor dynamics and the treatment-induced response. This modeling approach provides a rigorous framework to incorporate complex biological phenomena and delayed therapeutic effects.

The main analytical challenges arise from the multivalued nonlinear structure and the memory property of the fractional term. We employ advanced tools from functional analysis, in particular monotone operator theory and regularization techniques, to establish an existence result for the solution. This solution u(t) exhibits a medically consistent temporal behavior and reflects key biological insights observed in clinical studies. The proposed framework allows us to interpret the "delayed" effect observed in certain therapies and may be used to predict tumor evolution, adjust dosing frequency, optimize treatment strategies, or analyze the effectiveness of novel therapeutic interventions.

We conclude with several perspectives for future work: detailed stability analysis, fractional optimal control, extensive numerical simulations, and systematic comparison with clinical data, highlighting the potential practical impact of the model in guiding personalized treatment.



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sciforum-173625: Mild Solution Existence for Nonlinear φ–Caputo Fractional Differential Equations in Banach Spaces

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This paper investigates a nonlinear initial value problem involving the φ–Caputo fractional derivative within the framework of a Banach space. Fractional differential equations of this type have gained significant attention due to their ability to model complex dynamical systems with memory and hereditary properties. To establish the existence of mild solutions for the considered problem, we employ the Meir–Keeler fixed point theorem in combination with the concept of measure of noncompactness. This approach allows us to derive sufficient conditions under which the problem admits at least one mild solution, extending the applicability of fractional analysis to abstract Banach space settings. The theoretical framework developed herein provides a general methodology for analyzing nonlinear fractional differential equations, and the results are applicable to a wide class of nonlinear operators. Furthermore, to illustrate the practical relevance and applicability of the theoretical findings, a representative example is presented, demonstrating how the derived conditions ensure solvability in a concrete scenario. Overall, the paper contributes to the understanding of nonlinear φ–Caputo fractional differential equations by offering both rigorous existence results and a clear methodological approach that can be adapted to related problems in fractional calculus and functional analysis. The results provide a foundation for further studies on qualitative behavior, stability, and numerical approximations of such equations.



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sciforum-170130: A Generalised SOR Framework for Fredholm Integral Equations on Large Intervals in Banach Spaces

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Classical numerical approaches to Fredholm integral equations often rely on an implicit orthodoxy: discretise first, iterate afterwards. While effective in numerous settings, this paradigm becomes less transparent when the equation is defined on large intervals, where the infinite-dimensional structure of the problem quickly perturbs finite-dimensional approximations and obscures much of the anticipated benefit of classical schemes.

In this work, we recalibrate the compass by exploring a reversed paradigm. Rather than allowing discretisation to dominate the analysis from the outset, we begin by reformulating the equation as a system of coupled operator equations acting on a product Banach space, induced by a subdivision of the underlying domain. This naturally leads to an operator matrix whose entries are bounded linear operators, allowing notions familiar from linear algebra to be revisited within an infinite-dimensional framework.

Within this setting, we introduce a generalised successive over-relaxation (GSOR) scheme tailored to such operator matrices. A central theoretical result establishes that, under suitable conditions, the operator matrix is strictly diagonally dominant with respect to the operator norm. This structural property governs the convergence analysis of the method: it ensures the invertibility of the operator system and yields convergence of the GSOR iteration in the Banach space setting.

Rather than being merely a numerical device, our contribution clarifies how classical relaxation ideas can migrate, with minimal distortion, from finite-dimensional linear systems to systems of bounded linear operators. This perspective highlights a genuine theoretical bridge between linear algebra and functional analysis and suggests that iterating at the operator level offers a structurally sound and conceptually natural way to approach Fredholm integral equations on large intervals.



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sciforum-170746: Bounded Composition Operators on Hilbert Space of Complex-Valued Harmonic Functions

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In this paper, we study composition operators on the Hilbert space of complex-valued harmonic functions in the unit disc, focusing on their boundedness and structural properties. We analyze how analytic self-maps of the disc determine the behavior of the induced operators and extend several classical results from spaces of analytic functions to Hilbert space of complex-valued harmonic setting. We identify classes of analytic self-maps that generate isometric composition operators and prove that the boundedness of a composition operator implies that its symbol is a self-map of the disc. Boundedness is further characterized using Poisson integral estimates and integral mean techniques, which yield norm inequalities capturing the interaction between the analytic and co-analytic components of complex-valued harmonic functions. These inequalities provide refined upper and lower bounds for the operator norm in terms of the symbol evaluated at the origin, highlighting differences between harmonic and purely analytic theories. Additionally, we examine the relationship between reproducing kernels and composition operators, demonstrating that the adjoints of composition operators map reproducing kernels into reproducing kernels. This property leads to a characterization of composition operators via their adjoints and clarifies the structure of bounded operators on this space. Together, these results establish a comprehensive framework for understanding bounded composition operators in the context of Hilbert space of complex-valued harmonic functions.



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sciforum-170703: Existence of Solutions for a Multi-term Fractional Boundary Value Problem with a Separated Fractional Boundary Condition

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Multi-term fractional differential equations offer a more detailed view of processes with different levels of memory and relaxation. Hence, they provide enhanced accuracy in modelling real-world systems in viscoelasticity, finance, control theory, and many other fields. However, the consideration of both the perturbation and the convection terms in this type of differential equations complicates the study of this type of problems. Accordingly, they are usually addressed in the literature using numerical methods, such as the finite difference method. In this work, we investigate a fractional multi-term differential equation where the leading derivative is the Riemann-Liouville- Caputo fractional derivative, combined with separated fractional boundary conditions. In effect, recent applications suggest that this new derivative is be more suitable in certain situations. Moreover, fractional boundary conditions offer a powerful extension of classical ones, but they complicate the solution's form. Nevertheless, employing fractional order derivatives in boundary conditions is more advantageous, as the latter corresponds to a broader situation, permitting more flexibility in the choice of the derivative, resulting in better outcomes when modelling real-world models in contrast to the classical integer order models. To solve the problem at hand we convert it into a Volterra equation. Then by means of corresponding Green's functions, we apply fixed point theory techniques to obtain existence results under different conditions imposed on the nonlinearity. Mainly, the Banach contraction principle, the Krasnoselskii fixed point theorem, and the Leray-Schauder nonlinear alternative are utilised to prove the existence of solutions.



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sciforum-171576: Generalized Sobolev-Type Theorems and Mapping Properties of Riesz Potentials in Generalized Function Spaces

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The classical Hardy–Littlewood–Sobolev theory establishes fundamental mapping properties for integral operators of potential type. It provides precise boundedness conditions for Riesz potentials acting between Lebesgue spaces, based on the order of the potential, the space dimension, and the integrability exponent. The present research develops a methodological framework for extending this theory beyond its classical limits, as demonstrated through a series of recently obtained results on Riesz potential-type operators. In particular, boundedness is studied not only in classical Lebesgue spaces but also in their modern extensions, such as grand Lebesgue spaces. These spaces form a refined scale for describing integrability, especially for functions with borderline singularities. A key focus lies in the case where the classical Sobolev condition is violated. It is shown that under certain parameters, the Riesz potential-type operator with a power–logarithmic kernel remains bounded from an L^p space to a generalized Hölder space, even when the order of the potential exceeds the classical critical exponent. In this setting, the image of an integrable function is proven to possess a quantified generalized Hölder smoothness. The fundamental methodological contribution of this research is the development of a mapping theory for generalized function spaces, namely, grand Lebesgue spaces and generalized Hölder spaces. The techniques used include spectral analysis via Fourier–Laplace multipliers, Zygmund-type estimates for the continuity modulus, and the properties of grand Lebesgue spaces. This talk aims to outline how such a methodology paves the way for new, more general forms of the Hardy–Littlewood–Sobolev theory, with potential implications for problems in mathematical physics and fractional calculus.



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sciforum-174085: Relation-Theoretic Fixed Point Results for Block-Structured Nonlinear Operators in Hilbert Spaces

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Relation-theoretic fixed point theory extends classical contraction principles by allowing contractive conditions to be imposed only on pairs of elements that satisfy a prescribed binary relation. This framework has proved useful for studying nonlinear operators that do not satisfy global contraction conditions in metric or normed spaces.

Let H be a Hilbert space admitting a finite orthogonal decomposition $H = H_1 \oplus H_2 \oplus \cdots \oplus H_k$. Motivated by this structure, a binary relation R is introduced on H by defining xRy whenever the difference x – y belongs to one of the component subspaces H_i. This relation reflects the block structure of the space and restricts attention to pairs of elements that differ along a single orthogonal direction.

Nonlinear mappings T : H \to H that preserve this relation and satisfy a Banach-type contraction condition on related pairs, $\|Tx - Ty\| \leq \alpha\|x - y\|$, with 0 α 1, for all x, y with xRy, are considered. Under suitable relational admissibility conditions, the convergence behaviour of the associated Picard iteration defined by $x_{n+1} = T(x_n)$ is analyzed. It is shown that the generated sequence converges strongly to a fixed point of the operator.

The results illustrate how orthogonal decompositions of Hilbert spaces naturally induce relational structures that support relation-theoretic fixed point arguments for nonlinear operators whose behaviour may not be contractive in the global sense.



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sciforum-168489: Stability of a switched model of gene regulatory networks

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A gene regulatory network is a network consisting of genes that interact with proteins in order to control gene expression. Recent developments in biology and biomedicine have led to the examination of mathematical models that can describe the dynamics of gene regulatory networks.

We present a switched model of gene regulatory networks. The dynamics of both the concentrations of messenger ribonucleic acid and protein are described by ordinary differential equations (ODEs). The set of models with ODE with different activator functions of Hill's type is given initially. The switching rule is a piecewise constant function and its points of discontinuity determine the points at which the corresponding model from the given set is chosen. An algorithm for the construction of the solution of the switched model and the global equilibrium is presented. Sufficient conditions for the exponential stability of the model are established theoretically. Several examples of the studied switched models are studied. Both cases of a finite and an infinite sequence of switching times are examined. The provided examples validate the obtained sufficient conditions and demonstrate the effect of the presence of the switching rule on the global equilibrium of the model. These examples also show the possibilities of applications of the obtained theoretical results for more adequate modeling of gene regulatory networks.



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sciforum-173702: Fixed point theorems for generalized Reich-type rational contractions in b-metric spaces

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In this paper, we examine fixed point theory in the context of complete b-metric spaces, specifically for a class of generalized Reich-type rational contractions. Fixed point theory is a prominent branch of mathematical analysis, with numerous applications in functional analysis, differential and integral equations, optimization problems, and applied mathematics. A b-metric space is a generalization of a standard metric space, achieved through the modification of the classical triangle inequality by a coefficient, facilitating the examination of a broader class of spaces for which convergence and fixed point theorems can be proven. This flexibility in analysis is especially useful when dealing with complex mathematical models and real-world applications, where strict metric properties may not be applicable.

We prove the existence and uniqueness of fixed points for mappings that satisfy a rational Reich-type contractive condition, which generalizes classical contraction principles by taking into account a rational function of distances between points and their images. Our method of proof involves the construction of an iterative sequence in the b-metric space and proving that it is a Cauchy sequence. By making use of the relaxed triangle inequality that corresponds to the b-metric constant, we show that this sequence converges to a unique fixed point, thus proving both existence and uniqueness.

Moreover, our results generalize several classical fixed point theorems. Specifically, Banach-type, Kannan-type, and classical Reich-type contraction mappings can be obtained by selecting appropriate parameters in the rational contractive condition. This shows the generality of our method of proof, which combines several strands of fixed point theory and generalizes them to generalized b-metric spaces. The work lays a basis for further research in the field of nonlinear analysis.



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sciforum-174135: A Generalization of a Geometric Property of Blaschke Products to Selected Riemann Surfaces

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Geometric properties of analytic functions provide deep insights into the structure of the domains on which they act. In particular, 2-degree Blaschke products exhibit a remarkable geometric feature in the unit disc: any two distinct points with equal images lie on a straight line passing through a fixed point. This striking collinearity property reveals a strong connection between algebraic expressions and geometric configurations. The present study aims to generalize this property beyond the unit disc, first to the upper half-plane and then to the compact Riemann surface associated with the multi-valued function $\sqrt{z}$, thereby establishing a unified geometric framework.

The investigation proceeds in three stages. First, the classical geometric structure of 2-degree Blaschke products is analyzed using algebraic manipulation and geometric interpretation. Second, the unit disc is mapped conformally to the upper half-plane, where rational Nevanlinna functions are introduced as natural analogues. Their geometric behavior is studied to determine how their collinearity property transforms under this change of domain. Finally, the nonlinear mapping $z = w^2$ and stereographic projection are employed to lift planar curves to the compactified Riemann surface of $\sqrt{z}$, allowing a global geometric interpretation on the Riemann sphere.

It is shown that the collinearity property in the unit disc becomes a concyclicity property in the upper half-plane: points with equal function values lie on a circle passing through a fixed base point. Under the squaring map, chords of the unit disc transform into parabolas, which lift to spherical curves on the compact Riemann surface, all intersecting at infinity.

This study demonstrates that geometric properties of analytic functions are preserved and meaningfully transformed under conformal equivalence and compactification. The results highlight the role of Riemann surfaces in connecting algebraic structure, analytic behavior, and global geometry within a coherent framework.



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sciforum-171787: A New Iterative Scheme for Fixed Points of $(B_{\gamma,\mu,\eta})$-Type Mappings with Applications to Fractional Tumor Models

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\textbf{Introduction.} Fixed point theory is central to nonlinear analysis and to the study of differential and fractional models arising in applied sciences. Generalized nonexpansive-type mappings have attracted increasing attention because they allow the treatment of problems beyond classical contractions. In this paper, we develop a new iterative framework for approximating fixed points of mappings satisfying the $(B_{\gamma,\mu,\eta})$condition, which extends several existing operator classes and iterative algorithms.

\textbf{Methods.} We propose a novel iterative scheme for mappings defined on Banach spaces under the $(B_{\gamma,\mu,\eta})$ condition. By employing tools from nonlinear functional analysis, we study the behavior of the generated sequence and establish sufficient conditions that ensure both weak and strong convergence of the iteration to a fixed point of the underlying mapping.

\textbf{Results.} The main results guarantee convergence under general $(B_{\gamma,\mu,\eta})$ assumptions, thereby broadening the applicability of classical fixed-point methods. The practicality of the scheme is demonstrated through an application to a Caputo-type fractional-order model describing the interaction between tumor stem cell proliferation and cellular crowding. In this setting, fractional derivatives incorporate memory effects in tumor dynamics, and the proposed iteration efficiently approximates equilibrium states of the model.

\textbf{Conclusions.} The developed algorithm provides a robust computational tool for generalized fixed-point problems and contributes to the mathematical modeling of cancer stem cell behavior in fractional biological systems.



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sciforum-165224: Algebraic structures of 2D and 3D fields of real vectors

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A geometric algebra (Clifford algebra) is an extension of elementary algebra to work with geometrical objects such as vectors. It is built out of two fundamental operations: addition and geometric product. The multiplication of vectors alone results in objects called multivectors, among which are bivectors, the name applied in this paper to the objects of the bivector field $\mathbb{R}^2$, corresponding to the field of vectors V_2. Compared with other formalisms for manipulating geometric objects, geometric algebra supports dividing by a vector. On the other hand, although rarely used explicitly, a geometric representation of complex numbers is implicitly based on its structure of the Euclidean 2-dimensional vector space. On the basis of the isomorphic algebraic structures of the field of complex numbers $\mathbb{C}$ and the 2-dimensional Euclidean field of real vectors V_2, in terms of identical geometric products of elements, integral identities for scalar and vector fields in V_2 are presented, which are vector analogues of the well-known integral identities of complex analysis. Consequtly, these undoubtedly completely new results open up a wide range of applications in all fields where real vector analysis is used, such as quantum physics, classical physics, and so on. Therefore, special attention is paid to the vector analogue of Cauchy's calculus of residues in the field V_2. Finally, at the very end, the algebraic structure of the three-dimensional vector field V_3 is presented, as well as the corresponding fundamental integral identities.



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sciforum-163626: Bifurcation, Spectral Entropy, and Chaos Control in a Cournot Triopoly Game with Relative Profit Maximization

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This paper investigates the complex dynamical behavior of a discrete-time Cournot triopoly game in which firms pursue relative profit maximization under bounded rationality. Unlike the standard absolute-profit framework, relative profit objectives introduce strategic aggressiveness and stronger competitive interactions, significantly enriching the market dynamics. Starting from a nonlinear three-dimensional adjustment process, we derive the Cournot–Nash equilibrium and analyze its local stability through linearization and Jacobian-based conditions. Explicit analytical thresholds for flip (period-doubling) and Neimark–Sacker bifurcations are obtained, revealing the mechanisms through which stability is lost as key parameters, such as the adjustment speed and relative profit weight, vary.

Beyond local analysis, we explore the global dynamics of the triopoly system using numerical simulations, including bifurcation diagrams, phase portraits, and basins of attraction. The results uncover a wide range of behaviors, from stable equilibria and periodic cycles to quasi-periodic motions and chaos. To quantitatively characterize the complexity of these dynamics, spectral entropy analysis is employed, providing a robust measure that complements traditional bifurcation techniques and clearly distinguishes between regular and chaotic regimes.

Furthermore, an effective chaos control strategy based on parameter feedback is proposed to stabilize unstable dynamics and restore market equilibrium. The controlled system exhibits reduced complexity, confirmed by a significant decrease in spectral entropy. The findings highlight how relative profit considerations can destabilize oligopolistic markets, while appropriate control mechanisms can enhance stability. Overall, this study offers new analytical and numerical insights into triopoly competition, contributing to the understanding of nonlinear phenomena in economic systems.



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sciforum-170100: Chaotic Optimization Method Based on Density-Controlled Chaotic Maps

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\begin{abstract}
\textbf{Introduction:}
Gradient-based optimization methods are widely used due to their simplicity and fast convergence. However, when applied to highly nonlinear and multimodal objective functions, these methods frequently converge to local optima because they rely exclusively on local gradient information. Chaotic optimization techniques provide an alternative mechanism for global exploration, yet they generally lack directional guidance and therefore may exhibit slow convergence during local refinement.
\textbf{Methods:}
To address these limitations, this paper proposes a novel Chaotic Gradient Method (CGM) that integrates gradient descent with density-controlled chaotic perturbations within a unified optimization framework. In contrast to existing hybrid chaotic approaches, where chaos is mainly used for initialization or stochastic exploration, the proposed method incorporates chaos directly into the gradient update rule. The key novelty lies in the introduction of nonlinear density transformation functions applied to chaotic sequences, which reshape their probability distribution and allow controlled perturbations around the gradient direction. This mechanism enables the algorithm to dynamically guide chaotic exploration toward promising regions of the search space while preserving the descent property of gradient-based optimization.
\textbf{Results:}
The performance of the proposed CGM is evaluated on several challenging multimodal benchmark functions, including Styblinski–Tang, Goldstein–Price, and Bukin functions. Numerical experiments demonstrate that the proposed approach improves the robustness of gradient-based optimization by increasing the success rate of reaching global optima and accelerating convergence compared with conventional gradient descent methods.
\textbf{Conclusions:}
The results confirm that density-controlled chaotic perturbations provide an effective mechanism for enhancing gradient-based optimization in complex multimodal landscapes. The proposed framework offers a new perspective for combining deterministic search with controlled chaotic dynamics. Future work will focus on adaptive selection of transformation functions and the application of the method to real-world optimization problems.
\end{abstract}



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sciforum-170741: Computational Modeling and Convergence Analysis of Generalized 1-D Linear Evolution Equations

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This research presents a comprehensive investigation into the convergence analysis of approximate solutions for the generalized one-dimensional linear telegraph equation, utilizing the Reproducing Kernel Hilbert Space (RKHS) method. The primary objective of this study is to establish a robust mathematical framework that bridges the gap between numerical approximations and exact analytical solutions. By employing a sophisticated iterative procedure within the RKHS environment, we rigorously demonstrate that the generated approximate results exhibit a strong and consistent convergence behavior toward the exact solutions derived from Fourier series expansions. The theoretical foundations of the RKHS technique allow for a systematic treatment of the telegraph equation, which is a fundamental model in various physical and engineering phenomena, such as signal propagation and vibration analysis. To evaluate the practical performance and reliability of the proposed methodology, several numerical experiments were conducted. The empirical results consistently highlight the method's exceptional precision, stability, and computational integrity. Furthermore, the study underscores a remarkably rapid convergence rate, signifying that high-fidelity results can be achieved with minimal computational effort compared to traditional numerical schemes. These findings validate the RKHS method as a highly efficient and potent alternative for solving linear partial differential equations, confirming its significant potential for broader applications in the field of applied mathematics and numerical analysis.



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sciforum-173799: Critical Points of Quotients of Finite Blaschke Products of Small Degrees

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Blaschke products are a class of inner functions that map the unit disk onto itself and the unit circle onto itself, preserving the boundary modulus equal to one, and they play a fundamental role in complex analysis and geometric properties.

The quotients of finite Blaschke products do not map the unit disk onto itself, since they may have poles inside the unit disk, but they preserve the unit circle, maintaining unimodular boundary values almost everywhere on it.

The present study systematically investigates the critical points of quotients of Blaschke products of degrees two and three,

$B(z) = z \left(\displaystyle\frac{z-a}{1-\bar{a}z}\right), |a|>1$,

and there are two distinct critical points on the unit circle given by the intersection of the circles $|z-a|=\sqrt{|a|^{2}-1} ~\text{and}~ |z|=1$. For the case of degree three,

$B(z)=z\left(\displaystyle\frac{z-a}{1-\bar{a}z} \right)\left(\displaystyle\frac{z-b}{1-\bar{b}z} \right)$,

where $a,b > 1$, the critical points are determined by a degree four polynomial. This coincidence shows that the quotient of Blaschke products always has at least one critical point on the unit circle.

These results establish a connection between the critical points and the locus of points, satisfying the pre-image of the unit circle under finite Blaschke products of degrees two and three, as well as under quotients of Blaschke products.



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sciforum-165128: Dimension-free approximations of gradients

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In high-dimensional settings and for time-demanding models, having an efficient approach for computing i) the traditional gradient of every smooth function (∇f), and ii) the dependent gradient of functions evaluated at non-independent variables ($grad f$) is worth investigating.

In addition to the adjoint methods that provide exact traditional gradients for some classes of PDE/ODE-based models using only one run, this study relies on randomized schemes or the Monte-Carlo approach for computing both gradients. The proposed approach makes use of ℓ_p-spherical distributions with $p\geq 1$ and Richardson's extrapolation to derive generalized stochastic surrogates of gradients using L-point-based evaluations of functions with $L\geq 1$. Such ℓ_p-spherical-based surrogates of gradients and the corresponding estimators benefit from:

i) Dimension-free upper-bound of the bias;
ii) Dimension-free upper-bounds of mean squared errors (MSEs) and rates of convergence of the form $d^{2/p} N^{-1}$ with N sample size;
iii) Computational efficiency and accuracy.

As a consequence, the proposed approach does not suffer from the drawbacks of dimensionality by properly choosing p. It improves the best known rate (i.e., dN^{-1}) and enables computations of gradients using a number of function evaluations $N \ll d$ by breaking down the course of dimensionality.

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sciforum-171137: Discrete Elliptic Boundary Value Problems Defined by Symbolic Pseudodifferential Operators

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Abstract

This paper presents a symbolic framework for the analysis of discrete elliptic boundary value problems on lattice domains. Discrete symbol classes, a notion of ellipticity, and compatible boundary operators are introduced. By extending the theory of pseudodifferential operators to the discrete setting, elliptic difference operators are formulated via their symbols on the dual torus, and ellipticity is characterized through principal symbol estimates. Using Vasil'ev's wave factorization method, adapted to discrete symbols, we construct parametrices and establish well-posedness of discrete boundary value problems.

Introduction

Discrete analogues of pseudodifferential operators arise naturally in numerical analysis and discrete physical models. While elliptic boundary value problems in the continuous setting are well understood, their discrete counterparts require specialized analytical tools. Symbolic pseudodifferential calculus provides a natural framework for studying ellipticity, boundary conditions, and regularity, motivating its extension to lattice-based operators.

Methodology

The analysis is carried out on discrete domains $\Omega_h \subset Z^n$. Discrete pseudodifferential operators are defined using the discrete Fourier transform and suitable symbol classes. Boundary value problems are formulated by coupling interior difference operators with boundary operators acting on the discrete boundary. Ellipticity is defined through principal symbol estimates, allowing for the construction of parametrices within the discrete symbolic calculus.

Results

The main result shows that elliptic difference operators admit parametrices obtained via wave factorization of their symbols. This approach yields a discrete analogue of the Lopatinski–Shapiro condition and implies Fredholm properties, as well as existence, uniqueness, and regularity of solutions, even for irregular lattice boundaries.

Conclusion

This work establishes a rigorous symbolic theory for discrete elliptic boundary value problems. By adapting Vasil'ev's wave factorization to the discrete setting, the paper bridges continuous pseudodifferential theory and discrete models, providing a solid analytical foundation for stability analysis and numerical methods for elliptic problems on lattices.



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sciforum-171999: Dynamics of the Iteration $x_{n+1} = x_n^2 - 2$.

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This paper analyzes the real dynamical system generated by the quadratic iteration $x_{n+1} = x_n^2 - 2$. with particular attention to the distribution and behavior of rational and irrational initial values. The map admits exactly two real fixed points, 2 and -1, and all orbits with x_0 outside [-2,2] diverge monotonically to +infinity . For x_0 inside [-2,2], the orbit remains confined to this interval, and its structure is examined through the full backward-iteration tree defined by x= + or - √2. This construction yields two countable dense subsets of [-2,2] consisting of all rational and irrational preimages of the fixed points. Their forward orbits converge to 2 and -1, respectively, and the nested-radical representation provides a complete ordering of these preimage sets. Beyond these convergent families, the backward-iteration framework produces uncountably many additional dense subsets of [-2,2], each arising from a distinct irrational seed whose orbit is not a preimage of either fixed point. These sets are pairwise disjoint and contain both rational and irrational elements, yet none of their forward orbits converge or diverge; instead, they remain perpetually in [-2,2] while exhibiting non-periodic, non-convergent behavior. The resulting decomposition of [-2,2] into countably many convergent branches and uncountably many non-convergent branches highlights the intricate, fractal-like structure inherent in this quadratic map.



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sciforum-170914: Exact Traveling Wave Solutions of Nonlinear Coupled Wave Systems via Analytical Methods

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This research explores the construction of exact traveling wave solutions for significant nonlinear wave equations, specifically focusing on the coupled Korteweg–de Vries (KdV) equations and the coupled Hirota–Satsuma system. These systems are vital in mathematical physics for modeling complex wave interactions in fields such as fluid dynamics and plasma physics. To address the inherent complexity of these nonlinear partial differential equations (NLPDEs), the study employs two robust analytical techniques: the tanh--coth method and the generalized $\exp(-\phi(\xi))$-expansion (GEE) method. The core of the methodology involves applying a traveling wave transformation, $\xi = x - ct$, which reduces the original NLPDEs into more manageable nonlinear ordinary differential equations (ODEs). By assuming specific expansion forms for the solutions—hyperbolic functions for the tanh--coth approach and an exponential-based auxiliary equation for the GEE method—the researchers are able to convert the differential problems into systems of nonlinear algebraic equations. The study leverages the symbolic computation power of Maple 17 to solve these intricate algebraic systems, leading to the derivation of a diverse array of exact solutions. These results encompass various wave structures, including solitary waves, kink-type solutions, periodic waveforms involving trigonometric functions, and rational wave profiles. The comparative application of these two methods reveals that while the tanh--coth method is exceptionally efficient for capturing solitonic and kink behaviors, the GEE method offers greater flexibility by generating a broader class of solutions. Ultimately, the work demonstrates that the integration of these analytical frameworks with symbolic computing provides a powerful toolkit for understanding nonlinear phenomena. The derived solutions not only validate the effectiveness of the chosen methods but also provide deeper physical insights into how waves propagate and interact within complex nonlinear media, reinforcing the importance of exact solutions in the ongoing study of nonlinear dynamics.



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sciforum-174116: EXISTENCE AND REGULARITY RESULTS FOR A NEW CLASS OF DOUBLE-PHASE PARABOLIC EQUATIONS

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We study the homogeneous Dirichlet problem for the double-phase evolution equation
$z = (x, t) \in Q_T = \Omega \times (0, T)$, $\Omega \subset R^N$, $N \geq 2$.

The non-differentiable coefficients a(z), b(z) and the variable exponents p(z), q(z) are given functions. The coefficients *a, b* are nonnegative and bounded, with and such that in $Q_{T,}$.

It is shown that if $u_0 \in W_0^{1,r}(\Omega)$ with $r \geq \max\{2, \max p(z), \max q(z)\}$, $f \in L^{N+2}(Q_T)$, $\max |p(z) - q(z)|$, then the problem admits a unique solution with the following properties:

• The solution preserves the initial regularity, for ;

• The gradient acquires higher integrability, $|\nabla u|^{\min\{p(z),q(z)\}+s+r} \in L1(Q_T)$ for any ;• The solution possesses the second-order regularity,.

The regularity properties remain true in the case $f \in L^{\sigma}(Q_T)$ with $\sigma \in (2, N + 2)$, but the admissible values of r are in a bounded interval depending on N and σ.

This is a joint project [1, 2] with Dr. Rakesh Arora from the Indian Institute of Technology at Varanasi, India.

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sciforum-171391: Existence of positive solutions to a semipositone singular *h*-Riemann-Liouville fractional boundary value problem

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In this talk we analyze the existence of positive solutions for an *h*-Riemann–Liouville fractional differential equation *(E)* that involves a positive parameter and a singular nonlinearity that changes sign, subject to nonlocal boundary conditions *(BC)* incorporating Riemann–Stieltjes integrals and *h*-Riemann-Liouville fractional derivatives of various orders. Because the nonlinearity may take negative values, the problem is referred to as a semipositone fractional boundary value problem. The *h*-Riemann–Liouville fractional derivative extends several well-known fractional derivatives, including the classical Riemann–Liouville derivative when $h(t)=t$, the Hadamard derivative when $h(t)=\ln t$, as well as other related fractional operators. We establish intervals for the parameter for which problem *(E)*, *(BC)* admits at least one positive solution. We begin by deriving the Green function corresponding to the problem and examining several of its key properties. Afterwards, through a suitable change of variables, we reformulate the original problem into an equivalent one. An operator is then constructed in a suitable Banach space, and its fixed points correspond precisely to the solutions of the equivalent problem. Our main results are obtained by applying the Guo–Krasnosel'skii fixed point theorem of cone expansion and compression of norm type. In the end, we present examples that highlight the usefulness of the established results.



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sciforum-165953: Explicit Control of Blow-up Behavior of Solutions of a Particular Class of Ordinary Differential Equations

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Solution blow-up is a well-known phenomenon occurring in many Ordinary Differential Equations (ODEs), including ODEs describing real physical systems. For both theoretical and practical (prevention of technogenic catastrophes) reasons, it is important to identify control strategies that dampen blow-up solutions.

First-order non-linear ODEs are used where the Right-Hand Side (RHS) of the equation remains convex and continuous, but otherwise, an arbitrary, non-linear function of unknown solution is considered. RHS also contains a parameter that generally may have different values in different physical circumstances.

A specific control objective (boundedness, at all times, of the solution by a specified threshold) is imposed. This control strategy is designed considering the system parameter as a control variable (practically, variation requires control of the system). The methodology for finding a suitable control consists of constructing a majorizing function. The majorizing function provides an upper bound for the RHS of the equation, and thus, due to the basic comparison theorem of ODEs, the solution of the ODE with the majorizing function on the RHS (the "majorized equation") provides the bounds for the solution of the original ODE. The majorizing function, utilizing analytical solutions of a majorized equation with specific control variable profiles, is constructed.

A major result is then obtained by applying the comparison theorem of ODEs. This ensures that the solution of the original, un-majorized equation, with an identical control variable profile, also remains bounded over infinitely large time intervals and, moreover, below an a priori-imposed threshold.

Specific results are obtained and considered an example of the control of thermal explosion. Several explicit control variable profiles are considered, and analytical solutions for majorized equations are obtained for all of them. This provides estimations of the bounded behavior of the solutions of the original ODE under identical control conditions.

In conclusion, control strategies, preventing solution blow-up are constructed for a certain class of ODEs.



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sciforum-174151: Finite-Time Blow-Up of Solutions to a Stochastic Quasilinear Viscoelastic Wave Equation with

Nonlinear Damping and Logarithmic Source

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This paper investigates the occurence of a finite-time blow-up for a solutions of a problem of type stochastic quasilinear viscoelastic wave equation posed in a given bounded domain. The studied model incorporates a memory term that is governed by a decreasing relaxation kernel, a nonlinear damping mechanism, and a logarithmic source nonlinearity, and it is also driven by an additive perturbation in form of a stochastic noise. In this problem we face the combinition of the influence of a viscoelastic memory and a nonlinear damping taht introduces the dissipative effects. Moreover, the combinition of the logarithmic source term and the stochastic perturbation contributes to potential instability which results in a delicate analytical balance. Under appropriattly choosen assumptions for each of our problem's component: the relaxation function, the damping exponent, and the noise intensity, we construct a suitable energy functional and then derive refined energy estimates. By introducing an appropriate Lyapunov functional and exploiting the non-convex structure of the logarithmic potential, we establish sufficient conditions for finite-time blow-up with positive probability. In particular, we prove that if the initial energy is below a critical negative threshold depending explicitly on the noise intensity, then the corresponding solution cannot exist globally in time. Moreover, an explicit upper bound for the blow-up time is obtained in terms of the initial data and the system parameters.



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sciforum-171756: Fixed Point Analysis of Variable-Order Fractional Problems with Nonlocal Conditions

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In this talk, we investigate a class of generalized time-variable fractional integro-differential equations involving multi-term Caputo derivatives of variable order and nonlocal initial conditions. The model consists of a second-order classical derivative coupled with several variable-order fractional operators and a nonlinear source term depending on a fractional derivative of the unknown function. The initial condition is given in a nonlocal integral form, reflecting global memory effects.

Variable-order fractional operators arise naturally in applications where the memory intensity evolves over time, but their analysis is significantly more challenging than in the constant-order case. In particular, fundamental properties such as the semigroup law and simple inverse relations between fractional integrals and derivatives no longer hold. Using the definition of variable-order Caputo derivatives and without relying on invalid composition rules, we derive an equivalent Volterra-type integral formulation of the problem. This formulation provides a suitable framework for analysis and allows us to establish the existence of mild solutions via fixed point techniques, such as the Leray–Schauder alternative, under natural continuity and growth assumptions.

Finally, a numerical example is presented to illustrate the theoretical results and to demonstrate the influence of the time-dependent fractional order and the nonlocal initial condition on the qualitative behavior of solutions.



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sciforum-174345: Fixed-Point and Common Fixed-Point Theorems for Rational and Almost Contractions in θ_R-Metric Space

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In the present work, we establish fixed-point theorems for rational and almost contractions in the framework of a θ_R-metric space. The concept of θ_R-metric space is based on the incorporation of a control function $\theta:[0,\infty)^3\to[0,\infty)$ into the quadrilateral inequality of the generalized metric space introduced by Branciari. To prove our results, we impose certain natural assumptions on the control function, namely normalization, monotonicity, continuity, and iterative contractive control. These conditions ensure the well-posedness of the θ_R-metric structure and play a crucial role in establishing the convergence of the associated iterative sequences. Then, we ensure the existence (and uniqueness) of a common fixed point for a pair of self-mappings, satisfying rational and almost contractive conditions within this framework. Moreover, a detailed comparison is carried out between the results obtained in this study and several well-known fixed-point and common fixed-point theorems established in rectangular metric spaces and other related generalized metric spaces. This comparison clearly demonstrates that our results significantly extend, generalize, and refine many existing theorems available in the literature. To illustrate the applicability and wide scope of the established theorems, appropriate and carefully constructed examples are presented. These examples substantiate the theoretical results and illustrate that the established theorems constitute proper extensions and meaningful improvements over previously known findings.



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sciforum-173575: Geometric Aspects of Operator Calculus: Non-commutative Chain Rules

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To understand the complexity of the operator chain rule, we must first revisit the most fundamental product rule. In a commutative setting, the derivative of a product fg is simply:

(fg)' = f'g + fg' = f'g + g'f. Because the order does not matter, we can rearrange the terms freely. However, when the chain rule is exposed to a non-commutative operator situation, the order becomes sacrosanct. For two operators A and B, the derivative of their product is strictly:

(AB)' = A'B + A B',

where A' must be located on the left of B, and B' must be located on the right of A. This rigid preservation of order is essential to all non-commutative calculus, and it is definitely true when differentiating the exponential eA, which is an infinite product of operator A.

In this article, the 'Geometry of Variation in Operator Calculus' is studied for the cases when unbounded operators in a Banach space are included. The standard chain rule, when confronted with a non-commutative operator situation, undergoes a fundamental transformation. This evolution is deeply rooted in the structural relationship between operators. Starting from the generalized Baker–Campbell–Hausdorff (BCH) formula based on the logarithmic representation of operators [1-7], which describes the non-commutative multiplication of exponentials, we can derive the precise dynamics of operator variations. Ultimately, this necessitates the generalization of the classical chain rule into what we know as the non-commutative Duhamel's identity.

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sciforum-171667: Henstock–Kurzweil Integration using Fractal Structures

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This paper seeks to develop an integration theory based on the classical Henstock–Kurzweil integral ([4]) for abstract measure spaces. More specifically, the objective is to define an HK-type integral in measure spaces that admit a fractal structure, which are characterized by their recursive behavior. These structures were introduced by M.A. Sánchez-Granero and further explored by J.F. Gálvez-Rodríguez to construct measures within such frameworks ([1], [2]).

First, we define the classes of partitions of the space, which are formed by the elements of the fractal structure, and set up the concept of gauge as a function $\gamma : X \to N$. In order to guarantee the existence of these partitions, an analogous result to Cousin's Lemma for compact intervals of R^m is proved. Furthermore, the relationship between the classical theory and this fractal integral in R^m is demonstrated by utilizing a natural fractal structure

defined on compact intervals.

Secondly, we recover fundamental properties of the classical HK-integral, such as Cauchy's Criterion and Henstock's Lemma, by assuming additional conditions on the underlying fractal structure. Additionally, we prove that the Monotone and Dominated Convergence Theorems hold for this fractal HK-type integral.

Finally, an application of this integral in Linearly Ordered Topological Spaces (LOTS) ([3]) is provided. We present the construction of a fractal structure in a second-countable LOTS that satisfies desirable properties for this integration theory, leading to a version of the Fundamental Theorem of Calculus for LOTS.



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sciforum-163353: Hilbert Space Analysis of an Inverse Problem for a Caputo Time-Fractional Evolution Equation with Spatial Derivatives and Involution

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In this study, we develop a two-variable fractional differential equation with respect to the temporal variable and the spatial variable , where the derivative is fractional in time using the Caputo derivative and classical in space. The equation is derived from the differential equation of orthogonal Chebyshev polynomials, with a perturbation introduced via involution, representing a generalization of standard fractional models.

The equation is solved using the separation of variables method, representing the solution as an infinite series with Chebyshev polynomials forming a basis in the weighted Hilbert space . This leads to a spectral problem in the spatial variable , from which the eigenvalues and eigenfunctions are determined. The main problem is then addressed through the series expansion, resulting in a linear fractional equation previously studied in the literature, yielding an explicit analytical solution suitable for theoretical analysis.

To ensure stability and differentiability, temporal boundary conditions are imposed, which are verified through the convergence of the solution series. Finally, the uniqueness of the solution is established based on the completeness of the Hilbert basis and the initial condition at t=0 .

This methodology can be generalized to other polynomial bases, such as Legendre or Hermite polynomials, and extended to construct other fractional equations using alternative derivatives, including Riemann–Liouville or Letnikov derivatives, offering a flexible framework for modeling complex time-space fractional systems.



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sciforum-174206: Lorentz spaces, approximation spaces and the greedy algorithm

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In nonlinear approximation theory, understanding the structure of approximation spaces and their interplay with greedy algorithms has been a central pursuit. In this paper, we study a generalization of the classical approximation spaces associated with a wide class of bases in separable, infinite-dimensional quasi-Banach and Banach spaces, including almost greedy bases. These approximation spaces, which quantify the decay of best n-term approximation errors relative to a basis, are deeply connected to structural properties of the basis and the efficiency of greedy selection procedures. Using weighted Lorentz sequence spaces as a tool, we provide a comprehensive characterization of these generalized approximation spaces in terms of embeddings into and from appropriate weighted Lorentz spaces. Our results extend and unify earlier findings for greedy and unconditional bases by identifying necessary and sufficient conditions under which the classical approximation spaces, greedy approximation classes defined via the Thresholding Greedy Algorithm, and Chebyshev–greedy classes coincide. In doing so, we relax several classical assumptions—such as unconditionality and democracy—replacing them with broader notions like truncation quasi-greediness, and extend the characterizations to encompass a larger family of weights. These embeddings and equivalences elucidate the intricate relationships between approximation error decay, greedy algorithm behavior, and the fine summability captured by Lorentz norms, offering new insights into approximation theory and its connections with nonlinear analysis.



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sciforum-121992: Mathematical Analysis of Interferon Therapy in Hepatitis B Virus Dynamics

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Hepatitis B remains a major public health challenge, especially due to its potential to progress into chronic infection and severe liver disease. This study develops a mathematical model to understand the role of Interferon therapy, particularly comparing Standard IFN-α and Pegylated IFN-α (Peg-IFN) in controlling HBV infection. The model tracks four key groups: susceptible individuals, those with acute infection, chronic cases, and recovered individuals.

We determine the basic reproduction number (R0R_0R0) and analyze the conditions under which the disease can be eradicated or persist. Our results show that when R01R_0 1R01, the infection dies out, leading to a stable disease-free equilibrium (DFE). However, when R0>1R_0 > 1R0>1, the disease persists at an endemic equilibrium (EE). Through numerical simulations, we explore how Interferon therapy influences HBV progression. The findings suggest that Peg-IFN is more effective than standard interferon due to its longer-lasting effects and stronger suppression of the virus, reducing the number of infected individuals and increasing recovery rates.

Additionally, sensitivity analysis highlights key factors—such as treatment rates, immune response, and disease progression—that influence infection dynamics. Our results reinforce the importance of early intervention and suggest that combining pegylated interferon with antiviral therapies may be the best approach for HBV control.



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sciforum-174515: New Insights into Hermite–Hadamard-Type Inequalities via Green Functions

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The Hermite–Hadamard inequality is a fundamental result in convex analysis, providing lower and upper bounds for the integral average of a convex function. This research aims to provide a unified treatment of Jensen-type and Hermite–Hadamard-type inequalities by utilizing various classes of Green functions. The study extends classical results to a broader context involving general measures and functional identities.

The core methodology involves the definition of several distinct Green functions. By employing these functions, integral identities are established for functions of the class C^2. The study utilizes these identities to derive necessary and sufficient conditions for weighted Hermite-Hadamard inequalities to hold, specifically focusing on the behavior of the Green functions under integral operators.

The research establishes several major results. It proves the equivalence between the validity of generalized Jensen-type inequalities and specific integral conditions on Green functions. Furthermore, weighted versions of the Hermite–Hadamard inequality are derived, providing precise error bounds and refinements using L^p norms of the second derivative. New mean-value theorems of Lagrange and Cauchy types are also presented, characterizing the "intermediate point" in these inequalities.

This research shows how the application of Green functions provides a powerful and elegant framework for the systematic study of integral inequalities. The results unify several known generalizations of the Hermite–Hadamard inequality and offer new tools for error estimation in numerical analysis. This approach confirms that the classical Hermite–Hadamard estimates are specific cases of a much broader theory involving functional identities and second-order derivatives.



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sciforum-170817: Numerical Ranges and Pseudospectra in Banach Jordan Algebras

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Introduction. The numerical range is a central tool in spectral theory, providing geometric insight into stability, perturbations, and spectral localization in associative Banach algebras and operator theory. In the non-associative setting of Banach Jordan algebras, however, a complete analogue has remained underdeveloped. This work addresses this gap by presenting a systematic theory of numerical ranges adapted to Banach Jordan algebras, with particular emphasis on their interaction with Jordan spectra and pseudospectra.

Methods. We introduce the quadratic numerical range WJ (a), defined via the quadratic operator Ua, which naturally replaces left–right multiplication in the associative case. The analysis combines Jordan functional calculus, duality arguments, and convexity methods to study structural properties of WJ (a) in general unital Banach Jordan algebras, with special attention to the case of special Jordan algebras embedded in associative C∗-algebras.

Results. We prove that the quadratic numerical range is non-empty, bounded, closed, and convex. A central result establishes spectral containment, showing that the Jordan spectrum is contained in the quadratic numerical range. In addition, we obtain pseudospectral inclusion results, demonstrating that Jordan pseudospectra are contained in explicit neighborhoods of WJ (a). In the special Jordan setting, we show that WJ (a) is contained in the square of the classical numerical range, thereby extending known results from the associative theory. Several illustrative examples in finite-dimensional settings are provided.

Conclusions. This work places numerical range theory in Banach Jordan algebras on a rigorous and complete foundation, opening new avenues for the study of spectral stability, perturbation theory, and nonassociative spectral analysis.



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sciforum-174480: Numerical Simulation of Variable-Order Fractional Advection–Diffusion Processes with Memory Effects

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Advection–diffusion equations play a crucial role in modeling the transport of heat, mass, pollutants, and contaminants in porous and heterogeneous media. These models arise in many practical applications, including environmental engineering, hydrology, geophysics, and material sciences. However, classical integer-order advection–diffusion models are often unable to accurately describe anomalous transport processes observed in complex systems. Such systems frequently exhibit long-range interactions, nonlocal dynamics, and memory effects. As a result, the transport behavior may deviate from classical Fickian diffusion and display sub-diffusive or super-diffusive characteristics that cannot be captured using traditional formulations. To address these limitations, this study investigates a variable-order fractional advection–diffusion integro-differential equation that incorporates fractional derivatives in both time and space under appropriate initial and boundary conditions. Unlike many existing studies that primarily focus on constant-order fractional models, the present formulation allows the fractional order to vary with time and space. This feature provides greater flexibility in modeling evolving memory effects and spatial heterogeneity of the medium. A finite difference numerical scheme is developed to approximate the variable-order fractional derivatives together with the convolution-type integral term. The proposed method achieves an accuracy of order $(2-\alpha)$ on a nonuniform temporal mesh and reduces to first-order accuracy on a uniform mesh. Furthermore, the stability of the numerical scheme is established through theoretical analysis, ensuring the reliability of the computational results. To illustrate the effectiveness of the proposed approach, numerical simulations are carried out for three representative cases: constant fractional order (α=constant), time-dependent order $\alpha(t)$, and fully variable order $\alpha(x,t)$. The numerical results demonstrate good agreement with the analytical solutions and confirm that the proposed method effectively captures complex anomalous transport dynamics with high flexibility and accuracy.



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sciforum-174065: On divisor-counting ratios and the smoothness of integers

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Introduction.

Smoothness, roughness, and divisor structures are central topics in analytic and probabilistic number theory. In previous work, we introduced a ratio, R, associated with non-square integers, defined through a partition of their divisors, and conjectured that the condition R=2 is equivalent to P(n) being greater than the square root of n, where P(n) denotes the largest prime factor of n. Although this conjecture appears simple at first glance, its proof seems highly nontrivial. This difficulty motivates a broader investigation of the behaviour of R beyond the special case R=2.

Methods.

We analyse the general structure and distribution of the ratio R for non-square integers. Our approach combines asymptotic methods, heuristic arguments, and tools from probabilistic number theory, including the Dickman-de Bruijn function, to study how arithmetic properties such as smoothness and the size of the largest prime factor influence the possible values of R.

Results.

We identify several new patterns in the behaviour of R and provide evidence that its distribution reflects deeper structural properties of integer factorisation. In particular, we show that the case R=2 belongs to a broader family of phenomena, and we describe conditions under which other values of R arise.

Conclusions.

This work provides a more comprehensive perspective on the ratio R and highlights its potential as a tool for understanding smoothness and divisor structures. The results open several directions for future research, including a proof of the original conjecture and extensions to related arithmetic functions.



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sciforum-144537: On generalized distance functions in Fixed Point Theory

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The development of various generalizations of metric spaces has significantly enriched the study of fixed point theory, enabling the extension of classical results to broader and more flexible frameworks. In this talk, we examine several of these generalized metrics, with particular attention to the bipolar metric, suprametric, and perturbed metric. We investigate their topological properties, including completeness, compactness, and continuity structures, and discuss how these properties interact with fixed point principles.

A key aspect of our study is the introduction and analysis of remetrization techniques—methods of redefining distance functions while preserving completeness of the underlying space. Approaches can provide deeper insights into the behavior of iterative schemes and broaden the applicability of fixed point theorems. The necessary and sufficient assumptions of fixed point theorems will be compared in generalized metric space and induced metric space.

We also explore the stability properties of fixed point problems within generalized and remetrized spaces, highlighting differences and similarities in the convergence behavior of Picard iterative sequences. Comparative analysis reveals how these generalizations influence not only the existence and uniqueness of fixed points but also the efficiency and robustness of numerical methods used to approximate them. The presented results offer a unified perspective both on fixed point results and the scope of their applications, in that way combining both pure and applied mathematical contexts.



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sciforum-174943: On Generalized Variational Inequality Problems In Non-Absolute Cesàro Sequence Spaces

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Among other mathematical difficulties, the variational inequality problem is a broad problem that includes nonlinear equations, optimization problems, complementarity problems, and fixed-point problems. The pricing model of the option, economic equilibrium issues, and specific kinds of partial deferential equations are all studied using variational inequality. In particular classical-variational inequality problem has been broaden to survey a large group of problems arising in optimization theory, physics, economics, financial, structural transportation, and so forth. The study has expanded and epitomized in various fields through different techniques and ideas. Variational Inequality Problem has already defined in various infinite dimensional spaces like manifolds, Housdorff topological vector spaces, Hilbert spaces, Banach space, H-space etc. Also some authors has already introduced vector F-variational inequality problems in ordered topological vector spaces and differentiable -manifolds. Also, in one of our previous work we have already defined variational inequality problem on Cesàro sequence space and proved some result like monotonicity and existence theorem on it. The main aim of the work is to introduce the generalized version of variational inequality problems in non-absolute Cesàro sequence spaces Here at first,we have defined generalized variational inequality problem (GVIP) and generalized dual variational inequality problem(GDVIP) on non absolute Cesàro sequence space. We have defined homotopy and functional homotopy for our need.Next we have used KKM mapping to prove existence theorem of generalized Variational inequality problem on a non-absolute Cesàro sequence space to its dual space. Also we have proved some more properties like monotonicity of GVIP on - dual of non absolute Cesàro sequence space.



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sciforum-172555: On Inner Radii Estimates for Mutually Non-overlapping Domains via Green's Functions

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According to the Riemann mapping theorem, for an arbitrary simply connected domain $B\subset \mathbb{C}$ and a point $a\in B$, there exists a unique regular function $f(z)$ that univalently maps the given domain onto an open disk centered at the origin such that $f(a)=0$ and $f'(a)>0$. The radius of the resulting disk is defined as the conformal radius of the domain B at the point a. In the context of multiply connected domains, the concept of an inner radius serves as a crucial analogue, typically expressed through the Green function of the domain. This research focuses on the extremal problems associated with the products of inner radii for systems of non-overlapping domains, which remains a significant topic in geometric function theory. The study yielded new upper estimates for the products of inner radii of mutually non-overlapping domains containing fixed points on the unit circle. Taking into account these estimates we derived analytical formulas for the potential generated by a system of point sources located in specified configurations. These formulas allow for a formal description of the relationship between the positions of the points a_k and the maximum possible values of the inner radii products. The obtained estimates extend existing theorems in the field of univalent functions and potential theory. These findings have potential applications in mathematical physics, particularly in problems related to electrostatics and fluid dynamics where Green's functions are fundamental.



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sciforum-159436: On the (p, q)-compactness of Banach-valued Bloch mappings

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This work develops a comprehensive theory of what we call (p, q)-compact Bloch mappings, extending to the Bloch setting the concept of (p, q)-compact linear operators introduced by Ain, Lillemets, and Oja. We introduce and deeply study holomorphic mappings from the open unit disc in the complex plane in a complex Banach space, whose measures of the size of (p, q)-compactness associated with the Bloch range are finite. The collection of all zero-preserving (p, q)-compact Bloch mappings, endowed with a suitable norm, is shown to constitute a surjective s-Banach ideal of normalized Bloch mappings, where the exponent s is given by $s = pq/(p + q)$. This ideal becomes regular for the collection of all reflexive complex Banach spaces.

This paper establishes several structural properties of these mappings. We prove invariance under Möbius transformations and a linearization theorem that identifies a Bloch mapping as (p, q)-compact precisely when its associated continuous linear operator on the Bloch-free space is (p, q)-compact. This correspondence allows us to extend many classical results on operator ideals to the nonlinear Bloch framework. We also obtain factorization theorems for (p, q)-compact Bloch mappings through compositions involving compact Bloch mappings and (p, q)-compact linear operators. Furthermore, we introduce and analyze the subclass of (t, u, v)-nuclear Bloch mappings, providing characterizations and their ideal structure parallel to those known in operator theory.

Hence, this study unifies and generalizes previous results on compact and p-compact Bloch mappings, establishing a deep interaction between operator ideals and the geometry of holomorphic mappings on the open complex unit disc, and demonstrating the robustness of the (p, q)-compact setting under linearization, factorization, and Möbius invariance.



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sciforum-172009: On the Blow-up of Coupled Wave Equations with Logarithmic Nonlinearity

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This talk investigates a system of nonlinear wave equations exhibiting time-varying delay and logarithmic nonlinearity. We first prove the

local existence and uniqueness of solutions using semigroup theory. Our main result establishes that solutions with negative initial energy undergo

finite-time blow-up, generalizing the scalar case. Our objective throughout this paper is to provide a comprehensive analysis

of the following coupled nonlinear wave system. This system models

the interaction of two nonlinear wave fields subject to internal damping and

logarithmic-type source terms. The nonlinear damping functions g(ut) and g(vt)

contribute to energy dissipation, whereas the coupled source terms may act as

energy generators, depending on the size and structure of the solution.

The strong coupling between u and v, together with the presence of logarithmic

nonlinearities, leads to a delicate competition between damping and source

effects. As a result, solutions may exhibit different qualitative behaviors, including

global existence with energy decay or finite-time blow-up for certain classes

of initial data. We introduce the functional setting, state the main assumptions, and establish the

well-posedness of the problem by proving the existence and uniqueness of weak solutions using semigroup theory and monotone operator techniques. In Section 3, we study the finite-time blow-up of solutions with negative initial energy by constructing an appropriate Lyapunov functional and employing nonlinear differential inequalities together with the concavity method.



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sciforum-167849: On the Spectral Theory of Regularized Quasi-semigroups

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We investigate a time-dependent abstract Cauchy problem formulated as follows:
\begin{equation}
\begin{aligned}
x'(s) = A(s+t)x(s), \quad t, s \geq 0, \quad x(0) = Cx_0
\end{aligned}
\end{equation}
In this formulation, the function $x(s)$ represents an unknown function defined on the interval $[0,T]$ with values in a Banach space X. The operator C is a bounded injective linear operator on X, while $A(s)$ denotes a closed linear operator in X with constant domain $\mathcal{D}(A(t))=\mathcal{D}$ for all $t \geq 0$.

The solution to Equation (1) can be formally expressed as $x(t) = U(t,s)x_0$, where $\left\lbrace U(t,s)\right\rbrace_{t,s\geq 0}$ constitutes a two-parameter family of bounded linear operators on X, known as a C-quasi-semigroup or regularized quasi-semigroup. This concept, introduced by M. Janfada, generalizes classical C_0-semigroups to accommodate broader classes of evolution equations.

Our approach extends established spectral techniques from C_0-quasi-semigroups to the general framework of C-quasi-semigroups. The analysis investigates spectral properties of these operator families and their infinitesimal generators, which govern solution behavior.

We establish important spectral inclusion relationships between various spectra of C-quasi-semigroups and their infinitesimal generators. Specifically, we demonstrate spectral inclusions for Saphar, essentially Saphar, quasi-Fredholm, Kato, and essentially Kato spectra, providing comprehensive spectral characterization of these operators.

This work significantly extends the spectral theory of C_0-quasi-semigroups to regularized C-quasi-semigroups. The established spectral inclusion relations offer essential theoretical tools for analyzing regularized operators and their asymptotic properties, opening new perspectives for studying time-dependent differential equations in Banach spaces with regularization techniques.



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sciforum-170865: On the Stability of Solutions to Certain Tribonacci-Type Difference Equation Systems

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Difference equations play a fundamental role in describing the evolution of various phenomena over discrete time intervals. Unlike differential equations, which model continuous processes, difference equations are particularly suitable for systems where changes occur at specific time steps. Over the last twenty-five years of the twentieth century, the theory of difference equations witnessed remarkable development, driven by both theoretical advances and the increasing demand for discrete-time models in applied sciences.

A difference equation is essentially a functional relation among the terms of an unknown sequence, derived from known physical, biological, or economic principles. Once such a relation is established, the equation can be analyzed and solved using various mathematical tools, including analytical methods, numerical approximations, and computational techniques. Of particular interest in modern research are nonlinear and rational difference equations, whose dynamics often exhibit complex behaviors such as oscillations, bifurcations, and chaos.

In this context, several researchers have focused on the qualitative analysis of systems of difference equations. In particular, in 2013, Y. Yazlık, D. T. Tollu, and N. Taşkara investigated the form of solutions of certain systems of rational difference equations. Their work contributed significantly to the understanding of the structural properties and long-term behavior of such systems, and it has motivated further research on stability, boundedness, and convergence properties, especially for systems involving special number sequences such as Fibonacci and Tribonacci numbersj

In this work we interested the form of solutions, stability character and asymptotic of the system non-linear of difference equations in order p + 1.

8>>:

xn+1 = ±1

yn-(p-1)(xn-p±1)+1

x ±1

n-(p-1)(yn-p±1)+1yn+1 = ;

n 2 N0; p ≥ 1

where x

-p; x-(p-1); x-(p-2); : : : ; x0; y-p; y-(p-1); y-(p-2); : : : ; y0 are real initial values with the certain conditions.

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sciforum-168701: Pascal–Wronskian Matrix Algebras Associated with Bivariate s–Appell Polynomial Families

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Matrix-based representations provide a natural and effective way to encode analytic operations arising in generating-function calculus and polynomial systems. In this work, we explore a finite-dimensional matrix-algebraic framework associated with analytic generating kernels of bivariate s–Appell type. By introducing appropriate Wronskian coordinate vectors, we construct families of structured lower-triangular matrices of the Pascal type that act naturally on polynomial coordinate spaces and reflect underlying analytic transformations. This matrix formulation makes it possible to reinterpret classical analytic operations such as differentiation, translation, and recurrence in terms of matrix actions and binomial-type convolutions. Within this unified setting, several structural properties of the associated polynomial sequences, including recurrence relations, shift identities, and differential-type relations, can be systematically examined from a linear-algebraic and operator-theoretic perspective. The approach allows different classes of bivariate polynomial systems, including classical Appell-type constructions and more general systems, to be treated within a common finite-dimensional framework. By organizing generating-function-based structures through matrix algebras, the proposed viewpoint offers a coherent analytical tool for studying polynomial systems and their associated transformations. Overall, this work highlights the usefulness of structured matrix methods in mathematical analysis and demonstrates how finite-dimensional operator representations can provide insight into the analytic behavior and algebraic structure of bivariate polynomial families.



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sciforum-174327: Propagation of KdV-DIA and mKdV-DIA Solitons in an Unmagnetized Dusty Plasma with Kaniadakis Distributed Electrons

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In this article, we examine the propagation of small-amplitude dust ion-acoustic (DIA) solitary waves in an unmagnetized three-component dusty plasma composed of negatively charged mobile dust, ions, and electrons obeying the Kaniadakis distribution. By applying the standard reductive perturbation method, the Korteweg–de Vries (KdV) and the modified KdV (mKdV) equations are derived to explore the effects of key plasma parameters, viz., the Kaniadakis deformation parameter (κ), the dust charge number (Z_d), and the initial streaming speed of ions (u_{i0}) and dusts (u_{d0}), on the evolution of DIA solitary waves. A wide range of notable features emerges, showing how the solitary profiles respond to variations in key plasma parameters. The analysis reveals that for certain values of initial ion streaming speed and dust charge number, a non-existence region of KdV-DIA solitons arises. Both compressive and rarefactive KdV-DIA solitons and only compressive mKdV-DIA solitons are observed under the same plasma conditions. For compressive structures, the soliton amplitude increases with increasing Z_d and decreasing κ. The results further demonstrate that the Kaniadakis deformation parameter (κ) significantly modifies the properties of mKdV-DIA solitons, while it does not influence the characteristics of KdV-DIA solitons. In addition, the dependence of the width of DIA solitons on various plasma parameters is also investigated.



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sciforum-174208: Qualitative analysis of plant-herbivore interaction with Allee effect: stability, bifurcation and chaos control

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In this study, the dynamics of plant-herbivore interactions is explored while incorporating the Allee effect on prey population. This study offers valuable insights into the dynamics of plant-herbivore systems by examining the role of the Allee effect and its influence on population dynamics. The Allee effect, which occurs when reduced population size negatively impacts individual fitness and population growth rate, is considered a critical factor in understanding these interactions. This investigation is focused on analyzing the stability of the system through the examination of fixed points, including a trivial steady-state, a predator-free steady-state, and a coexisting steady-state. Also their local stability criteria is examined with the help of the method of linearization. Bifurcation analysis is utilized to explore conditions leading to qualitative changes in the system's behavior, including the emergence of complex dynamics. The system undergoes a transcritical bifurcation and Hopf bifurcation at positive steady-state. To address chaotic behavior, chaos control techniques is implemented to stabilize the system at the desired state including the emergence of chaotic attractors. Additionally, numerical simulations is conducted to validate the theoretical and mathematical analyses, offering a visual and qualitative comprehension of the system's behavior across different parameter settings. For numerical simulations, MATHEMATICA software is used to illustrate the study.



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sciforum-182865: Quantitative and asymptotic estimates for parabolic obstacle problems with a drift term

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We deal with the obstacle problem related to an operator with a drift-type lower-order term that in the linear case represents the one related to the Fokker–Plank equation, whose (normalized) solution describes the evolution of the probability density for a stochastic process. As the simplest possible model, we can consider the operator

The main novelty is the presence in the coefficient of the lower-order term of a singularity in the spatial variable. More precisely, we assume that the coefficient of the drift term lies in the Marcinkiewicz class weak-for a.e. time and satisfies the minimal time integrability assumption. The obstacle function is assumed to be time-continuous. Despite the lack of coercivity, we prove the well-posedness of a global solution to the obstacle problem and we describe the asymptotic behavior of such a solution. Moreover, we give quantitative asymptotic, stability estimates for the solutions to different problems. More precisely, we measure the distance in time of a solution to a parabolic obstacle problem from a solution to a stationary one. Fundamental tools in proving our results are a regularizing-in-time procedure and a suitable application of a Gronwall's type lemma. A bound on the distance of from bounded functions is needed. However, this restriction holds whenever is in the Lebesgue space .



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sciforum-169880: Revisiting Boundary Value Problems for Differential Equations and Ulam-type Stability

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Ulam-type stability investigates how small deviations in the input parameters affect the proximity of approximate solutions of differential equations to exact ones. This theory provides a rigorous framework for analyzing the stability of various equations such as difference, differential, functional, and integral equations. Ulam-type stability for initial value problems (IVPs) for various types of equations and derivatives (ordinary, partial derivatives, and any type of fractional derivatives) is well investigated and applied to some models. However, when applying Ulam-type stability to boundary value problems (BVPs), some conceptual misunderstandings appear. These observations motivate us to provide an overview, to discuss the meaning of this type of stability and to identify the key issues that arise when applying Ulam stability to BVPs. We propose three distinct approaches to overcome them. To enhance clarity and accessibility, we begin with nonlinear ordinary differential equations and subsequently extend the analysis to nonlinear fractional differential equations. In the first approach, we consider an integral inequality derived from the integral representation of the studied BVP. In the second approach, we construct a differential inequality with an inequality for the boundary condition. In both approaches, the solution of the BVP is independent of the chosen approximate solution of the inequality. Thus, the analysis centers on the closeness between this unique solution and any approximate solution satisfying the corresponding inequality that differs from the classical concept of Ulam stability. In the third approach, we adopt the classical framework of Ulam stability and we introduce a parameter into the boundary condition, later choosing this parameter depending on the particular approximate solution. In this way, the solution of the BVP becomes dependent on the selected approximate solution. Several examples are provided to illustrate the effectiveness of the proposed methods.



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sciforum-166499: Second-Order Projection Dynamical Model for Solving Inverse Mixed Variational Inequalities and Application

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In this paper, we introduce a new projection-based second-order dynamical system for solving inverse mixed variational inequality problems (IMVIs) with two time-dependent parameters. Such problems arise naturally in optimization and equilibrium theory and are often difficult to handle using standard first-order methods. The proposed dynamical model is designed by combining inertial effects with projection operators, which improves both stability and convergence behavior.

Under the assumptions that the underlying operator is strongly monotone and Lipschitz continuous, we establish the existence and uniqueness of solutions to the proposed system. Moreover, we prove that the equilibrium point of the dynamical system is globally stable. The stability analysis is carried out using an appropriate Lyapunov function, which provides a clear theoretical justification for the convergence of the trajectories.

Additionally, a discrete-time version of the continuous model is derived, resulting in an inertial projection-type iterative algorithm. It is demonstrated that, under suitable parameter choices, the generated sequence converges linearly to the unique solution of the IMVI. This discrete scheme is simple to implement and can be viewed as an efficient numerical realization of the continuous dynamics.

Finally, several numerical experiments are presented to illustrate the effectiveness of the proposed approach. The results confirm the theoretical findings and demonstrate the method's accuracy, fast convergence, and robustness when applied to inverse mixed variational inequalities and related optimization problems.



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sciforum-170163: Semiclassical Approximations for Fractional Quantum Mechanics

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Fractional quantum mechanics generalizes standard quantum mechanics to include nonlocality, memory effects, and fractal structures. It retains core quantum characteristics while introducing nonlocal dynamics, which poses substantial challenges for mathematical analysis. The semiclassical analysis, which is among the most significant mathematical frameworks for investigating conventional quantum mechanics, is lacking for fractional quantum mechanics, due to the unmatched difficulties raised by the nonlocal dynamics. In this talk, we will present recent progress toward the development of semiclassical analysis for fractional quantum mechanics, including both analytical and numerical investigations. Semiclassical approximations for the fractional Schrodinger equations will be presented, where ansatz in the form based on Wentzel–Kramers–Brillouin-Jeffreys (WKBJ), Hankel functions, and Fox-H functions are derived. In the semiclassical approximations, the phase and amplitude are proved to be determined by Hamilon-Jacobi type partial differential equations. The semiclassical approximations, as well as the Hamilton-Jacobi type partial differential equations, reduce consistently to those in the semiclassical analysis for standard quantum mechanics when the fractional order approaches integer order, which justifies that the derived semiclassical approximations generalizes those for standard quantum mechanics. The performance of different types of approximations will be compared, showing that the Fox-H function based approximation can achieve uniform accuracy near point sources, in constrast to those based on WKBJ or Hankel functions. Numerical experiments are performed to further justify the derived semiclassical apporixmations.



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sciforum-174259: Spectral problem for second-order ordinary differential equation with integral conditions

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Ordinary differential equations with nonlocal and integral boundary conditions have attracted significant attention due to their theoretical importance and wide range of applications. In this work, we investigate a spectral problem for an ordinary differential operator subject to integral conditions involving both the first and second derivatives of the unknown function.

The novelty of this work lies in the formulation of more general integral conditions that extend those studied by K. A. Darovskaya and A. L. Skubachevskii, where the integral conditions involve either the first or the second derivative of the unknown function. The proposed framework allows for a unified treatment of such conditions and leads to a broader class of differential operators.

A priori estimates for the solutions of the problem are obtained for sufficiently large values of the spectral parameter λ. These estimates play a key role in the analysis and provide a basis for studying the corresponding operator. In particular, they are used to investigate the spectral properties of the associated operator and to ensure the well-posedness of the problem.

The approach is based on methods of functional analysis and the theory of Fredholm operators. The obtained results generalize several known results in the literature and contribute to the development of the theory of differential equations with nonlocal conditions.



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sciforum-171272: Stability Analysis for Measles Infection with SEIRV+D Model

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Measles, a highly contagious disease, remains a significant public health challenge despite the availability of effective vaccines whose spread dynamics are influenced by population density, contact rates, and vaccination coverage. Mathematical modeling is essential for forecasting outbreaks and evaluating intervention strategies. Thus, we aimed to analyze the threshold dynamics of measles in Algeria.

This study used the SEIRV+D (Susceptible–Exposed–Infected-Recovered–Vaccinated+Deceased) model, which tracks six key groups, to analyze measles transmission. We performed equilibrium analysis, the Disease-Free Equilibrium (DFE) and derived Endemic Equilibrium (EE). The stability of these equilibria was analyzed through the basic reproduction number ($\mathcal{R}_0$). Stability analysis confirms that the DFE is locally asymptotically stable when $\mathcal{R}_01$, while the EE becomes locally asymptotically stable when $\mathcal{R}_0>1$, and the DFE is globally asymptotically stable when $\mathcal{R}_01$ and unstable if $\mathcal{R}_0>1$.

Furthermore, the detailed bifurcation analysis reveals the occurrence of a forward bifurcation at $\mathcal{R}_0=1$, and sensitivity analysis helped identify the parameters that most influence the basic reproduction number $\mathcal{R}_0$, highlighting the critical role of vaccination-related factors. Numerical simulations for Algeria demonstrate that increasing the vaccination rate from suboptimal coverage to the WHO-recommended threshold of 95% significantly reduces both the cumulative number of infections and measles-attributable deaths. The model clearly shows the direct relationship between vaccination coverage, the magnitude of $\mathcal{R}_0$, and the long-term disease burden. The main results show that measles elimination in Algeria was achieved through modest vaccination coverage.



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sciforum-168196: Stability Analysis of A Hotel Model And Assessment Using Additive Functional Equations

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This paper introduces a new class of systems of additive functional equations $H_K(p_K+ r_K+ f_K+q_{K1}+ q_{K2}+ s_K+t_K) = H_K(p_K)+ H_K(r_K)+ H_K(f_K)+ H_K(q_{K1})+ H_K(q_{K2})+ H_K(s_K)+ H_K(t_K)$ including parking availability, restroom facilities, food services, and service-related factors.

This provides a concrete applied framework that connects abstract functional equations with real-world modeling. The primary aim of the study is to establish the Ulam–Hyers (UH) stability of the proposed class of equations in complete normed linear spaces. To achieve this, a general control function is employed in conjunction with sumpowers of norms, product, powers of norms and mixed product-sum expressions involving powers of norms. Using a direct analytical approach, explicit stability conditions are derived for each functional equation considered. One of the significant contributions of this work lies in the introduction of multiple interrelated functional equations and the unified treatment of their stability analysis. Furthermore, an application is presented to demonstrate the practical significance of the theoretical results. A comparative discussion is also included to highlight the consistency of the results with established stability analyses and supporting mathematical computations.

All abbreviations are properly defined, and the equations are expressed in clear mathematical form to ensure readability and precision.



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sciforum-174516: Stochastic modeling and analysis of SIRS epidemic model with a general incidence: case study on COVID-19

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We consider a general-incidence SIRS epidemic model with stochastic dynamics in this paper. The general incidence function, as opposed to traditional methods, takes a more global picture of the dynamics that occur in the real world, such as the change in behavior and the saturation effect during transmission.

On the one hand, through Lyapunov analysis, we determine the existence and uniqueness of a global positive solution, that is, the consistency in the behavior of the system over time. On the other hand, we also obtain a stochastic threshold, an extension of the basic reproduction number, which provides a good condition at which the infection will be expected to fade away.

In order to supplement the theory, we perform numerical simulations. These not only confirm our findings in the analysis but also enable us to answer the question of how the model reacts to variations in important variables such as vaccination rates, incidence functions and noise levels. This assists in determining the real cause of disease dynamics. This flexibility allows the model to readily adjust to a variety of situations and be adjusted using actual data. In the end, this work provides a feasible and versatile instrument for predicting the trends in epidemics and analyzing the effectiveness of control measures in an unpredictable world.



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sciforum-145611: Study solutions to the coupled nonlinear fractional Drinfel'd–Sokolov–Wilson model

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There are several methods and techniques available for finding exact solutions to nonlinear differential equations, including the Darboux transformation, Ricatti method, Kudryashov method, Hirota bilinear transformation method, Lie symmetry method, extended tanh function method, G'/G expansion method, G'/G^2 expansion method, and the sine-Gordon approach, among others. Regarding the Drinfel'd–Sokolov–Wilson (DSW) equation, modified extended direct algebraic methods yielded solutions in the form of bell, anti-bell, periodic, and dark solitary waves in 2017, while series solutions were obtained using the Adomian decomposition method in 2022. In the field of fractional calculus, various types of fractional derivatives have been applied, such as the Beta derivative, Caputo fractional derivative, conformable fractional derivative, Riemann–Liouville derivative, and truncated M-fractional derivative. Many researchers are focused on constructing exact solutions for fractional differential equations. In 2023, singular bright, dark, periodic, bell, and lump-type water wave solutions to the coupled nonlinear fractional Drinfel'd–Sokolov–Wilson (FDSW) model with the Beta derivative were explored using the generalized rational exponential function method. However, the exact form of Weierstrass function-type solutions has not yet been established. Therefore, in this study, we aim to construct new travelling wave solutions for the FDSW model using the complex method and compare our results to those that are already known.



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sciforum-161927: Variational Structures and Weak Solution Frameworks in First-Order Nonlinear PDEs

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Introduction:

First-order nonlinear partial differential equations tend to lose smoothness quickly, so classical solutions only describe the evolution for a short time. After that, one has to rely on variational ideas and weak-solution frameworks to make sense of the equation. This work looks at Hamilton–Jacobi equations and scalar conservation laws and tries to bring out the shared analytical structure that appears in both settings once characteristics begin to break down.

Methods:

The approach uses convex analysis, weak convergence, and tools from Sobolev spaces and geometric measure theory. For Hamilton–Jacobi equations with convex Hamiltonians, the Legendre transform and the Hopf–Lax formula are used to build viscosity solutions and to understand why these variational representations remain meaningful after the loss of classical regularity. For scalar conservation laws, the analysis centers on entropy admissibility, the Rankine–Hugoniot jump condition, and the way shocks form. The Lax–Oleinik formula is examined in detail because it ties the two equations together and shows that both rest on similar minimization principles.

Results:

The study shows that viscosity and entropy solutions naturally emerge from the same underlying variational structure. The Hopf–Lax and Lax–Oleinik formulas give explicit solution representations that stay valid beyond the classical regime. Convexity ensures stability, and Sobolev/GMT techniques help describe the limiting behavior and the formation of singularities.

Conclusions:

The work provides a unified theoretical viewpoint on first-order nonlinear PDEs, where variational principles, convex duality, and weak-solution ideas fit together in a consistent and natural way. Many qualitative properties of these equations can be understood directly from analysis without relying on computational or numerical methods.



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Session 3. Statistics and Operational Research

sciforum-155023: Predictive Modeling of Student Academic Performance Using Multivariate Statistical Techniques and Machine Learning Algorithms

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Introduction. Student attrition and academic underperformance remain critical challenges in higher education institutions worldwide. Early identification of at-risk learners enables timely interventions that can significantly improve student outcomes. This study compares traditional multivariate statistical techniques with modern machine learning algorithms to predict student academic performance and identify learners requiring support.

Methods. We collected comprehensive data from 525 undergraduate students over four academic years (2020-2024) through administrative records, online questionnaires (87.3% response rate), and institutional databases using stratified random sampling. The dataset comprised 18 predictor variables including prior academic achievement, behavioral factors (attendance rate, weekly study hours), socio-demographic characteristics, and engagement indicators. We systematically compared six predictive models: Multiple Linear Regression, Classification and Regression Trees, Random Forests, Gradient Boosting Machines, XGBoost, and Support Vector Regression. Model performance was evaluated using 5-fold cross-validation with R^2 and RMSE metrics.

Results. Feature importance analysis identified five dominant predictors: previous academic performance (34.2%), class attendance rate (21.8%), weekly study hours (15.6%), entrance examination scores (12.4%), and parental education level (8.9%). Ensemble machine learning methods substantially outperformed traditional approaches. XGBoost achieved the highest performance (R^2=0.761, RMSE=0.378), representing 12-17% improvement over Multiple Linear Regression (R^2=0.634, RMSE=0.487). The optimal model identified at-risk students with 84.3% accuracy, segmenting learners into four risk categories: high-achievers (23%), on-track (42%), at-risk (28%), and critical-risk (7%).

Conclusions. This research demonstrates that advanced machine learning algorithms significantly outperform traditional statistical methods in predicting student academic performance, explaining over 76% of variance. A web-based dashboard implementing the XGBoost model enables real-time risk assessment and automated alerts for academic advisors. These findings illustrate the transformative potential of data-driven approaches for evidence-based early intervention strategies and educational planning initiatives.



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sciforum-174479: A Bayesian Adaptive Mixture Framework with Convergence Guarantees for Detecting Causal Emergent Features in Multi-Regime Time Series

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Introduction: Real-world time series often arise from mixtures of multiple causal generating processes, each subject to sudden emergence or parameter changes—phenomena that challenge classical models assuming a single dynamic process. While recent work introduces the Adaptive Logistic Model (ALM) to address this using nonlinear least squares, it lacks uncertainty quantification and formal convergence guarantees. This paper develops a Bayesian adaptive mixture framework that detects emergent dynamics, quantifies uncertainty, and provides theoretical convergence guarantees.

Methods: We propose a hierarchical Bayesian model where observations are generated by a mixture of nonlinear dynamic processes (e.g., logistic growth/decay) with unknown regime allocations and change points. Dirichlet process priors automatically infer the number of regimes, while Gaussian process priors capture parameter evolution. We derive a Markov chain Monte Carlo sampler and prove its geometric ergodicity under regularity conditions, establishing rates of posterior convergence. The framework outputs posterior probabilities for change-point locations and regime parameters, enabling uncertainty-aware forecasting and causal interpretation.

Results: Simulation studies demonstrate that the Bayesian framework accurately recovers true change points and regime parameters, with coverage rates matching nominal levels—an improvement over point-estimate methods. In empirical applications, the model detects known regime shifts in U.S. GDP growth (recessions), river flow data (flood events), and COVID-19 case counts (new variants), with change points aligning closely with documented external events. Forecast accuracy matches or exceeds the original ALM while providing uncertainty intervals.

Conclusions: This paper provides the first Bayesian extension of the Adaptive Logistic Model with formal convergence guarantees, enabling reliable detection of causal emergent features in multi-regime time series. The framework offers a mathematically rigorous tool for economists, hydrologists, and epidemiologists to understand when and why dynamics change.



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sciforum-174255: An Empirical Research for Likelihood-free Parameter Estimation Approach for NHPP-Based Software Reliability Models

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The non-homogeneous Poisson process (NHPP) is the most widely used stochastic counting model in software reliability. The maximum likelihood estimation (MLE) is useful when the likelihood function of NHPP is available. However, it is well-known that the MLE is bound to fail in the J-shaped distributions, such as in the Weibull and gamma distribution when the shape parameter is less than 1. The maximum likelihood estimator also does not exist inside the parameter space with positive probability. The maximum likelihood equations of the NHPP-based SRM cannot be solved, if and only if the observed time to last software failure is less than twice the mean observed-time-to-failure. Furthermore, in some generalized software reliability models, it is quite hard to obtain the likelihood function in a closed form. Therefore, we apply a likelihood-free estimation approach on NHPP-based software reliability models with finite mean value function. Our method is motivated by the maximum product of spacing estimation which provides the parameter estimation without the likelihood function and intensity function. In contrast to existing likelihood-free parameter estimation methods, such as least squares estimation, our method can yield an estimator that is consistent with the underlying NHPP probability law. We have demonstrated the predictive performance of our method through real-data analysis.



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sciforum-168672: An Evaluation of the Financial Performance of Logistics Companies in Malaysia using the Zmijewski Model

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The logistics industry plays a vital role in supporting economic growth by facilitating the efficient movement of goods and services and is a key component of Malaysia's supply chain and trade activities. However, logistics companies are highly exposed to operational risks, economic fluctuations, and financial uncertainties, particularly during challenging periods such as the COVID-19 pandemic and its aftermath from 2020 to 2024. Without systematic financial evaluation, stakeholders such as investors, management, and policymakers may face difficulties in identifying financially healthy and distressed companies. The purpose of this study is to assess the financial performance of logistics companies listed on Bursa Malaysia from 2020 to 2024 using the Zmijewski model. A total of 28 logistics companies were evaluated in this study. The findings indicate that 24 companies remained financially healthy throughout the five-year period, representing 85.71% of the sampled firms. The results suggest that the majority of logistics companies maintained sound financial conditions despite economic challenges during the study period. The financially unhealthy companies may use the financially healthy firms as benchmarks to improve their financial performance in the future. The findings of this study are significant as they assist investors in making informed investment decisions, enable company management to benchmark their financial performance for future improvement, and support policymakers in understanding the financial resilience of the logistics sector.



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sciforum-174326: Application of Phase-Type Distributions to Actuarial Lifetime Data under Left-Truncated and Right-Censored Observations

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Estimating lifetime distributions under left-truncated and right-censored (LTRC) data is an important problem in actuarial science because it directly influences premium calculation, reserve valuation, and mortality modeling based on life table data. In insurance practice, delayed entry due to policy enrollment age and incomplete observation due to the end of the study period occur simultaneously, producing observation bias and a complicated likelihood structure. Under this framework, reliable lifetime modeling requires appropriate statistical modeling. Phase-Type (PH) distributions provide a flexible class of lifetime models constructed from absorbing Markov processes and are dense in the class of positive-valued distributions. Their structural flexibility makes them particularly suitable for capturing complex hazard patterns observed in actuarial mortality data. This study applies PH distributions to actuarial life table data under the LTRC framework. In particular, we explicitly formulate and estimate PH distributions using life table data regarded as LTRC observations, which constitutes a novel application in this context. Model parameters are estimated via maximum likelihood. Since increasing the number of phases monotonically improves the likelihood, practical implementation requires careful consideration of model complexity. To address this issue, we employ the Extended Information Criterion (EIC), which incorporates bootstrap-based bias correction of the log-likelihood, to examine phase selection. Furthermore, we compare PH distributions with conventional lifetime distributions using EIC, providing a systematic evaluation of their relative performance under the LTRC setting. The numerical results demonstrate the practical applicability of PH distributions to actuarial lifetime modeling under LTRC data. We observe the trade-off between improved goodness-of-fit and increased model complexity as the number of phases grows, and show that EIC can be used to support practical analysis of model complexity and model comparison in this context.



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sciforum-161459: Prediction of Stock Market Index in Malaysia with Neural Network

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Prediction of the stock market index is important for investors and financial analysts to mitigate risks and achieve profits. Multilayer perceptron is an efficient neural network to learn non-linear relationships for stock price prediction with high accuracy. FTSE Bursa Malaysia KLCI (FBM KLCI) represents the economic performance of Malaysia. Therefore, it is important to monitor the market sentiment based on FBM KLCI. Stock price prediction becomes a strident challenge for the investors and financial analysts to mitigate risks and achieve profits. This research aims to predict the closing prices of FBM KLCI with neural networks comprisingtwo hidden layers. The data consists of historical stock data, including volume, opening, closing, and low and high prices from January 2019 to May 2025. Model comparison is performed using random forest (RF). The model performances are evaluated with the coefficient of determination (R^2), root mean squared error (RMSE), and mean absolute error (MAE). The result of this study shows that the neural network is more stable and consistent in predicting the next closing prices of FBM KLCI. This study is significant because it contributes to the field by offering an efficient method for predicting stock index prices, which is expected to guide investors and fund managers in their decision-making.



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sciforum-171278: A Bayesian Network Approach to Understanding Uncertainty and Interactions in the Human Development Index

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The Human Development Index (HDI) is a widely used measure of development based on health, education, and income indicators published by UNDP. Although HDI is easy to interpret, it is calculated using a fixed formula that does not show uncertainty or explain how these indicators influence each other. With the availability of long-term HDI data for many countries, more flexible statistical methods can be applied.

In this study, we use a Bayesian Network to model the relationships between HDI and its core components: life expectancy, expected years of schooling, mean years of schooling, and gross national income per capita. A Bayesian Network represents these indicators as connected variables, where the connections are learned from UNDP data rather than assumed in advance. The model is estimated using standard Bayesian statistical methods and validated using cross-country data.

The results are expected to show that HDI components are not independent and education plays a crucial role in influencing both income and health outcomes. The Bayesian Network allows us to estimate the probability distribution of HDI rather than a single value, revealing uncertainty in HDI scores and rankings. Policy simulation experiments demonstrate that improvements in different indicators lead to different HDI gains depending on a country's development structure.

This probabilistic framework extends the traditional HDI by incorporating uncertainty and interdependence among indicators. The proposed approach provides a useful statistical tool for development analysis and policy evaluation using official UNDP data.



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sciforum-170164: A Bayesian Structural Time Series Model with Graph-Based Regularization for Forecasting Urban Traffic Flow

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Accurate multi-step traffic forecasting in urban networks is essential for intelligent transportation systems, yet a key challenge remains: standard models often treat road segments independently, ignoring the critical spatial dependencies imposed by the road network's topology. To address this, we introduce a novel forecasting framework that integrates network structure directly into a probabilistic time series model. Our method develops a Bayesian Structural Time Series (BSTS) model for each key road segment, incorporating local trend, daily seasonality, and dynamic regressors. The central innovation is the application of a graph Laplacian prior on the posterior distributions of the contemporaneous coefficients across the network. This regularization, informed by the actual connectivity graph, facilitates information sharing between neighboring segments, thereby penalizing implausible spatial discontinuities in the learned parameters. Inference is performed via Markov Chain Monte Carlo (MCMC) sampling. Applied to high-frequency data from a 50-node subnetwork of a major European city, our graph-regularized model reduced the mean absolute percentage error (MAPE) for 60-minute forecasts by 18% on average compared to independent BSTS models and significantly outperformed vector autoregression (VAR) and LSTM benchmarks, especially during non-recurrent congestion. This demonstrates that formally incorporating network science principles via a graph-Laplacian prior into a state-space statistical framework yields substantially improved and spatially coherent forecasts, a methodology generalizable to other networked time series problems such as in economics or epidemiology.



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sciforum-169411: A Beta-New XLindley Lifetime Model with Applications

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Lifetime data arise in reliability engineering, medical studies, and biological sciences, where flexible probability models are required to describe skewed and positive observations. Classical lifetime distributions are often too restrictive and may fail to capture diverse hazard rate behaviors observed in practice. In this paper, we introduce a new three-parameter lifetime model constructed by applying the beta-generated mechanism to the polynomial exponential distribution. The proposed beta–new XLindley distribution extends the baseline family by incorporating additional shape parameters that enhance modeling flexibility. Several fundamental properties of the new model are derived, including the probability density function, cumulative distribution function, reliability function, and hazard rate function. Parameter estimation is carried out using the maximum likelihood method, and numerical optimization techniques are employed to obtain the estimators. The practical performance of the proposed distribution is illustrated using a real data set consisting of luteinizing hormone measurements. Model adequacy is assessed through standard information criteria such as AIC, BIC, AICC, and the log-likelihood. The results demonstrate that the beta-new XLindley distribution provides a better fit than several well-known competing lifetime models. Overall, the proposed distribution offers a flexible and effective tool for modeling positive lifetime data and is particularly suitable for applications in medical statistics and reliability analysis.



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sciforum-173389: A Comparative Analysis of Econometric and Deep Learning Models for Exchange Rate Forecasting: Evidence from Sri Lanka

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The main aim of this study is to compare the accuracy of econometrics and deep learning models in forecasting the exchange rate volatility of the US dollar and Sri Lankan rupee in a multivariate framework. Foreign currency movements in a country mainly arise from export and import transactions recorded in the current account, as well as from Foreign Direct Investments, bank borrowings, and other capital inflows recorded in the capital account. In addition, foreign exchange flows are influenced by economic, political, and financial uncertainties within the country. Accordingly, as crude oil price is the largest import item representing the country's current account, the 3-Month Dollar Sri Lankan Rupee Forward Rate, All-Share Price Index Returns, Deutscher Aktien Index Returns, Dow Jones Industrial Average Returns and Hang Seng Returns are selected as representations of the capital account via covered interest arbitrage conditions, the S&P 20 Sri Lanka Index and MSI Sri Lanka Index. These represent the relative uncertainty in the Sri Lankan market, where foreign markets use a set of independent variables with the USD/LKR exchange rate as the dependent variable. Daily data was collected from December 2011 to April 2023, and DCC-GARCH, LSTM and DCC-GARCH-LSTM hybrid models were employed for the comparison. According to the model accuracy results measured by MSE, RMSE and MAE, the USD/LKR exchange rate is best predicted using LSTM, followed by DCC-GARCH and the hybrid model. Sri Lankan exchange rates operate under managed conditions and are subject to policy changes, causing non-linear patterns that can be more accurately captured by LSTM models than by GARCH models, as the structure is primarily volatility-driven in such models. Furthermore, DCC-GARCH may not react instantly to sudden changes, but it effectively captures a change that has occurred. Hybrid models combine this slow adjustment with the faster reactions of an LSTM, which can create conflicting signals, making prediction difficult.



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sciforum-171501: A Deep Learning-based Comparative Analysis for EUR/USD Exchange Rate Prediction

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Foreign exchange rates play a significant role in global finance, impacting international trade, investment decisions, and economic stability. Due to their volatile and nonlinear behavior, accurately predicting currency exchange rates has become a crucial area of financial research. This study analyzes historical exchange rate data to identify complex temporal and spatial patterns using advanced deep learning techniques. In this study, the main objective is to evaluate and compare the predictive performance of five deep learning models for EUR/USD exchange rate prediction. The model architectures are Convolutional Neural Network (CNN), Multi-Kernel Convolutional Neural Network (Multi-CNN), Attention Mechanism (AM), and two hybrid models, namely, Deep Attentive Convolutional Fusion (DACF) and Deep Attentive Multi-Kernel Convolutional Fusion (DAMCF). A big data analysis is conducted using 5,352 daily Open, High, Low, and Close (OHLC) values for the EUR/USD exchange rate covering the period from 2003 to 2024. Weighted averaging and normalization were used as preprocessing techniques. Then, the methodology involves rolling window analysis, candlestick chart visualization, and the design of model architectures that include CNN layers, multi-scale convolution kernels, attention mechanisms, and hybrid models combining spatial and temporal features. The models are evaluated using RMSE, MAPE, and R^2. The experimental results show that all the models achieved considerable accuracy, with the three best performing models being DAMCF (R^2 = 0.9556), DACF (R^2 = 0.9210), and AM (R^2=0.9051). Further, the DAMCF model demonstrates the greatest ability to learn complex market patterns. These results demonstrate the potential of hybrid architectures in financial forecasting that combine CNN and AM. The suggested method provides insightful information for monetary policy planning, risk management, and algorithmic trading.



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sciforum-171790: A Flexible Location-Scale Burr XII Distribution with Applications in Cancer and Glass Fiber Data

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Accurate statistical modeling of lifetime and reliability data remains a significant challenge in fields such as survival analysis, engineering, and environmental studies, particularly when datasets exhibit varying skewness, heavy tails, and complex hazard rate structures. Classical distributions, including the Burr XII model, often demonstrate limited flexibility in capturing diverse distributional shapes and hazard behaviors observed in real-world data. In this study, a new and flexible distribution, referred to as the Location-Scale Burr XII (LS-Burr XII) distribution, is introduced by adding a location-scale transformation into the classical Burr XII model. The LS-Burr XII distribution captures a wide range of density shapes, including right-skewed, left-skewed, bell-shaped, J-shaped, and reversed J-shaped forms. It also accommodates diverse hazard rate behaviors, including increasing, decreasing, constant, bathtub, unimodal, and modified bathtub shapes. These features extend beyond the capabilities of the classical Burr XII distribution and many of its existing extensions. Several statistical properties of the proposed model are derived, including the quantile function, moments, moment generating function, and order statistics. Parameter estimation is carried out using the maximum likelihood method, and a Monte Carlo simulation study is conducted to assess the performance of the estimators. The practical usefulness of the proposed model is demonstrated using two real-world datasets, including leukemia cancer data from Saudi Arabia and glass fiber strength data obtained from the UK National Physical Laboratory. The performance of the proposed LS-Burr XII distribution is compared with the classical Burr XII model and other existing extensions using standard goodness-of-fit criteria. The results indicate that the proposed model offers greater flexibility and provides a better fit with the observed data. These findings suggest that the LS-Burr XII distribution offers a useful and competitive alternative for modeling complex lifetime data in reliability and biomedical applications.



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sciforum-171584: A Multivariate Evaluation of Water Quality and Regulatory Compliance from Diverse Sources

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In this study, a multivariate statistical framework is applied to evaluate water quality across multiple source types in Kano State, Nigeria. We evaluated a total of 33 water samples collected from 11 locations, encompassing drinking water, groundwater, industrial wastewater, and surface water. Six physicochemical parameters in the form of pH, electrical conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS), turbidity, and total suspended solids (TSS) were analysed. Descriptive statistics, one-way analysis of variance (ANOVA), correlation analysis, principal component analysis (PCA), k-means clustering, and water quality index (WQI) assessment were employed to characterize spatial variability and pollution patterns. The results indicate pronounced differences in water quality among source types, with surface water showing the highest overall quality (mean WQI = 88.4) and industrial wastewater the lowest (mean WQI = 56.6). Compliance with drinking water standards was highest for TDS (90.9%) and lowest for turbidity (39.4%). Cluster analysis identified four water quality groups, with industrial wastewater samples predominantly forming isolated clusters, reflecting elevated pollution levels. Significant moderate correlations were observed between EC and DO ($r = -0.66$, p 0.001) and between TDS and TSS ($r = 0.52$, $p = 0.002$), suggesting inter-parameter dependencies. These findings highlight the urgent need for improved industrial wastewater treatment and strengthened monitoring of groundwater resources to safeguard public health and water sustainability in the region.



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sciforum-158490: A Nonparametric Approach to Performability Analysis in Semi-Markov Systems

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This work introduces a **nonparametric estimator** for evaluating the performability of **semi-Markov systems**, formulated as the sum or integral of a real-valued functional stochastic process. The concept of performability, originally proposed by Meyer, extends classical reliability measures by incorporating performance-related aspects of system behavior. It represents a unified and comprehensive measure that captures both the reliability and performance of a stochastic system as it evolves over time under uncertainty.

For a **homogeneous continuous-time semi-Markov process** with a given state space and reward rate function, we develop **empirical nonparametric estimators** for key quantities such as the semi-Markov kernel, renewal matrix, semi-Markov transition matrix, and the mean performance of the system. These estimators are constructed without imposing restrictive parametric assumptions on the sojourn-time distributions, thereby offering improved flexibility, robustness, and adaptability in practical and theoretical applications.

Furthermore, the **asymptotic properties** of the proposed estimators are rigorously analyzed. In particular, we establish their **strong consistency** and **asymptotic normality**, providing a solid theoretical foundation for nonparametric inference in **homogeneous continuous-time semi-Markov process**. Finally, the usefulness and effectiveness of the theoretical results are demonstrated through a **numerical example**, confirming the practical relevance and applicability of the proposed approach to performability analysis in complex stochastic systems.



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sciforum-174286: A Note on Reliability Analysis of Multi-Stage Manufacturing Systems with Controlled Capacity Release

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Modern manufacturing systems are becoming increasingly complex as production lines integrate multiple interconnected processes. In multi-process mechanical manufacturing systems, deviations in upstream operations often propagate downstream, resulting in performance degradation and reliability loss in subsequent machines. To mitigate such degradation, this paper introduces the concept of release-controlled capacity, where each machine's operational capacity can be dynamically adjusted or released in response to system conditions. Continuous-time Markov chains (CTMCs) capture the stochastic degradation of machines by modeling transitions through discrete performance states, where systems can only move from higher to lower capacity due to wear or failure. Quality–Reliability (Q-R) dependency quantifies how upstream product quality deviations accelerate downstream machine degradation rates, linking product quality to system reliability. These two concepts provide the theoretical foundation for the proposed quality state-space model. A Controlled Capacity Release (CCR) mechanism allows for the dynamic activation of reserved resources to compensate for performance loss. It is driven by a combination of hardware resources and a control system. Unlike traditional "pure-death" models that only account for monotonic degradation, the proposed model incorporates CCR as probabilistic recovery transitions to higher-capacity states, effectively capturing the system's ability to restore performance through automated control or buffer utilization.

The proposed approach is validated through numerical experiments in a multi-stage manufacturing system case study. Results demonstrated that the CCR mechanism significantly slows down the rate of reliability degradation compared to traditional models. Furthermore, experimental results revealed that while higher recovery rates improve system stability, the benefits exhibit a diminishing-return effect due to system coupling and Q-R dependency.



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sciforum-165599: A Poisson-Based Exceedance Probability Model for Earthquake Occurrence Using PHIVOLCS Seismic Data

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This study presents a Poisson-based exceedance probability model rooted in stochastic process theory and statistical rate estimation to characterize earthquake occurrence in the Philippines using a PHIVOLCS-patterned seismic dataset. Earthquakes are modeled as realizations of a stationary Poisson counting process, where magnitude-threshold exceedances correspond to rare-event arrivals, analogous to demand or failure events in queueing and reliability systems. A 50-year catalogue comprising 5,895 events with magnitudes M ≥ 4.0 was analyzed using frequency–magnitude statistics to estimate intensity parameters for thresholds M ≥ 4.0, M ≥ 5.0, M ≥ 6.0, and M ≥ 7.0. These estimated rates were embedded in closed-form Poisson exceedance functions to compute probabilities at one-, ten-, and fifty-year horizons under standard assumptions of independence and temporal stationarity. The results yielded mean annual rates of 117.9, 14.04, 1.30, and 0.18 events for increasing magnitude thresholds, respectively. The exceedance probability of at least one M≥6.0 event was 72.7% within one year and approached unity over a decade, while M≥7.0 events exhibited a 16.5% annual exceedance probability that increased to over 99% within fifty years. From an operations research standpoint, these exceedance probabilities serve as inputs to stochastic optimization, enabling risk-informed decisions in capacity planning, resource allocation, and resilience optimization under uncertainty. The proposed framework demonstrates how classical stochastic models, widely used in queueing theory and reliability analysis, can be rigorously applied to seismic data, reinforcing the role of applied probability and statistics in interdisciplinary hazard modeling and decision science.



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sciforum-169739: A Probabilistic Fuzzy Framework for Decision Making Under Uncertainty in Complex Systems

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Decision-making problems in real-world systems are often affected by ambiguity, incomplete information, and uncertainty that cannot be adequately represented using classical deterministic or purely probabilistic models. While probabilistic approaches are effective in modeling random variability, they are limited to some situations where vagueness and subjectivity play a dominant role. This paper proposes a new probabilistic fuzzy decision-making framework to address such uncertainty in complex decision environments.

The proposed approach combines fuzzy set theory with probabilistic concepts and operations research principles, allowing the simultaneous treatment of stochastic uncertainty and linguistic imprecision. A generalized aggregation mechanism is developed to integrate fuzzy evaluations with probabilistic criterion importance, resulting in a comprehensive decision score for each alternative. Key theoretical properties of the framework, including consistency, boundedness, and stability with respect to uncertainty variations, are analytically investigated.

The applicability of the proposed framework is illustrated through representative multi-criteria decision-making scenarios involving conflicting criteria and imprecise information. The results demonstrate that the proposed approach provides more flexible and reliable decision outcomes compared to traditional crisp and purely probabilistic methods.

This study contributes to the advancement of decision theory and fuzzy systems, offering a mathematically sound and adaptable framework with potential applications in operations research, data analysis, and interdisciplinary decision-support problems.



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sciforum-170166: A Stochastic Epidemic Model with Deep Learning Correction for Real-Time Estimation of COVID-19 Under-Reporting

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Accurate real-time estimation of key epidemic parameters, particularly the effective reproduction number (R_t), is critically undermined by the pervasive and variable issue of case under-reporting in public health surveillance data, leading to biased models and flawed policy insights. To address this fundamental problem of unobserved true incidence, we develop a novel hybrid computational framework that synergistically integrates a mechanistic stochastic epidemiological model with a data-driven deep learning corrector. Our methodology first constructs a stochastic Susceptible–Exposed–Infectious–Removed (SEIR) model where the time-varying transmission rate is modeled as a flexible latent function using a Gaussian Process. The core innovation is the seamless coupling of this model to a Temporal Convolutional Network (TCN) module, which is trained jointly via amortized variational inference to learn the complex, non-stationary mapping between the model's simulated true incidence and the officially reported cases, thereby explicitly correcting for biases stemming from fluctuating testing capacity, healthcare access, and reporting behavior. Applied to COVID-19 case and mortality data from Italy, Germany, and France, our hybrid model significantly improved the accuracy and stability of R_t estimation, reducing 14-day-ahead forecast error for hospital admissions by 40% compared to a pure stochastic SEIR model and outperforming standard Bayesian filtering techniques. The TCN module provided interpretable, time-varying reporting probabilities, identifying periods of severe under-reporting (up to 70% correction) that correlated strongly with independent indicators of testing coverage. This paradigm successfully merges principled epidemiological theory with flexible machine learning, creating a robust tool for real-time situational awareness that provides reliable estimates of true transmission dynamics from incomplete data, with direct applicability to managing future outbreaks of emerging infectious diseases.



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sciforum-170887: A STUDY ON THE DEVELOPMENT OF A DEFECTIVE GOMPERTZ-G FAMILY OF DISTRIBUTIONS

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This study develops an advanced lifetime modeling framework through the formulation of the defective Gompertz-G family of distributions. Classical survival and reliability models often assume that all experimental units will eventually experience the event of interest. This assumption is frequently violated in biomedical, demographic, and industrial reliability studies, where a proportion of individuals may remain event-free indefinitely, representing a cured or long-term survivor group. To address this limitation, the defective distribution concept is integrated into the flexible Gompertz-G family, thereby extending its applicability to lifetime data characterized by incomplete failure.

The methodology employed in developing the proposed model is based on the T-X transformation technique. In this approach, a baseline random variable X with a specified distribution is transformed through a generator variable T following the Gompertz distribution. The T-X framework provides a systematic mechanism for constructing generalized families of distributions by compounding the cumulative distribution function of the baseline model within the generator structure. To introduce defectiveness, a defect parameter is incorporated into the transformed distribution, modifying the cumulative distribution function so that the total probability mass is less than unity, thereby capturing cure-fraction behavior.

Closed-form expressions for the probability density function, cumulative distribution function, survival function, and hazard rate function are derived. Additional statistical properties, including quantile function formulation and reliability measures, are established. Parameter estimation is developed to support inferential analysis and future empirical applications.



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sciforum-170919: An Adaptive Vector Barrier Interior-Point Method Using Majorant Functions

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This paper proposes an adaptive interior-point method for solving convex optimization problems subject to inequality constraints. The approach is based on a logarithmic barrier formulation in which the barrier parameter is taken as a vector rather than a single scalar. In contrast to classical interior-point methods that rely on uniform updates of the barrier parameter, the proposed algorithm introduces a componentwise adaptive strategy, allowing each constraint to be treated with an individual level of penalization. This flexibility improves the algorithm's ability to handle heterogeneous constraints and enhances numerical performance, particularly for large-scale problems.

A key feature of the method is the computation of the step size using a carefully constructed majorant function. This strategy eliminates the need for traditional line search procedures, thereby reducing computational overhead while maintaining robustness. The algorithm is designed to ensure that all iterates remain strictly within the feasible region, guaranteeing feasibility preservation throughout the optimization process. Furthermore, it is shown that the objective function value decreases monotonically along the iterations.

Rigorous theoretical analysis is provided to establish the descent property, feasibility preservation, and global convergence of the proposed method under standard assumptions for convex optimization. These results demonstrate that the algorithm converges to an optimal solution of the original constrained problem.

To evaluate the practical performance of the method, numerical experiments are conducted on a set of large-scale convex optimization problems. The results indicate that the proposed adaptive interior-point method outperforms classical interior-point approaches in terms of efficiency and robustness, highlighting its potential for solving high-dimensional constrained optimization problems.



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sciforum-170036: An Improved Version of Exponential Rayleigh Distribution with Statistical Properties and Diverse Applications

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Numerous classical probability distributions have shown little adaptability in recent decades when successfully representing the complexity of real-world data sets, including complex, symmetric, asymmetric, and skewed data sets. This has encouraged researchers to add more parameters to traditional models to create more flexible families of distributions. In this study, we introduced a novel extension of the exponential Rayleigh distribution utilizing a weighted general class of distributions (WG-ERD). The cumulative distribution function (CDF) and probability distribution function (PDF) of the proposed WG-ERD are given respectively as

$G(w)=\log(1+(1-\exp(-aw^2-cw))^b)/\log(2)$,

and

$g(w)=b(2aw+c)\exp(-aw^2-cw)(1-\exp(-aw^2-cw))^{b-1}/\log(2)(1+(1-\exp(-aw^2-cw))^b)$.

About its density and hazard functions, the suggested model is highly adaptable and provides a variety of behaviors. The statistical and reliability properties of the proposed distribution are thoroughly established, including the quantile function, moments, skewness, kurtosis, and order statistics. Parameter estimation employs both Bayesian and classical methods, including maximum likelihood, maximum product spacing, and Bayes estimators based on various loss functions. A simulation experiment illustrating the efficacy of the suggested distribution reveals that the Bayes estimator based on the square error loss function generates more precise parameter estimates than other approaches. Finally, two data sets are analyzed to investigate the new distribution's advantage and adaptability. When the suggested model is applied to the various probability distributions currently in use, we find that it provides the best fit compared to competing distributions based on specific evaluation criteria.



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sciforum-171392: Asymptotic Properties of M-estimators

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Functional statistics plays a central role in statistical research. In this study, we focus on **conditional models**, which can be formulated as follows: let X be a functional random variable and Y a multidimensional random variable. The prediction of Y given X is modeled through a mapping r(.) applied to X.

To approximate Y conditional on X, we construct estimators for functional parameters using the **kernel method**. Examples include regression, quantile, expectile, and conditional mode estimation.

After constructing an estimator of the functional parameter, the asymptotic analysis proceeds along two main lines:

First, we establish the **almost-sure uniform convergence** of nonparametric estimators for certain conditional models, specifying the corresponding rates of convergence.

Second, we derive the **asymptotic normality** of the estimator under standard regularity conditions. We also discuss its application in constructing confidence intervals. Furthermore, we provide an explicit expression for the **asymptotic covariance matrix.**

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sciforum-171075: Can Replacement-Level Fertility Reverse Population Decline? Evidence from Cohort–Component Projections

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Introduction

Advanced countries have experienced prolonged below-replacement fertility, leading to population aging and, in many cases, decline [1,2]. A key consequence is the contraction of childbearing-age cohorts, raising the question of whether restoring fertility to replacement level can stabilize population size [3].

Methods

This study adopts a theoretical cohort–component projection approach grounded in stable population theory and the concept of population momentum [3,4]. Starting from low-fertility-age structures, projections assume an immediate shift to replacement fertility, constant mortality, and zero migration. Population trajectories are assessed through cohort evolution, focusing on reproductive-age groups and momentum effects [5].

Results

The analysis demonstrates that populations shaped by sustained below-replacement fertility exhibit negative population momentum [3]. While replacement-level fertility slows decline, it does not stabilize population size. The extent of decline depends on past fertility suppression, leading to smaller reproductive cohorts and increased population aging [6].

Conclusions

The findings indicate that fertility restoration alone is insufficient to reverse population decline in advanced low-fertility societies. Age structure and demographic inertia strongly shape outcomes [3,4]. Policies must address long-term aging and structural decline beyond fertility measures [2].

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sciforum-174464: Centrality-Driven Community Detection for Efficient Petroleum Distribution Planning

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Petroleum distribution is an essential component of national infrastructure, directly influencing transportation, industry, and energy security. Network-based methods enable the analysis of structural properties of distribution networks compared with conventional routing approaches, such as point-point or standard vehicle routing problems (VRP). The study highlights the importance of network analysis using graph theory to optimize petroleum distribution systems and determine the optimal locations for establishing new depots by minimizing travel distance. This study focuses on the Gampaha District located in the western province of Sri Lanka, a region with high population density. A total of 66 fuel stations, including one terminal, were modeled as a weighted graph, where nodes represent stations and edges denote routes weighted by shortest-path distances obtained from Google Maps. While this approach reflects the road structure, it does not explicitly account for traffic congestion or road weight limits. Four centrality measures were used to identify structural properties of the network. Degree centrality revealed highly connected hubs, and closeness centrality identified the locations that can be approached within the shortest time. Betweenness centrality measures the frequency with which a particular node or edge is included in the shortest path. Eigenvector centrality determined how central the depot is to the system. To enhance regional efficiency, community structures within the network were detected using spectral clustering techniques. The eigengap heuristic was used to initially determine the optimal number of clusters. Within each cluster, the most suitable node for depot establishment was selected based on normalized centrality rankings, and its stability was measured using sensitivity analysis. The sensitivity analysis showed that the degree centrality was the most stable measurement. Four optimal clusters were identified, and the most influential nodes within each cluster were determined. Accordingly, Welisara, Gampaha, Katunayake, and Ja-Ela are the most suitable cities for establishing new depots. Overall, the findings demonstrate that the analysis is helpful for the strategic planning of petroleum distribution systems.



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sciforum-170737: CLOSED-FORM EXPRESSIONS AND THE ASYMPTOTICS TO MOMENTS FOR THE EXCESS GOMPERTZ–MAKEHAM DISTRIBUTION

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Gompertz's law, published 200 years ago, became the main demographic model. It postulated an exponential increase in human survival risk with age. Since then, this model and its extensions have been successfully used in biology, actuarial science, and other fields. These models can be used in applications related to reliability theory. This article derives an exact formula for Gompertz–Makeham residual life expectancy and for residual variance that can serve for computational convenience. The moments are expressed in a closed form by using a generalized integro-exponential function or Meyer's G function. This allows direct calculation using standard software. In addition, data analysis of complex systems shows that datasets can often be characterized by the behavior of probability distributions at great age. The asymptotic expansions of the first and second residual moments and the error estimate are obtained for large argument values. The results presented in the article can serve as a tool for applications in the theory of risk, reliability and extreme events.



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sciforum-174409: Economic Analysis of Redundant System with Repair/Replacement Facility and Correlated Life Time

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A cold standby system with two non-identical units with different failure rates is analyzed. The main emphasis is placed on how correlation between repair and failure times affects reliability measures. It involves examining the process of repair and replacement when a substandard unit experiences a failure. Assuming that the first unit remains operational during the repair or replacement process of the substandard unit, the system is considered to have failed when both units are in failure mode simultaneously. Various reliability measures and statistical distributions are used to assess the effectiveness of the system. An exponential distribution of the failure time, a general distribution of the time taken for repairs and Bivariate Exponentials are used for correlation. The time it takes for the entire system to fail when both units are in failure mode (MTSF), the proportion of time during which the system is operational (Availability), how often repair workers are needed to address failures, the duration in which repair workers are occupied (Busy Period Analysis), and the financial implications of the system's operation (Profit) are calculated using a Semi-Markov procedure and the Regenerative point method. The main focus is on understanding the reliability and effectiveness of a system with two non-similar units, emphasizing the correlation between repair and failure times. The analysis of this correlation can provide valuable insights into system performance and maintenance strategies. Graphs using MATLAB are prepared to present and interpret findings.



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sciforum-169883: Efficient Computation of Complementary Set Partitions with Applications to Generalized Cumulants

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This talk presents a new combinatorial framework for the efficient computation of complementary set partitions, which play a central role in the theory of generalized cumulants. Generalized cumulants are used to express joint cumulants of polynomial functions of random variables and arise in several areas of statistics, including likelihood theory, bootstrap methods, and time series analysis. Despite their broad applicability, the practical use of generalized cumulants is often limited by the high computational complexity involved in enumerating complementary set partitions.

Most existing approaches rely on connected graph representations, Laplacian matrix calculations, or symbolic algebra systems. Although theoretically sound, these methods quickly become impractical as the number of indices increases and are difficult to implement efficiently in non-symbolic programming environments. In this talk, we propose a novel and purely combinatorial algorithm that overcomes these limitations. The key idea is to characterize all non-complementary partitions using only two-block partitions of the block index set. Complementary set partitions are then obtained by exclusion, avoiding graph-based constructions altogether.

The resulting algorithm is conceptually simple, computationally efficient, and well suited for implementation in open-source, non-symbolic languages such as R. Numerical comparisons with existing methods show a substantial reduction in computation time for moderate and large partition sizes, confirming the scalability of the proposed approach.

From a statistical perspective, the talk also introduces an extension of generalized cumulants to settings involving repeated random variables. This extension is based on multiset subdivisions and their representation via multi-index partitions, allowing the inclusion of powers of random variables and more complex dependence structures. By exploiting a suitable labeling rule and a representation of set partitions as binary vector partitions, we derive closed-form expressions for generalized multivariate cumulants in terms of products of multivariate cumulants, together with a combinatorial interpretation of the associated coefficients.



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sciforum-171589: Estimation of Semi-Bilinear Time Series Models by the Method of Empirical Moments: Specification of Optimal Noise by Deep Learning

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This research proposes an innovative methodology for estimating coefficients in nonlinear semi-bilinear time series models. We develop a robust estimation framework based on an alternative approach using empirical moments, specifically designed to overcome the limitations of classical methods in the face of the complexity of these hybrid structures. The objective is to provide an efficient, accurate, and computationally viable inference process for these models, where a linear autoregressive component and a nonlinear bilinear operator dynamically interact. Extensive numerical simulations rigorously validate the performance and robustness of our approach. The results demonstrate a marked superiority in terms of bias, variance, and stability of the proposed estimators, compared to conventional estimation techniques, particularly in the context of small samples or pronounced nonlinearities. This methodological advance opens promising application perspectives for the analysis of complex sequential data in demanding fields such as financial markets, economic forecasting, and big data analytics. A complementary and original investigation extends this contribution by examining the critical influence of the specification of the innovation term. A systematic study is conducted by substituting the standard white noise assumption with more realistic and volatile noise structures, such as ARCH, GARCH, COGARCH, and PAR (Periodic Autoregressive Process). This analysis reveals and quantifies the significant impact of the noise distribution, heteroscedasticity, and correlation dynamics on the performance and final accuracy of the estimators, particularly when calibrated using deep learning algorithms. These results underscore the crucial importance of appropriate innovation modeling for optimizing inference and defining the practical conditions for the optimal application of our proposed method.



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sciforum-170475: Evaluation of Probability Distributions for Flood Frequency Analysis Using PDS

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Flood Frequency Analysis (FFA) is a key statistical tool used to estimate the magnitude and probability of flood events associated with different return periods. Traditionally, FFA relies on the Annual Maximum Series (AMS), which considers only the largest flood event recorded each year. However, in regions that experience multiple flood events annually, such as Attanagalu Oya in Sri Lanka, the AMS approach may fail to capture important secondary or tertiary floods. To overcome this limitation, the present study applies the Partial Duration Series (PDS) method, which includes all flood events exceeding a predefined threshold and therefore provides a more comprehensive representation of flood characteristics. A threshold range between 3.5 m and 5.0 m, with increments of 0.1 m, was systematically evaluated to identify the most suitable level for event extraction. To ensure statistical independence among flood events, a declustering technique was applied to remove dependent peaks. Five probability distributions, Gumbel, Generalized Extreme Value (GEV), Lognormal, Weibull, and Generalized Pareto Distribution (GPD), were fitted to the PDS dataset. Parameter estimation was performed using established techniques, including the Method of Moments, Maximum Likelihood Estimation, and L-moments, depending on the specific distribution. Model performance was assessed using Nash–Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), Root Mean Square Error (RMSE), and the RSR index. Results indicated that the GEV distribution provided the best overall performance (NSE = 0.9714, PBIAS = 0.1101, RMSE = 0.0252, and RSR = 0.1691), highlighting its suitability for design flood estimation and risk assessment in the study area. The Gumbel and Weibull models showed acceptable performance. The findings emphasize the importance of improved threshold selection and parameter estimation methods, as well as the potential integration of multivariate approaches to better capture flood dynamics and support effective hydrological planning and disaster risk management.



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sciforum-171449: Free-energy structure of the entropy–extropy ratio on the probability simplex

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Background:

Information measures such as Shannon entropy and its complementary quantity, extropy, play a central role in statistical physics, information theory, and eco-evolutionary dynamics. However, the geometric and thermodynamic interpretation of entropy–extropy relationships on the probability simplex remains largely unexplored.

Objective:

This work aims to establish a variational and thermodynamic structure for the normalised entropy–extropy ratio, and to determine whether it induces a dissipative gradient flow compatible with nonequilibrium relaxation.

Methods:

Using the Fisher–Shahshahani metric on the probability simplex, the Riemannian gradient flow is derived and expressed in replicator form. The relationship with Kullback–Leibler dissipation is analysed, and a generalised free energy functional is constructed to compare gradient dynamics.

Results:

The gradient flow is shown to be equivalent, up to time reparametrization, to the Fisher–Shahshahani gradient flow of the generalised free energy. The functional decreases monotonically along trajectories, the uniform distribution emerges as the unique equilibrium, and the evolution corresponds to nonequilibrium thermodynamic relaxation governed by the KL-divergence dissipation.

Conclusions:

The entropy–extropy ratio admits a free energy interpretation linking information geometry, replicator dynamics, and thermodynamic dissipation. This framework provides a structural measure of the balance between dispersion and organisation in probabilistic systems and suggests its relevance in quasi-stationary nonequilibrium regimes and to high dimensional limits.



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sciforum-174478: I-PASS: Interpretable Position-Aware Statistical-based Swap Operator

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Introduction: The swap operator in Simulated Annealing (SA) typically exchanges nodes randomly without knowledge of the route structure. This randomness wastes computation and slows convergence in Vehicle Routing Problems (VRPs). To incorporate spatial information, we propose an Interpretable Position-Aware Statistical-Based Swap Operator (I-PASS) that makes every swap decision spatially informed.

Method: Instead of random pairwise swaps, I-PASS, as an interpretable mechanism, employs geometric median analysis. For a candidate pair from routes A and B, it measures each node's distance to the coordinate-wise median of the remaining nodes in its current route, compared with the median of the destination route. Processed symmetrically, the swap is accepted only if it decreases individual distances to the medians or reduces the total distance across both routes, thereby optimizing spatial clustering.

Results: Experiments were run across 30 clustered VRP instances (20 customer nodes, 4 vehicles, 600 SA iterations). Results confirm that I-PASS significantly outperforms random-swap SA. The mean total route cost was reduced from 305.96 to 217.80, representing a 28.82% improvement. Additionally, the standard deviation dropped from 62.75 to 42.01, indicating more consistent solutions. Convergence curves show that I-PASS reaches lower cost values faster and maintains this advantage throughout the search.

Conclusion: Embedding spatial reasoning into a swap operator delivers substantial and consistent gains over blind random selection. I-PASS improves solution quality, reduces variance, and naturally clusters nodes into geographically coherent routes without needing a separate clustering step.



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sciforum-174383: Impact of Climate Change on Sri Lanka's Pepper Production and Export Industry

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Sri Lanka's pepper production and export industry is increasingly affected by climatic variability. This study examines the influence of temperature, rainfall, wind speed, and daylight duration on district-level pepper production (2018–2024) and national monthly pepper export volumes (2014–2024). Panel data analysis is employed to quantify the effects of climatic variables on pepper production, using Fixed Effect (FE) and Random Effect (RE) estimations, while the Difference Generalized Method of Moments (GMM) approach is applied to account for dynamic production persistence. Export behavior and forecasting performance are analyzed using the Autoregressive Distributed Lag–Error Correction Model (ARDL–ECM) and Seasonal Autoregressive Integrated Moving Average (SARIMA) model. The results show mean temperature has a positive and statistically significant contemporaneous effect on pepper production, while rainfall remains insignificant in static panel models. Difference GMM results confirm strong production persistence, with temperature emerging as the dominant positive driver and wind speed exerting a significant negative effect. Export modeling reveals short-run and long-run relationships between climatic variables and pepper exports. The ARDL–ECM framework confirms a stable long-run equilibrium, with about one-third of disequilibrium corrected within one month. Temperature and wind speed show significant lagged effects, while rainfall plays a limited role. Forecast comparisons indicate the ARDL model incorporating climatic variables outperforms SARIMA in predictive accuracy, although SARIMA better captures seasonal patterns. These findings show temperature and wind speed are key climatic drivers of Sri Lanka's pepper sector. The positive and persistent temperature effect suggests the need for adaptive crop management to address heat stress, while the negative impact of wind speed highlights the importance of protective measures such as windbreak systems. The identified lagged climatic effects and long-run equilibrium indicate climate shocks influence exports with delays, supporting the integration of climate indicators into export forecasting and trade planning. Strengthening climate-resilient production and climate-informed export strategies is therefore essential for sustaining sector stability and competitiveness.



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sciforum-168790: Interday and Intraday Chemotherapy Appointment Scheduling: a Patient-Centered Approach

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The number of new cancer cases is expected to increase by about 50 % over the next 20 years, and the need for chemotherapy treatments will increase accordingly. Treatments are usually provided in outpatient cancer centers, where patients with various types of cancers receive care. The treatment delivery must be carefully planned to optimize the use of limited resources, such as consultation and examination rooms, chairs and beds for the drug infusion, medical and nursing staff. The planning and scheduling of chemotherapy treatments involve different problems at different decision levels. In this work, we focus on the operational level and jointly address the interday and intraday multi-appointment scheduling problem. We determine the day and start time of the oncologist visit and drug infusion for a set of patients to be scheduled along a short-term planning horizon. We use a per-pathology policy, where the days of the week on which patients can be treated, depending on their pathology, are known. We consider different metrics that take into account the perspectives of both the cancer center and the patients. We formulate the problem as a multi-objective optimization problem, which is tackled by sequentially solving three problems in a lexicographic multi-objective fashion. The problems turn out to be computationally challenging; thus, we propose ad hoc decomposition approaches. The approaches are tested on real data from an Italian hospital and improve upon state-of-the-art solvers.

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sciforum-170656: Kernel-Based Nonparametric Tests for Exponentiality Against Decreasing or Increasing Residual Entropy Alternatives

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Introduction. Testing for exponentiality plays a central role in reliability theory and survival analysis, since the exponential distribution is uniquely characterized by a constant hazard rate and memoryless property. Classical goodness-of-fit procedures often rely on moment-based methods or distribution-function approaches. More recent developments emphasize information-theoretic measures such as entropy. In particular, residual entropy has proven useful for detecting departures from exponentiality under decreasing or increasing residual life uncertainty alternatives (see Ebrahimi, 1997; Benaoudia and Aissani, 2023), since under exponentiality, the residual entropy is constant.

Methods. In this paper, we propose a nonparametric test for exponentiality based on kernel estimators of Shannon entropy and residual entropy. The approach follows the framework introduced by Belzunce, Navarro, and Guillamon (2001), replacing histogram-based estimators with kernel smoothing techniques. This approach improves the smoothness and convergence of the estimators and reduces dependence on bin selection. A test statistic is constructed to test exponentiality, which exhibits constant residual uncertainty against decreasing or increasing uncertainty. Theoretical properties of the statistic are established under regularity assumptions, including almost-sure convergence of the empirical statistic to the theoretical one under the null hypothesis, applying the standard result on convergence of Stieltjes integrals and using the almost-sure convergence of the empirical kernel distribution to the theoretical distribution.

Results. Critical values of the proposed test are obtained via Monte Carlo simulations for various sample sizes and significance levels. Under regularity conditions, the test converges almost surely. Power studies under Weibull and Gamma alternatives show that the procedure achieves high sensitivity against increasing residual life uncertainty alternatives. Moreover, Pitman asymptotic efficiency comparisons indicate that the proposed kernel-based statistic consistently outperforms several competing entropy-based tests. It is not only effective in finite samples but also asymptotically more efficient in detecting exponentiality against monotonic residual entropy alternatives.

Conclusions. Overall, the proposed test provides a robust and efficient tool for assessing exponentiality. Its strong finite-sample behavior, superior asymptotic efficiency, and stability induced by kernel estimation make it especially suitable for applications in reliability and survival analysis. Future work may extend the methodology to multivariate lifetime models.



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sciforum-170889: Large Deviations and Applications

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This study examines rare event behavior using the principle of large deviations, offering a more nuanced probabilistic framework than the law of large numbers and the central limit theorem. Although the classical results characterize typical fluctuations around the mean, large deviation theory is concerned with the probabilities of atypical events and their asymptotic decay rates. This method is applied to two models originating from applied probability. The first pertains to the sojourn time within an M/M/1 queueing system, characterized by exponentially distributed service times that are crucial for assessing congestion and system performance. The second model deals with the count of erroneous seconds seen in telecommunications systems, which can be modeled by a Poisson distribution. We investigate the empirical mean for both contexts and produce theoretical large deviation estimates that are grounded in the respective log-Laplace transforms. To compare empirical probabilities with their theoretical counterparts, numerical simulations are conducted. The outcomes demonstrate a distinct exponential reduction of deviation probabilities with the growth of sample size, which aligns closely with large deviation predictions. The findings demonstrate the importance of large deviation principles for quantifying rare yet critical events and show their applicability in analyzing the performance and reliability of queueing and communication systems.



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sciforum-171415: Mathematical Analysis of the Dynamic Modeling of Heart Rate

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Most existing heart rate monitoring systems rely on fixed threshold values to trigger alerts, resulting in reactive responses that often fail to capture early physiological deterioration. Such approaches neglect the temporal structure of heart rate signals and their dynamic behavior. In this work, we propose a predictive framework for heart rate monitoring based on robust temporal analysis. The heart rate signal is modeled as a timedependent function and analyzed through discrete approximations of its first and second derivatives computed via finite-difference methods. These derivatives quantify the rate of change and acceleration of heart rate dynamics, enabling the identification of emerging risk patterns. Anomalies are detected using Z-scores calibrated to an individualized baseline. To ensure robustness under noisy real-world sensing conditions, the median and the Median Absolute Deviation (MAD) are employed as statistical estimators. The scaling factor 1.4826 · MAD is used to obtain a dispersion measure consistent with normal variability. The time-to-critical state is estimated by extrapolating the temporal evolution of the Z-score, using linear prediction in steady regimes and a quadratic formulation, solved analytically, when positive acceleration is observed. The proposed framework identifies risk trajectories that remain undetected by static threshold methods, particularly in scenarios involving rapidly accelerating heart rate. The time-to-critical estimation provides a quantitative prediction of imminent risk, enabling anticipatory monitoring rather than delayed alerting. The results demonstrate that integrating calculus-based temporal analysis with robust statistical modeling yields a transparent and mathematically consistent predictive framework for physiological monitoring. The approach also shows strong potential for extension to other biosignals and contributes to applied mathematics and statistical analysis of health-related time series.



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sciforum-170438: Mathematical Modeling and Multi-Period Resource Allocation for Invasive Plant Control

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Effective control of invasive plant species involves allocating limited management resources across space and time in a manner consistent with underlying population dynamics and operational constraints. This study presents a discrete-time, spatially explicit mathematical model describing the expansion of Chinese privet (*Ligustrum* spp.), incorporating key biological processes such as seed dispersal, vegetative root propagation, and heterogeneous environmental suitability across a landscape grid. Model parameters governing growth and dispersal are calibrated using published ecological studies and field data compiled by collaborators. The ecological dynamics are coupled with a constrained multi-period optimization framework formulated as a mixed-integer linear programming (MILP) problem that determines when and where control actions should be implemented to minimize long-term reinfestation risk with finite budgets and treatment capacity. To address the multi-period decision structure, the optimization is implemented using a rolling-horizon solution approach, allowing sequential allocation decisions while updating the system state over time. The decision model explicitly accounts for treatment thresholds, spatial prioritization rules, and logistical limitations, enabling the evaluation of realistic management strategies over successive time steps. Simulation results demonstrate that temporally coordinated interventions and targeted spatial prioritization substantially reduce invasion intensity compared to uniform or short-term control policies. In particular, early intervention in high-connectivity cells yields disproportionate long-term benefits by suppressing secondary spread pathways. The proposed integrated modeling approach provides a quantitative decision-support tool for comparing alternative intervention scenarios, assessing trade-offs between cost and effectiveness, and identifying robust management policies under uncertainty. Overall, the framework supports evidence-based, cost-aware planning for invasive species control programs and can be adapted to other spatially spreading invasive organisms.



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sciforum-171826: Maximum Likelihood Estimation and Properties of the Transmuted Exponential–Weibull–Exponential Distribution and its Comparison with Related Probability Distributions

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Introduction

Flexible lifetime distributions play a central role in both the theoretical development and practical application of survival and reliability analysis. Emerging experimental lifetime data in engineering and biological sciences often display skewness, heavy tails, and non-monotonic hazard rates that classical lifetime distributions fail to capture. Motivated by these limitations, this study introduces a new four-parameter lifetime distribution called the Transmuted Exponential–Weibull–Exponential (TE-W-E) distribution that extends the existing Weibull–exponential distribution. The TE-W-E is proposed to enhance the flexibility of the Weibull–exponential distribution for positive data.

Method

The TE-W-E distribution is constructed using the transmuted exponential-G generator to the Weibull–exponential distribution. The flexibility of the Weibull–exponential distribution was increased by inducing scale and transmuted parameters. Comprehensive derivations of its mathematical and statistical properties are presented. Expressions for the probability density, cumulative distribution, ordinary and central moments, moment generating, survival, and hazard functions were analytically derived. Model parameters were estimated using the maximum likelihood method, and the observed Fisher information matrix was derived to establish the asymptotic inference. Monte Carlo simulations were conducted to evaluate estimator performance under different sample sizes in terms of bias, variance, and mean squared error.

Results

The TE-W-E distribution is highly flexible, capable of modelling increasing, decreasing, and bathtub-shaped hazard rate functions. Simulation findings confirmed the consistency and efficiency of the maximum likelihood estimator. Application to two real datasets was demonstrated. The parameter estimates were obtained using the optim function in R software. The proposed TE-W-E model was compared with some well-established competing models: Weibull, Weibull–Exponential, and Weibull–Gamma. It outperforms the models based on likelihood and goodness-of-fit criteria: AIC, BIC, and CAIC. The new parameters contributed to the tail thickness and asymmetry.

Conclusion

The TE-W-E distribution is a robust model for lifetime data. Its flexibility and strong empirical performance make it a valuable contribution to survival and reliability analysis.



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sciforum-174485: Missing Data in Latent Transition Analysis: A Monte Carlo Simulation Study

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Introduction

Latent Transition Analysis (LTA) is widely used to model longitudinal changes in unobserved categorical states. However, applied researchers frequently encounter missing data, and there is limited guidance on how different missing data mechanisms, and analytic techniques used to address them, affect the recovery of latent classes and transition parameters. This study evaluates the performance of common methods used to handle missing data within an LTA framework under varying conditions.

Methods

We conduct a Monte Carlo simulation examining a two-class LTA model with binary indicators. Simulation conditions vary sample size, number of time points, number of indicators, missing data mechanism (MCAR vs. MAR), and missing data rate. Class membership follows a time-homogeneous transition matrix, and indicators follow class-specific emission probabilities with measurement invariance across time. Missingness is introduced randomly under MCAR and based on prior observations under MAR. Models are estimated using Full Information Maximum Likelihood (FIML), Multiple Imputation (MI), and weighting-based approaches.

Results

Results indicate that model performance depends strongly on the missingness mechanism and missing data rate. Parameter recovery was more accurate under MCAR than MAR missingness. FIML demonstrated stable performance across most scenarios. MI and weighting methods produced comparable results but were more sensitive to simulation parameters. Larger sample sizes and more indicators substantially improved latent class recovery and reduced bias in emission and transition parameter estimates across methods.

Conclusions

These findings highlight that no single missing data analytic technique is universally optimal. Method choice should be based on the characteristics of data and missingness. The results demonstrate how study design features—such as sample size and number of indicators—interact with the missingness mechanism and rate to influence latent class recovery and transition parameter estimation. Together, these findings highlight the importance of selecting the most appropriate analytic approach when applying LTA to longitudinal data with missingness.



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sciforum-173969: On Seasonal Autoregressive Processes Inference

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In the study of several real time series and other major fluctuations such as the trend,the cycle and the noise, the presence of seasonal fluctuations is one of the most important issues.

The investigation has an established practice provided that seasonal variations have been regarded as a disruptive element and then must be eliminated. However, these fluctuations are an integral part that must be studied in order to evaluate and forecast the studied model. A well-known practice for modeling seasonal data is to utilise an autoregressive model that is able to handle the presence of the seasonal patterns in the data. Autoregressive models are a kind of time-series model that utilise lagged values of the target variable to make predictions about future values. Notice that despite the fact that these data are obtainable in practice as sequences of discrete observed values, they are basically approached as functions. Functional autoregressive models are well known for the analysis of time series analysis. However, basic formulation is not suitable for investigating the seasonal behaviour in functional time series data. Hence, we introduce seasonal functional autoregressive processes to model time series. For the autoregressive process of order one, we provide conditions of stationarity and formulate limit theorems, and supply methods of estimation and prediction. The worthiness of these models is displayed via algorithmic investigations.



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sciforum-171645: Pathways to Healing: Determinants of Time-to-Repair in Obstetric Fistula Using an Exponentiated-Survival Model

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Background: Obstetric fistula is preventable, yet many women face prolonged waits before definitive repair. We sought to identify which care pathway factors are most strongly associated with earlier repair and to provide a practical, interpretable survival tool that distinguishes the majority of repair times from the smaller group with prolonged delays.

Methodology: We analysed 257 women with obstetric fistula, measuring weeks to repair and treating unrepaired cases as right-censored. We developed and fitted a parametric proportional-hazards survival model (Lehmann Type II (exponentiated-survival)) with an intuitive baseline that explicitly separates the majority of cases from the long tail, yielding closed-form survival, hazard, and quantile functions. Simulations were used to stress-test small-sample performance typical of single-centre cohorts. Covariates in the adjusted model were education, antenatal follow-up, delivery mode, labour duration (2, 2-4, >4 days), and stature (150 cm against ≥150 cm). Model adequacy was summarised with AIC/BIC and subgroup survival/hazard profiles.

Results: Two pathway factors were dominant. Formal education (HR = 2.87; 95% CI 1.93-4.26) and antenatal care (HR = 2.57; 1.71-3.88) were each associated with a higher instantaneous probability of repair, i.e., earlier repairs and fewer long waits. In contrast, a caesarean section compared to N/V was associated with a lower repair hazard (HR = 0.51; 0.34-0.79), consistent with more complex cases requiring specialist capacity. Labour duration and short stature were not independently strong after adjustment. Simulations confirmed estimator stability in modest cohorts and illustrated how parameter shifts move probability away from the long-wait tail.

Conclusion: Strengthening education-linked navigation and antenatal engagement should shift repairs earlier and reduce backlogs, while C/S-related cases warrant specialist triage and theatre skills to prevent accumulation in the long-wait tail. Because the model's parameter values and closed-form outputs translate directly into time-to-percentage-repaired forecasts, it is well suited for scheduling surgical camps, managing bed turnover, and tracking backlog risk in fistula programmes.



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sciforum-170675: Sharp Null Hypothesis Testing and Jeffreys-Lindley Paradox

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Introduction

Frequentist and Bayesian hypothesis testing frameworks are used extensively in empirical research for drawing scientific conclusions. However there are some instances where confusions arise e.g., Jeffreys-Lindley paradox is a case where the two frameworks contradict with each other. This has caused confusions among data analysts for selecting a methodology for their statistical inferences. Though the paradox goes back to 1950's there hasn't been a satisfactory resolution to it so far, especially for the empirical researcher.

Method

We show that the paradox arises mainly due to the fact that, in the frequentist approach, it is allowed to have type-*I* errors and difference between hypothesized parameter value and its observed estimate is assessed in terms of standard error of the estimate, no matter what actual numerical difference between them is and how small the standard error is, whereas in the Bayesian methodology this has no effect due to its definition of Bayes factors. In fact, the paradox is an instance of conflict between statistical and practical significance. This can be seen as a result of using sharp null hypothesis to approximate acceptable small range of values for the parameter. We also show how that the frequentist null hypothesis testing should be modified so that its conflicting conclusions with the Bayesian method can be avoided. We also show why and how any uncertainty in *p*-values can be addressed.

Results

We have shown how to resolve the Jeffreys-Lindley paradox through a mathematical analysis. And it is also shown how to perform sharp null hypothesis tests so that undesirable rejections of null hypotheses are avoided.

Conclusion

It is possible to give a mathematical explanation to the Jeffreys-Lindley paradox, thus resolving it, and modify the frequentist null hypothesis testing methodology so that it has no conflict with the Bayesian hypothesis testing.



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sciforum-157805: Staistical Methods for Safe Artificial Intelligence

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Being able to make reliable predictions is a crucial task in many Artificial Intelligence problems.

In mathematical terms, a prediction can be formulated as a classification problem, where any input data is associated with a class, or as a regression task, where we search for a suitable function that fits the data.

These two classes of prediction models serve different purposes and are useful in their own regard: classification is applied to medical diagnosis, credit rating, and test grading, while regression is used to predict blood pressure, house prices, or energy consumption.

Current metrics, such as MSE for regression and AUC (Area Under the Curve) for classification, appear largely unrelated and problem-specific.

We propose a novel family of metrics, grounded in Cramér and energy distances applicable to all types of response variables: continuous, ordinal, nominal, and extendable to multivariate settings. We show the effectiveness and versatility of our metrics in a range of real applications, from finance, health care, to human resource management. We also show that metrics can be extended to assess not only accuracy but also explainability and robustness, in a joint AI assessment framework. To derive an integrated metric, we consider alternative aggregation schemes: from weighted means to decision theoretic methods.



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sciforum-171122: Statistical Methods for Inference from Non-Probability Samples and their Application to a Health Barometer

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We are in the information age, and every day it becomes easier to obtain information on any topic and for any population of interest. Online surveys, large-scale datasets (Big Data), or social media are modern data sources that provide large samples without the need for substantial resources and within a short period of time. However, if one wishes to make estimates from this type of dataset, great care must be taken, since most of them are non-probability samples. Non-probability samples lack an exhaustive probabilistic sampling design, making it impossible to ensure the representativeness of the sample, which leads to biased estimates even when the sample is large (Meng, 2018).

In order to obtain more reliable and accurate estimates from this type of data, different statistical techniques for bias reduction have been developed. These methods require auxiliary information, and depending on the available auxiliary information, different types of techniques can be applied. If we know the population totals of our covariates, we can apply the Calibration technique. If we have a reference probability sample (in which the variable of interest is missing), we can apply Propensity Score Adjustment (PSA) to estimate the inclusion probabilities in our original sample, or Statistical Matching (SM) to predict the unknown variable of interest in the auxiliary sample. In this same situation, the Doubly Robust (DR) estimator can be applied, which combines both approaches. These are only some of the best-known techniques in this field. Unfortunately, there is no gold standard in practice, and the results will depend on the specific study in question.

In this work, we will study the problem of estimation based on non-probability samples, explore the different methods for inference from such samples, and examine their effectiveness in a real survey conducted by the Spanish Ministry of Health.



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sciforum-165386: Synergy of Binary Artificial Bee Colony Swarm Intelligent Optimizer and NSGA-II Evolutionary Algorithm for Renewable-Integrated Multi-Objective Profit-Based Unit Commitment

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The environmentally constrained Profit-Based Unit Commitment Problem (PBUCP) is a large-scale, nonlinear, mixed-integer, multi-objective optimization problem essential for operational planning in deregulated power systems. It determines optimal unit commitment and dispatch schedules to simultaneously maximize profit and minimize emissions under technical and market constraints. With increasing renewable penetration and stricter environmental regulations, conventional approaches that treat emissions merely as constraints fail to support comprehensive multi-objective decision-making. Renewable variability further introduces stochasticity and nonlinearity, making traditional optimization techniques less effective. This paper proposes a hybrid Binary Artificial Bee Colony–NSGA-II (BABC–NSGA-II) framework for a renewable-integrated multi-objective PBUCP. The BABC component efficiently handles discrete ON/OFF scheduling using adaptive neighborhood exploration, while NSGA-II optimizes continuous dispatch variables to generate a well-distributed Pareto front. The model explicitly considers profit maximization and emission minimization under constraints including minimum up/down time, ramp rate limits, spinning reserve, renewable uncertainty, power balance, and generation limits. The proposed method is validated on three benchmark systems: a 10-unit system with 20% renewable penetration, a 26-unit system with 30% wind–solar integration, and a 54-unit large-scale system with 40% renewable penetration over a 24-hour horizon. Comparative analysis against Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Multi-Objective Artificial Bee Colony (MOABC), and standard NSGA-II demonstrates superior performance. The proposed approach achieves 6.8%–9.4% higher profit, 11.2%–15.7% lower emissions, and approximately 12% improvement in hypervolume index, confirming enhanced convergence and diversity. The framework provides a scalable and robust decision-support tool for environmentally sustainable power system operation.



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sciforum-171512: A Network-Tuned Asset Allocation Framework: Integrating TMFG Filtering and Shapley-Valued Stock Selection for Emerging Markets

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The complex and non-linear dependencies inherent in emerging financial markets necessitate advanced filtering and allocation techniques to ensure portfolio resilience. This study proposes a novel network-tuned asset allocation model for the PRIBUMI Bursa Malaysia Zakat Index by integrating the Triangulated Maximally Filtered Graph (TMFG) approach with Shapley value-based optimization. Unlike traditional Mean-Variance models that often fail under extreme market correlations, this framework leverages network topology to enhance stock selection and weight distribution. The methodology is structured into four distinct phases. First, we process daily closing prices of Pribumi-indexed stocks to compute log returns and construct a high-dimensional correlation matrix. Second, the TMFG algorithm is applied to filter the network, preserving the most significant hierarchical dependencies while removing noisy links. Third, we analyze the resulting graph using centrality measures specifically degree, closeness, and betweenness alongside a calculated Peripheral Index to identify assets with high diversification potential. Finally, the selection is fed into a Shapley value framework, a cooperative game theory method that assigns portfolio weights based on each stock's marginal contribution to the collective risk-adjusted performance. The findings indicate that the TMFG-filtered network effectively isolates core influential stocks from peripheral diversifiers, with the latter often providing superior stability during periods of market stress. By utilizing the Shapley value for final allocation, the model ensures a fair and mathematically rigorous distribution of weights that accounts for the multifaceted interactions between assets. This research provides a robust tool for institutional investors and policymakers to mitigate contagion risk and optimize returns within the Malaysian equity market, offering a sophisticated alternative to conventional diversification strategies.



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Session 4. Applied Mathematics

sciforum-171715: A Sixth-Order Averaging Theory for Limit Cycles Bifurcating from Uniform Isochronous Cubic Centers

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In this study, we investigate the **bifurcation of limit cycles** from a class of **uniform isochronous cubic centers** in the plane under small continuous perturbations. Such systems provide classic yet challenging examples in **nonlinear differential equations**, offering valuable insight into the dynamics of planar polynomial systems and the emergence of **small-amplitude periodic solutions**. Understanding these bifurcations is fundamental for advancing the qualitative theory of planar systems and their applications in modeling oscillatory phenomena.

The differential system under consideration is given by:

$$\dot{x}=-y+x^{2}y+xy^{2}+\sum\limits_{i=1}^{6}\epsilon^{i}P_{i}(x,y),\quad \dot{y}=x+xy^{2}-x^{2}y+\sum\limits_{i=1}^{6}\epsilon^{i}Q_{i}(x,y),$$

where $P_{i}(x,y)$ and $Q_{i}(x,y)$ are cubic polynomials, and ε is a small perturbation parameter. Introducing **polar coordinates**, the system is transformed into a form suitable for the **averaging method**. Applying the **sixth-order averaging theory**, we derive **sufficient conditions for the existence of limit cycles** through the analysis of the averaged functions. This higher-order approach enables the detection of subtle bifurcation phenomena that may be missed in lower-order analyses.

Our analysis demonstrates that at most **three small-amplitude limit cycles** can bifurcate from the uniform isochronous cubic center under small continuous perturbations. The use of **higher-order averaging** reveals complex dynamics and interactions between the perturbation terms that are otherwise undetectable.

These findings enrich the **qualitative theory of planar polynomial differential systems** and showcase the effectiveness of **sixth-order averaging methods** in studying limit cycle bifurcations. The results highlight the intricate behavior of cubic systems and provide a robust framework for future investigations in **nonlinear dynamics**, with potential applications for **modeling oscillatory behaviors** in applied mathematics, physics, and engineering.



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sciforum-168001: Analysis of Multiplication Tables by Sum, Difference and Product: A New Approach to Primality

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This paper introduces a novel deterministic framework for the analysis of multiplication tables through three fundamental operations: tabular sum, tabular difference, and tabular product. While multiplication tables are traditionally regarded as elementary pedagogical tools, we demonstrate that they encode deep arithmetic structures when studied systematically. In particular, the tabular product leads naturally to a new approach to primality testing based on factorial and primorial constructions.

We formalize the tabular product as a structured product of table rows and show that its interaction with the greatest common divisor yields a reliable criterion for distinguishing prime and composite integers. To address computational limitations inherent to large factorials, a logarithmic optimization is introduced, relying on asymptotic approximations and adaptive depth control. This refinement allows the method to scale efficiently to very large integers without loss of determinism.

Furthermore, a primorial-based variant of the test is developed, eliminating redundant composite factors and significantly strengthening the detection of Carmichael numbers, which commonly evade classical probabilistic tests. A decimal regulation function is proposed to dynamically adjust the test depth as a function of the size of the integer under consideration.

Theoretical results are supported by explicit numerical examples, illustrating robustness, scalability, and algorithmic relevance. This work opens new perspectives for primality testing, cryptographic applications, and the foundational reinterpretation of elementary arithmetic structures.



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sciforum-171635: Existence of Global Positive Solutions to Order-[m] Tridiagonal Reaction-Diffusion Systems via Semigroup Methods

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Semilinear parabolic tridiagonal reaction-diffusion systems of order [m] model coupled diffusion-reaction processes in physics, biology, and chemistry. These systems take the form\frac{\partial U}{\partial t}-D\Delta U=F\left(U\right) \text{ \ \ \ \ dans \ }\Omega \times \left(0,+\infty \right) , with Neumann boundary conditions and positive initial data . Here, [\Delta_m] denotes the tridiagonal Laplacian matrix. Proving global existence, uniqueness, and positivity of solutions is vital for understanding long-term dynamics, yet remains challenging due to nonlinear reactions. This work establishes these properties for a broad class of reaction terms [f_i].

We employ compact semigroup theory generated by the tridiagonal diffusion operator [A = \operatorname{diag}(d_1,\dots,d_m) \Delta_m] on [[C(\overline{\Omega})]^m]. Key tools include positivity preservation through maximum principles and a priori bounds via comparison principles and fixed-point arguments in suitable Banach spaces, handling general nonlinearities with sublinear growth

Under assumptions of positive initial data and reaction terms satisfying [f_i(t,x,\xi) \geq 0] for [\xi \geq 0] with controlled growth, the system admits a unique global positive solution remaining bounded for all [t > 0].

These results provide a robust framework for tridiagonal reaction-diffusion systems, applicable to multi-species models. The semigroup-[L^1] approach extends to higher-order or non-local interactions, opening avenues for complex pattern formation studies.



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sciforum-171671: From Hamilton–Jacobi Theory to the Relativistic Schrödinger picture via von Neumann-like linear extension in tempered distribution spaces

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Introduction

This work establishes a novel connection between the relativistic Hamilton–Jacobi equation (HJE) and the relativistic massive Schrödinger equation (RSE) in free space, achieved without relying on the semiclassical limit ($\hbar \to 0$). The approach operates mode-by-mode on spectral fibers associating with any Minkowski momentum bra $S_p = p, . >$ the de Broglie wave η_p. The families S and η generate distinct subspaces in tempered distribution spaces: the former spans a real four-dimensional vector space isomorphic to Minkowski momentum space, while the latter comprises the full space of complex tempered distributions on Minkowski space.

Methods

The key families of distributions — Minkowski bras (S) and de Broglie basis (η) — span (via suitable subfamilies) the solution spaces of the HJE's and RSE's, respectively. Employing Schwartz linear algebra for complex tempered fields, we apply a von Neumann-style linear-continuous operator extension to lift the HJE (formulated in complex variables) from certainty momentum states $|p)$ to complex amplitude-probability states ψ. This extension mirrors procedures used in game theory and follows standard von Neumann techniques. The construction is further extended to the Maxwell–Schrödinger formalism - in complex tempered distribution 3-field - through de Broglie-Maxwell isomorphisms (Fe), which map wave distributions to corresponding electromagnetic-like fields while preserving translation representations, dispersion relations, and polarization structures.

Results

The principal finding demonstrates that the relativistic massive Schrödinger equations are von Neumann-like linear extensions of the relativistic HJE in complex form. These equations are uniquely determined spectrally by the Einstein energy-momentum relation within the tempered distribution framework.

Conclusions

This framework provides a vast, concrete (although partial) unification of classical relativistic mechanics, relativistic quantum mechanics for massive particles, and Maxwellian field theory - all within the setting of tempered distributions - offering new insights into the foundational relationships among these domains.



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sciforum-170433: Global Existence Results of Weak Solutions for a Class of Abstract Evolution Problems

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This research investigates an abstract Cauchy problem associated with a coupled reaction–diffusion system of two equations, subject to homogeneous Dirichlet or Neumann boundary conditions. The primary objective is to establish the global existence of a weak solution for this nonlinear system.

The authors simplify the analysis by applying a linear transformation ($\bar{v} = v - (c/(a - d))u$) to the original system. This transformation effectively decouples the principal parabolic operators, resulting in a reformulated system where each equation features a single diffusion term with constant coefficients.

The central theoretical achievement (Theorem 2.1) is the proof of existence for a positive global weak solution (u, $\bar{v}$) to the transformed system. The solution is constructed within the functional framework $C([0, T]; L^1(\Omega)) \cap L^1(0, T;)$ and is represented using variation-of-constants formulas involving two distinct contraction semigroups, $\{S_a(t)\}$ and {}, generated by the operators $a\Delta$ and $d\Delta$ in $L^1(\Omega)$, respectively.

Supporting lemmas establish crucial a priori estimates. Lemma 2.1 confirms the positivity of the solution, while Lemma 2.2 provides a uniform L^1-bound on the sum $u + \bar{v}$, dependent on initial data and domain parameters, which is vital for proving global existence.

The overall methodology hinges on the theory of compact semigroups and a priori estimates to overcome the nonlinearities represented by the reaction terms $\tilde{f}$ and $\tilde{g}$. This work contributes to the broader mathematical theory of nonlinear parabolic systems, with potential implications for modeling phenomena in physics, biology, and ecology where such coupled reaction–diffusion equations are prevalent.



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sciforum-171816: Green's Function for a One-Dimensional Fractional Viscoelastic Wave Equation

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We investigate the Green's function associated with a one-dimensional fractional viscoelastic wave equation driven by a Dirac delta source. The starting point of the formulation is the classical one-dimensional viscoelastic wave equation posed with a Dirac delta driving term, which defines the fundamental solution of the corresponding wave operator. Fractional effects are incorporated directly at the level of this forced equation by generalizing the time and space operators: the second-order time derivative is replaced by the Caputo fractional derivative of order $\alpha \in (1,2]$, while the spatial Laplacian is replaced by the Riesz fractional operator of order $\beta \in (1,2]$. This construction leads to a fractional wave equation with memory in time and nonlocality in space, formulated explicitly as a Green's function problem.

The Green's function is obtained by applying the Laplace transform in time and the Fourier transform in space to the fractional wave equation, reducing the problem to an algebraic equation in the transform domain. The inverse transforms yield an explicit representation of the fundamental solution in terms of Fox H-function series, which naturally arise from the combined action of the fractional temporal and spatial operators. The resulting expression provides an explicit form of the Green's function for the fractional viscoelastic wave equation with singular forcing.



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sciforum-171244: Invasion Dynamics and Therapeutic Effects in a Tumor–Immune Interaction Model

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Cancer remains one of the leading causes of morbidity and mortality worldwide, posing a significant global health challenge despite advances in therapeutic interventions. The process of tumor growth is a complex interplay among cancer cells, the immune system, and healthy tissues, and this interplay depends on the specific therapeutic approach. Mathematical modeling can be a valuable tool for dissecting these processes and identifying thresholds for different outcomes.

This work revisits and generalizes the widely used tumor-immune system model of de Pillis and Radunskaya by developing a set of nonlinear ordinary differential equations that incorporate the impact of therapy. Drug-cell interactions are modeled using Michaelis-Menten Kinetics, while immune suppression due to tumor invasion is represented by a Hill-type functional response. In this study, we establish fundamental dynamical properties of the system, including the positivity and boundedness of solutions, determine all equilibrium points, and characterize the local stability of the tumor-free state. In addition, we introduce a tumor invasion number that represents the threshold conditions governing successful tumor establishment.

In the context of cancer immuno-editing, the elimination, equilibrium, and escape stages are considered, and the parameter ranges governing transitions between these states via transcritical bifurcations are identified. Simulations of the system are also conducted to verify the findings, investigate the effects of various treatments on tumor-immunotherapy dynamics, and perform a sensitivity analysis to identify the key biological parameters that affect outcomes. The proposed framework enhances the theoretical understanding of tumor-immunotherapy interactions and may contribute to the development of more effective treatment strategies.



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sciforum-173449: Mathematical Modeling and Analysis of HIV Transmission in Bandung City, Indonesia

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HIV remains a major public health concern in urban areas of Indonesia, including Bandung City. Understanding its transmission dynamics is essential for designing effective control strategies. This study develops a mathematical model of HIV transmission incorporating real epidemiological data from Bandung City. The population is divided into several compartments representing susceptible individuals, HIV-infected individuals, and individuals under treatment. A nonlinear treatment function is introduced to reflect limited medical resources and treatment saturation effects. Model parameters are estimated using reported HIV case data through a **data fitting procedure based on a Genetic Algorithm (GA)**, which minimizes the difference between model simulations and observed data. This approach allows efficient exploration of the parameter space and provides reliable parameter estimates for the transmission and treatment processes. Based on the estimated parameters, the basic reproduction number is derived analytically and its estimated value is 2.56, indicating that the infection can persist in the population. Stability analysis of the disease-free and endemic equilibrium points is performed using linearization techniques. Furthermore, bifurcation analysis is conducted to investigate qualitative changes in system behavior with respect to key parameters, particularly the transmission rate and treatment effectiveness. Numerical simulations are presented to validate the analytical results and to illustrate the impact of nonlinear treatment and parameter variations on HIV transmission dynamics. The results show that nonlinear treatment significantly influences the stability of equilibria and may lead to backward bifurcation under certain conditions. This study provides a realistic mathematical framework for analyzing HIV transmission in Bandung City and offers valuable insights for optimizing HIV control and treatment policies.



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sciforum-174366: Overcoming Large-Domain Instability: A Block-Structured Newton-Nyström Algorithm for Nonlinear Integro-Differential Systems

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Nonlinear Fredholm integro-differential equations of the second kind play a pivotal role in modeling complex physical systems involving nonlocal interactions, memory effects, and long-range dependencies. However, when posed on extended intervals ($\tau \gg 1$), these equations present severe numerical challenges due to the loss of operator compactness, spectral degradation, and instability of conventional discretization schemes. Developing robust, structure-preserving algorithms for such large-domain problems remains an open and critical challenge in computational mathematics.

This work introduces a novel Dual Transformation–Linearization–Discretization (DT-L-D) framework specifically designed for nonlinear Fredholm integro-differential equations on extended intervals. The approach first applies a dual transformation: differentiating the original equation and decomposing the global domain into quasi-uniform subintervals, yielding a block-structured system that preserves coupling topology. Nonlinearity is then handled via Newton–Kantorovich iterative linearization in Banach space, followed by Nyström discretization to obtain a finite-dimensional linear algebraic system. Rigorous convergence analysis establishes quadratic convergence under explicit Lipschitz continuity and uniform invertibility conditions.

Numerical experiments on benchmark problems confirm the method's high accuracy, with global errors reaching 10^{-9} and residuals down to 10^{-15}. The algorithm demonstrates remarkable stability across intervals up to $\tau = 500$, requiring only 5–13 iterations for convergence. Crucially, the discrete iterates converge to the exact solution as the iteration count increases, independently of the discretization size—a theoretical advantage over classical discretize-then-linearize approaches.

The DT-L-D framework provides a reliable, efficient, and structure-preserving paradigm for solving nonlinear integro-differential equations on large domains. Its dimension-reduction capability (O(nN) complexity) and parallelization potential make it particularly valuable for scientific computing applications requiring high-precision solutions over extended intervals.



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sciforum-170231: Quantifying Reinfection-Driven COVID-19 Transmission with Physics-Informed Neural Networks

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The evolution of SARS-CoV-2 underscores the significance of immune escape and reinfection in the spread of epidemics. This study proposes a two-strain compartmental model of the Omicron and Delta variants of SARS-CoV-2 and combines it with the Physics-Informed Neural Network (PINN) method to estimate time-dependent epidemiological parameters using daily epidemiological and variant-specific COVID-19 data from the State of Tennessee. Furthermore, a methodical superiority of PINN has been revealed over traditional non-linear least squares methods. The model captures the dynamics of primary transmission among susceptible individuals and secondary transmission resulting from the reinfection of recovered individuals with the other variant, thereby providing a mechanistic understanding of partial cross-immunity.

The PINN assimilates the non-linear equations of the two-strain compartmental model into the learning process using automatic differentiation, thereby satisfying the equations with the observed infection and recovery data. Time normalization, scaling of the system states, and log parameterization are used to improve the stability of the optimization process and maintain the positivity of the estimated epidemiological parameters, which are hidden.

To quantify the effect of immune escape on the sustainability of the epidemic, we examine various reinfection cases, including no reinfection and bidirectional reinfection. The trained PINN is used to forecast epidemic trajectories over a 30-day horizon, capturing strain-specific dynamics, variant dominance, and the risk of resurgence. Overall, this work demonstrates that physics-informed neural networks provide a principled and interpretable framework for learning non-stationary multi-strain epidemic dynamics and enabling reliable short-term forecasting from real-world data.



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sciforum-171600: Regime-Dependent Diffusion–Gravity Dynamics in a Declining Population System: A Network-Based Analysis of Internal Migration in Japan

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Population decline has become a defining feature of many regional systems, with Japan's total population entering a sustained decline from 2009 onward, yet limited attention has been paid to how diffusion-based migration models perform under prolonged demographic contraction and systemic shocks. This study examines internal migration dynamics in Japan over a 22-year period (2004–2025) by modeling inter-prefectural population flows across the country's 47 prefectures as a spatial network governed by diffusion processes with long-range interaction effects. Annual prefecture-to-prefecture migration matrices are constructed and analyzed within a graph-based framework using a discrete Laplacian formulation augmented with gravity-type interaction terms. To account for structural changes over time, the analysis adopts a regime-based approach that distinguishes periods of demographic stability, sustained population decline, exogenous shock, associated with the COVID-19 period (2020–2021), and post-shock reconfiguration (2022–2025). Regimes are defined based on demographic and systemic transitions rather than equal temporal lengths, while model estimation is conducted on annual transitions to maintain consistency across periods. This framework allows for a systematic comparison of migration dynamics across contrasting demographic conditions. The results indicate that diffusion-based dynamics provide a reasonable representation of migration adjustment during periods of relative demographic stability, but exhibit reduced explanatory capacity during prolonged population decline and systemic shocks. In contrast, hybrid diffusion–gravity formulations are more robust across regimes by incorporating both local spatial interactions and long-distance hierarchical linkages. Post-shock periods display mixed migration behavior, suggesting partial re-stabilization without a full return to pre-decline diffusion patterns. By framing internal migration as a regime-dependent dynamical system, this study contributes to applied mathematics by clarifying the conditions under which diffusion operators remain suitable in declining population systems and when extended formulations are required. Although Japan serves as the empirical case, the proposed framework also applies to other regions experiencing demographic decline and spatial reorganization.



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sciforum-170552: Spectral collocation solution of some strongly nonlinear heat transfer problems

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Thermal analysis of extended surfaces (fins) is critical for preventing overheating in a wide range of industrial systems, from microelectronics to aerospace engineering. Governing differential equations for fin models, particularly those incorporating temperature-dependent thermal conductivity, surface heat flux, or radiative effects, are inherently strongly nonlinear. Such complexity resists exact analytical solution and demands the development of accurate, efficient, and stable numerical methods.

To address this challenge, we aim to introduce a spectral collocation method utilizing a basis of Fibonacci polynomials. The technique is designed to solve nonlinear initial and boundary value problems governed by ordinary differential equations, under Dirichlet, Neumann, or mixed-type constraints. The proposed framework systematically transforms the governing differential equation into a tractable system of nonlinear algebraic equations. Solving this system for spectral coefficients yields a highly accurate approximate solution. A rigorous theoretical foundation is established, including a proof of convergence and the derivation of a priori error bounds, both of which are subsequently validated through comprehensive numerical tests.

The method's practical efficacy and computational performance are demonstrated on two classic yet challenging benchmark problems from the heat transfer literature: (1) heat transfer in a longitudinal fin with temperature-dependent surface heat flux, and (2) the combined convecting–radiating cooling of a lumped system with variable specific heat. A detailed comparative analysis against established methods, including the Adomian decomposition method and variational iteration method, shows that the proposed Fibonacci-based spectral scheme delivers superior accuracy, faster convergence, and notable implementation simplicity. The obtained results confirm the method's potential as an accurate and efficient analytical-numerical tool, suggesting that further exploration and adaptation could extend its applicability to a broader range of strongly nonlinear problems in thermal engineering and applied mathematics.



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sciforum-170896: Two-stage method for identification of elastic moduli in FDM-printed polymers using guided wave dispersion

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Additive manufacturing is increasingly adopted in engineering practice for producing geometrically complex structures with high precision. However, predicting the mechanical behavior of polymer-based components remains challenging due to insufficiently accurate data on their elastic moduli, particularly under dynamic loading. Classical experimental mechanics methods primarily based on quasi-static tests are often unsuitable for accurately characterizing dynamic elastic properties. This study proposes a two-stage algorithm to solve an inverse coefficient problem for determining the elastic moduli of specimens fabricated from polymeric materials via fused deposition modeling (FDM), leveraging experimental dispersion characteristics of guided elastic waves. Surface out-of-plane velocities, measured using laser Doppler vibrometry, are processed with the matrix pencil method to extract dispersion curves. In the first stage, a fast method based on the Fourier transform of the waveguide's Green's matrix provides an initial approximation of the elastic moduli. This estimate is refined in the second stage by minimizing the discrepancy between theoretical and experimental dispersion relations; the objective function selectively weights experimental points in proximity to the current theoretical prediction, which improves convergence robustness. When validated on synthetic data, the two-stage approach reduces parameter estimation error by approximately 50 % compared to single-stage optimization. Experimental validation on FDM-printed specimens shows strong correlation between the identified Young's modulus and reference values obtained from standard uniaxial tensile tests, confirming the method's applicability for non-destructive dynamic characterization of additively manufactured polymers. This research is carried out with the financial support of the Kuban Science Foundation, Ortho-Market LLC in the framework of the project Num. NTIP-25.1/8.



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sciforum-174068: A Topological Framework for Detecting Chaos in Erbium-Doped Fiber Lasers

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Understanding dynamical transitions between periodic and chaotic regimes in nonlinear fiber lasers is essential for stability control and performance optimization. In this study, we investigate regime transitions in an erbium-doped fiber laser (EDFL) by integrating nonlinear dynamical analysis with Topological Data Analysis (TDA). The governing differential equations are solved numerically to generate time series across varying control parameters, and Lyapunov exponents are computed to identify stability boundaries and chaotic behavior. To capture the global geometric structure of the underlying attractors, we apply persistent homology to the time series and compute persistence diagrams and Betti curves as quantitative topological descriptors. In addition, the Mapper algorithm is used to construct graph representations of the attractors, enabling the extraction of topological and statistical features that characterize structural organization. Our results reveal clear topological transitions between periodic and chaotic regimes, with chaotic dynamics exhibiting significantly higher geometric complexity and distinct structural patterns in the corresponding graphs. Importantly, the evolution of topological invariants shows strong agreement with Lyapunov-based chaos indicators while simultaneously capturing global attractor reorganization that is not accessible through classical local stability measures alone. These findings demonstrate that TDA provides a robust and complementary geometric framework for detecting, classifying, and understanding dynamical regime transitions in nonlinear fiber laser systems, with potential applications in stability monitoring and control of advanced photonic devices.



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sciforum-145774: Bridging Analytical and Numerical Methods for Fractional 4D Chaotic Systems

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Fractional calculus has emerged as a powerful mathematical framework for modeling real-world systems characterized by memory, nonlocality, and complex dynamical behaviors. Unlike classical integer-order models, fractional-order formulations provide a more flexible description of processes with long-term memory and hereditary effects, which are commonly observed in physics, engineering, biology, and information sciences. In particular, fractional-order chaotic and hyperchaotic systems have received considerable attention for their ability to capture richer dynamical features, making them highly relevant in areas such as secure communications, signal encryption, random number generation, and nonlinear control. In this work, we explore a four-dimensional fractional-order chaotic model by integrating the Residual Power Series Method (RPSM) and the Caputo fractional derivative (CFD). The CFD is employed to obtain highly accurate numerical simulations that reveal the sensitivity of chaotic attractors to changes in the fractional order, while the RPSM provides analytical approximations that are computationally efficient, stable, and capable of handling diverse initial conditions. This hybrid framework bridges the gap between purely numerical and purely analytical methods, ensuring both accuracy and mathematical insight. Our findings show that fractional order is a key parameter for tuning system behavior between chaotic and stable regimes. This study contributes new insights into the modeling of hyperchaotic systems, with potential relevance for engineering, cryptography, and nonlinear sciences.



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sciforum-159051: A Complex Analysis-Based Framework for Harmonic Distortion Estimation in Single-Phase Power Systems

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Harmonic distortion remains a critical issue in modern single-phase power systems, primarily due to the increasing penetration of nonlinear loads and power-electronic devices. Accurate estimation of harmonic content is essential for maintaining voltage quality, ensuring equipment reliability, and supporting overall grid stability. Existing numerical approaches, including discrete Fourier transform (DFT)-based methods, often face limitations such as high sensitivity to noise, spectral leakage, and increased computational load.

This study introduces a complex-analysis-based mathematical framework for harmonic distortion estimation, offering improved analytical insight and computational efficiency. The distorted voltage waveform is modeled as a complex-valued periodic function, enabling decomposition through Fourier series in the complex plane. Key tools from complex variables—such as contour integration, residue theorem, and analytic continuation—are employed to derive harmonic coefficients with enhanced precision. Linear algebraic formulations and numerical approximation methods from advanced engineering mathematics (including iterative solvers and error minimization techniques) further optimize coefficient extraction and reduce computational overhead.

Simulation results on multiple non-sinusoidal test signals demonstrate that the proposed method achieves higher accuracy in estimating harmonic magnitudes and phases, with up to an 18% improvement in convergence compared to conventional DFT-based approaches. The framework also exhibits strong noise tolerance, providing clearer differentiation between dominant and weak harmonic components.

Overall, this work offers a mathematically rigorous and efficient methodology for real-time harmonic analysis in power systems. The framework bridges complex analysis with power-engineering applications and has strong potential for integration into modern power quality monitoring and control systems.



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sciforum-173790: A DERIVATIVE-FREE OPTIMIZATION METHOD ON HADAMARD MANIFOLD FOR SOLVING NONLINEAR MONOTONE SYSTEMS WITH APPLICATION IN IMAGE DEBLURRING

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This paper develops an innovative derivative-free optimization method for solving large-scale nonlinear monotone systems on Hadamard manifolds. The proposed algorithm is built as a convex combination of two classical conjugate gradient schemes, Fletcher–Reeves and Polak–Ribiere–Polyak, thereby inheriting the good global convergence properties of the former and the practical efficiency of the latter. Unlike conventional Riemannian optimization methods, which typically require gradients or Jacobians that may be unavailable or prohibitively expensive to compute on curved spaces, the new approach is genuinely derivative-free. It integrates hybrid conjugate gradient strategies with hypersurface projection techniques defined via retractions and vector transport, ensuring that all iterates remain on the manifold while preserving suitable conjugacy and descent properties. One feature of the algorithm is its function-based line search, which employs Armijo- and Wolfe-type conditions to guarantee sufficient descent without using derivatives of the underlying operator, thereby mitigating stagnation issues commonly observed in derivative-free schemes. Under standard assumptions of monotonicity and Lipschitz continuity, a rigorous convergence analysis establishes global convergence of the iterates to a solution of the monotone system. Extensive numerical experiments on test problems with dimensions up to 50,000 illustrate the method's efficiency, robustness, and competitiveness relative to existing state-of-the-art algorithms for large-scale nonlinear systems. Finally, when applied to an image restoration problem, the method successfully reconstructs severely degraded images, achieving high-quality reconstructions as quantified by standard performance metrics such as Peak Signal-to-Noise Ratio (PSNR) and Signal-to-Noise Ratio (SNR), demonstrating its practical relevance in imaging applications.



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sciforum-172598: A Dimensionally Consistent Mathematical Framework for Optimal Frequency Selection in Pulse-Width Modulated Systems

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This work establishes a complete mathematical framework for determining the optimal switching frequency in pulse width modulated systems, resolving a longstanding dimensional inconsistency in the literature. Two competing objectives govern these systems: efficiency, which decreases with switching frequency due to switching losses, and harmonic distortion, which also decreases with frequency through improved waveform reconstruction. This monotonic conflict in a single independent variable forms the core mathematical challenge. Two key insights are introduced. First, dimensional analysis shows that the harmonic distortion coefficient has physical units of frequency raised to the power 0.65 rather than being dimensionless as commonly assumed. The correct formulation expresses it as a dimensionless constant multiplied by nominal frequency to the same exponent. Second, the optimal switching frequency scales with rated power of 2500 watts rather than instantaneous power because switching loss coefficients are defined at nominal conditions. These corrections yield a dimensionally consistent closed-form solution that satisfies the necessary optimality condition, and the associated fixed-point iteration is proven to converge geometrically with contraction rate 0.39. Validation across five pulse width modulation controllers, including Constant Frequency, Variable Frequency, Hysteresis Band, Optimal Normalized Efficiency Total Harmonic Distortion Product, and Dual Mode, shows zero theoretical error after calibrating a single dimensionless coefficient to 0.001. A secondary contribution, the Normalized Efficiency Total Harmonic Distortion Product, unifies both objectives into one scalar metric with a frequency-independent upper bound of 0.711. The infinite dimensional optimization reduces to evaluation at three load points at 10%, 50%, and 100%, reducing computations from 10000 to 3 while preserving rigorous error bounds.



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sciforum-168078: A Feynman–Kac Approach to Conditional Mean–Field Models with Markovian Switching and Poisson Jump

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We investigate a class of *conditional* McKean–Vlasov stochastic differential equations with jump components and Markovian regime-switching, thereby extending classical mean-field frameworks to encompass discontinuous perturbations and environment-dependent dynamics. The models describe interacting particle systems whose evolution depends not only on the individual state and stochastic perturbations, but also on the *conditional distribution* of the system given an underlying filtration, providing a mathematically natural setting for partial information, common noise effects, and regime-driven interactions.

A comprehensive analysis of well-posedness, stability, and regularity is developed, revealing the delicate interaction between Poisson jump mechanisms, regime-switching dynamics, and conditional mean-field effects. A central contribution is the derivation of first- and second-order differentiability properties of the solution flow with respect to the probability measure, carried out through Lions' differential calculus on the Wasserstein space.

Furthermore, we show that the conditional McKean–Vlasov dynamics induce a novel class of nonlocal systems of partial integro-differential equations with terminal conditions. Under appropriate structural and regularity assumptions, we establish a probabilistic representation of the unique classical solutions of these systems via an extended Feynman–Kac-type formula.

These results provide a rigorous and unified connection between conditional stochastic particle systems and their associated analytical equations, significantly enriching the theory of mean-field models with jumps and switching. The framework opens new avenues for applications in areas such as systemic risk, neural network modeling, and controlled interacting systems under uncertainty.



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sciforum-170544: A Hybrid Physiological and Neural ODE Model with Probabilistic Outputs for Personalized Glucose Dynamics in Type 2 Diabetes

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Introduction:

Type 2 Diabetes Mellitus (T2DM) is a heterogeneous metabolic disorder characterized by insulin resistance, impaired insulin secretion, and altered hepatic glucose regulation, resulting in complex and patient-specific glucose dynamics. Accurate mathematical modeling of these processes is essential for understanding disease mechanisms and supporting personalized therapeutic strategies.

Methods:

We present a hybrid modeling framework that integrates a physiologically interpretable system of ordinary differential equations (ODEs) with Neural ODE residual dynamics and a probabilistic output mechanism. The physiological component explicitly models key glucose–insulin processes relevant to T2DM, including gastric emptying, intestinal glucose absorption, plasma glucose and insulin dynamics, and insulin action. Each state variable corresponds to a measurable or identifiable biological process, ensuring physiological plausibility. A Neural ODE component is introduced to learn residual dynamics from patient-specific glucose time-series data. A Gaussian Mixture Model (GMM) output layer enables probabilistic prediction.

Results:

The proposed model admits a well-defined and stable fasting equilibrium and generates physiologically consistent postprandial glucose trajectories. The Neural ODE residual component enhances adaptability to inter-patient variability, while the GMM output captures uncertainty and multimodal glucose responses.

Conclusions:

This hybrid Physiological–Neural ODE framework combines mechanistic interpretability, data-driven adaptability, and probabilistic forecasting, providing a robust mathematical foundation for personalized glucose dynamics modeling in Type 2 Diabetes.



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sciforum-170134: A Mathematical Study of Wild Boar–Ranger Interaction Dynamics

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Wild boars are among the most widely distributed ungulate species worldwide and play a significant role in maintaining ecological balance within forest ecosystems. Nevertheless, uncontrolled population growth leads to severe agricultural damage and increased traffic accidents, making population regulation necessary. At the same time, wild boars represent an important economic resource and, in some regions, a protected species, requiring management strategies that balance control and conservation.

In this work, we present a mathematical model describing the dynamics of wild boar populations at forest boundaries, with particular emphasis on spillover phenomena into surrounding human-dominated areas. Rather than modeling the entire population, we focus on individuals living near the forest edge, as these are primarily responsible for spillover events. The model incorporates ranger intervention as a control mechanism activated when spillovers occur, representing hunting or containment actions aimed at regulating population size without driving the species toward extinction.

The qualitative analysis of the model reveals the existence of biologically feasible equilibrium points, including a coexistence equilibrium and a ranger-free equilibrium. Using bifurcation theory, we demonstrate the presence of a transcritical bifurcation that governs the stability exchange between these equilibria. Furthermore, under certain parameter conditions, the system undergoes a Hopf bifurcation, leading to the emergence of stable periodic solutions. These oscillations correspond to recurrent spillover events that necessitate periodic deployment of rangers, resulting in increased management costs.

Numerical simulations are provided to support the analytical results and to illustrate the long-term behavior of the system under different management strategies. In particular, the proposed model provides useful insights into sustainable wild boar management and highlights the effectiveness of resource-based control strategies in stabilizing population dynamics.



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sciforum-170801: A Modified Level Set Framework for Physics and Uncertainty Informed Wildfire Spread

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A wildfire refers to an uncontrollable fire that spreads through vegetation, such as forests and grasslands, and poses a serious risk to ecosystems, infrastructure and human lives. Because wildfires are common throughout the world, it is very important to understand and model their spread so that we can better prepare our communities for their potential consequences. Most existing fire models, which were developed primarily, focus on only a few variables (i.e., wind velocity, slope, or Rothermel spread rate), making them less reliable in replicating how a wildfire propagates in reality. Therefore, this research presents a modified model for estimating the spatial extent of wildfires based on the use of the Level Set method and uncertainty. The factors considered in the modified model include wind speed and direction, slope, fuel type, moisture content, slope corrections, and uncertainty; and the slope corrector also considers slope steepness and tightness of the fuel pack in its definition, while the uncertainty considers the actual distance travelled from the ignition point. All computations were performed in MATLAB; and the shape of the fire was studied over time. Future studies will include detailed research on complicated ignition geometries, the effect of heterogeneity in the environment, and the impact of uncertainty on fire evolution, thus improving the dependability and utility of our model to predict and controlling wildfires. The study results demonstrate that the Level Set model can correctly depict the evolution of a fire's boundary.



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sciforum-171168: A Multi-Objective Optimization Framework for Manufacturing Defect Reduction in Material Extrusion 3D Printing

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Material extrusion 3D printing is one of the most versatile and accessible additive manufacturing techniques used by researchers and engineers across the globe. The technique is limited by manufacturing parameter-induced defects. These defects develop during the fabrication process, such as warping, poor layer adhesion, and dimensional inaccuracy. The defects can be controlled by optimizing process parameters, such as nozzle temperature, print speed, layer height, and cooling rate. Traditionally, parameter selection relies on iterative trial-and-error or single-objective optimization. These approaches often fail to capture the inherent trade-offs between conflicting quality characteristics. In this research, we used a systematic multi-objective optimization framework (MOO) to minimize manufacturing defects in the fabrication processing conditions.

We produced the specimens using the material extrusion 3D printing (ME3DP) method. We used polylactic acid (PLA) for fabricating the specimens in the ME3DP technique. PLA has good manufacturability and is a biodegradable material. We produced manufacturing defects by controlling the temperature and the basic components of material design used in the fabrication process, such as nozzle temperature, heated bed temperature, layer thickness, and infill density. We applied one of the mathematical and multi-attribute decision-making techniques for the MOO framework, used as 'Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA)'. We used the (MOORA) technique to find the most significant configuration for evaluating manufacturing defect formation during the fabrication process. The MOORA technique is prevalently used in process engineering and optimization in industrial applications. The method simultaneously integrates both beneficial and non-beneficial attributes by using a ratio-based system. It then converts a decision matrix into a ranking system-based sample configuration. The ranking system determines the best parameters to control to reduce the manufacturing defects during the fabrication process. Our investigation shows that the MOORA method successfully determines the best manufacturing processing parameters for the reduction in defects.



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sciforum-174510: A note on the convergence of Mann Type Iterations on Hadamard Manifolds with Applications

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In this paper, we propose a new iterative method inspired by recent developments in inertial techniques. The scheme is constructed by modifying the Mann-type iteration and incorporating inertial terms to improve the speed of convergence. The idea is to use information from both the current and the previous iterates so that the generated sequence approaches the solution more efficiently than the standard Mann process. We establish the strong convergence of the proposed algorithm under mild and natural assumptions on the underlying mappings. The proof relies on suitable auxiliary results and careful analysis of the sequence generated by the method. The assumptions imposed are standard in the literature and do not restrict the applicability of the algorithm to special cases. As a result, the convergence result holds for a broad class of nonlinear problems in Hilbert spaces. To highlight the usefulness of the method, we apply our main theorem to equilibrium problems, variational inclusion problems, and convex minimization problems. These applications show that the proposed iteration provides a unified framework for treating several important models in nonlinear analysis and optimization. In the final section, we include a numerical example to illustrate the convergence behavior of the algorithm and to support the theoretical results. The numerical outcome confirms that the method converges as predicted and demonstrates its practical effectiveness.



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sciforum-147254: A Novel Hepatitis B Epidemic Model with Vertical Transmission, Spontaneous Recovery and Optimal Control Analysis

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This research describes a compartmental epidemic model of Hepatitis B virus (HBV) transmission that includes vertical transmission and spontaneous recovery in acute patients. The model incorporates a saturated treatment response for persistently infected populations and a vaccination mechanism for susceptible populations. The basic reproduction number, R0, is calculated using the next-generation matrix approach, which provides important information on disease dynamics. To find out the most influential parameter of the model dynamics, a sensitivity analysis is carried out with the help of Latin Hypercube Sampling (LHS) along with the Partial Rank Correlation Coefficient (PRCC). The qualitative behavior of the model is investigated using stability analysis of disease-free and endemic equilibria. It is established that the disease-free equilibrium is globally asymptotically stable when R0 1, but the endemic equilibrium achieves global stability when R0 > 1. Pontryagin's Maximum Principle is used to optimize public health initiatives, resulting in three optimal control techniques that attempt to reduce the combined cost of treatment and immunization. The results provide a rigorous theoretical foundation for designing cost-effective interventions against HBV transmission. This work contributes a more biologically accurate and analytically rich model to the literature, offering new insights into the strategic control of HBV infection, particularly in regions where vaccination and treatment resources are limited.



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sciforum-174139: A parametric study on the effect of horizontal and vertical location parameters on surface deformation due to a buried tensile fault

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In the present study, a detailed parametric investigation is carried out to examine the influence of the horizontal and vertical location parameters d_1 and d_2 on surface deformation caused by a long inclined tensile fault located at an arbitrary position (d_1,d_2) in a homogeneous isotropic elastic half-space, where d_1 denotes the horizontal distance of the upper edge of the fault and d_2 denotes the burial depth of the upper edge of the fault. Closed-form analytical expressions for displacement components from Singh et al., 2016, are utilized to analyze the sensitivity of horizontal and vertical surface displacements with respect to variations in fault position. It is shown that in a uniform elastic half-space, deformation is invariant under horizontal translation, i.e., the horizontal parameter d_1 produces only a translational shift in the deformation field without altering its amplitude. In contrast, deformation is highly sensitive to burial depth, i.e., the burial depth parameter d_2 significantly affects the magnitude, decay rate, and spatial distribution of deformation. The results demonstrate that in physical interpretations, a deeper tensile fault produces weaker surface deformation and shallow tensile faults produce intense surface deformation, while moving the fault sideways only shifts the deformation zone. Further, the effect of dip angle is also considered in the analysis of this study.



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sciforum-171835: A Plant Disease Model Incorporating Environmental Inoculum and Seasonal Factors with Optimal Control Approach

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This paper introduces a three-variable mathematical model that integrates susceptible biomass (\(S\)), infected biomass (\(I\)), and environmental inoculum (\(E\)), offering a novel framework that extends beyond classical SIR-type models by explicitly incorporating inoculum ecology and climate-driven dynamics. The model captures nonlinear infection saturation, logistic host growth, seasonal forcing, and a control intervention representing management practices such as fungicide application or crop rotation. Analytical exploration of the system reveals the existence of both disease-free and endemic equilibria, with stability determined by the basic reproduction number, \(R_0\). When \(R_0 1\), the disease-free equilibrium is stable, leading to the eradication of infection and recovery of host biomass, whereas \(R_0 > 1\) results in endemic persistence sustained by environmental inoculum reservoirs. Possible outcomes include stable disease-free states, endemic equilibria, seasonal oscillations driven by climatic variability, and shifts toward eradication under effective control strategies. Sensitivity analysis highlights that \(R_0\) is strongly influenced by inoculum survival rates, host growth capacity, and seasonal forcing intensity, underscoring the ecological complexity of plant disease dynamics. Numerical simulations substantiate these theoretical findings, demonstrating that strong seasonal forcing can destabilize equilibria and generate recurrent epidemic waves, while optimal control interventions can suppress infection prevalence by reducing \(R_0\) below unity. The results emphasize the critical role of environmental reservoirs in sustaining epidemics and provide a robust theoretical foundation for designing sustainable agroecological forecasting and management strategies under climate variability.



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sciforum-173626: A Robust, Adaptive Hybrid Nonlinear Conjugate Gradient Method Ensuring Global Convergence

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Nonlinear conjugate gradient (NCG) methods are among the most effective techniques for solving large-scale unconstrained optimization problems. Their efficiency arises from low memory requirements, straightforward implementation, and strong performance in high-dimensional settings. A key component of NCG methods is the parameter βk\beta_kβk, which governs how the new search direction is generated from the current gradient and the previous direction. The selection of βk\beta_kβk plays a crucial role in determining both the convergence behavior and computational efficiency of the algorithm.

Several well-known formulas have been proposed for βk\beta_kβk, including the **Fletcher–Reeves (FR)**, **Polak–Ribiere (PRP)**, and **Hestenes–Stiefel (HS)** methods. The FR method is recognized for its solid theoretical convergence properties under standard line search conditions, yet it may exhibit slow progress in practice. On the other hand, PRP and HS often achieve faster numerical performance and better practical behavior, particularly for nonconvex problems. However, these methods may fail to guarantee global convergence unless additional safeguards are introduced to preserve the descent property.

To address these challenges, this work proposes a new adaptive hybrid formulation for βk\beta_kβk that combines the complementary strengths of FR, PRP, and HS. The proposed strategy dynamically balances robustness and efficiency by adjusting the influence of each formula based on the local characteristics of the objective function. A safeguarding mechanism is incorporated to ensure that the generated search direction maintains the descent condition at every iteration. Under standard assumptions and appropriate line search strategies, global convergence of the proposed method is established. Numerical experiments on benchmark problems demonstrate improved stability and competitive performance compared to classical NCG methods, without sacrificing theoretical guarantees.



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sciforum-173606: A Unified Transform Approach for Analyzing Fractional Differential Models with Diverse Fractional Operators

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This study presents a generalized integral transform (GIT) approach for analyzing and modeling a wide class of fractional-order mathematical systems arising in physical, engineering, and biological sciences. The investigated models include Newton's law of cooling, the logistic population growth equation, and the blood alcohol concentration model, each formulated using distinct fractional derivatives such as the Caputo, Caputo–Fabrizio (CF), modified Atangana–Baleanu–Caputo (mABC), and constant proportional Caputo (CPC) derivatives. These fractional operators effectively describe memory-dependent and non-local characteristics inherent in many natural and engineered processes. Analytical solutions of the proposed models are derived through the generalized transform method, and graphical illustrations are provided to demonstrate the influence of various fractional orders on system dynamics. The results reveal that the GIT technique offers a unified, powerful, and efficient framework for solving a broad spectrum of fractional differential equations with diverse kernels. Furthermore, it integrates several classical and modern transforms—including the Laplace, Sumudu, Elzaki, and Formable transforms—as special cases, thereby simplifying computation and enhancing both generality and adaptability. This unified formulation provides researchers with a flexible analytical tool capable of addressing diverse problems without redefining operators for each model. The comparative analysis validates the stability, accuracy, and consistency of the proposed technique. Overall, this work highlights the efficacy, robustness, and broad applicability of the generalized integral transform, establishing a firm foundation for future explorations of hybrid fractional models and their interdisciplinary applications.



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sciforum-170805: Adomian Decomposition Method Combined with Padé Approximation for Solving African Swine Fever Transmission Among Swine Farms.

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This research investigates the effectiveness of using Padé approximation in improving the accuracy of analytical solutions for a mathematical model describing the transmission dynamics of the African Swine Fever (ASF) virus. The ASF model consists of a Susceptible–Latent–Infectious–Susceptible–Contaminated (SLI–SC) compartmental framework that incorporates the role of contaminated human vectors. An analytical solution for the model is first constructed using the classical Adomian Decomposition Method (ADM) up to the eighth-order approximation. A comparison between the classical ADM solution and the Runge–Kutta–Fehlberg fourth–fifth-order (RKF45) numerical method reveals that, although ADM provides reliable approximations near the initial conditions, its accuracy deteriorates over larger time intervals due to slow convergence and a limited radius of convergence limitations. The key novelty of this study is the use of Padé approximations of orders of [4,4] and [3,5] to rationalize the ADM series solution. In contrast with traditional methods that solely use truncated series expansions, the hybrid ADM–Padé framework improves convergence behavior and extends the validity of the analytical solution over a wider time domain. By converting polynomial series into a rational form, the method reduces the divergence and instability that are common in long-term nonlinear system simulations. A systematic comparison among the classical ADM, the hybrid ADM–Padé technique, and the RKF45 numerical method shows that the ADM–Padé results closely agree with RKF45 solutions across an extended interval. Improved accuracy, stability and a wider convergence region were made available by Pade acceleration and further demonstrated via graphical simulations created in Maple. Overall, this work presents a strong and solid semi-analytical approach for solving nonlinear differential equation models in mathematical epidemiology. The hybrid technique improves solution accuracy for larger domains while guaranteeing quicker convergence. Consequently, ADM–Padé can be considered a robust, precise mathematical technique to solve epidemiological models arising in mathematical biology.



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sciforum-149293: AI-Augmented Mathematical Modeling of Spray Deposition and Environmental Impact in UAV-Based Precision Agriculture

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The accurate modeling of spray deposition dynamics is essential for assessing the efficiency and environmental consequences of UAV-based precision agriculture. Traditional fluid mechanics and physical dispersion models, while valuable, often struggle to capture the complexity of real-world spraying conditions influenced by canopy heterogeneity, wind variation, and nozzle type. This study proposes an AI-augmented mathematical framework that integrates partial differential equation (PDE)-based spray dispersion models with statistical learning methods to improve prediction accuracy. Random forests and gradient boosting algorithms are employed to calibrate and refine predictions from field-collected UAV spray data, while principal component analysis and multivariate regression identify the dominant factors affecting deposition efficiency, including droplet size, nozzle angle, wind speed, and canopy density. Experimental validation in orchard conditions demonstrates that the hybrid PDE–AI model achieves superior accuracy over traditional physics-only approaches, thus reducing the prediction error by more than 20%. Beyond operational optimization, the framework also quantifies reductions in pesticide use, water footprint, and CO_2 emissions, thereby linking mathematical modeling with sustainability objectives. The results confirm that combining mathematical analysis with AI not only improves predictive capability but also supports decision-making for environmentally responsible precision spraying practices. This research highlights the potential of hybrid mathematical–statistical approaches to advance sustainable agriculture.



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sciforum-168732: An Automated Persistent Topological Framework for Robust Multi-Scale Data Analysis

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Identifying scale-invariant geometric features in high-dimensional data remains a central challenge in data science. While the Mapper algorithm offers a powerful topological lens, its utility is often hindered by a critical dependence on manual parameter tuning and a lack of reproducibility. Conversely, persistent homology provides robust multiscale insights but lacks a direct, automated integration into structural discovery.

To bridge these gaps, we propose a fully automated topological framework that unifies Mapper with persistent homology to achieve principled, noise-resilient feature extraction. The core innovation is our Most Persistent Betti-1 (MPB-1) algorithm, which systematically extracts dominant one-dimensional homological features from persistence diagrams to compute a characteristic scale (ε). This scale guides the parameterization of the Mapper algorithm through a closed-form relationship, eliminating traditional trial-and-error.

We validate our framework on synthetic datasets, where it accurately recovers theoretical Betti-1 invariants, and on real-world applications including single-cell genomics and protein dynamics. Our results reveal robust topological signatures consistent with underlying biological structures. To our knowledge, this is the first automated Mapper framework that guarantees fidelity to persistent topological invariants. By embedding Betti-1 computation at its core, our method provides a reproducible foundation for detecting cyclic structures central to medicine and proteomics, thereby broadening the reach of topological data analysis across scientific domains.



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sciforum-168177: An Optimized Accelerator for Option Pricing Using Monte Carlo Simulation on a GPU

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The Monte Carlo simulation is a numerical computing algorithm that computes its outcome through repeated random sampling. It is a technique used to model the different types of uncertainty that impact the value of the investment or underlying instrument under consideration. This study used the Monte Carlo method on a GPU to investigate and assess the Arithmetic Asian Option. By utilizing the GPU's built-in parallelization capability, the study was able to accelerate pricing options more effectively and decisively when compared to the CPU implementation. It also evaluated the amount of power consumed by the GPU and optimized the power for greater efficiency. The effectiveness of the method was examined by utilizing the various paths that were constructed using a randomized function to test this assertion. Ten paths (samples) with ranges between 100,000 and 1,000,000 were taken into consideration. The GPU was utilized to enhance performance in terms of speedup, computation time, power consumption, and time complexity. The GPU's power utilization is then further optimized to improve performance. A detailed experiment using GPU and quad-core multiprocessor systems was conducted. The optimized accelerator for the GPU was coded using the CUDA programming language, libraries, and Application Programming Interface (API). Experimental results using different simulated scenarios demonstrated that the GPU was found to be more efficient in every scenario, both in terms of speed and power consumption. Additionally, the optimized GPU-accelerated optimizer results also showed increased speed and optimally reduced power consumption compared to the quad-core CPU counterpart. This approach will be beneficial in mathematical financial computing and stock market price forecasting.



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sciforum-171813: Analysis of Patch Fractal Antenna Design Using Mathematical Modelling

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This paper presents an analytical study of the use of mathematical modelling, such as the iterated function system (IFS), for patch fractal antenna design. Current, modern research in the field of communications focuses on the realization of compact communication systems. Therefore, they concentrate on reducing the size of individual devices and the constitution of elements, particularly antennas. Fractal geometries are generated by recursive transformations, which provide a rigorous mathematical framework for constructing self-similar sets through affine contraction mappings using an iterative procedure for compact, miniaturized self-similar structures. With each iteration n, the effective electrical length of the antenna increases. Finite element simulations validate the theoretical predictions, demonstrating close agreement between calculated and simulated resonant frequencies so that additional resonant frequencies appear, which enable wideband and multiband operations. The results confirm that the iteration order can be used as a systematic design parameter to achieve target frequency bands without relying just on numerical optimization. This work illustrates how mathematical concepts such as IFS and recursion can guide the analytical design of compact, multiband, or wideband fractal antennas for wireless communication systems and aims to demonstrate the role of applied mathematics in the systematic design and miniaturization of fractal antenna structures.



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sciforum-135468: Analytical Modeling of a Dynamic Probability Mixture via Sigmoidal Weighting for Heterogeneous System Degradation

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This paper proposes a novel mathematical model based on a dynamic mixture of Erlang and exponential distributions to capture complex degradation processes in heterogeneous systems. The core feature of the model is the use of sigmoidal weighting functions, defined as **ω(x) = 1 / (1 + exp(−r(x − a)))**, where **r > 0** and **a > 0**. This weighting mechanism allows the model to naturally switch dominance between mixture components, mimicking realistic physical stages of defect nucleation, propagation, and accelerated wear—a critical aspect for effective Prognostics and Health Management (PHM) and remaining useful life prediction.

The scientific novelty lies in the development of an analytical method for calculating the normalization constant **C** of the dynamic mixture. Unlike traditional approaches that rely solely on numerical integration, the proposed method yields a closed-form expression for the normalization constant using the Lerch transcendent function. Specifically, **C = (λ/r) * Φ(−exp(ra), 1, λ/r) + 1 − (μ^k / r^k) * Φ(−exp(ra), k, μ/r)**. This provides a precise analytical representation, significantly increasing calculation speed and stability in most scenarios. For cases where the Lerch function exhibits computational instability in modern CAS, an approximate method based on the Sommerfeld expansion for Fermi–Dirac type integrals is proposed. The error of this method is controlled by subsequent expansion terms, ensuring the precision required for engineering applications.

Model parameters are estimated via Maximum Likelihood Estimation with gradient-based optimization. To ensure reliable convergence, a dedicated initialization procedure based on the method of moments is proposed to establish robust initial values.

The proposed model was tested on synthetic data with known parameters and on real degradation trajectories from the NASA C-MAPSS dataset. The results indicate accurate parameter recovery in simulations and superior adaptability over conventional static mixtures when modeling nonlinear degradation in real heterogeneous systems.



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sciforum-170623: Analytical solution to geodesic equation in non-commutative gauge theory of gravity

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In this paper, we employ the non-commutative (NC) gauge theory of gravity to construct the deformed metric $\hat{g}_{\mu\nu}(r,\Theta)$ corresponding to the Schwarzschild black hole. This construction is performed using the Seiberg–Witten map and the Moyal–Weyl star product, which systematically incorporate the effects of non-commutativity through the parameter Θ. The resulting deformed metric provides a geometric framework to study the geodesic of a massive test particle in the presence of NC gravitational corrections. We begin by deriving the correction to the effective potential of the massive test particle, considering terms up to the second order in the NC parameter Θ. Subsequently, we obtain the geodesic equation for the massive test particle with second order in NC corrections. An analytical solution to this modified geodesic equation is presented using an approximation method suitable for weak-field and slow-motion limits. In addition, we plot several representative orbital trajectories of the massive test particle around the NC-deformed Schwarzschild black hole and analyze their physical behavior. All our results consistently reduce to the well-known commutative case in the limit $\Theta \rightarrow 0$, thereby preserving the coherence and consistency of the theory. Furthermore, we demonstrate that NC effects manifest only at the perihelion of the test particle's orbital motion.



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sciforum-166500: Archimedean intuitionistic fuzzy Maclaurin symmetric mean and Maximizing deviation method coupled social network analysis for multi-criteria group decision making

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The main objective of a group of decision-makers in a multi-criteria group decision-making (MCGDM) problem is to choose the best option from the available options. Prior to analysis, a number of issues must be resolved to select an appropriate alternative for an MCGDM problem. These issues include quantifying uncertainty in collected data, handling conflicting criteria, evaluating decision makers and criteria weights, properly fusing quantified information, and ultimately choosing the best alternative. The objective of this research is to establish an interactive MCGDM method for evaluating any MCGDM problem while addressing the above-listed challenges. The suggested MCGDM approach employs intuitionistic fuzzy sets (IFSs) to quantify uncertainty in gathered data, assesses decision makers' weights based on their social network, determines criteria weights using the maximizing deviation method, aggregates the data using the Archimedean t-norm and t-conorm (ATT)-based weighted average, and selects the optimal option using the intuitionistic fuzzy Maclaurin symmetric mean and score function. In order to enable manufacturing companies to modify their development strategies for a digital reform in a timely way, the proposed MCGDM technique is used to evaluate the digital reforms of China's manufacturing sector. The results show that the suggested method is practical, flexible, and suitable to assess any MCGDM problem in real life.



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sciforum-171769: Asymptotic Analysis of Even Hermite–Sobolev Orthogonal Systems

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This poster presents an analysis of an even Hermite–Sobolev system associated with the Gaussian weight rho(x) = exp(−x^2) on the real line. The considered system is generated from normalized even Hermite functions and naturally arises in functional analysis, spectral theory, and the asymptotic study of generalized orthogonal systems.

Let r ≥ 1 be a fixed integer. The family of functions is defined by polynomial expressions for the initial indices and by integral representations involving even Hermite functions for higher orders. A fundamental property of this construction is that the r-th derivative of the system coincides with the classical even Hermite functions. We first prove that this family forms an orthogonal system with respect to a Sobolev-type inner product restricted to the space of even functions. This orthogonality reflects the intrinsic differential structure of the system and highlights its close connection with Hermite analysis.

The main objective of this work is to investigate the asymptotic behavior of the system as the index tends to infinity. By combining the classical Plancherel–Rotach asymptotic formulas for Hermite functions with the steepest descent method applied to the associated integral representations, we identify three distinct asymptotic regimes: the oscillatory (bulk) region, the transition region, and the exponential (outer) region. In particular, we show that the asymptotic behavior in the transition region is governed by the Airy function, revealing a universal feature characteristic of Gaussian-based orthogonal systems. Finally, numerical illustrations are provided to demonstrate the consistency between the asymptotic results and computational observations.



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sciforum-170790: Bifurcation Analysis of a Two-Dimensional Cancer–Immune Model with Antigenicity and Strong Allee Effect

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Mathematical modeling of tumor–immune dynamics has become an essential tool for understanding the nonlinear behavior of cancer progression and control. In this talk, we investigate a two-dimensional cancer growth model that has been enhanced by incorporating two biologically relevant mechanisms: tumor antigenicity and a strong Allee effect governing cancer cell survival thresholds. These additions allow for a more realistic representation of tumor establishment and immune system recognition. Our analysis begins with the identification and classification of the model's equilibrium points across biologically feasible parameter ranges. We employ analytical and numerical techniques to determine stability and construct bifurcation diagrams. Particular attention is given to codimension-1 bifurcations, such as saddle–node and Hopf bifurcations, which signal qualitative transitions in tumor dynamics. We further extend the analysis to codimension-2 bifurcations, specifically Bogdanov–Takens, Bautin, and cusp bifurcations, to delineate regions in parameter space with complex dynamic behavior. We derive explicit conditions on key parameters that delimit dynamic regimes of tumor suppression, coexistence, and growth. Critical threshold curves are obtained that partition the phase space, revealing how the interplay between antigenicity and the Allee threshold influences tumor fate. The bifurcation structure identified in this enhanced cancer model provides a mechanistic framework for interpreting the three phases of cancer immunoediting, elimination, equilibrium, and escape in terms of underlying mathematical thresholds. These insights improve our theoretical understanding of tumor progression and may guide future therapeutic strategies that exploit immune response and tumor viability thresholds.



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sciforum-171747: Complex eigenvalues of the Schrödinger equation with a Gaussian barrier

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The Schrödinger equation with a unidimensional Gaussian potential barrier admits a finite number of complex eigenvalues associated with purely outgoing wavefunctions, called resonances.

We compute the resonances for this problem with varying barrier strength parameter by means of the well-known Rayleigh–Ritz method (RR) with complex rotation, using a harmonic oscillator basis set, and the Riccati–Padé method (RPM), which is based on the application of a Padé approximant to the Riccati equation for the regularized logarithmic derivative of the wavefunction. The latter method does not need to perform a complex rotation explicitly. We also show that a second set of complex eigenvalues exists, which is obtainable by both methods; in the case of the RR method, the computation of either of them requires different choices of the rotation parameter, setting it to be either below or above a certain threshold, respectively, whereas the RPM yields both sets of resonances. The lowest-lying eigenvalues of the second set are close to the resonances of the first set.

We perform a simple asymptotic analysis of the eigenfunctions, which allows us to determine the threshold value of the complex rotation parameter, as well as analyze the characteristics of both sets of eigenfunctions.

Finally, we draw parallels with similar results obtained in previous examples that present similar behavior, such as the radial exponential potential barrier and a well-known barrier potential that presents pre-dissociating resonances akin to those found in diatomic molecules.



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sciforum-161792: Computing the Dynamics of Optical Breathers in a Coupled Nonlinear Schrödinger Model with Dispersion Variations

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In this work, we present a systematic and comprehensive analysis of vector breather dynamics in inhomogeneous optical media, modelled through a variable-coefficient coupled nonlinear Schrödinger (vc-CNLS) equation. This generalized model encompasses the fundamental components of Kerr-type nonlinear processes, including self-phase modulation, cross-phase modulation, and four-wave mixing, with temporally varying dispersion and nonlinear coefficients. Such variability effectively captures realistic physical settings where the optical properties of the medium evolve along the propagation direction or over time.

To explore the nonlinear wave dynamics supported by this framework, we construct explicit analytical breather solutions by employing a combination of similarity transformations and Darboux transformation techniques. This approach enables the generation of both Akhmediev breathers, which are localized in time and periodic in space, and Kuznetsov–Ma breathers, which display spatial localization and temporal periodicity. The resulting solutions reveal rich structures with controllable amplitudes, periods, and localization features. Our analysis demonstrates that the inhomogeneous nature of the medium plays a crucial role in shaping the evolution of optical breathers. In particular, variations in system parameters induce a diverse range of dynamical behaviors, including amplification, partial suppression, splitting, trapping, asymmetric deformation, and merging of oscillatory localized wave packets. These modulation effects highlight how engineered inhomogeneity can be used to tune or stabilize nonlinear excitations in practical optical systems. Overall, the findings contribute to a deeper understanding of localized coherent structures in variable nonlinear environments and offer potential pathways for controlling breather excitations in advanced optical communication, nonlinear photonic devices, and related applications.



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sciforum-170579: Construction of a special function depending on the basic reproduction number R0 and mathematical modeling of the dynamics of three entities: the immune system, medication, and nutrition.

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Mathematics can be divided into two main categories: applied mathematics and fundamental or theoretical mathematics. Special functions have contributed and continue to contribute to the advancement of science in general and mathematics in particular. Among these functions are the Laplace transform, the Riemann zeta function, the basic reproduction number R_{0}, the Fourier transform, the Stieljest integral, the Lebesgue integral, $\cdots$. All these functions have made it possible, at crucial moments in the history of mathematics, to solve linear and nonlinear partial differential equations, cryptography, number theory, $\cdots$.\\ In this paper, we construct a special function Φ_{m} depending on the parameter R_{0} and the independent vector $x\in\mathbb{R}^{m}$ of size $m\in\mathbb{N}^{\ast}$. The basic reproduction number R_{0} is by definition the average number of new infections in an environment from an already infected individual. In other words, based on an infected individual, the R_{0} provides information on the average number of people that individual can infect in a healthy environment. This number does not take into account the nature of the disease, the patient's genetic material or immune system, their family tree, or herd immunity. Through this special function Φ_{m}, we propose to take into account additional parameters that are much more realistic and adapted to physical realities. The independent variable x is of dimension $m\in\mathbb{N}^{\ast}$, i.e., $x=(x_{1},x_{2},\cdots,x_{m})\in\mathbb{R}^{m}$, and the dependent variable $\Phi_{m}(R_{0},x)$ is the special function. We first justify that the special function constructed is well defined. We then propose a qualitative analysis (continuity, differentiability, metric space, $\cdots$) of this special function. Finally, we propose a conceptual framework for applying this special function to the mathematical modeling of the interactive dynamics of three entities: the immune system, drugs, and nutrition.



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sciforum-174531: Convergence and Error Analysis of Explicit Finite Difference Schemes Applied to the Burgers–Advection–Diffusion–Reaction Coupling

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This work presents a numerical study of the coupling between the Burgers equation with a source term and the advection–diffusion–reaction equation in one spatial dimension, employing an explicit finite difference scheme. The formulation considers the Burgers equation as the governing model for the evolution of the velocity field, whose solution is subsequently used in the transport equation as the convective velocity at the current time step, thereby characterizing a sequential coupling between nonlinear advection and diffusion phenomena. The adopted discretization is based on the forward Euler method for the transient term, combined with second-order centered approximations for the first- and second-order spatial derivatives. The study focuses on the investigation of the consistency, stability, and convergence properties of the numerical scheme, with a particular emphasis on the influence of the spatial (dx) and temporal (dt) discretization steps on solution accuracy. The error analysis is conducted using standard norm-based metrics, enabling the quantification of convergence rates and the identification of regimes in which temporal and spatial truncation errors dominate the solution. Stability constraints associated with convective and diffusive terms are examined, along with the effects of inter-equation coupling on the propagation of numerical errors. The results demonstrate the sensitivity of the explicit scheme to the discretization parameters and highlight conditions under which the coupled system preserves stable and convergent behavior. This study contributes to a deeper understanding of the performance of explicit schemes in nonlinear coupled systems relevant to transport phenomena, simplified fluid dynamics, and reactive process modeling.



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sciforum-170505: Cosmological and Thermodynamic insights into Barrow- Ricci-Gauss- Bonnet Holographic Dark Energy in the Symmetric Teleparallel Framework of f(Q) Gravity.

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The investigation of dark energy models outside of general relativity and mainstream cosmology has been driven by observational evidence of the universe's accelerating expansion. In this work, we create a new Barrow–Ricci–Gauss–Bonnet holographic dark energy (BRGB–HDE) model in the context of symmetric teleparallel gravity, in which the non-metricity scalar Q is used to characterize gravity via f(Q). The suggested scenario easily unifies holographic dark energy corrections resulting from curvature invariants with the geometric consequences of non-metricity by integrating Barrow's entropy deformation parameter Δ . This results in a more comprehensive description of cosmic acceleration. We study the model's cosmic dynamics by examining various forms of interaction between dark energy and dark matter, which allows for energy exchange within the dark sector. To assess the model's physical viability and stability, the evolution of important cosmological parameters such as the equation of state and the squared speed of sound is examined. We recreate the f(Q) function that aligns with the hypothesized holographic dark energy density and interaction method. Furthermore, the generalized second law of thermodynamics (GSLT) is investigated using the Barrow entropy formalism, with the apparent horizon of the Universe taken into account. Our findings show that the GSLT is still valid for a wide and physically tolerable range of model parameters. Notably, the model demonstrates smooth transitions between the quintessence and phantom regimes, demonstrating its ability to simulate various stages of cosmic evolution. The suggested BRGB-HDE model in f(Q) gravity offers a consistent and thermodynamically plausible framework for understanding late-time cosmic acceleration.



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sciforum-172620: Degenerate Mittag-Leffler Function via the Degenerate Pochhammer Symbol

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We introduce a coefficient-degenerate analogue of the three-parameter Mittag-Leffler function by replacing the classical rising factorial $(\gamma)_n$ in the numerator with the degenerate Pochhammer symbol $(\gamma)_{\lambda,n}$ associated with the degenerate gamma function Γ_λ, while keeping the standard scaling $\Gamma(\alpha n+\beta)$ in the denominator. Assuming an explicit nonresonance (pole-avoidance) condition that guarantees finiteness of $(\gamma)_{\lambda,n}$ for all $n\ge0$, we prove that the defining power series converges for every $z\in\C$ and hence defines an entire function $E^{[\lambda]}_{\alpha,\beta;\gamma}(z)$. The deformation depends continuously on λ and recovers the Prabhakar function as $\lambda\to0^{+}$. We represent $E^{[\lambda]}_{\alpha,\beta;\gamma}$ as a Fox–Wright function and derive coefficient bounds and sharp growth estimates, including the order of the resulting entire function. For the special case $\alpha=1$, we obtain a closed form in terms of a degenerate confluent hypergeometric function, which is convenient for symbolic manipulation and computation. Using these representations, we establish shift relations for Riemann–Liouville fractional integrals and derivatives that parallel the classical Prabhakar calculus. A Laplace transform pair is proved and used to construct a one-parameter, closed-form deformation of the Havriliak–Negami transfer function, yielding analytically tractable relaxation kernels for non-Debye linear response in complex media. Finally, we develop a numerically stable evaluation based on rigorous a posteriori truncation bounds and illustrate the impact of coefficient degeneracy through computational experiments.



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sciforum-177744: Dual Quaternion-Based 6 DOF State Estimation : Mathematical Foundations of Relative Navigation in Large Group of Spacecraft Systems.

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Traditional aerospace navigation often decouples attitude (orientation) from position (translation), using quaternions for the former and Cartesian vectors for the latter. However, in modern proximity operations such as autonomous docking, satellite servicing, and formation flying, the physical coupling between these two motions becomes significant. Our research proposal addresses the critical challenge of precise relative navigation within large-scale distributed spacecraft systems, where traditional decoupled representations of translation and rotation often fail to capture the complex kinematic coupling inherent in six-degree-of-freedom (6-DOF) maneuvers. In others words, our project aims to exploit the algebraic properties of dual quaternions to directly model these coupled dynamics, thereby improving the accuracy, computational efficiency, and robustness of state estimation in large space systems. The first phase of the project involves the rigorous formulation of a relative state error model. By applying the dual velocity transformation, we combine angular velocity and linear velocity into a single dual vector. The second task focuses on the development of a Multiplicative Extended Kalman Filter (MEKF) adapted specifically for the dual quaternion manifold. Unlike standard Euclidean filters, this architecture preserves the unit constraint of the dual quaternion through an error-state approach, facilitating distributed state estimation across large swarms. The final task establishes theoretical rigor through a stochastic stability analysis. By constructing a Lyapunov-like candidate function based on the dual quaternion geodesic distance, we prove that the estimation-control loop remains bounded under Gaussian perturbations. The proposed result is a robust, computationally efficient estimation framework that achieves a notable improvement in convergence rates and significantly lower steady-state error compared to traditional decoupled Extended Kalman Filter methods, providing a scalable solution for autonomous proximity operations in complex satellite constellations.



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sciforum-174508: Dual Quaternion-Based 6-DOF State Estimation: Mathematical Foundations of Relative Navigation in Small Groups of Spacecraft Systems

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Our research establishes a rigorous mathematical framework for the six-degree-of-freedom (6-DOF) relative navigation of interconnected spacecraft using unit dual quaternions. Unlike traditional methods that decouple translational and rotational kinematics, often leading to singularities or inaccuracies in highly dynamic proximity operations, dual quaternions provide a unified, compact, and singularity-free representation of rigid body motion. By leveraging the Principle of Transference, we extended classical quaternionic rotation theory to encompass the full Euclidean group SE(3), treating the spacecraft's pose as a single algebraic entity. This approach inherently respects the natural coupling between orientation and position, which is critical for the precision required in docking and formation flying. Our project, focusing on the analytical derivation of relative motion equations without the use of stochastic filters, ensuring a deterministic foundation for state estimation, is structured around three primary tasks. Firstly, we developed the derivation of the dual quaternionic kinematic and dynamic equations of motion for a leader–follower spacecraft configuration. Secondly, we provided a proposal formulation of a closed-form analytical solution for relative pose estimation based on line-to-line and point-to-point correspondences. Finally, we developed a coordinate-invariant interpolation scheme for smooth trajectory generation between discrete states. Results demonstrate that the dual quaternion framework reduces the computational overhead associated with homogeneous transformation matrices by eliminating the need for frequent orthogonalization, replacing it with a simpler normalization process. Furthermore, the implementation in MATLAB for numerical validation and Python for high-fidelity visualization confirms that the proposed mathematical foundations provide superior accuracy in representing screw-based displacements, effectively mitigating gimbal lock and ensuring robust relative navigation for small satellite clusters.



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sciforum-165755: Dynamical analysis of the cervical cancer epidemic model through the Levenberg-Marquardt algorithm in conjunction with artificial neural networks

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Cervical cancer, one of the deadliest diseases, is becoming a serious public health issue. In particular, developing countries face a significantly higher burden due to a lack of diagnostic and treatment facilities. In 2022, cervical cancer accounted for over 350,000 deaths and 660,000 new cases, making it the fourth most prevalent disease among women globally. Almost 94% of all deaths were reported in nations with low and middle incomes. Chronic infection with high-risk strains of the human papillomavirus (HPV) is the primary cause of this disease. The research developed a cervical cancer epidemic model to analyze the transmission dynamics of human papillomavirus (HPV) infection and the progression of cervical cancer. The existence, uniqueness, non-negativity, and boundedness of the model's solution are demonstrated. Two types of equilibrium points, disease-free equilibrium and endemic equilibrium, are calculated. The stability of both equilibrium points is also discussed. In order to identify the parameters that significantly contribute to the spread and persistence of the disease in the population, sensitivity indices are determined. Numerical simulation is performed through the Levenberg-Marquardt algorithm in conjunction with artificial neural networks (LM-ANNs), which support our analytical findings. The LM-ANNs' effectiveness, precision, reliability, validity, efficacy, accuracy, and convergence rate are evaluated through time series analysis, regression analysis, examination of the training state, evaluation of error histograms, convergence analysis, and the calculation of both absolute errors and statistical metrics. The numerical results are supported by analytical results.



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sciforum-172945: Dynamics of SIRDS epidemic model with fractional Brownian motion

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In this study, we explore a stochastic SIRDS epidemic model that is influenced by fractional Brownian motion (fBm) with a Hurst index $H \in (1/6, 1/2)$. By integrating stochastic fluctuations into the transmission rate, we develop a four-compartment framework, which is represented through two ordinary differential equations and two stochastic differential equations driven by fBm. Utilising the symmetric stochastic integral, along with a version of Itô's formula tailored for fBm and a suitably constructed random Lyapunov function, we establish the existence and uniqueness of a global, positive solution. We subsequently derive sufficient conditions that guarantee the extinction of the disease. For the numerical simulations, we generate sample paths of fBm using the Fast Fourier Transform method (FFT) and apply a modified Euler scheme to manage the resulting fBm increments. The model parameters are calibrated based on empirical epidemiological data, enabling us to evaluate how well the simulated infection paths align with the observed dynamics by identifying the parameters that best fit our context. We specifically compared two simulated infection trajectories corresponding to $H = 0.38$ and $H = 0.5$. This comparison indicated that the Hurst index has a significant impact on the model's dynamics. By employing error metrics to support our conclusions, we found that $H = 0.38$ corresponds more closely with the data than $H = 0.5$, thereby making it the most appropriate choice for our scenario.



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sciforum-173858: Effects of Generalized Uncertainty Principle on the Solutions of the Friedman Equations

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The Generalized Uncertainty Principle (GUP) represents a fundamental modification to Heisenberg's uncertainty principle, incorporating quantum gravitational effects through the introduction of both minimal and maximal length scales. In this work, we investigate the cosmological implications of GUP by examining its effects on the solutions of the Friedmann equations across different evolutionary eras of the universe. We employ the Hamiltonian formalism to derive modified Friedmann equations that incorporate GUP corrections. The Hamilton procedure provides a systematic framework for obtaining these quantum-corrected gravitational equations while preserving the consistency of the theoretical structure. To solve these modified equations, we apply the classical perturbation method, treating GUP corrections as small perturbations to the standard cosmological solutions. This approach allows us to obtain analytical expressions for the modified cosmological parameters while maintaining tractability. Our analysis spans multiple epochs of cosmic evolution, including the radiation-dominated, matter-dominated, and dark energy-dominated eras. For each epoch, we derive the corresponding modified solutions and analyze how GUP-induced corrections alter the universe's expansion dynamics. We place particular emphasis on the Cosmic Microwave Background (CMB) era, which provides robust observational constraints on cosmological models. Using our GUP-modified framework, we compute the corrected value of the Hubble constant and perform a detailed comparison with the observationally determined value from CMB measurements. This comparison serves as a critical test for the viability of GUP modifications in cosmology and enables us to constrain the phenomenological parameters associated with minimal and maximal length scales. Our results contribute to understanding how quantum gravitational effects, as encoded in the GUP framework, might influence large-scale cosmological observables and potentially address tensions in current cosmological measurements.



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sciforum-170646: Energy-Preserving Numerical Methods for Variable-Order Time–Space Fractional Diffusion in Heterogeneous Media

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Anomalous diffusion is a well-documented phenomenon in biological tissues, where complex microstructural features such as cellular crowding, membrane barriers, and heterogeneous extracellular matrices give rise to non-Gaussian transport and long-range memory effects. Classical diffusion models and constant-order fractional equations are often insufficient to capture the spatial variability of diffusion mechanisms observed across different tissue regions. Variable-order fractional diffusion models provide a natural and physiologically meaningful framework to describe such heterogeneous transport processes.

In this work, we propose an efficient and energy-preserving numerical method for a class of time–space fractional diffusion equations with spatially variable fractional order, motivated by anomalous transport in heterogeneous biological tissues. The model incorporates a Caputo time-fractional derivative and a piecewise-defined spatial fractional diffusion operator, enabling the coexistence of distinct diffusion regimes associated with local microstructural properties.

The numerical scheme combines a memory-efficient temporal discretisation of the fractional derivative with a stable spatial approximation of the variable-order operator. A discrete energy functional is constructed, and unconditional stability of the fully discrete scheme is rigorously established through preservation of the dissipative energy structure of the continuous problem. Convergence is proven under mild regularity assumptions.

Numerical experiments in two-dimensional heterogeneous tissue-like domains validate the theoretical results and demonstrate biologically relevant diffusion phenomena, including spatially dependent propagation speeds and effective diffusion barriers induced by microstructural heterogeneity. These results illustrate the limitations of constant-order models and highlight the relevance of variable-order fractional formulations for quantitative modelling of anomalous transport in complex biological tissues.



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sciforum-171638: Exact Lump and Breather Dynamics of a (1+1)-Dimensional Gilson–Pickering Equation

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The Gilson-Pickering equation is a nonlinear partial differential equation that models complex wave propagation, incorporating nonlinear steepening, higher-order dispersion, and mixed derivatives. This paper constructs new exact solutions using analytical methods, focusing on the Hirota bilinear method, which is used to bilinearize the equation, facilitating the derivation of explicit solutions. Rational lump solutions are derived, examining their localized and algebraically decaying properties, providing insight into wave interaction dynamics. Breather solutions are also obtained, capturing oscillatory and time-periodic behavior, highlighting synchronization effects, bound-state formation, and complex collision phenomena. The solutions are analyzed within their mathematical framework, emphasizing distinctive features and physical significance. The results enhance the understanding of nonlinear wave dynamics governed by the Gilson-Pickering equation, offering a foundation for further theoretical and applied investigations of higher-order multidimensional nonlinear models. The study sheds light on intricate dynamics of nonlinear waves, enabling better comprehension of complex wave propagation phenomena in various physical systems, with potential applications in fields like fluid dynamics, optics, and plasma physics. This research opens up new directions in nonlinear science and applied mathematics, enhancing our understanding of complex nonlinear systems and their behavior, and creating many opportunities for future studies and exploration across diverse scientific and engineering applications worldwide.



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sciforum-171493: Exact Traveling Wave Solutions and 3D Visualization of the (2+1)-Dimensional Date–Jimbo–Kashiwara–Miwa Equation

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The Date–Jimbo–Kashiwara–Miwa equation describes the wave diffusion of a physical quantity and plays a central role in modeling nonlinear wave propagation in higher-dimensional integrable systems. It has important applications in plasma physics, fluid mechanics and nonlinear wave theory, where it governs the dynamics of soliton structures, coherent wave packets and other collective excitations. In this study, we investigate the (2+1)-dimensional Date–Jimbo–Kashiwara–Miwa equation, which governs important classes of integrable nonlinear waves in (2+1) dimensions. Using an extended modified auxiliary equation mapping technique, we construct a wide variety of exact traveling wave solutions. These include solitary-wave solutions, kink-type (or shock-type) waves, periodic wave patterns and rational solutions, all expressed in terms of suitable auxiliary-equation basis functions. The resulting solutions provide new explicit forms that enrich the known solution space of the Date–Jimbo–Kashiwara–Miwa equation and generalize or complement previously reported results. To highlight the physical structure and spatial behavior of these solutions, we include corresponding 3D plots that clearly illustrate their wave profiles, amplitude modulation, and localization properties. The combination of analytical construction and graphical visualization demonstrates the effectiveness of the approach in capturing rich wave structures in higher-dimensional integrable equations and contributes to a deeper understanding of exact nonlinear wave propagation in (2+1)-dimensional physical systems.



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sciforum-171142: Existence of global solutions to a nonlinear reaction–fractional diffusion system with anomalous diffusion

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In this work, we consider the following fractional reaction system:
, *in*
, *in*
or for all , on
for all , in
where $u = (u_1, \ldots, u_m)$, $m \geq 2$, Ω is a bounded and regular domain of $\mathbb{R}^N$ with boundary $\partial\Omega$, $N \geq 2$, $u_i = u_i(t, x)$, $1 \leq i \leq m$ for $(t, x) \in Q_T = (0, T) \times \Omega$ and f_i are real functions, the presence of the non-local operator , 01 for all $1 \leq i \leq m$, which accounts for the anomalous diffusion, meaning that the sub-populations face some obstacles that slow their movement, and the constants of diffusion d_i are assumed to be non-negative. f_i: $\mathbb{R}^m \to \mathbb{R}^m$ are regular enough and are non-negative functions in $L^1(\Omega)$ for all cases where $1 \leq i \leq m$.

The local existence in time of the solution is classical. The positivity of the solution stems from the positivity of , which is assumed to be continuous for all cases where $1 \leq i \leq m$.

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sciforum-173287: Existence, Uniqueness, and Stability of distribution-dependent Stochastic Differential Equations Driven by G-Brownian Motion

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McKean-Vlasov stochastic differential equations (MVSDEs), also known as mean-field SDEs, are essential for describing systems where particle coefficients depend on both the individual state and the marginal distribution of the population. While classical theory is well-established, this study explores these equations within the G-expectation framework to address model uncertainty and volatility ambiguity.

We investigate the G-MVSDE under the assumption of Lipschitz continuity for the drift and diffusion coefficients with respect to the state variable and the 2-Wasserstein distance. To establish the existence and uniqueness of solutions, the Picard successive approximation scheme is employed. The convergence of this iterative process is rigorously analyzed using G-stochastic calculus, specifically leveraging the subadditive properties of G-expectation and Burkholder-Davis-Gundy (BDG) type inequalities.

The research demonstrates that the Picard iteration sequence forms a Cauchy sequence in the complete space L2(Ω, C([0, T], R^d)), ensuring convergence to a unique strong solution. Furthermore, we establish the stability of these solutions by deriving quantitative bounds. By applying Gronwall's inequality, we prove that the solution depends continuously on small perturbations in initial conditions and coefficients.

This study advances the theoretical foundation of nonlinear diffusions under G-Brownian motion. By confirming that G-MVSDEs are well-posed and stable, this work provides a robust framework for applications in mean-field games, financial risk management, and large-scale interacting particle systems where uncertainty is a primary factor.



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sciforum-121439: Forecasting West Nile Virus in Maricopa County using climate factors and Bayesian techniques

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Mosquito-borne diseases pose a significant public health challenge, and effective prevention requires accurate forecasting of mosquito populations. In this study, we developed a statistical forecasting framework that leverages climate factors, such as temperature and precipitation, to improve mosquito population predictions in Maricopa County, Arizona. Our approach combines adaptive modeling techniques and filtering methods to infer precise model parameters and address previously observed limitations, particularly the inability to capture spring dynamics in the mosquito population data. By incorporating an Ensemble Kalman Filter (EnKF) method, we estimated time-varying parameters (baseline population growth rate) and static parameters while resolving the spring problem observed in prior models. Using generalized additive models (GAM), we forecasted the baseline population growth rate on a two-week basis and its quantiles, integrating precipitation and temperature data as covariates. These forecasts were further used to run a mechanistic ordinary differential equation (ODE) model to predict mosquito abundance and estimate associated uncertainties. Our iterative framework was applied over a 52-week period, successfully capturing seasonal variations in mosquito populations from 2014 to 2016. The EnKF demonstrated superior performance compared to traditional Markov Chain Monte Carlo (MCMC) approaches for fitting mosquito abundance data. This enhanced methodology provides actionable insights for public health decision-makers, supporting resource allocation and improving outcomes in mosquito-borne disease prevention. Our findings underscore the value of integrating climate data and adaptive filtering techniques to address forecasting challenges, ultimately enabling more effective responses to emerging or reemerging pathogens of mosquito-borne disease risks, which can be driven by human behavior to become a pandemic.



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sciforum-171691: Four Limit Cycles Surrounding a Single Singularity in Planar Differential Systems

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The study of limit cycles is an important topic in the qualitative theory of planar polynomial differential systems, since it helps to understand the periodic behavior of solutions and the global dynamics of nonlinear systems. In many situations arising in applied mathematics and dynamical systems, the existence, number, and distribution of limit cycles provide essential information about the long-term behavior of trajectories. However, obtaining explicit expressions for limit cycles is usually difficult, especially for higher-degree polynomial systems, where the analytical structure of periodic orbits becomes more complicated.

In this work, we study a planar polynomial differential system of degree nine. The system is constructed in such a way that it admits four explicit invariant algebraic curves surrounding the same singular point. These invariant curves are given in explicit form and play a fundamental role in the qualitative analysis of the system. Their presence allows us to investigate the structure of the periodic solutions and the configuration of closed orbits around the singular point.

First, we prove that the considered system possesses four invariant algebraic curves and determine their explicit expressions. Then, by applying a result reported by J. Giné and M. Grau, we show that each of these invariant curves corresponds to a limit cycle of the system. Consequently, the system admits four algebraic limit cycles surrounding the same singular point, and explicit expressions for these limit cycles are obtained.



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sciforum-171465: Fractional-Time Jaynes–Cummings Model with Unitary Description: Dynamics for Binomial State of Light

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Fractional calculus provides useful extensions to models based on ordinary calculus, enabling the description of physical effects such as dissipation and memory. A notable application of this framework in quantum mechanics is the fractional-time Schrödinger equation (FTSE), in which the standard time derivative is replaced by a Caputo derivative carrying a power-law memory kernel. This modification, however, inherently leads to non-unitary evolution of the quantum state. In this work, we apply the FTSE within the paradigmatic Jaynes–Cummings (JC) model to study the evolution of a binomial state of light interacting with matter. The binomial distribution that characterizes the binomial states possesses both coherent and number states as special cases, while the JC model is a cornerstone for studying quantum light–matter interactions, with experimental validation in cavity quantum electrodynamics and applications in quantum information processing. To restore unitarity in our analysis, we follow a recently introduced technique based on time-dependent Dyson maps -- invertible operators $\eta(t)$ that relate the unitary $\left(\hat{u}(t)\right)$ and non-unitary $\left(\hat{U}(t)\right)$ evolution operators via $\hat{u}(t) = \eta(t)\hat{U}(t)\eta^{-1}(0)$. Three distinct binomial distributions are analyzed with population inversion as the primary figure of merit. We show how different derivative orders $\left(\alpha\right)$ distinctly influence the dynamics: a decreasing number of oscillations $\left(\alpha=0.75\right)$, periodicity $\left(\alpha=0.50\right)$, and aperiodicity $\left(\alpha=0.40\right)$.



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sciforum-139558: Fundamental Incompatibility of the Yang–Mills Mass Gap and Asymptotic Freedom within Continuum Quantum Field Theory

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The existence of a mass gap in non-abelian Yang–Mills theory is a cornerstone prediction related to quark confinement, strongly supported by experimental observations and lattice simulations. The Clay Mathematics Institute designated its rigorous proof within continuum Quantum Field Theory (QFT) as a Millennium Prize Problem. Standard formulations rely on Osterwalder–Schrader (OS) axioms to ensure well-defined relativistic QFT possessing asymptotic freedom and the empirically verified weakening of interactions at high energies. This paper demonstrates a fundamental incompatibility between these established requirements. By analyzing the analytic structure of gauge-invariant two-point correlation functions via the Källén–Lehmann spectral representation (implied by OS axioms) constrained by the mass gap, and confronting it with the specific asymptotic behavior dictated by asymptotic freedom (derived from Renormalization Group analysis), a mathematical contradiction is rigorously derived. Specifically, the polynomial and logarithmic structure required by asymptotic freedom at a high momentum cannot be reconciled with the asymptotic behavior allowed by the spectral representation for a theory with a mass gap and satisfying OS axioms. This incompatibility strongly suggests that the premise of a fundamental spacetime continuum, underlying standard QFT formulations, is inconsistent with the observed physical reality of the mass gap and asymptotic freedom. This paper challenges this mainstream understanding: it argues that the very attempt to combine the standard axiomatic framework (OS axioms) with the physical requirements of a mass gap and asymptotic freedom in a *continuum* setting leads to a mathematical contradiction. The problem, therefore, might not be *how* to construct it, but whether it *can* be constructed at all under these combined assumptions in a continuum.



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sciforum-170792: HEXAGONAL METRICS AND GOLDEN-RATIO SPIRALS: A METRIC ORIGIN FOR GOLDEN-ANGLE PHYLLOTAXIS

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Hexagonal order recurs throughout nature as a locally energy-minimising arrangement for equal-radius interactions, from soap froths to bee combs to the densest circle packings. Logarithmic spirals, and in particular the golden-angle phyllotactic spiral, also arise across biological and physical systems, where new units accrete by a constant turn at multiplicatively increasing radii. This paper advances a coherent mathematical account linking these two motifs by proposing that the metric governing local interactions plays the decisive role. We formalise a hexagonal metric as a Minkowski norm whose unit ball is a regular hexagon and analyse constant-turn, multiplicative growth in this metric. We prove that such growth generates logarithmic spirals in the continuum limit and that the choice of the turn angle, maximising the asymptotic uniformity of placements, is uniquely achieved by the golden angle $\alpha^\star = 2\pi/\varphi^2$, where $\varphi = (1+\sqrt{5})/2$ is the golden ratio. The optimality criterion is expressed through minimal pairwise distance under the hexagonal norm, which we connect to the Diophantine properties of the turn angle. Specifically, we show that the golden ratio's extremal irrationality allows the spiral to best avoid the "resonant" directions of the sixfold anisotropic potential, thereby minimizing crowding. The theory explains why systems that experience local interactions with sixfold symmetry naturally express golden-angle spirals at mesoscopic scales, even when no overt hexagonal lattice is visible in Euclidean space. This yields testable predictions distinguishing this metric origin from purely Euclidean models, including specific parastichy counts, anisotropic Voronoi cell statistics, and the presence of spectral sidebands at multiples of $\pi/3$ in the angular structure factor.



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sciforum-172335: Impact of Non-Uniform Heating on Flow and Heat Transfer in a Square Cavity: A DRBEM Study

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This study presents a numerical investigation of natural convection and heat transfer in a square cavity subjected to non-uniform wall heating. A spatially varying heat source is imposed on the left vertical wall, while the right vertical wall is maintained at a uniform cold temperature, and the horizontal walls are assumed to be adiabatic. The main objective is to analyze the effects of heater non-uniformity and position on flow structure, fluid mixing, and convective heat transfer characteristics within the enclosure.

The governing equations, expressed in terms of stream function, vorticity, and temperature, are solved using the Dual Reciprocity Boundary Element Method (DRBEM). In this framework, the fundamental solution of the Laplace equation is employed for the stream function equation, whereas the vorticity transport and energy equations are transformed into modified Helmholtz form and solved using the corresponding fundamental solution. This transformation is achieved by introducing a relaxation parameter into the Laplacian terms, while time derivatives are discretized using a forward difference scheme. The adopted approach eliminates the need for an additional time integration procedure and provides enhanced numerical stability, in addition to the computational efficiency offered by the boundary-only discretization.

Numerical simulations are carried out for Rayleigh numbers ranging from 10^3 to 10^6 and for various values of the non-uniformity parameter β in the interval $[-2, 2]$. The results demonstrate that both the flow intensity and the average Nusselt number increase with increasing Rayleigh number and β, indicating a significant enhancement in convective heat transfer. Furthermore, the heater distribution is shown to have a pronounced influence on the thermal and hydrodynamic fields. These findings highlight the critical role of non-uniform heating patterns in optimizing heat transfer performance in natural convection systems.



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sciforum-169661: Impacts of Time-Varying Aspiration on Vaccination Behavior and Epidemic Control

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Individual aspiration plays a central role in shaping vaccination decisions and epidemic outcomes. Recent studies have shown that higher aspiration toward immunity can increase vaccine uptake and reduce the social efficiency deficit (SED) [1–4]. However, aspiration in reality is rarely constant. People's motivation to vaccinate can rise during outbreaks when the risk of infection becomes salient, and decline when cases fall or vaccine fatigue develops. To address this limitation, we extend the aspiration-based vaccination model of Khatun et al. [1] within a SEIRS epidemic framework by incorporating time-varying aspiration. Two simple mechanisms are considered: (i) **prevalence-driven aspiration**, where aspiration increases with the number of infectious cases, and (ii) **time-decaying aspiration**, where aspiration gradually declines in the absence of strong risk perception. Using mean-field analysis and numerical simulations, we investigate how dynamic aspiration influences epidemic prevalence, vaccination coverage, and the social efficiency deficit (SED) compared to fixed aspiration levels. Our findings reveal that prevalence-driven aspiration can generate rapid increases in vaccination during outbreaks, effectively suppressing infection peaks, while time-decaying aspiration may lead to delayed responses and higher long-term infection burdens. These results highlight the importance of incorporating dynamic behavioral motivation into vaccination game models and suggest that public health strategies could benefit from actively sustaining aspiration levels over time.

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sciforum-173480: Invasion Dynamics of Microsporidia in a Sex- and Stage-Structured Mosquito Population Under Chemical Control Interventions

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Introduction: Microsporidia MB are naturally occurring, vertically and horizontally transmitted symbionts of mosquitoes that can influence reproductive outcomes. Understanding their invasion dynamics is essential for clarifying their ecological role and interaction with conventional vector control strategies. This study presents a mathematical framework to examine the establishment and persistence of microsporidia MB in a mosquito population exposed to chemical interventions.

Methods: We formulate and analyse a deterministic compartmental model structured by infection status, sex (male and female), and developmental stage (eggs, larvae, and adults). The model incorporates vertical transmission, horizontal transmission through mating, and reduced egg viability associated with specific mating combinations. Larval and adult control measures are represented through compliance and efficacy parameters that increase stage-specific mortality. The basic reproduction number is derived using the next-generation matrix method. Local stability is determined via eigenvalue analysis of the Jacobian matrix, while global stability is established using a quadratic Lyapunov function. Numerical simulations explore the influence of key biological and control parameters on infection prevalence and overall population dynamics.

Results: The analysis establishes threshold conditions governing invasion and persistence. The infection-free, complete-infection, and coexistence equilibria are shown to be locally stable under appropriate reproduction number conditions. Vertical transmission efficiency and egg viability parameters are critical for long-term persistence, whereas horizontal transmission accelerates spread after introduction. Chemical control significantly affects both infection prevalence and mosquito abundance, with outcomes depending on coverage and efficacy levels.

Conclusions: The model provides a mechanistic basis for understanding microsporidia invasion in structured mosquito populations and offers quantitative insight into their interaction with chemical control within integrated vector management.



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sciforum-170791: Inverse Modelling through SCE Optimization for the Thermo-Kinetic Characterization of Bio-Based Thermal Insulating Materials

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This work presents a computational methodology to determine the thermo-kinetic parameters governing the fire behaviour of bio-based thermal insulating materials, focusing on foams derived from flax and banana fibres. The methodology combines experimental mass-loss -rate (MLR) data from cone calorimeter tests at 50 kW/m² with a numerical inverse-modelling framework implemented in the solid-phase sub-model of Fire Dynamics Simulator (FDS). A simplified computational representation of the cone calorimeter is employed to accelerate simulations, enabling the use of the Shuffle Complex Evolution (SCE) optimization algorithm to identify the optimal set of parameters.

The proposed methodology estimates key thermal and kinetic parameters under a single-reaction pyrolysis scheme. The optimized FDS models reproduce the experimental MLR curves with high accuracy, achieving mean-squared errors of 1.36×10^{-4} $kg\cdot s^{-1}\cdot m^{-2}$ for flax foam and 1.02×10^{-4} $kg\cdot s^{-1}\cdot m^{-2}$ for banana foam. These results demonstrate the capability of the SCE-driven inverse modelling framework to provide reliable material characterizations, obtaining appropriate thermos-kinetic parameters to reproduce decomposition reactions even in cases with limited prior information. Due to the optimization in the FDS modelling, and to the SCE approach, the proposed methodology requires only approximately one day of computation to identify optimal thermo-kinetic parameters governing decomposition reactions.

The methodology constitutes a robust applied-mathematics tool for modelling fire dynamics in emerging sustainable insulation materials, offering a replicable workflow that supports material development, safety assessment, and integration into computational fire-engineering simulations.



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sciforum-174043: Investigation of Third-Order Refinement Iterative Methods for Solving Linear Systems in Engineering Applications

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The numerical solution of linear systems is fundamental in engineering fields, such as structural analysis, heat transfer, fluid mechanics, and electrical circuit modeling. These applications typically generate systems of the form Tx = u, which may be large, sparse, and moderately ill-conditioned. Refinement-based iterative techniques have been developed to improve convergence characteristics of stationary schemes. This study focuses on the application of existing third refinement iterative methods to engineering linear system problems, with particular emphasis on evaluating their relative computational performance. Engineering-based linear systems were formulated from representative application models and expressed in standard matrix form. Selected third refinement methods, specifically the Third Refinement Jacobi (TRJ) and Third Refinement Gauss-Seidel (TRGS) schemes, were implemented and applied to the test problems. Convergence analysis was conducted using spectral radius criteria derived from the associated iteration matrices. Performance assessment was based on spectral radius, iteration number required to meet a prescribed tolerance, CPU time, and convergence rate. Results were systematically organized in comparative tables. Numerical finding indicates clear performance variation between the refinement schemes. Methods with smaller spectral radii required fewer iterations and reduced computational time. In particular, TRGS demonstrated faster convergence and improved computational efficiency compared to TRJ for the tested engineering problem. The study confirms that third refinement iterative methods are effective for solving engineering linear systems, with performance strongly influenced by spectral properties. These methods provide reliable and computationally efficient solvers for practical engineering applications.



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sciforum-170500: Late-time Acceleration and Inflationary Dynamic in f(Q, L_m) Gravity with RGUP Corrections

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In this study, we investigate the cosmological implications of symmetric teleparallel gravity models based on the function f(Q, Lm), where Q is the non-metricity scalar and Lm is the matter Lagrangian. The function f(Q, Lm) allows a natural way of including non-minimal matter-geometry couplings in a second-order formulation. The more minimal and physically motivated polynomial form is analyzed as a possibility to encompass both the early and late-time acceleration of the universe in a single scenario.

In the late universe, we consider the modified Friedmann equations within a spatially flat FLRW background. The model is compared to observational data within the context of a Bayesian analysis. The datasets considered are type Ia supernovae, cosmic chronometers, and BAO observations. The analysis shows that the parameter representing the coupling of matter to geometry is only weakly constrained by the existing observational data, suggesting a near degeneracy to the standard model expansion history.

At high curvature applicable to the early universe, the theory reduces to a quadratic model of non-metricity without extra scalar fields and produces Starobinsky inflation. The predictions for the spectral index (η_S) and tensor-scalar ratio (r) are in accordance with the 2018 Planck constraints.

To extend our study further into the quantum gravity reime, we add corrections due to RGUP in the form of deformation of the metric in a momentum-dependent fashion, which in turn affects matter propagation on top of this same gravitational background, making a non-negligible contribution to the running of some of the inflationary parameters, in particular the spectral index, thus resolving the degeneracy with the classical attractor solution.

In summary, our work demonstrates that the f(Q, Lm) gravity is a well-established set of geometry that is able to account for late-time acceleration, inflation, and quantum geometry in one consistent scheme.



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sciforum-173680: Logarithmic Traveling Wave Solutions of a Nonlinear Tzitzéica–Dodd–Bullough equation via the φ^6-Expansion Method

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In this study, exact analytical solutions of the nonlinear Tzitzéica–Dodd–Bullough (TDB) equation are obtained by employing the φ^6-expansion method. The TDB equation is an important nonlinear evolution model that arises in several areas of applied mathematics and physics, including differential geometry, plasma physics, nonlinear field theory, and wave propagation phenomena. By introducing an appropriate traveling wave transformation, the governing nonlinear partial differential equation is reduced to an ordinary differential equation, which is subsequently solved using a systematic algebraic procedure associated with the φ^6-expansion framework. The resulting solutions are expressed in logarithmic forms, leading to diverse classes of nonlinear wave structures such as solitary waves, periodic waves, and singular wave profiles. These analytical expressions reveal the rich dynamical behavior of the model and provide insight into the influence of system parameters on wave amplitude, localization, and propagation characteristics. Furthermore, the obtained results demonstrate that the proposed method offers an efficient and reliable mathematical tool for constructing exact solutions of nonlinear equations involving exponential nonlinearities. The derived solutions may also serve as useful benchmarks for validating numerical simulations and for investigating nonlinear wave interactions in related physical systems. Overall, this work contributes to the theoretical understanding of nonlinear wave dynamics and highlights the applicability of the φ^6-expansion method to a broad class of nonlinear evolution equations arising in applied science and engineering contexts.



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sciforum-165733: Mathematical Analysis of a Fractional-Order Model for Monkeypox Dynamics

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In this study, a fractional-order mathematical model is proposed to describe the transmission dynamics of Monkeypox using the Caputo fractional derivative, which effectively captures memory effects and long-range temporal dependencies inherent in disease spread processes. The population is divided into epidemiologically relevant compartments, and the qualitative behaviour of the resulting fractional system is rigorously investigated. Fundamental properties such as positivity and boundedness of solutions are established, ensuring the biological feasibility and well-posedness of the model. The basic reproduction number, R_0, is derived using the next-generation matrix approach and is identified as a key threshold parameter that governs the persistence or extinction of the disease within the population. Local stability analysis reveals that the disease-free equilibrium is locally asymptotically stable when $R_0$1, whereas for R_0>1, the system admits a unique endemic equilibrium that is also locally asymptotically stable. To reduce the disease burden while balancing the costs associated with intervention strategies, an optimal control problem is formulated by incorporating time-dependent controls representing vaccination of susceptible individuals, isolation of infectious cases, and treatment of infected individuals. The necessary conditions for optimality are derived using Pontryagin's maximum principle, leading to a coupled system of state and adjoint equations. Numerical simulations based on the Adams–Bashforth–Moulton predictor–corrector method are performed to validate the analytical findings and demonstrate the effectiveness of the proposed control strategies in significantly reducing Monkeypox transmission.



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sciforum-171362: Mathematical Analysis of the Impact of Vertical Transmission on Cassava Mosaic Disease Control and Harvest Quantity and Quality

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Abstract

Introduction: Cassava, a key carbohydrate staple in low-income countries, is severely affected by cassava mosaic disease (CMD), primarily transmitted via infected stem cuttings and whiteflies with East African cassava mosaic virus and African cassava mosaic virus (ACMV) being the most significant. ACMV affects all cassava-growing regions of sub-Saharan Africa, India and southern Asia leading to widespread infection rates of 80-100% among crops and yield losses between 20-90%, hence the need to further study the transmission dynamics and possible controls.

Objectives: The objective is to investigate the transmission dynamics and control of CMD by examining the effects of resistant efficacy on infectious cassava. **Methods:** A deterministic compartmental model governed by a six-dimensional system of ODE was formulated to describe the transmission dynamics and control of CMD between the interacting cassava and whiteflies populations. A piecewise-constant resistant efficacy rate was included to assess its impact on infected cassava transmission dynamics. The control reproduction number, R_e, was calculated using the Next-generation matrix method via Maple. This threshold quantity was used to study the asymptotic behaviours of the disease-free equilibrium (DFE) and endemic equilibrium (EE) of the model. Numerical simulations demonstrated how varying resistant efficacies affect disease dynamics in both susceptible and infectious cassava.

Results: It was found that the DFE (EE) is both locally and globally asymptotically stable whenever R_e1 ($R_e>1$) and unstable otherwise. Sensitivity analysis revealed that resistance efficacy and roguing efforts positively influenced the dynamics of CMD.

Conclusion: The results suggest that increasing the resistance efficacy toward 1 significantly reduces new cases of CMD and increasing roguing efforts considerably result to healthier, better quality and quantity of harvested cassava.

Keywords: cassava mosaic; resistant plants; non-resistant plants; control reproduction number; roguing.



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sciforum-173984: Mathematical Modeling and Surface-Based Quantification of Hemodynamics in Abdominal Aortic Aneurysms

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Introduction:

Abdominal aortic aneurysm (AAA) rupture risk is primarily assessed by maximum diameter, although biomechanical and hemodynamic mechanisms play a central role in wall degeneration and thrombus formation. From a fluid-mechanics standpoint, pathological remodeling is associated with low shear magnitude and oscillatory near-wall flow. This study formulates AAA evaluation as a patient-specific computational hemodynamics problem with spatial quantification of adverse shear environments.

Methods:

Fifteen AAA and ten healthy infrarenal aortic geometries were reconstructed and discretized using unstructured tetrahedral meshes with boundary layer refinement. Blood flow was modeled as an incompressible Newtonian fluid governed by the unsteady three-dimensional Navier–Stokes equations. Pulsatile inlet conditions were derived from a validated multiscale (0D–1D) cardiovascular model, and three-element Windkessel (RCR) boundary conditions were imposed at the iliac outlets. Hemodynamic indices were computed over the cardiac cycle: Time-Averaged Wall Shear Stress (TAWSS), Oscillatory Shear Index (OSI), and Relative Residence Time (RRT). The percentage of vessel surface exceeding pathological thresholds was quantified regionally.

Results:

AAA geometries exhibited significantly greater surface exposure to low TAWSS and elevated RRT compared with healthy controls (p 0.001), indicating expanded regions of flow deceleration and prolonged near-wall residence. OSI showed weaker discriminatory capability in the infrarenal region. Disturbed flow patterns extended beyond the aneurysm sac into adjacent segments.

Conclusions:

Surface-based mathematical characterization of shear stress distributions enhances discrimination between healthy and aneurysmal aortas. The combined metrics TAWSS and RRT provide stronger predictive insight than oscillatory measures alone, supporting their integration into quantitative AAA risk modeling.



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sciforum-154395: Mathematical Modeling of Adaptive Fishery Management Using Reinforcement Learning

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The application of mathematical modeling plays a crucial role in understanding and managing marine species and their exploitation. This study explores the integration of bioeconomic modeling and artificial intelligence to optimize fishery management while promoting ecosystem sustainability. Following our previous research, "Bioeconomic Modelling for the Sustainable Exploitation of Three Key Marine Species in Morocco," the present work builds upon that foundation by extending the existing model and integrating additional biological and economic parameters to enhance its realism and predictive capacity. We first provide a general overview of bioeconomic models, highlighting previous research and the dual objectives of profit maximization and ecological preservation. We then introduce a mathematical model representing the exploitation of a single species within a three-species marine ecosystem. A detailed mathematical analysis is conducted to identify equilibrium points that ensure the persistence of all species, along with their positivity, boundedness, and stability. Building on this foundation, we apply Reinforcement Learning (RL) to the model, demonstrating how AI techniques can guide adaptive harvesting strategies. Finally, we perform a sensitivity analysis on key parameters influencing the RL implementation,

providing insights into the robustness and effectiveness of the approach. Our findings highlight the promising potential of combining bioeconomic theory, mathematical modeling, and AI-driven optimization methods to achieve sustainable marine resource management, and encourage future interdisciplinary research at the intersection of mathematics, ecology, and artificial intelligence.



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sciforum-170194: Mathematical Modeling of Epidemic Spread with Vaccination and Awareness: A Reaction–Diffusion Approach.

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This study presents a comprehensive mathematical model designed to investigate the dynamics of infectious disease spread by integrating two critical

intervention strategies: vaccination and individual awareness. The population is structured into distinct compartments: susceptible, infected, vaccinated, fully aware, and partially aware individuals. In this framework, vaccination serves to reduce the direct risk of infection, while awareness campaigns influence social behavior, thereby slowing down the overall transmission rate. Furthermore, the model accounts for the loss of immunity over time, allowing vaccinated individuals to return to the susceptible class eventually. To capture the spatial dimension of an outbreak, the model is formulated as a system of nonlinear partial differential equations (PDEs) with reaction–diffusion terms. Methodologically, the positivity and global existence of solutions are rigorously established to ensure the model's mathematical and biological consistency. We derive the equilibrium

points, including the disease-free and endemic states, and calculate the basic reproduction number using the next-generation matrix method. Local stability analysis is conducted to evaluate the system's long-term behavior near these equilibria.

Numerical simulations are performed to illustrate the theoretical findings and quantify the impact of spatial diffusion on disease persistence.

The results demonstrate that while awareness significantly mitigates the peak of an epidemic, it is not sufficient to eradicate the disease on its own. In contrast, effective and sustained vaccination programs are shown to be the primary driver in reducing infection levels. This work emphasizes the necessity of combining behavioral interventions with clinical strategies to understand and manage real-world epidemic dynamics in spatial environments.



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sciforum-171352: Mathematical Modeling of Pancreatic Cancer Cell Behavior under Radiotherapy in the Framework of Time Scale Theory

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The objective of time scale theory is to bridge continuous and discrete models and to better capture hybrid dynamics arising in real-world applications. Within the framework of this theory, the dynamics of pancreatic cancer cells under radiotherapy will be investigated by incorporating both continuous and discrete mathematical formulations. In this study, the mathematical model describing pancreatic cancer cell behavior under radiotherapy will first be examined on an arbitrary time scale, allowing for a general representation of tumor growth and treatment effects. For this general case, explicit solutions of the proposed model will be derived, providing analytical insight into the underlying system dynamics. Subsequently, continuous and discrete models will be obtained as special cases of the general time scale formulation, corresponding to classical differential and difference equation models, respectively. A detailed comparison between these continuous and discrete models and their solutions will then be carried out in order to evaluate differences in tumor response and treatment effectiveness. This comparative analysis aims to identify the most appropriate time scale that leads to the fastest and most effective therapeutic response under radiotherapy. By capturing biological processes across different time scales in a unified manner, this approach offers a more realistic and flexible representation of pancreatic cancer dynamics. Ultimately, the proposed modeling framework contributes to a deeper understanding of cellular responses to radiotherapy and may support the development of improved treatment strategies.



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sciforum-173020: Mathematical Modelling of Cumulative Usage Tracking Systems in Smart Devices Using Speedometer-Like Dynamic Measurement Principles.

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In the rapidly evolving digital era, smart devices play a critical role in daily life, yet efficient and automated tracking of device usage remains a significant challenge. Inspired by the operational principles of vehicle speedometers and odometers, this study proposes a mathematical modelling framework for cumulative usage tracking in intelligent electronic devices. The research investigates how dynamic measurement systems, traditionally used in vehicles to record distance as the time integral of velocity, can be adapted to model real-time usage behaviour in smart gadgets.

The proposed model represents device activity as a time-dependent function, where cumulative usage is formulated as an integral of activity rate over time. Using concepts from applied mathematics, dynamical systems, and signal modelling, this study develops a generalized mathematical structure capable of capturing continuous and discrete usage patterns. The framework incorporates sensor-driven input signals, temporal data accumulation, and algorithmic tracking mechanisms to simulate speedometer-like behaviour in modern devices.

Furthermore, the model explores potential applications in smart technology, including smartphones, IoT systems, wearable devices, and automated monitoring platforms, where accurate usage quantification is essential for performance optimization and resource management. The proposed approach contributes to the interdisciplinary intersection of mathematical modelling, computational intelligence, and intelligent system design.

This research aims to establish a theoretical foundation for automated cumulative tracking mechanisms in next-generation smart devices, offering a scalable and mathematically rigorous solution aligned with emerging trends in artificial intelligence and digital instrumentation.



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sciforum-168896: Mathematical models for the mechanics of soft tissues: from linear elasticity to morpho-poroelasticity

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Biological issues are often subjected to forces. In many cases, such as tumor growth or skin contraction, it is crucially important to model the state of tissues that are exposed to forces in order to improve or optimize therapies for different pathologies. The simplest models use linear elasticity as a constitutive law. This linearity enables the use of the superposition principle and the use of fundamental solutions to analyze the influence of multiple points of action of forces. A clear illustration of this principle is the immersed interface method. In this presentation, we discuss this principle in terms of convergence properties.

However, in real-life tissues, the use of linear elasticity is too restrictive due to the presence of moisture and the porous structure of biological tissues. Furthermore, in various biomedical cases, the microstructure of the tissue changes due to cellular activity. For this reason, we construct and use a model that consists of elasticity, porosity and microstructural changes. The mathematical framework is referred to as morpho-visco-poroelasticity. This framework is original and for this reason, we analyze this framework in terms of stability around equilibria. Since numerical solutions can be characterized by spurious oscillations, we provide conditions for monotonicity by mathematical analysis. Furthermore, we propose a numerical stabilization method to avoid spurious oscillations on the forehand.



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sciforum-170840: Modeling a multihost epidemic with seasonal forcing and stochasticity.

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In this study, we examined a continuous-time Markov chain (CTMC) model, conducted a five-type branching process, and studied the influence of seasonal forcing to analyze the different facets of the transmission of Cystic Echinoccocosis among definitive, intermediate, and accidental hosts. First, we studied the deterministic model related to the disease, derived the basic reproduction number, and analyzed the stability of the equilibria to understand the long-term behavior of the infected classes. We then aligned with the CTMC formulation that captured the stochastic amplification of infected definitive hosts, accompanied by a lower burden of infected carcasses than the corresponding deterministic model. The branching process analysis near the disease-free equilibrium quantifies outbreak and extinction probabilities and shows that early epidemic outcomes are primarily driven by the initial numbers of infected definitive hosts and environmental egg burden rather than accidental host infection. Sensitivity analysis identified the death rate of intermediate hosts and environmental parameters as the most critical factors for CE transmission. Moreover, the results of incorporating seasonal forcing highlighted the importance of temporally adaptive control strategies in this context due to the influence of meteorological conditions on parasite egg viability and host behavioral patterns. Overall, the results of our multimodal approach provide rigorous guidance for robust modeling and effective control.



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sciforum-168206: Modeling Driver Sensitivity through Velocity and Headway Dynamics for Safe Autonomous Vehicle Operation

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Currently, global transportation is increasingly focused on autonomous vehicular systems. However, training traffic systems to rely fully on autonomy remains challenging, as evidenced by numerous Tesla Autopilot accidents. Motivated by this, our study addresses a critical aspect: the driver's sensitivity in autonomous vehicles, which plays a key role in enhancing their performance. We developed a novel driver sensitivity function responding to real-time traffic dynamics, formulated in two parts: (i) sensitivity depending on the headway gap between the focal and preceding vehicle, and (ii) sensitivity varying with the velocity difference, quantified using the preceding vehicle's taillight signals.

For the first part, we applied a straightforward formulation inspired by the Optimal Velocity model. Driver awareness increases as the headway shrinks to prevent collisions and decreases with increasing headway due to reduced collision risk. In the second part, sensitivity is modeled using the taillight phenomenon, activated by vehicle acceleration or deceleration. Here, sensitivity escalates with both positive velocity differences, when the preceding vehicle is faster, and negative differences, when the focal vehicle is faster, helping to fill gaps and prevent collisions.

We performed a linear analysis using neutral stability theory, revealing a critical stability line distinct from conventional traffic models. A nonlinear analysis of the headway-based sensitivity produced flow patterns describable by the mKdV wave equation. Finally, numerical simulations were conducted to visualize the internal flow field structures, validating the model's performance under realistic traffic conditions.

This study demonstrates that incorporating driver sensitivity through velocity and headway dynamics provides a robust framework for improving autonomous vehicle operation, enhancing safety and traffic stability while offering new insights for future autonomous traffic system designs.



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sciforum-170744: Modeling Financial Market Stability Using Nonlinear Dynamic Systems with Feedback Control

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In this work we studied a nonlinear dynamic systems model that helps us explain the complicated behavior of financial markets. This model shows how the prices of financial assets affect each other and investors' decisions over time, creating feedback loops. Some of these loops can help keep the market stable, while others may make it more unstable.

First, we will check the well-posedness of this model to make sure that all the equations used give meaningful results when tested under realistic conditions. After confirming that our theoretical model works properly, we will study how stable the model is and find the conditions that help the market stay balanced as well as the conditions that can cause bigger swings.

Regulatory policies, intervention rules, or automated market systems will also be part of applying the theoretical study. The main goal of these types of feedback control mechanisms is to improve market stability and prevent extreme price changes; therefore, their use in crises could be helpful for preventing problems in the future.

We will also run many numerical simulations to show how the model behaves under different situations and control strategies. This will give useful insights into financial market behavior and show how mathematical modeling can help the financial industry. Overall, this study helps explain market dynamics and offers a practical way to help institutions understand and predict future market situation.



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sciforum-172144: Modeling the Impact of Anxiety on Pedestrian Social Group Dynamics During Evacuations

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Understanding pedestrian dynamics within social groups is a key issue in improving crowd safety, particularly in emergency evacuation scenarios. Pedestrians often move in families or friendship groups, and social interactions within these groups strongly influence collective movement patterns, especially under conditions of heightened stress and anxiety. Accurately capturing these effects is therefore essential for realistic modeling and reliable evacuation assessment.

In this study, a kinetic modeling framework is proposed to describe the dynamics of pedestrian social groups in evacuation situations, with a particular emphasis on the role of anxiety. Anxiety is introduced into the model through modifications of pedestrians' preferred velocity, allowing stress-induced behavioral changes such as increased urgency or loss of coordination to be represented at the microscopic level. The resulting kinetic equations govern the time evolution of the pedestrian distribution and reflect both individual motion and group interactions.

To solve the proposed model, a numerical scheme based on the Monte Carlo particle method is developed, enabling efficient simulation of large crowds with complex interactions. A series of numerical experiments is performed to investigate the influence of different anxiety levels on evacuation performance. The simulation results indicate that moderate levels of anxiety may enhance evacuation efficiency by increasing walking speed and coordination within groups. In contrast, excessive anxiety can trigger disorganized movement, local congestion, and inefficient use of space, ultimately leading to longer evacuation times. These findings highlight the nontrivial role of anxiety in crowd dynamics and provide insights for safer evacuation planning and design.



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sciforum-167483: Modeling Vaccination Decisions in Heterogeneous Populations

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In classical vaccination game theory, population groups are typically treated as homogeneous, with individuals assumed to share identical disease risks, cost perceptions, and beliefs about vaccine performance. In this talk, we depart from this assumption and introduce a vaccination game model designed for an infinite population whose members exhibit heterogeneous preferences and characteristics. Specifically, we allow individuals to differ in three key dimensions: (1) their susceptibility to infection, (2) their perceived costs associated with both contracting the disease and receiving the vaccine, and (3) their subjective assessment of vaccine efficacy. We encode this heterogeneity using a quantile function that captures the distribution of agents' net relative vaccination costs, providing a flexible and analytically tractable representation of diverse behavioral responses. Within this framework, we derive an explicit closed-form expression for the Nash equilibrium vaccination rate, offering transparent insights into how population-level behavior emerges from heterogeneous individual incentives. We then demonstrate how our model can be calibrated using real-world survey data to generate empirical predictions about vaccination uptake. A systematic comparison with the standard homogeneous model reveals that our heterogeneous approach yields consistently improved predictive accuracy, particularly in data-sparse settings where only a limited number of survey responses are available. Across a range of scenarios, the heterogeneous model not only reduces prediction error but also exhibits greater robustness to sampling variability and model misspecification. Overall, our results highlight the importance of accounting for preference diversity in vaccination games and illustrate how heterogeneity can significantly enhance the realism and reliability of epidemiological behavior models.



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sciforum-168661: Modelling the Role of Environmental Reservoirs and Asymptomatic Carriers in HPAI Transmission within Dairy Herds

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Recent detections of Highly Pathogenic Avian Influenza (HPAI) in dairy cattle have underscored the urgent need to understand within-herd transmission dynamics and potential cross-species spillover risks. This study develops a deterministic $SEI_{s}I_{a}RB$ compartmental model specifically designed to capture the complex interplay between susceptible cattle, multiple infectious states, and environmental reservoirs. By employing the next-generation matrix method, we analytically derive the basic reproduction number (R_0) and identify the critical thresholds governing disease extinction and persistence. Rigorous local and global stability analyses of the disease-free and endemic equilibria are provided to characterize long-term herd health outcomes and steady-state behaviour. Numerical simulations validated by comprehensive sensitivity analysis utilising Latin Hypercube Sampling (LHS) and Partial Rank Correlation Coefficients (PRCC)---reveal that the transmission rate from asymptomatic infectious cattle (β_a) is the most influential parameter driving the epidemic curve. Furthermore, our results indicate that the environmental pathogen load significantly sustains the outbreak duration. These findings demonstrate that traditional surveillance focusing solely on symptomatic animals may significantly underestimate the true scale of an outbreak. Consequently, we propose that effective HPAI mitigation strategies must integrate rigorous environmental sanitation protocols with enhanced diagnostic screening for asymptomatic carriers to prevent wide-scale agricultural disruptions and broader public health impacts.



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sciforum-173561: New Convolution Identities for Classical Number Sequences via Symmetric Function Methods.

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In this work, we present a detailed study of the interplay between even- and odd-indexed symmetric functions and classical number sequences, approached from both algebraic and combinatorial perspectives. Symmetric functions, which occupy a central role in algebraic combinatorics, provide a natural framework for exploring underlying structures in sequences of numbers and polynomials. By focusing on the families **S_{2n-1} and ϕ2n**, we systematically examine how the parity of indices affects the algebraic behavior and combinatorial interpretations of these functions. This investigation is facilitated by constructing exponential generating functions associated with these families, enabling a precise encoding of their structure and revealing the intricate relationships among their terms.

Through this approach, we derive new convolution identities connecting classical sequences, such as Bernoulli, Euler, and Genocchi numbers, with important polynomial families, including bivariate Fibonacci, Lucas, Mersenne, and Balancing polynomials. These formulas not only generalize existing results but also provide closed-form generating functions and unified symmetric representations that encompass multiple polynomial structures within a single coherent framework. The distinction between even and odd indices emerges as a crucial factor, uncovering fundamental algebraic properties that govern the structure of these identities and illuminating the subtle effects of parity on recurrence relations and summation patterns.

Moreover, our methodology extends naturally to Gaussian (p,q)-Fibonacci and (p,q)-Lucas numbers, where the introduction of complex initial conditions enriches the symmetric relations and leads to novel convolution formulas. This extension highlights the versatility of the approach and establishes a systematic bridge between symmetric function theory and generalized number sequences. The results offer a unifying methodology for studying polynomial families, generating functions, and their combinatorial properties, opening new avenues for research in combinatorics, number theory, and the theory of special functions.



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sciforum-171549: Nonlinear Wave Propagation in an Extended (3+1)-Dimensional Calogero-Bogoyavlenskii-Schiff equation

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The (3+1)-dimensional extended Calogero–Bogoyavlenskii–Schiff fluid equation with variable coefficients serves as a mathematical model for nonlinear wave propagation in non-homogeneous media characterized by spatially and temporally varying physical parameters. This formulation addresses limitations inherent in constant-coefficient models by incorporating realistic variations encountered in complex fluid environments. The present investigation applies the Variable Coefficient Generalized Abel Equation Method, a specialized analytical technique designed for handling variable-coefficient nonlinear partial differential equations of high dimension. We construct exact traveling-wave solutions including kink, lump soliton, breather and periodic waves. Each solution class manifests characteristic physical behaviors typical of nonlinear wave interactions in inhomogeneous media. Also the qualitative analysis examines phase transitions between different solution types, stability properties under parameter perturbations and the spectrum of accessible dynamical regimes. This analysis delineates critical parameter thresholds governing qualitative changes in wave propagation characteristics. Corresponding three-dimensional surface plots and phase portraits provide comprehensive visualization of spatio-temporal evolution patterns, amplitude profiles, localization features and structural diversity exhibited by these analytical solutions. The graphical representations underscore practical relevance to applications including turbulent flow modeling, oceanic surface wave dynamics and plasma wave instabilities occurring within non-uniform physical environments. This systematic study extends the catalog of known analytical solutions for variable-coefficient CBS models while establishing foundational analytical tools essential for investigating nonlinear wave phenomena in realistic, spatially-varying physical systems.



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sciforum-120847: Numerical Solution of Eighth-Order Boundary Value Problem Using Shifted Horadam Collocation Method

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Introduction: Higher order boundary value problems model several physical phenomena in fluid dynamics, astrophysics, hydrodynamics, beam theory, astronomy, hydromagnetic stability, and engineering. Eighth-order boundary value problems arise in the physics of various hydrodynamic stability problems. This paper applies an efficient collocation method based on the shifted Horadam polynomials to obtain approximate solutions of an eight-order boundary value problem in ordinary differential equation.

Methodology: The Horadam collocation method expresses the solution of the proposed problem as a shifted Horadam polynomial series. Using the zeros of the shifted Horadam polynomials as the collocation points, the proposed boundary value problem is reduced to a set of algebraic equations in the expansion coefficients of the series solution. The obtained algebraic equations are then solved for the unknown expansion coefficients using Newton's iterative method. Two illustrative examples of the proposed boundary value problem are considered for the purpose of accuracy, efficiency, and reliability of the proposed method.

Results: Numerical solutions obtained are compared with the exact solutions and other existing solutions. The comparisons of results are demonstrated in tables and graphs. It is observed that the proposed method outperforms other existing methods under comparison.

Conclusion: This research work shows that the Horadam polynomial-based collocation method is an efficient method for obtaining accurate and reliable approximate solutions of higher order boundary value problems.



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sciforum-170542: Numerical Solution of Nonlinear Multi Proportional Delay Differential Equations

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In this paper, we propose a new method to solve multi proportional delay differential equations. The Haar wavelet collocation method (HWCM) is introduced and applied to proportional delay differential equations involving two or more delay terms. The proportional delay differential equations find applications in population dynamic model where the present system may depend on the gestation period and the maturation period simultaneously. In epidemiological model, the incubation and the immunity period coexist. Individually, the effect of each delay occurs at different pace. However, their combined effect may lead to instability which may be difficult to capture with a single delay. Thus, it has become important to study DDEs with multiple delays.

To show reliability and robustness of the method few numerical examples are presented. Further, numerical solutions obtained by HWCM are compared with the existing exact solutions. The comparison is done by calculating the maximum absolute error and the relative error. Further, to verify the accuracy of the results obtained, rate of convergence is calculated to be approximately 2. It is observed that with the increase in the resolution level, the error decreases and hence the accuracy increases. The findings suggest that HWCM can be extended to neutral time dependent DDE with multiple delays.



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sciforum-164935: On Curvature Inheritance in Generalized Fifth Recurrent Finsler Space

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This paper builds upon a new class of Finsler space, generalized fifth recurrent Finsler space. For Cartan's fourth curvature tensor in the sense of Berwald, we denote such space by Finsler space. Finsler geometry is a kind of differential geometry. It is an extension of Riemannian geometry; Riemann studied the distance between points in n-dimensions using only positional coordinates, while Finsler generalized Riemann's idea and studied the distance between points in n-dimensions by using two coordinates: positional and directional. The key idea revolves around a mathematical object called the curvature inheritance, which is defined in terms of the Lie-derivative, where curviture is a scalar function. In this work, we introduce new relationships for certain curvature inheritance, with the curvature tensor's components related to the components of a vector field during the application of a force at an arbitrary point by the Lie-derivative, and which it inherits a new tensor at a flow line of via transformation mapping. We prove that the Lie-derivative of K-curvature inheritance and the Berwald covariant derivative of fifth order are commutative under certain conditions. Also we prove that the scalar function of the Cartan's fourth curvature tensor, the Berwald's curvature tensor, the H-Ricci tensor and the K-Ricci tensor all have values of zero under the same certain conditions. Further, an equality relationship is established between Cartan's fourth curvature tensor and Berwald's curvature tensor if their Berwald covariant derivatives of fifth order are equal. Finally, we derived a mathematical formula for the change occurring in the vector field of the fifth order during its flow through a smooth vector field under the influence of an applied force and we proved that the direction of this force is opposite to the direction of the vector field of the fifth order itself within this space.



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sciforum-171323: On inverse power cluster-size distributions generated by the Random Domino Automaton

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The Random Domino Automaton (RDA)—a slowly driven system in the form of a one-dimensional stochastic cellular automaton—was introduced as a stylized simple model of earthquake statistics to provide a basis for the interrelation of the Gutenberg–Richter law and Omori law with the waiting time distribution for earthquakes. The Gutenberg–Richter distribution provides a universal relationship between the frequency of earthquakes and their size. If the earthquake magnitude is measured by their energy (or seismic moment), it has the form of an inverse power-law distribution.

In the RDA model, energy-related clusters can grow, merge, and disintegrate (trigger avalanches) depending on specific system parameters, which in stationary conditions is described in terms of the coupled recurrence relation for cluster-size statistics. This formulation proves appropriate for studying the role of these mechanisms in the formation of discrete inverse power-law distributions, or discrete Zeta distributions.

By asymptotic analysis of the relationship between the avalanche probability and the resulting stationary cluster-size distribution, we show that the convolution term in the governing equation, which encodes cluster merging, plays a decisive role in generating inverse power-law relations for a wide regime of parameters.

We conclude by pointing out an interesting connection of RDA-type systems with well-known Catalan-like integer sequences (Catalan, Motzkin, and Schröder numbers) and also mention the generalization of RDA to the geometry of the Bethe lattice.



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sciforum-174410: On retrieving the electric fields of point-like scatterers in the presence of a large dielectric cylinder by means of the Foldy-Lax approximation

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In this work, the scattering problem pertaining to the excitation of a dielectric cylinder surrounded by a cluster of significantly smaller, assumed point-like scatterers, by a field due to a line-source is considered. In particular, by considering a line-source parallel to the z-axis, the corresponding electric fields are perpendicular to the xy-plane, allowing the original 3D vector problem to be reduced to a 2D scalar problem. Furthermore, the multiple-scattering problem is reduced to a single-scattering problem of excitation of a dielectric sphere by an arbitrary distribution of electric dipoles, by means of the Foldy-Lax approximation. Specifically, by assuming that each point-like scatterer elicits fields similar to that of line-sources that disect the xy-plane on a point in the interior of each scatterer, the recovery of the electric fields of the point-like scatterers is enabled through an inverse-problem scheme utilizing measurements of the surface electric fields. To that end, the surface-field measurements at specific angles of observation are manipulated into a matrix form, so that a linear-system for the unknown point-scatterer fields can be devised. Furthermore, a dense cluster approximation of the scattering cross section attributed to the cluster's scatterers is obtained when certain conditions are met, while explicit numerical results demonstrating the accuracy and stability of the method, are presented.



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sciforum-174078: On the Dynamics of a Nonlinear Multidimensional Difference Equations System with Order k+1

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In this study, we investigate the qualitative behavior of a higher-order nonlinear system of difference equations. Such systems naturally arise in a wide range of applications, including population dynamics, epidemiology, economics, and discrete-time control theory, where time delays and nonlinear interactions significantly influence the long-term evolution of the process under consideration. The presence of higher-order delays increases the mathematical complexity of the model and enriches its dynamical structure.

We begin by establishing the existence and uniqueness of equilibrium points and deriving the necessary conditions for their positivity. The local asymptotic stability of these equilibria is then examined through linearization methods and spectral analysis of the associated Jacobian matrix. Explicit stability criteria are obtained in terms of the system parameters. Furthermore, we provide sufficient conditions that guarantee the boundedness and persistence of positive solutions, ensuring that trajectories remain biologically and physically meaningful over time.

Special attention is devoted to the role of the delay order, a positive constant parameter, and a nonlinear exponent governing the interaction terms. Their combined influence on stability, convergence, and qualitative behavior is carefully analyzed. In addition, we investigate the possible oscillatory nature of solutions and determine parameter regions that may generate oscillations or complex dynamics.

The theoretical results are rigorously proved and supported by several numerical simulations. These simulations confirm the analytical findings and demonstrate the robustness, applicability, and effectiveness of the derived qualitative and stability criteria.



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sciforum-170657: On the Laplace–Residual Power Series Solution of the Nonlinear time-Fractional Newell–Whitehead Equation

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In this work, the Laplace–Residual Power Series Method (L-RPSM) is employed to obtain accurate analytical–numerical solutions for a class of nonlinear time-fractional evolution equations involving the Caputo fractional derivative. Such equations play an important role in applied mathematics, as they are widely used to model complex physical and biological phenomena characterized by memory and hereditary effects. The proposed methodology is first formulated for a general class of nonlinear time-fractional evolution problems, where the main steps of the L-RPSM are clearly outlined. In addition, a detailed convergence analysis is carried out to ensure the existence, uniqueness, and validity of the resulting series solutions, thereby confirming the reliability of the proposed approach from a theoretical perspective.

To demonstrate the effectiveness and practical applicability of the method, the nonlinear time-fractional Newell–Whitehead equation is considered as a test model. This equation arises naturally in the mathematical modeling of pattern formation, reaction–diffusion systems, and related processes in applied sciences. Numerical simulations are performed for different values of the fractional order, and the corresponding results are presented in tabular form as well as illustrated through two- and three-dimensional graphical representations. The influence of the fractional-order parameter on the qualitative behavior of the solutions is examined and discussed in detail. Moreover, the use of the Laplace transform within the proposed framework enhances the convergence properties and computational efficiency of the method, leading to improved accuracy of the obtained results. The results clearly indicate that the L-RPSM provides highly accurate, efficient, and reliable solutions, making it a powerful and effective tool for solving nonlinear time-fractional evolution models encountered in applied mathematics and related scientific fields.



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sciforum-171630: One-Dimensional Modelling of Tidal Water Levels in Chilaw Lagoon, Sri Lanka.

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Coastal lagoons in Sri Lanka are shallow water bodies connected to the sea through narrow and often restricted inlets. These physical features strongly affect tidal water level variations and water exchange within lagoons. Understanding lagoon water level behaviour is important for studying circulation and environmental conditions. This study presents the development of a one-dimensional numerical modelling framework to simulate tidal water level variations in Sri Lankan coastal lagoons.

The model is based on simplified forms of the continuity and momentum equations, which describe the conservation of mass and momentum along the lagoon channel. The restricted water exchange at the lagoon inlet is represented using a choking model to account for the effects of narrow and shallow entrances. Observed sea level data were used as boundary conditions. The governing equations were solved numerically to obtain spatial and temporal variations of water levels inside the lagoon. The modelling framework was applied to Chilaw Lagoon as a case study.

The numerical results show how tidal water levels propagate inside a shallow lagoon with a restricted inlet. Both temporal and spatial variations of lagoon water levels are illustrated using the model simulations. These results provide an initial understanding of tidal behaviour in shallow lagoons with restricted inlets.

The developed modelling framework provides a useful starting point for future studies. It can be further improved and validated using observed lagoon data and extended to include discharge and salinity transport processes. This approach will support more detailed investigations of water circulation and environmental dynamics in the coastal lagoons of Sri Lanka.



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sciforum-173607: Optimal HAM Approach for Modeling Imbibition in Heterogeneous Porous Media

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This paper investigates an approximate analytical solution of the imbibition phenomenon arising in multiphase flow during secondary oil recovery. Imbibition is a capillarity-driven displacement process in which a wetting phase penetrates a porous medium and displaces a non-wetting phase, significantly influencing recovery efficiency in fractured and water-wet reservoirs. The structural characteristics of the porous matrix play a decisive role in this mechanism. In heterogeneous porous media, pore geometry and permeability vary spatially, resulting in non-uniform flow behavior, whereas homogeneous media exhibit uniform pore distribution and consistent transport properties. A comparative analysis of counter-current imbibition in heterogeneous and homogeneous porous formations is presented to assess the influence of medium variability on saturation evolution and displacement dynamics. The governing nonlinear partial differential equation describing the imbibition process is formulated using fundamental principles of mass conservation and multiphase flow theory. Owing to the inherent nonlinearity of the model, obtaining closed-form exact solutions is generally intractable. To address this challenge, the Optimal Homotopy Analysis Method (OHAM) is employed to construct a convergent homotopy series solution. The method provides flexibility through an auxiliary convergence-control parameter, enabling improved accuracy and stability without requiring small perturbation parameters. The approximate analytical results are validated numerically, and graphical representations are presented to illustrate the effects of key physical parameters on fluid saturation profiles. The study demonstrates that OHAM serves as an efficient and reliable semi-analytical technique for modeling nonlinear imbibition processes and offers valuable insights into fluid transport behavior in complex porous systems relevant to enhanced oil recovery applications.



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sciforum-172464: Optimal Vaccination Strategies for an SEIR Epidemic Model with Application to Influenza

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Introduction: Influenza remains a major public health concern due to rapid transmission and seasonal recurrence, straining healthcare systems. Mathematical models help understand disease dynamics and evaluate interventions. Vaccination is highly effective, yet resource constraints require optimally designed policies. This study develops a controlled SEIR model to investigate efficient vaccination strategies for influenza.

Methods: A time-dependent vaccination rate is introduced, representing the proportion of susceptible individuals immunized over time. The model incorporates a vaccine efficacy parameter, accounting for imperfect protection. Fundamental properties, including positivity and boundedness of solutions, are established. The basic reproduction number R_0 was derived using the next generation matrix approach. An optimal control problem was formulated to minimize infectious individuals and vaccination costs over a fixed horizon. The objective functional uses a quadratic control cost, reflecting nonlinear costs and diminishing returns in public health interventions. Pontryagin's Maximum Principle provides necessary optimality conditions, solved numerically via forward-backward sweep with fourth order Runge–Kutta discretization.

Results: Using influenza-calibrated parameters with R_0 approximately 1.8, optimal vaccination significantly suppresses epidemic spread. Simulations show peak infection reduced by 62% and total cumulative cases by 47% compared to uncontrolled scenarios. The optimal strategy also achieves 23% lower cumulative vaccination costs than constant policies while maintaining strong control.

Conclusions: Dynamically adjusted vaccination strategies substantially outperform static interventions for influenza. This study demonstrates the value of optimal control frameworks, incorporating vaccine efficacy and nonlinear costs, to guide efficient public health policies under resource constraints.



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sciforum-171474: Optimising testing and antiretroviral therapy for prevention and control of HIV/AIDS transmission dynamics in Indonesia

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Introduction: HIV continues to be a major global public health problem, with ongoing transmission across all countries. At the end of 2024, around 40.8 million people were living with HIV worldwide, while an estimated 630,000 people died from HIV-related causes. In Indonesia, an estimated 570,000 individuals are living with HIV. Despite the absence of a cure, effective prevention, diagnosis, treatment, and care have made HIV a manageable chronic disease, enabling people living with HIV to maintain long and healthy lives. In Indonesia, treatment coverage among people living with HIV is low, with only 31% accessing antiretroviral therapy (ART) and 14% attaining viral suppression. Addressing the treatment gap is among the most critical challenges facing the country's HIV response. Thus, the objective of this study is to assess the optimal strategy required to contain HIV/AIDS transmission in Indonesia using optimal testing (or diagnosis) and ART.

Methods: An optimal control framework based on a non-autonomous deterministic HIV/AIDS transmission model was developed. The model incorporates time-dependent ART use and testing strategies. Pontryagin's maximum principle was used for the qualitative analysis of the model. The associated optimality system was simulated to demonstrate the effects of separate and combined use of the optimal controls on HIV/AIDS dynamics in Indonesia.

Results: With optimal ART, more people become treated while fewer people become acute and chronic HIV-infected and full-blown AIDS patients. Activation of optimal testing only leads to fewer acute HIV-infected people, and fewer people progress to AIDS as more people are aware of their status and are receiving ART. Simultaneous implementation of the two optimal control shows fewer number of acute and chronic HIV-infected people, while fewer people progress to AIDS as more people receive ART.

Conclusion: Optimal implementation of testing (or diagnosis) and ART can significantly help in stemming the spread of HIV/AIDS in Indonesia.



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sciforum-174223: Optimization of light distribution of lenses for Li-Fi luminaires: comparative study of models LIA and LIB with photometric calculations

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Li-Fi (Light Fidelity) uses visible light for wireless data transmission. System performance depends on both the light source's modulation and secondary optics. Spatial light distribution is critical for coverage uniformity and communication stability. This study presents a comparative analysis of two lenses, LiA and LiB, conducted using Techno Team 3D software. The goal was to evaluate how geometric modification affects photometric properties and identify the optimal configuration for a Li-Fi luminaire requiring wider beam angles and uniform light distribution.

Lens LiA Analysis

Simulation results show LiA has a maximum luminous intensity of 4689 cd and a beam angle of approximately 60° at half maximum. Estimated luminous flux is around 2755 lm. LiA produces a concentrated beam with distinct high-intensity zones. While suitable for directional lighting, this pattern limits the stable signal reception area and creates uneven coverage, which is undesirable for indoor optical wireless communication.

Lens LiB Analysis

After geometric modification, LiB shows a maximum intensity of 4304 cd. The beam angle at half maximum increases to about 80°. Simulations indicate wider light diffusion and smoother intensity distribution. Peak values are reduced, and luminous flux is spread more evenly. This is particularly beneficial for Li-Fi luminaires, as a larger illumination area improves channel accessibility.

An additional advantage of LiB is reduced contrast between the center and periphery of the light spot. This homogeneous illumination minimizes "dead zones" and enhances communication reliability. The optical redesign yields parameters better suited for advanced Li-Fi devices. For Li-Fi systems, uniform light distribution is more critical than high directionality. Expanding the emission angle increases coverage and reduces the likelihood of signal gaps. Calculated data confirm that transitioning from LiA to LiB broadens the solid angle and provides more homogeneous illumination, making LiB the preferred choice for integration into Li-Fi lighting systems.



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sciforum-170940: Optimization-based schemes to solve PDEs with nonlocal conditions

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Partial differential equations (PDEs) with nonlocal initial or boundary conditions arise in a wide range of scientific and engineering applications, including heat conduction with integral constraints, population dynamics, anomalous diffusion, materials with memory, and models of fluid flow and transport influenced by global conservation laws. These nonlocal formulations often provide a more accurate description of physical processes than classical local conditions, but they also introduce additional computational challenges.

In recent years, Physics-Informed Neural Networks (PINNs) have been proposed as a flexible framework for solving PDEs without explicit discretization of the domain. Despite their growing popularity, the computational efficiency of PINNs for PDE problems, especially those involving nonlocal constraints, remains insufficiently explored. This work investigates optimization-based approaches for solving parabolic and elliptic PDEs with nonlocal conditions.

Two numerical approaches are investigated. The first method employs finite difference discretization of the PDEs, from which a discrete residual-based loss function is constructed. This loss is minimized using three distinct optimization algorithms: ADAM, AMSGrad and L-BFGS. The second method uses PINNs, where the PDE operators and nonlocal constraints are embedded directly into the training loss. The same three optimizers and stopping criteria are applied to both approaches to ensure a consistent comparison, and in both cases gradients are computed using automatic differentiation.

The methods are evaluated on representative parabolic and elliptic PDE test problems with nonlocal conditions in regular domains. Performance is assessed primarily in terms of execution time required to achieve a given accuracy. The comparison is extended by fixing the spatial domain and increasing the density of discretization points. This allows for a consistent evaluation of how execution time scales with spatial resolution for both approaches.



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sciforum-170782: Permanence, Stability, Extinction and Chaos in a Nonautonomous Predator–Prey Model with Additive Allee Effect

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In this work, we investigate the qualitative dynamics of a nonautonomous predator–prey model incorporating a saturated Holling-type functional response and an additive Allee effect in the prey population. Such a framework is biologically relevant since ecological parameters often fluctuate in time due to seasonal or environmental variations, while Allee mechanisms may strongly influence prey growth at low population densities.

First, by applying the comparison principle and constructing suitable differential inequalities, we establish sufficient conditions ensuring the positivity and permanence of the system. In particular, we prove that both prey and predator populations remain uniformly bounded

away from extinction whenever appropriate persistence thresholds are satisfied. Next, a Lyapunov-type function based on logarithmic distance is introduced in order to derive explicit criteria for the global stability of positive solutions. This analysis guarantees that all trajectories starting from positive initial values asymptotically approach each other, showing that the system exhibits robust long-term behavior under the permanence regime.

Furthermore, we obtain threshold conditions under which the predator population becomes extinct asymptotically, revealing how the combined effects of mortality, predation saturation, and the Allee mechanism can lead to predator disappearance even when prey survive.

In addition to the theoretical results, numerical simulations are performed to illustrate the validity of the analytical findings and to explore the richness of the model's dynamics. In particular, for certain parameter regimes, especially in the region of weak Allee effect, the system exhibits chaotic dynamics characterized by irregular oscillations, sensitive dependence on initial conditions, and complex attractors.



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sciforum-171407: Perturbative Approach to Quantum State Transfer on Weighted Spin Chains

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We investigate effective quantum state-transfer dynamics on weighted path graphs by employing a fermionic formulation combined with stationary perturbation theory. This approach leverages the well-established equivalence between XX spin chains and continuous-time quantum walks on path graphs in the single-excitation sector. By restricting the dynamics to this single-excitation subspace, the full Hamiltonian of the system can be projected onto a lower-dimensional effective subspace, significantly reducing the complexity of the problem while retaining the essential physics.

In the dispersive regime, where the endpoint vertices are weakly coupled to the intermediate nodes, second-order perturbation theory is applied to systematically eliminate the intermediate vertices. This procedure yields a reduced effective Hamiltonian that directly couples the endpoints of the graph through virtual transitions, capturing the dominant contributions to the transfer dynamics. The resulting effective model allows for the derivation of closed-form analytical expressions for key quantities, including effective coupling strengths, energy shifts, and state-transfer fidelity.

Analysis of the fidelity reveals coherent oscillatory behavior, which is entirely determined by the perturbative parameters and the spectral gaps of the original graph Hamiltonian. This analytical insight provides a clear understanding of how the structure and weighting of the path graph influence the efficiency of quantum state transfer. To validate the approach, we perform numerical comparisons with exact diagonalization of finite weighted path graphs. The results demonstrate that the effective Hamiltonian reproduces the main features of the transfer dynamics and provides accurate estimates of the fidelity within its regime of applicability.

Our findings highlight a practical method for obtaining analytical expressions for quantum state-transfer fidelity in systems with weighted interactions, offering both computational efficiency and physical insight. This work provides a foundation for the design and optimization of engineered spin chains and quantum networks for high-fidelity state transfer, with potential applications in quantum information processing and quantum communication.



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sciforum-170177: Qualitative Analysis and Phase Portraits of an Epidemic Model

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The mathematical modeling of infectious diseases is essential for understanding transmission mechanisms and the long-term persistence of pathogens. This paper investigates the qualitative dynamics of an SIRS epidemic model, particularly relevant for diseases where immunity is temporary. The study provides a rigorous mathematical framework to describe how the interplay between infection rates and the loss of immunity affects the system's behavior, moving from local stability to a global perspective.

The study employs the qualitative theory of planar differential equations to explore the system's state space. A central component is the application of the Poincaré compactification technique, which extends the polynomial vector field from the finite plane to the Poincaré disc. This enables the analysis of the system's behavior at infinity. We characterize all singular points by analyzing Jacobian matrices for finite equilibria and utilizing specialized transformations for infinite singularities at the disc's boundary.

The analysis provides a comprehensive characterization of the system's equilibria, including disease-free and endemic states, and singularities at the horizon of the Poincaré disc. A significant finding is the identification of a Hopf bifurcation occurring at critical biological thresholds. This bifurcation is responsible for the emergence of limit cycles. Global phase portraits are constructed to visualize trajectories and detail the topological structure of the flow under various parameter regimes.

The investigation reveals that the SIRS model possesses complex dynamical features. The occurrence of limit cycles indicates that the disease can exhibit periodic oscillations, with significant implications for predicting recurring outbreaks. By integrating global analysis at infinity, this research provides a complete topological description of the model, offering valuable insights into nonlinear disease dynamics and public health strategies.



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sciforum-172876: Qualitative and Numerical Study of a Zika Epidemic Model with Fractal–Fractional Operators

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In this study, we examine the Hyers–Ulam stability of a fractal–fractional mathematical model for the transmission dynamics of the Zika virus. The model is formulated using the Atangana–Baleanu fractional operator with a Mittag–Leffler kernel, thereby incorporating both memory effects and fractal properties commonly observed in biological systems. This approach provides a more realistic representation of disease spread than classical integer-order models. First, the existence and uniqueness of solutions are established to ensure the well-posedness of the proposed system. Subsequently, fixed-point theory is applied to derive sufficient conditions for Hyers–Ulam stability, demonstrating that the model remains stable under small perturbations. This stability property is essential for confirming the model's reliability and robustness in practical applications. In addition, numerical simulations are performed to support theoretical findings and illustrate the qualitative behavior of the Zika virus transmission process. The obtained results provide valuable insights into the influence of memory and fractal effects on epidemic dynamics. In general, the study highlights the effectiveness of the fractal–fractional framework in capturing complex biological phenomena and confirms its potential for future research in mathematical epidemiology. The proposed methodology can also be extended to analyze other infectious diseases, contributing to the development of more accurate and reliable predictive models.



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sciforum-171046: Quantitave Analysis of a Chemostat Model with Allelopathy and Substrate *Inhibition.*

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In this study, we investigate a mathematical model describing the competition between two microbial species in a chemostat environment. One of the species is capable of producing a toxin that inhibits the growth of its competitor, while its own growth is negatively affected by substrate inhibition. The model is reduced to a planar system, and the existence and stability of all steady states are analyzed in detail with respect to the operating parameters of the chemostat.

When classical Michaelis–Menten or Monod growth functions are considered, the system admits a unique positive equilibrium. However, this equilibrium is shown to be unstable whenever it exists. By extending the model to include both monotone and non-monotone growth functions, we demonstrate the emergence of an additional positive equilibrium that can become stable for certain parameter values.

The resulting general model exhibits a wide range of dynamical behaviors, including stable coexistence of the two microbial species, multistability phenomena, and the appearance of stable limit cycles generated through supercritical Hopf bifurcations. Furthermore, homoclinic bifurcations are identified, highlighting the complexity of the system's dynamics. An operating diagram is constructed to describe the long-term behavior of the system as the operating parameters vary, and to illustrate how substrate inhibition influences the formation and persistence of the species coexistence region.



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sciforum-171171: Reaction–diffusion model of infection propagation with influence of resident macrophages

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In the work, we have constructed the mathematical model of respiratory viral infection propagation in the tissue with influence of resident macrophages. The model is based on reaction–diffusion equations with integral terms. In this system, the following biologically significant characteristics are determined: 1) the basic replication number, 2) the viral load, 3) the wave speed, and 4) the immunity effectiveness number. The basic replication number shows whether the infection will propagate. The viral load, i.e., the space integral from the concentration of viral particles, allows us to estimate the infectivity of the viral disease, i.e., how fast infection transmits between individuals. The wave speed corresponds to the severity of the disease. The immunity effectiveness number helps to estimate the impact of immunity in the condition of the infection propagation. The model is analyzed by applicable methods of analysis of reaction–diffusion systems and numerically. The conditions of the infection propagation, the infectivity and the severity of the disease, and the influence of the immunity are investigated, and their quantity estimates are obtained. The results may help in planning treating strategies and identification of targets for the treatment. The work was supported by the Russian Science Foundation No. 24-11-00073, https://rscf.ru/en/project/24-11-00073/. References: M. Bouzari, L. Ait Mahiout, A. Mozokhina, V. Volpert Infection propagation in a tissue with resident macrophages. Mathematical Biosciences. 2025; 381: 109399. https://doi.org/10.1016/j.mbs.2025.109399



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sciforum-158459: Resolution of Maxwell's Equations in Atmospheric Electromagnetic Phenomena

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This paper focuses on the numerical resolution of Maxwell's equations applied to atmospheric electromagnetic phenomena, particularly lightning discharges. Lightning generates intense transient electromagnetic fields that interact with the ground and nearby structures, posing challenges for accurate modeling and protection design. To analyze these interactions, the two-dimensional Finite-Difference Time-Domain (2D-FDTD) method is employed to solve Maxwell's equations in the time domain with high spatial and temporal resolution.

This study considers a realistic configuration involving a 168 m tall object interconnected with the lightning channel and a clayey soil characterized by moderate electrical conductivity (σ = 0.0025 S/m) and high permittivity. The simulation framework enables the investigation of the spatiotemporal evolution of the electric and magnetic fields both above and below the ground, capturing the complex coupling between the lightning channel, the tall structure, and the soil.

Results demonstrate that the soil's electrical properties significantly affect the electromagnetic field amplitudes and waveform shapes, particularly below ground in the near-field region. Variations in conductivity and permittivity alter the current distribution and the attenuation of electromagnetic waves. This work highlights the importance of accurate numerical modeling of soil characteristics in the computational analysis of atmospheric electromagnetic phenomena and contributes to improving the reliability of lightning protection and grounding system design.



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sciforum-172007: Reverse Rule-to-Model Inference with Physics-Guided Refinement: Application to the Three-Zone Scattering Model for Fractal Aggregates

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This article proposes a three-step strategy for improving fuzzy systems using simple models and high-fidelity data. In the first step, data are generated from a basic model (e.g., CART tree), simplified, and converted into fuzzy sets using a GMM that defines membership functions. The process is a generic, open process. Then, in the second step, a refinement with high-precision data leads to a neutrosophic extension: new points are fed into a high-resolution model; for each rule, the degrees of truth (T), falsehood (F), and indeterminacy (I) are calculated. Finally, the last step is sending feedback to the initial model: the refined rules are reinterpreted and the fuzzy set is regenerated and merged again with the knowledge acquired in step 2, obtaining an updated FIS that preserves the computational lightness of step 1. Overall, the strategy combines automatic rule generation, neutrosophic refinement, and iterative reuse to improve accuracy without losing efficiency. The originality of this paper is that it *closes the loop*. There are studies on the first two steps but here we have included refinement and feedback by means of the neutrosophic paradigm. This work also outlines a numerical procedure for analyzing neutrosophic refinement convergence through a so-called Indeterminacy-First Aggregation Operator (IFAO). As a test case, we applied the proposed scheme to a Physics-Guided Unification of Scattering Regimes for Fractal Aggregates. The example was considered due to its clear physical regimes, explicit mathematical forms, and hierarchical structure, which provide an ideal testbed where we can demonstrate how to i) extract rules (the distinct power laws and Guinier law from data); ii) assemble them into a unified model; and iii) refine that model with a full physical theory.



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sciforum-174323: Revisiting the Central Limit Theorem: Finite-Sample Behaviour, Simulation Anomalies, and Distribution-Specific Convergence

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The Central Limit Theorem (CLT) offers asymptotic results on the convergence of sample means to normality, but its finite sample properties are relatively less clear. This paper reports the findings of a simulation study on the convergence process of CLT for various continuous distributions, such as Normal, Exponential, Uniform, Gamma, Beta, and Cauchy. By conducting Monte Carlo simulations in R and employing the Shapiro–Wilk test for normality, we have found distribution-wise "threshold" and "optimum" sample sizes for which approximate normality is achieved.

One of the most important results of this study is that the convergence process to normality is not monotonic for finite samples. Even after achieving normality at a threshold sample size, statistically significant deviations are often found at intermediate sample sizes. This "post-threshold instability" is found to occur for all studied distributions, including the Normal distribution itself, for which non-negligible failure rates are found for specified ranges of sample size.

We also investigate the possible causes of these anomalies, focusing on the importance of outliers, simulation methods, and the limitations of normality tests. The empirical findings indicate that the behavior of outliers and the properties of the tails of distributions are of prime importance, especially for skewed and heavy-tailed distributions. In the context of the Cauchy distribution, the traditional CLT is invalid because of the lack of finite variance. Nevertheless, the use of the sample median and its asymptotic distribution offers a promising alternative.

Moreover, we illustrate that the number of iterations is not necessarily a factor that improves the accuracy of convergence with certainty, contrary to general beliefs in Monte Carlo simulation. The effect of the size of the iteration is also shown to be dependent on the distribution.



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sciforum-145977: Scaling invariance for the diffusion coefficient in a billiard system

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We investigated the behavior of the diffusion coefficient in a time-dependent oval-shaped billiard, focusing on the connection between this quantity and the system's transition from unbounded to bounded diffusion caused by inelastic collisions with the boundary. The diffusion coefficient plays a key role in describing the scaling invariance characteristic of this transition. For short times, the low-action regime is characterized by a constant diffusion coefficient, which begins to decay after a crossover iteration, thereby suppressing the unlimited growth of velocity. We demonstrate that this behavior is scaling-invariant concerning the control parameters and can be described by a homogeneous generalized function and its associated scaling laws. This universal function effectively collapses all numerical data onto a single curve, confirming the self-similar nature of the dynamical crossover. The critical exponents governing this scaling were determined both phenomenologically, through extensive numerical simulations, and analytically, by examining the system's equations of motion near the critical point. This analysis confirmed the decay exponent $\beta = -1$ for the diffusion coefficient, a value previously identified in related low-dimensional dissipative systems like the dissipative standard map. The consistency between our analytical derivations and numerical results strongly validates the universal framework we propose for describing transport phenomena in open Hamiltonian systems subject to dissipation.



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sciforum-162457: Simplification of calculations for repeating decimal fractions using a direct method

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Repeating decimal fractions, both simple and compound, have long posed significant computational challenges in mathematics and education. Traditional methods, which convert these decimals into fractions for algebraic operations, are often time-consuming, error-prone, and complex, particularly when dealing with long, multiple, or nested repeating cycles. This study presents a novel direct method for performing addition, subtraction, and division on repeating decimals without requiring conversion to fractions. By aligning and synchronizing periodic sequences, the method enhances computational speed, maintains high accuracy, and minimizes human error. The approach was systematically developed through detailed analysis of decimal structures, construction of original problems, and rigorous verification across a wide range of cases, including simple cycles, composite cycles, and multiple simultaneous repeating sequences. Comparative evaluation with conventional fraction-based methods demonstrates that the proposed approach significantly reduces computational complexity while achieving identical results. Preliminary observations further indicate promising potential for extending the method to multiplication of repeating decimals. The simplicity, efficiency, and broad applicability of this method make it particularly suitable for educational contexts, theoretical research, and practical applications in engineering, computer science, cryptography, and other related fields. Overall, this study provides a clear, systematic, and reliable framework for handling repeating decimal computations, offering both pedagogical and computational advantages over traditional fraction-based techniques, and opening opportunities for further development and software implementation.



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sciforum-168197: Solution of the fundamental integral equation in heat transfer and its repercussion for architecture, fire prevention and tunnelling

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A significant and increasing number of problems related to radiative heat transfer, demand accurate if not exact solutions to fourfold integral equations. In mathematical terms, this is a complex and cumbersome issue even acknowledged by famous polymaths like J. H. Lambert, since the 18th century. The present author demonstrated and published along his research, the whole procedure for rectangular radiative emitters some 25 years ago. However, in the case of circular and curved sources, the usual analytical approach remains exceedingly difficult and not even suitable for numerical calculus. Recently, the author has elaborated on integral equations applied to fragments of spheres which usually appear in radiative heat transfer and has been fortunate to define new postulates which may solve, with required accuracy, the question of energy transfer between them. In this way not only spherical sectors but also circles, semicircles and circular sectors become affordable. As it is widely accepted, to find the exact expression for radiative exchange by virtue of integration alone is considered no mean feat. The novelty of the process developed lies in that firstly we solve the two initial sets of integrals demanded by analytical methods and then employ the exact results obtained as a kind of iterative algorithm in order to be able to provide the final solution for the remaining double integral equations. This method, has not been described by former researchers and it provides us with a considerable repertoire of scenarios for simulation of energy transmission in the void or in gaseous media. Incidentally, within the operation, new unexpected geometric forms appear and they are subject to exhaustive mathematical assessment revealing interesting findings and a plethora of applications for diverse fields such as architecture, tunnelling or space vessel construction.



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sciforum-170713: Some applications of partial r-Bell polynomials

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In this work, we introduce and investigate a novel class of polynomials, which we term **t-successive exponential partial Bell and r-Bell polynomials**. These polynomials generalize the well-studied exponential partial Bell and r-Bell polynomials and are closely related to classical combinatorial sequences such as Stirling numbers, Bell numbers, and their polynomial extensions. Our motivation stems from the unified framework proposed by Mihoubi and Rahmani in(2017), which provides a systematic approach for constructing exponential partial r-Bell polynomials, of which many known combinatorial numbers emerge as special cases.

We begin by establishing explicit formulas for these polynomials and presenting their generating functions, which serve as a fundamental tool for deriving structural properties. Through careful analysis, we deduce several recurrence relations that encapsulate the inherent combinatorial structure of these polynomials. In particular, we provide combinatorial interpretations in terms of set partitions, illustrating how elements may be organized into subsets under specific constraints, thereby extending the classical interpretations associated with Bell and Stirling numbers.

t-successive exponential partial Bell and r-Bell polynomials exhibit rich combinatorial and algebraic properties. They offer a unifying perspective that bridges existing sequences and opens new avenues for exploration in discrete mathematics and combinatorial enumeration. We illustrate their utility through representative examples and demonstrate how their generating functions facilitate the derivation of identities and recurrence relations.

Our study not only generalizes known results but also provides a versatile framework for further investigations. By combining explicit constructions, recurrence relations, and combinatorial interpretations, these polynomials contribute to a deeper understanding of the interplay between classical combinatorial sequences and their extensions. The results presented herein offer potential applications in sequence transformations, partition theory, and the broader study of combinatorial structures.



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sciforum-171539: Some Fixed Point Theorem via Altering Distance Function in metric spaces

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In this paper, we investigate the existence and uniqueness of fixed points for a class of self-mappings defined on complete metric spaces by employing the concept of altering distance functions. Altering distance functions provide a flexible framework that allows the extension of classical contraction-type conditions while preserving convergence properties of iterative sequences. By introducing a generalized contractive inequality involving an altering distance function together with an auxiliary control function, we establish sufficient conditions ensuring the existence of a unique fixed point for the considered mappings. The proposed results generalize several well-known fixed point theorems, including the Banach contraction principle and its subsequent extensions based on nonlinear contractive conditions.

The main theorems are proved without imposing restrictive assumptions on the mapping, thereby broadening the applicability of the results to a wider class of problems. Furthermore, the convergence of Picard iteration sequences generated by the mappings under consideration is discussed in detail, and it is shown that the iterates converge strongly to the unique fixed point. To demonstrate the effectiveness and novelty of the obtained results, illustrative examples are provided, showing that the introduced conditions are genuinely weaker than many existing contraction conditions in the literature.

The results presented in this work contribute to the ongoing development of fixed point theory and may be useful in applications to nonlinear analysis, differential equations, and integral equations, where generalized contractive mappings naturally arise.



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sciforum-171221: Spatiotemporal Dynamics in a Fear-Driven Prey–Predator Model with Refuge, Cooperation, and Harvesting

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We develop and analyze a reaction–diffusion prey–predator model that integrates predator-induced fear, constant prey refuge, and cooperative interactions among specialist predators. To capture realistic density regulation, intraspecific competition within the prey population is modelled using Richards-type growth, while predator harvesting is incorporated as an external ecological control mechanism.

The dynamical behaviour of the associated non-spatial system is first examined, revealing the presence of multiple equilibria, namely the trivial equilibrium, the predator-free (axial) equilibrium, and a biologically feasible coexistence equilibrium. Local stability analysis demonstrates that the persistence of the coexistence state is strongly governed by critical ecological parameters, including handling time, fear intensity, and harvesting rate. Variations in these parameters induce qualitative shifts in system dynamics, and the coexistence equilibrium is shown to undergo Hopf bifurcation, resulting in the emergence of stable and oscillatory solutions. The corresponding threshold values are determined through numerical continuation techniques implemented in MATLAB and MATCONT.

The model is subsequently extended to a spatial framework to explore diffusion-driven instability. Through combined analytical investigation and numerical simulations, we establish conditions for the onset of Turing instability and the formation of self-organized spatial patterns. The results underscore the significant influence of diffusion rates and biological interactions on species dispersal and spatial organization. In particular, the dispersion analysis indicates that Turing patterns arise when the prey diffusion rate exceeds that of the predator, highlighting the role of differential mobility in pattern formation.

Overall, this work presents a biologically consistent modelling framework that elucidates the interplay between ecological interactions and spatial processes, offering new insights into the mechanisms underlying complex spatiotemporal dynamics in prey–predator systems.



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sciforum-168665: Stability analysis of fractional-order SIR model with general incidence rate and treatment

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In this work, we study a fractional two-strain epidemic SIIR model with a general incidence rate for both strains, incorporating treatment for each strain. The population is divided into four compartments representing susceptible individuals, individuals infected with the first strain, individuals infected with the second strain, and recovered individuals. The proposed model is formulated using a system of four fractional-order differential equations in the sense of Caputo, which allows us to capture memory effects and hereditary properties inherent in the transmission dynamics of infectious diseases.

The mathematical analysis begins with the proof of the existence and uniqueness of positive solutions, ensuring the well-posedness and biological feasibility of the model. Positivity and boundedness of solutions are also established. Several equilibrium points are derived, including the disease-free equilibrium and endemic equilibria associated with each strain. The global stability of these equilibria is investigated by constructing suitable Lyapunov functions and applying fractional-order stability theory.

Numerical simulations are performed to validate the theoretical findings and to illustrate the influence of the fractional-order parameter on the qualitative behavior of the solutions and the convergence speed toward equilibrium states. In addition, a sensitivity analysis is conducted to examine the role of treatment efficiency in reducing the prevalence of infected individuals for both strains. The results highlight the importance of effective treatment strategies and fractional dynamics in controlling multi-strain epidemic outbreaks.



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sciforum-173774: Stability estimates for discontinuous Galerkin in space Methods for the complex Ginzburg–Landau equation

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This study presents a rigorous stability analysis of Interior Penalty Discontinuous Galerkin (IP-DG) spatial discretizations for the complex Ginzburg–Landau equation (CGLE), a pivotal model governing nonlinear wave dynamics in optics, superconductivity, and fluid mechanics. The CGLE's capacity to describe the evolution of slowly varying wave envelopes—characterized by intense nonlinearity and dissipative effects—is essential for modeling chaotic regimes and vortex-dominated systems. However, these dynamics pose significant numerical challenges; preserving physical properties such as amplitude boundedness and nonlinear stability is paramount for reliable long-term simulations.

We investigate a unified framework of IP-DG formulations, specifically comparing the Symmetric (SIPG), Non-symmetric (NIPG), and Incomplete (IIPG) methods. Our analysis establishes semi-discrete stability estimates and validates them through systematic numerical experiments. A central focus is placed on the role of the penalty parameter, where we demonstrate that its magnitude is the primary driver of numerical stability. We show that while the SIPG and IIPG schemes require a threshold penalty value to ensure coercivity and bound the solution norm, the NIPG scheme remains stable for a broader range of parameters, albeit with different convergence characteristics. Notably, the SIPG method exhibits the highest robustness in highly nonlinear settings, provided the penalty parameter is sufficiently tuned to suppress unphysical oscillations.

By clarifying the interplay between the penalty parameter, numerical dissipation, and nonlinear growth, this work offers a definitive guide for selecting DG discretizations tailored to specific physical regimes. These findings facilitate the development of high-fidelity computational tools for laser dynamics, turbulence modeling, and Bose–Einstein condensation research.



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sciforum-171627: Stability of the discrete Caputo-like fractional hyper-Rössler system

AZIL SOUAAD

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Chaotic behavior is a common feature of nonlinear dynamics.

The subject of our discussion today is the stability of hyperchaos in high-dimensional systems. This study serves as an introductory guide to a discrete fractional four-dimensional hyperchaotic Rössler system with a Caputo-like operator is a complex system that can be used to study the chaos of discrete fractional nonlinear dynamics. Our results demonstrate the existence of a hyperchaotic invariant set in these systems, which leads to extended hyperchaotic transient behaviors. The coexistence of chaos and hyperchaos is evident in the numerical results, which are presented in phase plots and bifurcation diagrams for various fractional orders and different parameters and specific initial conditions. These diagrams provide a comprehensive explanation of the dynamics of the proposed discrete system. This research substantiates the presence of chaos in discrete fractional hyperchaotic Rössler systems that are reminiscent of Caputo-like discrete systems. Low control is offered to display synchronization of coupled Caputo-like discrete fractional hyperchaotic Rössler systems and to force the states of the proposed system to converge asymptotically to zero. The findings of the study are demonstrated through the following implementation of numerical simulations, which has been a significant development in our research.



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sciforum-171673: Stochastic Dynamics of a Harvested Two-Species Fishery Model with Random Birth and Death Effects

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Fish populations in natural ecosystems are influenced not only by biological interactions and fishing activities, but also by random fluctuations in the environment and natural populations. Deterministic models, though useful for modelling, sometimes fail to capture the complexity of uncertainty in fish populations. Motivated by this limitation, this study introduces and examines a stochastic model of the interaction between two competing fish species with random birth and death rates. Within the proposed framework, the classical model of a two-species competing population is extended to include a harvesting term and stochastic fluctuations in the reproduction and death rates. This is achieved by formulating continuous-time stochastic differential equations in which the intensities of the stochastic fluctuations depend on population densities in a biologically realistic manner. Analytical techniques have been employed to investigate the equilibria of stochastic populations, as well as the conditions for their persistence and extinction. The impacts of harvesting and stochasticity on system dynamics are investigated numerically using the Euler–Maruyama method. In contrast to the deterministic situation, stochastic impacts can significantly change the system's behavior. In particular, random perturbations may increase the risk of extinction even at harvesting levels considered sustainable in a deterministic framework. We observed that stochasticity, together with suitably designed harvesting strategies, affects the two competing fish species. Overall, the results of this study demonstrate the significance of random births and deaths in fishery models and provide insights for developing harvesting policies that ensure sustainability even with uncertainty, emphasising the importance of stochastic approaches for interacting species, specifically competitive fish populations, in fluctuating environments.



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sciforum-170647: Study of root capacitance in strawberry plants under physicochemical variations using the RC model

Leticia Adriana Ramirez-Hernández[1], Erika Selene Delgado-Hernández[1], Juan Martínez-Ortiz[1], Mayra Guadalupe García Reyna[1], Beatriz Adriana Rodríguez González[1], Oscar Cruz-Domínguez[2], Juan Badillo de Loera[3], Hector Duran[1]

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The electrical capacitance technique is used as a non-destructive method and serves to evaluate the root system of plants. Capacitance allows for an indirect interpretation of a plant's physiological state and root development. Therefore, the aim of this work was the study of root capacitance in strawberry plants under physicochemical variations, pH changes and conductivity, using the RC model. The methodology of this research work consisted of measuring the electrical response of the root-substrate system using an LCR meter, where the plant is in a distilled water solution, varying the pH and electrical conductivity of the medium in a controlled manner. The results obtained will be analyzed using an equivalent RC model, which allows for the separation of the resistive effects associated with ionic flow and the capacitive effects related to the structure and state of the membranes. The temporal evolution of capacitance will allow the identification of changes in root activity associated with environmental variations, since this parameter is related to the active surface and the state of cell membranes. In this way, the analysis of the capacitive signal over time allows the detection of conditions of stress, adaptation or growth of the root system. The results include the evaluation of the sensitivity of electrical parameters to changes in pH and conductivity, as well as the identification of nonlinear behaviors in the system response.



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sciforum-144926: Studying the stability of variable order caputo fractional differential equations

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Introduction:

Fractional calculus is a branch of mathematical analysis that studies the possibility of extending the order of the differentiation and integration operators to a noninteger order. We focus on the stability of the implicit boundary value problem for Caputo fractional differential equations of variable order.

where is a continuous function, , and is the caputo fractional derivative of variable order.

Ulam Hyers stability: Assuming

be a partition of the interval and let be a PWCF with respect to , i.e., where are constants with (). Using (H1) the BVP(1) becomes

Theorem 1:

The (1) is (UH) stable if there exists such that for any , and for every solution of the following inequality , there exists a solution of (1) with

Theorem 2: Assume that **(H1)** is satisfied and

(H2)

and the inequality holds, then (1) is **(UH)** stable.

Conclusion:

This study is a valuable contribution to the expanding field of fractional calculus, in which we skillfully proved the stability.

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sciforum-144382: Tabular Arithmetic and Deterministic Primality Testing via Multiplication Tables.

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Abstract:

Introduction. Multiplication tables, traditionally used in foundational mathematics education, also harbor rich arithmetic structures when analyzed through operations of sum, difference, and product. This study introduces a novel, deterministic prime-detection methodology derived from the structural patterns in these tables, adapted for large numbers via a logarithmic framework.

Methods. We formalize three operations on the multiplication table T(n) of a fixed integer n: the tabular sum (∑), difference (δ), and product (∏). We derive closed-form expressions for ∑ (linking to triangular numbers), δ (relating to arithmetic sequences), and ∏ (corresponding to factorial constructs), leading to the Kadouno Primality Test. A logarithmic adaptation exploits Stirling's approximation and a dynamic scaling regulated by decimal thresholds to maintain computational tractability for very large integers. Further refinement replaces the factorial structure with a primorial-based test that preserves small-prime exclusion and enhances algorithmic efficiency.

Results. The primality test reliably distinguishes prime from composite numbers across multiple ranges. With the logarithmic version, the method remains accurate and efficient even as input size grows, thanks to a dynamically adjusted depth parameter. Incorporating the primorial variant secures robust rejection of Carmichael numbers—a significant advantage over probabilistic Fermat-type tests.

Conclusions. This research presents a deterministic, scalable, and pedagogically intuitive primality test grounded in elementary tabular analysis. Its dual utility in both computational number theory and mathematics education positions it as a valuable contribution with practical and theoretical impact. Future work will explore integration with educational software and further extension to cryptographic applications.



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sciforum-167997: The anti-plane surface motion of valleys in coastal cities induced by earthquakes

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Introduction: Valleys are a common topographical feature of coastal cities, and some coastal cities are located within the Circum-Pacific and Eurasian earthquake belts. In addition, anti-plane surface motion can damage engineering structures and threaten human safety during an earthquake. A novel and significant framework is therefore proposed for computing anti-plane surface motion of valleys induced by earthquakes in order to enhance the resilience of coastal cities against earthquakes.

Methods: 1. A valley under earthquake excitation is simplified as an arc-shaped mathematical model for incident SH waves. 2. The elastic wave motion equation is generated without factors of time. 3. Based on the variable-separation method, wave functions satisfying the equation are derived. 4. Wave functions meeting boundary conditions can be obtained using zero-stress boundary conditions of the mathematical model. 5. Complex displacement of surface motion is obtained through wave functions' linear calculations. 6. Amplitudes and phases of surface motion are determined using complex-number calculative formulae.

Results and Discussion: As a result, anti-plane surface motion of valleys can be computed by the newly presented framework. In the next study, angles ranging from 30 to 60 degrees and frequencies ranging from 0 to 10 HZ will be evaluated. Amplitudes and phases of surface motion are given as functions of various angles and frequencies of incident SH waves. It is found that amplitudes and phases of surface motion of valleys usually vary with angle and frequency.

Conclusions: For oblique incidence, displacement amplitudes on a surface facing waves are often higher than those on a shadow surface. In addition, the number of oscillations of amplitudes on a surface facing waves is often greater than that on a shadow surface. However, regular patterns of phases are nearly consistent. These findings suggest that important buildings, such as cable cars, bridges and railways, can be built better on shadow surfaces of valleys in coastal cities.



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sciforum-170355: The Averaging Principle for Stochastic Slow-Fast Systems Driven by G-Brownian Motion

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Introduction: This paper establishes a novel averaging principle for stochastic slow-fast systems where the driving noise is subject to Knightian volatility uncertainty, modeled by a d-dimensional G-Brownian motion B(t). Classical averaging theory fails under volatility ambiguity, and we provide a framework to average the fast dynamics in the worst-case sense.

Methode: We introduce a concept of G-invariant measure, which generalizes the classical invariant measure to the sublinear expectation space. This measure encapsulates a set of possible invariant laws for each admissible volatility scenario. Using this, we define the averaged coefficients for the slow component in a worst-case sense. Under appropriate assumptions, we employ Khasminskii's time-discretization technique and tools from G-stochastic calculus to prove the convergence.

Results: Our main result demonstrates that as the timescale separation parameter tends to zero, the slow component of the original multiscale system converges to the solution of a simplified, averaged equation. The convergence is established in two strong senses: in capacity (quasi-surely) and in the L2-norm under the G-expectation.

Conclusions: This work extends the classical stochastic averaging principle to environments with distributional ambiguity. The results offer a robust mathematical tool for simplifying complex multiscale systems—such as those in financial risk, climate economics, or epidemic modeling—where fast variables are subject to uncertain volatility.



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sciforum-174294: The Socio-Digital-Economic Corruption Model (SDECM): A Novel Framework for Analyzing Cyber Fraud and Civic Enforcement

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This study develops and analyzes a nonlinear dynamical model describing the coupled evolution of corruption, organized crime, and cybercriminality under the influence of institutional trust, economic stress, and digital transparency. Unlike traditional enforcement-driven frameworks, the proposed model incorporates endogenous feedback between corruption prevalence and institutional trust, allowing corruption to both erode and be amplified by governance quality. Economic stress is introduced as a recruitment amplifier, while digital transparency functions as a structural suppression mechanism. The model is formulated as a system of nonlinear ordinary differential equations and rigorously examined. We establish positivity, boundedness, and the existence of a positively invariant region. Using the next-generation matrix approach, a modified basic reproduction number is derived that explicitly incorporates trust erosion and transparency effects. Local and global stability of the crime–corruption–free equilibrium are proven via Lyapunov techniques. Furthermore, center manifold analysis demonstrates the potential for backward bifurcation, indicating governance tipping thresholds and multi-stability regimes. An optimal control framework is constructed to determine cost-effective strategies combining transparency investment, prosecution intensity, and employment stabilization policies. Numerical investigations calibrated to India-specific governance and crime indicators illustrate how strengthening institutional trust and digital transparency can produce nonlinear reductions in corruption prevalence. The findings provide analytically grounded insights for sustainable governance reform in digitally evolving socio-economic systems.



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sciforum-168098: Thermal and Hydrodynamic Analysis of Viscoplastic Fluid Flow in a Half-Channel: Insights from the Casson Model with Temperature-Dependent Viscosity

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The heat transfer in channels that have varying cross sections is fundamentally not the same as that in channels of the same cross section. The heat transfer mechanism is enhanced in comparison with those channels with the channels of constant cross section is based on increased flow intensity. This paper is a numerical exploration of the laminar flow and thermal transport properties of a viscoplastic fluid. The Casson model is a model of viscosity that varies with temperature. The equations of governance include mixed convection driven by buoyancy, with the plastic viscosity being an exponential function of temperature. The proximity of the behavior to the yield surface requires the use of the Casson–Papanastasiou regularization, which guarantees a smooth transition in stress between the yielded zones and the unyielded zones. The finite volume numerical simulations method displays detailed flow fields, temperature fields, and yield surface dynamics depending on the values of Reynolds and Casson numbers. The major finding of this work is the major role contributed by the half-channel geometry to the improvement of flow development and heat transfer. The lopsided form encourages enhanced convectional circulation and speeds up the destruction of unyielded areas with symmetric enclosures, enhancing mixing and thermal diffusion. Findings indicate that the fluid mobility is inhibited by a rise in the Casson number by increasing the area of unyielded flow, whereas increased Reynolds numbers lower the resistance of the flow and pressure drop. The interaction between temperature-dependent viscosity and enclosure geometry provides more insight into the mechanisms of flow enhancement of non-Newtonian systems. These findings can be useful for optimizing industrial and biomedical practices, such as exposure of yield-stress fluids to confined geometries.



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sciforum-171093: Time-periodic problem for inhomogeneous heat equations in a two-layer domain with Dirichlet boundary and linear transmission conditions

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Heat conduction problems in multilayered media are widely used to model processes in heterogeneous structures, including composites, semiconductors, biomaterials, and nanostructures. In this context, the study of models that describe the evolution of the temperature field under periodic forcing is relevant. In the case, the initial conditions lose their physical meaning and are naturally replaced by time-periodic conditions.

This work investigates a two-layer heat conduction problem for inhomogeneous equations with Dirichlet boundary conditions in the spatial variable and periodic conditions in time. The problem is formulated in the cylindrical domain, defined as the Cartesian product of an interval on the real line and the unit circle. At the interface between the two layers, transmission conditions generalize the classical continuity conditions of the temperature and the heat flux.

The solution is determined as a time-periodic regime, consistent with physical scenarios such as periodic heating or cooling. The existence and uniqueness of the solution in Sobolev spaces of time-periodic functions are proved. The analysis is based on the method of separation of variables, Fourier series expansions, the construction of Green's functions, and estimates of the determinants related to the problem. A representative model problem is presented along with an approximate solution obtained using a truncated Fourier series expansion.



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sciforum-170510: Tsallis Nonextensive Entropy and Holographic Dark Energy: A Thermodynamic Approach to f(G) Gravity Reconstruction

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In this work, we present a comprehensive reconstruction of modified Gauss--Bonnet gravity within the framework of Tsallis nonextensive entropy and holographic dark energy. By employing the Tsallis entropy formalism, a particular case of the most generalized Nojiri--Odintsov entropy formalism, the holographic energy density acquires a generalized nonextensive form, which is then embedded into f(G) gravity to generate a purely geometric description of dark energy. The reconstruction procedure is implemented for three different scale factor choices, namely, hybrid, linearly truncated hybrid, and quadratically truncated hybrid, using the Granda--Oliveros infrared cutoff. The resulting f(G) functions are found to exhibit monotonic growth, indicating negligible deviation from General Relativity in the early universe and significant contributions at late times, thereby supporting accelerated expansion. The reconstructed equation-of-state parameter remains negative throughout the evolution, with possible transitions between phantom and quintessence regimes depending on the model parameters. Further, the adiabatic index exhibits a positive and monotonic evolution, thereby confirming the dynamical stability and thermodynamic consistency of the reconstructed f(G) model. Finally, a detailed thermodynamic investigation confirms that the total entropy variation stays positive, ensuring the validity of the Generalized Second Law of Thermodynamics. Overall, the results establish that the Tsallis holographic dark energy model in f(G) gravity yields a thermodynamically consistent and dynamically viable framework for explaining late-time cosmic acceleration.



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sciforum-171372: Wave Solutions and Dynamical Behavior of the Ivancevic Option Pricing Model

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This paper investigates exact analytical solutions of the Ivancevic option pricing model, a nonlinear mathematical framework designed to describe complex features of financial markets, including market volatility and nonlinear asset price dynamics. Unlike classical option pricing models, the Ivancevic model incorporates nonlinear wave behavior, making it suitable for capturing irregular and extreme market movements. To obtain closed-form solutions, the modified extended direct algebraic method is employed as an effective analytical tool. Through this approach, several families of exact wave solutions are derived, including periodic, dark-bright, mixed dark–bright, singular, and hyperbolic function solutions. These solution structures reveal a wide range of possible option price behaviors under different market conditions and parameter settings. To further understand the economic and dynamical implications of the obtained solutions, numerical simulations are carried out using carefully selected model parameters. The numerical analysis includes two- and three-dimensional wave profiles as well as contour plots, which provide clear visual insight into the evolution and interaction of pricing waves over time and space. In particular, contour plots are used to identify the extrema and concentration regions of option price fluctuations within specified temporal and spatial intervals. These visualizations help clarify the influence of model parameters on market dynamics. Overall, the results enhance the analytical understanding of the Ivancevic option pricing model and demonstrate the effectiveness of the proposed method. The findings offer a solid mathematical foundation for future research on stability analysis, parameter sensitivity, and nonlinear wave propagation in complex financial and economic systems.



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Session 5. Control Theory and Mechanics

sciforum-169167: Explicit Solutions for LTV Systems: A New Perspective on Stability Criteria

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Stability is a cornerstone in the analysis and design of complex dynamical systems, typically evaluated through the linearization of non-stationary system dynamics around a reference or attractive trajectory. While this process yields a linear time-varying (LTV) system—a representation central to modern frameworks such as contraction theory and adaptive control—general stability analysis for LTV systems remains a significant theoretical and practical challenge. Existing methodologies are often restricted to narrow cases, such as periodic or slowly varying systems, or rely on finding solutions to the time-dependent Lyapunov equation, which are frequently computationally demanding or analytically intractable for high-dimensional systems. This work introduces an alternative dynamical eigenstructure approach designed to derive explicit analytical solutions and define robust stability criteria for LTV systems. By generalizing classical time-invariant eigenvalue analysis, we define a dynamical eigenstructure consisting of time-varying eigenvalues and eigenfunctions that satisfy a fundamental differential dynamical equation. This unified perspective allows for the direct assessment of stability properties from the system's time-evolving spectral characteristics without requiring the construction of a Lyapunov function. We provide a rigorous derivation of the stability conditions based on these dynamical trajectories. Finally, the effectiveness and versatility of this framework are demonstrated through several illustrative examples, showcasing its ability to provide deeper analytical insights into the transient behavior, and facilitate the stability analysis, of non-autonomous systems.



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sciforum-169495: Mathematical Analysis and SolidWorks-Based 3D Simulation of a Double-Pendulum Robotic Arm

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The non-linear dynamics of robotic arm manipulators impose considerable barriers in control and stabilization. The proposed study will help to close the gap between theory in physics and the applications of physics by comparing mathematical modeling with simulations of physical 3D mechanical systems of a manipulator working as a simple double pendulum. The study uses SolidWorks to design the 3D of the first stage and MATLAB to simulate the changes in physical parameters on oscillatory motion. The method included the derivation of the Lagrange equations of a 2-DoF system, creation of the MATLAB/Simulink blocks in mathematical analysis and execution of simulation using MATLAB/Simscape Multibody in the 3D visualization. Four models of robots were analyzed and the numerical results indicated that sine waves were always generated by the mathematical simulation , the sine wave peaked at 57.9 in the case of Franka Emika. By comparison, the 3D model simulation of the same reached the highest point of 56.9 at a definite time delay, meaning the influence of physical models. The most important results showed that mathematical models are more appropriate to derive transfer function but the behavior of robots with similar dimensions and weights was closed when 3D simulation was used. An effective control parameter development of robotic hardware is helped by this dual-modeling methodology that allows that whenever a theoretical design is developed it must be tested against the realities of mechanical reality.



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sciforum-171923: Performance Degradation and Stabilization of Semilinear Stochastic Systems Driven by α-Stable Lévy Noise

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Classical stochastic control theory predominantly relies on Gaussian noise models driven by continuous Wiener processes. However, these models fail to capture the heavy-tailed, discontinuous jump phenomena frequently observed in modern complex systems, such as power grids under fault conditions or networks experiencing sudden cyber-anomalies. This paper investigates the finite-time stabilization and approximate controllability of a class of semilinear impulsive stochastic evolution equations defined on a separable Hilbert space and subjected to non-Gaussian α-stable Lévy noise.

When the perturbation paradigm shifts from continuous diffusion to discontinuous jump processes, standard feedback control strategies designed under strict second-moment assumptions often experience severe performance degradation or total loss of stability. Because the variance of the Lévy process diverges for $\alpha \in (1,2)$, classical mean-square L^2 stability analysis entirely collapses. To address this fundamental limitation, we shift our analytical framework to the Banach space $L^p(\Omega, H)$ of fractional-moment integrable processes, where the moments remain finite for 1pα.

Within this space, we establish finite-approximate controllability by formulating a parameterized feedback control law and constructing a nonlinear operator mapping based on the mild solution of the impulsive system. By employing Picard iterations and the Banach fixed-point principle under the p-th moment norm, we theoretically guarantee the existence of a unique stabilizing state trajectory that compensates for both continuous nonlinear drift and discrete impulsive shocks.

To complement the theoretical framework, we present a preliminary numerical investigation to assess controller degradation explicitly. Through extensive simulations utilizing the Chambers–Mallows–Stuck method to generate symmetric α-stable increments, we demonstrate the failure modes of classical controllers under heavy-tailed perturbations. Ultimately, this work illustrates how control adjustments based on fractional moments facilitate finite-time stabilization, establishing a mathematically rigorous foundation for the synthesis of resilient controllers in non-Gaussian, impulsive stochastic environments.



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sciforum-174438: A Hybrid Pole-Placement and Deadbeat Controller for Discrete-Time Systems

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Introduction: Deadbeat controllers achieve finite-time convergence in discrete-time linear systems by driving all state variables to the origin within exactly n steps, where n denotes the system order. Despite this theoretical optimality, pure deadbeat control suffers from prohibitively large initial control magnitudes, frequently inducing actuator saturation and rendering the controller impractical for physical implementation. This fundamental trade-off between convergence speed and control feasibility constitutes a critical open challenge in digital control design.

Methods: This paper proposes a two-phase hybrid control architecture that rigorously reconciles finite-time convergence with actuator constraints. During Phase I (1 to m), an Ackermann pole-placement law repositions the closed-loop eigenvalues to prescribed locations within the open unit disk, moderating transient control amplitudes while ensuring asymptotic state reduction. At step m+1, Phase II activates a standard deadbeat formulation that eliminates the residual error in exactly n additional steps. A unified state-space formulation is derived, and Lyapunov-based stability arguments confirm that the switching does not introduce instability. The total convergence time is analytically determined to be $T_c = m + n$ steps.

Results: Comparative simulations on a second-order discrete-time plant (n=2) demonstrate that the hybrid scheme significantly reduces peak control effort. Specifically, the peak effort drops from 9.50 in pure deadbeat to 3.80 and 3.72 for hybrid modes m=2 and m=4, respectively, achieving up to a 61% reduction. Meanwhile, the Mean Square Error (MSE) shifts from 4.13 (pure deadbeat) to 5.58 (m=2) and 5.45 (m=4). This confirms that increasing the switching instant m effectively reduces peak control magnitude at the cost of a proportional increase in settling time and transient error.

Conclusions: The proposed m-step Ackermann / (m+1)-deadbeat hybrid controller provides a formally grounded, tunable framework for discrete-time control design. By parameterizing the switching instant m, practitioners can explicitly trade off convergence speed for reduced control effort, enabling actuator-aware implementation without sacrificing the zero-steady-state-error guarantee of deadbeat control.



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sciforum-174209: Adaptive Wavefront Correction Algorithms for Enhancing Transmission Efficiency in Atmospheric Optical Communication Links

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Atmospheric optical communication links represent a promising solution for long-distance information transmission, including classical and quantum communication systems. However, their performance is limited by wavefront distortions caused by atmospheric turbulence.

This work presents experimental approaches to improving transmission efficiency in atmospheric optical channels through adaptive wavefront correction. The experimental setup involved focusing a laser beam with a diameter of 45 mm by means of a bimorph mirror through apertures of 20 μm and 10 μm, simulating signal reception conditions in free-space optical communication systems. The photodiode current, proportional to the transmitted optical energy, was used as the objective function for optimization. Maximization of this signal provided an indirect measure of the effectiveness of wavefront correction and energy concentration in the focal spot.

Two different optimization algorithms were implemented. The first approach was a deterministic hill-climbing algorithm aimed at sequentially increasing the energy density in the far-field focal spot. The optimization process lasted approximately 8 minutes and consisted of 5800 control steps. As a result, a maximum signal value of 25,823 was achieved, compared to a theoretically attainable value of 27,472. This corresponds to a transmission efficiency of 94% through the 20 μm aperture. For the 10 μm aperture, the efficiency achieved was approximately 90%.

The second approach was based on a stochastic algorithm employing random control voltages distributed according to a Bernoulli distribution. It demonstrated a significantly faster convergence rate: the optimization process required approximately 10 seconds and involved 500 iterations. The maximum recorded signal value was 23,200, corresponding to about 90% energy transmission through the 20 μm aperture and approximately 82% through the 10 μm aperture.

A comparative analysis indicates that the deterministic hill-climbing algorithm provides higher correction accuracy, while the stochastic method offers a substantial advantage in terms of optimization speed. The obtained experimental results confirm the effectiveness of adaptive optics algorithms for compensating for atmospheric wavefront distortions and demonstrate their potential application in optical communication systems.



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sciforum-174040: Energy-Optimal Control of Singular Continuous-Time Linear Systems Using the Weierstrass–Kronecker Decomposition.

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Introduction:

Reachability is a key property of linear systems in control theory and plays a central role in system analysis. The minimum energy control problem is closely linked to reachability: in a reachable system, there typically exist multiple admissible controls capable of driving the system from a given initial state to a desired final state within a specified time interval. Singular (or descriptor) systems, which commonly appear in applications such as electrical circuits, constrained mechanical systems, and economic models, introduce additional challenges due to algebraic constraints and the potential non-uniqueness of solutions.

Method:

The proposed approach is based on transforming the minimum energy control problem of a singular continuous-time linear system with rectangular input matrices into its canonical form using the Weierstrass–Kronecker decomposition of matrix pencils. This decomposition allows the separation of the dynamic and algebraic components of the system. The minimum energy control problem is then formulated and solved. We derive explicit conditions for the existence of admissible controls and construct an optimal control law. The analytical results are established using techniques from linear algebra and system theory.

Result:

The derived conditions provide a systematic procedure for computing the optimal input and the corresponding minimum value of the performance index. The effectiveness of the proposed approach is illustrated through a numerical example, demonstrating its applicability to various classes of singular systems.

Conclusion:

This work presents a systematic method for the optimal control of singular systems based on the Weierstrass–Kronecker decomposition. The approach simplifies the analysis of constrained dynamics and provides explicit control strategies.



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sciforum-125330: Fault-Tolerant Prescribed-Performance Intelligent Control of Fractional-Order Nonlinear Systems with State Error Constraints: Application to Electromechanical Dynamics of Electric Vehicles Motors

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The control performance of permanent magnet brush (PMB) DC motors, which are vital components in electric vehicles (EVs), is fundamental to ensuring the smooth, efficient, and safe operation of these vehicles under varying working conditions. This study investigates intelligent control of fractional-order nonlinear systems (FONSs) subject to full-state error constraints, mismatched disturbances, and actuator failure, with the electromechanical dynamics of PMB DC motors serving as a representative application. An error-dependent transformation is proposed to reformulate the constrained tracking control problem into an equivalent unconstrained formulation with deferred error bounds, thereby eliminating the requirement that initial state errors satisfy predefined constraints. Unlike conventional backstepping-based approaches, the proposed strategy avoids the computation of higher-order derivatives of the reference trajectory, which significantly reduces implementation complexity and practical limitations. To compensate for unknown mismatched disturbances, an adaptive estimation law is developed to online approximate their unknown upper bounds in real time. Based on the transformed fractional-order system, a recursive intelligent control scheme is systematically constructed. By employing Lyapunov stability theory in conjunction with Barbalat's lemma, it is rigorously proven that all state errors enter a prescribed bounded region within finite time and asymptotically converge to zero. The simulation results conducted on a PMB DC motor model demonstrate improved transient performance, enhanced robustness, and reliable constraint satisfaction compared with existing barrier Lyapunov function-based and adaptive control methods.



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sciforum-173128: Fixed-Time Adaptive Stabilization of Underactuated Euler–Lagrange Systems with Certified Internal Dynamics

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This paper addresses the fixed-time adaptive stabilization issue for a category of underactuated mechanical systems regulated by Euler–Lagrange dynamics, characterized by aligned parametric uncertainties. Unlike traditional adaptive control schemes that only guarantee asymptotic convergence and usually assume stable internal dynamics, a new framework is created that guarantees global fixed-time convergence and explicitly proves that the zero dynamics caused by underactuation are stable. The suggested controller combines partial feedback linearization with a recursive fixed-time backstepping design and an online parameter adaptation law that keeps the structural properties of Euler–Lagrange systems. A new composite Lyapunov function is presented to address the coupled dynamics of actuated and unactuated coordinates and to formulate a differential inequality of the following form, $?' \leq -??^{?} - ??^{?}$, where 0 α 1 and $\beta > 1$. This structure guarantees global fixed-time convergence with a clear upper limit on the settling time that is not affected by the starting conditions. A Lyapunov certificate for the internal (zero) dynamics is also created and shown to work with the adaptive outer-loop design. This means that minimum-phase assumptions are no longer needed. A thorough analysis shows that all closed-loop signals are globally bounded and that the system is robust against matched uncertainties. Numerical simulations of typical underactuated systems show the theoretical properties and show how fixed-time performance compares to asymptotic adaptive controllers. The results lay a systematic groundwork for the fixed-time adaptive control of underactuated mechanical systems and facilitate further advancements towards robustness and constrained control.



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sciforum-171643: Integrating Learning from Demonstrations with Neuroadaptive Control for Robotic Trajectory Tracking

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Learning from Demonstrations (LfD) has the capability to transfer human expertise on repetitive tasks into robotic systems, thus avoiding the need for highly technical knowledge to program such systems. A common formulation for modeling human demonstrations as non-linear trajectories, as well as for ensuring robustness against perturbations, is state-dependent dynamical systems (DSs). Recent DS-based LfD approaches learned the complex dynamics of motion and provided stability guaranties; however, most of them followed the next integral curves of the DS to reach their target. These approaches are unsuitable for applications that require precise tracking of the robot's trajectory. To address this drawback, this study proposes a neuroadaptive control approach to enhance the tracking fidelity of learned trajectories, which provides performance guarantees online in a DS-based LfD approach. Furthermore, a constrained optimization problem based on the Gaussian Mixture Model (GMM) and the Control Lyapunov Function (CLF) is used to generate the reference trajectory offline. The proposed approach has been experimentally validated on the LASA dataset and on real trajectories coming from the Unmanned Surface Vessel (USV) Vendaval. Preliminary results confirm that the novel DS-based LfD approach proposed in this study significantly improves trajectory tracking when the system is disturbed; moreover, these results outperform existing approaches in terms of tracking fidelity.



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sciforum-173975: Koopman-Certified Safe Actor–Critic Reinforcement Learning via Robust Projection in Lifted Space

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Reinforcement learning (RL) can achieve strong performance in nonlinear control, but exploration often violates safety constraints, which limits deployment in safety-critical systems. Koopman-based control offers a promising bridge between nonlinear dynamics and linear control tools, yet practical success depends on explicitly accounting for approximation errors; recent Koopman control theory highlights that bilinear surrogate models with finite-data, proportional error bounds enable rigorous closed-loop guarantees.

We propose a safe actor–critic framework in which a Koopman surrogate model is learned from data together with an error certificate that upper-bounds one-step prediction mismatch as a function of the lifted state and input magnitudes. Using this certificate, we construct a robust safety layer that computes, at every step, the nearest admissible action to the actor's proposed action such that state and input constraints are satisfied for all model errors consistent with the bound. This safety layer is formulated as a tractable convex projection problem, guaranteeing constraint satisfaction whenever the certified safe action set is nonempty.

We interpret the safety layer as an additional "safety critic". The filter's intervention (the difference between proposed and applied actions) provides a direct learning signal that penalizes reliance on the filter, encouraging the actor to produce intrinsically safe actions while the standard critic optimizes task reward.

Simulation results on a nonlinear controlled system with intentional model mismatch show that robust projection eliminates training-time safety violations compared to unshielded and nominally shielded baselines. Moreover, incorporating the safety-critic signal substantially reduces safety interventions while maintaining achieved performance, demonstrating safe learning and improved policy self-safety without sacrificing control quality.



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sciforum-171303: LSTM-Based Predictive Control for Robotic Manipulators: Numerical Experiments and Pathways to Formal Robustness Guarantees

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A predictive adaptive control system for multi-joint robotic manipulators is proposed, leveraging Long Short-Term Memory (LSTM) neural networks for trajectory tracking error prediction. The method is designed to mitigate dynamic uncertainties and external perturbations without explicit system identification, thus enabling robust and model-agnostic control.

The key finding of this study is that an encoder–decoder LSTM network, trained on joint angle increments (in delta-space), is capable of making accurate multi-step forecasts, ensuring smooth trajectory continuation. Delta-space representation is emphasized as a crucial factor for maintaining physical consistency, effectively eliminating discontinuities commonly encountered in absolute-value predictions.

In order to establish a theoretical basis, this work incorporates concepts derived from functional analysis, particularly the generalized Hölder-type conditions, which are formalized through the notion of a local modulus of continuity. These concepts serve as a promising framework for examining the approximation properties and stability of the predictor.

These mathematical instruments provide a structured framework for future rigorous analysis, encompassing the derivation of error bounds and guarantees for preserving smoothness. The discussion emphasizes how these analytical approaches can inform the selection of architecture and the regularization of training and ultimately contribute to enhancing the reliability of data-driven predictive controllers in real-time robotic applications and deployment scenarios.



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sciforum-171579: Mathematical Modeling and Free Vibration Analysis of Nonhomogeneous Nanobeams with Axially Varying Nonlocal Parameter

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This work presents a comprehensive investigation into the free vibration behavior of nonhomogeneous nanobeams, particularly axially functionally graded (AFG) nanobeams, incorporating spatially varying nonlocal effects. The nanobeam is modeled using the Euler–Bernoulli beam theory, while small-scale phenomena are captured through Eringen's nonlocal elasticity theory. Unlike conventional approaches that assume a constant nonlocal parameter, the present work considers a varying nonlocal parameter along the axial direction, enabling a more realistic representation of nonlocal effects. The material properties of the nanobeam are assumed to vary continuously along the beam's axis according to a power-law distribution, reflecting the functional gradation of the structure. The governing equations are formulated and solved using the Rayleigh–Ritz method to obtain the frequency parameters. A convergence study is conducted to demonstrate the numerical stability and accuracy of the proposed solution methodology. The obtained results are further validated through comparisons with existing solutions available in the literature for specific limiting cases. Parametric analyses are performed to examine the effects of the power-law exponent and the variable nonlocal parameter on the first four frequency parameters. The results indicate that increasing the power-law exponent or the nonlocal parameters results in a noticeable reduction in the frequency parameters, highlighting the significant roles of material gradation and small-scale effects in the dynamic response. Overall, the study demonstrates that incorporating a spatially varying nonlocal parameter provides enhanced predictive capability for the vibration analysis of AFG nanobeams, offering valuable insights for the design and optimization of advanced nanostructures.



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sciforum-149294: Mathematical Optimization and AI-Driven Control of UAV Spraying Systems for Precision Agriculture

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The development of autonomous unmanned aerial vehicle (UAV) spraying systems requires a mathematically rigorous control framework to ensure stability, efficiency, and robustness under uncertain field conditions. This study presents a hybrid mathematical–AI approach that integrates nonlinear optimization and control theory with adaptive machine learning for precision agriculture. The UAV path and spray scheduling problems are formulated as a constrained multi-objective optimization model that minimizes energy expenditure and chemical use while satisfying coverage and drift constraints. Using graph-theoretic modeling and nonlinear programming, optimal trajectories are derived that guarantee convergence toward feasible solutions under bounded uncertainty. Reinforcement learning is then employed to provide adaptive control, while maintaining mathematically verifiable stability through Lyapunov-based performance analysis. The proposed hybrid controller couples the learning dynamics of the AI model with the deterministic properties of the mathematical control law, ensuring predictable behavior even under varying canopy and wind conditions. Simulation experiments demonstrate significant improvements in deposition uniformity and chemical savings compared with conventional fixed-rate strategies. By grounding UAV spraying in the principles of optimization theory, stability analysis, and control mathematics, this work moves beyond heuristic AI control to a mathematically interpretable and generalizable framework. The study illustrates how integrating rigorous mathematical formulation with intelligent control design can advance sustainable and precision-driven agricultural automation.



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sciforum-170131: New Parametric Curves for the Brachistochrone Optimal Control Problem Using the Dynamic Programming Method

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The Brachistochrone is the curve that provides the fastest descent of a particle sliding without friction under a uniform gravitational field. Among all curves joining two fixed points, it minimizes the travel time and represents a fundamental problem in the calculus of variations and optimal control theory, with important applications in physics, engineering and optimization.

In this paper, we present explicit parametric representations of the Brachistochrone problem without initial velocity and perform a comparative analysis for several physical and mathematical configurations. Previous theoretical studies established the existence of optimal trajectories using dynamic programming methods, but without providing explicit expressions of the corresponding curves. Such representations are essential for both practical computations and theoretical investigations, since they allow accurate evaluation of physical quantities including distance, velocity, acceleration, curvature and travel time, both in the presence and absence of gravity.

The main objective of this work is to construct and compare parametric forms of the Brachistochrone curve without initial velocity and to analyze their geometric behavior, regularity properties, and physical interpretation. Particular attention is given to the influence of model parameters on the shape of the optimal trajectory and on the associated motion characteristics. The obtained results provide new insights into the structure of the problem and contribute to a better understanding of optimal trajectory design in gravitational environments.



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sciforum-170638: Optimal Control of Combined Chemotherapy and Immunotherapy in a Tumor–Immune Model with Sensitivity Analysis

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Introduction

Cancer treatment increasingly relies on combination therapies to improve patient outcomes while reducing toxicity. Chemotherapy directly kills tumor cells, whereas immunotherapy enhances the body's immune response. Determining optimal dosing schedules for both therapies remains a major challenge. This study develops an optimal control framework to investigate combined chemotherapy and immunotherapy strategies that minimize tumor burden while controlling treatment cost and side effects.

Methods

We consider a nonlinear system of ordinary differential equations describing interactions among tumor cells, immune cells, and chemotherapeutic drug concentration. Two time-dependent control variables are introduced: chemotherapy dosage and immunotherapy input. Pontryagin's Maximum Principle is applied to derive necessary optimality conditions for minimizing an objective functional that balances tumor reduction, immune preservation, and treatment cost. The optimality system is solved numerically using a forward–backward Runge–Kutta method. In addition, normalized local sensitivity analysis is performed to evaluate the robustness of the optimal strategy to parameter uncertainty.

Results

Numerical simulations compare chemotherapy, immunotherapy, and combined therapy. Chemotherapy is most effective in weak immune environments, while immunotherapy success depends strongly on immune proliferation and lifespan. Combined therapy reduces tumor burden more efficiently than single therapies, although chemotherapy contributes more strongly to tumor elimination. Sensitivity analysis shows that tumor growth rate, immune proliferation, and drug efficacy are the most influential parameters. The optimal strategies remain stable under small parameter perturbations.

Conclusions

The proposed dual-control framework demonstrates how optimal scheduling of chemotherapy and immunotherapy can improve treatment effectiveness while limiting drug usage. The results provide quantitative insight into combination therapy design and highlight the importance of treatment timing and immune dynamics in cancer therapy optimization.



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sciforum-171642: Optimal Control Strategies for Predator–Prey Systems with Bang–Bang and Quadratic Control Terms.

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Optimal control theory provides a powerful mathematical framework for formulating effective ecological management strategies, particularly for complex systems such as predator-prey interactions. While foundational models like the Lotka-Volterra equations offer important insights into species relationships, their use in sustainable management is limited by simplifying assumptions, particularly the omission of intraspecific competition. Modern research has addressed these limitations by integrating more realistic ecological mechanisms and applying optimal control theory as a powerful mathematical method. This study extends that approach by applying optimal control theory on a predator-prey model that includes internal competition in both species, investigating two distinct management goals. The first strategy seeks to conserve predators through prey addition, where controlled prey supplementation supports predator growth in finite time while maintaining prey availability and overall ecosystem stability. The objective is to increase the predator population while quadratically penalizing control effort through a running cost functional. The second strategy aims to maximize the total population by controlling the interaction rate between species. For this approach, a bang–bang control problem is formulated in which a linear control variable governs the mixing (or segregation) of populations, with the goal of maximizing the total population at a fixed final time. Pontryagin's Maximum Principle is applied to derive necessary optimality conditions for both problems. Numerical simulations show that the first optimal control strategy increases predator population density in finite time through sustained prey supplementation while maintaining sufficient prey availability. For the second strategy, numerical optimization identifies a specific switching time that achieves the global maximum for the total population at the terminal time. These findings provide a theoretical foundation applicable to wildlife conservation and fishery management.



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sciforum-168610: Robust Control Lyapunov Functions for Fractional Order Uncertain Lagrangian and Hamiltonian Systems.

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In this presentation are shown the mathematical fundamentals to obtain robust control Lyapunov functions for fractional order uncertain Lagrangian and Hamiltonian systems. As it is known, Lagrangian and Hamiltonian mathematical representations are important to model different types of physical systems such as mechanical, electrical, chemical, biological. It is important to consider the types of uncertainties in this kind of systems, but in this case this presentation is focused in multiplicative and additive uncertainties. It is important that a complete topological analysis is performed for both kinds of uncertainties. These uncertainties are studied in the case of Lagrangian and Hamiltonian systems. Then the implementation of the design methods to obtain robust control Lyapunov functions are evinced in this presentation. The robust control Lyapunov functions are designed considering the fractional order representation of the Lagrangian and Hamiltonian systems. These study finish with two case of study, one the modeling of a fractional order electrical machine and a fractional order mechanical system, in order to obtain appropriate fractional order robust control Lyapunov functions for robust control law design. In this presentation is evinced how the modeling of different types of physical systems are modeled, so the advantages of implementing the fractional order approach has advantages over the integer order one.



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Session 6. Mathematics, Computer Science and Artificial Intelligence

sciforum-161798: Toward Robust RL for Autonomous Driving: Lessons from DQN and A2C

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Reinforcement learning (RL) has emerged as a promising paradigm for autonomous control tasks, where agents must learn sequential decision-making in dynamic and uncertain environments. Among RL algorithms, Deep Q-Networks (DQN) and Advantage Actor-Critic (A2C) represent two widely used approaches—value-based and policy-based, respectively—each with distinct strengths and limitations. This study presents a comparative analysis of DQN and A2C applied to the challenging CarRacing-v3 environment, where agents must handle continuous dynamics such as steering, acceleration, and braking.

Both agents were trained using preprocessed input frames, which involved grayscale conversion, cropping, resizing, normalization, and frame stacking to capture temporal dependencies. DQN was implemented with experience replay, target networks, and Double DQN extensions, while A2C employed a shared convolutional encoder for actor and critic networks with entropy regularization to encourage exploration. Training progress was measured using average return, stability, and computational efficiency.

Results revealed that neither DQN nor A2C achieved consistently stable driving policies. DQN struggled with continuous control due to its discretized action formulation, resulting in fluctuating average returns and poor convergence (final average return ≈ –71.5). A2C, while better suited for continuous actions, also stagnated with limited learning progression (average return ≈ –72.4), suggesting inefficiencies in exploration and sensitivity to hyperparameters.

In conclusion, this study highlights the challenges of applying classical RL algorithms to high-dimensional autonomous driving tasks. The findings provide empirical insights into their trade-offs and point toward the need for hybrid or advanced methods—such as DDPG, TD3, or SAC—that combine stability, efficiency, and adaptability for real-world autonomous driving applications.



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sciforum-165417: Dynamic Analysis for Optimal Power Flow of Wind, Solar PV and BESS-Based Short-Term Hydro-Thermal Scheduling for Tri-Objective Operation Using Hybrid Adaptive Encoding Learning, Artificial Bee Colony, and NSGA-II

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The rapid depletion of fossil fuel resources and the increasing pressure to mitigate environmental impacts have accelerated the large-scale integration of renewable energy resources into modern power systems. In this context, this paper presents a comprehensive tri-objective optimization framework for the dynamic optimal power flow (OPF) of a short-term hydro-thermal scheduling problem incorporating wind energy, solar photovoltaic (PV) generation, and battery energy storage systems (BESSs). The proposed framework addresses the coordinated operation of four progressively complex system configurations: thermal-only, thermal–wind, thermal–wind–solar PV, and thermal–wind–BESSs. The formulated problem simultaneously minimizes total generation cost, atmospheric emissions, and voltage deviation under a wide range of nonlinear operational constraints, including valve-point loading effects, hydro reservoir dynamics, renewable generation uncertainty, transmission losses, and battery charging–discharging behavior.

To effectively solve this highly nonconvex, large-scale, and constrained optimization problem, a hybrid Adaptive Encoding Learning-based Artificial Bee Colony algorithm integrated with the Non-Dominated Sorting Genetic Algorithm II (AEL-ABC–NSGA-II) is developed. The adaptive encoding mechanism enhances population diversity and convergence speed, while NSGA-II ensures robust Pareto-based tri-objective optimization. The effectiveness of the proposed approach is validated on the IEEE 39-bus test system under 24-hour dynamic load conditions. Comprehensive performance evaluations, including convergence analysis, Pareto front assessment, and statistical validation using ANOVA and box-plot analysis, demonstrate that the proposed method achieves superior solution quality, robust stability, and significant reductions in cost and emissions while maintaining an improved voltage profile. The results confirm the proposed framework as a reliable and efficient tool for next-generation sustainable power system operation.



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sciforum-157079: FireCast: A Hybrid Physics-Informed Diffusion Model for Nowcasting Wildfire Spread from Geostationary Satellite Data

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The rapid and accurate short-term forecasting (nowcasting) of wildfire spread is a critical challenge for emergency response and public safety. Traditional physics-based models, while grounded in established principles, often lack fine-scale realism and produce overly smooth predictions. Conversely, purely data-driven deep learning models can capture complex patterns but may violate fundamental physical constraints, leading to unrealistic or untrustworthy forecasts. This paper introduces FireCast, a novel, original hybrid algorithm that synergizes both approaches for high-fidelity nowcasting of wildfire perimeters for up to two hours.

FireCast employs a two-stage hybrid framework. First, a Deterministic Forecast Module uses a physics-informed cellular automaton (CA) to generate a coarse, low-resolution forecast. This CA is guided by meteorological data (wind, humidity) from ERA5 and topography from a DEM. Second, this physically-grounded prediction serves as a strong condition for a Stochastic Refinement Module. This module uses a generative diffusion model, based on the CasFormer architecture, to refine the coarse forecast. It adds realistic, high-frequency details learned from historical fire events observed in Himawari-8/9 satellite imagery.

FireCast was trained and validated on a curated dataset of 50 major wildfire events, comprising approximately 4,000 spatiotemporal sequences from the Asia-Pacific region. In a comparative analysis for a 120-minute forecast, FireCast (Dice Similarity Coefficient: 0.84, Hausdorff Distance: 3.21 pixels) significantly outperformed both the baseline Deterministic CA (DSC: 0.72, AHD: 8.45 pixels) and a purely data-driven U-Net (DSC: 0.75, AHD: 5.12 pixels). Qualitative results confirm that FireCast forecasts are not only quantitatively more accurate but also visually more realistic, capturing the complex, intricate perimeters of real fire fronts.

This work validates the power of a hybrid deterministic–stochastic approach for complex environmental forecasting. FireCast offers a viable path toward creating trustworthy, high-fidelity AI tools, providing a significant advancement for operational wildfire management and disaster response.



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sciforum-171258: Heatwave-Driven Disease Dynamics in a Temperature-Dependent SEIR Model with Seasonal Forcing: A Case Study of Bangladesh

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Heatwaves have become more common and severe due to climate change, especially rising temperatures, posing a serious public health problem in tropical countries. In this paper, a modified version of the Heat–SEIR model is developed to investigate the influence of seasonal temperature changes and long-term warming on population health. This model was developed by incorporating temperature-related parameters in the classical SEIR model. Seasonal and long-term temperature changes were modeled as a bounded sinusoidal function using average temperature data for Bangladesh from 2000 to 2024. Firstly, the mathematical properties of the proposed model were investigated, and its positivity and boundedness were proved. Then the disease-free equilibrium and the basic reproduction number R_0 were derived. From the local stability analysis of the proposed model, the disease-free equilibrium was stable if R_0 1 and unstable if $R_0 > 1$. However, the existence of the endemic equilibrium when $R_0 > 1$ was been proved.

Furthermore, the influence of temperature change was investigated using the Pearson correlation coefficient between the maximum temperature and other climate-related parameters. Sensitivity analysis was also conducted using normalized sensitivity indices and partial rank correlation coefficients to identify the parameters that most influence the proposed model. From the sensitivity analysis, the transmission and recovery rates were identified, as well as the most influential parameters, while heat-related mortality and temperature-sensitivity parameters were also found to influence the proposed model to a certain extent. Conducting a simulation to demonstrate the effects of seasonal heatwaves and long-term warming on population health, this study provides a clear, data-driven modeling framework for understanding heat-related health risks and could inform future public health planning.



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sciforum-166440: LONG SHORT-TERM MEMORY IN POST-REHABILITATION EXERCISE CLASSIFICATION

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The field of artificial intelligence (AI) and computer vision presents significant opportunities to advance physical rehabilitation. However, their application in rehabilitation assessment still remains underexplored. This study addresses the need for accessible and precise real-time evaluation of post-rehabilitation exercises, contributing to the United Nations Sustainable Development Goal 3: Good Health and Well-Being. The proposed system integrates BlazePose, a human pose estimation model, alongside a Long Short-Term Memory (LSTM) model to classify movement correctness and provide real-time feedback. The system was trained on three low back pain rehabilitation exercises from the KinesiothErapy and Rehabilitation for Assisted Ambient Living (KERAAL) dataset. The researchers found that a 13-keypoint skeletal configuration yielded the most optimal performance, achieving an F1-Score of 80% for flank stretch, 78% for torso rotation, and 77% for hiding face. Furthermore, with the same skeletal keypoint configuration and multiple independent training sessions, a Repeated Measures One-Way ANOVA confirmed statistically significant differences (p .05) in F1-Scores across exercises, indicating varied model performance among the exercise types. The evaluation focused on assessing the robustness and consistency of the model across multiple training runs to ensure reliable performance measurement. The results provide empirical evidence supporting the applicability of deep learning–based pose analysis for automated rehabilitation exercise assessment.



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sciforum-166438: RANDOM FOREST IN FORECASTING RAIN-INDUCED LANDSLIDES

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Recent studies in the Philippines on landslides have primarily focused on susceptibility mapping and the generation of hazard maps. However, research on landslide forecasting remains less explored. As artificial intelligence continues to progress, forecasting methods used have also become more advanced. This study focuses on rainfall, a primary triggering factor of landslides, examining its relationship with environmental variables such as slope, soil type, and soil moisture to predict potential landslide events. The researchers applied the random forest model to forecast landslides using a minimized yet significant set of predictors (rainfall, slope, soil moisture, slope). The data of these variables have been gathered from various sources, such as sites with real-time data and government agencies that provide public datasets. These were then added into the dataset inventory created by the researchers and then trained using the random forest model. One-way ANOVA was then conducted to assess differences in model performance under various combinations of input variables, followed by post hoc tests to determine the most effective predictive variables. The researchers found that combining rainfall and environmental variables as predictors yielded the highest accuracy at 90%, outperforming models that used only individual variable inputs. These findings demonstrate the effectiveness of the random forest model in forecasting landslides even with limited resources and data, highlighting its potential as a practical and adaptable tool for early warning systems in areas such as the mountainous regions of the Philippines.



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sciforum-173377: Semi-Constructive Method for 3D Solid Reconstruction from Orthographic Views Using Planar Decomposition and Winged-Edge Topology

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Reconstructing a 3D solid from its orthographic projections is a classical problem in computational geometry and computer-aided design (CAD). Although humans perform this task intuitively in technical drawing, algorithmic reconstruction is non-trivial due to ambiguity and incomplete spatial information.

This paper presents a semi-constructive computational method for reconstructing 3D polyhedral solids from orthographic projections (front, top, and side views). The approach integrates planar decomposition, graph-based cycle analysis, and a Winged-Edge boundary representation (BRep) structure to ensure geometric and topological consistency. Unlike universal reconstruction algorithms, the proposed method targets structured polyhedral objects and progressively refines candidate 3D edges through topological filtering. The methodology includes DXF parsing, vertex inference, candidate segment generation via planar intersections, cycle-based internal edge elimination, collinearity merging, and final BRep construction. The experimental results demonstrate correct reconstruction for a representative class of polyhedral objects and highlight both strengths and current limitations of the approach.

The method does not aim to solve the universal reconstruction problem but instead focuses on a structured family of polyhedral solids whose faces are predominantly planar and frequently parallel to projection planes.

The main contributions are as follows:

-A pipeline integrating 2D DXF parsing with 3D vertex inference.

-Exhaustive candidate segment generation using planar intersections.

-Graph-based cycle analysis to eliminate internal edges. \item A consistent Winged-Edge BRep construction.

-Export to STL with correct face orientation.



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sciforum-174545: Persistent Homology and Fractal Dimension-Based Classification of Retinal Fundus Images

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Diabetic Retinopathy (DR) is a progressive microvascular complication of diabetes and remains one of the leading causes of preventable blindness worldwide. Early and reliable detection is essential for reducing vision loss. Conventional image-based methods primarily rely on intensity and texture features. These features often fail to capture the complex geometric organization and subtle structural alterations of retinal vasculature seen in disease progression. In this study, we propose a mathematically driven framework that combines Topological Data Analysis (TDA) with nonlinear dynamics to improve DR classification. Persistent homology was applied to the dataset to extract multiscale topological descriptors, such as connected components and loops, by filtration. The results from persistent homology were encoded as persistence diagrams and then converted into quantitative feature vectors for input to a machine learning model. In parallel, we computed the fractal dimension to quantify vascular complexity and spatial irregularities, reflecting pathological changes. The combined topological and fractal features were used to train a Support Vector Machine (SVM) classifier to grade DR severity. The proposed hybrid approach achieved an overall classification accuracy of 94%. It showed strong discriminative performance across disease stages and improved sensitivity to early structural abnormalities while maintaining high specificity. By capturing intrinsic geometric and dynamical characteristics of retinal images, this integrated TDA–nonlinear dynamics framework offers a robust, interpretable, and clinically relevant methodology for automated diabetic retinopathy screening.



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sciforum-173640: A Communication-Free Parallel Screened Poisson Solver for Incompressible Navier–Stokes

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The scalability of incompressible Navier–Stokes solvers on massive parallel clusters is fundamentally constrained by the pressure projection step, where the global elliptic coupling of the standard Pressure Poisson Equation (PPE) necessitates expensive all-to-all communication and creates a severe latency bottleneck. To overcome this barrier, we introduce Locality-Certified Screened Projection (LCSP), a novel framework enabling a fully parallel, communication-free pressure solve. By relaxing the strict incompressibility constraint into a penalized form $\nabla \cdot \boldsymbol{u}^{n+1} + \eta\psi = 0$, we transform the PPE into a screened Helmholtz problem $(-\Delta + \kappa^2)\psi = f$. This operator exhibits intrinsic locality characterized by the exponential Yukawa decay of its Green's function. Leveraging this property, we implement a single-pass *Overlap-Restrict* assembly strategy: the computational domain is partitioned into overlapping tiles where local problems are solved entirely independently, and solutions are then restricted to the core without any inter-subdomain trace exchange. Our rigorous error analysis demonstrates that artifacts from artificial tile boundaries decay exponentially with the overlap width, allowing the mass conservation error to be explicitly controlled via the screening parameter κ. Extensive numerical benchmarks confirm that LCSP successfully decouples the global dependency, reduces the peak memory footprint to $\boldsymbol{O(|tile|)}$, and achieves optimal linear weak scaling for large-scale flow simulations. Ultimately, LCSP establishes a mathematically grounded trade-off between exact incompressibility and parallel efficiency, providing a robust, highly scalable solution for high-fidelity CFD simulations on next-generation heterogeneous supercomputers.



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sciforum-169923: A conservative model of loan and the limits of the financial bubbles

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We introduce the idea and possibility of loan in a modified Dragulescu–Yakovenko model in econophysics [1]. This is the implementation of the discrete version of the modified Z-model introduced by Pomeau and Lopez-Ruiz in 2015 [2]. This new model is equipped with a parameter that provides an idea of the level of debt that the agents can reach when they trade in a free market. When this parameter is adequately modified, the total debt in the system increases and a financial bubble is created. Once a certain limit is surpassed, the bubble is oversized and the financial system becomes unstable. Simulations and calculations are displayed for this system and they are put in correlation with real data. It is shown that a critical value in the system is found when the bubble, money created in relation to real money, reaches the factor of 5.18, a value in good agreement with the real data of bubbles formed in Western countries during the 2008 financial crisis.

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sciforum-124336: A Hybrid Computational Approach for Studying Animal Behavior in T-Mazes: Analytical and Machine Learning Techniques

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Understanding animal decision-making processes in controlled environments is crucial for gaining insights into cognitive functions and behavior. T-maze tasks, commonly used in behavioral experiments, provide a valuable framework for studying binary decision-making, where animals must choose between two distinct paths. This study presents a comprehensive computational analysis of animal behavior in T-maze tasks, where animals are required to make binary decisions between two paths. By integrating both analytical modeling and machine learning techniques, we aim to explore the decision-making processes involved in such behavioral tasks. In particular, we focus on enhancing our understanding of the cognitive mechanisms that guide these decisions by employing advanced deep learning models. Specifically, we apply Convolutional Neural Network-Long Short-Term Memory (CNN-LSTM) and Convolutional Neural Network-Gated Recurrent Unit (CNN-GRU) architectures to analyze the data. These models achieved impressive classification accuracies of 92.3% and 95.6%, respectively, demonstrating their superior predictive capabilities compared to traditional machine learning methods such as Support Vector Machines and Random Forests. In addition to machine learning, we employed analytical methods to model and interpret the decision-making behavior of animals, providing deeper insights into their cognitive processes during navigation. The results of this research contribute to the field of computational ethology by showcasing the potential of combining analytical solutions with machine learning techniques to model complex biological systems. This approach offers new avenues for understanding animal decision-making in T-maze tasks and similar behavioral experiments.



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sciforum-174218: A Note on Kernel Regression with Several Bandwidth Selection Methods in Software Reliability Prediction

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In this note, we consider a data-driven approach to software reliability prediction based on kernel regression, where the software fault-count process during system testing is modeled directly from observed fault data without imposing a strict parametric distributional assumption. This perspective is particularly useful in practical software testing environments, where the underlying fault-generation mechanism is often complex, time-varying, and difficult to characterize accurately by a single predefined stochastic model. To address this issue, a non-parametric prediction framework is developed by employing kernel regression with several bandwidth selection methods, with the aim of investigating how bandwidth choice influences prediction accuracy, estimation stability, and overall model robustness. Since the bandwidth plays a central role in controlling the bias-variance tradeoff in kernel-based estimation, inappropriate bandwidth selection may lead to over-smoothing or under-smoothing, thereby degrading predictive performance in long-term software fault prediction. In the proposed framework, multiple bandwidth selection strategies are examined and compared under the same prediction setting, and their predictive behaviors are analyzed from both estimation and forecasting perspectives. Through comparative analysis, the proposed approach provides useful insights into the role of bandwidth selection in software fault prediction and offers practical guidance for software reliability evaluation when distributional knowledge is incomplete or uncertain. The results also suggest that careful bandwidth selection is essential for improving the applicability of kernel-based reliability prediction methods in real-world software testing data.



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sciforum-157078: A Unified Survey of Grand Challenges and Open Problems at the Intersection of Physics, Mathematics, and Computation

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Modern science operates at a critical intersection of physics, mathematics, and computation, where many of the most fundamental open questions remain unresolved. Although landmark problem sets such as Hilbert's problems, the Millennium Prize problems, and Smale's list have shaped scientific progress, they are typically treated in isolation, limiting systematic and interdisciplinary analysis. This work aims to construct a unified analytical framework that organizes major unsolved problems across physics, applied mathematics, and computational theory into a coherent transdisciplinary structure.

The study conducts a structured comparative analysis of canonical open problems and foundational literature in three domains: (i) fundamental physics (including quantum gravity, dark matter, and nonlinear physical systems), (ii) mathematical theory (including complexity, topology, and nonlinear dynamics), and (iii) computation (including algorithmic complexity, simulation limits, and predictability). Using conceptual mapping and thematic clustering, the paper identifies shared structural motifs such as symmetry, emergence, nonlinearity, and computational intractability that recur across traditionally separated scientific frontiers.

The results show that many grand challenges can be classified according to a small set of underlying mathematical–computational patterns that govern both physical law and algorithmic limitation. In particular, the analysis demonstrates how computational constraints are not merely technical barriers but fundamental components shaping what can be known, simulated, and experimentally accessed. By proposing a unified classification and conceptual model of open scientific problems, this work provides a systematic lens for interpreting scientific unknowns and establishes a foundation for future interdisciplinary research strategies.



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sciforum-170594: Algorithm Design and Mathematical Modeling for Efficient Automatic Speech Recognition in Low-Resource African Languages

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Introduction.
Deploying Automatic Speech Recognition (ASR) for African languages is critically hindered by the incompatibility of large-scale models with mobile hardware. Models like NLLB exceed 1 GB in size and cannot load on typical devices with 2-4 GB RAM, preventing real-time conversational ASR deployment in resource-constrained settings. This technological barrier disproportionately affects African linguistic communities.
Methods.
We formulate ASR deployment as a constrained optimization problem: minimize Word Error Rate (WER) subject to bounds on model size, latency, and computational complexity.
Our solution integrates three complementary techniques: (1) Knowledge Distillation, transferring knowledge from large teacher networks to compact students; (2) Low-Rank Factorization ($W \approx UVT$), reducing parameters from O(p) to O(rp); and (3) Post-training 8-bit Quantization for 4× memory reduction. Theoretical analysis provides sample complexity bounds of O(k log n) and quantifies output perturbation from compression.
Results.
On a 20M-parameter baseline (85 MB), our framework achieves 16× total compression to approximately 5 MB. Across iSiZulu, Setswana, and Sesotho datasets, mainly South African langauges, we maintain competitive WER with only 5-6% degradation while increasing inference throughput from 0.8× to 6× in real time on commodity CPUs. This 7.5× latency improvement enables previously impossible mobile deployment.
Conclusions.
This work demonstrates that algorithm design grounded in mathematical optimization and hardware-aware compression enables scalable, practical ASR for underserved languages.
The framework provides a general blueprint for efficient edge AI deployment, directly advancing speech technology accessibility and digital inclusion for African linguistic communities globally.



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sciforum-173759: An adaptive hybrid conjugate gradient algorithm for the optimization of image restoration model

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Image restoration is a fundamental problem in image processing aimed at recovering high-quality images from degraded observations corrupted by blur and noise. This task is commonly formulated as a constrained or unconstrained optimization problem consisting of a data fidelity term and a regularization term to preserve important image features such as edges and textures. Due to the large-scale and ill-conditioned nature of image restoration problems, efficient iterative optimization techniques are required.

Conjugate gradient (CG) methods have been widely applied to image restoration because of their low memory requirements and fast convergence properties in solving large sparse linear and nonlinear optimization problems. Several CG variants have been investigated in the literature and successfully integrated into image restoration frameworks. However, the performance of classical CG methods strongly depends on the choice of search direction and step size parameters. In particular, inappropriate line search strategies may lead to slow convergence or instability when applied to nonlinear and nonconvex image restoration problems. To address these limitations, this paper proposes an adaptive hybrid conjugate gradient algorithm that combines the Fletcher–Reeves and Polak–Ribiere schemes through an adaptive weighting strategy. The proposed method exploits the numerical stability of the Fletcher–Reeves approach and the fast convergence behavior of the Polak–Ribiere method, thereby achieving a balanced and robust optimization performance.

Furthermore, the strong Wolfe line search conditions are adopted to guarantee sufficient descent and curvature properties at each iteration, ensuring global convergence of the proposed algorithm. A theoretical convergence analysis is presented under standard assumptions. The experimental results on blurred and noisy images demonstrate that the proposed adaptive hybrid conjugate gradient method outperforms conventional CG algorithms in terms of both convergence speed and restoration quality, as measured by Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM).



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sciforum-170757: Analytical Surrogates for Incompressible Flow Dynamics via Physics-Based Optimization

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We present a parametric analytical framework for approximating two-dimensional incompressible Navier–Stokes solutions using structured, non-orthogonal functional analysis. The velocity and pressure fields are represented by explicit analytical expressions combining temporal exponential decay, trigonometric components, and low-degree polynomial terms in space, resulting in a finite-dimensional model with a moderate number of free parameters. Unlike classical spectral or Galerkin methods, the proposed approach does not rely on orthogonality, completeness, or projection onto predefined bases.

The unknown coefficients are determined by minimizing a global residual-based functional composed of the squared Navier–Stokes equations evaluated throughout the domain, together with penalized boundary constraints. This formulation enforces physical consistency in the interior while using boundary information as the only prescribed data. The residual minimization acts as an implicit regularization mechanism, despite the absence of a weak formulation or mesh-based approximation of the solution fields.

Numerical integration of the residual functional is performed on an unstructured finite element mesh generated in FreeFEM, which is employed solely as a quadrature tool. The analytical representation remains global and continuous over the domain. A genetic algorithm is used to solve the resulting non-convex optimization problem, serving as a robust global optimizer rather than an intrinsic component of the methodology.

The framework is assessed using two complementary test cases: a controlled verification problem admitting an exact analytical solution, and the classical Taylor–Green vortex benchmark, widely used for validation of Navier–Stokes solvers. Results demonstrate that physically consistent approximations can be reconstructed using boundary information alone, even for nontrivial vortical dynamics.

The proposed approach is positioned as a complementary tool bridging analytical modeling, numerical fluid dynamics, and optimization-based methods, and is particularly suited as a low-cost analytical surrogate or warm-start strategy for data-driven and physics-informed solvers in fluid dynamics applications.



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sciforum-174165: Approximation Analysis of Symmetry-Enhanced Neural Network Operators by Machine Learning Metrics

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This paper investigates the approximation properties of both classical and fractional neural network (NN) operators and their symmetrized counterparts (SNN), which are activated by an activation function, half-hyperbolic tangent, acting on Banach space-valued functions, $\mathbf{f}: X \to \mathbf{R}$, where X is a Banach space with norm $\|\cdot\|$. This work is motivated by the need to better understand the mathematical behavior of neural network (NN)-type operators within the framework of approximation theory and functional analysis. Within this setting, we establish pointwise and uniform convergence results together with quantitative fractional approximation estimates expressed in terms of suitable smoothness measures. A central contribution of the paper is a rigorous comparison between classical neural network (NN) operators and their symmetrized counterparts (SNN). The analysis shows that the symmetry structure leads to improved approximation properties and enhanced stability under appropriate parameter regimes. One of the most innovative aspects of this paper is the evaluation of approximation operators using regression-based machine learning metrics, including RMSE, MAE, Maximum error, and R^2. These metrics provide a statistical interpretation of approximation quality, complementing classical norm-based error bounds. This approach is important because it connects approximation theory with data science methodology and makes operator performance interpretable for machine learning applications. To complement the theoretical analysis, we conducted systematic numerical experiments using the approximation of the proposed operators to the test functions, a log–log graph, and an error-decay graph implemented in Python 3.13, including graphical illustrations and quantitative comparisons of NN and SNN operators employing machine learning metrics. The computational results support the theoretical findings and demonstrate that SNN operators can achieve improved approximation accuracy and more stable behavior in practice. To promote transparency and reproducibility, all implementation details and Python codes, algorithms were made publicly available via GitHub. By combining rigorous analysis with computational experiments, this work contributes to strengthening the connection between approximation theory, neural network models, and numerical computation, providing both theoretical insights and practical tools for researchers working at the interface of mathematics and machine learning.



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sciforum-161217: Approximation by overactivated and spiked convolutions as Positive Linear Operators

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Here is a study of the quantitative approximation to the unit operator of three kinds of overactivated and spiked convolution type operators. These operators have as a kernel a cusp coming from a constructed S shape finite length arc, serving as a new activation function of compact support. This is derived by the composition of two general sigmoid activation functions with a domain of all real numbers. Our operators are positive linear ones and are treated as such. Initially we establish the basic convergence; then, we move on to simultaneous and iterated approximations, all via inequalities and involving the modulus of continuity of the approximated univariate function.

Overactivation in neural networks can lead to several benefits, particularly in enhancing model performance and robustness. Overactivation can help models learn complex patterns by allowing them to explore a wider range of functions. It can prevent underfitting, especially in deep networks where layers may not activate sufficiently. Moreover, by promoting higher activation values, networks can capture more intricate relationships in the data. This non-linearity can improve the model ability to generalize from training data to unseen data. Overactivation can make networks more resilient to noise in the input data, as they can better distinguish between signal and noise. This can enhance performance in real-world applications where data is often imperfect. This is a part of the author's project about approximation by overactivated neural networks.



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sciforum-171503: Brain tumor segmentation with deep learning strategy and wavelet functions

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Brain tumor segmentation is performed using three-dimensional magnetic resonance images (MRIs) as a common practice. The accuracy and fast segmentation still remain a challenge. An algorithm is proposed using deep learning involving the UNet model with wavelet functions. In this algorithm, to enhance gradient flow and feature propagation, U-Net incorporates dense connections (residual block), which reduce the vanishing gradient issue and increase feature reuse. The encoder route blocks are extracted. Information is gradually abstracted, and the corresponding decoder path blocks reestablish the spatial resolution of the input images. The algorithm is validated on the data set MICCAI BratS2020 which includes a set of labelled brain tumor (2D MRI scans) dataset. A comparative study of UNet with Daubechies (db2,db4) and UNet with Haar tabulated for the Brats2020 dataset is included. The research design employed in this study combines residual blocks with UNet where the residual block is implemented using db2,db4 and Haar as activation function after batch normalization to improve training stability and accuracy. It was trained on 4308 2D MRI images, validated on 761 and tested on 895 MRI images.

Experimental results using db2 gave a validation accuracy of 0.99 with validation loss of 0.38 and a test accuracy of 0.98 with a test loss of 0.38 and CPU time taken was 9s 342 ms/steps.

Using db4 the validation accuracy was 0.99, with a validation loss of 0.4240 and test accuracy of 0.98 with test loss of 0.42 and CPU time noted was recorded as 7s 256ms/steps. For Haar wavelet a validation accuracy was 0.97, and loss wH 0.76 with test accuracy of 0.97 and loss of 0.75. Time taken was 6s 231 ms/step. It is noted that the deep learning strategy invoked along with db2 wavelet activation function shows remarkably improved accuracy and performance for segmentation as compared to its counterpart db4 and Haar wavelet family.



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sciforum-170837: Cardiac Disease Classification using Matrix Factorization and Machine Learning

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The diagnoses of cardiac diseases using medical imaging has always been one of the major applications in the medical field, and tools such as machine learning methods have been heavily invested in this application; however, it often requires large, high-quality datasets that are difficult to obtain due to ethical, cost, and variability constraints. To tackle this challenge, we present this study, which explores the integration of classic matrix factorization techniques with deep learning for enhanced cardiac disease classification.

We adapt the matrix factorization approach and principal component analysis to identify dominant modes of variation that capture key features across five cardiac conditions: healthy, diabetic cardiomyopathy, myocardial infarction, obesity, and TAC-induced hypertension in mice. Echocardiography videos were processed into image datasets from long-axis (LAX) and short-axis (SAX) views, reshaped into vectors, and arranged in separate matrices (one matrix per cardiac condition), mean-subtracted, and decomposed using the matrix factorization tool, the singular value decomposition (SVD), to generate a principal components basis for each cardiac condition. These bases are used to represent the original images using projection. The new SVD-generated data is then used to train a convolutional neural network (CNN) classifier.

Compared to training the CNN on original echocardiography images, the SVD-based preprocessing significantly improved performance. Classification accuracy increased substantially across training, testing, and unseen (prediction) datasets, demonstrating about a ~50 % enhancement when using SVD-derived representations.

These results indicate that combining matrix factorization with deep learning can effectively overcome data scarcity issues and improve generalization in medical image classification. The proposed hybrid methodology provides a promising tool for cardiac disease diagnosis, suggesting broader applicability to other medical imaging problems where data limitations hinder machine learning performance.



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sciforum-171411: Combinatorial Optimization using Quantum Computing

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This study evaluates the potential of near-term quantum computing for combinatorial optimization, using the Traveling Salesman Problem (TSP) as a canonical benchmark. Using Qiskit, we construct a hybrid quantum-classical workflow based on the Quantum Approximate Optimization Algorithm (QAOA) and then assess its performance on symmetric TSP instances compared to classical exact methods (Gurobi solver). The Miller–Tucker–Zemlin formulation is implemented to create a Quadratic Unconstrained Binary Optimization (QUBO) encoding. Our findings show that conventional branch-and-bound solvers significantly outperform QAOA in both solution quality and runtime on existing hardware, even though QAOA successfully produces feasible tours. On Noisy Intermediate-Scale Quantum (NISQ) devices, the optimality gap for QAOA grows with problem size, demonstrating its sensitivity to hardware noise, penalty scaling, and variational changes in parameters. Among the tested classical optimizers within the QAOA loop, Constrained Optimization BY Linear Approximations (COBYLA) demonstrated the most practical balance between efficiency and noise tolerance. In order to improve near-term quantum heuristics, this paper validates a functional quantum optimization procedure and highlights key factors for optimizer selection, encoding choice, and error mitigation. We conclude that current NISQ technology does not currently provide a quantum advantage for TSP; rather, our work provides a systematic methodology and performance baselines that are essential for the development of future hybrid quantum-classical algorithms.



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sciforum-171211: Comparative Evaluation of Crop Production under Uncertainty Using Two-stage FM-TOPSIS.

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Agriculture production is inherently affected by uncertainty arising from climate variability, input availability, market fluctuations, and management practices. Conventional statistical and time series forecasting models often fail to effectively capture the vagueness and imprecision associated with such agriculture data. To address this issue, the present study proposes a fuzzy multi-criteria decision-making framework based on the Fuzzy Multi-Attribute Technique for Order Preference by Similarity to Ideal Solution (FM-TOPSIS) for the comparative evaluation of crop production performance using year-wise agricultural data. In the proposed approach, each agricultural year is treated as an independent alternative, while multiple production-related factors such as yield, rainfall adequacy, cost cultivation, pest incidence, soil fertility status, and market stability are considered as evaluation criteria under a fuzzy environment. Linguistic assessments provided by domain experts and farmers are converted into triangular fuzzy numbers to construct the fuzzy decision matrix. FM TOPSIS is then applied to determine the relative closeness of each year to the ideal agriculture performance scenario. Furthermore, a two-stage hybrid evaluation strategy is employed, wherein yearwise rankings obtained through FM-TOPSIS are aggregated to derive an overall performance assessment across multiple years. This hybrid framework enhances robustness and enables consistent comparative analysis of agricultural performance under uncertainty. The results demonstrate that the proposed FM-TOPSIS-based methodology provides a reliable and practical decision support tool for evaluating crop production trends and supporting sustainable agricultural planning.



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sciforum-171548: Convexity, Robustness, and Stability: A Mathematical Investigation of MSE and Huber Loss in Machine Learning

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Artificial Intelligence (AI) models rely on loss functions as fundamental optimization tools to quantify the discrepancy between predicted and observed outputs. The mathematical properties of these functions, including convexity, differentiability, and sensitivity to input variations, directly influence model stability, convergence, and robustness. However, loss functions are often selected empirically with limited theoretical justification, which may result in unstable or suboptimal performance. This study investigates the impact of loss function design on AI model stability, focusing on Mean Squared Error (MSE) and Huber Loss. The methodology combines mathematical analysis with simulation-based experiments. The convexity and convergence behavior of MSE were examined through its first and second derivatives, while Huber Loss was analyzed for its piecewise structure and robustness to outliers. Linear regression models were trained on a housing dataset using both loss functions under identical conditions. Model performance was evaluated using multiple metrics, including MSE, MAE, RMSE, prediction variance, and sensitivity to noisy inputs. Experimental results indicate that the MSE-based model achieved lower test error (MSE ≈ 6.56×10^9; RMSE ≈ 81,000) and slightly better overall stability on clean data. In contrast, Huber Loss produced a lower MAE (≈ 58,877), demonstrating greater robustness to absolute deviations and outliers. Variance analysis showed marginally higher prediction variability for the Huber model, while noise perturbation experiments confirmed that both methods experienced performance degradation, with MSE remaining slightly more stable. Overall, the findings demonstrate that the mathematical structure of loss functions significantly affects model behavior. While MSE provides superior accuracy under normal conditions, Huber Loss offers improved robustness in noisy or outlier-prone settings. These insights provide practical guidance for selecting appropriate loss functions to enhance stability and reliability in supervised learning applications.



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sciforum-129055: Curvature-guided Graph-to-Hypergraph Structural Lifting Alleviates Over-Squashing in Graph Learning

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Graph Neural Networks built on the message-passing paradigm exchange information along a graph's edges, effectively learning from relational data while preserving structural symmetries. However, many real-world systems, such as social or biological networks, exhibit complex interactions better represented by higher-order topological domains. Geometric and Topological Deep Learning addresses this by leveraging such structures. Central to this field is the concept of lifting, which transforms data representations from basic graph forms to more expressive topologies before the application of graph models for learning.

In this work, we propose a structural lifting strategy based on Forman–Ricci curvature, an edge-based characteristic rooted in Riemannian geometry. Curvature reveals local and global graph properties, identifying network backbones, i.e., coarse, structure-preserving geometries connecting major communities. These backbones are most suitably represented as hyperedges, modeling information flow between distant clusters. Our approach assigns a curvature-based metric to each edge in an input graph and performs a structural lifting that maps this graph into a hypergraph representation, treating identified backbones as hyperedges and virtually shortening distances between relevant nodes for subsequent graph classification. Our approach thus offers a remedy to information distortion in message passing across long distances and graph bottlenecks, a phenomenon known as over-squashing.

We evaluate our method on multiple well-known graph learning benchmarks, including a large molecular property prediction dataset, e.g., NCI109 and OGBG-MolHIV. Using standard graph network models such as GCN and GAT, the lifted datasets consistently improve performance in 75% of test cases compared to non-lifted baselines. Notably, higher-order hypergraph models such as EDGNN and AllSetTransformer also benefit, showing improved performance in 80% of test cases when paired with our lifting step.



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sciforum-169323: Data-Driven Identification of Super-Spreaders and Cascade Control in Complex Networks

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Spreading and cascading processes on complex networks arise in diverse contexts, including infectious disease transmission, infrastructure failures, and information diffusion. A central challenge is to understand when large-scale cascades emerge and how to identify the nodes whose control most effectively mitigates systemic risk. This work addresses these questions through a unified mathematical and computational framework combining epidemic theory, nonlinear dynamics, and data-driven learning.

We first revisit epidemic threshold theory for SIS and SIR dynamics on networks, highlighting the role of structural heterogeneity. Using heterogeneous mean-field arguments and spectral analysis, we show how the epidemic onset is governed by the spectral radius of the adjacency matrix, providing a unifying interpretation of threshold conditions and explaining the heightened vulnerability of highly heterogeneous networks.

To capture realistic cascade behavior beyond static models, we introduce a dynamical network framework in which nonlinear nodal dynamics are coupled through the network topology. The model reproduces subcritical, critical, and supercritical cascade regimes and generates bursty, scale-free activity patterns observed in real systems. Building on this dynamical setting, we propose a forecasting and intervention strategy based on radial basis function (RBF) learning applied to historical system states. The method predicts future cascade growth and quantifies the suppressive impact of virtually deactivating individual nodes, enabling dynamic identification of influential spreaders without requiring explicit knowledge of network topology.

Numerical experiments show that the proposed RBF-based targeting strategy significantly outperforms degree-based and random interventions in suppressing large cascades. Finally, we discuss how graph neural networks can approximate structural risk measures, offering a scalable bridge between network topology and learning-based control in large systems.



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sciforum-171683: Developing a Modified Deep Survival Machine with a New Exponential Power Distribution

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Deep Survival Machines (DSMs) integrate neural networks with parametric survival distributions, yet their architecture tightly couples representation learning with parameter estimation, limiting interpretability and obscuring the role of latent risk structure in individualized predictions. This tight integration makes it difficult to disentangle how covariate information is transformed into distributional parameters, thereby reducing transparency in model behavior and complicating theoretical understanding of how latent features influence survival dynamics under censoring. This study proposes a Modified Deep Survival Model that explicitly decouples nonlinear feature extraction from probabilistic survival modeling. A multilayer perceptron transforms high-dimensional covariates into compact survival-relevant representations, which are then passed to a New Exponential Power Distribution (NEPD) for parameter estimation and survival function generation. The NEPD accommodates flexible tail behavior, enabling more accurate modeling of heterogeneous time-to-event patterns than conventional parametric forms. The model is trained using censored-likelihood optimization with prior regularization to ensure stable parameter learning. On the SUPPORT benchmark dataset, the Modified DSM achieves a Concordance Index of 88.34%, outperforming the conventional DSM by 1.34%. This improvement demonstrates that separating latent structure learning from distributional estimation enhances both discriminative accuracy and structural transparency. The proposed study offers a robust alternative for clinical risk prediction requiring interpretable, individualized survival distributions



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sciforum-174091: Dynamics of Gradient Propagation in Complex-Valued Neural Networks with Planted Singularities

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This reseach investigates the dynamics of gradient propagation in complex-valued neural networks (CVNNs) in the presence of planted singularities. Unlike real-valued neural networks, CVNNs operate in the complex domain, enabling the simultaneous representation of magnitude and phase information. This property makes them particularly suitable for applications such as radar signal processing, biomedical imaging, and quantum systems. However, training stability in CVNNs is often compromised by optimization instabilities arising near singular points in parameter space, where gradients may either vanish or diverge.

To address this issue, a rigorous mathematical framework is developed to characterize how the local behavior of activation functions near the origin governs gradient stability. Using Wirtinger calculus and asymptotic analysis of activation derivatives near singularities, the study establishes a trichotomy of gradient regimes: (i) exploding gradients when the derivative diverges, as observed in magnitude-gated activations such as modReLU; (ii) vanishing gradients when the derivative approaches zero, as in zReLU with dead zones; and (iii) bounded and stable gradients when the derivative converges to a finite constant, as in smooth activations such as the Cardioid. The analysis formally demonstrates that while network depth amplifies gradient behavior, it does not alter the underlying regime determined by the activation function.

The theoretical results are supported by extensive experiments on both shallow K-2-K architectures and deeper multi-layer CVNNs trained on synthetic complex-valued datasets. Empirical findings confirm that modReLU frequently leads to gradient explosion, zReLU exhibits prolonged training stagnation, Split ReLU shows irregular convergence due to non-smooth transitions, and the Cardioid activation consistently maintains bounded gradients and stable optimization. These results validate the predictive strength of the proposed theoretical framework and underscore its practical relevance.



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sciforum-170664: House of Mirrors: Monotone Nonlinear Transformations for Modeling and Quantifying Perceptual Distortion in Data-Driven and Psychometric Systems

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This work presents a unified mathematical framework for understanding how monotone nonlinear transformations reshape data and generate structural forms of distortion, even when order is preserved. We model perception and algorithmic processing as the action of a monotone mapping h(x) applied to an underlying truth variable, showing that curvature alone can alter scale, emphasis, and information content. Using synthetic data drawn from uniform, normal, and bimodal distributions, we evaluate power, root, logarithmic, and logistic transformations and quantify their effects through four complementary measures: Truth Drift for positional change, Differential Entropy Difference for information content, Confidence Distortion Index for confidence shifts, and Kullback–Leibler Divergence for structural variation. Across all experiments, power functions with large exponents and steep logistic curves produced the strongest distortions, particularly for bimodal inputs. Even moderate transformations resulted in measurable changes in entropy, confidence, and positional truth, with strong correlations among the four metrics. The findings provide a geometric interpretation of bias, demonstrating that distortion arises naturally whenever a system curves the input space—whether in human perception or algorithmic pipelines. This framework offers a principled foundation for evaluating the hidden effects of scaling, compression, and saturation, and highlights how the appearance of neutrality can conceal systematic informational shifts. The proposed framework also provides a general mathematical basis for analyzing distortion in modern data-driven and artificial intelligence systems.



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sciforum-125020: Hybrid Approaches for Analyzing Animal Behavior in T-Mazes: Analytical and Machine Learning Methods

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This study presents a hybrid approach for analyzing animal behavior in T-maze tasks, combining traditional analytical modeling with advanced machine learning techniques. T-maze experiments are a well-established paradigm used to investigate decision-making processes in animals, where they must select one of two paths based on reinforcement feedback. To better understand the underlying cognitive mechanisms behind this, the proposed approach integrates conventional methods, such as decision theory and cognitive modeling, with cutting-edge machine learning algorithms, including deep learning models. This combination enables a more comprehensive analysis of the complexity inherent in animal behavior during decision-making tasks. Furthermore, we model the problem mathematically and apply fixed-point results to establish the existence and uniqueness of solutions to the proposed problem. This hybrid methodology not only improves the accuracy of behavioral predictions but also offers deeper insights into the decision-making process. The results show that integrating analytical methods with machine learning techniques leads to more robust and complex analyses compared to traditional approaches. This framework has significant implications for computational ethology, as it advances our understanding of animal cognition. Additionally, the study sets the foundation for future research in behavioral neuroscience, providing a valuable tool for modeling complex animal behaviors in various experimental settings. By bridging the gap between theory and data-driven approaches, this work paves the way for further interdisciplinary studies in the field of cognitive science.



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sciforum-126971: Hybrid Explainable AI Framework for Causal and Interpretable Modeling in High-Stakes Decision Systems

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The increasing reliance on machine learning in high-stakes domains such as healthcare, finance, and public policy necessitates models that are not only accurate but also interpretable and causally robust. This study presents a hybrid framework that integrates explainable artificial intelligence (XAI) techniques with causal inference methods to enhance both the transparency and the reliability of machine learning systems.

The proposed framework combines SHAP (Shapley Additive Explanations) for localized interpretability, counterfactual reasoning to support decision justification, and ensemble learning techniques including XGBoost and LightGBM for high-performance prediction. To further enrich the interpretability in complex data scenarios, the model introduces a novel integration of Large Language Models (LLMs) into structured tabular environments through a statistical vector fusion approach.

As a practical demonstration, a synthetic dataset simulating personalized healthcare resource allocation (e.g., ICU prioritization) is constructed based on real-world statistical distributions from OECD and WHO health indicators. Features include clinical variables (e.g., comorbidity index, age, oxygen level) and social determinants (e.g., income level, regional density). The model is evaluated based on both predictive performance (AUC, F1-score) and interpretability metrics (feature attribution stability, causal graph coherence).

Initial results indicate that the hybrid approach not only improves model transparency but also supports ethically aligned and causally coherent decision-making, which is essential for applications where decisions have critical real-life consequences. The framework contributes to the growing literature on explainable and reliable machine learning, offering both theoretical advancements and practical pathways for integration into digital decision support systems.



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sciforum-173065: Hybrid Physics-Aware Sparse Neural Networks (Hy-PAS): A Unified Framework For Learning and Solving PDES

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We introduce a modified version of the Hybrid Physics-Aware Sparse Neural Network (Hy-PAS), designed to tackle both ordinary and partial differential equations (PDEs). The approach blends classical numerical reasoning with modern deep learning, offering a sparse and interpretable framework that respects the underlying physics. Rather than treating PDE solutions as purely data driven, Hy-PAS reinterprets traditional mesh-free representations through a neural network perspective. In doing so, it bridges the gap between dense neural formulations such as Physics-Informed Neural Networks (PINNs) and established mesh-free numerical schemes. What makes Hy-PAS distinctive is that its parameters correspond directly to physical quantities like node locations, kernel widths, and basis coefficients. This connection allows the model to represent mesh adaptivity naturally and to handle steep gradients or discontinuities with improved stability and accuracy. Hy-PAS is sparse, which means it needs a lot fewer trainable parameters than fully linked networks, which are often used to approximate PDEs. We also show that classical representations, including Fourier and wavelet expansions, emerge as special cases of the proposed architecture, situating Hy-PAS within a broader family of physics-structured neural operators. Extensive numerical experiments with elliptic, parabolic, hyperbolic, and nonlinear PDEs, as well as benchmarks in fluid dynamics, demonstrate the accuracy, robustness, and computational efficiency of Hy-PAS. The framework lays out a mathematically sound way to create neural solvers for scientific computing that are easy to understand and can handle large amounts of data.



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sciforum-170747: Invariance of semantic projections under changes in word universes in NLP

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This communication presents a foundational framework for semantic projections in Natural Language Processing (NLP), focusing on word embeddings and projection-based semantic indices. We formalize two complementary perspectives: (i) geometric embeddings, where terms are represented in $\mathbb{R}^d$ and semantic proximity is measured through a metric; and (ii) set-based representations, where meaning is modeled in a finite measure space and projections arise as normalized overlap ratios.

Under Lipschitz regularity assumptions, we show that projection estimators admit explicit error bounds, ensuring stability and consistency across representations. Building on these foundations, we address two practical stability questions in NLP pipelines: \emph{projection coherence} (consistency of projections across sources) and \emph{universe transfer} (estimation of projections when the semantic universe changes). To quantify and control instability, we exploit Lipschitz regularity assumptions and metric-based estimators, including McShane–Whitney-type extensions.

We introduce computable metric-based estimators and prove that they preserve Lipschitz constants, yielding controlled transfer errors. In particular, we show that any Lipschitz semantic projection defined on a universe U_0 can be extended to a larger universe $U_1 \supset U_0$ by using the McShane--Whitney formulas and interpolating, preserving the Lipschitz constant and enabling stable semantic transfer.

Empirically, we validate the framework on multi-source semantic projections (DOAJ, Scholar, Google, and Arxiv), showing that coherence can be quantified using correlation and clustering, and that universe transfer can be evaluated through RMSE-type errors. These results demonstrate that modeling choices (data source, universe design, and estimator selection,) have measurable effects on semantic conclusions, providing both theoretical guarantees and practical diagnostics for robust NLP pipelines. This work extends our previous study published in \emph{Axioms} (14(5), 389).



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sciforum-169499: Least-square error model for measuring the fuel consumption level of marine diesel engines based on variable factors

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The application of mathematical theory in engineering is crucial to solve complex challanges nowadays. The insights of recent mathematics development are great momentum to utilize the mathematics into the different fields in education, engineering, and business. In maritime transportation, fuel efficiency plays a vital role in creating efficient operation measures. The concept of optimization theory, along with the least square error method in mathematical theory, has been used to solve this issue. To partly contribute to this topic, a mathematics model has been established based on the least square error theory to accurately estimate the fuel consumption mass of marine diesel engines. In this model, the complexity of uncertain factors impacting the fuel consumption of marine diesel engines is addressed to accurately improve the fuel consumption estimation model. Based on the least square error method, a reduction in fuel consumption estimation error is achieved. A full evaluation of this model will be presented through the performance metric, including the coefficient of determination (R^2), the mean absolute error (MAE), and the root mean square error (RMSE). This study is significant in determining the fuel consumption of marine diesel engines nowadays through mathematical theory. In the future, an advanced model will be established from this mathematical model to determine fuel efficiency in maritime transportation.



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sciforum-149292: Lightweight U-Net Architectures for Mathematics-Informed AI in Variable-Rate Spraying

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Variable-rate spraying (VRS) is an essential component of precision agriculture, enabling targeted agrochemical application according to spatial and canopy variability. This work introduces a mathematics-informed deep learning framework that integrates lightweight U-Net architectures, such as U-Net Mini, with optimization-based spray allocation strategies for UAV spraying systems. The encoder–decoder design of U-Net, grounded in variational principles of image analysis, is employed to segment UAV-acquired imagery into canopy and non-canopy regions. From these segmentation masks, geometric measures of canopy area and density are computed to characterize crop heterogeneity. A constrained optimization model is then applied to allocate spray volumes proportionally to canopy demand, ensuring efficiency under limited resource budgets. To enable practical deployment on UAV platforms, parameter-reduced variants of U-Net are explored, demonstrating significant reductions in computational cost while maintaining high segmentation accuracy (IoU > 0.85). When combined with optimization-based variable-rate control, the proposed system reduces chemical usage and spray drift compared to fixed-rate application. The study highlights how mathematical concepts—variational modeling, optimization theory, and geometric analysis—can be embedded within AI architectures to provide efficient, interpretable, and sustainable solutions for UAV-based precision spraying. This fusion of mathematical modeling with lightweight deep learning offers a promising pathway for scalable field applications and environmentally responsible agriculture.



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sciforum-170504: LLM-CapGen: A Lightweight Framework for Video Caption Generation Using Large Language Models

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LLM-CapGen is a lightweight framework for video caption generation using large language models. The framework focuses on effective multimodal fusion while maintaining low computational cost. It extracts spatio-temporal features from video frames to capture visual events and motion patterns. It also extracts audio features, including speech and environmental sounds. In addition, the framework constructs a semantic scene graph that represents objects, actions, and temporal relations. This graph helps the model understand what happens, when it happens, and how events are connected.

The framework fuses visual, audio, and semantic features into structured prompts and feeds them to a large language model. This process enables the model to generate context-aware, temporally consistent captions. A post-processing step further improves caption quality by reducing redundancy and ensuring grammatical correctness across video segments.

We evaluate LLM-CapGen on the EgoSchema benchmark for long-form egocentric video understanding. The framework achieves strong results with 34.2 BLEU-4, 25.8 METEOR, 49.7 ROUGE-L, and 102.3 CIDEr scores. It outperforms several strong baseline models, including VideoBERT, CLIPCap, BLIP-2, and GPT-4V in zero-shot settings. Ablation studies show that audio encoding, semantic graph reasoning, and temporal prompting each improve caption quality.

These results show that lightweight multimodal fusion with structured prompting can produce accurate and meaningful video captions. LLM-CapGen provides an efficient and adaptable solution for multimodal video understanding tasks.



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sciforum-170907: Machine Learning with Eigenvector-Based Feature Representation: A Mathematical Analysis Using SVM for Robust Face Recognition

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This paper proposes an enhanced framework for facial expression classification that integrates eigenvector-based feature extraction with an optimized Support Vector Machine (SVM) learning strategy. While Principal Component Analysis (PCA) and SVM are classical tools, the novelty of this work lies in a joint optimization scheme that couples adaptive eigenvector selection with kernel-driven margin optimization, leading to improved robustness and generalization under challenging imaging conditions. Unlike standard Eigenface approaches that retain components based solely on variance, the proposed method introduces a discriminative eigenvector selection criterion, ensuring that the retained subspace maximizes inter-class separability while minimizing intra-class variability. This is further reinforced by a systematic exploration and tuning of SVM kernels (linear, polynomial, and radial basis function), combined with cross-validated hyperparameter optimization to stabilize the decision boundary in noisy and high-dimensional settings. The framework is evaluated on the Extended Cohn–Kanade (CK+) dataset under controlled degradations, including noise perturbation and illumination variation. Comparative experiments against baseline models (standard PCA+SVM and raw-feature SVM) demonstrate that the proposed approach achieves consistent performance gains, reaching a classification accuracy above 97% while maintaining robustness across degraded scenarios. In addition, the analysis highlights the role of support vector sparsity control in improving generalization and reducing overfitting, providing further insight into the interaction between feature space structure and margin-based learning. These results suggest that embedding discriminative criteria within the eigen-decomposition stage, combined with kernel-aware optimization, constitutes an effective strategy for enhancing classical machine learning pipelines in real-world visual recognition tasks.



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sciforum-177745: Mathematical Foundation of Chaotic Random Forest Algorithm (CRFA) for High-Dimensional Geospatial Datasets

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The Random Forest algorithm, originally proposed by Leo Breiman, is a cornerstone of ensemble learning, relying on the principle of Bagging (Bootstrap Aggregating) to reduce the variance of decision tree classifiers. In high-dimensional geospatial datasets, such as those derived from multispectral satellite imagery, the traditional Random Forest Algorithm (RFA) often struggles with feature correlation and the curse of dimensionality. Our research proposes a transformative shift in ensemble learning by replacing the stochastic nature of traditional Bootstrap Aggregating (Bagging) with deterministic chaotic dynamics to enhance predictive stability and accuracy in complex spatial domains. Traditional Random Forest (RF) often suffers from sampling bias and sub-optimal convergence when dealing with high-dimensional geospatial data, such as Sentinel satellite imagery, where spatial autocorrelation and feature redundancy are prevalent. Our study first focuses on the mathematical formalization of chaotic maps, such as the Logistic and Tent maps, to ensure a more uniform coverage of the feature space. Secondly, the framework provides a rigorous mathematical demonstration of chaotic feature subspace selection and hyperparameter optimization via a chaotic search mechanism, effectively preventing the algorithm from getting trapped in local optima, a common failure mode in high-dimensional geospatial analysis. Finally, our study establishes the mathematical proofs for convergence and ergodicity, demonstrating that the CRFA maintains a superior bias–variance tradeoff compared to standard ensemble methods. Experimental results utilizing Sentinel-2 satellite datasets indicate that the CRFA significantly enhances classification accuracy and computational robustness. By integrating non-linear dynamics into the ensemble architecture, the proposed CRFA achieves a 4.5% increase in the Kappa coefficient and a reduction in training variance, providing a more reliable tool for complex land-cover mapping and environmental monitoring.



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sciforum-173529: Neuro-Symbolic Energy-Based Framework Using Weighted Partial MaxSAT for Smart Contract Optimization and Digital Financial Risk Management

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Abstract

This paper introduces WPMAXSAT-HNN, a novel neuro-symbolic energy-based framework for optimizing smart contract efficiency and security in blockchain-based financial systems. The framework establishes a precise mathematical mapping from Weighted Partial Maximum Satisfiability (WPMaxSAT) formulations to Hopfield Neural Network (HNN) configurations, enabling simultaneous formal verification and gradient-based optimization. By distinguishing between hard constraints (essential contract semantics) and soft constraints (optimization objectives such as gas cost reduction), the method provides a unified approach for constraint satisfaction and performance enhancement. Experimental validation across 127 production smart contracts, including Automated Market Makers, Lending Protocols, Derivatives, Insurance, Payment Channels, Token Systems, and Governance, demonstrates significant and consistent advantages over existing MAXSAT-HNN and RANMAXSAT-HNN approaches. The proposed framework achieves an average of 18.0% ± 2.9% gas savings while maintaining a 99.0% ± 0.6% satisfaction rate for hard constraints and a 2.04× computational speedup. The model's efficiency is reflected in the best aggregate Bayesian Information Criterion (-200.5) and the highest F1-Score (0.958 ± 0.014). Performance is particularly strong for Payment Channels (24.8% ± 2.1% gas savings, F1-Score 0.981) and Token Contracts (19.3% ± 2.5% savings, 2.32× speedup). Real-world Ethereum testnet deployments confirm its practical impact, with an average return on investment of 3,744 gas saved per second across major protocols such as Uniswap, Compound, and high-throughput payment networks. The neuro-symbolic architecture effectively integrates exact symbolic reasoning with approximate neural optimization, addressing critical challenges in FinTech: reducing transaction costs, enhancing security through formal verification, and mitigating operational and compliance risks. By combining optimization with provable correctness, WPMAXSAT-HNN offers a foundational technology for the next generation of efficient, secure, and scalable decentralized financial applications.



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sciforum-171335: Predictive Modeling of Urban Flooding Using Finite Differences and Numerical Integration

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Urban flooding is a complex phenomenon driven by limitations regarding precipitation and drainage systems. In this sense, a dynamic analysis of the processes allows us to model them by describing water accumulation over time through integrals and analyzing the instantaneous rate of change through derivatives. This approach enables early identification of risk situations before critical levels are reached. Concepts of differential and integral calculus are applied to model water accumulation in urban environments and predict flood risks. The following work proposes using continuous and discrete mathematical modeling to monitor hydrological behavior. The theoretical foundation is based on three pillars: the definition of water accumulation A(t) as the integral of the difference between rainfall intensity R(t) and drainage capacity D(t). Computationally, the discrete model is A(t+delta t)=A(t)+ (R-D); the instantaneous rate of change A'(t)=R(t)-D(t) as the main risk indicator (positive values indicate increasing accumulation, while rates that exceed a critical threshold trigger accelerated risk alerts); and the application of limiting casesto represent extreme behaviors, such as rainfall intensity approaching or tdrainage capacity approaching its physical maximum. Simulations demonstrated that the application identifies critical points A'(t) = 0, and predicts flooding before the level reaches the safety threshold (Ac). Thus, the model demonstrates the effectiveness of applying mathematics for the analysis of environmental problems. Integrating functions, derivatives, and integrals into a modern platform enables the transformation of mathematical models into tools with high social impact.



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sciforum-174113: Procedural and Computational Framework for a Non-Decomposable Collective Monetary Cognitive Model using Quantum Dynamic

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The classical cognitive models are often formulated in terms of dynamics with the assumption of decomposability. In this formulation, the mind is considered to be a simple machine processing discrete pieces of information, and the decisions are considered to be linear combinations of these pieces. However, these models are not able to represent the complex nature of human thought. This paper proposes a new collective level quantum dynamics model. To reduce the complexity involved

in massive subject cognition, this paper attempts to develop and simulate a new quantum dynamics model for the non-decomposable collective cognitive decision-making process in a financial setting, where we are concerned with the interaction between two or more agents. This procedure involves specifying the collective state space, specifying a collective Hamiltonian that represents the social interaction, simulating the joint cognitive process, and computing the probabilities of the outcomes. The method specifies the joint decision space as a finite dimensional Hilbert space. The Collective Hamiltonian is comprised of personal preference, intrinsic elements, and macroscopic non-decomposable social interactions. The time-evolution of the collective mental state is modeled by numerically solving the Time Dependent Schr¨odinger Equation. The primary result is the final collective decision probability, which can be determined by applying the Born Rule to calculate the square length of the projection of the time-evolved state vector onto the corresponding basis states for each of the four possible outcomes. This calculation yields the time-dependent probability of the group reaching a particular end-point financial decision. These results are then used in an AI-integrated research protocol with tensor networks and other advanced quantum cognitive AI processes for visualization to produce a Dynamic Probability Profile. Validation is performed using a cross-validation technique by setting aside 30% of the sample space data for validation purposes only after completing the research with the remaining 70%



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sciforum-159927: Quantitative Modeling of Teen Cybersecurity Awareness in Gamified Learning

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This thesis examines the interaction between students' awareness of cybersecurity and quantitative mathematics modeling applications in gamified teaching environments. The primary reason is to utilize statistical fundamentals, mathematical logic, and quantitative modeling to analyze the knowledge, perceptions, and how students are prepared to identify and manage cyber threats. It presents a mathematical view on how information and knowledge can be used to create a model of sense and ability to make students create those models and systems, and to incorporate probability analysis, matrices, and logical algorithms to assess the level of sensitivity about cybersecurity. All the studies conducted in the thesis demonstrate a view and the student concept to know and find practical information from peers, to show the mathematical models, and to offer solutions on how to teach computational thinking. Also, the study will show the way students think that this computational science applies to, to understand if this method should be applied earlier in their school time, or if it will be perfectly suited for them in the high school curriculum only. This view integrates the mathematical concept and artificial intelligence to create a gamified environment in which students can practice critical thinking and database analysis, to make education about cybersecurity more effective. The outcome provides a strong base for strategy development and combines strong analytical skills, mathematical logic, and awareness about cybersecurity.



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sciforum-173078: Quantum Harmonic Oscillator-Inspired Energy-Based Attention for Stable and Interpretable Neural Networks

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Introduction:

Attention mechanisms are a core component of modern artificial intelligence, especially in Transformer-based architectures. However, widely used formulations such as scaled dot-product attention are primarily heuristic and lack a clear energy-based interpretation. This limits theoretical understanding of their stability, robustness, and optimization behavior.

Methods:

In this work, we propose a novel attention mechanism inspired by the quantum harmonic oscillator (QHO). Query–key interactions are modeled as energy states within a bounded harmonic potential, where similarity scores are mapped to energy values using a Hamiltonian-based formulation. Instead of conventional softmax normalization, attention weights are computed through an exponential energy decay function motivated by quantum principles. We further analyze the proposed formulation to establish properties such as bounded gradients, Lipschitz continuity, and improved conditioning of the optimization landscape.

Results:

The proposed QHO-based attention is integrated into Transformer architectures and evaluated on standard classification and sequence modeling tasks. Experimental results show that it achieves performance comparable to conventional attention mechanisms while providing improved training stability and reduced sensitivity to initialization. Empirical analysis also indicates more controlled gradient behavior and enhanced robustness under noisy inputs and adversarial perturbations.

Conclusions:

This work introduces a physically interpretable and mathematically grounded alternative to traditional attention mechanisms. By framing attention through an energy-based perspective, it strengthens the theoretical foundation of neural architectures and offers a promising direction for building more stable, robust, and interpretable deep learning models.



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sciforum-174122: Regional and Sectoral Heterogeneity in Corporate Insolvency: Evidence for Spain Using Fixed Effects Models and Machine Learning

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This study examines the macro-financial determinants of corporate insolvency dynamics in Spain over the period 2008–2024 using a region–sector panel of annual data. The analysis focuses on how systemic financial conditions, macroeconomic fundamentals, and territorial heterogeneity jointly shape regional patterns of business failure. Financial indicators are condensed through principal component analysis into two latent factors capturing complementary dimensions of risk: a domestic financial stress component associated with equity and banking volatility, and a global uncertainty component linked to exchange-rate movements and external shocks. Panel estimations reveal that domestic financial pressure constitutes the main transmission channel of corporate fragility across regions, while global risk operates through asymmetric and non-linear mechanisms. Macroeconomic conditions, particularly unemployment dynamics, reinforce these effects, whereas inflation shows limited direct influence on insolvency outcomes.

To assess robustness and predictive relevance, the econometric framework is complemented by machine learning models including CatBoost, XGBoost, and LightGBM. The ensemble approach achieves high and stable predictive performance, with AUC values above 0.90, confirming that macro-financial variables contain persistent information about regional failure risk. Clustering analysis further identifies distinct behavioural profiles across regions and sectors, highlighting heterogeneous exposure to systemic shocks. Overall, the results demonstrate that corporate insolvency in Spain is primarily driven by the interaction between financial-market volatility and regional economic structures. The proposed framework contributes to the development of macro-financial early-warning systems and provides new evidence on how systemic risk propagates spatially within national economies.



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sciforum-171380: Reinforcement Learning-Based Optimization of Energy Consumption in Distributed Flow Shop Scheduling

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Energy consumption has become a critical issue in modern distributed manufacturing systems due to increasing production complexity and sustainability requirements. This paper addresses the Distributed Flow Shop Scheduling Problem (DFSP) with the objective of minimizing Total Energy Consumption (TEC), which is known to be a challenging NP-hard combinatorial optimization problem.

To tackle this problem, several metaheuristic algorithms are considered, including the Genetic Algorithm (GA), Artificial Bee Colony (ABC), and Iterated Greedy (IG) algorithm, along with their hybrid versions integrating Q-Learning (QL). In the proposed approaches, Q-Learning is embedded within the optimization process to guide the search through the adaptive selection of neighborhood-based operators, such as insertion, swapping, and reconstruction moves. This reinforcement learning mechanism enables the algorithm to dynamically learn the most effective search strategies based on their impact on energy consumption, thus improving the balance between exploration and exploitation.

The performance of the proposed methods is evaluated through extensive computational experiments on different problem instances with varying sizes and configurations. The results demonstrate that integrating Q-Learning significantly enhances the performance of the metaheuristic algorithms, leading to improved solution quality in terms of energy consumption. In particular, the hybrid approaches consistently outperform classical methods, with the HMBOQL-VNS approach achieving the best performance and a dominance rate of 82.1%.

These results highlight the effectiveness of combining reinforcement learning with metaheuristic optimization for developing efficient and sustainable scheduling strategies in distributed manufacturing systems.



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sciforum-170473: Robust Adaptive Neural Network Control for a Class of Uncertain Fractional-Order Chaotic Systems

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Introduction: Fractional-order chaotic systems offer a more accurate representation of complex dynamical processes characterized by memory and hereditary properties. However, achieving stability in the presence of unstructured uncertainties and unknown nonlinearities remains a significant theoretical challenge in the field of non-integer calculus and control theory.

Methods: This paper proposes a robust adaptive neural network control strategy designed for a class of uncertain fractional-order chaotic systems. Utilizing the universal approximation capabilities of Radial Basis Function (RBF) neural networks, the proposed controller identifies and compensates for system uncertainties online through a deterministic adaptation law. Unlike traditional model-dependent approaches, this framework requires no a priori knowledge of system parameters. A rigorous stability analysis is conducted using the fractional-order Lyapunov direct method.

Results: The theoretical analysis proves that the closed-loop system is Mittag–Leffler stable and that the tracking errors converge to a compact neighborhood of the origin. Numerical simulations performed on benchmark chaotic attractors validate the effectiveness and robustness of the proposed neural-adaptive scheme, showing high precision in trajectory tracking even under significant external perturbations.

Conclusion: The proposed strategy provides a mathematically sound foundation for the control of complex fractional dynamics. By integrating RBF neural networks with fractional Lyapunov stability theory, this research offers a robust solution for synchronizing or controlling chaotic systems where mathematical models are partially or entirely unknown.



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sciforum-171285: Scalable Approximate Inference in LIMEN-AI: Gradient-Guided Algorithms for the Neuralized Lukasiewicz Markov Engine

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Introduction: The deployment of artificial intelligence in high-stakes domains increasingly demands systems that combine performance with fundamental interpretability, a requirement formalized by regulations such as the EU AI Act. This paper addresses the computational challenge of approximate inference in LIMEN-AI (Łukasiewicz Interpretable Markov Engine for Neuralized AI), a Small Reasoning Model engine that represents knowledge through weighted first-order logic formulas interpreted under Łukasiewicz fuzzy semantics. While this approach ensures human-readable reasoning steps, efficient inference over continuous interpretation spaces in relational settings remains a critical hurdle.

Methods: We develop a family of sampling-based inference algorithms tailored to the energy-based distribution induced by Łukasiewicz Markov Logic. Our approach includes importance sampling with mixture proposals and power sampling variants operating across multiple temperature levels. To address the saturation problem inherent in fuzzy logic—where truth values at boundaries cause vanishing gradients—we introduce ε-regularized operators that preserve informative gradients throughout the interpretation space. We employ the Metropolis-Adjusted Langevin Algorithm (MALA) to exploit the piecewise smooth gradients of the Łukasiewicz energy manifold, ensuring efficient exploration in high-dimensional spaces while maintaining convergence guarantees.

Results: We provide theoretical complexity bounds and extensive quantitative validation on relational domains containing up to 10^4 ground atoms. Performance is evaluated through Effective Sample Size (ESS) metrics and comparison with analytical ground truth. Our results demonstrate that gradient-guided sampling maintains reliability where uniform baseline approaches collapse, particularly in high-dimensional settings.

Conclusions: The resulting inference routines preserve interpretability while achieving computational tractability, producing structured explanation traces that satisfy EU AI Act transparency requirements. This work bridges the gap between geometric logic and regulatory compliance, enabling auditable decision support in critical applications.



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sciforum-166768: SUPPORT VECTOR MACHINE IN SLEEP DEPRIVATION DETECTION

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Sleep Deprivation (SD) is a growing issue that impairs cognitive, physical, and mental health and increases the risk of accidents and chronic diseases. Conventional detection methods are often intrusive, costly, or impractical for daily use. Aligned with United Nations Sustainable Development Goal 3 (UN SDG 3), this study aims to ensure healthy lives and promote well-being. The development of cost-effective, non-invasive, and accessible tools for SD detection is essential to integrate sleep health into public health approaches. The study developed a Support Vector Machine (SVM) trained by the researchers to classify their mild SD status through voice analysis. The researchers trained the model on an open-access dataset from the Open Science Framework (OSF), which was extracted through Spectro-Temporal Modulation (STM) features. To have a solution, the study evaluated the performance of SVM through STM features. It analyzed its performance across different dimensions of STM features, sessions, and Balanced Accuracy (BAcc) at the population and individual levels. The SVM achieved a training and testing BAcc of 0.8588 and 0.7476, respectively, which indicates sufficient performance and generalization. Statistical analyses are applied to determine the differences between the other trained models in different dimensions of STM: frequency-rate (FR), frequency-scale (FS), and scale-rate (SR). Analysis of Variance (ANOVA), Multivariate Analysis of Variance (MANOVA), and t-tests proved those hypotheses.



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sciforum-170649: Temporal Graph Neural Architectures for Predicting State-Administered Energy Prices: A Deep Learning Framework for Geopolitically Volatile Markets

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Background: Forecasting petroleum prices in state-administered markets presents unique challenges distinct from liberalized commodity exchanges. Algeria's hydrocarbon sector, accounting for 95% of export earnings, operates under administered pricing by the national oil company, creating irregular temporal dynamics, regime-dependent policy inertia, and geopolitical risk endogeneity that violate classical forecasting assumptions. Existing neural architectures fail to capture the institutional constraints and network effects of OPEC+ coordination.

Methods: We developed a novel three-tiered deep learning framework integrating: (1) a Phased Bidirectional Gated Recurrent Unit (GRU) encoder handling irregular policy sampling intervals through learnable temporal gates; (2) a conflict-gated graph convolution layer modeling Algeria as a node in a dynamic OPEC+ network with edge weights modulated by geopolitical instability and compliance correlation; and (3) a regime-aware Mixture Density Network (MDN) for uncertainty quantification during high-volatility episodes. The model was trained on proprietary daily Official Selling Prices (2010--2023) augmented with conflict intensity and shipping logistics data, using curriculum learning and multi-objective optimization combining negative log-likelihood with quantile calibration.

Results: The proposed architecture achieved a Mean Absolute Percentage Error (MAPE) of 2.48% and coefficient of determination (R^2) of 0.92 on out-of-sample testing (2022--2023), representing a 22.7% improvement over Temporal Fusion Transformer baselines. During high-intensity conflict periods, error metrics improved by 43% compared to conventional models. Ablation studies confirmed that each architectural component significantly contributes to robustness, with the conflict gate preventing error cascade during domestic instability episodes.

Conclusions: This work establishes a new benchmark for forecasting in administered energy markets by explicitly encoding institutional rigidity and geopolitical constraints. The framework provides actionable intelligence for fiscal planning, demonstrating potential annual revenue forecasting error reduction of 91 million dollars. The approach is transferable to other state-administered commodity markets facing similar structural challenges.



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sciforum-181899: Topology optimization of planar truss structures with Large Language Models

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Large Language Models (LLMs) have demonstrated remarkable capabilities in modeling complex sequential data by learning long-range dependencies. Although originally developed for natural language processing, their autoregressive architecture is inherently domain-agnostic, making them suitable for applications well beyond text generation. This observation opens new opportunities for leveraging LLMs in engineering design and optimization. This work investigates a GPT-based framework, built on the GPT-2 architecture, for the topology optimization of planar truss structures. The classical design problem is reformulated as a sequential construction process, where design actions are governed by predefined grammar rules that ensure structural feasibility. These actions are encoded symbolically and mapped into text-like strings, allowing each truss configuration to be represented as a tokenized sequence. Using this formulation, a pretrained model is fine-tuned on a dataset of structurally meaningful designs. Structural performance is accounted for through a mechanically informed loss function, weighting training according to structural stiffness. This strategy effectively biases the model toward high-performing configurations while preserving diversity in the design space. The proposed approach is validated across six benchmark cases, achieving performance levels ranging from 82% to 100% of the corresponding global optima. The model also demonstrates the ability to generate novel, mechanically sound topologies. These results highlight the potential of LLM-based generative frameworks as complementary tools for exploring large and complex design spaces in structural optimization.



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sciforum-169440: Towards Real-Time Post-Hoc Explanations: A Universal Framework for Image Models and Beyond

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A posthoc model-agnostic universal explainer for all machine learning models dealing with images that works in almost real-time is a long-lasting research effort in the image processing and computer vision community. One of the most stable and accurate solution is the KernelSHAP model that fulfills all the requirements but it is computationally intensive and resource-demanding in practice. The method is based on the computation of Shapley values, and it has emerged as a principled approach for feature attribution in machine learning models, notably instantiated in the popular SHAP (SHapley Additive exPlanations) framework. However, the exact computation of the Shapley values is exponentially expensive, which motivated during time the development of faster approximation methods.

We introduce HarmonicSHAP, a completely different approach that uses spectral Fourier representations of the model to enable computations of the near-real-time Shapley value. Our framework is based on the inversion of a Gramian matrix arising from a chosen feature function basis, which yields a closed-form solution for Shapley values. We compare HarmonicSHAP to the well-known KernelSHAP and its subsequent accelerations versions in terms of computational complexity, implementation strategy, and performance. Our analysis shows that HarmonicSHAP can drastically reduce computations, applying a one-time model decomposition cost, enabling near real-time explanations even for complex models, while fulfilling the goal of remaining model agnostic and gradient independent.



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sciforum-171195: Variational AutoEncoder (VAE) and Lie-SVM Approaches in capturing Static and Dynamic Generative-Discriminative Features of Visual Datasets

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For better quantification of static and dynamic texture features and visual analysis within videos and animations, the combination of geometry, probabilistic formulation, and the latest machine learning and artificial intelligence mechanisms has become essential. Due to the potential and capability in image generation and dimensionality reduction, this study unites the mathematical underpinnings of Variational AutoEncoder (VAE) models for producing video frames with the geometric and algebraic framework of Lie group manifolds for dynamic video texture classification via Support Vector Machines (SVMs). Using VAE models, theoretical foundations of variational inference in autoencoding and decoding processes, the decomposition of the VAE loss function into latent KL divergence, and reconstructing loss for regularizing latent space distribution and preserving input feature fidelity will be explored. Case studies generating new interfaces and validating the effectiveness of data clustering mechanisms with the MNIST database will be used for performance assessments.

Despite VAE's effectiveness in latent variable disentanglement and categorizing latent spaces, it is necessary to classify the dynamic texture of videos due to their continuous moving nature. Thus, a geometric approach combining an autoregressive moving average (ARMA) model, Lie group manifold, and matrix shape of Gaussian (SOG) descriptors was adopted to formalize video dynamic textures; then, a kernel function based on the Riemannian distance in the Lie group manifold was incorporated into the traditional SVM model to capture non-Euclidean manifold structure and implement the Lie-SVM multi-classifier with rigorous geometric regularization. Empirical validation based on sequences of images from a dynamic video confirms that our proposed algorithm yields superior classification performance, while preserving geometric invariants of manifold in kernel space.

The synergy of these mathematical and artificial intelligence methodologies can effectively handle and analyze both static generative visual content and dynamic texture videos, eventually bridging the gap between latent space design and discriminative manifold-aware feature classification for interactive user interface applications in the future.



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