Synergies between Dynamics, Control, Machine Learning, and Artificial Intelligence

The interaction between dynamics, control, machine learning, and artificial intelligence is transforming applied sciences, expanding boundaries, and creating new approaches for tackling complex, multidisciplinary problems. The emergence of machine learning and AI techniques, when combined with classical tools of dynamics and control, has enabled innovative solutions in areas such as transportation systems, healthcare, robotics, and large-scale data analysis. This mini-symposium aims to explore how these technologies intersect by addressing the development of new methodologies for modeling, control, and prediction of complex systems, as well as the challenges of adapting and implementing them in real-world environments. Case studies and practical applications that illustrate the profound impact of these tools will be presented, alongside discussions of the theoretical and computational advances necessary for their evolution.

Organizadores:

Americo Cunha Jr (LNCC / UERJ),
Valeriano Antunes de Oliveira (UNESP),
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Programação resumida

1º bloco

Optimal Control Under Parameter Uncertainty

Maria Soledad Arona (EMAp / Fundação Getúlio Vargas)

Synchronization and Graph Structure

Elbert E. N. Macau (Universidade Federal de São Paulo)

Machine Learning Aided Time-correlated Closures of Turbulence Models

Julia Domingues Lemos (École Normale Supérieure de Lyon)

Long-time Dynamics of Water-wave Models

Roberto de Almeida Capistrano Filho (Universidade Federal de Pernambuco)

2º bloco

Control of Antiretroviral Treatment for HIV-Positive Individuals via Computational Intelligence
Rosana Sueli da Motta Jafelice (Universidade Federal de Uberlândia)

Possibilities of Deep Learning in Medical Imaging
Apresentador: Vinícius de Carvalho Rispoli (Universidade deBrasília)

CAR-T Cell Immunotherapy: Indication of Clinical Markers via Mathematical Modeling
Emanuelle Arantes Paixão (Laboratório Nacional de Computação Científica)

Surrogates as Versatile Tools in Engineering Design
José Hugo Elsas (Laboratório Nacional de Computação Científica)

Optimal Control Under Parameter Uncertainty

Maria Soledad Arona
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Our research focuses on optimal control problems with parameter uncertainty, which involve optimizing systems governed by families of controlled ordinary differential equations. These equations are parameterized on a probability space representing the range of possible parameter values. We develop necessary optimality conditions and numerical algorithms tailored to this problem class. We show applications in fishery management and optimal search strategies, demonstrating the applicability of our methods in real-world scenarios.

Synchronization and Graph Structure

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Synchronization is an ubiquitous phenomenon in nature, present even in various processes that are fundamental to life, such as neuronal activities. Inspired by nature, solutions for numerous technological challenges have been built upon synchronization processes. Surprisingly, synchronization can occur even with extremely low coupling strength between oscillators. In fact, this phenomenon can arise in scenarios involving an exceedingly large number of oscillators. In such cases, the connection structure among them—which can be represented using graph formalism—plays a fundamental role in enabling synchronization. This work explores the relationship between classes of graph structures and synchronization, presenting general conditions under which the phenomenon is expected to occur. Based on the results, it identifies so-called “minimal” structures for which synchronization is a generic condition for broad classes of oscillators.

Machine Learning Aided Time-correlated Closures of Turbulence Models

Julia Domingues Lemos
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Even though turbulent fluid motion has been the subject of decades of active research, it still lacks an analytic description. Practical applications often require some level of modelling of small scales of motion, which we approach here in the form of a closure problem for a turbulence model. We aim to build a theoretically solid closure for the Sabra model, based on a dynamical rescaling of velocity fluctuations with the aid of machine learning tools. The rescaling will provide us with universal statistics, while a suitable machine learning tool will allow us to learn such statistics from data. This approach allows us to reproduce statistics of the fully resolved model, while including important information about the dynamics of and energy dissipation happening at small scales.

Long-time Dynamics of Water-wave Models

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Water-wave models play a crucial role in understanding, predicting, and controlling the dynamics of surface water waves across various real-world scenarios, including oceanic waves, waves in lakes and rivers, and those affecting man-made structures. These models integrate mathematical, physical, and numerical frameworks with wide-ranging applications in environmental science, engineering, and maritime industries. In this talk, we will explore key mathematical results for several water-wave models, highlighting their relevance to real-world applications.

Control of Antiretroviral Treatment for HIV-Positive Individuals via Computational Intelligence

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The combination of a classical system of ordinary differential equations (ODEs), which models the bloodstream dynamics of HIV-positive individuals, with parameters obtained through a type 2 interval Fuzzy Rule-Based System (FRBS) employing restricted interval arithmetic to represent antiretroviral treatment, can yield promising results. The input variables for the FRBS are treatment adherence and drug potency—both critical factors in the management of HIV-positive patients. The infection rate of CD4+ T lymphocytes by HIV and the virus production rate serve as output variables of this type 2 interval FRBS. CD4+ T lymphocytes are the primary cells targeted by HIV upon entering the bloodstream. Thus, the numerical solutions of the ODE system provide time-dependent ranges for uninfected and infected CD4+ T lymphocytes, free virus particles, and virus-specific cytotoxic T lymphocytes (CTLs) that attack infected cells. First and foremost, it is emphasized that studying the type 2 interval FRBS yields more informative and robust results. Moreover, by employing restricted interval arithmetic, one obtains, at each moment in time, intervals for uninfected and infected CD4+ T lymphocytes, free virus particles, and CTLs, contingent upon treatment adherence and drug potency. This information can play a crucial role in persuading HIV-positive individuals to adhere properly to antiretroviral treatment.

Possibilities of Deep Learning in Medical Imaging

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Deep learning also stands out in the field of medical imaging, offering a wide range of applications. In this context, this lecture will address some of the contributions of this technology to the area. It will discuss the challenges of image segmentation and classification, as well as their significance in diagnosis and treatment. The use of generative networks will be explored and highlighted in two contexts: data augmentation and compressive sensing, demonstrating how a priori information can accelerate the reconstruction of medical images. Additionally, physics-informed neural networks can be applied in medical imaging, as they enable the simulation of cardiac flow based on images. Finally, the potential of language models in supporting automated diagnosis will be discussed, integrating images with other medical tests and opening new frontiers for AI-assisted medical practice.

CAR-T Cell Immunotherapy: Indication of Clinical Markers via Mathematical Modeling

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Mathematical and computational modeling can significantly aid in improving cancer treatments and clarifying various challenges in the field. CAR-T cell immunotherapy is a treatment that enhances the patient's own immune system, achieving remarkable success, particularly against blood cancers. Despite high remission rates, long-term disease recurrence remains frequently documented in the literature and is a major concern. In this context, research into clinical markers—parameters that enable the classification of distinct response groups to therapy and even predictive insights—stands out. In this work, we developed an online platform for calibrating a mathematical model that simulates CAR-T cell

Surrogates as Versatile Tools in Engineering Design

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Designing sophisticated engineering projects is challenging, not least because they usually require a large number of physics simulations—both to cover different boundary conditions and to explore various possible designs. Machine learning models have demonstrated the potential to circumvent some of these challenges by employing surrogate models that replace a portion of the simulations to be executed, using previously run simulations as training data. In this presentation, I will showcase two applications in the marine engineering domain of oil and gas risers: Bayesian Optimization for Riser Designs, and Optimal Execution of a Portfolio of Simulations using Active Learning. In both cases, surrogate models are used to predict the outcomes of finite element simulations that have not yet been performed— in the first instance as a function of parameters defining the riser's geometry, and in the second by defining the boundary conditions of a riser with fixed geometry. We demonstrate the practical benefits that this approach has brought to practitioners in market contexts, as well as potential avenues for further developments in the future. This approach not only slashes computational overhead but also paves the way for more agile, real-time design iterations. It represents a bold step forward in engineering innovation, where embracing data-driven methods can revolutionize traditional simulation workflows and unlock new possibilities in complex system design.