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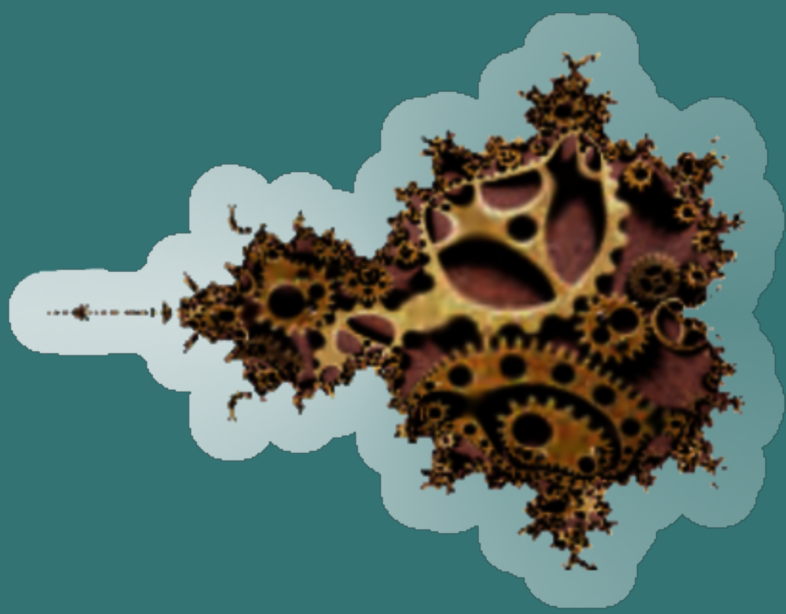

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About

COMPENG

COMPENG is a series of international workshops founded in 2010 aimed at providing a forum for experts and professionals working on the latest developments in complexity science and its application in an engineering perspective.

Previous editions of the workshop were held in Rome, Italy (2010); Aachen, Germany (2012); Barcelona, Spain (2014); Catania, Italy (2016); Florence, Italy (2018); Florence, Italy (2022).

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Timetable

CT: Contributed Talk, KL: Keynote Lecture.

Monday, 22th

8:45–9:15	**Registration**		
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10:15–11:00	KL	**G. Biroli**	Generative AI and Diffusion Models: A Statistical Physics Analysis
11:00–11:20	**Coffee break**		
	Machine learning [Chair: Lorenzo Buffoni] - Room A		
11:20–11:40	CT	**M. Negri**	Self-attention as an attractor network: pseudo-memories without backpropagation
11:40–12:00	CT	**E. Ventura**	Learning and Unlearning: using physics to bridge classification, memory, and generative modeling in biologically plausible neural networks
12:00–12:20	CT	**L. Chicchi**	Complex Recurrent Spectral Network
12:20–12:40	CT	**G. Peri**	Spectral Parameterization of Residual Neural Networks
12:40–13:00	CT	**R. Pacelli**	Spectral Parameterization in Fully Connected Networks: Understanding Optimal Size through Analytical Approaches
	Engineering methods and applications I [Chair: Giacomo Innocenti] - Room B		

11:20–11:40	CT	**C. Hajiyev**	GNSS-Based Relative Navigation for Two Satellite Formation Under Uncertainty Using Three-EKF Architecture
11:40–12:00	CT	**K. Tamersit**	Ultrasensitive Gas Nanosensor Based on Doping-less Carbon Nanotube Tunnel Field-Effect Transistor with a Sensitive Drain-Gate
12:00–12:20	CT	**M. Vela Nunez**	Streamlining the Testing for the PLATO Instrument Control Unit Startup of the Application Software Post-Boot Execution
12:20–12:40	CT	**P. Corsi**	Ship Manoeuvrability Modeling for Autonomous Navigation
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14:20–14:40	CT	**L. Giambagli**	Global Synchronization of Simplicial and Cell Complexes
14:40–15:00	CT	**C. Tomaselli**	Leveraging eigenvector centrality to control multiconsensus in multi-agent systems
15:00–15:20	CT	**N. K. Aidara**	A comprehensive Evaluation of Community Detection algorithms on different types of network
	Data analysis [Chair: Massimo Materassi] - Room B		
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15:00–15:20	CT	**C. Wolff**	Comparative Network Analysis of Migration and Commuting in Rhineland-Palatinate: 2012-2021
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16:40–17:00	CT	**P. De Lellis**	Early warning signals for psychopathology
17:00–17:20	CT	**E. Russo**	Integration of rate and phase codes by hippocampal cell-assemblies supports flexible encoding of spatiotemporal context
17:20–17:40	CT	**P. Bonifazi**	Linking hubness, embryonic neurogenesis, transcriptomics and diseases in human brain networks
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	Engineering methods and applications II [Chair: Giacomo Innocenti] - Room B		
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Tuesday, 23th

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12:00–12:20	CT	**P. De Lellis**	Modeling and control of opinion dynamics in the presence of higher-order interactions
12:00–12:20	CT	**M. Lodi**	A comparative analysis of different virtual inertia controllers in power grids with renewable energy sources: effect on the stability
	Nonlinear dynamics I		

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12:00–12:20	CT	**S. Torres**	Analysis of Collaborative Work through Conversational Patterns
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14:00–14:20	CT	**A. Yassin**	Network Backbone Extraction using Link Prediction
14:20–14:40	CT	**A. Lorusso**	Smart Restoration: AI for Historic Facades
14:40–15:00	CT	**R. Pillai**	Investigating speech as a standalone modality to detect dementia using deep learning techniques
15:20–15:40	CT	**N. K. Aidara**	A Comparative Analysis of Machine Learning Algorithms for Detection of Node Centrality in Complex Networks
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14:00–14:20	CT	**K. Kovalenko**	Why Are There Six Degrees of Separation in a Social Network?
14:20–14:40	CT	**N. K. Aidara**	Detecting Influential Nodes with Centrality Measures via Random Forest Approach in Social Networks

14:40–15:00	CT	**N. Mellor**	First Observations of Criticality from Ca^{2+} Avalanches in GBM Networks in vitro
15:00–15:20	CT	**A. Corso**	A generative model for spatial complex systems: power grid and brain network applications
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	Nonlinear dynamics II [Chair: Francesca Di Patti] - Room A		
15:40–16:00	CT	**E. Cutuli**	Cell dynamical interactions under hydrodynamic stimuli in microchannels
16:00–16:20	CT	**M. Bucolo**	Low-cost acusto-mechanical stimulation to tune particle displacement inside microchannels
16:20–16:40	CT	**R. Concas**	Electronic circuit for chaos and synchronisation in laser physics
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19:30	**Social Dinner**		

Wednesday, 24th

	Chaos and complexity across neural and nonlinear electronic systems I [Chair: Ludovico Minati] - Room A		
09:20–09:40	CT	**M. Frasca**	Reconstructing the topology of pairwise and higher-order interactions of coupled dynamical systems
09:40–10:00	CT	**C. Li**	Geometry and Distribution Control of Complex Oscillation in Memristive Circuits
10:00–10:20	CT	**A. De Candia**	Models of critical neural dynamics and inhibition based on neon lamps
10:20–10:40	CT	**L. Faes**	Dissecting the complexity of physiological and brain network systems through multivariate information measures
	Remote monitoring [Chair: Riccardo Meucci] - Room B		
09:20–09:40	CT	**G. Lacanna**	Holographic and seismic comparative modal analysis on Radicofani fortress
09:40–10:00	CT	**D. Spina**	Continuous Structural Health Monitoring of Civil Structures from Ambient Noise Analysis: The OSS SHM Project
10:00–10:20	CT	**M. Betti**	Analysis of 35 years of monitoring data of the Dome of Santa Maria del Fiore in Florence
10:20–10:40	CT	**M. Locatelli**	SWIR digital holography and imaging through smoke and flames
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	Chaos and complexity across neural and nonlinear electronic systems II [Chair: Ludovico Minati] - Room A		
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11:20–11:40	CT	**S. Houri**	On Constructing Frequency-Multiplexed Networks based on Nonlinear MEMS Devices

11:40–12:00	CT	**L. Ricci**	Estimating connectivity strength via time scales of observability
12:00–12:20	CT	**L. Minati**	Across neurons and silicon: some ideas about the relationship between unusual electronic circuits and neuroscience
	Laser dynamics and optics [Chair: Riccardo Meucci] - Room B		
11:00–11:20	CT	**J. Roversi**	Quantum information transfer with high fidelity using entangled states between connected microtoroidal cavities.
11:20–11:40	CT	**R. Zard**	Minimal universal laser model is analogous to a memristor
11:40–12:00	CT	**G. Nunzi Conti**	Optomechanical Parametric Oscillations in PhoXonic Cavities: applications in flow cytometry
12:00–12:20	CT	**K. al Naimee**	Random encryption process in optical fiber link
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List of Abstracts – Talks

Monday 22th

Self-attention as an attractor network: pseudo-memories without backpropagation

Francesco D'Amico[1], **Matteo Negri**[1,2]

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[2] CNR Nanotech, Sezione di Roma

Transformers are one of the most successful architectures of modern neural networks. At their core there is the so-called attention mechanism, which recently interested the physics community as it can be written as the derivative of an energy function in certain cases: while it is possible to write the cross-attention layer as a modern Hopfield network, the same is not possible for the self-attention, which is used in the GPT architectures and other autoregressive models. In this work we show that it is possible to obtain the self-attention layer as the derivative of local energy terms, which resemble a pseudo-likelihood. Then, we show numerically that the self-attention dynamics has attractors even if there is no global energy function. Finally, we leverage the analogy with pseudo-likelihood to design a recurrent model that can be trained without backpropagation: the dynamics shows transient states that are strongly correlated with both train and test examples. Overall we present a novel framework to interpret self-attention as an attractor network, potentially paving the way for new theoretical approaches to understand transformers.

Learning and Unlearning: using physics to bridge classification, memory, and generative modeling in biologically plausible neural networks

Enrico Ventura[1]

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The human brain is a complex organ that has fascinated scientists since a long time. Its remarkable capabilities include retrieval of memories, classification of concepts and creative generation of new examples inspired by the environment. Even modern artificial neural networks, such as classifiers and generative models, are trained on large amounts of data to accomplish the same type of tasks with a considerable degree of precision. Nevertheless, such machines appear to be either significantly slow and energetically expensive to train, suggesting that the current paradigm for statistical learning might be inconsistent with the functioning of the brain system, which in turn learns faster while conserving a substantial recurrent architecture. One of the major challenges for the scientific community is to create artificial machines that are closer to biological information processing systems, both in the way they learn and in the topological structure. Achieving this goal would introduce more efficient technological devices as well as boosting a deeper comprehension of the brain functioning. Statistical mechanics, a branch of physics that deals with complex systems, has made significant contributions to the study of both artificial and biological neural networks by modeling them as simple graphs of interconnected units with adjustable interactions. Several algorithms have been proposed to optimize the neural connections to enable the network to mimic real brain functions. Among the first contributions to this field there is John Hopfield's model as a prescription for the synaptic connections to store a set of external stimuli that allows to memorize a limited number of stimuli up to a limited degree of corruption [1]. Further studies, such as Elizabeth Gardner's, introduced the idea of changing synaptic connections to optimize memory storage [2][3], while Hinton and coworkers showed that a similar neural network can effectively learn distributions of large amounts of external stimuli and create new ones from the neural dynamics [4]. In this talk I will firstly present the difference and the formal analogies between classification, memorization and generation in neural networks. Subsequently, I will sketch a particular learning prescription that can solve a matrix factorization problem problem in a fully unsupervised fashion. This method can be mapped into a training a neural network that is able to classify a number of classes that scales extensively with the number of neurons in the graph [5]. I will then relax this prescription towards a learning algorithm that is more biologically plausible, consisting in a Hebbian initialization of the synaptic connections followed by a anti-Hebbian Learning of an ensemble of stimuli. This procedure is generally known in the literature under the name of Unlearning algorithm [2]. I will thus show that, by Learning and Unlearning, we can optimize the performance of a recurrent neural network in a wide range of tasks, such as memory retrieval and generation of new examples. It will be evident that a network trained according to this method can memorize examples in a more robust fashion with respect to the Hopfield model, reaching a performance that is comparable with the best associative memory models in literature [6,7]. In this matter, the example of spatial correlated memories, such as the ones learned by the hippocampus in the brain, will be displayed, giving a more tangible representation of the concept of robustness of the network. Successively, I will test the algorithm on a larger amount of data in order to show that it can very well learn a model that approximates the distribution of the data, de-facto reproducing the performance of a so-called Boltzmann Machine [8]. The conclusion of my talk will present some open problems left by my investigation, while wrapping up the useful contributions to both the neuroscience and artificial intelligence domains.

References

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[6] M. Benedetti, E. Ventura, E. Marinari, G. Ruocco, F. Zamponi, Journal of Chemical Physics, 2022.
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[8] E. Ventura, S. Cocco, R. Monasson, F. Zamponi, arXiv:2311.09418, submitted to Machine Learning, Science and Technology, 2024.

Complex Recurrent Spectral Network

Lorenzo Chicchi[1]

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May 24, 2024

In this work we have introduced an advanced version of the RSN [1], termed the Complex Recurrent Network ($\mathbb{C}$-RSN) [2]. The $\mathbb{C}$-RSN model confines non-linearity to specific nodes, rather than allowing it to fade away over time. This design ensures that the model's characteristics remain unchanged, avoiding the temporal convergence towards linearity as seen in the RSN.

Like the RSN, the $\mathbb{C}$-RSN employs a spectral decomposition to define neuron interactions, with a subset of eigenvectors and eigenvalues as trainable parameters. These eigenvalues are constrained to have magnitudes less than one, while the remaining eigenvectors and eigenvalues are fixed and unaltered during training. Notably, the fixed eigenvalues are complex values with a modulus of one, each associated to a specific frequency. The designed architecture guides the asymptotic dynamics towards a subspace defined by the set of eigenvectors associated to the fixed and complex eigenvalues. Moreover, these eigenvectors share the last neuron of the collection, thus allowing for the construction of a signal as a weighted sum of sinusoidal functions corresponding to the frequencies of the fixed eigenvalues.

In this context, we formulated a classification problem where the network learns to reproduce distinct temporal activities for different input classes on the last neuron. Tested with the MNIST dataset, the $\mathbb{C}$-RSN model demonstrated state-of-the-art accuracy. Its classification capability remains consistent over time as the system stabilizes. Once trained, the model can sequentially classify multiple inputs. The final activity observed in the last neuron not only reveals the classes of the various inputs but also the temporal intervals between their introductions, showcasing the model's capacity for handling complex classification tasks.

References

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[2] Lorenzo Chicchi, Lorenzo Giambagli, Lorenzo Buffoni, Raffaele Marino, and Duccio Fanelli. Complex recurrent spectral network. Chaos, Solitons & Fractals, 184:114998, 2024.

Spectral Parameterization of Residual Neural Networks

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In theoretical machine learning, the Teacher-Student paradigm is often employed as an effective metaphor for real-life instruction. In this framework, a Student network is trained on data generated by a fixed Teacher network until it matches the Teacher's ability to perform the assigned task. This setup mimics the educational process, where a student learns and eventually masters the knowledge imparted by a teacher. Under these conditions, it is plausible to speculate that the Student's ability to handle the given task could eventually be stored in a subset of the entire network. This subset should, to some extent, resemble the fixed Teacher structure according to suitable metrics, while being approximately invariant across different architectures of the Student network. This implies that the knowledge and skills acquired by the Student network are not only a reflection of the Teacher's instructions but also possess a certain robustness and adaptability across various structural forms. In this work, we present a novel parameterization for feedforward fully connected neural networks with skip connections, grounded in the spectral decomposition of the underlying graph. This approach leverages the mathematical properties of spectral decomposition to provide a more detailed and insightful understanding of neural network structures. Remarkably, the structure of the eigenvector matrix of several popular architectures can be inferred, and its inverse is analytical. This allows for precise mathematical manipulation and understanding of the network's internal modules. This decomposition generalizes preexisting structural derivations, allowing us to describe every feedforward network in terms of the spectral structure of the adjacency matrix. By framing the network in this way, we can better understand how different components and layers interact and contribute to the overall function of the network. Through this representation, the eigenvalues control the number and depth of bundles of connections that go from one layer to the next, thereby tuning a proxy for the network's functional complexity. This means that the spectral properties of the network can be directly linked to its ability to perform complex tasks, providing a quantifiable measure of its capabilities. Working within this framework, we were able to isolate a stable Student substructure that mirrors the Teacher's complexity. This substructure not only reflects the knowledge imparted by the Teacher but also demonstrates a degree of stability and resilience, ensuring that the learned abilities are preserved across different implementations and conditions. This finding has significant implications for the design and training of neural networks, suggesting new avenues for optimizing and understanding their performance.

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Empirical evidence of kernel shape renormalization in Bayesian one-hidden layer networks with multiple outputs

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The effectiveness of deep learning is believed to dwell in their ability to extract meaningful features from training examples, that can be later used to infer properties of unseen data. This mechanism, known as feature learning, is usually measured by the diversification of weights' distribution after training with respect to initialisation. In this talk, I will show how to analytically quantify this difference in Bayesian fully-connected networks with single and multiple outputs, in the so-called thermodynamic proportional limit. In particular, I will present an effective description of this learning problem in terms of a renormalised kernel function, whose shape completely incorporates the effect of training. Additionally, I will show that such kernel shape renormalisation is in one-to-one correspondence with non-trivial correlations that arise between readout vectors of different output classes.

GNSS-Based Relative Navigation for Two Satellite Formation Under Uncertainty Using Three-EKF Architecture

Chingiz Hajiyev[1], **Tuncay Yunus Erkec**[2], **Demet Cilden-Guler**[1], **Ulviye Hacizade**[3]

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The concept of satellite formation flying in a stochastic environment pertains to the coordinated movement of multiple spacecraft to achieve a unified objective. In a satellite cluster configuration, the separation between satellites can vary from 10 meters to 10 kilometers, with potential coverage limitations mitigated by employing multiple identical satellites for global coverage. Each satellite within such a formation adapts its trajectory relative to a designated mother spacecraft, adhering to mission requirements. A satellite control system is essential in managing the inter-satellite nonlinear dynamics within predefined parameters.

Conventional methodologies for autonomous relative navigation in dual satellite formations have demonstrated superior accuracy but are often costlier, computationally intensive, and contingent upon system coverage. This research proposes an autonomous relative navigation approach for dual satellite formations utilizing a three-stage Extended Kalman Filter (EKF) based on Global Navigation Satellite System (GNSS) data. The proposed methodology involves estimating the states of the mother and follower satellites using nonlinear GNSS measurements and Keplerian orbital elements, incorporating J2 perturbations. The differences in state estimates between the mother and follower satellites serve as inputs to the EKF, facilitating estimation of relative satellite states. Furthermore, a novel approach integrates the state vectors derived from three EKFs utilizing the Hill-Clohessy-Wiltshire (HCW) relative motion model, enhancing accuracy by accommodating satellite motion perturbations.

Simulation results validate the theoretical framework for GNSS-based autonomous relative navigation in dual satellite formations. Additionally, tasks such as docking, formation flight, and collision avoidance can be executed by transmitting control signals to the mother and follower satellites based on the output of the navigation algorithms.

Keywords - Small Satellite, GNSS, Formation Flight, Relative Navigation, Extended Kalman Filter

Ultrasensitive Gas Nanosensor Based on Doping-less Carbon Nanotube Tunnel Field-Effect Transistor with a Sensitive Drain-Gate

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In this paper, we propose a new gas nanosensor based on a coaxial gate doping-less carbon nanotube tunnel field-effect transistor, utilizing a computational quantum simulation approach. The doping-free paradigm is employed while engineering the required doping profile electrostatically. The gas sensing principle relies on the gas-induced change in drain gate work function. The nanosensor is analyzed in terms of potential distribution, transfer characteristic behavior, band diagrams, and sensitivity. Additionally, a comprehensive and deep analysis is conducted by studying the energy-position resolved current spectrum. Simulation results demonstrate the high sensitivity of the band-to-band tunneling (BTBT) mechanism in the p-type conduction branch due to the gas-induced change in drain gate work function. The obtained results underscore the efficiency of using electrostatic doping gates as sensing and selective elements to design CMOS-compatible, sensitive, ultra-scaled, and high-performance doping-less/junction-less TFET-based gas nanosensors. Moreover, the low-voltage operation of the nanosensor together with the recorded sub-thermionic subthreshold swing, positions it as a compelling candidate for Internet of Things (IoT) applications, where the energy efficiency is a prerequisite.

Keywords - Gas sensor, carbon nanotube (CNT), NEGF simulation, field-effect transistor, work function, band-to-band tunneling (BTBT).

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Streamlining the testing for the PLATO Instrument Control Unit startup of the Application Software post-boot execution

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PLAnetary Transits and Oscillations of Stars (PLATO), the third medium-class mission of the European Space Agency's (ESA) Cosmic Vision program, is scheduled for launch in 2026 and stands out with its unique approach to exoplanet exploration.

The core of PLATO's On-Board Data Processing System (DPS) features a meticulously designed architecture comprising various components, including an Instrument Control Unit (ICU) and 12+2 Digital Processing Units (DPUs). These elements are interconnected via a SpaceWire network incorporating 6 routers, serving as the backbone for seamless communication among the Payload's diverse components.

The Application Software (ASW) of the ICU assumes a critical role in the operational framework of the PLATO system. Upon system boot-up, the ASW assumes responsibility for overseeing essential functions crucial to mission success. These include managing data transmission, encompassing both data collection and processing. The ASW adeptly manages day-to-day satellite operations, adapting to different operational modes and facilitating communication with ground control stations. Additionally, the ASW configures parameters for the Data Processing Unit (DPU), monitors Failure Detection, Isolation, and Recovery (FDIR) processes, performs image stacking, and efficiently manages hardware compression. Notably, the ASW effectively handles a daily data volume of 435 Gb on the ground.

Conversely, the PLATO Boot Software (BSW) plays a pivotal role in mission success with its streamlined yet crucial tasks during system startup. It ensures the integrity of the startup process, including critical functions such as board diagnostics and initiation of the ASW. The BSW's responsibilities extend to system and hardware initialization, including SpaceWire communication, systematic checks for SDRAM integrity, comprehensive boot reporting, maintenance of a consistent heartbeat, housekeeping duties, and event generation. It also oversees the nominal boot sequence and executes telecommands.

Together, the PLATO ICU's BSW and ASW synergistically contribute to the overall functionality of the satellite. While the BSW focuses on system startup and initialization phases, the ASW manages continuous, mission-specific operations throughout the satellite's mission lifespan.

The seamless transition from the BSW phase to the ASW phase is critical for initializing and configuring the PLATO payload, enabling the satellite to fulfill its designated functions reliably and efficiently in its operational environment.

Before initiating the ASW application, the BSW conducts a verification process to ensure that the ASW does not load into the section of SDRAM already utilized by the BSW. This process includes integrity checks where the BSW verifies the integrity of the compressed ASW image stored in Non-Volatile Memory (NVM) before decompressing it into SDRAM. Integrity checks are also conducted on the ASW after decompression in SDRAM.

Of particular significance is the TCL test verification and validation process, crucial for ensuring the accuracy and reliability of the PLATO ASW startup post-boot. Rigorous testing and verification procedures, including software regression tests using a reprogrammed TCL script, are employed to validate PLATO ASW functionality. These tests, conducted on setup-configured images stored in MRAM memory, play a vital role in minimizing errors and ensuring PLATO mission success.

This paper thoroughly explores the critical role played by the PLATO ICU's BSW during the startup process, emphasizing testing and functionality verification to ensure accurate ASW startup post-boot. Achieving this goal involves launching setup-configured images stored in MRAM memory, executed through a reprogrammed TCL script designed for software regression tests.

In conclusion, the seamless transition from BSW to ASW phases, supported by comprehensive TCL test verification and validation, is paramount for PLATO's payload operational efficiency and success in achieving its scientific objectives.

Keywords - PLATO P/L, ICU, BSW, ASW, image stacking, TCL tests, verification and validation

SHIP MANOEUVRABILITY MODELING FOR AUTONOMOUS NAVIGATION

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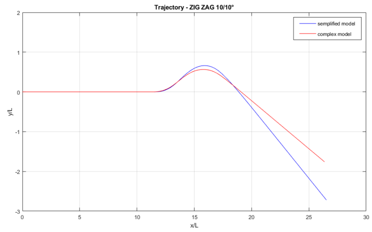
Describing the maneuverability of a vessel is crucial for various applications, particularly for optimizing the control system of Maritime Autonomous Surface Ships (MASS) or Unmanned Surface Vehicles in general (USVs). The controlling algorithm and philosophy for autonomous vessels is complex, as it must account for numerous variables, scenarios, and safety considerations to ensure the reliable and safe operation of the vessel. This complexity stems from the need for real-time decisions in complex dynamic scenarios, including maneuvers of the vessel at constant speed, speed variation, the effect of the environmental forces (waves, currents, and wind), or a combination of those. For the need to have a safe, stable, and reliable model in all the previous conditions with standard computational power, it's necessary to simplify the algorithm as far as possible. By simplifying and optimizing the model, we can reduce the likelihood of computational errors, improve the algorithm's stability, and enhance the predictability of MASS behavior.

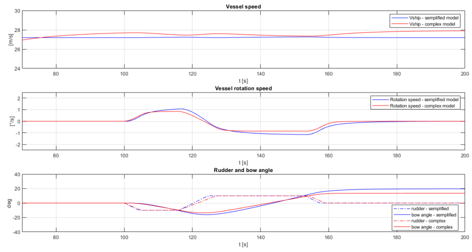
Therefore, this paper aims to identify a maneuverability simulation model that offers a good compromise between model complexity and the fidelity of results, for effective control of a MASS vessel during the navigation phase.

One of the requirements to control MASS includes the integration between route planning and automatic motion control. A maneuverability model of the vessel is needed both during the design phase to evaluate the geometrical constraints of the planned route due to the vessel dynamic and during the navigation of the MASS to set the control of the propulsion and steering system of the controlled vessel. A new 3 DOF maneuverability model based on a few essential parameters has been developed and compared with a well-validated more complex maneuverability model.

The core of this work is the comparison of the results obtained using the two models, on the same vessel, modeling the same real-navigation scenarios. The paper shows the efficacy of the simplified model, specifically, we show that under certain assumptions and operating conditions, the simplified model provides sufficiently accurate predictions of vessel behavior. Some typical sea trial maneuvers like ZIG ZAG and turning circles with a rudder angle limited to 10 and 20 to evaluate the model accuracy in maneuvers closest to a real scenario were simulated. In the following plot are shown part of the result obtained.



(a)



(b)

Figure 1: Simulation results.

By presenting these results, we contribute to the ongoing discourse on maneuverability modeling and control strategies for autonomous surface vessels. Our results offer practical insights into the design and implementation of control systems for MASS, emphasizing the importance of balancing model complexity with computational efficiency and real-world applicability.

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A Double Node Upset Resilient Latch for Nanoscale CMOS Technology

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This paper introduces a new Double Node upset radiation hardened latch design to enhance the reliability of data storage devices under exposure to alpha particles or high-energy radiation, causing Single Node Upset (SNU) or Double Node Upset (DNU). Radiation-hardened latches are crucial in asynchronous digital integrated circuits, particularly in space applications where radiation-induced errors can alter node voltage states and impact circuit output.

The proposed latch design is immune to both Single Node Upset and Double Node Upset due to its unique construction. It utilizes the Interlocked feedback hold technique to mitigate radiation-induced errors, thereby enhancing system robustness in harsh environments. The design employs three transmission gates, three Muller C elements, and three clocked Muller C elements.

Comparative analysis, corner analysis, and simulations were performed using Cadence Virtuoso EDA tool in 90nm CMOS Technology, demonstrating the scalability and practicality of the proposed design for on-chip implementation and semiconductor manufacturing standards. Results indicate a 29.79% reduction in total power consumption, a 42.04% decrease in switching power, and an 18.09% reduction in D to Q delay compared to the latest latch designs. Moreover, the proposed latch achieves a 42.5% improvement in energy delay product.

Corner analysis revealed superior performance of the proposed latch across various conditions, with increasing delay and decreasing power consumption as the transitions from FF (Fast-Fast) to SS (Slow-Slow). The proposed design consistently outperforms reported designs in reliability, power efficiency, and speed.

Overall, this design offers significant enhancements in reliability, power efficiency, and speed, making it well-suited for modern data storage elements in radiation-prone environments, ensuring flexible and dependable operation.

Keywords - soft error, radiation hardening, double node upset, transmission gate, Muller C element

Synchronization of phase oscillators with diffusion-mediated coupling

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Phase oscillators are dynamic systems that model a variety of physical and biological phenomena. This work explores a system of nonlinear integro-differential equations describing phase oscillators coupled through diffusion-mediated interactions. The coupling mechanism is nonlocal and incorporates the historical behavior of the oscillators [1]. The Green functions associated with this coupling depend on the system's geometry and boundary conditions, considering bounded linear, rectangular, and circular domains [2].

In the fast relaxation (adiabatic) limit, where the mediating substance reaches instantaneous equilibrium, the system reduces to coupled differential equations without memory effects. In this limit, the Green functions align with those previously derived by Kuramoto and Nakao [3]. The study investigates collective behaviors of phase and frequency synchronization using suitably defined order parameters. These parameters demonstrate a transition from non-synchronized to synchronized states as the coupling strength increases.

Additionally, the research explores the impact of oscillator removal, revealing that increased coupling strength is necessary to maintain synchronization in the system [4]. Furthermore, the paper examines synchronization suppression caused by external time-delayed feedback control [5].

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Global Synchronization of Simplicial and Cell Complexes

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Topological signals, i.e., dynamical variables defined on nodes, links, triangles, etc., of higher-order networks, are attracting increasing attention. Synchronization, the spontaneous ability of coupled oscillators to operate in unison, is fundamental to many biological rhythms and technological systems. Traditionally studied on network nodes and links, synchronization has recently been extended to higher-order interactions found in brain networks, social networks, and protein interaction networks. Higher-order networks, such as hypergraphs, simplicial, and cell complexes, capture these many-body interactions, significantly enhancing our understanding of complex systems. Despite recent advances in the synchronization of oscillators on higher-order networks, the study of collective phenomena of topological signals remains in its infancy. In this context, we combine topology and nonlinear dynamics to determine the conditions for global synchronization of topological signals on both simplicial and cell complexes. Our study demonstrates that on simplicial complexes, topological obstructions specifically prevent odd-dimensional signals from achieving global synchronization. Conversely, cell complexes can overcome these obstructions, allowing signals of any dimension to achieve global synchronization in certain structures. Furthermore, we have analyzed the synchronization phenomenon using only Dirac coupling, which involves coupling signals across different dimensions without relying on intradimensional coupling typically achieved with the Hodge Laplacian. This analysis reveals that synchronization can be attained in simplicial complexes even without the use of the Laplacian. We support our findings with both numerical simulations and analytical methods, providing a comprehensive understanding of how synchronization can be achieved in these complex systems.

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Leveraging eigenvector centrality to control multiconsensus in multi-agent systems

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In a multi-agent system, multiconsensus is a dynamic behavior where the agents split into groups, also called clusters, and the states of the units belonging to the same group approach a common trajectory, which typically differs from cluster to cluster.

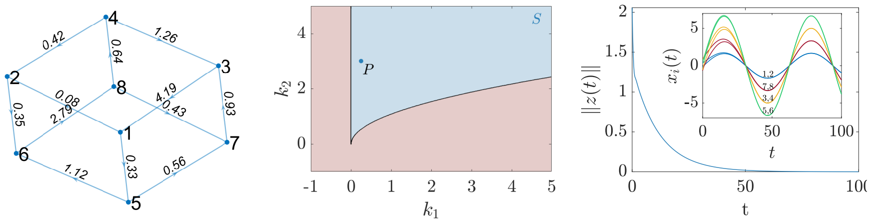
In literature, this dynamic behavior has been induced through several approaches, such as satisfying the in-degree balanced condition [1], admitting an external equitable partition [2, 3], or displaying symmetries [4]. In our work, we rely on a communication protocol that induces the system to reach a trajectory that is parallel to the eigenvector centrality of the adjacency matrix describing the interaction network. This enables the formation of clusters of nodes with identical eigenvector centrality values. Specifically, we consider a multi-agent system where each unit has a second-order dynamics described by the following equation:

$$\begin{aligned}\dot{x}_i &= v_i \\ \dot{v}_i &= ax_i + bv_i + k_1\left(\frac{1}{\rho(A)}\sum_{j=1}^{N} a_{ij}w_{ij}x_j - x_i\right) + k_2\left(\frac{1}{\rho(A)}\sum_{j=1}^{N} a_{ij}w_{ij}v_j - v_i\right) + u_i\end{aligned}$$

where $i = 1, \dots, N$, with N number of nodes, a and b are two constant scalars, $A = \{a_{ij}\}$ is the adjacency matrix of the interaction graph, which is assumed to be unweighted, directed and strongly connected, and $\rho(A)$ is the spectral radius of A. The parameters k_1 and k_2 are also assumed to be tunable.

The control action aiming to induce the multiconsensus consists of two steps. We first select the weights w_{ij} such that matrix A achieves an eigenvector centrality $\hat{p}$ which reflects the target multiconsensus. Next, we adjust the gains k_1 and k_2 to ensure the stability of the multiconsensus error dynamics. In particular, we consider both the cases of leaderless ($u_i = 0, \forall i = 1, \dots, N$) and leader-follower multiconsensus (where the dynamics of a reference node is used as control input u_i), providing analytical conditions for multiconsensus.

As an example, we show the case of leaderless multiconsensus. In particular, we consider the graph in Fig. 1(a), where the edges' weights have been selected such that the adjacency matrix has the following eigenvector centrality: $\hat{p} = [1, 1, 3, 3, 4, 4, 2, 2]$. The blue region in Fig. 1(b) represents the stability region, namely the values of the couples (k_1, k_2) for which the multiconsensus error dynamics $z(t)$ is stable. By selecting (k_1, k_2) in correspondence with the point $P = (0.25, 3)$ in Fig. 1(b), the multiconsensus error $z(t)$ asymptotically reaches 0, and the system achieves multiconsensus, as shown in the inset of Fig. 1(c). Although this control strategy requires the interaction network to be strongly connected, it can be proved that it allows reaching a desired multiconsensus state by controlling just a single arbitrary node.



(a) (b) (c)

Figure 1: (a) Controlled interaction network with the edges' weights selected such that the adjacency matrix has the eigenvector centrality $\hat{\mathbf{p}}$. (b) Stability region (in blue), namely the values of the couple (k_1, k_2) for which the error dynamics is stable. (c) temporal evolution of $\|\mathbf{z}(t)\|$ (main panel) and $x_i(t)$ (inset) when $(k_1, k_2) = (0.25, 3)$.

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A comprehensive Evaluation of Community Detection algorithms on different types of network

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Detecting community structure in networks is a fundamental problem across various domains, from social network analysis to biology. There is still a lack of comprehensive evaluations comparing established community detection techniques to emerging methods like PercoMVC, Walkscan, and Paris on diverse real-world networks with varying topologies. This study aims to fill this gap by providing an extensive comparative analysis involving well-established techniques like Louvain, Label Propagation, Infomap, Girvan-Newman, Walktrap, as well as recently proposed methods such as PercoMVC, Walkscan, and Paris. We empirically evaluated these eight algorithms on diverse real-world networks including social networks (Facebook ego network), collaboration networks (scientific co-authorship, jazz musicians), biological networks (malaria genes). The analysis relies on a comprehensive set of internal and external quality metrics [1] such as modularity (Newman-Girvan, Erdos-Renyi), cut ratio, conductance, expansion, density-based measures (edges inside, fraction over median degree), normalization metrics (normalized cut) and surprise. The Friedman rank test is employed to assess statistical significance. The results reveal intriguing patterns, shedding light on the inherent strengths, weaknesses and biases of different algorithmic approaches. Their performance varies across different network types. Louvain excels on dense networks by optimizing modularity, while Label Propagation outperforms on sparse networks by minimizing inter-community links. PercoMVC [2] exhibits robustness across datasets due to its multi-resolution approach, often achieving competitive performance regardless of network type. In contrast, Paris struggles on larger sparse networks. Figure 1 provides a visual synopsis comparing the performance of the eight studied community detection algorithms, evaluated using multiple internal and external metrics on the diverse real-world networks. This study provides valuable insights to guide practitioners in selecting the most suitable community detection technique based on the network characteristics at hand. It highlights the complementary strengths of algorithms like Louvain and Label Propagation on dense and sparse networks respectively, as well as the versatility of PercoMVC. The in-depth analysis contributes to a better understanding of community detection techniques and their applicability across diverse real-world scenarios. Future work could explore extending the analysis to temporal, attributed or multi-layer networks.

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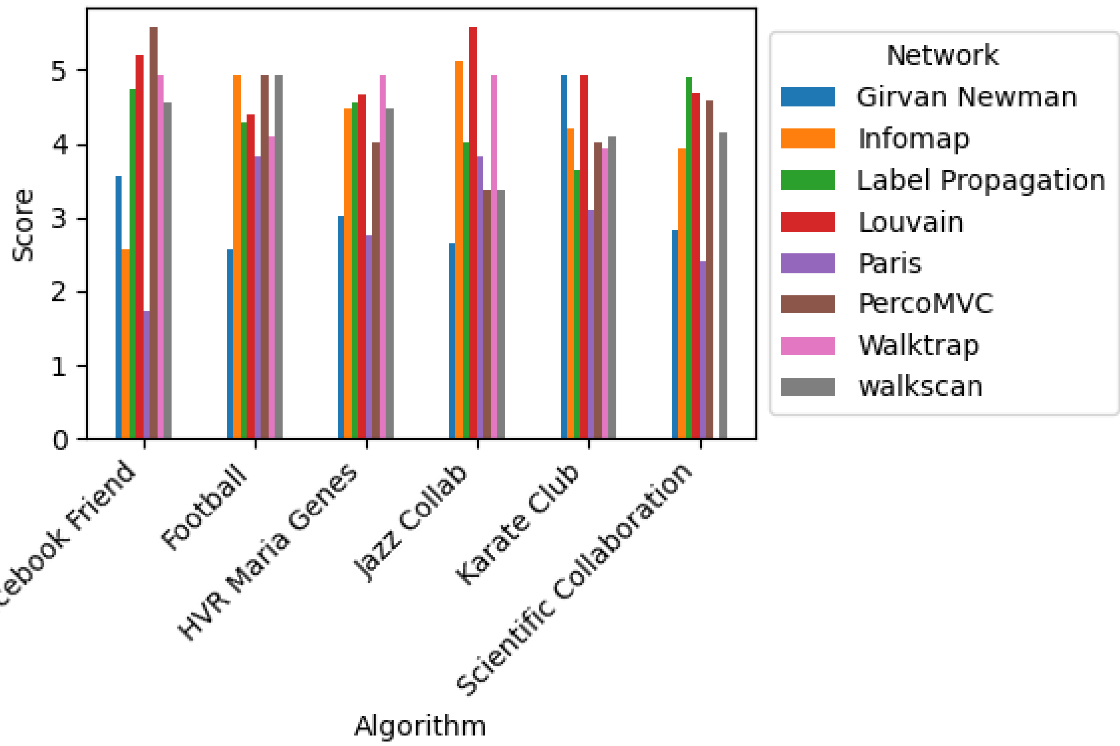

Figure 1: Comparative performance of community detection algorithms across different network types using various quality metrics and Friedman Test

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On D-Stability Analysis via LMI-Based Nonsingularity Detection

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The study of uncertain dynamical systems has played a key role in engineering since long time. A class of uncertain dynamical systems of particular interest is characterized by having the time derivatives of the states expressed as linear functions of the states multiplied by independent positive parameters. This class is common to various areas, such as biology, economics, and engineering. Stability of this class is known in the literature as D-stability since it is equivalent to the Hurwitz stability of a constant matrix pre-multiplied by a diagonal matrix whose diagonal entries are the independent positive parameters, see, e.g., [2], [5]. Several methods have been proposed for establishing D-stability, in particular through linear matrix inequalities (LMIs). This is the case of [4] where sufficient conditions are obtained based on diagonal common Lyapunov matrices, [3] where improved conditions are presented based on common Lyapunov matrices, and [6], [1] where less conservative conditions are proposed based on parameter dependent Lyapunov matrices. In particular, [6] proposes an LMI sufficient condition for establishing stability with respect to a subset of the admissible diagonal matrices, which tends to the set of admissible diagonal matrices as a chosen parameter tends to zero. Also, [1] investigates structural stability of decomposable systems and proposes an LMI condition that is not only sufficient but also necessary, however, the necessity in this condition is obtained for an unknown degree of the Lyapunov matrices that has to be chosen.

This extended abstract aims to propose a novel approach for establishing D-stability. The first step consists of generating a polynomial function of the diagonal matrix whose positivity is equivalent to D-stability. This is achieved by exploiting a nonsingularity equivalence through the use of determinants. The second step consists of establishing positivity of the generated polynomial by establishing feasibility of a system of LMIs. This is obtained by comparing the generated polynomial with a positive reference and by exploiting the Gram matrix method. The proposed condition is sufficient, and it is conjectured that it is also necessary as no counterexample has been found yet. The computational burden of this condition is investigated by deriving upper bounds on the numbers of rows and variables of the LMIs.

Compared with the existing LMI conditions, the proposed one may have four advantages. The first advantage is to be less conservative. The second advantage is to present a smaller computational burden. The third advantage is not to introduce approximations of the problem. The fourth advantage is not to require the choice of parameters that may affect the feasibility.

As an example, consider

$$A = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ -2 & -1 & 1 & 0 & 0 \\ 0 & 0 & -2 & 0 & 1 \\ 0 & 0 & 1 & -1 & 0 \\ 1 & 0 & -2 & 1 & -3 \end{pmatrix}$$

The problem is to establish whether A is D-stable, i.e., DA is Hurwitz for all diagonal positive definite matrices D.

The table below summarizes the results obtained with the existing conditions and with the proposed one. For [6], ϵ is the parameter that defines the subset of diagonal matrices considered (whole set as ϵ tends to zero). For [1], δ is the minimum degree of the Lyapunov function in d required to prove D-stability. The quantities NR and NV denote the number of rows and variables in the LMIs.

condition	outcome	NR, NV
[6]	none, infeasible with $\varepsilon = 10^{-4}$	$175, 325$
[1]	D-stable, $\delta = 2$	$385, 2941$
proposed	D-stable	$62, 112$

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Exploring Imputation Techniques for Climatic Time Series Data in the Sudanian Zone, West Africa

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This paper explores the performance of imputation techniques for climatic time series data in the Sudanian Zone, West Africa. Three methods were evaluated: Singular Spectrum Analysis (SSA) and its multivariate variant (mSSA), Random Forest, and Multiple Linear Regression models. Results indicate that SSA excels in capturing patterns for independent variables, while mSSA performs better with highly correlated features. Despite mSSA's faster processing, SSA remains preferable overall. Multiple Imputation by Chained Equations (MICE) was employed to enhance Random Forest and Multiple Linear Regression imputations. While both models demonstrate competence in imputing most variables, SSA consistently outperformed others when sensors fail to record data simultaneously. Challenges arose with lengthy missing segments, impacting imputation accuracy. This study advances imputation techniques, providing insights into handling missing data in climatic time series analysis.

Keywords - Singular Spectrum Analysis, imputation techniques, climatic time series, Multiple Imputation by Chained Equations (MICE), West Africa.

Detection of anomalous samples based on automatic thresholds

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The high demand for better services in cellular networks is the motivation behind the evolution of said network. Currently, the Open Radio Access Network (O-RAN) paradigm was proposed to provide more intelligent management of the user radio access, improving the quality of services, by applying Artificial Intelligence (IA); and Machine Learning (ML) algorithms. Despite their high potential, ML is highly dependent on the integrity of applied data, especially in the training stage. To avoid any data alteration, in this work an algorithm for anomaly detection in network metrics is proposed. This approach is based on a state machine to determine the network behaviour and Otsu thresholding. The algorithm performance is evaluated on data obtained from a 5G microcell.

Keywords - Attack on data, Key Performance Indicators, Detection, Otsu thresholding, State Machine.

Comparative Network Analysis of Migration and Commuting in Rhineland-Palatinate: 2012-2021

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This paper presents a comparative study of migration and commuting networks in Rhineland-Palatinate from 2012 to 2021. We investigate the evolution of these networks and explore their structural characteristics. Our findings reveal dense networks in both domains, with the migration network exhibiting greater complexity. We observe network density and connectivity fluctuations over time, influenced by factors such as international migration trends. Additionally, centrality analysis highlights distinct patterns between rural and urban districts, shedding light on the drivers of human mobility within the region.

Introduction

Understanding human mobility dynamics, particularly migration and commuting patterns, is vital for practical applications such as spatial planning and demographic analyses. Despite numerous studies on these topics, there remains ambiguity in understanding their interdependencies and external influences. This paper compares the evolution of migration and commuting networks in Rhineland-Palatinate, Germany, from 2012 to 2021. Using a complex network analysis approach, we unravel the intricacies of these networks and shed light on their structural characteristics. This comparative analysis offers valuable insights into the dynamics of human mobility within the region, addressing a significant gap in current research.

Results Data for the analysis are provided by the Rhineland- Palatinate State Statistical Office (RLPSSO) for migration flows and the Federal Employment Agency (BA) for commuter data. The resulting networks aggregated at the county level contain 24 rural and 12 urban districts. Both networks exhibit dense connectivity relative to their size, with the migration network featuring approximately 150 more edges than the commuter network. The commuter network shows a steady increase in connectivity from 2018 to 2021, while the migration network experiences a decline during this period, possibly due to decreased international migration. It led to the migration network surpassing the commuter network in density. Notably, the migration network formed a complete graph from 2015 to 2017, likely influenced by heightened international migration. The contrasting trends observed between the migration and commuter networks underscore the nuanced dynamics of human mobility within Rhineland-Palatinate. The decline in migration network connectivity suggests a shifting demographic landscape within the region. This decline may affect various socioeconomic factors, including labor markets and population distribution. Conversely, the continuous increase in commuter network connectivity highlights the resilience of local commuting patterns, possibly driven by employment opportunities and urbanization trends. The distinct centrality patterns observed between the migration and commuter networks further emphasize the differential influences shaping human mobility within rural and urban districts. While rural and urban districts exhibit high centrality in the migration network, urban districts dominate the commuter network, reflecting varied commuting behaviors driven by job accessibility and economic factors. In conclusion, our study provides valuable insights into the dynamics of migration and commuting networks within Rhineland-Palatinate. The contrasting trends observed underscore the complex interplay of factors shaping human mobility, with implications for spatial planning, economic development, and demographic analysis within the region. Further research into the drivers of these trends will be crucial for informed policy-making and sustainable regional development.

Keywords - Complex Network Analysis, Spatial Data

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Is the cortical dynamics ergodic?

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Cortical neurons in vivo display significant temporal variability in their spike trains even in response to the same stimulus. This variability is explained only in part by the intrinsic stochasticity of the spike-generation mechanism. In fact, to account for the levels of variability observed in the experiment, one needs to assume additional fluctuations in the level of activity over longer time scales [1]. But what is the origin of these fluctuations in the "firing rates"? Some theories explain them as a result of precise adjustments of the synaptic connectivity [2]. According to an alternative scenario, slow fluctuations in the "rates" are instead a signature of non-ergodicity [3], due to the partially-symmetric synaptic connectivity, consistently with anatomical observations [4]. It is unclear, however, whether such ergodicity breaking occurs also in spiking neural networks, due to the presence of fast temporal fluctuations in the synaptic inputs generated by the spiking variability [5].

To address this question, we study the dynamics of sparsely-connected networks of inhibitory quadratic-integrate-and-fire (QIF) neurons [6], with arbitrary levels of symmetry, q, in the synaptic connectivity. The connectivity (i.e., adjacency) matrix is random for q = 0 and fully symmetric for q = 1. The neurons also receive a spatially-homogeneous, time-constant excitatory drive, which is dynamically balanced by the recurrent synaptic inputs [6]. As shown in Fig. 1 (a-b), this results in low and heterogeneous average levels of activity across neurons, and temporally irregular spike trains, mimicking prominent features of the activity observed in the cortex [7].

To investigate the ergodicity of the network dynamics, we estimate over time intervals, T, of increasing duration, the single-neuron "firing rates", starting from different initial distribution of the membrane voltages (for the same network). If the dynamics is ergodic, the difference D between the estimates obtained from different initial settings should go to zero for suitably long time windows (i.e., as 1/T for sufficiently large T). This is, in fact, what happens in random networks (i.e., q = 0; Fig. 1 (c)). In partially symmetric networks q > 0, the onset of the "ergodic" regime occurs at longer and longer times. The situation becomes dramatic for the fully symmetric network ($q = 1$), where D does not decay even for time windows that are 5 order of magnitudes longer than the membrane time constant as shown in Fig 1 (c) (red solid line); the network dynamics is non-ergodic, at least in a weak sense. In this regime, the network activity is sparse, with a large fraction of almost-silent neurons, and the auto-covariance function of the spike trains exhibits long time scales (Fig. 1 (d)), as routinely observed in experimental recordings [8].

Our results support the idea that many features of cortical activity can be explained by the non-ergodicity of the network dynamics [3]. In particular, in this regime, the activity level of the single neurons can significantly change depending on the "microscopic" initial conditions, providing a simple explanation for the large trial-to-trial fluctuations observed in the experiment.

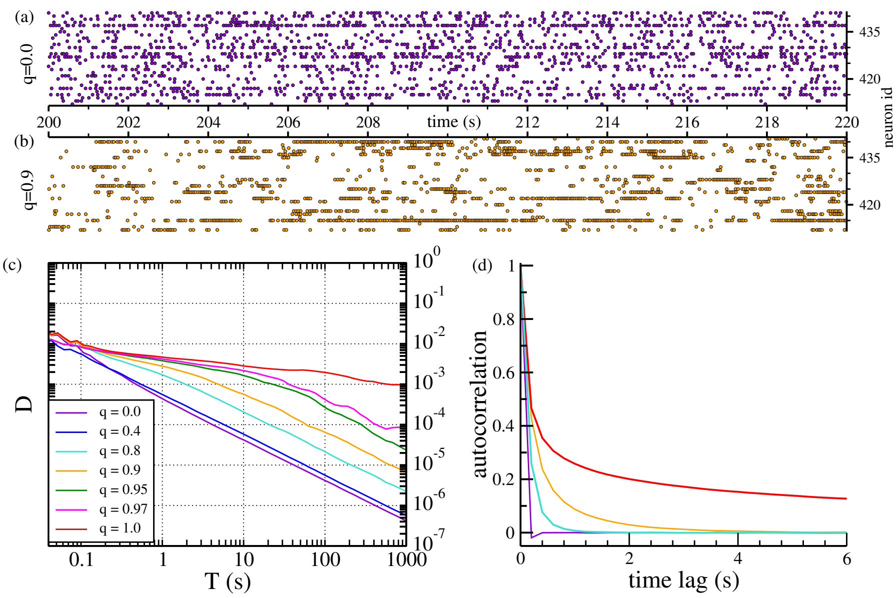

Figure 1: Raster plot of the spiking activity of 40 neurons for q=0 (a) and q=0.9 (b). (c) Average difference D as a function of the time interval duration T. D is obtained by considering for each neuron 5 different initial conditions for a given network, and by averaging over all the neurons N=3000 and over 5 different network realizations. (d) Population-averaged autocorrelation function of single neuron spike-count averaged over 2 network realizations.

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Nonlinear Time-series Analysis of MEA Recordings in cultured neuronal networks

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The brain is a complex system characterized by interacting regions with distinct identities and functionalities. Understanding differences in electrophysiological activity and connectivity among these regions is crucial for deeper insights into brain dynamics. This study focuses on neural cultures derived from mouse embryonic stem cells, specifically differentiating into three brain regions: hippocampus, isocortex, and entorhinal cortex.

Electrophysiological activity was recorded using multi-electrode arrays (MEA), revealing distinct behaviors among these networks. The entorhinal and isocortical networks exhibited critical behavior with synchronous activity characterized by precise onsets within the network. In contrast, hippocampal networks did not show such synchronized behavior.

The analysis employed self-organized criticality theory to characterize neuronal avalanche formation. Examination of avalanche size and duration distributions indicated two distinct behaviors: critical networks displayed power-law distributions, while subcritical networks exhibited power-law distributions with exponential cut-offs. These behaviors correlated with the level of activity synchronization observed.

Connectivity analysis further emphasized the differences between critical networks, which displayed high synchronization, and subcritical networks with lower synchronization levels.

Early warning signals for psychopathology

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Many real-world phenomena share a common feature: the potential for sudden and difficult to reverse transitions into less desirable states. This applies to a wide range of domains, from ecosystems to social structures [1]. The theory of dynamical systems has identified early warning signals (EWSs) that can precede these so-called "critical transitions," enabling intervention before the system becomes locked into an undesired state. Recently, mental health researchers have explored the utility of EWSs for predicting transitions into unhealthy states (i.e., psychiatric disorders), which can be perceived as alternative stable states opposed to the "healthy" ones. Notably, critical slowing down-based early warning signals have exhibited potential as a predictive tool for identifying transitions into depression or other mental diseases. In this work, we define $x_i = [x_{i1}, \dots, x_{in}]^T$ as the mental state of the individual i, with $x_{ij} \in \mathbb{R}$ being the variable associated to the j-th symptom, emotion, or transdiagnostic factor pertaining to the i-th individual. The mental health dynamics for individual i are given by the following dynamical equation:

$$\dot{x}_{ij} = f_j(x_{ij}, x_{ij1}, \dots, x_{ijm}, u_i, w_i), \quad j = 1, \dots, n; \quad y_i = h(x_{i1}, \dots, x_{in}, \nu_{ij}),$$

where $j1, \dots, jm$ are the neighbors of node j, i.e., the symptoms affecting the dynamics of symptom j (see the right panels of Fig. 1 for examples of inter-symptoms relationships); f_j describes how an individual's mental state is influenced by their own symptom history and the contextual factors in their environment, represented by the state of neighboring symptoms, and by the "outside world" through the variable $u_i \in \mathbb{R}^m$. Note that f_j also depends on the random variable $w_i \in \mathbb{R}^q$, which represents the uncertainty inherent in the model. This uncertainty arises from various sources, such as the complexity of the underlying dynamics, and the inability to fully capture all the relevant factors affecting the symptoms within the mathematical formalization. The variable $y_i \in \mathbb{R}^p$ corresponds to what we are actually able to measure of the overall mental state of an individual, whereby we typically have $p < n$; function h is a nonlinear function of the symptoms, and of a random variable $\nu_{ij} \in \mathbb{R}$, which represents the uncertainty that may arise from recall biases, subjective interpretation, distortions or other influences that may affect the accuracy of the patient's narration. In practical applications, we are not aware of the functional form of f_j and h, and only have at our disposal a multivariate time-series

$y_i(1), \ldots, y_i(T)$ of the noisy measured mental state of an individual. The objective is then that of an early identification of the onset of critical transitions in an individual mental state, so to make an early detection, for instance, of a crisis that is about to take place and change medications in a timely manner. In this work, we compare two viable approaches for early warning, the kernel change point on running statistics, kcpRS [3], and the time-varying change point autoregressive model of order 1, TVCP-AR(1) [4] on a case study of a 57 years-old man with a history of major depression [2], summarized in Figure 1.

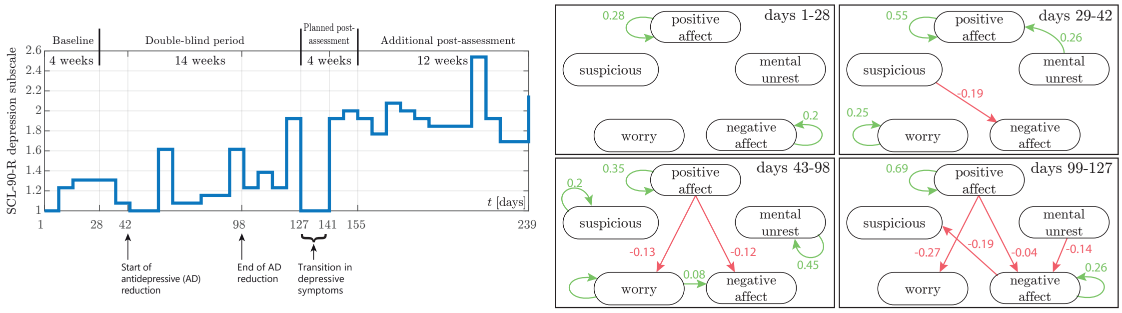

Figure 1: (adapted from [2]). The top-left panel reports the study timeline, while the bottom-left the raw weekly measurements of depressive symptoms $y(t)$. The gray area highlight the time window where the transition to depressive symptoms took place. The right panels report the network of symptoms during the phases of the case study, reconstructed using the spatial correlation of the symptoms.

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Integration of rate and phase codes by hippocampal cell-assemblies supports flexible encoding of spatiotemporal context

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Spatial information is encoded by location-dependent hippocampal place cell firing rates and sub-second, rhythmic entrainment of spike times. These 'rate' and 'temporal' codes have primarily been characterized in low-dimensional environments under limited cognitive demands; but how is coding configured in complex environments when individual place cells signal several locations, individual locations contribute to multiple routes and functional demands vary? Quantifying rat CA1 population dynamics during a decision-making task, we show that the phase of individual place cells' spikes relative to the local theta rhythm shifts to differentiate activity in different place fields. Theta phase coding also disambiguates repeated visits to the same location during different routes, particularly preceding spatial decisions. Using unsupervised detection of cell assemblies alongside theoretical simulation, we show that integrating rate and phase coding mechanisms dynamically recruits units to different assemblies, generating spiking sequences that disambiguate.

Linking hubness, embryonic neurogenesis, transcriptomics and diseases in human brain networks

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Understanding the architectural principles that shape human brain networks is a major challenge for systems neuroscience. We hypothesize that the centrality of the different brain circuits in the human connectome is a product of their embryogenic age, such that early-born nodes should become stronger hubs than those born later. Using a human brain segmentation based on embryogenic age, we observed that nodes' structural centrality correlated with their embryogenic age, fully confirming our hypothesis. Distinct trends were found at different resolutions on a functional level. The difference in embryonic age between nodes inversely correlated with the probability of existence of links and their weights. Brain transcriptomic analysis revealed strong associations between embryonic age, structure-function centrality, and the expression of genes related to nervous system development, synapse regulation and human neurological diseases. Our results highlight

two key principles regarding the wiring of the human brain, “preferential age attachment” and “the older gets richer”. In this talk, I will especially focus and link some evidences from this model to the genetics, transcriptomics and pharmacology relating to epilepsy and channelopathies. In particular, we will focus on the GABAergic circuits’ lesion induced by epilepsy and the impact of the inhibition of the neuroinflammatory response via the JAK/STAT pathways.

Funding
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Group ICA of wide-field calcium imaging data reveals the retrosplenial cortex as a major contributor to cortical activity during anesthesia

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Large-scale cortical dynamics play a crucial role in many cognitive functions such as goal-directed behaviors, motor learning, and sensory processing. It is well established that brain states including wakefulness, sleep, and anesthesia modulate neuronal firing and synchronization both within and across different brain regions. However, how the brain state affects cortical activity at the mesoscale level is less understood. This work aimed to identify the cortical regions engaged in different brain states. To this end, we employed group ICA (Independent Component Analysis) to wide-field imaging recordings of cortical activity in mice during different anesthesia levels and the awake state. Thanks to this approach we identified independent components (ICs) representing elements of the cortical networks that are common across subjects under decreasing levels of anesthesia toward the awake state. We found that ICs related to the retrosplenial cortices exhibited a pronounced dependence on brain state, being most prevalent in deeper anesthesia levels and diminishing during the transition to the awake state. Analyzing the occurrence of the ICs, we found that activity in deeper anesthesia states was characterized by a strong correlation between the retrosplenial components and this correlation decreases when transitioning toward wakefulness. Overall, these results indicate that during deeper anesthesia states coactivation of the posterior-medial cortices is predominant over other connectivity patterns, whereas a richer repertoire of dynamics is expressed in lighter anesthesia levels and the awake state.

Liquid Identification through SDR: System Design and Performance Analysis

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Oral hygiene is paramount for good oral health, which the World Health Organization recognizes as an integral part of systemic health. Saliva is frequently called a "mirror of the body" since it can reflect both the physiological and pathological conditions in the entire human organism [1], and it is probably the most practical specimen for oral health monitoring, as it is readily available.
As the recent COVID-19 pandemic demonstrated, timely and precise virus detection has been proven as an effective solution to reduce the spread of the virus and track the epidemic. Rapid antigen diagnostics has played a significant role in this field because of its convenience, low cost, and high accuracy [2], and contributed to reducing the pressure on the hospitals for testing purposes.
Here, we'd like to propose proper mechanisms to analyze the content of saliva, among other liquids, and quickly identify biomarkers that indicate the insurgence of any illness while keeping the same paradigm of the rapid COVID-19 tests, i.e., giving patients a system to run tests in the local pharmacy (i.e., a controlled environment), or even at their own home.
This system, as depicted in Figure 1, is a testament to precision. It measures the liquid's natural response in the frequency domain, utilizing a sensor at radio frequency and a reading system based on a Software Defined Radio (SDR) [3] platform. The measurements are meticulously collected and then processed by an algorithm that follows a machine-learning approach, specifically implementing a neural network trained with data collected using the same platform in the dataset population phase.
Currently, the sensor is implemented on a Printed Circuit Board (PCB) as we continue to fine-tune its operating parameters. This includes investigating the liquids' response at various frequency ranges and determining the minimum amount of liquid necessary to obtain stable and reliable results. The reader platform is designed with user-friendliness in mind, featuring a fully automatic calibration mechanism that can be triggered by the user at any time. It also allows rapid response acquisition in the frequency domain with extremely low power radiations. The measurement time required for a full acquisition depends on the desired frequency resolution (at the highest, 3 MHz) and the frequency band (at most, 3 GHz). The AI-based algorithm enables liquid identification through a pattern-matching-based approach, extracting proper features by comparing the frequency responses of known liquids used for training and the actual measured one.

Soon, (i) the PCB will be substituted by a low-cost biosensor. Given the sensor's very

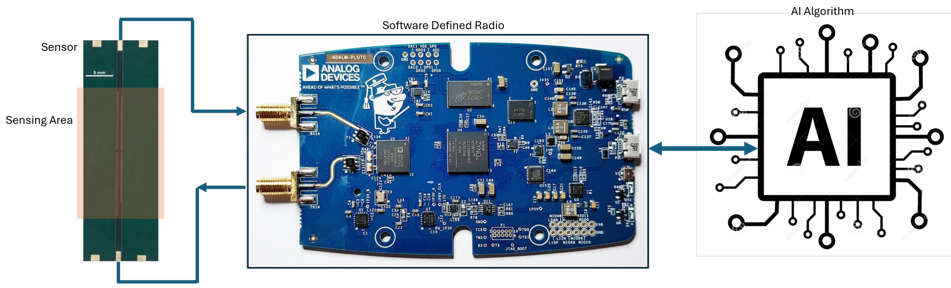

Figure 1: Scheme of the proposed liquid identification system.

low-complex shape and structure, it will be made of edible material, greatly improving its ease of disposal. (ii) We will identify the most significant frequency bands so that the reader platform might scan on narrow frequency ranges, reducing the measurement time and, if needed, increasing the frequency resolution (i.e., less than 3 MHz). (iii) The dataset on which the algorithm's training is based will be further enriched, improving both the detection's reliability and the overall performance of the entire system.
To some extent, our approach has similarities with [4,5]. Still, contrarily to them, our solution also works for smaller quantities of liquid, allowing for medical application, where biomarkers should be identified in a few saliva drops.

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Negative Capacitance Junctionless Graphene Nanoribbon Tunneling FET as DNA Nanosensor: A Quantum Simulation-Based Proposal

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In this paper, a new high-performance DNA sensor based on metal-ferroelectric-metal junctionless graphene nanoribbon tunneling field-effect transistor is suggested through a quantum simulation method. The principle of the label-free DNA detection is based on the dielectric-modulated paradigm [1], [2]. The computational approach used to assess the suggested DNA sensor is based on a rigorous quantum simulation considering the coupled solutions of the non-equilibrium Green's function (NEGF) [3], Poisson equation, and the Landau-Khalatnikov theory [4]. The computational proposal has encompassed the transfer characteristics, the drain current, the ferroelectric-induced potential amplification, and sensitivity. It has been found that the ferroelectric-induced gate voltage amplification can boost significantly the sensing performance of the proposed DNA detector. The results acquired suggest that the envisioned DNA nanosensor, based on negative capacitance junctionless graphene nanoribbon tunneling field-effect transistor, holds potential as an effective choice for cutting-edge point-of-care diagnostics.

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Error Detecting and Correcting Master Slave Flip Flop design in NTV Regime

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In the domain of cutting-edge nano-scale technologies, crafting high-performance systems within stringent power limits is a notable challenge. A significant barrier in this pursuit involves reducing the need for extensive timing buffers under unfavorable conditions. Although Near-Threshold Voltage (NTV) circuits offer advantages in improving energy efficiency, their effectiveness is undermined by increased variations observed in the near/subthreshold range. These variations not only introduce reliability concerns but also amplify susceptibility to errors, necessitating innovative solutions to address these issues.

In response to these challenges, our work endeavors to introduce a pioneering variation-aware, high-performance resilient flip-flop design. This novel approach is meticulously crafted to identify and rectify errors stemming from setup time violations within the data path due to Process, Voltage, and Temperature (PVT) variations. The design integrates a sophisticated combination of components, including a multiplexer, an error detector, and a master-slave flip-flop, to effectively manage variations. By offering a comprehensive solution, our design aims to enhance both the reliability and performance of NTV circuits, thereby overcoming the limitations posed by heightened PVT variations.

Extensive simulations have been conducted to evaluate the efficacy of our proposed design. The results demonstrate significant improvements across various metrics, including delay, power consumption, and layout area, when compared to existing methodologies in literature. Notably, the proposed design achieves a substantial reduction in D–Q propagation delay, while also outperforming previous approaches in terms of the Area Energy Delay product (AEDP) and average power consumption. These findings underscore the potential of our design to serve as a promising solution for advancing the efficiency of energy-efficient circuits operating in the near-threshold voltage regime. Furthermore, our work highlights the importance of considering the intricate interplay between design parameters in achieving optimal performance in NTV circuits. By incorporating sophisticated error detection and correction mechanisms, our design not only mitigates the impact of variations but also ensures robust operation under diverse operating conditions. This holistic approach to circuit design underscores the significance of addressing reliability concerns in parallel with performance optimization, especially in applications where stringent power constraints are paramount.

In conclusion, our work represents a significant step towards addressing the challenges associated with designing high-performance circuits within constrained power budgets. By introducing a variation-aware, high-performance resilient flip-flop design, we aim to pave the way for the development of more reliable and efficient NTV circuits, thereby unlocking new possibilities for energy-efficient computing in the near-threshold voltage regime. Moreover, this scheme reduces average power dissipation by 36.81%, 22.70%, 28.03%, 8.09% and propagation delay by 33.33%, 43.24%, 49.89%, 51.46% at 0.4V, compared with the presented HTD, META, iRAZOR, NTSD techniques respectively.

Keywords - Circuit reliability, Low power design, Near-threshold regime, Resilient circuits, Variation aware Flip-Flop design.

DFEA-Net: Dual-branch Feature Extraction and Adaptation Network for Object Detection in Low-light Environments

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Object detection faces numerous challenges in low-light environments. Most approaches focus on image enhancement as a preprocessing step to address low-light conditions, relying heavily on enhancement algorithms' performance. However, these techniques sometimes fail in extreme low-light conditions. This paper presents a novel method for direct feature extraction and adaptation to detect objects in low-light environments without relying on enhancement as preprocessing. We propose the Dual-branch Feature Extraction and Adaptation Network (DFEA-Net), comprising the Dual-branch Feature Extraction (DFE) network, adaptation network, and detection network. The DFE network extracts features from low-light images using both the input image and a derived image, enhancing the extraction of low-light features. Additionally, we introduce the Feature Refinement Block (FRB) to further enhance features by leveraging derived image features and employing adaptive refinement. We evaluate DFEA-Net's performance on the Ex-dark dataset and a synthetic dataset, demonstrating its superiority over existing techniques for improving low-light image quality and object recognition. Our approach achieves state-of-the-art performance in low-light conditions while maintaining comparable results under normal lighting.

Keywords - Deep Learning, Object Detection, Low-light image enhancement, Feature Extraction.

Optimal Control of Non-linear Epidemiological Model for Epidemic Preparedness and Response

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The uncontrolled Epidemiological Model generally follows an unstable characteristic. To control such systems, it requires creative, complex, and interdisciplinary strategies. The major outbreak of COVID-19 in India as well as in the world was declared a pandemic by the WHO. With increasing cases and economic collapses, the entire world came to a halt. The question arises: what can be an effective exit strategy if another such pandemic is declared? The answer lies in the unorthodox field i.e. control engineering, which is quite uncommon in epidemiological modeling.

In this paper, S-E-I-R (Susceptible-Exposed-Infectious-Recovered) Epidemiological Modelling is shown using non-linear equations, and an optimal control strategy has been utilized to reduce the number of exposed and infectious individuals of disease transmission during future epidemic/pandemic situations. The COVID-19 transmission dynamical model has been considered as a motivational example in this study due to its recent implications on all our lives. The S-E-I-R model is utilized for accurately representing the transmission dynamics of spread of the infectious diseases.

The mathematical model is shown using non-linear set of differential equations and it helps to monitor how the individuals move among various compartments (i.e. Susceptible, Exposed, Infectious and Recovered) within a population. This paper primarily focuses on tactical implementation of control interventions, so that infectious populations reduces and vaccination rate increases. Using these measures on the spread of the disease, a practical knowledge is available for politicians as well as public health professionals, making it easier for them to keep the disease spread under control.

Through the integration of SEIR modelling with intricate optimal control strategy, this study provides a precise plan for improving epidemic preparedness and response. The study also emphasizes on the necessity of multidisciplinary work culture among control engineers, epidemiologists and public health professionals. The optimal control technique utilized here is based on Pontryagin's Maximum Principle which works on the framework of solving Hamiltonian equations under constrained situations and deducing optimal control trajectories. The system efficiency is tested using numerical simulations and analytical evaluations using MATLAB platform under various parameter variations. The findings reveal that the optimal control strategy is able curb the spread of the disease and reduce the infectious population in required timeframe. It also shows the positive effects of vaccination on the transmission dynamics of COVID-19 model. This helps one define future policies when vaccines had to be developed for unknown future disease spread. The vaccination rate is taken as a constrained control input with the intent to minimize the percentage of infectious individuals.

Keywords - Optimal Control, Epidemiological Model, Pontryagin's Minimum Principle, COVID-19, Infectious Diseases

Tuesday 23th

Synchronization of interconnected microgrids

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Energy communities and microgrids play pivotal roles in the ongoing energy transition, facilitating renewable energy integration and fostering new energy markets. As microgrids become increasingly prevalent, the dynamics of energy exchange and power flow management among them pose significant challenges. This study explores the synchronization of interconnected microgrids to ensure grid stability and optimize operational efficiency. By leveraging a decentralized synchronization algorithm inspired by the AIMD (Additive-Increase, Multiplicative-Decrease) principle, microgrids autonomously adjust their participation in energy markets based on local frequency measurements. This approach allows microgrids to maximize revenue while mitigating adverse effects on grid stability. Experimental results demonstrate the efficacy of the proposed algorithm in maintaining desired grid frequencies and managing power exchanges among microgrids effectively.

AIMD Synchronization The AIMD (Additive-Increase, Multiplicative-Decrease) algorithm has been widely utilized in the Internet congestion control problem to optimally and fairly share bandwidth among connected users [5]. Similarly to the original problem, here we assume that microgrids (MGs) gently increase in an additive fashion their probability to operate in a desired “market mode” where they can sell power to other MGs. This scenario is known to increase frequency oscillations that may be inconvenient for the power grid. Accordingly, when the frequency starts assuming values that may be dangerous for the safe operation of the power grid (denoted as “capacity event”), a multiplicative step occurs and the probability of operating in “market mode” drops to a lower value. Conversely, more frequently the MGs operate in “ancillary mode” where they start providing frequency regulation services.

In this fashion, the overall mechanism allows the MGs to maintain their operational freedom as much as possible (e.g., to increase their revenues by operating in the energy market), while mitigating the effect on the power grid. The advantages of this solution are that it can be implemented in a fully decentralized fashion (each MG can measure the local frequency at the point of connection of the MG with the grid), and that it can be also implemented in an unsynchronized way to prioritize some MGs, if desired. In the last case, some MGs may have a larger or smaller probability to react to the capacity event, so that some MGs may be selected with a larger probability to provide the required frequency regulation services.

Conclusions Appropriate synchronization strategies are required to orchestrate a large number of interconnected microgrids in a transmission grid. If microgrids operate in an uncoordinated fashion, frequency stability issues may occur in the power grid. Decentralized and flexible synchronization algorithms are attractive to guarantee autonomous management and operations of microgrids.

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Chaos and Synchronization in the UJT relaxation oscillator

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Nonlinear electronic oscillators play an important role in a variety of electrical applications, ranging from individual components to the modelling of networks and the development of power grids. Additionally, the study of nonlinear oscillators can find many applications in other fields such as geology, chemistry, and biology. A preeminent example is the use of nonlinear relaxation oscillators for the modelling of neural spiking behaviour. Hence, understanding the collective interaction and synchronization phenomena among these oscillators is essential, as evidenced by important recent studies in this area [1-4].
In this work, we present the dynamical behaviour of a two-dimensional nonlinear relaxation oscillator described by a system of coupled nonlinear differential equations.
In electronic circuits the presence of nonlinear active elements can enable the emergence of self-sustained oscillations and in this context, the UJT (Uni Junction Transistor) can be employed to construct relaxation oscillators where the junction acts as an electrically controlled switch that allows the current to flow only after a triggering potential point.
In this circuit the UJT is connected to a capacitor and a load resistor, where the charge and the current are measured. The resulting waveforms present two distinct time scales corresponding to the charge and discharge of the capacitor and the impulsive current flowing through the resistor creating a two-stroke oscillator.
In the work [5] a new mathematical model capable of satisfactorily describing its behaviour was presented. This continuous model reproduces the dynamics of the free oscillator, and when subject to perturbation, it is capable of reproducing the observed complex dynamical behaviour, such as the transition to chaos through the torus breakdown that was not properly described in previous models of this system [6,7].
Finally, we explored synchronization phenomena by diffusively coupling a network of oscillators and by employing Turing pattern formation techniques we assessed the stability of the synchronized state in relation to its topological properties.

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Modeling and control of opinion dynamics in the presence of higher-order interactions

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We consider a group of N individuals that need to form an opinion on a two-option choice influenced by an opinion leader, the individual $N+1$. The i-th individual has opinion x_i, where $x_i = 0$ means that individual i has a neutral opinion; $x_i > 0$ and $x_i < 0$ correspond, instead, to an individual leaning toward option 1 or 2, respectively, and higher values of $|x_i|$ mean that the opinion of the i-th agent is more extreme. The individuals are coupled through the hypergraph $H = (V, E)$, whereby social interactions are not only pairwise, but they can involve more than two agents at the same time. Namely, each hyperedge $\epsilon \in E$ is a pair of ordered, disjoint subsets of V. The first subset, $T(\epsilon)$, contains the tails, and the second, $H(\epsilon)$, the heads of ϵ, with the tail nodes trying to influence the opinion of the head nodes in the group interaction taking place on hyperedge ϵ. The opinion dynamics of the i-th coupled agent is described by

$$\dot{x}_i = f(x_i, \mu_i) + \sum_{\epsilon \in E^*_p, i} \sigma_\epsilon (x_{\epsilon\mathcal{T}} \alpha_\epsilon - x_{\epsilon h} \beta_\epsilon) + \sum_{\epsilon \in E^*_{uc}, i} k_\epsilon (x_{N+1} - x_{\epsilon h} \beta_\epsilon), \quad i = 1, \ldots, N,$$

whereas the opinion leader has dynamics $\dot{x}_{N+1} = f(x_{N+1}, \mu_i)$, as it is not influenced by the other individuals; note that function $f(z, \mu_i) = -3z + \mu_i \tanh(z)$ is so that, when $\mu_i > 3$, an isolated agent has an unstable equilibrium at the neutral opinion $z = 0$, and two stable equilibria $z = \pm\bar{x}_i$ leaning toward each of the two options [1]. The vectors α_ϵ and β_ϵ stack the weights of the tails and heads of hyperedge ϵ, respectively, and are such that $\alpha_\epsilon^T 1_{|T(\epsilon)|} = \beta_\epsilon^T 1_{|H(\epsilon)|} = 1$, and the set E^*_{uc} (E^*_p) is the set of hyperedges not containing the opinion leader (containing the opinion leader) that have i as a head; $x_{\epsilon\mathcal{T}} \in \mathbb{R}^{|T(\epsilon)|}$ and $x_{\epsilon h} \in \mathbb{R}^{|H(\epsilon)|}$ are row vectors whose elements are the state of the agents that are tails and heads of hyperedge ϵ, respectively. Finally, for a hyperedge $\epsilon \in E_{uc}$, σ_ϵ is its coupling strength, and for $\epsilon \in E_p$, k_ϵ is the control gain of the associated leader's feedback control action.

We consider the case in which the hypergraph describing social interactions, extracted from [2], is divided into 15 communities of 10 nodes each. The scope of the opinion leader is to bring the opinion of the followers as close as possible to its own. However, in the presence of limited resources the leader can only decide to influence one of the 15 communities through directed hyperedges. By linearizing equation (1) and using Lyapunov stability theory, we are able to identify the selection that yields the smallest difference

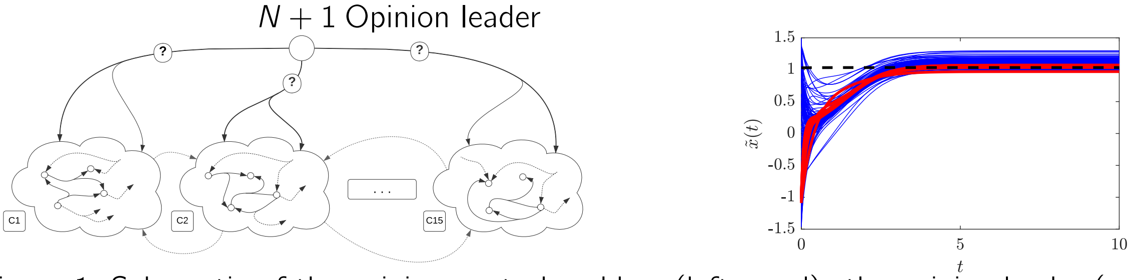

Figure 1: Schematic of the opinion control problem (left panel): the opinion leader (node $N+1$) tries to influence the opinion of a network of 150 with heterogeneous extremism levels μ_i, whereby nodes with larger μ_i will have more extreme stable equilibria when decoupled. The followers are organized in 15 communities C1, . . . ,C15, and the leader need to choose which one to control. The right panel shows the opinion dynamics when controlling community 3, so that the norm of the opinion differences between the followers (solid red and blue lines for community 3 and for the remaining communities, respectively) and the leader (dashed black line) is minimized.

in norm between the opinion of the leader and that of the followers. A schematic of the control problem and the dynamics in correspondence of the optimal choice of the community to control are illustrated in Figure 1.

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A comparative analysis of different virtual inertia controllers in power grids with renewable energy sources: effect on the stability

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Maintaining a synchronous state of generators is of central importance to standard operation in a power grid; indeed, a loss of synchrony among power generators may cause the outages of power grids with cascading catastrophic failures, as in the Western American network in 1996 [1]. The so-called inertia of the grid [2] is a measure of the power system's ability to counteract the frequency changes, i.e., to remain synchronized and stable when triggered by external disturbances. Renewable energy sources (RESs) are interfaced with the grid through power converters without the intrinsic inertia of synchronous machines, and their presence in power grids has recently increased [3], [4]. A strong presence of RESs reduces the global inertia of the system, thus compromising its stability and reliability [5], [6].

For this reason, it is fundamental to develop power converter controllers that provide synthetic inertia by mimicking the electro-mechanical characteristic of a synchronous machine. In this study, we investigate the performances of three different power converter control techniques able to generate virtual inertia, namely grid-following with swing equation emulation [7], grid-forming with swing equation emulation [8], and synchronverter [9]. The reference framework is a 3-bus system that comprises (i) a synchronous generator, serving as a grid equivalent, with a rated power of 10 MW and a fixed inertia of 3s, (ii) a RES with a rated power of 1 MW and variable inertia, and (iii) a time-varying load. The analysis focuses on the grid reaction to a rapid load increase; this sudden change allows analyzing the grid stability and its capability to adapt to variable demand scenarios. In particular, we investigate how the virtual inertia values provided by the three compared techniques and the physical distance d between the grid and the RES affect the grid frequency and stability.

The obtained results show that, by increasing d, the network can become unstable when the grid-following control method is used.

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Discovering the governing equations of a chaotic circuit

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In this work, we present an experimental study aimed at identifying the governing equations of a nonlinear circuit from experimental data. The procedure is based on the sparse identification method introduced in [1], and the ultimate goal of this work is to provide an experimental validation of this procedure. The identification process involves acquiring the state variables, as shown in Figure 1(a), and their derivatives. These derivatives can either be directly derived from the circuit or computed numerically. To model the circuit's behaviour, we construct a library $\Theta(x)$ of potential nonlinear terms. This library includes a range of candidate terms, encompassing both linear and nonlinear functions of the circuit's state variables. By leveraging sparse regression techniques, we iteratively refine this library to identify the minimal set of terms necessary to describe the system dynamics. This process includes the identification of unknown factors $\boldsymbol{\xi}_i$, which are the sparse coefficient vectors corresponding to each individual column. These individual sparse coefficient vectors $\boldsymbol{\xi}_i$ are then used to construct the sparse matrix Ξ. The iterative refinement process ensures that our model remains parsimonious while capturing the essential features of the system's behaviour. The presence of null elements in the sparse matrix allows us to eliminate spurious functions from our library $\Theta(x)$. Consequently, we derive the governing equations of the system. After deriving the governing equations, we use them to reconstruct the system's behaviour, resulting in the reconstructed variables shown in Figure 1(b). The reconstructed trajectory, defined using these variables depicted in Figure 1(d), is then compared with the attractor from experimental data as shown in Figure 1(c) to validate our study. This comparison demonstrates the success of our study. By iteratively adjusting the model parameters to minimize the error between the actual and reconstructed data, we ensure that our model captures the underlying dynamics of Chua's circuit.

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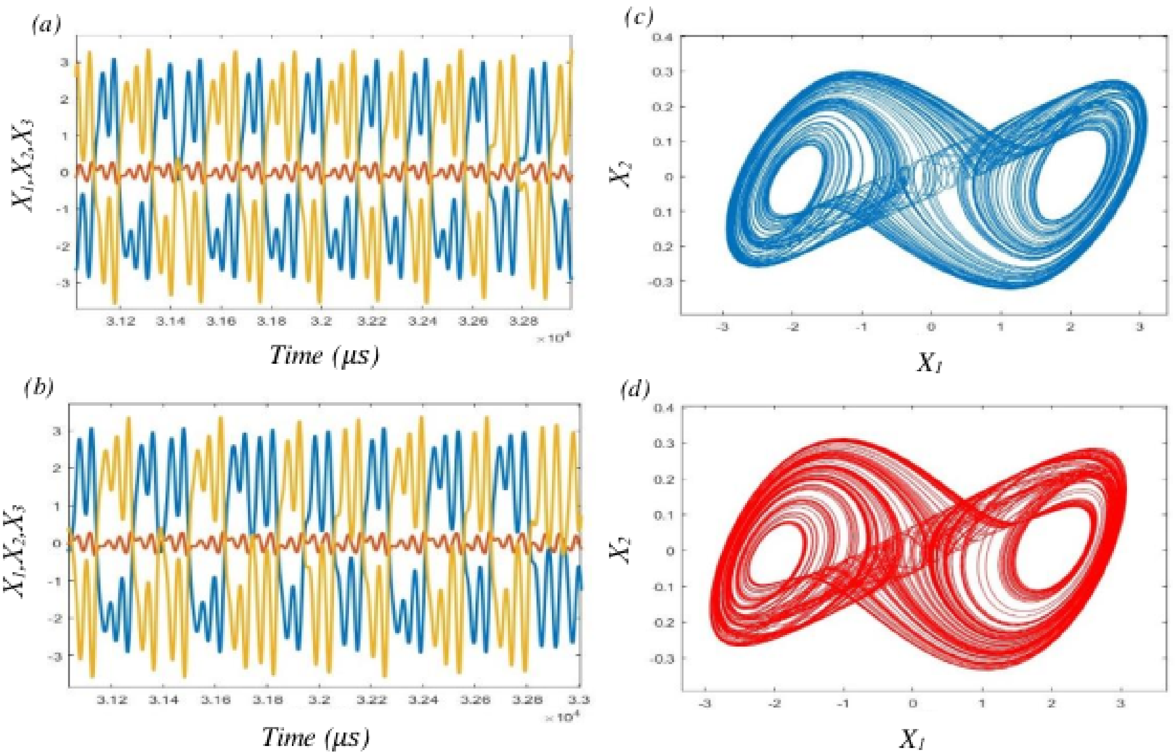

Figure 1: (a) State variables from the electronic circuit, (b) Reconstructed state variables, (c) Attractor from the electronic circuit, (d) Reconstructed attractor.

Forecasting Container Throughput at Klaipėda Port Terminal: A Comparative Study Using Linear and Multi-Criteria Methods

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Problem statement The rapid expansion of industrial infrastructure driven by advancements in Industry 4.0 has significantly heightened the demand for more port logistics [1]. The continuous growth in cargo volumes presents complex challenges as container ships increase in size and capacity, leading to a surge in the volume of containers handled by terminals. This necessitates improved efficiency and throughput at ports to accommodate the rising demand. Addressing these challenges requires strategic foresight to plan for future growth. This study focuses on the Klaipeda port terminal, aiming to analyze statistical data to forecast container throughput up to the year 2040 using both linear and multi-criteria forecasting methods that include calculating optimistic and pessimistic values with a margin of error and comparing our findings with previous studies. Additionally, we examine various factors influencing port terminal efficiency that could be enhanced to further increase throughput, such as quay crane operations [2], loading/unloading methods, scheduling, ship docking times, and the impact of weather.

Results Key findings suggest that the Klaipeda port container throughput is projected to increase from 1,050,000 TEU in 2023 to 1,321,044 TEU by 2040 using the linear method (see Figure 1), with an estimated margin of error of approximately 250,000 TEU.

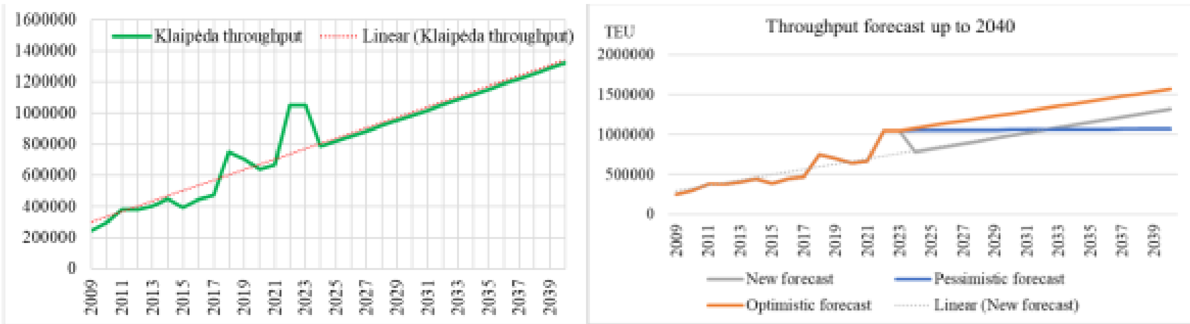

Figure 1: Klaipeda Port throughput prediction up till 2040.

The multi-criteria forecasting method, incorporating a wider array of factors, offers a more refined prediction, potentially adjusting these values based on a broader spectrum of influencing variables. Comparative analysis with earlier studies reveals that older forecasts align closely with actual throughput, especially in optimistic scenarios.

Conclusions In conclusion, our forecasting models predict a strong growth trajectory for the Klaipėda port terminal, driven by infrastructural improvements and operational enhancements. These findings emphasize the necessity of ongoing evaluation and adaptation in port logistics to address the changing demands of the transportation sector. The application of multi-criteria forecasting improves the precision of these predictions, underscoring its significance in strategic planning for port operations.

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Analysis of Collaborative Work through Conversational Patterns

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Various studies have analyzed the field of individual well-being in teamwork using advanced signal processing and machine learning techniques, providing a more objective and continuous approach compared to traditional survey-based methods [1]. This research draws on the importance of integrating pedagogy with advanced technologies to enhance learning environments and provide meaningful, data-driven feedback to both students and educators [2]. In this context, analyzing communication structures helps teams understand and improve their interaction dynamics. For instance, analyzing turn-taking in conversations and visualizing the social structure of the team can highlight communication patterns that are not immediately apparent [3].

At this point, it is emphasized how educational intervention can support educators in identifying when and how to intervene to foster more effective collaboration within the work teams of their students, based on observations of collaborative behavior. These findings underscore the potential of multimodal learning analytics technologies to enhance the assessment and support of collaboration in educational settings [5]. Additionally, it is highlighted that using objective data can significantly improve the way virtual teams communicate and address internal issues, though it does not necessarily translate into improved performance or team cohesion [4]. These findings highlight the utility of real-time feedback platforms in enhancing collaborative learning remotely, especially in contexts where physical interactions are not possible [6]. Particularly, this research poses the question: How does the identification of conversational patterns relate to performance during the development of a collaborative activity in remote learning environments?

This research is conducted in a laboratory of emerging technologies at a private institution in Mexico. The methodological development of the study includes a specific session where students participated voluntarily. The workshop timetable details a series of activities and tasks structured within a team experimentation session. The session starts with team formation and session setup, including adjustments in Zoom and software installation, which in this case refers to a logistic web-based simulator developed by MIT.

Initially, participants arrive and are introduced to the event, marking the beginning of the workshop's practical component, which lasts approximately 45 minutes. During this time, teams actively engage in a designated task. After completing the teamwork, five minutes are allocated to save the obtained results.

Based on the analysis of the datasets related to the identification of conversational patterns and performance in remote learning environments, it was observed that specific conversational patterns significantly correlate with higher performance levels. Teams who engaged in frequent, constructive dialogue and demonstrated clear, goal-oriented communication tended to perform better in the collaborative activity. These patterns included asking clarifying questions, providing detailed explanations, and consistently offering constructive feedback. The data indicated that such interactive and supportive conversational behaviors helped to maintain focus, enhance understanding, and foster a more collaborative learning atmosphere, ultimately leading to improved performance outcomes.

Additionally, the datasets revealed that groups exhibiting less effective conversational patterns, such as dominance by a single participant or lack of engagement, were more likely to struggle with their collaborative task. These groups often showed lower performance metrics, highlighting the importance of balanced and inclusive communication. The time-segmented analysis further revealed that periods of high engagement and balanced participation were associated with better performance. The analysis suggests that fostering an environment where all participants feel encouraged to contribute and engage in meaningful dialogue is crucial for the success of remote collaborative activities.
In conclusion, analyzing collaborative work through conversational patterns presents an opportunity for educators and researchers to integrate tools into the teaching and learning process that enable the identification of characteristics of personalized learning. This offers the chance to create structured discussion formats and incentives for active participation, providing feedback based on data collected during pedagogical activities conducted in remote learning environments.

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Stochastic simulations of non-stationary multifractal processes: application to turbulence

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Fully developed turbulence is often considered as a prototype of complex system, with a large range of scales involved and huge fluctuations called intermittency. In such system there is the so-called Richardson-Kolmogorov cascade, where the energy is injected at large scales, and is transferred from large to small scales in the inertial range, until the dissipation scales where energy dissipates into heat. In the inertial range, the velocity field possesses scaling and intermittent properties with multifractal characteristics: the increments $\Delta V_\ell = V(x+\ell) - V(x)$ (where V is one component of the velocity vector, x is the position and ℓ is an increment in the inertial range) are characterized through their statistical moments of order $q > 0$. They write $\langle|\Delta V_\ell|^q\rangle \approx \ell^{\zeta(q)}$ where "$\langle . \rangle$" denotes statistical average, and $\zeta(q)$ is a moment function which characterizes the non-stationary multifractal process. The analytical expression of this function depends on the stochastic process considered. For example, for the classical lognormal multifractal velocity field (Frisch 1995; Schmitt and Huang, 2016) it is a quadratic function. This is a very general property of turbulent time series, found for the velocity field as well as for passive scalars such as the temperature field.

For many applications in the atmospheric or oceanic environments, or in engineering, the generation of stochastic simulations possessing multifractal scaling properties as described above are needed. We propose here a stochastic algorithm to generate an intermittent time series possessing the relevant multifractal properties. This is written through a stochastic integral $W_H(t) = \int K_H(t,s)\epsilon(s)dW(s)$ where $H > 0$ is a parameter ($H = 1/3$ for the turbulent velocity field), $\epsilon(t)$ is a process obtained through a multiplicative cascade which mimics the energy flux, $W(s)$ is a Wiener process and the kernel $K_H(t,s)$ is chosen so that to obtain the relevant scaling properties. We generate here many realizations of the stochastic process $W_H(t)$ for different values of $H \in [0,1]$, and we show that we obtain the desired scaling properties with the correct parameter values, in the framework of lognormal multifractals. This approach can have applications for non-stationary simulations of multifractal fields in atmospheric and oceanic turbulence, in fluid engineering and also in finance.

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Prediction of antimicrobial resistance of Klebsiella pneumoniae from genomic data through machine learning

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Antimicrobials, such as antibiotics or antivirals, are medications used to prevent and treat infectious diseases across humans, animals, and plants. However, Antimicrobial Resistance (AMR) arises when bacteria, viruses, and parasites become unresponsive to these medications, rendering them ineffective. Despite the availability of substantial data, a gap still persists in applying predictive modeling to support antibiotic prescription decisions, highlighting the urgent need for an evidence-based framework in clinical decision support systems for antimicrobial management. Recent literature highlights attempts to use machine learning (ML) algorithms to enhance antibiotic prescribing practices [1, 2].

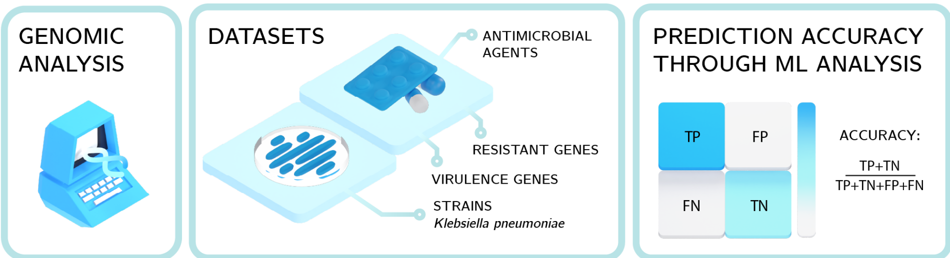

Figure 1: Overview of the approach used for predicting resistance/susceptibility to an antimicrobial agent from genomic data. In the definition of accuracy TP=True Positive, TN=True Negative, FP=False Positive, FN=False Negative.

This study aims to classify bacterial strains as either resistant or susceptible using ML techniques, offering rapid and accurate predictions of resistance from genomic data. Klebsiella pneumonia serves as a specific focus in this research. The study begins by utilizing genomic data from two datasets: one developed within this study, the Biometec dataset, and another publicly available [3]. These datasets are the result of genomic analysis techniques and they contain information regarding the presence or absence of resistance and virulence genes in various bacterial strains, as well as the susceptibility or resistance of these strains to different antimicrobial agents.

The data from the two datasets were preprocessed: specifically, a correlation analysis using the Pearson Correlation Coefficient (PCC) was conducted to identify significant data for the analysis, and data balancing was performed using the Synthetic Minority Oversampling Technique (SMOTE). These preprocessed data were then utilized as input for six distinct ML algorithms, generating binary predictions indicating the resistance or susceptibility of the strains to the antimicrobial agent. The evaluation of the accuracy for the prediction demonstrated that, despite the smaller size of the datasets, they exhibited good performances in predicting antibiotic resistance. This suggests the robustness and generalizability of the models across different subsets of data, even when faced with variations in strain origin and dataset size.

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Network Backbone Extraction using Link Prediction

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Backbone extraction methods aim to reduce the size of a network while preserving its essential structural properties. They can be broadly categorized into structural and statistical approaches. Structural methods aim at preserving the network's topology, while statistical methods aim to retain edges that deviate significantly from a null hypothesis model.

This study introduces a novel approach to backbone extraction based on link prediction. Indeed, both techniques aim at predicting the likelihood of a link between two nodes in a network. For this task, link prediction methods use various similarity measures or machine learning techniques. The proposed approach leverages link prediction scores to filter links in a network. Let's consider similarity-based link prediction methods. The proposed framework proceeds as follows: 1) Remove an edge from the network and compute its similarity score. Repeat this process on all the network edges. 2) Sort the edges based on their similarity scores. 3) Extract the backbone corresponding to the top X fraction of edges with the highest scores and the nodes attached and the bottom Y fraction of edges with the lowest scores and the nodes attached. Keeping the top X fraction of edges preserves the predictable edges based on the similarity assumption, aligning with the principles of structural backbone extraction methods. In contrast, retaining the bottom Y fraction of edges captures the unpredictable edges that deviate from the similarity assumption, similar to the statistical backbone extraction methods that retain edges deviating from a null hypothesis.

We extract the backbone of the American Elementary School social network (339 nodes, 16,546 edges) using a statistical method (disparity filter), a structural method (high salience skeleton), and the proposed approach (using the common neighbor similarity function). The disparity filter preserves $\approx 10\%$ of the edges for a typical statistical significance level $\alpha = 0.05$. The high salience skeleton preserves $\approx 7\%$. To compare our approach, we extract the backbone, keeping 10% of the edges (90% predictable and 10%

unpredictable edges). While the disparity and high salience skeleton maintain all nodes, the former consists of four components, whereas the latter has a single component. In contrast, our proposed method isolates approximately 8% of the nodes for this fraction of edges, yet all its nodes remain within a single component.

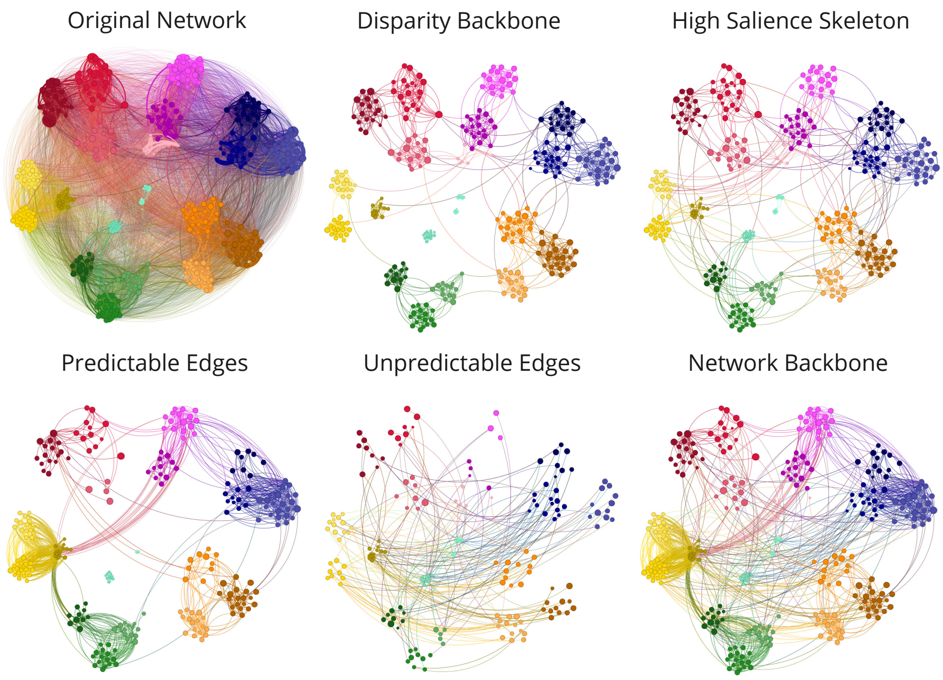

Figure 1: The original network, disparity, high salience skeleton, predictable and unpredictable backbone components, and the proposed approach's backbone. Colors denote different grades, and shades represent classes within grades.

Fig. 1 illustrates the extracted backbones. Observing the extracted edges, we notice that the disparity backbone and high salience skeleton predominantly link nodes within the classes of the same grade. Indeed, these edges form $\approx 91\%$ and 80% of the backbones, respectively. On the other hand, we notice that the top predictable ones predominantly link nodes within and between classes of the same grade. Conversely, the unpredictable edges primarily connect nodes from distinct grades. These cross-grade interactions pose challenges for prediction, as they lack substantial common neighbors. Ultimately, examining the combined backbone, we observe that roughly half of the edges connect nodes within the same class, while the other half bridge nodes across different classes at $\approx 50\%$.

This hybrid approach leverages the strengths of both structural and statistical backbone extraction methods, providing a comprehensive and nuanced representation of the network's essential structure and significant deviations. In our forthcoming research, we aim to expand our exploration of link prediction methods beyond similarity-based approaches.

Index Terms: Backbone Extraction, Link Prediction.

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Smart Restoration: AI for Historic Facades

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The protection of cultural heritage is a critical activity for all all those countries characterized by a great history of which evidence remains not only in written documents, but also in the remains and ruins of ancient civilizations. Many times such heritage is expressed not only in old ruins but also in ancient structures perfectly integrated with the modern natural and urban landscape. Such structures may be ancient churches, historic buildings of the nobility or institutions, monuments and more. Of course, all such structures must be preserved and maintained over time, to keep them safe and not create danger to citizens, but also trivially to preserve the ancient beauty of such buildings, and keep them perfectly integrated into the contemporary landscape. The safeguarding of such structures can be perpetrated in various ways, including with the support of modern technologies such as sensors mounted on monuments, safeguarded using Internet of Things paradigms and protocols (IoT) [1]. Such technologies can be used to implement predictive and preventive maintenance on the buildings. However, it is inevitable for an ancient building to deteriorate over time in both its exterior and interior structure, deterioration that is accelerated when environmental conditions are unfavorable. Considering the external facade of a historic building, it can be easily damaged by weather events, such as rain, snow, hail, by the sun, but also by simple moisture. The manner and severity with which these structures are damaged also depends on the material that is subjected to these types of stresses. The damages must also be identified and classified on the basis of such materials and the cause of the deteriorations. The restoration of historic buildings and monuments deals with such issues. The aim is to restore deteriorated and damaged structures to their original splendor by resolving the various damage that is occurring. The restoration of historic buildings, with particular reference to the facades goes firstly through the identification and classification of such damages. The restoration process involves applying screens (standard sign) from the huge facade orthophotos of historic buildings to identify the damages. Once these damages have been identified, restoration of the building is carried out in accordance with the identified materials and damages. The for such damages there exist a standard notation that identifies the various damages with specific screens to be applied on the orthophoto. The work of identifying and recording these damages, as it is done nowadays, requires formed architects and engineers, who manually apply these screens, using programs such as Autocad. However, this process is very time-consuming and prone to errors, hence the idea of creating an automated system based on artificial intelligence (AI) [2]. For these reasons, the subject of this paper is the proposal of a tool based on machine and deep learning for automatic identification and classification of defects in facades of historic buildings. Specifically, we will propose a framework that allows scanning of historic buildings in order to obtain high-resolution orthophotos of such facades, which can be analyzed by machine learning algorithms for automatic identification of these issues. Such orthophotos will be splitted in such a way as to be processable by today's machine learning algorithms, capable of processing images, classifying and editing them to highlight details of interest. We will evaluate the various possibilities in terms of machine learning and deep learning technologies. These techniques will range from those aimed at solving detection problems, to semantic segmentation [3][4], to the application of the new frontiers of AutoML [5] [6] techniques for image classification. The goal is to identify the most appropriate techniques to be applied in the analyzed context, with particular reference to the available dataset, based on orthophotos of facades made available by the students and teachers of the restoration course at the University of Salerno. The identification of such techniques will be finalized in the future to the realization of a tool that fed with orthophotos of facades of historic buildings, will return the corresponding image able to highlight the problems in the facade respecting the standards in force in Italy.

Keywords - Artificial Intelligence, Facade Damage Analysis, Automatic Damage Identification, Deep Learning, Predictive Maintenance

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Investigating speech as a standalone modality to detect dementia using deep learning techniques

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Dementia poses significant challenges due to its multifaceted impact on memory, cognition, and decision-making abilities, severely affecting daily life. Early detection is crucial for effective intervention and management. Traditional diagnostic methods are resource-intensive and require extensive cognitive assessments. This study proposes a novel approach to dementia detection focused solely on speech signals using deep learning models. Unlike previous studies combining speech and linguistic data, we concentrate exclusively on speech features to identify concise markers for dementia recognition. Machine learning (ML) algorithms analyze dataset patterns, while deep learning (DL) models process extensive speech data, revealing complex dementia-related speech patterns. The Dementia Bank dataset provides speech samples from individuals with varying cognitive impairments. Our method shows promising results compared to existing studies, emphasizing non-invasive, cost-effective dementia screening for earlier diagnosis and intervention, improving quality of life for patients and caregivers.

Detecting Influential Nodes with Centrality Measures via Random Forest Approach in Social Networks

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Detecting influential nodes is crucial for applications like information diffusion, viral marketing, disease containment, and network vulnerability analysis. Traditional centrality [1] metrics like degree, betweenness, closeness, and eigenvector centrality quantify node importance based solely on network topology. While insightful, many existing approaches focus on only one of these centrality measures [2], overlooking the combined importance signaled by multiple centrality metrics. Machine learning techniques can leverage rich node features but require extensive feature engineering. In this paper, we propose a machine learning approach to identify influential nodes in complex networks by innovatively combining multiple centrality measures as topological features and employing a Random Forest classifier.

The proposed approach uniquely combines a set of six well-established centrality measures as topological features: degree, betweenness, closeness, eigenvector, PageRank, and clustering coefficient. This comprehensive feature set captures different aspects of topological significance. A powerful Random Forest classifier is then trained on these features to detect influential nodes. The process involves three main steps:

1) **Feature Extraction** - Six centrality measures are computed for each node: degree, betweenness, closeness, eigenvector, PageRank, and clustering coefficient. This set captures different aspects of topological significance.

2) **Data Preprocessing** - A feature matrix X is constructed with the centrality measures as columns. A target vector y indicates whether each node is influential or not.

3) **Model Training** - The feature matrix X and target vector y are used to train a Random Forest classifier. It builds multiple decision trees on random subsets of the data and aggregates their predictions to classify nodes as influential or not.

Thus, this novel methodology uniquely combining topological centrality measures and the predictive power of machine learning offers a robust and interpretable solution to accurately identify influential nodes in complex networks. It was evaluated on three real-world datasets - Cora (citation network), CA-HepTh (collaboration network), and

Facebook (social network).Figure 1 shows a summary of the results for three network datasets using our method and several baseline methods for identifying influential nodes. Results demonstrated high accuracy ranging from 92.25% to 97.18%, with consistently high precision, recall, and F1-scores, outperforming baseline methods including logistic regression, SVM, and graph neural network approaches [2].

PERFORMANCE METRICS

Datasets	Metric	Methods						
		LR	SVM	RCNN	InfGCN	SGNN	DeepInfNode	Our Approach
Cora	Precision	87.1	88.8	88.2	90.7	90.6	91.4	89.55
	Recall	59.6	75.1	61.3	79.8	74.2	73.3	93.78
	F1-Score	82.9	81.4	73.2	84.1	81.7	88.4	93.59
CA-HepTh	Precision	91.3	91.0	91.1	90.6	88.1	93.4	96.99
	Recall	79.3	90.2	69.7	90.3	87.6	88.2	95.88
	F1-Score	81.2	89.1	79.7	90.7	90.7	91.2	96.43
Facebook	Precision	81.2	86.1	89.2	88.8	85.3	91.5	96.99
	Recall	45.0	84.5	89.3	75.1	79.1	87.2	95.88
	F1-Score	52.6	85.4	83.7	81.4	84.4	92.6	96.43

Figure 1: Performance metrics.

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Assessing Centrality Measures as Attack and Defense Strategies in the Air Transportation Network

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The emergence of attack-defense games provides a new perspective for assessing the security of complex networks. By examining the strategies and underlying dynamics, we can anticipate potential vulnerabilities and develop more effective defense measures [1]. This study presents a static zero-sum game model to analyze attack and defense strategies on networks. We investigate five targeted strategies based on influential centrality measures.

More specifically, we consider the air transport network to investigate the effectiveness of Degree (D), Betweenness (B), Closeness (C), Eigenvector (E), and PageRank (PR) centrality measures as attack (AS) and defense (DS) strategies. The game model assumes an attacker and a defender as the players in a one-shot game. It also assumes player rationality and perfect knowledge. Both players have equal capacity for attacking and defending nodes. We use $\Gamma(G)$ as the performance measure to evaluate network performance under various couples of attack and defense strategies. It is defined as the size of the largest connected component of the network G after removing attacked but undefended nodes. The attacker's payoff is defined as follows:

$$UA(X,Y) = \frac{\Gamma(G) - \Gamma(\hat{G})}{\Gamma(G)} \in [0,1]$$

where $\Gamma(G)$ is the network's performance before the attack, and $\Gamma(\hat{G})$ is the network's performance after the attack. The sum of the attacker's and defender's payoffs is always equal to zero, as the game is a zero-sum game. $UA(X,Y)$ represents the attacker's payoff and $UD(X,Y)$ represents the defender's payoff.

In this game, attackers and defenders use different centrality measures to target important nodes in a network. Nodes are either defended or attacked based on their rankings from these measures. Both sides operate within a budget constraint denoted by θ. When players choose the same strategy, all attacked nodes are defended, resulting in zero payoffs.

Figure 1 illustrates the performance of various centrality measures. Most attack strategies reach their peak payoff at mid-range θ values and then decline. In contrast, Betweenness

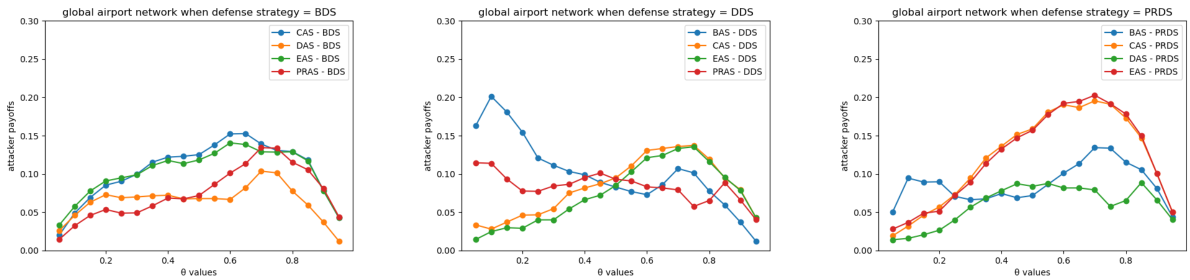

Figure 1: Attacker payoffs as a function of the attack (defense) range parameter θ when all strategies faces respectively betweenness degree and eigenvector defense strategy. On the x-axis, we represent the values of the attack (defense) range parameter θ, and on the y-axis the attacker's payoffs.

centrality peaks around $\theta \approx 0.2$ to $\theta \approx 0.35$. Indeed, nodes with the highest Betweenness centrality connect communities and may have low centrality measures in other contexts. As θ approaches 1, the undefended airports become unimportant. BDS is most effective against DAS, consistently keeping attacker payoffs low, while CAS, EAS, and PRAS perform better against BDS, especially around $\theta \approx 0.6$. DDS shows moderate effectiveness, with BAS initially having a high payoff that declines significantly after $\theta \approx 0.3$, whereas PRAS maintains moderate payoffs. EAS and CAS see a gradual increase in payoffs, peaking around $\theta \approx 0.7$ before slightly decreasing. PRDS is less effective against CAS and EAS, which peak around $\theta \approx 0.6 - 0.7$, while BAS peaks at $\theta \approx 0.2$ but declines sharply after that, and DAS consistently shows the lowest payoffs. CDS and EDS both show attack strategy payoffs peaking in the mid-range of θ values, with BAS showing the highest initial payoffs peaking around $\theta \approx 0.15 - 0.4$ for CDS and $\theta \approx 0.15$ for EDS, followed by a decline. CAS maintains low and stable payoffs across θ values for CDS and EDS. DAS peaks around $\theta \approx 0.3$ for both strategies and then declines, with higher payoffs than CAS but lower than BAS and PRAS. PRAS shows high initial payoffs for CDS and EDS, peaking early and declining, remaining higher than CAS and DAS until $\theta \approx 0.7$. Overall, Betweenness centrality is particularly effective early on, but other strategies like PRAS, CAS, and EAS show better performance at higher θ values. This suggests that hybrid defense strategies that combine various centrality measures may offer a more robust defense against a range of attack strategies.

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“Why Are There Six Degrees of Separation in a Social Network?"

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A wealth of evidence shows that real-world networks are endowed with the small-world property, i.e., that the maximal distance between any two of their nodes scales logarithmically rather than linearly with their size. In addition, most social networks are organized so that no individual is more than six connections apart from any other, an empirical regularity known as the six degrees of separation. Why social networks have this ultrasmall-world organization, whereby the graph’s diameter is independent of the network size over several orders of magnitude, is still unknown. We show that the “six degrees of separation” is the property featured by the equilibrium state of any network where individuals weigh between their aspiration to improve their centrality and the costs incurred in forming and maintaining connections. We show, moreover, that the emergence of such a regularity is compatible with all other features, such as clustering and scale-freeness, that normally characterize the structure of social networks. Thus, our results show how simple evolutionary rules of the kind traditionally associated with human cooperation and altruism can also account for the emergence of one of the most intriguing aFributes of social networks.

A Comparative Analysis of Machine Learning Algorithms for Detection of Node Centrality in Complex Networks

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Identifying central nodes [1] in complex networks is a crucial task with applications across various domains,including social media, biology, transportation, and communication systems. Understanding the structure and dynamics of these networks is vital for numerous applications, such as influence maximization, community detection, and network vulnerability analysis. Numerous centrality measures have been proposed to quantify the importance of nodes in a network, including degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. However, choosing the most appropriate centrality measure for a given application or network can be challenging, as different measures capture different aspects of centrality. Machine learning [2] algorithms have shown promise in addressing this challenge by learning patterns and relationships from network data, potentially capturing complex interactions and non-linear relationships that traditional centrality measures may overlook. In this study, we investigate the effectiveness of various machine learning algorithms for detecting node centrality in complex networks, using centrality measures as input features.

We evaluate the performance of Random Forest, Support Vector Machines (SVM), Logistic Regression, K-Nearest Neighbors (KNN), Naive Bayes, Linear Discriminant Analysis (LDA), and Multi-Layer Perceptron (MLP) on four real-world network datasets: CORA, Scientific collaboration, Jazz collaborations, and College football.We employ SIR (Susceptible-Infected-Recovered) simulations to quantify each node's influence and label the top 20% as influential. A feature matrix X is constructed with the centrality measures as columns. A target vector y indicates whether each node is influential or not. Extensive experiments are conducted to assess the models' accuracy, precision, recall, and F1-score, with results visualized through insightful graphs comparing the performance across different datasets.Figure 1 illustrates the comparative performance of various machine learning algorithms (Random Forest, SVM, Logistic Regression, KNN, Naive Bayes, LDA, and MLP) across four different network datasets (CORA, Scientist, Football, and Jazz), showcasing their accuracy, F1-score, precision, and recall metrics.

Our results demonstrate that the Random Forest algorithm consistently outperforms other models across most datasets, achieving high scores on most metrics. The consistent high performance of Random Forest can be attributed to its ability to capture non-linear relationships and handle multicollinearity among features. Future research directions include investigating alternative feature sets and incorporating temporal dynamics.

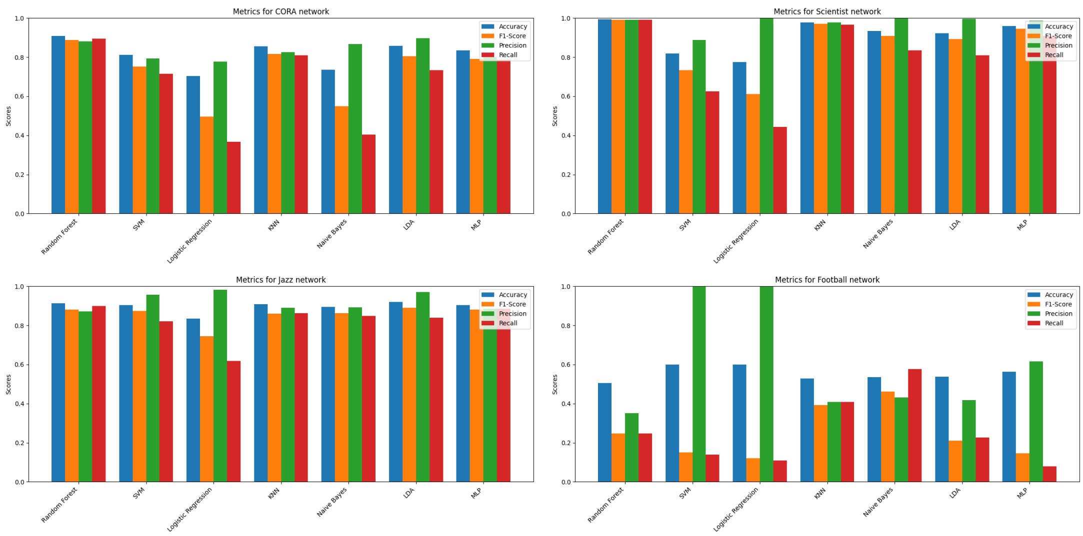

Figure 1: Performance Metrics of Machine Learning Algorithms on Different Network Datasets.

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First Observations of Criticality from Ca^{2+} Avalanches in GBM Networks in vitro

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This study aims to investigate if signatures of criticality exist in the Ca^{2+} dynamics of GBM networks in vitro. Glioblastoma (GBM) is the most common and aggressive primary adult brain cancer. Patients diagnosed with glioblastoma have a poor prognosis, and even with state-of-the-art treatment, the median survival time is $\sim$15 months. GBM's resistance to treatment partly originates from GBM tumors' ability to form functionally connected networks. Calcium (Ca^{2+}) has been shown to play a vital role in cell adhesion, cell mobility, and within GBM cancer networks, driving tumorigenesis. Thus, investigating the dynamics of Ca^{2+} signaling in GBM networks may lead to new clues for novel therapeutic targets.

In this work, we sought to investigate if the Ca^{2+} communication in GBM networks was a critical system. Criticality theory hypothesizes that a system exhibiting criticality is organized near a phase transition, where information transfer is maximized. To test this hypothesis, primary patient-derived mesenchymal GBM cells were grown in vitro, and their spontaneous Ca^{2+} time-series signals were recorded using live-cell fluorescence microscopy. Ca^{2+} signals were then processed spatiotemporally to identify avalanches of Ca^{2+} activity, defined as occurring when neighboring cells were active with overlapping Ca^{2+} signals. Avalanches were characterized by their size (total number of cells involved) and profile (number of simultaneously active cells over time).

The Ca^{2+} avalanches were assessed for signatures of criticality, including power-law scaling of avalanche size and shape collapse in avalanche profiles. The study observed two main hallmarks of a critical system in the network Ca^{2+} communication of GBM cells in vitro: spontaneous avalanches exhibiting power-law scaling across all sizes, and self-similarity across all size scales with shape collapse upon appropriate rescaling to a single profile.

The significance of GBM networks operating at a critical point suggests that GBM Ca^{2+} network communication confers emergent functional benefits to the tumor, promoting tumorigenesis, growth, and invasion—a prominent feature of this aggressive adult brain tumor.

A generative model for spatial complex systems: power grid and brain network applications

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Heterogeneous real-world systems can be described as spatial networks and, thus, represented as sets of nodes and edges embedded in space. In social networks, space is relevant since people typrodcally make relationships in their neighbourhood; loads and generators in power systems are physically connected by lines requiring building costs; also axons are more likely to connect nearby brain regions [1]. Real-world topological features can be replicated in synthetic networks produced by the so-called generative models. In the field of network science, generative models are designed to produce ensembles of networks using a stochastic process integrated into the model [2]. Our goal is to develop a versatile generative model capable of reproducing spatial characteristics observed in networks, particularly focusing on power grids and brain networks, which serve as case studies in our research.

Our generative model is divided in two main steps to output the final synthetic network. Firstly, it fixes synthetic node positions in the space, by choosing one among four levels of physical constraints aimed at reproducing specific topological features of real networks. Secondly, it builds the synthetic topological structure connecting couples of nodes (i, j) with edges by selecting between two different approaches, each with a different attachment law. Specifically, both attachment laws select node i with the same probability. Node j is selected with different probabilities by two attachment laws. Under the first attachment law, edges connecting distant nodes are less likely than those connecting close nodes,

$$\prod_{i} = \frac{\bar{k}_i - k_{t_i}}{\sum_{m=1}^{N}(\bar{k}_m - k_{t_m})} \quad \text{and} \quad \prod_{1j} = \frac{s_{ij}^{-\alpha}}{\sum_{m=1}^{N} s_{im}^{-\alpha}}$$

Under the second attachment law, edges are built following the distribution of Euclidean edge distances of real network,

$$\prod_{2j} = \frac{\prod_{Rs}(s_{ij})}{\sum_{m=1}^{N} \prod_{Rs}(s_{im})} \quad \text{where} \quad \prod_{Rs} = \frac{s_{R_{ij}}}{\sum_{i=1}^{N} \sum_{j=i+1}^{N} s_{R_{ij}}}$$

In both cases, the network construction follows an iterative procedure, where links are progressively added to the network, while targeting at satisfying the final desired node degrees. As a first case study, we use the proposed generative model to synthesize networks reproducing the key features of power grids. We consider the UCTE (Union for Coordination of Transmission of Electricity) European transmission network [3] made up of 1254 nodes (of which 378 are generators and 876 loads) and 1812 links. In our analysis, we divide the grid into five spatial sub-networks following a geographical criterion. Specifically, we analyse (a) Portugal and Spain; (b) France, Belgium, Luxemburg, and Switzerland; (c) Italy; (d) Germany; and (e) Czech Republic, Slovakia, Poland, Austria, Hungary, Slovenia, and Croatia. We make statistical comparisons (see Fig 1) between real and synthetic networks analysing several topological measures and performing One Sample Kolmogorov–Smirnov test to prove the effectiveness of our generative model through the statistical significance described by its p-value output.

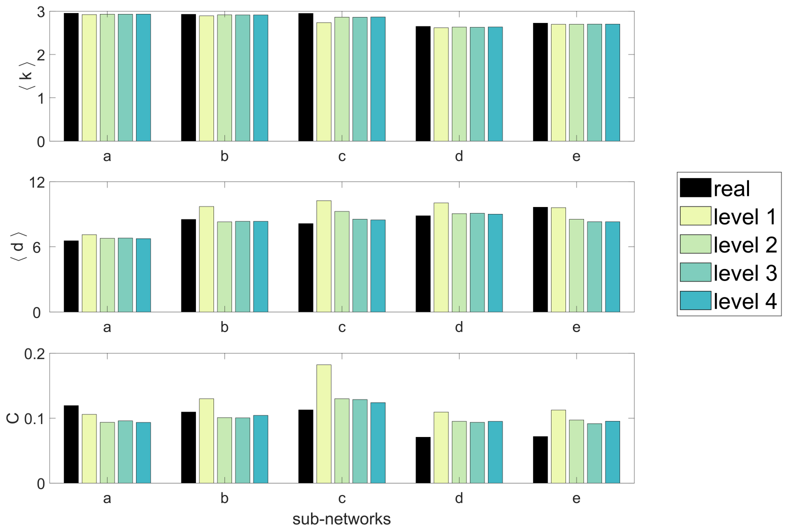

Figure 1: Results of three topological features, mean degree $\langle k \rangle$ (top panel), averaged shortest path length $\langle d \rangle$ (middle panel), and global clustering coefficient $\langle C \rangle$ (bottom panel), are shown. We here report results on the four different levels averaged on 100 networks. Measures are divided in five groups, from a to e, for each of the five power grid sub-networks.

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Cell dynamical interactions under hydrodynamic stimuli in microchannels

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Moving to the investigation of single cell to a cell culture paves the way to different open issues, with potential great impact in the organ-on-a-chip development [1,2], where a specific microfluidic chip is designed to simulate the cell environment and mechanisms (growth and death). In our study we assess the possibility to use hydrodynamical force to characterize cell-to-cell dynamics in healthy and unhealthy conditions. To evince these potential insight, two suspensions of yeast cells (10^8 in 10 [ml]), one in healthy status and the other undergone to death through a pro-apoptotic stimulus with H_2O_2 [3], were fed into a microchannel with an oscillating hydrodynamic pressure of amplitude A= 0.05 [ml/min] and frequencies f_i . Cell dynamics were recorded in an area of the microchannel using a CCD camera. Two scenarios were considered (see Fig.1). In Protocol I, a sinusoidal input with a frequency f_i = 0.01 [Hz] was supplied for 120 seconds. Protocol II lasted three minutes. The input pressure at f_i = 0.1 [Hz] was applied and cell dynamics recorded during the first minute. Then, both the pressure and camera were turned off and, after a one-minute transition, spontaneous cell dynamics were recorded again in the third minute. Cell mean velocities and counting were determined by the video analysis using an ad-hoc DPIV-based algorithm developed by the authors [4]. Fig. 2(a)-(c) show the velocity signal trends for both protocols. The signal spectrum in Protocol I is in Fig. 2(b), while the two spectra in Protocol II, for the first and third minutes of recording, are in Fig. 2(d)-(e). The dominant frequency corresponds to the input pressure, which is omitted in the spectra to highlight other dynamics but is clearly visible in the velocity trends. Analyses revealed that viable cells exhibit significantly higher temporal velocity oscillations compared to H_2O_2 stimulated cells, indicating a heightened response to hydrodynamic stimulation, probably due to membrane changes. Additionally, a broad-band dynamic at higher frequencies (7-15 [Hz]) was observed, especially in viable cells at the lower input pressure frequency of f_i = 0.01 [Hz], even with the input pressure applied. At a higher input frequency of f_i = 0.1 [Hz], this effect was reduced but still present, regardless of whether the pump was ON or OFF. This high-frequency dynamic was significantly reduced in H_2O_2 stimulated cells under all conditions but was more evident at the lower frequency stimulation. These findings indicate that viable cells exhibit input-induced vibrations, which could benefit applications in tissue engineering and regenerative medicine by enhancing cellular growth and differentiation. Future work will test different cell types, vary flow rates, and monitor transition times.

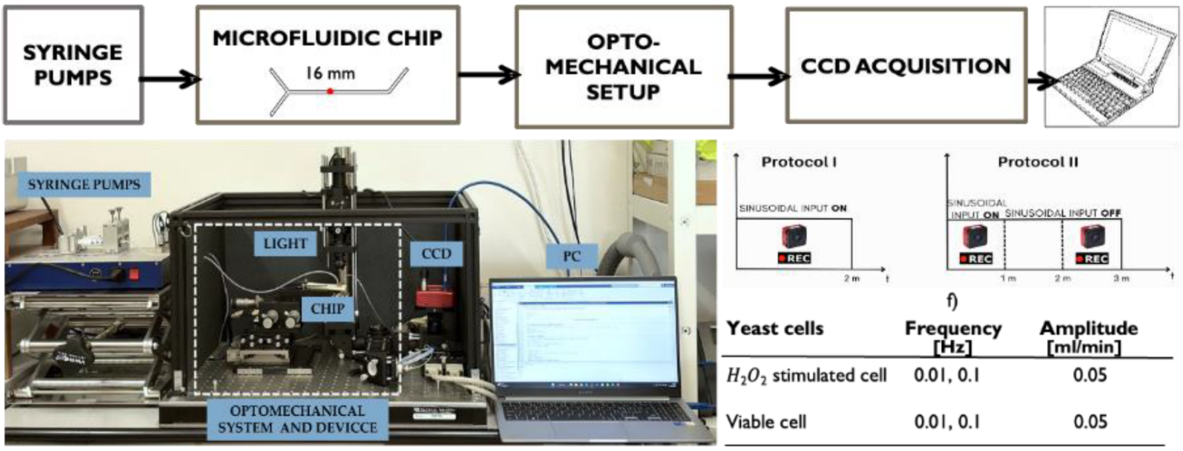

Figure 1: Experimental setup, protocols, and campaign.

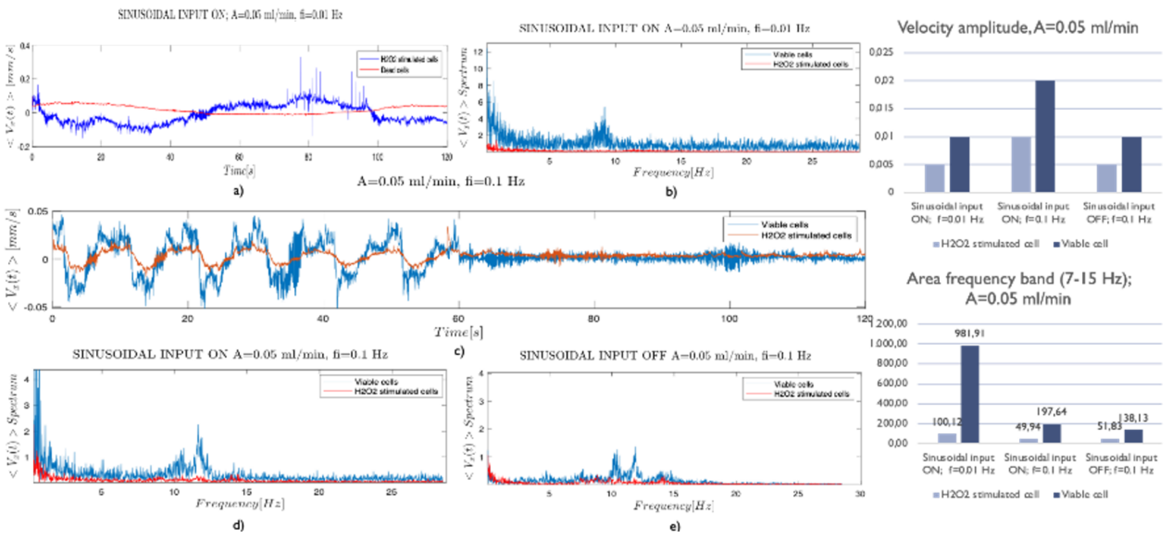

Figure 2: Experimental results: mean velocity trends, spectra, and comparison bar plot.

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Low-cost acusto-mechanical stimulation to tune particle displacement inside microchannels

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Manipulating cell populations at the micro-scale typically requires expensive equipment. This work investigates a non-invasive and low-cost approach to control cell arrangement and behavior in a microchannel, potentially enabling new solutions for cell sorting, patterning, and aggregation in biomedical applications [1,2]. An external stimulus generated through acousto-mechanical transduction was used to modulate cell dynamics. A smartphone-driven audio speaker, integrated into the central inlet of a hydrodynamic focusing microfluidic device, emitted G-sharp tones to create customized harmonic flow patterns (see Fig. 1). This approach translated audio signals into axial oscillations of the inlet tube, facilitating harmonic modulation of flow rates and transmitting it to micro-particles [3]. The device, consisting of three inputs that merge into a central microchannel, was tested in various geometric configurations.

Two types of micro-particles, i.e., yeast cells and silica beads (5 and 6 μm in diameter), were investigated. Firstly, they were fed into the central inlet, keeping plugged the lateral ones, using two constant hydrodynamic pressure values: 0.001 ml/min and then 0.005 ml/min. Next, fluid was fed into both the central and lateral channels, with flow rates of 0.001 ml/min for the central and 0.005 ml/min for the laterals. To apply the acousto-mechanical stimulus, a G-sharp note was emitted at one-second intervals, alternating with a one-second pause, for a total acquisition time of 60 s (see Fig. 1). Cell dynamics within a specific microchannel region were recorded using CCD video acquisition. Cell mean velocities and counting were determined through video analysis employing a DPIV-based algorithm developed by the authors [4].

Fig. 2 illustrates the velocity trends and spectra for each of the three experimental conditions. The time-domain signals show that by combining a constant flow with the acousto-mechanical stimulus, a periodic behavior can be induced in the micro-particles. Each stimulus causes particle deceleration, leading to a system slowdown, which is more pronounced in silica beads than in yeast cells. All spectra display a dominant frequency of 0.5 Hz, as imposed by the protocol. Additionally, high-frequency peaks in the 15-20 Hz band are observed for yeast cells at a flow rate of 0.001 ml/min but disappear at

0.005 ml/min, indicating a reduction in cell-to-cell interaction. Activating the lateral channels shifts the high-frequency cell behavior to the 20-25 Hz band, demonstrating the significant impact of channel configuration on micro-particles behavior. These findings highlight the potential of a low-cost actuation system for cellular manipulation using various configurations of microfluidic geometries.

Future work will focus on evaluating the system's effectiveness with different cell types and exploring new configurations of acousto-mechanical stimuli, including tones whose own frequency can be detected within the analyzed frequency spectrum.

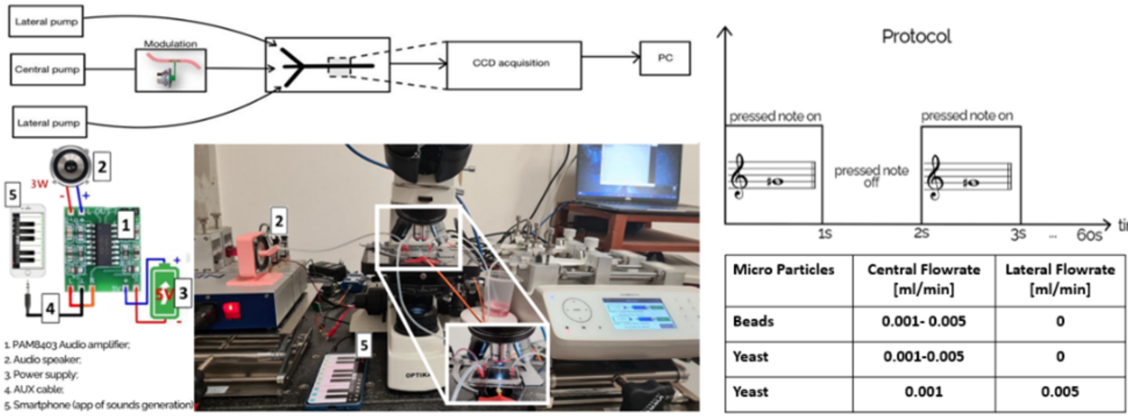

Figure 1: Experimental setup, protocols, and campaign.

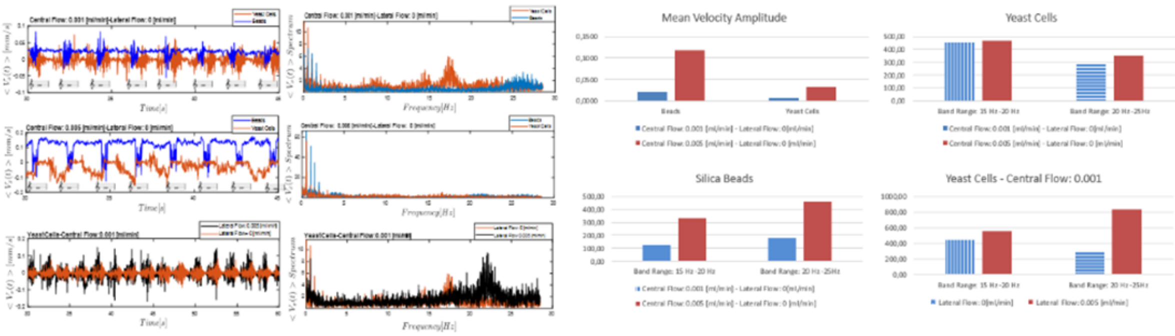

Figure 2: Experimental results: mean velocity trends, spectra, and comparison bar plot.

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Electronic circuit for chaos and synchronisation in laser physics

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The laser with electro-optic feedback has represented a significant breakthrough in laser physics, as feedback circuits are commonly used to stabilize the output power and emission frequency. For the first time, about 40 years ago, a feedback circuit was used to induce chaotic emission in a laser. In other words, a simple feedback circuit consisting of a bias signal could destabilize a laser. From a dynamical point of view, we have a nonlinear system consisting of three differential equations for the three variables: the laser intensity, the population inversion, and the feedback voltage [1].
For an appropriate choice of the control parameters, linked to the type of laser used and the pump mechanism, which are therefore specific to the laser and the feedback circuit, it is possible to achieve chaotic behavior, i.e., behavior highly sensitive to initial conditions [2].
A peculiarity of the laser with feedback is that it can exhibit two types of chaos: one of a local type where the transition to chaos occurs through successive subharmonic bifurcations of a limit cycle, and the other of a global type linked to the presence of a homoclinic orbit around which it is possible to have chaos. This latter type of chaos is characterized by pulses that are almost all of the same height but erratically separated in repetition time.
In this work, the laser is simulated electronically with the aim of synchronizing the two chaotic behaviors. By changing the coupling strength between two lasers, the transition from complete synchronization to explosive synchronization has been found and characterized [3].

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Access.

Orthogonality Catastrophe with Incompatible Observables: Dynamical Scaling and Thermodynamics

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The orthogonality catastrophe, discovered by P.W. Anderson in 1967, describes how a local perturbation can cause the ground state wave-function of a many-body fermionic system to become orthogonal to its original state in the thermodynamic limit of many particles. Here we consider a one-dimensional fermionic gas with a localized neutral impurity perturbing the system, within a quench dynamics. The sensitivity of the gas to the perturbation is quantified by the Loschmidt echo that can be assessed by means of an interferometric scheme. In this context, the inverse-Fourier transform of the Loschmidt echo returns the Kirkwood-Dirac quasiprobability (KDQ) distribution of the work done by the impurity on the fermionic system whose Hamiltonian is suddenly changed by means of a tunable interaction strength. The orthogonality catastrophe is reflected on the quasiprobability distribution of work, which changes depending on the state of the gas when the perturbation occurs. In this regard, we observe the emergence of non-positive quasiprobabilities as an effect of the non-commutativity of the initial state of the gas with its Hamiltonian perturbed by the impurity. The loss of positivity is directly responsible for a reduction of the minimal time imposed by quantum mechanics, in terms of quantum speed limits, for inducing the orthogonalization of the fermionic gas state. The corresponding quantum Fisher information, measuring the indistinguishability of the gas states before and after the quench, is equal to the variance of work with respect to the initial state whose unperturbed value is well captured by the KDQ distribution. Notably, these findings hold also in case the fermionic gas is made of just a few particles. This study represents a first attempt to quantitatively access non-equilibrium features, exhibiting non-classicality, of a many-body system subject to a quench dynamics.

Wednesday 24$^{\text{th}}$

Reconstructing the topology of pairwise and higher-order interactions of coupled dynamical systems

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Network science has been successful in modelling physical, biological and social systems as large aggregates of dynamical units, pairwise coupled by the links of a complex network. This is, however, too strong a limitation, as recent studies have revealed that higher-order interactions and dependencies are indeed present in ecosystems, social groups, and in the human brain. Knowing the precise patterns of such higher-order interactions is therefore fundamental to understand and predict the behavior of these systems. Often we do not have direct access to which unit is interacting with which in a system, and we need to reconstruct this information from measurable quantities, such as the states of the nodes at different times. This problem has been studied in the case of (pairwise) networks, but is open in the case of higher-order networks, i.e. when the units of the system can interact not only in pairs, but also in groups of three or more. In this talk, we will discuss the solution we propose to solve this problem for the most general case of higher-order networks, and in the most general case of dynamics. Namely, we propose an optimization-based method to infer the high-order structural connectivity of a complex system from its time evolution. Given any system made by many dynamical units/nodes coupled through pairwise and higher-order interactions, our method allows to fully reconstruct the topology of such interactions by solving an optimization problem based on the measurement of the states of the nodes at different times. In more detail, assumed that one knows the functional form of the isolated dynamics at the nodes, and the ones ruling the interactions, it is possible to write down a system of algebraic equations where the unknowns are the coefficients of the adjacency matrix (describing the pairwise interactions) and the adjacency tensors of any order (describing the higher-order interactions). At this point, one can formulate several optimization problems to find a solution. For instance, taking into account that interactions are usually sparse, one can search for the solution which maximizes sparsity. We apply our method to a microbial ecosystem, which may be of relevance in modeling populations of coupled bacteria for the study of anti-microbial resistance. The system is modeled by Lotka-Volterra equations where both pairwise and three-body interactions exist. With our approach, we are able to demonstrate the successful reconstruction of the whole structure, effectively detecting which nodes/populations are interacting in pairs and which in groups of three nodes/populations. To show the generality of the approach, we also study a system of coupled chaotic oscillators, whose structure of interactions is a simplicial complex with undirected and unweighted hyperedges. The results show that our method can help to understand and predict the behavior of complex systems, such as microbial ecosystems and coupled nonlinear oscillators, shedding new light on a variety of physical phenomena where higher-order interactions have a fundamental role.

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Acknowledgements This talk is based on the paper [1], currently under review. The work is supported by the MUR PNRR Extended Partnership Initiative on Emerging Infectious Diseases (Project no. PE00000007, INF-ACT).

Geometry and Distribution Control of Complex Oscillation in Memristive Circuits

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Memristive circuit has attracted great interests because its complex oscillation behaviors including chaos and multistability demonstrate tremendous application in chaotic secure communication and circuit information storage; therefore, an effective method for regulating and controlling the complex oscillation in memristive circuits is of great significance in chaos-oriented engineering. In chaotic systems non-bifurcation parameters can control the amplitude and offset of chaotic signials, and attractor reproducing can be realized based on offset boosting. Memristive circuit as a special nonlinear system has the similar property of amplitude control and offset boosting. This presentation aims to introduce the issue of regulating and controlling chaotic oscillation in memristive system with different memristor models. Through the analysis of the degree distribution and variable-dependence relation according to the characteristics of nonlinear functions, a new method for controlling the size and position of the attractor is constructed based on non-bifurcation parameter; by means of revising the balance of polarity or introducing offset modulation function, a new structure of conditional symmetry or a new type of self-reproducing system can be coined which output pairs or lattice of coexisting attractors. Further joint regulation and control of the memristive oscillation can be achieved including geometric regulation and multi-attractor regulation in physical memristive circuit with memristor chips or equivalent units. The exploration can not only reveal the regulation mechanism of the oscillations in memristive circuits theoretically, but also puts forward a set of methods for attractor control which can promote the application of memristive circuits.

Models of critical neural dynamics and inhibition based on neon lamps

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I will present the results obtained in the last years about the study of models of critical neural dynamics, from networks of leaky integrate and fire neurons to the stochastic Wilson Cowan model, and highlight the connections with networks of non-linear electronic systems. Critical behaviour in neural systems is usually associated to the presence of a second order transition, in the directed percolation universality class. I will show that in many cases models of neural dynamics display a line of first order transitions, with characteristic phenomena as hysteresis and bistability (or multistability). While a second order transition has been connected with the flexibility and dynamical range of the brain, needed to respond in an effective way to a large number of external inputs, first order transitions can be related to the ability to switch between different persistent dynamical states, important for memory persistance or task performance. I will then illustrate different mechanisms that can drive the network from a first order transition to a critical point and then to a smooth behaviour without discontinuities. One of this mechanisms is the tuning of a global inhibition acting at the network level in an aspecific way. A similar phenomenology can be observed in non-linear electronic systems, such as networks of glow lamps connected by capacitive links and to an external potential. I will highlight the similarities between this systems and models of neurons, and the corresponding role of a global inhibition, represented in this case by a global resistance between the network of lamps and the external potential.

Dissecting the complexity of physiological and brain network systems through multivariate information measures

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[2] Department of Engineering, University of Palermo, Italy.

Advancements in biomedical instrumentation and signal processing tools are boosting the development of new approaches for the data-driven modelling of complex physiological and brain systems. With a growing body of theoretical and empirical research, predominantly within the field of network neuroscience, there is a surge of interest in exploring the intrinsic dynamics and the interaction patterns among simultaneous recordings of physiological and brain signals originating from diverse human organs or brain units. Such analyses are underpinned by fast advances in the research areas of information theory (IT), graph theory and the theory of dynamical systems. Here, we present an information-theoretic framework designed to detect and quantify interactions of different order within physiological and brain dynamic networks whose temporal evolution is mapped by different types of random processes. The framework includes measures designed to assess interactions organized in a hierarchical order: interactions of order 1 reflect the individual dynamics of a single network node and are quantified by measures of entropy rate and information storage; interactions of order 2 (pairwise interactions) reflect the coupling between two nodes and are quantified by measures of mutual information rate (MIR) and transfer entropy rate (TER); interactions of order > 2 (higher-order interactions) reflect the synergistic/redundant cooperation among several nodes and are quantified through the O-information rate (OIR) or via Partial Information rate Decomposition (PIrD). The theoretical formulation of the measures presented above is first showcased in benchmark examples of simulated networks. Then, the practical implementation of the framework is illustrated along with context-specific estimation strategies in two applicative scenarios: neural spike-train networks mapped through point-process data, and physiological oscillatory networks modelled by continuous Gaussian processes. In the first scenario, we demonstrate how the measures of memory utilization rate within an individual point process and of information shared (MIR) and transferred (TER) between pairs of point processes, estimated via model-free distance-based entropy estimators, reveal the development of functional networks in spontaneously-growing cultures of cortical neurons. In the second scenario, we illustrate the potential of linear parametric models implemented in the frequency domain to describe pairwise and higher-order interactions via spectral estimates of the MIR, OIR and PIRD measures applied to multivariate physiological time series reflecting brain and cardiovascular oscillations.

Holographic and seismic comparative modal analysis on Radicofani fortress

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In this article, we performed the modal analysis on the historical building Rocca di Radicofani located in Tuscany, Italy. The experimental analysis has been conducted by comparing two techniques: Infrared Digital Holography (IRDH) and the more traditional seismic measurements. We show how the holographic technique in the infrared range is able to detect the same structural frequencies and modal shapes of seismic analysis. IRDH uses a long wavelength laser radiation (10.6 μm) which allows monitoring a large area of buildings with a high level of precision (0.1 μm) without the need to physically access the structures such as traditional seismic analysis. The remarkable sensitivity and the capacity to work remotely make the holographic technique a significant promise in the field of structural dynamics, especially for buildings with architectural or historical constraints or in case of damaged buildings. In addition, the ability of the holographic technique to detect the modal parameters can be used to monitor their evolution in time in order to verify the structural health of historical structures without affecting their functionality and making the method fast and cheap.

Continuous Structural Health Monitoring of Civil Structures from Ambient Noise Analysis: The OSS SHM Project

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The Seismic Observatory of Structures (OSS) was established in 1995 with the installation of the first seismic monitoring system and has expanded to encompass over 170 monitoring systems. These systems, apart from seven bridges and five dams, along with a couple of towers and bell towers, are mostly installed on public buildings such as schools, town halls, and hospitals. From its inception, the OSS was designed as a strong-motion network aimed at collecting data on the behavior of civil structures during earthquakes that could potentially damage them. In recent years, however, the need to continuously monitor the building stock of our country to detect possible damage not directly attributable to seismic events has become increasingly important. Thus, the Structural Health Monitoring (SHM) project was conceived to ensure periodic monitoring of modal parameters to control the conservation state over time under ordinary service conditions. Initially starting with a few pilot structures, the project now involves 20 OSS structures, including all the bridges. The approach adopted in the project is based on the tracking of modal parameters, which involves monitoring the values over time of the experimental modal frequencies and shapes of the structure. An abnormal variation in modal parameters compared to their “physiological” behavior can be associated with the presence of structural damage or material degradation. In the OSS-SHM project, four 30-minute recordings of ambient noise are acquired and analyzed daily for each monitored structure at Coordinated Universal Time intervals: [1:00 1:30], [7:00 7:30], [13:00 13:30], and [19:00 19:30]. From these ambient noise recordings, natural frequencies and modal shapes of the structures are extracted, generally referencing from three to five modes. This extraction is performed using automated procedures, employing the Stochastic Subspace Identification (SSI) technique in conjunction with an adaptive modal filter that enhances individual harmonic components present in the signals.
It is well-documented in literature and numerous studies that the dynamics of structures depend on variations in environmental parameters, particularly temperature. To distinguish between “physiological” and “pathological” behavior, the dependency of frequencies on temperature was characterized, and a “physiological” domain was determined. Within this domain, there is a 90

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Analysis of 35 years of monitoring data of the Dome of Santa Maria del Fiore in Florence

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This paper reports the data obtained from the static and dynamic Structural Health Monitoring systems installed on the Dome of Santa Maria del Fiore in Florence and discusses the main outcomes concerning its structural behavior. The actual monitoring system started working in January 1988 as static and environmental monitoring; additions to this system were subsequently made in 2003, while the dynamic monitoring components were installed in 2018. A preliminary analysis of this updated dataset, while confirming past insights on the evolution of the Dome's damage pattern, opens new research questions. By improving knowledge on the structural behavior against static and dynamic loading, these results can direct further data exploration of the Structural Health Monitoring measurements and future actions, thus contributing to the protection of this heritage masterpiece. The main objectives of this study are hence to evaluate the Structural Health Monitoring system performance until today, and to update and confirm past understanding of structural behavior of the Dome, with a preliminary exploration of the monitoring data that, since 2018, contain both static and dynamic measurements.

KEYWORDS: Static and dynamic data, SHM, Cultural Heritage, Damage pattern, System identification.

SWIR digital holography and imaging through smoke and flames

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Digital Holography is an interferometric imaging technique with various and significant applications in many different areas, such as non-destructive testing, 3D imaging, microscopy, etc. Digital holography is usually realized using visible radiation; in this region of the electromagnetic spectrum, however, the stability requirements necessary to preserve the interferometric pattern, containing the information about the investigated scene, are quite stringent. Furthermore, the field of view of digital holography is directly proportional to the wavelength and inversely proportional to the pixel pitch and, considered the typical modern visible detectors (CCD, CMOS), it is rather modest at these wavelengths. Moving toward longer wavelengths the stability requirements become less stringent and a larger field of view is available. The Short Wavelength Infrared (SWIR) region, despite its interesting peculiarities and appealing applications in the imaging field, has not yet been fully investigated in Digital Holography (DH). Here we present a compact and robust SWIR DH setup and demonstrate the peculiar and remarkable advantages offered by SWIR radiation for macroscopic object investigation. In particular, we focus our attention to a specific application, previously demonstrated using Long Wavelength IR DH, that is vision through smoke and flames and demonstrate the great potential of SWIR DH in the field of fire rescue. The capability of imaging a scene through smoke and flames is, indeed, a highly desirable goal due to its potential application in the field of fire rescue. Vision in such impaired conditions would let rescuers move safely in a fire scenario and would help them in identifying/individuating human being or things hidden behind smoke and flames. Current visible imaging systems cannot see either through smoke or through flames. Standard thermo-cameras can see through smoke (and are indeed used by firefighters for this purpose) but are blinded by flames. Indeed the image of the flames, focused on the focal plane array by the lens detector, covers and hides the scene of interest. In particular, the radiation emitted by the flames of a real fire scenario, may reach very high power density values which, in principle, can saturate any detector, depending on various parameters: detector sensitivity, detector spectral range, detector-flames distance, detector exposure time, flame temperature, presence of a lens in front of the detector. This last factor, in particular, always impair the vision of any scene behind a flame, even if it does not lead to the detector saturation, since the flame temperature is usually higher than the remaining part of the scene. On the contrary DH in the Infrared range is able to see through both smoke and flames. Vision through smoke is mainly due to the well know capacity of IR radiation to penetrate almost undisturbed through smoke. Vision through flames is instead related to two different peculiarities of the technique. First of all, since the radiation emitted by the flame is not coherent with the laser radiation, it does not contribute to the generation of the interferometric pattern containing the information relative to the scene. Secondly, DH allows to numerically reconstruct a scene without the need to focus its image on the focal plane array of the detector. For this reason, the radiation emitted by the flame does not focus onto the detector but is instead distributed over the whole focal plane array and any saturation effect is reduced.

Multifractality in Electronic Circuits and Beyond: Exploring Physical Systems

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The concept of complexity, understood as the result of the nonlinear interaction among system elements leading to emergent phenomena, has been extensively explored in recent decades. The system's spontaneous collective behavior is revealed in its hierarchical structure, which can be analyzed using multifractal formalism. Within this framework, complexity can be quantitatively characterised as the degree of development of a multifractal organisation represented by a multifractal spectrum. This approach has found wide application in the investigation of various natural systems, enabling the identification and quantification of complexity in natural sciences and beyond. Given the abundance of multifractal behaviour in nature, a current challenge is to develop artificial models that mimic natural behaviours. In this contribution, we will demonstrate the concept of multifractality using examples from natural systems, particularly neural and economic systems, where multifractal behaviour is well-established, leading to intriguing conclusions with practical applications [1]. The focus will be on highlighting the appearance of multifractal behavior in an artificial dynamical systems [2]. We will demonstrate that multifractality can arise spontaneously in time series generated by a chain of four Rössler systems with directed couplings, both in numerical simulations and in physical realisation through analogue electronic circuits. The discussion will cover the constraints required to induce complex behavior in the presented system. Finally, we will concern the potential of this work in constructing "toy models" of complex systems and advancing physical reservoir computing.

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On Constructing Frequency-Multiplexed Networks based on Nonlinear MEMS Devices

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This work presents the first demonstration of a frequency multiplexed 3-limit cycles network in a multimode microelectromechanical nonlinear resonator. The network is composed of libration limit cycles and behaves in an analogous manner to a phase oscillator network. The libration limit cycles, being of low frequency, interact through the stress tuning of the resonator, and result in an all-to-all coupling that can be described by a Kuramoto model. Beyond the typically present cubic nonlinearity the modes in question do not require any special frequency ratios. Thus, an interconnect free Kuramoto network is established within a single physical device without the need for electrical or optical coupling mechanisms between the individual elements.

The paper presents a novel approach to constructing oscillator networks using a single nonlinear microelectromechanical system (MEMS) device. Traditional oscillator networks typically require the coupling of individual, nearly identical, oscillators [1-2], but this work proposes a method to generate multiple nodes which are synchronized within a single device. The focus is on creating a network of frequency multiplexed limit cycles within the device, and utilizing nonlinear mode-coupling present in micro- and nano-electromechanical systems (M/NEMS) to synchronize them. The work leverages the concept of "librator" limit cycles [2], which are limit cycles taking place in the rotating frame of a harmonically driven resonator, and generated using synchronous feedback circuits, Fig. 1(a). These librator limit cycles exhibit unique properties that make them suitable for coupling within the device. This work outlines the theoretical framework for generating and synchronizing these limit cycles, highlighting the importance of amplitude-phase coupling and quasi-dc transmission of information between the various frequency multiplexed limit cycles, Fig. 1(b). Experimental validation is provided using a piezoelectrically actuated GaAs MEMS clamped-clamped beam device. Libration limit cycles are generated around different modes of the device, and synchronization is demonstrated both to an externally injected tone and between interacting librators. The dynamics of the device are investigated through parameter sweeps, revealing regions of synchronization and partial synchronization, Fig. 1(c).

This work emphasizes the potential of this approach for constructing oscillator networks with MEMS devices. The ability to control network properties experimentally opens up possibilities for applications in various fields, including neuromorphic computing and reservoir computation. The proposed method offers potential for implementation to

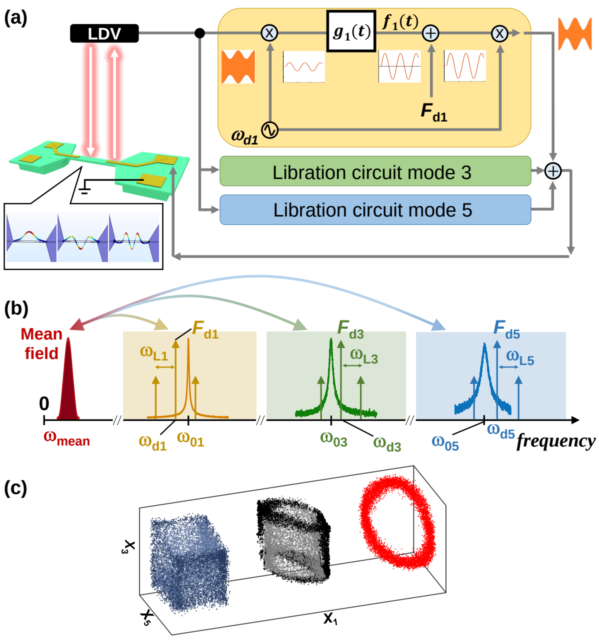

Figure 1: (a) Synchronous feedback loop used to generate librator limit cycles. (b) Librator limit cycles are generated around the harmonic drive which due to Duffing nonlinearity generates a low frequency mean field. (c) demonstration of the unsynchronized (left), partially synchronized (center), and fully synchronized (right) states.

systems beyond MEMS devices, such as optical resonators and microwave cavities.

Keywords - MEMS, Kuramoto, oscillator synchronization

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Estimating connectivity strength via time scales of observability

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Given two nodes of a possible network, a link can be identified by observing a correlated activity over time of the signals generated by each node. A few years ago, a method to identify links was proposed [1] that relies on the assessment of quasi-zero-delay cross-correlation between these time series. As a major development, the method, which is referred to as Cross-correlation Time scale of Observability (CTO), was shown to have an apparent, power-law relationship with mutual information (MI) [2]. The relationship is theoretically upheld by a model in which delta-like signals are superimposed to white noise, thus providing a solid base to CTO. The core element of the method is the identification of a link according to the significance of the linear cross-correlation coefficient between the two original signals, assessed via generation of surrogate time series thereof. In this talk, we report on a development of the method in which the linear cross-correlation coefficient is replaced with a measure based on symbolic representation. As a major consequence, the method, which was devised to work in a neuroscience context [3]–[5] on time series corresponding to positive, power signals, is deemed to become applicable to any kind of signal, for example field amplitudes.

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Across neurons and silicon: some ideas about the relationship between unusual electronic circuits and neuroscience

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What makes the brain unique, and what exactly is unique about it from a physical perspective, after all? I will try to approach these questions by first highlighting two aspects. One, the profound differences with respect to present-day computers, and engineered systems in general. Two, how Nature has leveraged, to construct brains, some phenomena that are actually universal, pervasive in other systems, and thus possible to replicate electronically at some level. I will discuss how similar emergent behaviors can be observed across rather diverse systems, and how comparing brain activity to some rather unusual electronic circuits could be inspiring, both for neurophysiology and for electronic engineering. I will briefly overview my recent research attempting to "summarize" in simple electronic circuits, mainly so-called chaotic oscillators, some phenomena arising in other biological and physical scenarios, especially in brain dynamics. Firstly, a gallery of these rather unusual circuits will be walked through, surveying some oscillators based on individual transistors and other electronic components. Secondly, simple networks of these circuits will be considered, demonstrating the spontaneous emergence of phenomena commonly observed in neural recordings, such as community structures, remote interdependences, and so on. Thirdly, some applications will be discussed, comprising the creation of physical instead of simulated in-silico disease models, bio-inspired pattern generation, and engineering applications such as in distributed sensing. While by no means a comprehensive introduction to this young multidisciplinary field, this presentation should hopefully provide some ideas regarding how engineering and neuroscience can mutually inspire each other.

Quantum information transfer with high fidelity using entangled states between connected microtoroidal cavities.

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The emerging field of optical microresonators includes research and development of individual and coupled planar and essentially three-dimensional microresonators devices. Toroidal microcavities with a high-quality factor (10 8) has allowed the construction of arrays for sensing with multiple functions, as well as opening the possibility of its use as repeaters for quantum communication. In the case of quantum information transfer, there is the possibility of transferring entangled quantum states with high fidelity, where the repetition of a state generated in one of the nodes can be transferred between the elements of the array. In this presentation we explore the generation and transfer of entangled states between coupled microtoroidal cavities for different types of couplings. Such cavities support two counter-propagating whispering-gallery modes (WGMs) that are coupled to each other. The generation and transfer of entangled states was analyzed for three types of couplings: via bridge qubit, evanescent fields, and optical fiber. For each of these proposals, we discuss the generation of entanglement associated with different initial states of the system. In the case of coupling via a bridge qubit, we show that it is possible to transfer, with high fidelity, a maximally entangled state between the two modes of the first cavity to the two modes of the second cavity via the qubit. An interesting result regarding the generation of entangled states between the two WGMs of distinct cavities and qubit-field mode is the strong dependence on both the interaction between the intracavity modes and the initial state of the system. In the case of couplings via evanescent fields and optical fiber, it is possible to select entangled states between the propagating and counterpropagating modes of distinct cavities through the interaction between the intracavity modes. Furthermore, unlike the coupling via a bridge qubit, the transfer of entangled states between cavities is independent of the interaction between intracavity modes. Finally, dissipative effects were also considered.

Minimal universal laser model is analogous to a memristor

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In 1971, more than half a century ago, Leon Chua postulated the existence of a missing circuit element [2] by considering the three basic building blocks of an electric circuit: the capacitor, the resistor, and the inductor, as well as the three laws linking the four fundamental circuit variables, namely, the electric current i, the voltage v, the charge q, and the magnetic flux φ. Using logical deduction, he concluded that it is necessary, for the sake of completeness, to postulate the existence of a fourth circuit element, which he named the *memristor*, since it behaves like a nonlinear resistor with memory. On April 30th, 2008, the journal *Nature* announced that the missing circuit element, postulated thirty-seven years earlier by Leon Chua, had been built in HP Labs [11, 13]. Since then, a "hunt for *memristor* devices" has started. In 2013, Ginoux and Rossetto [5] showed that the singing arc, a forerunner device used in Wireless Telegraphy, was probably the very first *memristor*, as well as the neon tube and the triode both used by Van der Pol [12]. In 2018, Ginoux et al. [7] established that the Uni Junction Transistor was also a *memristor*. Three years ago, Ginoux et al. proved that the Two Stroke Relaxation Oscillator was a *memristor*, a result that could be generalized to a whole class of relaxation oscillators [8]. Due to the fact that the singing arc, the neon tube, and the minimal universal laser model can be considered as plasma, and since both the neon tube and triode have been proven to be *memristor*s, the question arose whether the minimal universal laser model was also a *memristor*. Using such analogy and starting from the minimal universal laser model [1, 10] and the seminal works of Chua [2-4, 9], we derived from such a model a reduced two-dimensional minimal universal laser model involving two variables X and y. By considering that the variations of the population inversion y are induced by the voltage modulation and that X is used for modeling the intensity variations, we obtained a set of equations for the corresponding generic *memristor* from which we deduced its memristance $M(q)$. We then plotted loci of $(i(t); v(t))$ in the $v - i$ plane and obtained a pinched hysteresis loop, which is the fingerprint of memristive devices. This leads us to conclude that the minimal universal laser model is also analogous to a *memristor*.

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Optomechanical Parametric Oscillations in PhoXonic Cavities: Applications in Flow Cytometry

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We report on the experimental and theoretical analysis of optomechanical parametric oscillations in hollow spherical phoxonic whispering gallery mode resonators due to radiation pressure and stimulated Brillouin scattering. The optically excited acoustic eigenmodes of the phoxonic cavity act as efficient ultrasound sensors and miniaturized flow cytometers.

Keywords—whispering gallery modes; nonlinear optics; optomechanics; parametric interactions

Microbubble resonators (MBR) are micro-sized optical resonators belonging to the Whispering Gallery mode (WGM) family. In analogy with other WGM resonators, MBRs are realized to show high quality factors, high finesse, and little modal volumes. MBRs can sustain photon and phonon interactions and act as dual photonic-phononic or phoxonic cavities.

We will report the results obtained using MBRs as optical sensors for the characterization of photoacoustic (PA) contrast agents and then as micro-cavities for the collection of emission from single-photon sources (SPS).

The first application focuses on two experiments aimed at implementing the MBR as an all-optical transducer for the characterization of photoacoustic (PA) contrast agents. In both experiments, the MBR plays the double role of vial containing the PA agent and of optical sensor, allowing to reach ultracompact configurations with an active volume below 100 nl.

More specifically, in the first experiment the MBR resonances are used to sense the ultrasound wave produced by the PA contrast agent and deduce its photostability curve. To challenge the system, this measurement is performed in a static [1] and in a flow-cytometry configuration [2], showing that in both cases the photostability curve is measurable.

In prospective, the miniaturization of the MBR promises better performance and the mechanical spectrum, which has an important role in the sensing mechanism, could be exploited through positive interference or lock-in amplification. In addition to the characterization of PA contrast agents, the system could be implemented in the analysis of flowing sample. MBRs can also perform a measurement of the contrast agent absorption spectrum. In this case, the MBR reconstructs the agent absorption spectrum by detecting the temperature increase produced by the optical absorption. In practice, this temperature increase is detected by reading the shift of a WGM resonance, effectively implementing the MBR as a thermo-optical sensor [3].

The second study focuses on the implementation of an MBR as a micro-cavity for highly efficient Brillouin lasers and the potential as mass sensors.

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Random encryption process in optical fiber link

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We have presented a novel way to encrypt a ciphertext. In this work, a 1x2 controllable optical switch is utilized in the link. A 2x1 optical fiber switch is a device used in fiber optic networks to control the path of optical signals. It has two input ports and one output port, allowing it to switch between two different optical signals and direct one of them to a single output.
We encrypt streams of data nonlinearly. Then, the encrypted information (data) is transmitted through one port of the input. The encrypted data is combined with random binary pulses. The coupler has been randomly controlled by feeding it a chaotic signal.
Chaos was generated using an electro-optical feedback method, and the state of chaos can be altered by changing the influencing factors. In this way, the transmitted data was doubly encrypted.
The transmission rate of the data was 1 M/s.

Useful Information

Talks will be held at the **GGI – Galileo Galilei Institute for Theoretical Physics**, Largo Enrico Fermi, 2, 50125 Firenze FI, Italia. Website: www.ggi.infn.it

The **social dinner** will take place at **Villa Galileo**, via Pian dei Giullari, 42, Firenze FI, Italia. The house where Galileo Galilei spent the last part of his life. Website: https://www.sma.unifi.it/p474.html