SIAM 2025

Searchable Abstracts Document

SIAM Conference on Control and Its Applications (CT25)

July 28–30, 2025

Montréal Convention Center, Montréal, Québec, Canada

This document was current as of July 15, 2025. Abstracts appear as submitted.

SIAM
3600 Market Street, 6th Floor
Philadelphia, PA 19104-2688 U.S.
Telephone: 800-447-7426 (U.S. & Canada) +1-215-382-9800 (Worldwide)
meetings@siam.org

IP1

Mean Field Control and Games on Large Networks

Contemporary technological systems often have a network structure of both great scale and complexity; examples are provided by the internet, electrical power grids and air traffic systems. Furthermore, the natural world reveals a vast array of networks of great complexity such as microbiome networks, foodwebs and the human brain with its approximately 86 billion neurons and 100 trillion connections. These networks support dynamical processes, often with feedback loops which are inherent, designed or a combination of both. The challenges provided by artificial and natural network systems include the analysis of network growth and decay, state process predication, centralized and multi-agent stabilization and optimization, and the design of oscillatory behaviours. This talk will present contemporary formulations of large population dynamic processes on networks in terms of Optimal Stochastic Control and Mean Field Games on graphon and graphexon graph limits. The results will include the existence and uniqueness of optima and equilibria for large populations on sparse and dense limit networks, their approximation to finite populations problems on finite networks, and the notion of Nash locations.

Peter E. Caines
McGill University
peterc@cim.mcgill.ca

IP2

Controlability and Stabilization of the Beam Equation with Piezoelectric Actuators in Presence of Saturation and Hysteresis

This presentation deals with the general problem of nonlinear control of distributed parameter systems. More specifically a flexible beam equipped with a piezoelectric actuator in the self-sensing configuration is considered. The model is composed by a partial differential equation, describing the deformation dynamics, interconnected with an ordinary differential equation describing the electric charge dynamics. Firstly, the exact controllability problem is solved with various sets of initial conditions. Then the well-posedness of the linear model is stated, together with its global asymptotic stability, when a voltage control law, containing terms of the self-sensing configuration, is applied. Finally, the more realistic assumption of the presence of hysteresis in the electrical domain is introduced. Applying a passive control law, the well-posedness and the global asymptotic stability of the nonlinear closed-loop system are established.

Christophe Prieur
CNRS, Université Grenoble Alpes, France
christophe.prieur@gipsa-lab.fr

IP3

Deep Learning Meets System Theory: A Collaborative Frontier in Control Engineering and Data Science

Deep neural networks (DNNs) have been explored in control systems for decades, but recent research at the intersection of deep learning and control theory has gained significant momentum. Deep learning addresses many longstanding challenges in control, such as the curse of dimensionality, while system and control theory enhances the effectiveness and explainability of learning methods. This talk focuses on DNN applications in data assimilation (DA) and optimal feedback control. DA integrates observations with models to estimate system states, often involving high-dimensional nonlinear systems with chaotic or shock-wave behaviors. For these cases, DNN offers significant advantages over conventional DA algorithms. Moreover, the concept of observability in control theory provides a means to assess whether the data used in training DNN contains sufficient information for accurate estimation. In optimal feedback control, solving the Hamilton-Jacobi-Bellman equation is computationally prohibitive in high dimensions. Yet, deep learning has demonstrated success in tackling such problems. Additionally, the Pontryagin Maximum Principle serves a dual role: it not only provides data for training deep neural networks but also offers valuable insights for adaptively generating additional data in regions where it is most needed.

Wei Kang
Naval Postgraduate School
wkang@nps.edu

SP1

Activity Group on Control and Systems Theory Best SICON Paper Prize Lecture #1 - Learning Stationary Nash Equilibrium Policies in N-Player Stochastic Games with Independent Chains

We consider a subclass of N-player stochastic games, in which players have their own internal state and action spaces while they are coupled through their payoff functions. It is assumed that players' internal chains are driven by independent transition probabilities. Moreover, players can receive only realizations of their payoffs, not the actual functions, and cannot observe each others' states and actions. For this class of stochastic games, we first show that finding a stationary Nash equilibrium (NE) policy without any assumption on the reward functions is intractable. However, for general reward functions, we develop polynomial-time learning algorithms based on dual averaging and dual mirror descent, which converge in terms of the averaged Nikaido-Isoda distance to the set of ϵ-NE policies almost surely or in expectation. In particular, under extra assumptions on the reward functions such as social concavity, we derive polynomial upper bounds on the number of iterates to achieve an ϵ-NE policy with high probability. Finally, we evaluate the effectiveness of the proposed algorithms in learning ϵ-NE policies using numerical experiments for energy management in smart grids.

Rasoul Etesami
urbana
etesami1@illinois.edu

SP2

Activity Group on Control and Systems Theory Best SICON Paper Prize Lecture #2 - Integer Optimal Control with Total Variation Regularization

We consider optimal control problems with integer-valued control inputs and a total variation regularization term in the objective so that the feasible set is weakly-* sequentially closed in the space of functions of bounded variation. We derive first-order optimality conditions of the optimal control problem as well as trust-region subproblems with partially linearized model functions using local variations of the level sets of the feasible control functions. We also prove that a function space trust-region algorithm produces sequences of iterates whose limits are first-order optimal points. We show how the arising (sub)problems may be discretized and approximated correctly and give an outlook on a domain decomposition technique that can accelerate the solution process.

Paul Manns
Mathematik
TU Dortmund
paul.manns@tu-dortmund.de

Annika Schiemann
TU Dortmund
manns, paul ¡paul.manns@tu-dortmund.de¿

SP3

Activity Group on Control and Systems Theory Prize Lecture - Bridging Physics and Data: Kernel-based Modelling of Positive Dynamical Systems

The process of estimating models from data, known as system identification, has a rich history in systems and control. The traditional approach starts with a class of finite-dimensional parametric models and formulates system identification as parameter estimation in this class. More recently, inspired by developments in machine learning, a new nonparametric approach has emerged. This approach leverages the theory of reproducing kernel Hilbert spaces (RKHSs) and formulates system identification as function/operator estimation in a suitably chosen RKHS. At the core of this approach is the celebrated representer theorem, which reduces a typically infinite-dimensional optimisation problem to a tractable finite-dimensional one. A major challenge in system identification is the incorporation of prior knowledge of the physical properties of the real system, such as stability, positivity, and dissipativity. Incorporating such knowledge enhances the reliability and robustness of the estimated model by ensuring that simulated behaviour aligns with real-world behaviour. In this talk, we show how certain positivity properties can be incorporated into an RKHS framework and address the challenge of estimating models that satisfy these properties. To this end, we derive new representer theorems for optimisation over positive operators/functions, thus rendering the corresponding problems tractable. This prize lecture will be presented by Brayan Shali, Katholieke Universiteit Leuven, Belgium, behalf of Henk van Waarde, University of Groningen, Netherlands.

Henk van Waarde
University of Groningen
h.j.van.waarde@rug.nl

Brayan Shali
Katholieke Universiteit Leuven, Belgium
brayan.shali@kuleuven.be

JP1

Joint Plenary Speaker with the SIAM/CAIMS Annual Meetings (AN25): Stackelberg Strategies for the Control of Partial Differential Equations

In this talk, we will present a Stackelberg strategy to control PDEs. We will act on the system with two controls: one as a leader and the other as a follower. We will discuss the different problems as the main objective is null controllability, and the follower is optimization. As an example, we present some existing results for the heat equation (See Lions, J.-L.: Some remarks on Stackelbergs optimization. Math. Models Methods Appl. Sci. 4(4), 477487 (1994), Araruna, F.D., Fernndez-Cara, E., da Silva, L.C.: Hierarchic control for the wave equation. J. Optim. Theory Appl. 178(1), 264288 (2018), Araruna, F.D., Fernndez-Cara, E., Guerrero, S., Santos, M.C.: New results on the StackelbergNash exact control of linear parabolic equations. Syst. Control Lett. 104, 7885 (2017)) and a result for the Boussinesq system (T. Takahashi, L. de Teresa, Y. Wu-Zhang, Stackelberg exact controllability for the Boussinesq system, Nonlinear Differ. Equ. Appl. (2024) 36 pp.). Then, we will present a result inverting the objectives of the leader and the follower for the heat equation (Calsavara, B.M.R., Fernndez-Cara, E., de Teresa, L., Villa, J.: New results concerning the hierarchical control of linear and semilinear parabolic equations. ESAIM Control Optim. Calc. Var. 28, 1426 (2022)). The leader will have an optimization target, and the follower will have a null controllability one. We briefly discuss a similar problem but for a wave equation (L. de Teresa, and J.-A. Villa A new hierarchical control for the wave equation, Wave Motion 134 (2025) 9 pp.)

Luz de Teresa
Universidad Nacional Autónoma de México, Mexico
ldeteresa@im.unam.mx

CP1

Feedback Control of Thin Liquid Films Falling Down Inclined Planes

We outline methods to control a thin liquid film falling down an inclined plane towards an unstable flat solution by injecting or removing fluid from the base. The two-phase Navier-Stokes equations that govern the dynamics of a falling liquid film pose a challenging control problem: it is an infinite-dimensional, nonlinear system with complex boundary conditions, and we are limited to a finite-dimensional boundary control. By using a hierarchy of successively simplifying assumptions, we show that a linear quadratic regulator (LQR) control can be used to stabilize the otherwise unstable flat (or Nusselt) solution. We demonstrate that applying the LQR controls to the Navier-Stokes problem is successful well outside the parameter regime that the simplified models are designed for, and also in cases where observations of the system are restricted.

Oscar Holroyd, Radu Cimpeanu, Susana Gomes
University of Warwick
o.holroyd@warwick.ac.uk, radu.cimpeanu@warwick.ac.uk, susana.gomes@warwick.ac.uk

CP1

Bilinear Optimal Control of a Non-Smooth Semilinear Elliptic Equation

This work addresses a bilinear control problem involving both pointwise constraints on the control variable and a non-smooth term in the cost functional. The state equation is defined by a non-smooth semilinear elliptic partial differential equation. We provide a comprehensive analysis of this optimal control problem, including regularity properties of the state equation and the existence of optimal solutions. To tackle the challenges posed by the non-smooth nature of the control problem, we introduce a regularization technique that allows us to establish first-order optimality conditions via an adjoint system. A limit analysis is performed to derive a system of C-stationary type. Finally, we discuss strong stationarity conditions under a "Constraint Qualification' assumption.

Cyrille Kenne

University of British Columbia
kenne@math.ubc.ca

CP1

Sparse Spectral Methods for Approximating PDE Solutions in Particle Flow

In sequential Monte Carlo, a method for performing the Bayesian computation *prior* × *likelihood* is to derive the law of motion of a particle ensemble: a particle flow. This enables sampling from complex distributions while avoiding issues such as particle degeneracy and the need for resampling. However, some particle-flow implementations require solving a partial differential equation (PDE) whose coefficients depend on the density of particles. The solution to this PDE must typically be approximated as analytical solutions are limited to specific cases. Traditionally, spectral methods for approximating the solution are based on the tensor product formulation in which the solution is represented as a weighted sum of products of univariate basis functions. Using N_B bases per coordinate of the N_X-dimensional domain leads to $(N_B)^{N_X}$ unknowns. Thus, even for problems of moderate dimensionality, current computational resources are insufficient to support the full tensor-product grid necessary for an accurate approximation. In this work, we propose an approximation based on a sparse grid/hyperbolic cross technique to solve the PDE in more general settings. The solution is approximated with multivariate polynomial bases whose span is dense in the space of solutions under mild assumptions on the underlying distribution. We show the accuracy of our technique for sampling from Gaussian and non-Gaussian distributions.

Augusto Magalhães
Department of Chemical and Metallurgical Engineering
Aalto University
augusto.magalhaes@aalto.fi

Muhammad Emzir
King Fahd University of Petroleum and Minerals
muhammad.emzir@kfupm.edu.sa

Francesco Corona
Aalto University
francesco.corona@aalto.fi

CP1

Convergence Analysis of Nonlinear Parabolic PDE Models with Neural Network Terms Trained with Gradient Descent

Many engineering and scientific fields have recently become interested in modeling terms in partial differential equations (PDEs) with neural networks (NNs). The resulting PDE model, a function of the NN parameters, can be calibrated to available data by optimizing over the PDE using gradient descent, where the gradient is evaluated by solving an adjoint PDE. In this talk, we discuss the convergence of this adjoint optimization method for training NN-PDE models in the limit where both the number of hidden units and the number of training steps tend to infinity. Specifically, for a general class of nonlinear parabolic PDEs, we prove convergence of the NN-PDE solution to the target data (i.e., a global minimizer). The global convergence proof requires addressing several technical challenges, since the PDE system is both nonlinear and non-local. Although the adjoint PDE is linear, the NN training dynamics involve a non-local kernel operator in the infinite-width hidden layer limit, where the kernel lacks a spectral gap for its eigenvalues. This poses a unique mathematical challenge that is not encountered in finite-dimensional NN convergence analysis. We establish convergence by proving that an appropriate quadratic functional of the adjoint is globally Lipschitz and then applying a cycle of stopping times analysis to prove that the adjoint solution weakly converges to zero. Leveraging the definition of the adjoint PDE, this yields the global convergence of the original NN-PDE.

Konstantin Riedl
Technical University of Munich
Konstantin.Riedl@maths.ox.ac.uk

Justin Sirignano
Mathematics, University of Oxford
justin.sirignano@maths.ox.ac.uk

Konstantinos Spiliopoulos
Boston University
Department of Mathematics and Statistics
kspiliop@bu.edu

CP2

A Linear Test for Nonlinear Controllability Using Sub-Laplacians

In this talk, I will present an application of Sub-Laplacian operator associated with a driftless control affine system. I will show how invertibility of the sub-Laplacian operator implies a weaker form of controllability of the control system, where the reachable sets of a neighborhood of a point have full measure. From a computational point of view, one can then use the spectral gap of the (infinite-dimensional) self-adjoint operator to define a notion of degree of controllability. I will briefly discuss how the result can be proved using two different dual perspectives, using ideas from optimal transport theory and the Koopman formalism.

Karthik Elamvazhuthi
University of California, Riverside
karthikevaz@lanl.gov

CP2

Carleman Estimates for a Timoshenko Beam and Application to Inverse Problems

We consider a Timoshenko system, consisting in two coupled hyperbolic equations, modelling the transverse vibrations of a beam of length L throughout a time T. Our goal is to establish a Carleman estimate, with observations taken either from the right endpoint L or from (a,b) a subinterval of (0,L), for the Timoshenko system with Dirichlet-Dirichlet boundary conditions type. To prove this result, we transformed the Timoshenko system into a system of two wave equations. Then we established Carleman estimates for a wave equation with homogeneous Dirichlet conditions in the boundary and interior cases. Finally, we applied these inequalities to the Timoshenko system. Afterwards, we exploit our main result to solve inverse problems consisting of determining unknown coefficients or source terms of a Timoshenko system with Dirichlet-Dirichlet boundary conditions, using either boundary or interior observations. To do so, in the case of source terms, we derive, from the Carleman estimates we have established, observability estimates ensuring the uniqueness of the solution and the stability of the problems. To solve the inverse coefficient problems we reformulate them into inverse source problems and then we follow the previous method. These results obtained complement those of the present literature where the Timoshenko system is considered without potential terms and the unknown terms in the inverse problems are determined using another technique than the Carleman estimates one.

Thomas NANCY
Université des Antilles
tjnancy@outlook.fr

Louis TEBOU
Florida International University
tebou@fiu.edu

Carole Louis-Rose
Université des Antilles
carole.louis-rose@univ-antilles.fr

CP2

Stabilization of the Schrdinger Equation Through Boundary Interaction with a Heat Equation

We consider the Schrdinger equation coupled at the interface with a heat equation. The dissipative damping is introduced solely through the boundary connections by the heat equation. We formulate the coupled system as an abstract evolution equation in an appropriate Hilbert space and use linear semigroup theory to establish its well-posedness. Then, under certain assumptions on the geometry of the spatial domain, we prove the exponential stability of the solution. The proof relies on a frequency domain approach, which consists in verifying that the imaginary axis is contained in the resolvent set of the system and analyzing the behavior of the resolvent operator on the imaginary axis. This resolvent analysis is carried out using a contradiction argument combined with the multipliers technique.

Salah-Eddine Rebiai, Fatima Zohra Sidiali, Nedjma Mekseh
University of Batna 2
s.rebiai@univ-batna2.dz, f.sidiali@univ-batna2.dz, nmekseh@gmail.com

CP2

Finite-Approximate Controllability for Partial Neutral Functional Evolution Equations

In this article, we introduce the concepts of finite-approximate controllability in the framework of semilinear neutral functional differential equations, focusing on first-order systems within a separable Hilbert space. We establish sufficient conditions for achieving finite-approximate controllability of the semilinear neutral functional differential equation by demonstrating that if the linear part of the system is approximately controllable, then under suitable conditions, the nonlinear part is also finite- approximately controllable. Our approach relies on fixed-point techniques to derive these results. Finally, we provide an example to show the applicability of our theoretical results.

Akhilesh Verma, Jaydev Dabas
Indian Institute of Technology Roorkee
a_verma@as.iitr.ac.in, jay.dabas@gmail.com

CP3

Sliding Mode Attitude Maneuver of Spacecraft with Consideration of Singularity Avoidance of Control Moment Gyros

To maintain and maneuver the attitude of large satellites representative of international space stations, and for small satellites requiring agile and large-angle attitude maneuvers, actuators are required that can provide high torque output. To solve this problem, a control moment gyro (CMG) is used, which is capable of generating a higher torque than a reaction wheel (RW), which is conventionally used for attitude control. However, there are combinations of gimbal angles in CMG systems, called singularities, where torque cannot be output in a particular axis direction. The objective of this study is to construct an attitude control system for spacecraft that takes into account the singularity avoidance of CMGs. The effectiveness of proposed method is verified by the numerical simulation.

Yuichi Ikeda
Shonan Institute of Technology
ikeda@mech.shonan-it.ac.jp

CP3

Degradation-Aware Optimal Control Operating for Mini-Grids: A Two-Time Scale Approach

A mini-grid is a small-scale power system that distributes energy locally, providing a reliable and cost-effective solution in areas where extending the main grid is impractical. Operation of these systems requires balancing energy distribution with long-term battery health. To address this, we formulate a degradation-aware optimal control problem that involves dynamics evolving on different time scales: state-of-charge and battery temperature change within hours or minutes, while state-of-health, influenced by these quantities, degrades over years. A two-time scale averaging approach is employed to develop an efficient optimization algorithm. Finally, numerical results demonstrate the effectiveness of the proposed method.

Nina Kliche, Dietmar Hoemberg
Weierstrass Institute for Applied Analysis and Stochastics
kliche@wias-berlin.de, hoemberg@wias-berlin.de

CP3

On Temperature-Dependent Inverse Parameter Identification Problems in Piezoelectricity

Piezoelectric materials are a fundamental component in various electronic devices, ranging from everyday items such as headphones and toothbrushes to advanced medical and industrial applications such as ultrasound imaging and diesel fuel injection. A thorough understanding of the behaviour of these materials, described by a coupled PDE system for mechanical displacement and electrical potential, is essential, especially given their temperature-dependent properties. As manufacturers' material data often deviates considerably from the actual material data, yet many applications require high precision, a consistent and reproducible characterisation of the temperature-dependent material parameter set is crucial. Therefore, we address the problem of identifying the temperature-dependent parameters of a piezoelectric PDE system based on measured or simulated data, respectively. Therein, the underlying PDE system is discussed and the forward operator of the inverse problem is analysed using a classical reduced approach. Furthermore, we propose adapted optimisation and regularisation procedures based on modified regularised Newton-type methods. Finally, we linearise the inverse problem by discretising the temperature domain

and provide numerical results.

Raphael Kuess, Andrea Walther
Humboldt-Universität zu Berlin
raphael.kuess@hu-berlin.de, andrea.walther@hu-berlin.de

CP3

Shape Optimization of Green Spaces for Reduce Urban Heat Island Effect in Urban Environments

Urban heat islands (UHI) have become a major problem for rural areas as a consequence of urbanization and industrialization. It concerns urbanized area where temperatures are higher than in surrounding areas. To reduce this effect, the implantation (and design) of green spaces in dense cities is a pertinent solution. In this work, we use the optimal control techniques to find the optimal shape of green spaces for mitigating UHI Effect, especially, the thermal effect. We consider city a porous media system and the transport mechanism of fluid (wind) in the cities is governed by the Navier-Stockes-Forchheimer porous media. It is actually based on non-stationary turbulent fluid dynamics coupled with heat equation considering building/soil radiation effects. We compute two-dimensional direct numerical simulation. We show the results for temperature and velocity fields. This work presents the governing equations, the control optimal algorithm and discusses the results of the predictions of the flow problems constituting the initial validation space of the model.

Houari Mechkour
Ecole Centrale dElectronique (ECE-Paris)
houari.mechkour@ece.fr

Waleed Mouhali
ECE
waleed.mouhali@ece.fr

Mohammed Louaked
Caen University
mohammed.louaked@unicaen.fr

Nacer sellila
Université Gustave Eiffel
sellila.nacer@gmail.com

CP4

Control-Based Conditions for Graph Distinguishability

The graph distinguishability problem investigates whether a graph can be uniquely identified by the spectrum of its adjacency matrix, specifically determining if two graphs with the same spectrum are isomorphic. This issue is central to spectral graph theory and has significant implications for graph machine learning. In this paper, we explore the intricate connections between graph distinguishability and graph controllability–an essential concept in the control of networked systems. Focusing on oriented graphs and their skew-adjacency matrices, we establish controllability-based conditions that ensure their distinguishability. Notably, our conditions are less restrictive than existing methods, enabling a broader class of graphs to satisfy the distinguishability criteria. We illustrate the effectiveness of our results with several examples. Our findings highlight the applications of network control methods in tackling this crucial problem in algebraic graph theory, with implications for machine learning and network design.

Obaid Ullah Ahmad
The University of Texas at Dallas
ObaidUllah.Ahmad@utdallas.edu

Muhammad Raza, Mudassir Shabbir
Information Technology University, Lahore, Pakistan
mraza@itu.edu.pk, mudassir.shabbir@itu.edu.pk

Xenofon Koutsoukos
Department of Electrical Engineering & Computer Science
Vanderbilt University
Xenofon.Koutsoukos@vanderbilt.edu

Waseem Abbas
University of Texas at Dallas, Richardson, TX
waseem.abbas@utdallas.edu

CP4

Automation of a Thermo-Hydraulic Industrial Process with a Wireless Networked Control System

The automation of a thermo-hydraulic industrial process as a benchmark for a Wireless Networked Control System is presented. Networked control systems are of great importance in industry and academic research to validate designs, optimize control, and demonstrate their effectiveness in various applications. This paper presents the details of an industrial temperature control experiment for modeling and networked control methods. The application takes into account actual process characteristics such as discrete sampling time, wireless communication with the process, and model mismatch. Simulations and experiments conducted with the equipment are presented. The performance of the closed-loop is measured by quantifying the error rate using a PID controller with a Kalman filter. The Kalman filter compensates for the delays and information loss introduced in the control network. The findings indicate the system's capacity to ensure stability while exhibiting a maximum percentage of information loss of 50% and an average delay of 5 seconds.

Mercedes Chacón Vásquez
UNIVERSITY OF COSTA RICA
Universidad de Costa Rica
mechechv@gmail.com

CP4

Robust Signal Decompositions on the Circle

We consider the problem of decomposing a piecewise constant function on the circle into a sum of indicator functions of closed circular disks in the plane, whose number and location are not a priori known. This represents a situation where an agent moving on the circle is able to sense its proximity to some landmarks, and the goal is to estimate the number of these landmarks and their possible locations—which can in turn enable control tasks such as motion planning and obstacle avoidance. Moreover, the exact values of the function at its discontinuities (which correspond to disk boundaries for the individual indicator functions) are not assumed to be known to the agent. We introduce suitable notions of robustness and degrees of freedom to single out those decompositions that are more desirable, or more likely, given this non-precise data collected by the agent. We provide a characterization of robust decompositions and give a procedure for generating all such

decompositions. When the given function admits a robust decomposition, we compute the number of possible robust decompositions and derive bounds for the number of decompositions maximizing the degrees of freedom. We also generalize some of the results to the setting where the path of the agent and the supports of the indicator functions are not necessarily circular. We consider some applications involving simultaneous localization and mapping (SLAM) as well as tracking of moving landmarks.

Aral Köse
Bogaziçi University
aral.kose@std.bogazici.edu.tr

Daniel Liberzon
University of Illinois Urbana-Champaign
liberzon@illinois.edu

CP4

Modeling of Rumor Propagation in Large Populations with Network Via Graphon Games

Rumors spread at lightning speed in the digital age. In this talk, we will explore how rumor (such as fake news) propagates in large populations that are interacting on a network and how different policies affect the spread. We propose a graphon game model by extending the SKIR model that is used to model rumor propagation and implementing individual controls and weighted interactions with other agents to have controlled dynamics. The agents aim to minimize their own expected costs non-cooperatively. We give the finite player game model and the limiting graphon game model to approximate the Nash equilibrium in the population. We give the graphon game Nash equilibrium as a solution to a continuum of ordinary differential equations (ODEs) and provide existence results. Finally, we give a numerical approach and analyze examples where we use piecewise constant graphon.

Huaning Liu, Gokce Dayanikli
University of Illinois Urbana-Champaign
huaning3@illinois.edu, gokced@illinois.edu

CP4

A New Non-Decomposition Approach to Study Fractional-Order Clifford-Valued Delayed Neural Networks and Its Application to Multispectral Image Encryption

This work investigates the global Mittag-Leffler (GML) projective synchronization problem for fractional-order Clifford-valued delayed neural networks (FOCLVDNNs) using novel inner product-based inequalities. Unlike traditional approaches that are based on decomposition into real-valued systems, new inequalities based on the sign function and the norm of Clifford numbers are developed to directly analyze the dynamics of FOCLVDNNs. By constructing a new general Lyapunov function, we establish synchronization criteria that encompass GML complete synchronization and GML anti-synchronization as special cases. The proposed criteria are validated through numerical simulations and graphical analysis. Furthermore, these results are applied to design a multispectral image encryption algorithm, with experimental results confirming its efficiency for secure communication applications.

Manoj N
SRM Institute of Science and Technology,
Kattankulathur, Chengalpattu, Tamil Nadu, India
c84651@srmist.edu.in

CP4

Steering Opinion Dynamics Through Control of Social Networks

This talk will introduce a novel control approach for opinion dynamics on evolving networks. The controls act to modify the strength of connections in the network, rather than influencing opinions directly, with the overall goal of steering the population towards consensus at a target opinion. This requires that the social network remains sufficiently connected, the population does not break into separate opinion clusters, and that the target opinion remains accessible. I will present several approaches to addressing these challenges, considering questions of controllability, instantaneous control and optimal control. Each of these approaches provides a different view on the complex relationship between opinion and network dynamics and raises interesting questions for future research.

Andrew Nugent, Susana Gomes, Marie-Therese Wolfram
University of Warwick
andjnugent@gmail.com, susana.gomes@warwick.ac.uk, m.wolfram@warwick.ac.uk

CP5

Optimal Control of Stochastic Convective Brinkman-Forchheimer Equations: Hamilton-Jacobi-Bellman Equations and Viscosity Solutions

In this work, we consider the following two- and three-dimensdional stochastic convective Brinkman-Forchheimer (SCBF) equations in torus $\mathbb{T}^d,\ d \in \{2,3\}$:

$$\mathrm{d}\boldsymbol{u} + \left[-\mu\Delta\boldsymbol{u} + (\boldsymbol{u}\cdot\nabla)\boldsymbol{u} + \alpha\boldsymbol{u} + \beta|\boldsymbol{u}|^{r-1}\boldsymbol{u} + \nabla p\right]\mathrm{d}t = \mathrm{dW},\ \nabla\cdot\boldsymbol{u} = 0,$$

where $\mu, \alpha, \beta > 0,\ r \in [1,\infty)$ and W is a Hilbert space valued Q−Wiener process. Using the dynamic programming approach, we study the infinite-dimensional second-order Hamilton-Jacobi (HJB) equation associated with an optimal control problem for SCBF equations. For the supercritical case, that is, $r \in [3,\infty)$, we first prove the existence of a viscosity solution for the infinite-dimensional HJB equation, which we identify with the value function of the associated control problem. By establishing a comparison principle, we prove that the value function is the unique viscosity solution and hence we resolve the global unique solvability of the HJB equation in both two and three dimensions.

Sagar Gautam
Indian Institute of Technology Roorkee - IIT Roorkee
India
sagar_g@ma.iitr.ac.in

CP5

On Inverse Problems for Stochastic Optimal Controls

The inverse problem in optimal control theory involves determining the performance index that makes a given control law optimal. Kalman (1964) first conducted a detailed analysis of this problem for the infinite-horizon linear-quadratic regulator. In this presentation, we propose an optimization framework for solving the inverse problem in finite-horizon stochastic control in continuous time. This approach determines the performance index from a given control law or state process using the value function of the forward problem and generalizes Nakano (2023). Based on this framework, we present a numerical method for solving the inverse problem in linear-quadratic regulator systems. Furthermore, we provide theoretical analysis, particularly showing that our method generalizes Schrödingers problem and Nelsons problem.

Yumiharu Nakano
Graduate School of Innovation Management
Tokyo Institute of Technology
nakano.y.ee47@m.isct.ac.jp

CP5

Finite-Approximate Controllability of Impulsive Stochastic Functional Evolution Equations

This paper investigates the finite-approximate controllability of semilinear impulsive stochastic functional evolution equations in Hilbert spaces. We first establish the existence and uniqueness of a mild solution under suitable conditions. We then derive sufficient conditions for the finite-approximate controllability whenever the corresponding linear problem is approximately controllable. The nonlinear functions adhere to Carathodory conditions, which offer broader applicability and are less stringent than the classical Lipschitz conditions. The Picard iterations, Bihari's inequality, fixed-point principles, and the resolvent-like operator technique are used to derive our results. Finally, we apply our findings to verify the finite-approximate controllability of the nonlinear stochastic heat equation involving the impulse effect and the time delay property.

Nidhi Shukla
Indian Institute of Technology Roorkee
n_shukla@as.iitr.ac.in

CP6

Tracking Control in the Wasserstein Space

We consider an optimal tracking control problem which is posed in the Wasserstein space of probability measures. This optimal control problem trades off between tracking error (as measured by the Wasserstein distance) and control effort (as measured by a norm on the velocity field). We show how this nonlinear, infinite-dimensional optimal control problem can be solved by leveraging the geometric structure of the Wasserstein space. We show that in certain notable cases, optimal solutions decouple, in the sense that the optimal transport portion of the problem and the optimal control portion can be solved independently of each other. We also investigate the causality structure of solutions to this problem and propose a model-predictive control scheme that achieves real-time tracking of reference measures.

Max Emerick, Bassam Bamieh
University of California Santa Barbara
memerick@ucsb.edu, bamieh@ucsb.edu

CP6

Convergence Rates of Approximations for Viscosity Solutions of Path-Dependent Hamilton-Jacobi-Bellman Partial Differential Equations

We consider approximations for viscosity solutions of path-dependent Hamilton-Jacobi-Bellman (HJB) partial differential equations (PDEs). It is known that discrete-time approximations converge to viscosity solutions of the path-dependent HJB PDEs as the time-step size goes to 0. In this presentation, we pursue a viscosity solution method for convergence rates of HJB PDEs which is possibly applicable to more general path-dependent PDEs. Using the specific form of the penalized smooth distance functional, we obtain convergence rates for path-dependent PDEs by viscosity solution arguments. For a particular model, we show that the convergence rate matches that of Euler approximations by direct error estimates for value functionals.

Hidehiro Kaise
Department of Mathematics, Kumamoto University
kaise@kumamoto-u.ac.jp

CP6

Hilbert Space-Valued Lq Mean Field Games: With and Without Common Noise.

This paper presents a comprehensive study of linear-quadratic (LQ) mean field games (MFGs) in Hilbert spaces, generalizing the classic LQ MFG theory to scenarios involving N agents with dynamics governed by infinite-dimensional stochastic equations. In this framework, both state and control processes of each agent take values in separable Hilbert spaces. We first study the well-posedness of a system of N coupled semilinear infinite-dimensional stochastic evolution equations establishing the foundation of MFGs in Hilbert spaces. We then specialize to N-player LQ games described above and study the asymptotic behaviour as the number of agents, N, approaches infinity. We develop an infinite-dimensional variant of the Nash Certainty Equivalence principle and characterize a unique Nash equilibrium for the limiting MFG. Finally, we study the connections between the N-player game and the limiting MFG, demonstrating that the empirical average state converges to the mean field and that the resulting limiting best-response strategies form an ϵ-Nash equilibrium for the N-player game in Hilbert spaces. Lastly, we consider the system with a common noise. In this setting, the offset equation and the mean field evolve as infinite-dimensional stochastic equations (both are deterministic in the absence of common noise). Consequently, the mean field consistency equations take the form of a system of forward-backward stochastic equations.

Hanchao Liu
HEC Montréal
Hanchao.liu@hec.ca

Dena Firoozi
HEC Montreal
University of Montreal
dena.firoozi@hec.ca

CP6

On the Continuity of the Minimal Time Function in Sweeping Processes with Discontinuous Perturbations

Sweeping processes have become a fundamental class of dynamical systems with a wide range of applications involving areas such as elastoplasticity, control theory, mechanics, hysteresis, image processing, and traffic equilibria. Over the past few decades, research activity on sweeping processes has become pivotal in the development and understanding of nonsmooth analysis as well as the theory of differential inclusions. In this talk, we explore the regularity of the minimal time function associated with a sweeping process influenced by a discontinuous perturbation of dissipative type. Our main result introduces a Petrov-type sufficient condition that ensures the continuity of this function under our fully discontinuous setting. Additionally, we discuss the broader implications of our contribution in the context of HamiltonJacobi theory.

Vinicio R. Rios
Louisiana State University
vrios3@lsu.edu

CP6

Near-Optimal Performance of Stochastic Economic MPC

We present first results for near optimality in expectation of the closed-loop solutions for stochastic economic MPC. The approach relies on a recently developed turnpike property for stochastic optimal control problems at an optimal stationary process, combined with techniques for analyzing time-varying economic MPC schemes. We obtain near optimality in finite time as well as overtaking and average near optimality on infinite time horizons.

Jonas Schießl
Chair of Applied Mathematics
University of Bayreuth
Jonas.Schiessl@uni-bayreuth.de

Ruchuan Ou
Institute of Control Systems
Hamburg University of Technology
ruchuan.ou@tuhh.de

Michael H. Baumann
Chair of Applied Mathematics
Universität Bayreuth
michael.baumann@uni-bayreuth.de

Timm Faulwasser
Institute of Control Systems
Hamburg University of Technology
timm.faulwasser@ieee.org

Lars Grüne
Mathematical Institute
Universitaet Bayreuth
lars.gruene@uni-bayreuth.de

CP6

Optimal Control of PDEs for Mappings into Manifolds

In this talk, we consider optimal control problems with partial differential equation (PDE) constraints involving mappings into manifolds. This class of problems differs from the classical setting of linear spaces in various ways. Specifically, the treatment of variational problems on manifolds requires the use of special techniques. We derive optimality conditions and discuss the application of Newton's method for their numerical solution.

Laura Weigl
Chair of Applied Mathematics
University of Bayreuth
laura.weigl@uni-bayreuth.de

Anton Schiela
University of Bayreuth
anton.schiela@uni-bayreuth.de

CP7

On Characterizing Optimal Learning Trajectories in a Class of Learning Problems

In this talk, we provide a mathematical framework that exploits the relationship between the maximum principle and dynamic programming for characterizing optimal learning trajectories in a class of learning problem, which is related to point estimations for modeling of high-dimensional nonlinear functions. Here, such characterization for the optimal learning trajectories is associated with the solution of an optimal control problem for a weakly-controlled gradient system with small parameters, whose time-evolution is guided by a model training dataset and its perturbed version, while the optimization problem consists of a cost functional that summarizes how to gauge the quality/performance of the estimated model parameters at a certain fixed final time w.r.t. a model validating dataset. Moreover, using a successive Galerkin approximation method, we provide an algorithmic recipe how to construct the corresponding optimal learning trajectories leading to the optimal estimated model parameters for such a class of learning problem.

Getachew K. Befekadu
Department of Electrical Engineering & Computer Science
The Catholic University of America
befekadu@cua.edu

CP7

Adaptive Step Sizes for Stochastic Gradient Descent

The choice of the step size (or learning rate) in stochastic optimization algorithms, such as stochastic gradient descent, plays a central role in the training of machine learning models. Both theoretical investigations and empirical analyses emphasize that an optimal step size not only requires taking into account the nonlinearity of the underlying problem, but also relies on accounting for the local variance within the search directions. In this presentation, we introduce a novel method capable of estimating these fundamental quantities and subsequently using these estimates to derive an adaptive step size for stochastic gradient descent. Our proposed approach leads to a nearly hyperparameter-free variant of stochastic gradient descent. We provide theoretical convergence analyses in the case of strongly convex problems. In addition, we perform numerical experiments focusing on classical image classification tasks. Remarkably, our algorithm exhibits truly problem-adaptive behavior when applied to these problems that exceed theoretical boundaries.

Frederik Köhne
University of Bayreuth
frederik.koehne@uni-bayreuth.de

Leonie Kreis
Interdisciplinary Center for Scientific Computing
Heidelberg University
leonie.kreis@iwr.uni-heidelberg.de

Anton Schiela
University of Bayreuth
anton.schiela@uni-bayreuth.de

Roland Herzog
Heidelberg University
roland.herzog@iwr.uni-heidelberg.de

CP7

Unknown Input Observer-Based Physics-Informed Neural Network Design for State Estimation

The system dynamics of most engineering applications are often unmeasurable or unavailable due to measurement costs or complexity. Furthermore, a major challenge affecting these systems is the presence of unknown faults, with actuator faults being the most significant. These faults can degrade system performance or even compromise stability. Therefore, it is essential to estimate or reconstruct the state of the system under actuator faults. To address this issue, this work focuses on the design of an unknown input observer-based physics-informed neural network (PINN) for estimating system dynamics and actuator faults. Additionally, sufficient stability and convergence criteria will be developed for the proposed observer design. Finally, the theoretical approach will be validated through a case study.

Vijayakumar Muthusamy
Anna University Regional Campus, Coimbatore
vijaymaths048@gmail.com

CP7

Toward Benchmarking Data-Driven and Model-Based Anomaly Detection: A Control Theoretical Perspective

Conventionally, anomaly detection and isolation employ model-based approaches to monitoring residual signals between nominal and off-nominal system behaviors, with well-established theoretical foundations for their performance. Despite the complexity, nonlinearity, and uncertainty in modern large-scale systems, machine learning has radically expanded the range of anomalies these techniques can empirically handle when fused with data. As highlighted in M. Saquib Sarfraz et al (2024), however, the rapid proliferation of deep-learning methods has outpaced the establishment of rigorous benchmarking protocols, leading to inconsistent evaluations and the risk of over-engineering without clear evidence of practical benefits. Motivated by these concerns, our work bridges the gap between empirical success and theoretical understanding by providing a concise overview of formal guidelines grounded in control theory for selecting and applying both data-driven and model-based anomaly detection techniques. As a standardized and transparent evaluation platform for existing and emerging anomaly detection frameworks, we also introduce a nominal benchmark involving multi-spacecraft formation control that accommodates various types of nonlinearities and uncertainties.

Hiroyasu Tsukamoto
Department of Aerospace Engineering, The Grainger College of
University of Illinois Urbana-Champaign
hiroyasu@illinois.edu

Joudi Hajar
Caltech
JHAJAR@CALTECH.EDU

CP7

Filtration-Based Reinforcement Learning for Optimal Ensemble Control

Research into reinforcement learning (RL) approaches to optimal control has attracted considerable attention in recent years. However, RL notably suffers from the curse of dimensionality when applied to ensemble systems comprising a large number of components. In this talk, we will propose a novel RL architecture and derive effective computational algorithms to learn optimal control laws for arbitrarily large ensemble systems. In our approach, we model the ensemble system as a parameterized control system defined on an infinite-dimensional function space. We introduce a moment kernel transform to map an optimal ensemble control problem to a problem defined on a reproducing kernel Hilbert space. This transformation allows a finite-dimensional kernel representation of the optimal ensemble control problem. Leveraging this representation, we develop an effective RL algorithm with hierarchical structures to learn the optimal ensemble control policy. To further enhance the algorithm's efficiency, we implement early stopping at each hierarchy and show its fast convergence property through the construction of a convergent spectral sequence. The performance and efficiency of the proposed algorithm are validated using practical ensemble control problems arising in robotics and quantum control.

Wei Zhang, Jr-Shin Li
Washington University in St. Louis
wei.zhang@wustl.edu, jsli@wustl.edu

MS1

GN-SINDyC: Greedy Sampling Neural Network SINDy with Control for Catalytic CO2 Methanation

The SINDy method has proven its versatility in multiple successful applications in a wide range of scientific and engineering fields. These include, but are not limited to, fluid dynamics, neuroscience, epidemiology, and robotics. This work follows the recent GN-SINDy extension of the standard SINDy approach, including several steps to further improve the performance of the standard, vanilla SINDy. Among others, we mention using the Q-DEIM algorithm to sample the data set and select solely the most meaningful measurement pairs, which are fed into a DNN. This learns the nonlinear mapping between the spatiotemporal pairs and the measured quantities of interest, and the underlying physics of the data set. The output of the DNN serves as a function approximation which is used to construct the dictionary and compute (partial) derivatives via automatic differentiation. Finally, the coefficient vector is estimated using stochastic gradient descent, optimized based on a specific loss function with multiple components. The application here is to model the dynamic operation and control of a CO2 catalytic methanation reactor. We report on the accuracy and computational efficiency of GN-SINDyC to identify reliable surrogate models that can improve renewable energy conversion processes.

Luisa Peterson
Max Planck Institute, Magdeburg, Germany
peterson@mpi-magdeburg.mpg.de

Ali Forootani
Helmholtz Centre for Environmental Research - UFZ

ali.forootani@ufz.de

Ion Victor Gosea
Max Planck Institute Magdeburg
gosea@mpi-magdeburg.mpg.de

Kai Sundmacher
Max Planck Institute for Dynamics of Complex Technical Sys.
sundmacher@mpi-magdeburg.mpg.de

Peter Benner
Max Planck Institute Magdeburg
benner@mpi-magdeburg.mpg.de

MS1

Data-driven model reduction for control - an overview

This talk will provide a general overview of the topic of data-driven model reduction for control, ranging from traditional system theoretic reduction methods to recent developments in non-intrusive and data-driven surrogate modeling. In particular, a brief summary of the MS contributions will be presented.

Tobias Breiten
Technical University of Berlin
tobias.breiten@tu-berlin.de

MS1

(Data-Driven) Balancing Truncation for Bilinear-Quadratic Output Systems

We discuss so called bilinear-quadratic output (BQO) systems of the form

$$\dot{x}(t) = Ax(t) + \sum_{k=1}^{m} N_k x(t) u_k(t) + Bu(t), \qquad x(0) = 0,$$
$$y(t) = Cx(t) + \begin{bmatrix} x(t)^T M_1 x(t) \\ \vdots \\ x(t)^T M_p x(t) \end{bmatrix},$$

where $A \in \mathbb{R}^{n\times n}, B \in \mathbb{R}^{n\times m}, C \in \mathbb{R}^{p\times n}$, $N_k \in \mathbb{R}^{n\times n}$ for $k = 1, \dots, m$, $M_i \in \mathbb{R}^{n\times n}$ for $i = 1, \dots, p$, $t \in T := [0, \infty)$. $x(t) \in \mathbb{R}^n$ describes the state, $u(t) \in \mathbb{R}^m$ the input and $y(t) \in \mathbb{R}^p$ the output of the system. It is assumed that M_i is symmetric because $x(t)^T M_i x(t) = x(t)^T M_i^T x(t) = \frac{1}{2} x(t)^T (M_i + M_i^T) x(t)$ holds. We propose algebraic Gramians for BQO systems and show their relation to certain generalized Lyapunov equations. Furthermore, we propose a balancing algorithm that allows us to truncate of certain states in order to generate a reduced order system. Finally, we sketch a data-driven formulation for balanced truncation of BQO systems that does not require access to the system representation itself. We illustrate our approach numerically.

Heike Fassbender
TU Braunschweig
h.fassbender@tu-braunschweig.de

Serkan Gugercin
Virginia Tech
Department of Mathematics
gugercin@vt.edu

Till Peters
TU Braunschweig
till.peters@tu-braunschweig.de

MS1

What to sample for data-driven balancing-based reduced models

Balanced Truncation (BT) is a widely recognized gold standard in model reduction, providing an effective way to simplify complex dynamical systems while preserving key input-output properties. Recently, a quadrature-based approach, known as QuadBT, demonstrated how to achieve the accuracy of Lyapunov-based BT using only input-output data, eliminating the need for full system knowledge. In this talk, we explore various extensions of BT, including positive-real BT and bounded-real BT, which are particularly relevant for passivity-constrained and control applications. If time permits, we will also discuss formulations for extending these techniques to certain classes of nonlinear dynamics.

Serkan Gugercin
Virginia Tech
Department of Mathematics
gugercin@vt.edu

MS2

Linear Quadratic Optimal Control of Partial Differential-Algebraic Equations

This talk addresses the linear quadratic (LQ) controller design for a class of linear partial differential-algebraic equations (PDAEs). On a finite-time horizon, we establish the existence and uniqueness of an optimal control. Without the explicit projection of the PDAE, we derive a system of coupled Riccati-like differential and algebraic equations that yield the optimal solution. Next, introducing notions of exponential stabilizability and detectability for the PDAEs under consideration, we consider infinite-time LQ control for PDAEs. We also derive an algebraic Riccati-like equation to compute the optimal control, without the need for the projections. Numerical simulations are conducted to illustrate the theoretical findings.

Ala Alalabi
North Carolina State University
alaawaddah93@gmail.com

Kirsten Morris
Dept. of Applied Mathematics
University of Waterloo
kmorris@uwaterloo.ca

MS2

Adaptive Sensitivity Control for a Feedback Loop and a Consensus Model with Unknown Delay

I will present a method for estimation of a globally constant but unknown delay in a negative feedback loop, where only an upper bound on the possible values of the delay is given. The method is based on detecting the decay rate of the solution throughout its evolution and guarantees that the estimate converges to the true value of asymptotically for large times. In a second step, the estimated delay is used to adaptively control the sensitivity (feedback gain) of the loop with the goal of reaching optimal rate of convergence towards equilibrium. This approach is distinguished from traditional feedback control methods by leveraging the systems sensitivity as a control parameter. Moreover, I will show how the method adapts for controling the sensitivity in a linear opinion formation model with unknown delay. Here the estimation of the delay is based on the decay properties of the quadratic fluctuation of the agents opinions, employing appropriate approximations and some heuristic arguments. In both cases I will present numerical examples illustrating the performance of the method.

Jan Haskovec
King Abdullah University of Science and Technology
jan.haskovec@kaust.edu.sa

MS2

Linear-Quadratic Optimal Control for Boundary Controlled Networks of Waves

Linear-Quadratic optimal controls are computed for a class of boundary controlled, boundary observed hyperbolic infinite-dimensional systems, which may be viewed as networks of waves. The main results of this manuscript consist in converting the infinite-dimensional continuous-time systems into infinite-dimensional discrete-time systems for which the operators dynamics are matrices, in solving the LQ-optimal control problem in discrete-time and then in interpreting the solution in the continuous-time variables, giving rise to the optimal boundary control input. The results are applied to two examples, a small network of three vibrating strings and a co-current heat-exchanger, for which boundary sensors and actuators are considered.

Anthony Hastir
Wuppertal university
hastir@uni-wuppertal.de

Birgit Jacob
University of Wuppertal, Germany
bjacob@uni-wuppertal.de

Hans Zwart
Department of Applied Mathematics
University of Twente
h.j.zwart@utwente.nl

MS2

Backstepping-Based Encirclement Control for Leader-Follower Multi-Agent PDE Systems

This talk presents a novel distributed encirclement control strategy for Partial Differential Equation (PDE)-based multi-agent systems, utilizing both in-domain and boundary control mechanisms ensuring collision avoidance. Unlike previous studies, our research focuses on a three-dimensional encirclement control framework and applies PDE control to the system. The targets of interest are dynamic and constrained to move within a three-dimensional space. Our approach addresses multiple sequential challenges. Using the backstepping method, we design controllers for boundary agents, leaders, to tackle three main objectives without any collisions: translating agents towards the targets, reforming their formation, and achieving a successful enclosing in a distributed manner. Once the targets are enclosed, the agents must then do rotation around them and, if necessary, adjust their formation to preserve the encirclement. To address these subsequent challenges, we implement in-domain control for the agents to fulfill all requirements. The application of these multi-step distributed controls is essential for enhancing the tracking and coordination among the agents, thereby improving the effectiveness of the encirclement control. Stability of the closed-loop system is analyzed using the Lyapunov method. Finally, simulations are conducted to assess the efficacy of our proposed methodology.

Milad Hasanzadeh
Department of Mechanical Engineering
Texas Tech University
m.hasanzadeh@ttu.edu

Shuxia Tang
Department of Electrical Engineering & Computer Sciences
University of California, Berkeley
shuxiatang.control@gmail.com

MS3

Mean-Field Optimalcontrol ForMagnetically Confined Fusion Plasma

In this talk we address the challenge of confining high-temperature plasma in magnetic fusion devices. In particular, we propose a mean-field optimal control constrained to the evolution of the Vlasov-Poisson equations with BGK-type collisions, where the external magnetic fields act as control actuator to promote the confinement in a bounded domain. In order to efficiently synthesize such control for such comples dynamics, we follow a reduced-horizon approach. Hence, we derive a feedback strategy on the equation of motion based on an instantaneous prediction of the discretized system, providing consistency with the mean-field control dynamics. Furthermore, we show that we can extend this control approach also in presence of uncertainties, which severely affect this process due to erroneous measurements and missing information and further enhance prediction of the plasma dynamics via deep-neural network. Numerical simulations validate the effectiveness of our approach, demonstrating the ability of external magnetic fields to steer the plasma away from device boundaries.

Giacomo Albi
Università degli Studi di Verona
giacomo.albi@univr.it

MS3

Exploratory Investment-Consumption with Non-Exponential Discounting

We extend the classic Merton's optimal investment-consumption problem to the reinforcement learning (RL) framework. Additionally, we incorporate a general non-exponential discounting function to capture the individual's risk preferences, which leads to time inconsistency in the exploratory control problem. Under standard entropy regularization and logarithmic utility, we obtain closed-form equilibrium investment-consumption policies. Specifically, the optimal investment policy follows a Gaussian distribution, while the optimal consumption policy follows a Gamma distribution. To validate our theoretical results, we develop and implement two RL algorithms—one based on the policy evaluation approach and the other on the q-learning approach—demonstrating their effectiveness through simulation studies.

Yuling Max Chen
Department of Statistics

University of Waterloo
yuling.chen@uwaterloo.ca

Bin Li
University of Waterloo
Department of Statistics and Actuarial Science
bin.li@uwaterloo.ca

David Saunders
Department of Statistics and Actuarial Science
University of Waterloo
dsaunder@uwaterloo.ca

MS3

Single Level Deep Learning Approach to Solve Stackelberg Mean Field Games

In this talk, we introduce general form bi-level Stackelberg mean field games to approximate a game between a regulator and a large number of agents evolving on a continuous state space and discuss how to write it as a single-level problem to propose an efficient numerical solution. In the model, the agents in the population play a non-cooperative game and choose their controls to optimize their individual objectives by interacting with the regulator and other agents in the society through the population distribution. The principal can influence the resulting mean field Nash equilibrium through incentives to optimize her own objective. We analyze this game by using a probabilistic approach and rewrite this bi-level problem as a single-level problem, give theoretical convergence results, and propose a machine learning based approach. We finalize with some examples such as mitigation of systemic risk in banking system. (joint work with Mathieu Lauriere.)

Gokce Dayanikli
University of Illinois Urbana-Champaign
gokced@illinois.edu

MS3

Multiple Objectives and Abrupt Context Changes in Mean Field Games

The challenge of balancing multiple conflicting objectives is very common in realistic applications of optimal control theory. Since the optimal balance depends on one's priorities, this gives rise to a (typically infinite) set of Pareto-optimal controls. In problems with many small and independent decision makers, Mean Filed Games (MFGs) provide an excellent formalism which proved to be useful in many application areas. In this talk, we will show how MFGs can be extended to handle interactions of decision makers whose priorities vary both in time and across the population. Our approach will be illustrated on problems from epidemiology and traffic engineering.

Alexander Vladimirsky
Cornell University
vladimirsky@cornell.edu

MS4

Carleman Estimates and Simultaneous Boundary Controllability of Uncoupled Wave Equations

We analysed the null controllability of a one-dimensional system of two uncoupled wave equations with the same potential a depending on space and time. Both equations are submitted to the same boundary control h at the left endside of the interval, whereas in the right endpoint, one is submitted to the homogeneous Dirichlet boundary conditions and the other one, to the homogeneous Neumann boundary conditions. This simultaneous boundary controllability problem associated to uncoupled wave equations, seems new even in the conservative case ($a \equiv 0$). Its resolution is based on the use of Hilbert Uniqueness Method (HUM for short) developed by J.-L. Lions, which consists in reducing the controllability problem for a given distributed system to obtaining an inverse or observability estimate for the corresponding adjoint system. First, we proved an observability estimate for the conservative adjoint system by using the multipliers method. Then in the nonconservative case, we have shown a Carleman inequality for the adjoint system by introducing appropriate weight functions. The latter result is the main contribution of this work. To achieve it, we first assumed that all initial and final displacements are zero, and then we were able to establish it by dropping the null displacements constraint. Finally, we deduced the null controllability result under the assumption that the controllability time is large enough ($T > 4$).

Carole Louis-Rose
Université des Antilles
carole.louis-rose@univ-antilles.fr

Louis Tebou
Department of Mathematics
Florida International University
teboul@fiu.edu

MS4

Identification of the Uncertainty Distribution for Scalar Conservation Laws

In uncertainty quantification there is often made the assumption of knowing the exact distribution of the uncertain parameters. Here, we only assume to know the family of the underlying distribution and fit the parameters using an identification approach. We follow a first discretize then optimize strategy and consider a so-called discontinuous stochastic Galerkin method consisting of a spatial discontinuous Galerkin scheme and a Multielement stochastic Galerkin ansatz in the random space. We derive first-order optimality conditions and tailor a gradient descent method for the task of fitting the parameters. The theory will be underpinned by numerical results.

Claudia Totzeck
Bergische Universität Wuppertal
totzeck@uni-wuppertal.de

MS5

Stochastic Mean Field Games on Large Sparse Network Limits

In common with Graphon Mean Field Games (GMFG), the Graphexon MFG (GXMFG) systems are given by the linked equations on a time interval of (i) the Hamilton-Jacobi-Bellman (HJB) PDE for the value function V for a generic agents stochastic control at any node, (ii) the Fokker - Planck-Kolmogorov (FPK) equation for the McKean-Vlasov stochastic differential equation (SDE) for the local mean field of the generic agent, and (iii) the specification of the best response feedback law. The GMFG framework is formulated in terms of graphons and hence is restricted to the limits of asymptotically dense networks, whereas its generalization in the GXMFG formulation includes the limits of both asymptotically sparse and dense graph sequences without restrictions. The mathematical expression of this generalization consists in the replacement of bounded measurable functions by measures. The GXMFG systems in this work employ second order (wrt graph node location) differential terms in the dynamics which model the edge-wise influence of neighboring subpopulations in the sparse graph limit. Existence and uniqueness results are provided for the solution of the GXMFG equations and the path towards the corresponding epsilon-Nash results indicated. Work with Minyi Huang.

Peter E. Caines
McGill University
peterc@cim.mcgill.ca

MS5

Scalable Policy-Based Rl Algorithms for Pomdps

The continuous nature of belief states in Partially Observable Markov Decision Processes (POMDPs) presents significant computational challenges in learning the optimal policy. In this talk, we consider an approach that solves a Partially Observable Reinforcement Learning (PORL) problem by approximating the corresponding POMDP model into a finite-state Markov Decision Process (MDP) (called Superstate MDP). We first derive theoretical guarantees that improve upon prior work (by a factor proportional to the expected horizon) that relate the optimal value function of the transformed Superstate MDP to the optimal value function of the original POMDP. Next, we propose a policy-based learning approach with linear function approximation to learn the optimal policy for the Superstate MDP. Additionally, we provide finite-time performance guarantees, which show that the number of Superstates grows polynomially with respect to the desired approximation accuracy, providing a scalable solution to the PORL problem. Our finite-time bounds include, for the first time, an analysis of the error incurred due to applying standard TD learning to a problem where the underlying model is not an MDP.

Rasoul Etesami
urbana
etesami1@illinois.edu

Ameya Anjarlekar, R Srikant
University of Illinois Urbana-Champaign
ameyasa2@illinois.edu, rsrikant@illinois.edu

MS5

A New Approach to Principal-agent Problems with Volatility Control

Cvitanic, Possamai, and Touzi (2018) [1] introduced a framework for continuous-time principal-agent problems using dynamic programming and second-order backward stochastic differential equations (2BSDEs). Here, we propose an alternative formulation of the principal-agent problem, solvable with simpler techniques based solely on BSDEs. Our approach leverages a key observation from [1]: if the principal observes the output process continuously, she can compute its quadratic variation pathwise. Instead of incorporating this information into the contract as in [1], we assume the principal can directly control this process in a 'first-best' manner. Then, inspired by Sannikov's method (2008), we demonstrate that this reformulated problem yields the same solution as the original. More precisely, using the penalisation contracts from [1], we show that the 'first-best' outcome can be achieved even without direct control of quadratic variation, eliminating the need for 2BSDEs. This streamlined approach enhances accessibility and paves the way for extensions to complex multi-agent settings, which we will briefly discuss.

Alessandro Chiusolo
Princeton University
ac8541@princeton.edu

Emma Hubert
Princeton University
Department of Operations Research and Financial Engineering
eh3988@princeton.edu

MS5

Tbd 3

We revisit the work of Mitter and Newton on an information-theoretic interpretation of Bayes' formula through the Gibbs variational principle. This formulation allowed them to pose nonlinear estimation for diffusion processes as a problem in stochastic optimal control, so that the posterior density of the signal given the observation path could be sampled by adding a drift to the signal process. We show that this control-theoretic approach to sampling provides a common mechanism underlying several distinct problems involving diffusion processes, specifically importance sampling using Feynman–Kac averages, time reversal, and Schrödinger bridges.

Maxim Raginsky
University of Illinois at Urbana-Champaign
maxim@illinois.edu

MS6

Numerical Solution of Optimal Control Problems Using Orthogonal Collocation at Legendre Gauss Lobatto Points

A novel method is described for solving optimal control problems using direct collocation at Legendre-Gauss-Lobatto points. The method incorporates a noncollocated support point in the state approximation, thus increasing the degree of the approximating polynomial and leading to several notable outcomes. First, the resulting discretization has equivalent differential and integral forms. Second, the transformed adjoint system presents a system of $N+1$ equations in $N+1$ unknowns and, consequently, the costate approximation is well-behaved and does not exhibit oscillatory behavior. Third, the transformed Karush-Kuhn-Tucker conditions of the associated nonlinear programming problem are a discrete representation of the continuous first-order optimality conditions. Additionally, the described method discretely defines the control at both endpoints of the time interval, thus mitigating a limitation of previously developed methods that employ collocation at Legendre-Gauss and Legendre-Gauss-Radau points. Finally, two numerical examples are presented. The first example, a nonlinear one-dimensional boundary value optimal control problem with a smooth profile, demonstrates computation of high-accuracy state, control, and costate solutions as a function of the mesh size. The second example, the minimum-time double-integrator optimal control problem, demonstrates the method can be used to accurately capture discontinuous control profiles and optimize the corresponding switch times.

Gabriela Abadia-Doyle
University of Florida
Department of Mechanical and Aerospace Engineering
gabadia97@ufl.edu

Anil Rao
University of Florida
anilvrao@ufl.edu

MS6

Convergence Rates for hp-Orthogonal Collocation Schemes

t is shown that either Gauss or Radau hp-orthogonal collocation discretizations of optimal control problems can be reformulated as Runge-Kutta schemes. Consequently, the convergence rate of the hp discretization can be determined from the order conditions for the Runge-Kutta discretization of optimal control problems. In optimal control, the number of conditions that must be satisfied by the coefficients of the Runge-Kutta scheme grow very fast relative to the order of the scheme. For example, for order 7, the coefficients need to satisfy 481 conditions. Nonetheless, it is found that an s-stage scheme has order 2s for Gauss and 2s-1 for Radau collocation. When control constraints are present, the best possible order for a Runge-Kutta scheme is typically 2. This convergence rate can be achieved when the Runge-Kutta scheme scheme satisfies some additional identities. Both the Gauss and Radau hp-orthogonal collocation schemes satisfy these identities.

William Hager
University of Florida
Department of Mathematics
hager@ufl.edu

MS6

Adaptive Constrained Optimal Guidance Using Adaptive Gaussian Quadrature Collocation

An optimal guidance algorithm is developed that is capable of incorporating inequality path constraints. At the start of each guidance cycle, the guidance algorithm solves an optimal control problem over the remaining horizon. Furthermore, if, at the start of a guidance cycle, a path constraint function value lies within a user-specified margin of the path constraint limit, the objective functional of the optimal control problem is modified to include a term that attempts to increase the path constraint margin in order to ensure that path constraints remain below their limits. The performance of the optimal guidance algorithm is assessed on multiple atmospheric entry guidance problems, and this assessment includes analysis via Monte Carlo simulation. The results of this research show that the optimal guidance algorithm maintains feasibility with respect to the path constraints in a very high percentage of cases, even in the presence of uncertainties and disturbances.

Emily Palmer
University of Florida
Department of Mechanical and Aerospace Engineering
emilypalmer@ufl.edu

MS7

The Role of Active Boundary Control and Jump Damping in the Stability of Serially Connected Piezoelectric-Elastic Smart Structures

This study investigates the stability of a transmission problem featuring alternating magnetizable piezoelectric and elastic beams under various partial damping scenarios in ten distinct cases. Practical implementations of boundary and distributed damping designs are analyzed to understand the stability of each component and its impact on the overall system. The first case, involving viscous damping on each piezoelectric beam, demonstrates both strong and exponential stability. The second case, incorporating viscous damping in one piezoelectric beam and boundary damping at a junction, exhibits immediate exponential stability. In the third case, a single viscous damping in the elastic beam ensures strong stability under specific conditions, with the potential for exponential and polynomial stabilities under further arithmetic conditions. Surprisingly, in the fourth case, introducing viscous damping on the elastic beam results in conditional exponential and polynomial stability. In the fifth case, the strategic addition of a third damping restores unconditional exponential stability while maintaining practicality. In the last five cases, we study the Role of Active Boundary Control and Jump Damping.

Mohammad Akil
Université Polytechnique Hauts-de-France
mohammad.akil@uphf.fr

MS7

Turnpike Phenomena in Optimal Control Problems

We provide a characterization of the exponential turnpike property for infinite dimensional generalized linear-quadratic optimal control problems in terms of structural properties of the control system, such as exponential stabilizability and detectability. The proof relies on the analysis of the exponential convergence of solutions to the differential Riccati equations to the algebraic counterpart, and on a necessary condition for exponential stabilizability in terms of a closed range test. Besides, we provide a necessary condition that requires exponential stabilizability of the optimal control problem on the unobservable subspace of the state space.

Roberto Guglielmi
University of Waterloo
rguglielmi@uwaterloo.ca

MS7

A Two-Level Reduction Approach for Optimal Control of Agent Based Models

Agent-based models (ABMs) capture complex collective behaviors emerging from simple individual rules in fields like mathematical biology, ecology, and social dynamics. However, their high dimensionality makes simulations and analysis computationally expensive.To address this, we first apply clustering techniques to group agents based on behavioral similarities, reducing their number while preserving key system features. This enhances computational efficiency and simplifies interactions. Then, we employ model order reduction (MOR) via Proper Orthogonal Decomposition (POD) to further reduce dimensionality while maintaining essential properties like consensus formation. This two-level reduction enables optimal control of the reduced system, ensuring efficient yet accurate representations of large-scale multi-agent dynamics. We apply the proposed framework to both first and second-order models, broadening its use in complex ecological networks and multi-agent systems. Acknowledgements. This work is supported by the NRRP, M4 C2 I1.4 - Call for tender No. 3138/2021, Decree No. 3175/2021 MUR, funded by NextGenerationEU. Award Number: Project code CN00000033, Concession Decree No. 1034/2022 MUR, CUP B83C22002930006. Project title: National Biodiversity Future Center - NBFC.

Angela Monti
National Research Council, IAC
angela.monti@cnr.it

Fasma Diele
Istituto per Applicazioni del Calcolo
M. Picone, CNR, Italy
fasma.diele@cnr.it

Dante Kalise
Imperial College London
d.kalise-balza@imperial.ac.uk

MS8

Closing the Lagrangian Traffic Control Loop: Modeling, Actuation, Sensing, and Reconstruction-Based Control

As the connected and automated vehicles (CAVs) enter the road in increasing numbers, a new Lagrangian paradigm for traffic control is becoming possible. As opposed to the classical, Eulerian traffic control, which requires additional stationary equipment, the Lagrangian approach uses CAVs as sensors and actuators, enabling new flexible solutions without relying on conventional road traffic management infrastructures. This talk discusses how CAVs can be directly used as major components of a traffic control loop. After giving some preliminaries about the traffic models, we first discuss the mechanisms to use CAVs to provide actuations and local traffic measurements. Since traffic measurements are now only available in the vicinity of CAVs, the full traffic state needs to be estimated and reconstructed before control can be applied. Additionally, if the traffic model is not known as a-priori, the reconstruction data can be used to identify the dynamics, along with the model describing the influence of CAVs on the rest of traffic. Finally, using the traffic state predictions acquired from the learned model, we are able to implement a control law which dissipates congestion and improves the throughput.

Mladen Cicic
University of California, Berkeley
cicic@berkeley.edu

MS8

Freeway Traffic Management Via Kinetic Compartmental Models

In this study, a family of finite volume discretization schemes for LWR-type first order traffic flow models (with possible on- and off-ramps) is proposed: the Traffic Reaction Model (TRM). These schemes yield systems of ordinary differential equations (ODEs) that are formally equivalent to the kinetic systems used to model chemical reaction networks. An in-depth numerical analysis of the TRM is performed. The paper assesses incremental asymptotic stability for TRM discretized systems of ordinary differential equations (ODEs), hinting a new freeway traffic state estimation concept: open-loop stable state estimators. Finally, it proposes a unified freeway dynamic speed and ramp metering control approach via the modification of the reaction dynamics.

Sondre C Wiersdalen
Chalmers University of Technology, Gothenburg, Sweden
chanon@chalmers.se

Jean Auriol
CNRS, L2S, CentraleSupélec, Université Paris-Saclay
jean.auriol@centralesupelec.fr

Mike Pereira
Mines Paris
PSL University
mike.pereira@minesparis.psl.eu

Balazs Kulcsar
Chalmers University of Technology
kulcsar@chalmers.se

MS8

From Micro to Macroscopic: Leveraging Connected Automated Vehicles for Traffic Control

Emerging technologies of autonomous driving and wireless communications enable vehicles that used to be physically-connected, human-controlled become cyber-connected, machine-programmed. Leveraging enhanced control and sensing capabilities beyond those of human-driven vehicles (HV), connected automated vehicles(CAVs) are expected to substantially improve the efficiency, stability, and safety of transportation systems. In mixed-autonomy traffic, where CAVs and HVs coexist, two primary challenges arise: modeling the cruising and lane-changing dynamics of CAVs at both microscopic and macroscopic levels, and designing CAV-based control strategies to optimize traffic flow through information sharing and vehicle coordination. This talk will first address CAV-based control problems in microscopic mixed traffic. Cruising control strategies for CAVs are developed to ensure not only smooth and safe driving behaviors for the ego vehicle but also to stabilize the surrounding HVs. Specifically, a safety-critical traffic control framework will be presented, leveraging control barrier functions to guarantee collision-free safety for both CAVs and HVs. The second part of the talk will focus on macroscopic models, introducing Partial Differential Equation-based traffic modeling and backstepping control design to mitigate stop-and-go traffic using ramp metering on freeways.

Huan Yu
ntelligent Transportation Thrust, Systems Hub,
Guangzhou
The Hong Kong University of Science and
Technology(Guangzhou
huanyu@ust.hk

MS8

Boundary Consensus of Networked Hyperbolic Systems with Application to Traffic Synchronization

Despite an increasing interest in the consensus problem of networked PDE systems over the years, there are still open challenges due to communication constraints (e.g. unidirectional communication, communication failures and package dropouts). In this talk, we will present some of our recent results and ongoing work on a theoretical framework for studying a variety of boundary consensus problems of networked hyperbolic systems under fixed/switching communication topologies, including exponential consensus, stochastic consensus, PI consensus and event-triggered consensus. In addition, we will present the application results to the synchronization of multi-lane road traffic flow systems.

Jingyuan Zhan
Beijing University of Technology
jyzhan@bjut.edu.cn

Liguo Zhang
Beijing University of Technology, China
zhangliguo@bjut.edu.cn

Christophe Prieur
CNRS, Université Grenoble Alpes, France
christophe.prieur@gipsa-lab.fr

MS9

Data-driven Reduced-order Models for Control of Soft Swimming Robots

Soft swimming robots provide a quieter and safer solution to underwater exploration than modern autonomous underwater vehicles, which are often propeller-driven. Anguilliform swimming is an effective mode of locomotion utilized by elongated fish like eels and oarfish to travel long distances. It is characterized by the use of full-body undulations that produce thrust and it proves highly energy efficient. In this talk, we describe a method to leverage the Lagrangian nature of the model equations of the anguilliform swimmer to learn structure-preserving linear reduced-order models via Lagrangian Operator Inference. The data comes from simulations of an approximately 250,000 degrees-of-freedom nonlinear finite element model which is excited by a frequency-sweep of inputs with that drive typical biological patterns. We then use these second-order structured models for model predictive control of the centerline trajectory of the soft robot. We compare the controllers performance with other controllers derived from prominent linear model reduction techniques.

Boris Kramer, Harsh Sharma, Mike Tolley, Iman Adibnazari
University of California San Diego
bmkramer@ucsd.edu, hasharma@ucsd.edu, tolley@ucsd.edu, iadibnaz@ucsd.edu

MS9

Streaming Operator Inference for Online Adaptive Model Reduction

Operator Inference is a data-driven reduced modeling method that learns a low-dimensional dynamical system model from system state trajectory data. The method first reduces the dimension of the data by projecting the state trajectory data onto its leading principal components. Then, the method assumes a polynomial ansatz for the time derivative of the reduced state and fits the matrix operators defining the polynomial terms to data by solving a linear least squares problem. In contrast to nonlinear regression methods like deep learning, Operator Inference framework is analyzable, interpretable, and scales well to moderately large systems: the main computational operations are standard linear algebra operations for that are efficiently implemented in standard packages. In this talk, we present Streaming Operator Inference, which adapts the method to the extremely large-scale setting where the data are too large to store and must be streamed.

Elizabeth Qian
Georgia Institute of Technology
eqian@gatech.edu

MS9

Agnostic Control on the Fly

We study the problem of optimally controlling a linear dynamical system with stochastic process noise where the system parameters are unknown, and the cost function is specified over a finite time horizon. We propose a computational framework to find a control strategy that minimizes the maximal performance gap between our policy and the optimal policy for a known parameter value, also known as the worst-case regret. In particular, we consider the case of a single unknown parameter, and find that the policy that minimizes worst-case regret is a Bayesian strategy for a particular choice of prior probability for the unknown parameter. Interestingly, this prior probability is concentrated at a finite number of values, even though the actual parameter may be any value in an interval. We perform numerical experiments for a model problem and compare our approach with existing algorithms designed for an infinite time horizon.

Jacob Carruth
Princeton University
jcarruth@math.princeton.edu

Maximilian Eggl
Max Planck Institute for Brain Research
meggl@princeton.edu

Charles Fefferman
Princeton University, USA
cf@Math.Princeton.EDU

Clarence Rowley
Princeton University
Department of Mechanical and Aerospace Engineering
cwrowley@princeton.edu

MS9

Online Learning of Quadratic Manifolds from Large-Scale and Streaming Data for Nonlinear Model Reduction

Dimensionality reduction with quadratic manifolds augments linear approximations in subspaces with quadratic correction terms. While previous works rely on linear approximations given by projections onto the first few leading principal components of the training data, we instead construct subspaces so that the corresponding linear approximations can be corrected most efficiently with quadratic terms. We present a greedy method for the subspace construction that selects basis vectors from leading as well as later principal components. The greedy selection allows us to determine a basis that can leverage the quadratic corrections most efficiently. This is in contrast to choosing as basis the leading principle components, which results in the best linear approximation but is not necessarily most informative for the quadratic correction terms. Properties of the greedily constructed manifold allow applying linear algebra reformulations so that the greedy method scales to data points with millions of dimensions and peta-bytes of data when using a streaming-based construction of the quadratic manifold.

Paul Schwerdtner
New York University
ps5136@nyu.edu

Benjamin Peherstorfer
Courant Institute of Mathematical Sciences
New York University
pehersto@cims.nyu.edu

MS10

Concerning the Uniqueness of Weak Solutions for Biot-Stokes PDE Dynamics

In this talk, we discuss the issue of uniqueness of weak solutions for Biot-Stokes coupled dynamics. The PDE model comprises a 3D system of poroelasticity coupled to a 3D incompressible Stokes flow via a 2D interface, where kinematic, stress-matching, and tangential-slip conditions are prescribed. In particular, the Beaver-Joseph-Saffman boundary conditions are in place, which are known to mathematically describe interfacial contact between a given porous medium and incompressible viscous flow. Our previous work provided a construction of weak solutions, these satisfying the associated finite energy inequality. However, several issues related to the dynamic coupling hinder a direct approach to obtaining uniqueness and continuous dependence of weak solutions. In particular, low regularity of the hyperbolic (Lam) component of the model precludes the use of the solution as a test function, which would yield an a priori estimate. In considering degenerate and non-degenerate cases separately, we utilize two different approaches. In the former, energy estimates are obtained for arbitrary weak solutions through a systematic decoupling, and well-posedness of weak solutions is inferred. In the latter case, an abstract semigroup result is invoked to obtain uniqueness via a precise characterization of the adjoint of the dynamics operator.

George Avalos
University of Nebraska-Lincoln
Department of Mathematics and Statistics
gavalos2@unl.edu

MS10

Stability Results for Semilinear Evolution Equations with Memory and Time-Dependent Time Delay Feedback

We deal with semilinear evolution equations with memory and time-dependent time delay feedback. Under suitable assumptions on the coefficient of the delay feedback, we are able to prove that solutions corresponding to small initial data are globally defined and satisfy an exponential decay estimate. The standard assumption used so far to deal with wave-type equations with time-dependent time delay is that the time delay function belongs to the Sobolev space $W^{1,\infty}(0,+\infty)$ and satisfies the following condition: $\tau'(t) \leq c < 1$. Here, instead, we work in a very general setting, namely we only assume the time delay function is continuous and bounded from above. Also, we will illustrate some applications of our theoretical results.

Elisa Continelli
University of Padova
elisa.continelli@math.unipd.it

Cristina Pignotti
University of L'Aquila
pignotti@univaq.it

MS10

Shearing Dynamics in Partially Damped Viscoelastic Systems

The characterization of stability for partially damped beam systems with shearing viscoelasticity is addressed. This means that the damping feedback is effective on the shear force but other stains are not damped, giving the notion of partially damped systems. The mathematical results of this talk can be found in references "M. O. Alves, E. H. Gomes Tavares, M. A. Jorge Silva, J. H. Rodrigues, On Modeling and Uniform Stability of a Partially Dissipative Viscoelastic Timoshenko System. SIAM J. Math. Anal. 51, (2019) 4520-4543" and "E. H. Gomes Tavares, M. A. Jorge Silva, T. F. Ma, H. P. Oquendo, Shearing Viscoelasticity in Partially Dissipative Timoshenko-Boltzmann Systems, SSIAM J. Math. Anal. 56, (2024) 1149-1178", where applications in partially damped Timoshenko beam systems with short and long memory are presented. Our results fully characterize stability through the memory kernel and structural coefficients of the beam system.

Marcio A. Jorge da Silva
State University of Londrina
marcioajs@uel.br

MS10

Variational Parameter Recovery in the 2D Navier-Stokes Equations

Given a finite dimensional approximation of flow velocity governed by the Navier-Stokes equations, we seek to estimate the kinetic viscosity. We propose an algorithm that solves optimal control problems on finite time intervals using the previous problem's solution as an initial condition. We show existence of solutions to the optimal control problems as well as a necessary optimality condition for these problems. We further discuss the convergence of the algorithm to the true viscosity.

Sarah Strikwerda
University of WisconsinMadison
sstrikwerda@wisc.edu

Vincent R. Martinez
CUNY Hunter College
vrmartinez@hunter.cuny.edu

Xiang Wan
Loyola University Chicago
xwan1@luc.edu

MS11

Universal Approximation in Deep Neural Networks: A Controllability Approach

In this talk, we explore the expressive power of deep neural networks, especially ResNets. By idealizing deep ResNets as continuous-time control systems, the problem of interpolation and approximation can be reformulated as controllability problems. Leveraging this perspective, we establish universal interpolation and universal approximation results for a broad class of control systems. These results provide a general guarantee for the expressive power of deep ResNets, independent of specific architectural choices. Additionally, we discuss the distinction between universal approximation and universal interpolation in the context of control systems, highlighting its implications for understanding approximation rates in deep neural networks.

Jingpu Cheng
National University of Singapore
chengjingpu@u.nus.edu

MS11

Large-scale Coupled HJB Systems in Nonlinear Model Reduction

Many physical applications involve modeling a complex system as a high-dimensional system of ordinary differential equations. The high dimensionality of these models introduces significant computational challenges in trying to analyse the systems behaviour, which is often known as the curse of dimensionality. One way to alleviate the complexity of such problems is by using reduced-order modeling to create a low-dimensional system that preserves important characteristics. This talk focuses on nonlinear model reduction using moment matching for nonlinear dynamical systems whose input is generated by a signal generator system. Under certain assumptions, there exists an invariant manifold associated with the solution of a Sylvester-like partial differential equation (PDE) which relates to the steady-state response of the system [Isidori, Nonlinear Control Systems, 1995]. We introduce a procedure to numerically approximate the solutions to these invariance equations using the Galerkin spectral method, which involves expanding the solution through a basis of globally supported functions and using a Newton iteration on the coefficients. These approximate solutions to the invariance equation can then be used to construct reducedorder models. We demonstrate this methods ability to achieve moment matching in interconnected systems involving implicitly defined nonlinear signal generators, and in nonlinear problems of dimension up to 1000.

Carlos Doebeli, Dante Kalise, Alessandro Astolfi, Giordano Scarciotti, Joel Simard, Alessio Moreschini
Imperial College London
c.doebeli22@imperial.ac.uk, d.kalise-balza@imperial.ac.uk, a.astolfi@imperial.ac.uk, g.scarciotti@imperial.ac.uk, j.simard18@imperial.ac.uk, a.moreschini@imperial.ac.uk

MS11

A Network Model for Urban Planning

We study a mathematical model to describe the evolution of a city, which is determined by the interaction of two large populations of agents, workers and firms. The map of the city is described by a network with the edges representing at the same time residential areas and communication routes. The two populations compete for space while interacting through the labour market. The resulting model is described by a two population Mean-Field Game system coupled with an Optimal Transport problem.We prove existence and uniqueness of the solution and we provide several numerical simulations.

Adriano Festa
Disma - Politecnico di Torino, Italy.
adriano.festa@polito.it

Fabio Camilli
Università di Chieti e Pescara
fabio.camilli@unich.it

Luciano Marzufero
Università di Bolzano
luciano.marzufero@unibz.it

MS11

Numerical Computation of Mean Field Games Using Cole-Hopf Transformation and Fictitious Play

Controlling large-scale multi-agent systems (MAS) is a critical challenge in today's highly interconnected society. In this presentation, we propose a method using Mean Field Games (MFG) to overcome the computational challenges associated with MAS control problems. By combining the Cole-Hopf transformation and fictitious play, we first derive a linear iterative MFG (LIMFG), which solves the nonlinearity and coupling problems inherent in MFG. Numerical schemes for LIMFG can ensure ease of implementation while guaranteeing solution convergence. We discretize the LIMFG using two approaches: a finite difference method and a Monte Carlo method. The former uses an explicit Euler scheme for time discretization, which allows convergence analysis by tracking the error through discretization and iteration. The latter uses the Feynman-Kac formula to express the PDE solution as the expected value of the solution to an SDE, allowing efficient computation for high-dimensional problems that mesh-based methods cannot handle. This presentation reviews the advantages and disadvantages of these methods and their potential for solving complex MAS control problems.

Daisuke Inoue
Toyota Central R&D Labs
daisuke-inoue@mosk.tytlabs.co.jp

MS12

Exponential Decay in a Delayed Wave Equation with Variable Coefficients

In this talk, we consider a wave equation that incorporates strong damping and a time delay term, both with weighted coefficients. Previous studies, such as *[S. Nicaise, C. Pignotti, Stability and instability results of the wave equation with a delay term in the boundary or internal feedbacks, SIAM J. Control Optim., 45 (2006)]*, have established exponential stability under the condition that the weight of the damping (or strong damping) dominates the weight of the delay term. This idea has also been extended to cases involving weighted coefficients, as demonstrated by *[A. Benaissa, S. Messaoudi, A. Benguessoum, Energy decay of solutions for a wave equation with a constant weak delay and a weak internal feedback, Electron. J. Qual. Theo., (2014)]*. Our study introduces a new perspective: we achieve exponential stability and, remarkably, identify scenarios where the delayed term does not need to be dominated by the damping term, yet the system remains exponentially stable. A numerical example will be presented validating our result.

Waled Al-Khulaifi
KFUPM
waled.alkhulaifi@kfupm.edu.sa

Manal Alotibi, Nasser-Eddine Tatar
KFUPM, Department of Mathematics
manal.alotibi@kfupm.edu.sa, tatarn@kfupm.edu.sa

MS13

**Neural Operators Can Play Dynamic Stackelberg

Games

Dynamic Stackelberg games are a broad class of two-player games in which the leader acts first, and the follower chooses a response strategy to the leader's strategy. Unfortunately, only stylized Stackelberg games are explicitly solvable since the follower's best-response operator (as a function of the control of the leader) is typically analytically intractable. We address this issue by showing that the *follower's best-response operator* can be approximately implemented by an *attention-based neural operator*, uniformly on compact subsets of adapted open-loop controls for the leader. We further show that the value of the Stackelberg game where the follower uses the approximate best-response operator approximates the value of the original Stackelberg game. Our main result is obtained using our universal approximation theorem for attention-based neural operators between spaces of square-integrable adapted stochastic processes, as well as stability results for a general class of Stackelberg games.

Ibrahim Ekren, Guillermo Alvarez
University of Michigan
iekren@umich.edu, guialv@umich.edu

Anastasis Kratsios
McMaster University
anastasis.kratsios@unibas.ch

Anastasis Kratsios
ETH Zürich
anastasis.kratsios@unibas.ch

Xuwei Yang
McMaster University
yangx212@mcmaster.ca

MS13

Symmetric Finite Player Nash Equilibria for Markov Chains

The structure of Nash equilibria in dynamic games is often too complicated to lend itself to analysis, making them difficult to use in applications. In recent years, the mean field formalism has been extensively used by many groups to provide tractable models, as initiated independently by Caines, Huang & Malhame, and Lasry & Lions. The central ingredient of this approach is the exchangeability of players. In the mean field limit, this allows us to replace the aggregate quantities of the players by the distribution of a representative one. In this talk, we consider the problem in the finite-player setting and study the subset of strategies that respect this symmetry. We provide general existence results and discuss several representative examples to illustrate these results in concrete settings.

Felix Hoefer
Princeton University
fh6011@princeton.edu

H. Mete Soner
ETH
hmsoner@ethz.ch

Atilla Yilmaz
New York University
atilla@gmail.com

MS13

Linear-quadratic Graphon Mean Field Games with Risk-sensitive Costs

We consider a linear-quadratic mean field game model with risk-sensitive costs, where the agents interact through a dense network. We analyze the existence of a solution within the graphon limit and present the epsilon Nash equilibrium analysis for the obtained decentralized strategies. For current performance estimates, the standard L_2 error estimates well-known in risk neutral mean field games are no longer adequate while the model heterogeneity makes it infeasible to use the direct approach which starts with the N-player-based solution and next passes to an infinite population. Our equilibrium analysis depends on carefully handling exponential type error estimates.

Tian Chen
Shandong University
chentian43@163.com

Minyi Huang
Carleton University
School of Mathematics and Statistics
mhuang@math.carleton.ca

MS14

Feedback Stabilization Via a Quantum Projection Filter

In this paper, we examine the case of an incorrectly initialized open quantum system that undergoes imperfect and indirect measurement. This scenario involves introducing an additional state to represent the estimated quantum state. To reduce the computational burden of calculating the quantum filter in real-time, we propose an exponential quantum projection filtering method. This approach involves projecting the time evolution trajectory of the quantum system state onto a lower-dimensional submanifold embedded within a higher-dimensional space. Subsequently, we investigate N-level quantum angular momentum systems coupled with the projection filter to analyze the long-term behavior of these systems when a feedback controller is present. We establish sufficient conditions for the feedback controller that ensure exponential stabilization of the coupled stochastic system toward an eigenstate of the measurement operator. After that, we provide a simplified filter to guarantee the strength of our dimension reduction technique in attaining the feedback stabilization. To demonstrate the effectiveness of the projection filtering scheme, we provide simulation results based on a specific example involving four-level coupled quantum angular momentum systems.

Ibrahim Ramadan
LSS Centrale Supelec
ibrahim.ramadan@laas.fr

Nina H. Amini
CNRS Researcher
nina.amini@lss.supelec.fr

Paolo Mason
cnrs

paolo.mason@lss.supelec.fr

MS14

Quadratic-Exponential Coherent Feedback Control of Linear Quantum Stochastic Systems

This talk considers a risk-sensitive optimal control problem for a field-mediated interconnection of a quantum plant with a coherent (measurement-free) quantum controller. The plant and the controller are multimode open quantum harmonic oscillators governed by linear quantum stochastic differential equations, which are coupled to each other and driven by multichannel quantum Wiener processes modeling the external bosonic fields. The control objective is to internally stabilize the closed-loop system and minimize the infinite-horizon asymptotic growth rate of a quadratic-exponential functional which penalizes the plant variables and the controller output. We obtain first-order necessary conditions of optimality for this problem by computing the partial Frechet derivatives of the cost functional with respect to the energy and coupling matrices of the controller in the frequency domain and state space. An infinitesimal equivalence between the risk-sensitive and weighted coherent quantum LQG control problems is also established. In addition to variational methods, we employ spectral factorizations and infinite cascades of auxiliary classical systems. Their truncations are applicable to numerical optimization algorithms (such as the gradient descent) for coherent quantum risk-sensitive feedback synthesis.

Igor G. Vladimirov
Australian National University
igor.g.vladimirov@gmail.com

Ian Petersen
University of New South Wales,
Australian Defence Force Academy
i.r.petersen@gmail.com

MS15

Sparsity Preserving Formulations for Quadratic Feedback Control of Fluids

Polynomial approximations to Hamilton-Jacobi-Bellman (HJB) equations are effective strategies for designing feedback control laws or finding energy functions for nonlinear balancing in polynomial systems. These strategies have been demonstrated by the works of Krener, Navasca, and others. In recent works, the use of Kronecker products and other tensor-based strategies have exploited structures that enable low-degree approximations for systems with dimensions in the hundreds or more. One hurdle to overcome appears in sparse differential algebraic equations (DAE) where index-reduction methods can destroy sparsity. Even in the differential equation (DE) case, sparsity is often destroyed in generalizations of traditional Lyapunov solvers such as the Bartels-Stewart algorithm. This talk will survey the use of Kronecker product polynomials in approximating HJB equations and provide a demonstration of the benefits of quadratic feedback controllers on a benchmark flow control problem. We will then describe an algorithm that preserves sparsity in the large linear system solves required to compute cubic approximations to the HJB equation for DAEs.

Hamza Adjerid, Ali Bouland, Jeff Borggaard
Virginia Tech
hamzaadjerid@vt.edu, bouland@vt.edu, jborggaard@vt.edu

MS15

Data-Driven Methods for T-Product-Based Dynamical Systems

In this talk, I introduce a novel framework for the data-driven analysis and control of T-product-based dynamical systems (TPDSs), where the system dynamics are governed by the T-product between a third-order dynamic tensor and a third-order state tensor. Traditional data-driven methods typically require unfolding or flattening tensor data, which can discard essential higher-order structural information. In contrast, our approach operates directly within the tensor domain, preserving the inherent multidimensional structure of the data. I will examine the data informativity of TPDSs with respect to system identification, stability, controllability, and state feedback, and present model order reduction techniques specifically designed for TPDSs. The effectiveness of the framework will be demonstrated through numerical examples.

Shenghan Mei
The University of North Carolina at Chapel Hill
shmei@unc.edu

Ziqin He
Department of Mathematics
University of North Carolina at Chapel Hill
zhe21@unc.edu

Yidan Mei
University of North Carolina at Chapel Hill
ymei@unc.edu

Xin Mao
UNC Chapel Hill
xinm@unc.edu

Anqi Dong
KTH Royal Institute of Technology
anqid@kth.se

Can Chen
University of North Carolina at Chapel Hill
canc@unc.edu

MS15

Algebraic Riccati Tensor Equations with Applications in Multilinear Control Systems

In a recent paper [Chen, C. and Surana, A. and Bloch, A. and Rajapakse, I, Multilinear time invariant system theory, SIAM Journal on Control and Optimization, 59(1), 749776, 2021], the authors initiated the control-theoretic study of a class of discrete-time multilinear time-invariant (MLTI) control systems, where system states, inputs, and outputs are all tensors endowed with the Einstein product. They established criteria for fundamental system-theoretic notions such as stability, reachability, and observability through tensor decomposition. Building on this new research direction, the purpose of our paper is to extend the study to continuous-time MLTI control systems. Specifically, we define Hamiltonian tensors and symplectic tensors, and we establish the Schur-Hamiltonian tensor decomposition and the symplectic tensor singular value decomposition (SVD). Based on these concepts, we propose the algebraic Riccati tensor equation (ARTE) and demonstrate that it has a unique positive semidefinite solution if the system is stabilizable and detectable. To find numerical solutions to the ARTE, we introduce a tensor-based Newton method. Additionally, we establish the tensor versions of the bounded real lemma and the small gain theorem. A first-order robustness analysis of the ARTE is also conducted. Finally, we provide a numerical example to illustrate the proposed theory and algorithms.

Guofeng Zhang
The Hong Kong Polytechnic University
guofeng.zhang@polyu.edu.hk

Yimin Wei
Department of Mathematics
Fudan University
ymwei@fudan.edu.cn

MS16

Non-Autonomous Wave Equations: Controllability and Stability

We consider a non-autonomous wave equation on (0,1) with degeneracy at x = 0. Clearly the presence of a non-autonomous term and of a degenerate function leads us to use different spaces with respect to the standard ones and it gives rise to some new difficulties. However, thanks to some suitable assumptions on the functions, one can prove some estimates on the associated energy that are crucial to prove the controllability at a fixed time T or to obtain a uniform exponential decay.

Genni Fragnelli
University of Siena
genni.fragnelli@unisi.it

MS16

Existence of Solutions to Coupled Navier Stokes-Plate interaction PDE System

In this work, we consider a fluid-structure interaction (FSI) system which models the interaction of a fluid flow with a deformable elastic structure and arises in various aeroelastic and biomedical applications; e.g., the fluttering of an airplane/airfoil wing, the movement of wind turbines and bridges, the control of ocular pressure in the eye, and sloshing. The FSI model describes the vibrations of the fluid within the 3D cavity as it interacts with the 2D elastic membrane on the free upper boundary of the cavity. Our main objective is to establish the existence of weak solutions to the said fully nonlinear FSI model, with both Navier Stokes and plate nonlinearities in place.

Pelin Guven Geredeli
Clemson University
pgerede@clemson.edu

MS16

Small-Time Bilinear Control for a Class of Nonlinear Parabolic Evolution Equations

In this talk, I will present some recent results on small-time reachability properties of a nonlinear parabolic equation, controlled via a bilinear control, defined on a torus of arbitrary dimension. Assuming a saturation condition on the control operators, we establish the property of small-time approximate controllability between states that share the same sign. Furthermore, in the one-dimensional case, we extend this result by combining it with a local exact controllability property. This approach allows us to demonstrate the small-time exact controllability of any positive state to the ground state of the evolution operator. This is a joint work with A. Duca and E. Pozzoli.

Cristina Urbani
University of Rome Tor Vergata
Accademia Nazionale dei Lincei
cristina.urbani@unimercatorum.it

MS17

A Simulation-Free Deep Learning Approach to Stochastic Optimal Control

We propose a simulation-free algorithm for the solution of generic problems in stochastic optimal control (SOC). Unlike existing methods, our approach does not require the solution of an adjoint problem, but rather leverages Girsanov theorem to directly calculate the gradient of the SOC objective on-policy. This allows us to speed up the optimization of control policies parameterized by neural networks since it completely avoids the expensive back-propagation step through stochastic differential equations (SDEs) used in the Neural SDE framework. In particular, it enables us to solve SOC problems in high dimension and on long time horizons. We demonstrate the efficiency of our approach in various domains of applications, including standard stochastic optimal control problems, sampling from unnormalized distributions via construction of a Schrdinger-Fllmer process, and fine-tuning of pre-trained diffusion models. In all cases our method is shown to outperform the existing methods in both the computing time and memory efficiency.

Mathieu Lauriere
NYU Shanghai
ml5197@nyu.edu

Eric Vanden-Eijnden
Courant Institute
New York University
eve2@cims.nyu.edu

Mengjian Hua
New York University
mh5113@nyu.edu

MS17

Separable Optimal Value Functions and Their Approximation by Neural Networks

We show that separable functions can be approximated by neural networks for which the number of parameters grows only polynomially with the space dimension. We also demonstrate that the number of data points needed for training a neural network taylored to the separable structure is much smaller than for a general network structure. Motivated by these results, we derive conditions on optimal control problems under which the optimal value function can be approximated by separable functions.

Mario Sperl
Chair of Applied Mathematics
University of Bayreuth
mario.sperl@uni-bayreuth.de

Lars Gruene
University of Bayreuth

lars.gruene@uni-bayreuth.de

Luca Saluzzi
Sapienza
University of Rome
luca.saluzzi@uniroma1.it

Dante Kalise
Imperial College London
d.kalise-balza@imperial.ac.uk

MS17

Koopman-Based System Identification and Optimal Control of Unknown Nonlinear Systems with Stability Guarantees

Learning for control of unknown nonlinear systems with formal guarantees remains a challenging task. In this talk, we first introduce a novel data-driven resolvent operator-based system identification method via learning the (infinitesimal) generator of the Koopman operators of the dynamical systems, which avoids approximation of the time derivative and improves temporal sampling efficiency. Building on this framework, we demonstrate that the computed generator can also be used to derive Lyapunov functions for the unknown systems, providing insights into the stability properties. Furthermore, by leveraging the identified continuous-time dynamics through the generator learning framework, we achieve optimal control of the unknown systems by solving the Hamilton-Jacobi-Bellman (HJB) equations via policy iteration (PI). In the PI process, accurate neural network solutions for the generalized HJB equation (a linear PDE) can be attained, which converges to the true solution of the HJB equation in an iterative manner. The resulting value functions also serve as Lyapunov functions, thereby guaranteeing both optimality and stability.

Ruikun Zhou
University of Waterloo
ruikun.zhou@uwaterloo.ca

Yiming Meng
University of Illinois Urbana-Champaign
ymmeng@illinois.edu

Zhexuan Zeng
Huazhong University of Science and Technology
xuanxuan@hust.edu.cn

Jun Liu
University of Waterloo
j.liu@uwaterloo.ca

MS19

Properties of Turnpike Functions for Discounted Markov Decision Processes

This paper studies discounted Markov Decision Processes (MDPs) with finite sets of states and actions. Value iteration is one of the major methods for finding optimal policies. For each discount factor, starting from a finite number of iterations, which is called the turnpike integer, value iteration algorithms always generate decision rules which are deterministic optimal policies for the infinite-horizon problems. This fact justifies the rolling horizon approach for computing infinite-horizon optimal policies by conducting a finite number of value iterations. This paper describes properties of turnpike integers and provides their upper bounds.

Eugene A. Feinberg
Stony Brook University
eugene.feinberg@stonybrook.edu

Gaojin He
University of California San Diego
ghe@ucsd.edu

MS19

Dimension-free Bounds on the N-player Nash System and Applications

This talk will be about N-player stochastic differential games, as well as the partial differential equations (PDEs) and forward-backward stochastic differential equations (FBSDEs) which describe their Nash equilibria. While our study is largely inspired by mean field game theory, we focus on large but finite N. Our main results are about monotone games with weak interactions between players. In particular, we show that for such games, it is possible to obtain quantitative estimates on both the Nash system (which describes closed-loop equilibria) and the Pontryagin system (which describes open-loop equilibria) which are dimension-free, in that they are independent of the number N of players. These bounds have a number of interesting consequences, most notably an estimate on the difference between open-loop, closed-loop, and distributed equilibria of the game. This estimate confirms and quantifies the intuition that when interactions between players are weak, the information structure of the game is not important. This is joint work with Marco Cirant and Davide Redaelli.

Joe Jackson
The University of Chicago
jsjackson@uchicago.edu

MS19

Optimal Control Approach for Analysis of Nonlinear Filter

Dissipation is at the heart of any stability theory for dynamical systems. For Markov processes, dissipation is referred to as the variance decay. This talk is concerned with extension of variance decay to the study of conditioned Markov processes (nonlinear filter). Specifically, the following questions are of interest:

Q1. What is the appropriate notion of variance decay for a nonlinear filter? And how is it related to filter stability?

Q2. What is the appropriate generalization of the dissipation equation for the nonlinear filter?

Q3. How is it related to the hidden Markov model (HMM) properties such as ergodicity, observability, and detectability?

In this talk, we provide an answer to each of these questions based on a newly discovered duality between nonlinear filtering and optimal control.

Prashant G. Mehta
Department of Mechanical Science and Engineering
University of Illinois at Urbana Champaign

mehtapg@illinois.edu

MS19

Viscosity Solution of Stochastic Hamilton-Jacobi-Bellman Equations in the Wasserstein Space

In this talk, we shall introduce a viscosity solution theory of the stochastic Hamilton-Jacobi-Bellman equation in the Wasserstein spaces for the mean-field type control problem which allows for random coefficients and may thus be non-Markovian. The value function of the control problem is proven to be the unique viscosity solution. Various challenges and techniques will be introduced and addressed.

Jinniao Qiu
University of Calgary, Canada
jinniao.qiu@ucalgary.ca

Hang Cheung, Alexandru Badescu
University of Calgary
hang.cheung@ucalgary.ca, abadescu@ucalgary.ca

MS20

A Switch Point Algorithm Applied to a Harvesting Problem

We investigate an optimal harvesting problem of a spatially explicit fishery model that was previously analyzed. On the surface, this problem looks innocent, but if parameters are set to where a singular arc occurs, two complex questions arise. The first question pertains to chattering, a phenomenon in which the optimal control possesses a singular arc that cannot be concatenated with the bang-bang arcs without prompting infinite oscillations over a finite region. 1) How do we numerically assess whether or not a problem chatters in cases when we cannot analytically prove such a phenomenon? The second question focuses on implementation of an optimal control. 2) When an optimal control has regions that are difficult to implement, how can we find alternative strategies that are both suboptimal and realistic to use? Although the former question does not apply to all optimal harvesting problems, most fishery managers should be concerned about the latter. Interestingly, for this specific problem, our techniques for answering the first question results in an answer to the second. Our methods involve using an extended version of the switch point algorithm (SPA), which handles control problems having initial and terminal conditions on the states. In our numerical experiments, we obtain strong empirical evidence that the harvesting problem chatters, and we find three alternative harvesting strategies with fewer switches that are realistic to implement and near optimal.

Summer Atkins
University of Alabama in Huntsville
Department of Mathematical Sciences
Summer.Atkins@uah.edu

Maia Martcheva
University of Florida
maia@ufl.edu

William Hager
University of Florida
Department of Mathematics
hager@ufl.edu

MS20

Optimal Control of Virotherapy in a Tumor Model

Oncolytic virotherapy result in using genetically-modified viruses in order to infect tumor cells while safe-guard healthy cells. Here we propose two novel mathematical models that describe the interaction between three populations, i.e. tumor cells, infected tumor cells and virus particles, for small and large tumors, by assuming density and frequency-dependent virus transmission, respectively. Both the infection due to the virus and to the infected tumor cells were considered, as well as the mortality of the cells due to the activation of the immune system by the virus population itself, features encountered in vaccinia virus population. Moreover, we assumed that the tumor cells can grow following a generalized logistic law. For both the models an optimal control problem was formulated, i.e. find the optimal virus input in time, needed to minimize the population of the tumor cells, infected and not, at the end of the treatment as well as during the treatment. Furthermore, also the cost of the treatment itself and the sided effect of it were taken into consideration. One of the main results suggest that is important for the virus population to be able to propagate trough the non-infected tumor cell, meaning the immune response on the virus infected tumor cells, and as a consequence their mortality, must to be lower than that of the non-infected tumor cells.

Stefania Allegretti
University of Potenza
stefania.allegretti@studenti.unibas.it

Iulia Martina Bulai
University of Sassari
imbulai@uniss.it

Jessica Kingsley
University of Tennessee- Knoxville
jkingsl1@vols.utk.edu

Suzanne M. Lenhart
University of Tennessee
Department of Mathematics
slenhart@utk.edu

Giulia Orr
University of Sassari
gorru@uniss.it

MS20

Modeling and Optimal Control for Melanoma Combination Regimens

Improvements in drug regimens can make a difference in both clinical trial success and patient outcomes. The use of mathematical models and optimal control can be used to predict best regimens, which can then be tested experimentally and clinically. I will show some of our recent work using data to inform a model of melanoma, and our analysis of the model and optimization of combination therapy. Techniques include sensitivity analysis, identifiability analysis, and optimal control. I will also discuss some of the work that remains to be done.

Mahya Aghaee, Victoria Cicchirillo, Kyle Adams, Alberto Riva

University of Florida
mahya.aghaee@medicine.ufl.edu, vcicchirillo1@ufl.edu, adams.k@ufl.edu, ariva@ufl.edu

William Hager
University of Florida
Department of Mathematics
hager@ufl.edu

Ashley Brown, Elias Sayour, Domenico Santoro, Rowan Milner, Bently Doonan, Helen Moore
University of Florida
ashley.brown@medicine.ufl.edu, elias.sayour@neurosurgery.ufl.edu, dsantoro@ufl.edu, milnerr@ufl.edu, bently.doonan@medicine.ufl.edu, helen.moore@medicine.ufl.edu

MS20

Incorporating Awareness, Misinformation and Optimal Control in a Model of SARS-CoV-2

In the last five years, SARS-CoV-2 posed devastating effects on public health, and there is growing concern about the proliferation of misinformation. In this project, we formulate an SEIR-type model of SARS-CoV-2 with three susceptible compartments, consisting of adherent, non-adherent, and misinformed individuals. We derive the disease-free equilibrium and the media-dependent reproduction number of our model. The global stability of the disease-free equilibrium and the uniform persistence of SARS-CoV-2 are established. Unknown parameter values of our model are estimated, using data on the cumulative number of cases of symptomatic infections humans in the state of Georgia. Numerical simulations suggest a decrease in prevalence when susceptible humans transition from misinformed to adherent susceptible humans, and when adherent susceptible humans send media related messages on the spread and control of SARS-CoV-2. Furthermore, there is an increase in the media-dependent reproduction number with an increase in misinformation. Finally, an optimal control of awareness and misinformation problem is formulated and analyzed.

Eric Numfor
Augusta University
Department of Mathematics
enumfor@augusta.edu

MS21

Maximum Entropy Random Walk on Hypergraph

Interactions among groups of individuals, rather than simple pairwise connections, are best captured by hypergraphs, whose hyperedges represent high-order relationships. Modeling diffusion and random processes in such systems requires new approaches beyond traditional graph-based methods. This paper introduces a framework for maximum entropy random walks on hypergraphs, building on and extending recent work in random walks on hypergraphs and maximum entropy walks on networks. Unlike methods that rely on projecting hypergraphs onto second-order networks, our approach directly optimizes within uniform hypergraphs, preserving the high-order structure. To achieve this, we develop an efficient numerical solver based on the Sinkhorn-Schrdinger algorithm, enabling scalable computation through matrix and tensor rescaling. Through numerical simulations and real-world applications, we demonstrate the advantages of fast-mixing behavior and improved diffusion in systems with high-order interactions.

Anqi Dong
KTH Royal Institute of Technology
anqid@kth.se

MS21

T-Product-Based Time-Varying Systems Theory

T-product-based time-varying systems provide a structured and computationally efficient framework for modeling multi-dimensional dynamical processes across various applications, including video processing, networked systems, and biomedical signal processing. However, the system-theoretic properties of such systems remain largely unexplored. In this article, we address this gap by investigating the controllability and observability of T-product-based time-varying systems, deriving tensor-based rank conditions that generalize classical criteria to the tensor setting. Leveraging the block circulant structure of the T-product in the Fourier domain, we develop efficient formulations that significantly reduce the computational complexity of analyzing system-theoretic properties. Numerical examples further demonstrate the effectiveness and efficiency of the proposed approaches.

Yidan Mei
University of North Carolina at Chapel Hill
ymei@unc.edu

Shenghan Mei
The University of North Carolina at Chapel Hill
shmei@unc.edu

Ziqin He
Department of Mathematics
University of North Carolina at Chapel Hill
zhe21@unc.edu

Xin Mao
UNC Chapel Hill
xinm@unc.edu

Anqi Dong
KTH Royal Institute of Technology
anqid@kth.se

Can Chen
University of North Carolina at Chapel Hill
canc@unc.edu

MS21

Decentralised Graphical Network Stability Certificates via Davis-Wielandt Shell

Advances in communication and network technologies have driven the rapid growth of modern networked control systems such as power grids, social networks, distributed optimization algorithms deployed across a network of computation devices, and even the communication network itself. These networks face challenges brought by common factors such as large scale, high nonlinearity, heterogeneity, and delays, all of which complicate their analysis and design. This motivates the development of scalable, decentralised, and robust control-theoretical tools tailored for networks. In this presentation, we will highlight some recent progress in this area of research. The well-established singular-value-based gain and the recently revitalized phase con-

cepts have been exploited in depth for network stability analysis, both offering strong graphical insights. We first explore a frequency-wise combination of these two tools to generate mixed gain-phase network stability certificates. Then, we introduce the Davis-Wielandt shell a graphical representation that integrates both gain and phase information of a matrix to reduce the conservatism in these certificates. These tools can handle network dynamics with large phase lag and delays, laying the foundation for further investigation into topics such as network delay margins. Throughout, we will also illustrate, in the context of network congestion control, their application to practical networks.

Ding Zhang
Hong Kong University of Science and Technology
ding.zhang@connect.ust.hk

Li Qiu
The Chinese University of Hong Kong, Shenzhen
qiuli@cuhk.edu.cn

MS21

Exponential Maps for Designing Periodic Trajectories for Nonlinear Systems with Bang-Bang Controls

We focus on the problems of existence and design of periodic trajectories for nonlinear control systems with bang-bang input signals. Such trajectories arise as extremals in periodic optimal control problems for control-affine systems with non-strictly convex costs. A particularly important application that motivates our study is the optimization of periodic operations in nonlinear chemical reactions, where the goal is to maximize the product yield. After parameterizing the considered class of inputs by switching times, we reformulate the original problem in terms of designing compositions of exponential maps corresponding to the flow components during relevant time sub-intervals. These compositions of flows are represented by the exponential map of the vector field, obtained using iterations of the Baker-Campbell-Hausdorff-Dynkin (BCHD) formula. We prove that the existence of a periodic solution for the original control problem is equivalent to the existence of a periodic solution for an associated autonomous system, which we refer to as the BCHD-extension. The construction of a truncated BCHD-extension is explicitly presented for a given truncation length of the iterated Lie brackets. This methodology is then applied to a mathematical model of a controlled nonisothermal chemical reaction of the hydrolysis type. We show that the BCHD-extension of this model possesses a steady-state corresponding to a periodic operating mode of the reaction under periodic bang-bang actuation.

Alexander Zuyev
Max Planck Institute for Dynamics of Complex Technical Syst.
zuyev@mpi-magdeburg.mpg.de

Peter Benner
Max Planck Institute Magdeburg
benner@mpi-magdeburg.mpg.de

MS22

Memory-Augmented Adaptive Control Architecture for Switched Systems

In this talk, we present a memory-augmented adaptive control architecture for switched uncertain systems. We will introduce the notion of intermittent initial excitation (IIE), which serves as a less stringent condition compared to the traditional persistence of excitation for switched systems. Our analysis will encompass a class of linear and nonlinear switched systems. When the IIE condition is met and a dwell-time constraint on the switching signal is satisfied, we show that the memory-augmented architecture ensures closed-loop stability and convergence of the tracking and parameter estimation errors. Finally, we will discuss the limitations of this architecture and explore future research directions that do not rely on prior knowledge of the switching signal. Finally, we will discuss the limitations of this architecture and explore future research directions that do not rely on prior knowledge of the switching signal. In particular, the methodology proposed in this work operates under the assumption of a known switching signal, a condition not commonly met in numerous practical applications spanning robotics, aerospace, and power systems, among others. Consequently, a pertinent need exists within the switched adaptive control literature to develop methodologies that cater to scenarios where the switching signal is unknown.

Pritesh Patel
University of Southampton
priteshpatel.iitd@gmail.com

Sayan Basu Roy
IIIT Delhi
sayan@iiitd.ac.in

Shubhendu Bhasin
Department of Electrical Engineering, IIT Delhi,
Hauz Khas, New Delhi, India - 110016
sbhasin@ee.iitd.ac.in

MS22

Switched Linear Systems: Stability and Matrix Commutators

Switched systems find wide applications in modelling, analysis and control of a large class of complex systems. Due to various interesting qualitative behaviour exhibited by these systems, stability has been a key concern for researchers. Among many tools and techniques employed in the study of stability of switched systems, we will explore a comparatively less explored route of Lie algebra. The role of commuting and close to commuting properties of constituent subsystems matrices towards guaranteeing stability will be discussed. We will focus on switched systems whose some or all subsystems are unstable and switching signals obey prior restrictions on admissible switches between the subsystems and admissible dwell times on the subsystems. The analysis involves matrix commutators and combinatorics. The proposed techniques find applications in the design of time-scheduling algorithms for networked systems operating with shared communication networks of limited bandwidth. The results, to be presented, appeared in: [A. Kundu, On stabilizability of switched linear systems under restricted switching, IEEE Transactions on Automatic Control, vol. 67, no. 4, 2022, pp. 2060-2067], [A. Kundu, On the design of stabilizing cycles for switched linear systems, IEEE Control Systems Letters, vol. 4, no. 2, 2020, pp. 385-390], [A. Kundu, Scheduling networked control systems under jamming attacks, Proceedings of the 59th IEEE Conference on Decision and Control (CDC), 2020, pp. 3298-3303].

Atreyee Kundu

Department of Electrical Engineering, IIT Kharagpur
West Bengal, India - 721302
atreyee@ee.iitkgp.ac.in

MS22

Stability Analysis of Switched Differential Algebraic Equations

We present a Lie algebraic decomposition-based criterion for stability of switched differential algebraic equations (switched DAEs). A switched DAE is a family of linear differential algebraic equations (descriptor system) and a switching logic that orchestrates switching amongst these subsystems. Systems which undergo switching and are also subjected to algebraic constraints can be naturally modeled as switched DAEs. In particular, we show that if the Lie algebra generated by the differential flows associated with the subsystems can be decomposed into its radical and a compact Lie algebra, assuming that the subsystems are individually stable and regular, then the switched DAE is globally exponentially stable for a class of switching signals. Stability is guaranteed for the set of all switching signals which have a non-zero infimum of the switching durations. Furthermore, we show that a switched DAE satisfying the Lie algebraic criterion is not necessarily stable for all arbitrary switching signals. This is in stark contrast with the Lie algebraic criterion for conventional switched systems, which guarantees stability for all arbitrary switching signals. We demonstrate this phenomenon with an example which satisfies the Lie algebraic criterion, but is unstable when subjected to exponentially fast switching signals.

Debasattam Pal
Department of Electrical Engineering
Indian Institute of Technology Bombay, Powai, Mumbai
debasattam@ee.iitb.ac.in

Phani Raj
Amrita School ofEngineering Bangalore
Bengaluru, India
phaniraj3br069@gmail.com

MS22

Model Reduction of Switched Systems Via Midpoint Gramians

We propose a novel model-reduction approach for switched linear systems with a known switching signal. The class of considered systems encompasses switched systems with mode-dependent state dimension as well as impulsive systems. Our proposed method utilizes suitable reachability and observability Gramians to identify simultaneously difficult to reach and difficult to observe states, which will then be removed. Since reachability and observability properties of a switched systems depend strongly on the switching signal, our method is expected to produce smaller reduced models compared to reduction methods which are independent of the switching signal. In particular, our method will result in mode-dependent state-dimension and can therefore better take into account the local reachability and observability properties. By fixing the switching signal, the switched system can also be viewed as a linear time-varying system. However, existing model reduction methods for linear time-varying systems assume sufficiently smooth coefficient matrices (jumps are not allowed) and also would result in a fully time-varying (and not piecewise-constant) reduced model, which is usually not desired. This presentation is based on [Hossain & Trenn, IEEE TAC 69(1), pp. 535–542, 2024] and presents some extension by allowing non-zero initial conditions and an additional discrete input affecting the jump map, which have been utilized in [Hossain & Trenn, DAE-Panel , Vol. 3, 2025].

Stephan Trenn
System, Control and Applied Sciences - Bernoulli Institute
University of Groningen, 9747 AG, Groningen, The Netherlands
s.trenn@rug.nl

Md. Sumon Hossain
Department of Mathematics & Physics
North South University, Dhaka, Bangladesh
sumon.hossain@northsouth.edu

MS23

Dynamic Driving and Routing Games for Autonomous Vehicles on Networks: A Mean Field Game Approach

As this eras biggest game-changer, autonomous vehicles (AV) are expected to exhibit new driving and travel behaviors, thanks to their sensing, communication, and computational capabilities. However, the majority of studies assume AVs are essentially human drivers but react faster, see farther, and know the road environment better. We believe AVs most disruptive characteristic lies in its intelligent goal-seeking and adapting behavior. Building on this understanding, we propose a dynamic game based control leveraging the notion of mean-field games (MFG). I will first introduce how MFG can be applied to the decision-making process of a large number of AVs. To illustrate the potential advantage that AVs may bring to stabilize traffic, I will then introduce a multi-class game where AVs are modeled as intelligent game-players and HVs are modeled using a classical non-equilibrium traffic flow model. Last but not the least, I will talk about how the MFG-based control is generalized to road networks, in which the optimal controls of both velocity and route choice need to be solved for AVs, by resorting to nonlinear complementarity problems. The latest advance in learning MFGs will also be discussed.

Xuan Sharon Di
Columbia University
sharon.di@columbia.edu

MS23

Some New Results on Mean Field Games of Controls

Mean field games of controls model large-scale interactions between rational agents who take into account the joint distribution of other players states and controls. They commonly arise in economics applications, for example, when the equilibrium is determined through the market price. There are still relatively few theoretical results on these models, which involve complex nonlinear systems of PDEs. In this talk I will present some recent results showing that such systems are well-posed under conditions that have not previously been addressed in the literature.

Jameson Graber
Baylor University

jameson_graber@baylor.edu

MS23

Convex Duality Approaches for Graphon Mean Field Systems

A novel approach to optimal control in large-scale, nonlinear multi-agent networks is presented by leveraging Convex Duality Optimal Control (CDOC) within the framework of Graphon Mean Field Systems (GMFS). The fundamental idea of convex duality methods for optimal control is the introduction of a weak formulation that embeds the original (strong) optimal control problem into a convex linear program over the space of Radon measures. This approach, originally proposed by Vinter and Lewis and later extended by Fleming and Vermes, has been primarily applied to single-agent settings. However, extending these methods to multi-agent systems presents a significant challenge due to the nonlinearity introduced by agent interactions. The key innovation in our approach lies in the careful construction of the operators and functionals which maintain the population's current strategy and only permitting variations in an individual agent's strategy, hence, ensuring that the associated optimization problem maintains linearity. This sets the stage for the application of convex duality relations between the spaces of measure and function, and enables the application of the Fenchel-Rockafellar duality theorem to derive optimality conditions for multi-agent systems. This work highlights the power and versatility of convex duality methods in addressing a wide range of control challenges in large-scale networked systems, showcasing their potential beyond traditional applications.

Ali Pakniyat
University of Alabama
apakniyat@ua.edu

MS23

Control of Large-Scale Heterogeneous Systems: An Extended Graphon Mean-Field Approach

Networks play a central role in modeling complex systems such as financial markets, power grids, social interactions, and epidemiology. As these systems scale in size and complexity, developing robust and efficient analytical tools becomes essential. This talk examines dynamical systems of interacting agents or particles with heterogeneous connections, represented through graph structures. By employing graphon theory, we analyze the large-population limit, proving a propagation of chaos result that yields a collection of mean-field stochastic differential equations. We further address the control of these non-exchangeable McKean-Vlasov systems from the perspective of a central planner capable of influencing asymmetric interactions. Leveraging tools tailored for this framework, such as derivatives along flows of measures and the corresponding It calculus, we establish that the value function of this control problem satisfies a Bellman dynamic programming equation in a function space over the Wasserstein space. To illustrate the applicability of our approach, we present a linear-quadratic graphon model with analytical solutions and apply it to a systemic risk example involving heterogeneous banks. Based on joint works with: A. De Crescenzo, F. Coppini, F. De Feo, M. Fuhrman and I. Kharroubi.

Huyn Pham
Ecole Polytechnique
huyen.pham@polytechnique.edu

MS24

Existence of an Optimal Control for the Multiscale System of Coupled Poroelasticity Equations and Lumped Hydraulic Circuit

Important biomechanical processes in the body, such as tissue perfusion, are governed by both local and global effects. Our proposed model uses a 3D system of partial differential equations to model the local area of tissue perfusion as fluid flowing through a deformable poroelastic medium. The corresponding global effects of the circulatory system are then modeled by a system of ordinary differential equations, using the electrical analog of hydraulic components to describe the system. The two systems are coupled across an interface of the porous medium via boundary conditions, which preserves the continuity of mass and the balance of stresses. For the optimal control problem, we utilize a quadratic cost functional with target values for the poroelastic displacement and pressure solutions minimized over a set of controls. The analysis of this multiscale interface coupling and control problem is important in the study of the development and progression of glaucoma in the eye, as the development of this disease has been linked to intraocular pressure and tissue perfusion (local factors), but also blood pressure (global factor). Our goal is to better understand the relation between all these factors and their influence on glaucoma. For the multiscale system with linear poroelasticity equations and non-linear hydraulic circuit, we give results on the wellposedness of solutions and existence of an optimal control to the minimization problem.

Matthew Broussard
NC State University
mbrouss@ncsu.edu

Lorena Bociu
NC State University
Raleigh, NC
lvbociu@ncsu.edu

Sarah Strikwerda
University of WisconsinMadison
sstrikwerda@wisc.edu

MS24

Exponential Consensusand l_∞−stabilityfor An Hegselmann-Krausemodel Withleadership and Time-Delayed Interaction

We study an opinion formation model that describes an interaction between agents influenced by a group of leaders. Moreover, the interaction between all the agents is delayed thanks to the presence of time-delay terms. In this framework, we study the convergence to consensus and the stability in l_∞ for this model type to justify the mean-field limit procedure. Indeed, the stability result together with the uniform consensus estimate for the particle model enables us to extend the asymptotic consensus to the continuum model.

Chiara Cicolani
Università degli Studi dell'Aquila

chiara.cicolani@graduate.univaq.it

MS24

A Mixed Peridynamical Approach to Beams

We will report on some recent results concerning a new model for beams, obtained by the sum of a classical operator and a nonlocal peridynamical one. In particular, stability and instability results will be faced.

Dimitri Mugnai
Università della Tuscia
dimitri.mugnai@unitus.it

MS25

Learning Value Functions with Second Order Information

This talk is devoted to recent results on the approximation of high-dimensional HJB PDEs via machine learning methods. We will discuss supervised learning of high-dimensional value functions using high-order data, a.k.a. Sobolev training. We expand our previous work on gradient-augmented learning for value functions to incorporate second-order (Hessian) information. Unlike gradient information that is available directly from PMP solvers, the Hessian values is recovered by solving a non-autonomous Riccati equation depending on the optimal trajectory. Hence, it is crucial to understand the dimension/nonlinearity regime where the cost of obtaining second-order information is justified in term of data efficiency.

Dante Kalise
Imperial College London
d.kalise-balza@imperial.ac.uk

MS25

Optimal Estimation of Nonlinear Systems with Stable Error Dynamics

State estimation involves estimating the states of a noisy dynamical system, given a mathematical model and measurements, both of which contain errors. The Kalman filter is an optimal filter for estimating the states of linear dynamical systems with white Gaussian noises of known mean and covariance. However, state estimation for nonlinear, high-dimensional systems remains a challenging task. We propose a pathway to optimal estimation of high-order systems by using neural networks. In particular, we use a type of Jordan recurrent neural networks, which we term as Jordan structure-based long short-term memory network(JLSTM). We apply this approach to several nonlinear dynamical systems and compare the results with those obtained using the Elman structure-based long short-term memory network(ELSTM) and a Kalman filter approach - Kalman filter for linear systems, and extended Kalman filter for nonlinear systems.The results indicate that for nonlinear systems, long short-term memory networks can reduce estimation error and computation time. Furthermore, JLSTMs require less training to achieve performance comparable to the ELSTMs.Additionally, we present an input-to-state stability analysis for the error dynamics in several examples of Jordan-based network estimators.

Avneet Kaur, Kirsten Morris
Dept. of Applied Mathematics
University of Waterloo
a93kaur@uwaterloo.ca, kmorris@uwaterloo.ca

MS25

A Residual Training Algorithm for Deep Learning in Regression

Deep neural networks are widely regarded as powerful tools for solving nonlinear problems in science and engineering. However, as problem complexity increases, achieving high accuracy becomes more difficult due to non-convex optimization and the proliferation of hyperparameters. Moreover, traditional methods often prioritize minimizing mean squared error (MSE) while overlooking L_∞ error a key metric in many applications. To address these challenges, we propose a structured framework for neural network design and tuning. In our approach, an artificial neural network incrementally grows by adding new blocks informed by prediction errors. This residue training process leads to improved overall accuracy. We discuss how to take advantage of the structure of the residuals to guide the choice of loss function and number of parameters to use. Furthermore, we investigate how different activation functions influence both MSE and L_∞ metrics. Numerical results confirm the effectiveness of our approach, providing a practical strategy for developing high-fidelity neural network models.

Ethan Mulle
University of California Santa Cruz
emulle@ucsc.edu

Qi Gong
University of California, Santa Cruz
qigong@soe.ucsc.edu

Wei Kang
Naval Postgraduate School
wkang@nps.edu

MS25

The Role of Duality in Data Driven Control

Data-driven control (DDC), that is learning controllers directly from observed data, has attracted substantial attention in recent years due to its advantages over model-based control. By avoiding a potentially expensive identification step, these methods hold the promise of achieving improved performance with lower computational cost. However, while indeed avoiding conservatism by directly working with an exact representation of the consistency set (all plants consistent with the observed data), naively applied these methods can lead to computationally expensive optimization problems. For instance, for the case of polynomial dynamics and data corrupted by ℓ_∞ noise, many DDC problems can be recast as a semi-algebraic optimization in $\mathcal{O}(n^2)$ variables, where n is the dimension of the state. Given the poor scaling properties of semi-algebraic optimization solvers, this approach is limited to small order systems. In this talk we will highlight the central role that duality can play in substantially reducing computational complexity. We will illustrate these results with several applications including safe control of non-linear systems, enforcing contractivity, and handling error-in-variables scenarios. In the first two cases, using duality allows for scaling the number of indeterminates back to $\mathcal{O}(n)$. In the error-in-variables case the number of variables becomes independent of the length of the data sequence used for training

Mario Sznaier, Jian Zheng, Andreas Oliveira
Northeastern University
msznaier@ece.neu.edu, zheng.jian1@northeastern.edu, franciscodemelooli.a@northeastern.edu

Jared Miller
University of Stuttgart
jared.miller@imng.uni-stuttgart.de

MS26

Introduction to Port-Hamiltoinan Systems (phs)

In this talk, we provide a concise introduction to port-Hamiltonian (pH) systems, a class of control systems that inherit a physics-based state-space formulation. This structure makes them particularly well-suited for the control and analysis of multi-physical systems. As an extension of Hamiltonian systems, pH systems naturally possess a Hamiltonian function that describes the systems energy and serves as a Lyapunov candidate. Additionally, pH systems account for energy dissipation and enable coupling via port variables, facilitating system decomposition. We also offer an overview of the key themes addressed in this minisymposium, which include advanced control applications, the control and stability of distributed pH systems, and data-driven as well as learning-based approaches to pH systems.

Hannes Gernandt
Fraunhofer IEG, Cottbus, Germany
gernandt@uni-wuppertal.de

MS26

Irreversible Port-Hamiltonian Systems

Originating in macroscopic mechanics, port Hamiltonian formulations were proposed and intensively used for the modular modelling and control of conservative and dissipative multiphysics systems for which the thermal domain does not need to be explicitly represented. Yet in many cutting-edge engineering applications, for example within the fields of soft robotics, process control, material sciences, etc.. temperature plays a central role and needs to be explicitly taken into account. Several attempts have been made to extend port Hamiltonian and Lagrangian formulations to this class of systems. Among them, the Irreversible port Hamiltonian formulations (IPHS), are particularly promising for their simplicity, their constructiveness and the amount of information they can encode. In this talk we first recall some definitions and properties of IPHS. We show how this structure allows to cope with the first and second principles of Thermodynamics and how the interconnection of two controlled IPHS via thermal ports has to be (co-)state modulated in order to ensure the closed-loop IPHS structure. This modulation and closed loop invariants are used to derive efficient controllers via energy shaping and entropy assignment. We then present some recent extensions to boundary controlled distributed parameter systems defined on a 1D spatial domain and show, on the heat equation example, how similar energy shaping and entropy assignment techniques can be used for control design.

Yann Le Gorrec
FEMTO-ST AS2M, ENSMM
yann.le.gorrec@ens2m.fr

Hector Ramirez
Universidad Técnica Federico Santa María
hector.ramireze@usm.cl

MS26

Port-Hamiltonian Modeling and Control for Cardiac Assist Device(s)

Dielectric elastomer actuators (DEAs) are soft actuators composed of dielectric elastomer layers sandwiched between compliant electrodes. These actuators demonstrate low response time, large deformation and are bio compatible, making them highly promising candidates for biomedical applications. As an example, DEAs hold potential for use in cardiac assist devices by replacing a section of the aorta to treat heart failure. However, these actuators encounter electro-mechanical instability when the applied voltage exceeds a certain limit. Consequently, the use of DEAs is limited in terms of energy efficiency. This talk introduces an energy-based modeling framework and control strategies for DEAs, which integrates their intrinsic non-linearties coming from geometric considerations, materials nonlinear behavior, electro-mechanical coupling, as well as interactions with the fluid. Moreover, the model captures the aforementioned electro-mechanical instabilities. The proposed model has been validated with experimental data. We show that passivity-based control with the adjunction of integrators allows to stabilize the DEA system at a desired position, and can reject external perturbations.

Ning Liu
UBFC/FEMTO-ST AS2M
ning.liu@femto-st.fr

Yann Le Gorrec
FEMTO-ST AS2M, ENSMM
yann.le.gorrec@ens2m.fr

Amal Hammoud
FEMTO-ST AS2M, SUPMICROTECH
amal.hammoud@femto-st.fr

MS26

Predictive Control of Port-Hamiltonian Systems and Its Application to Heating and Gas Networks

The port-Hamiltonian framework is well equipped to model a large class of multi-physics systems, explicitly using the passivity properties for interconnecting the subsystems and for interconnection with other systems. Many physical systems can be represented as port-Hamiltonian systems. These systems, which are a generalization of the classical Hamiltonian systems, are first developed to provide a unified framework to model systems consisting of different physical domains via energy as the 'lingua franca'. On the other hand, optimal control problems are ubiquitous in systems and control in various forms based on different cost functions. Considering the similarities between the optimality Hamiltonian, which is fundamental in Pontryagin's Maximum Principle and the Hamiltonian evolving as the total energy in energy-based modeling, a natural minimum energy optimal control problem is studied in [Schaller et al., "Control of port-Hamiltonian systems with minimal energy supply", European Journal of Control, 2021] for linear continuous-time port-Hamiltonian systems. In this work, we first define the strict dissipativity properties of a discrete-time port-Hamiltonian system to analyze a minimum energy optimal control problem. Next, we exploit the slow long-term behaviour of the optimal solutions to study the closed loop performance of model predictive (receding horizon) controllers. Finally, we apply the results to examples of heating and gas networks.

Arijit Sarkar
Brandenburg University of Technology Cottbus - Senftenberg
sarkar@b-tu.de

Vaibhav Kumar Singh
University of Groningen
vks.iitb29@gmail.com

Manuel Schaller
Technische Universität Ilmenau, Germany
manuel.schaller@mathematik.tu-chemnitz.de

Karl Worthmann
Technische Universität Ilmenau
karl.worthmann@tu-ilmenau.de

MS27

Optimal Quantum Control Using Ensemble Quantization

The robust manipulation of ensembles of quantum systems exhibiting variations or uncertainties in the system parameters and dynamics has been a long-standing problem in the field of quantum control. Existing methods for addressing quantum ensemble control primarily rely on the use of state-space models that describe the time evolution of quantum states. In this talk, we introduce a distinctive quantum control paradigm by mapping the quantum ensemble control problem to a dual problem defined on a coordinate system established by a moment transform. This transformation introduces a new type of quantization in quantum systems, enabling tractable systems-theoretic analysis and effective optimal control design, which are typically opaque. Subsequently, we develop an iterative computational algorithm to solve the transformed optimal moment control problems. We conduct a convergence analysis for the proposed algorithm and demonstrate its applicability and effectiveness on various challenging pulse design problems in quantum control.

Jr-Shin Li, Wei Zhang
Washington University in St. Louis
jsli@wustl.edu, wei.zhang@wustl.edu

MS27

Exploring the Robustness of Stabilizing Controls for Stochastic Quantum Evolutions

In this work we analyze and bound the effect of modeling errors on the stabilization of pure states or subspaces for quantum stochastic evolutions. Different approaches are used for open-loop and feedback control protocols. For both, we highlight the key role of dynamical invariance of the target: if the perturbation preserves invariance, it is possible to prove that it also preserves its attractivity, under some additional assumptions. In addition, we prove boundedness in mean of the solutions of perturbed systems under open-loop protocols. For the feedback strategies, in the general case without assumptions on invariance, we provide bounds on the perturbation effect in expectation and in probability, as well as specific bounds for non-demolition nominal systems.

Weichao Liang
Université Paris Saclay
weichao.liang@yahoo.com

MS28

The Analysis of an Inverse Problem for a Fluid-Solid Interaction Model

In this talk we will consider a one-dimensional fluid-solid interaction model governed by the Burgers equation with a time varying interface. It is a preliminary simplified version of other more complicate and more realistic models in higher dimensions. We will see the results we have obtained for the inverse problem of determining the shape of the interface from Dirichlet and Neumann data at one end point of the spatial interval. In particular, we will establish uniqueness results and some conditional stability estimates. For the proofs, we have used and adapt some lateral estimates that, in turn, rely on appropriate Carleman and interpolation inequalities (following results in “[M. Yamamoto, Carleman estimates for parabolic equations and applications]’). The results that will be shown in this talk have been published in “[J. Apraiz, A. Doubova, E. Fernández-Cara, M. Yamamoto, Inverse problems for one-dimensional fluid-solid interaction models]’.

Jone Apraiz
Universidad del País Vasco
jone.apraiz@ehu.eus

Anna Doubova
Universidad de Sevilla
doubova@us.es

Enrique Fernández-Cara
University of Sevilla, Spain
cara@us.es

Masahiro Yamamoto
Graduate School of Mathematical Sciences
The University of Tokyo, Japan
myama@next.odn.ne.jp

MS28

Scalar Balance Laws with Singular Nonlocal Sources

We will present a local well-posed result for entropy admissible solutions with a single shock of scalar balance laws, with singular integral of convolution type kernels. In a neighborhood of the shock curve, a description of the solution is provided for a general class of initial data.

Evangelia Ftaka
NC State University
eftaka@ncsu.edu

MS28

Stability estimates for Korteweg-De Vries-Burgers equations with time delay

We consider a generalized Kortewegde VriesBurgers equation with indefinite damping and time delay in the whole real line. Under appropriate conditions on the damping mechanism and the time delay feedback, global well-posedness and exponential decay estimates are established for the linearized equation and the nonlinear model. Our results are obtained by using semigroup techniques and appropriate Lyapunov functionals.

Cristina Pignotti, Ibtissam Issa
University of L'Aquila
pignotti@univaq.it, ibtissam.issa@univaq.it

MS28

Attractors in Non-Dissipative Hyperbolic Dynamics with Nonlinear Dissipation

Long time behavior of a nonlinear plate subject to nonlinear and nonlocal damping and unstable flow of gas is considered. The latter leads to a non-dissipative character of the resulting dynamics. A case study of suspension bridges under unstable flow of gas is given as an illustration. In order to forge long time coherent structure and resulting stability, nonlinear feedback control in a form of nonlinear damping is applied. The important features-consequences of the model are: (i) the dynamical system does not have a gradient structure, (ii) the nonlinearity of the damping leads to an overdamping effect which leads to the so called stability paradox preventing applicability of known methods for proving attractivness of related dynamics. In order to contend with the difficulties, new methodology based on barriers method is developed. The ultimate result provides an existence of global ,finite dimensional attractor in finite energy space. PDE hyperbolic unstable dynamics is reduced asymptotically to a finite dimensional system. The results provided extend these in [1] to the case of nonlinear and nonlocal damping. [1] D. Bonheure, F. Gazzola, I. Lasiecka, J. Webster. Long-time dynamics of a hinged-free plate driven by a non-conservative force. Ann Inst. H. Poincare, Anal Non-Lineaire, 39, pp 457-500, 2022. This is a joint work with Jose Rodriguez - Okinawa Institute of Technology, Japan and Madhumita Roy - North Carolina State University, Raleigh.

Irena M. Lasiecka
University of Memphis
lasiecka@memphis.edu

Madhumita Roy
North Carolina State University.
mroy@memphis.edu

Jose Rodrigues
Okinawa Institute of Science and Technology
jose-rodrigues@oist.jp

MS29

Optimal Control for Quantifying Rare Events in Time-Irreversible Sdes

Time-irreversible SDEs with small noise model ecological, biological, and engineering systems. The large deviations theory estimates the invariant measure near attractors and expected exit times and most probable escape paths from their basins in terms of the quasipotential function, a counterpart of the potential energy for time-reversible systems. I will discuss an approach for computing the quasipotential based on deterministic optimal control and Pontryagins maximum principle capable of handling degenerate and geometric noise. Its Hamiltonian path-shooting version finds quasipotential barriers and the most probable escape paths for high-dimensional systems, such as arrays of nonlinear oscillators with periodic forcing and noise. Its Lagrangian manifold-tracing version computes the quasipotential in whole regions of low-dimensional systems such as two-species ecological models.

Maria K. Cameron
University of Maryland
mariakc@umd.edu

MS29

Population Size in Stochastic Population Dynamics

We study how environmental stochasticity influences the long-term population size in certain discrete-time stochastic models. The difficulty is that even when one can prove that there is coexistence, it is usually impossible to say anything about the invariant probability measure which describes the coexisting species. We are able to circumvent this problem for some important ecological models by noticing that the per-capita growth rates at stationarity are zero. For more complicated models we use a recent result by Cuello to explore how small noise influences the population size. We show that in certain cases environmental fluctuations lead to an increase in population size, contrary to the Cushing-Henson conjecture.

Alexandru Hening, Siddharth Sabharwal
Texas A&M
ahening@tamu.edu, siddhutifr93@tamu.edu

MS29

Optimal Control Methods for Predicting Rare Events in Complex Systems

In this talk, we will explore the connections between optimal control and rare event prediction theory. We will survey the methods for estimating rare event probabilities along with computation of associated paths using the Hamilton Jacobi Bellman PDE and Koopman operators. Despite the rapid growth of autonomous systems and their integration into real-world applications, their accurate assessment of their accuracy and efficacy remains challenging due to high dimensionality of external uncertainty, model error, and mix of discrete and continuous variables. Consequently, the uncertainty analysis of models of autonomous systems remains untenable for most settings. In this work, we adapt rare event estimation methods to models of autonomous systems. We construct novel combinations of extreme value theory and dynamic importance sampling methods that are able to accurately estimate the failure probability of reinforcement learning models by constructing biased actions. We show that the approach is also able to discover intentionally poisoned reinforcement learning models with hidden modalities of failures.

Tuhin Sahai
SRI International
tuhin.sahai@sri.com

MS29

Recent Progress in Sampling via Diffusion Model, Fine Tuning, and Stochastic Optimal Control

The algorithmic task of sampling from unnormalized density (or probability mass function if it is a discrete setup) has been studied for decades due to its importance. Diffusion model on the other hand is a much more recent technology that powers generative AI. Even more recently, stochastic optimal control started to provide an effective way for fine-tuning a diffusion model. Can these contemporary technologies help sampling? This talk will briefly report several recent advances in this regard.

Molei Tao
Georgia Tech
mtao@gatech.edu

MS30

Stochastic Dynamic Field Games on Graphons

Graphon Field Games (GFGs) are a type of mean field game where each agent attempts to match the average state of its neighbors via a graphon, with quadratic costs for deviating from the local average and quadratic control costs. In this talk, we define stochastic GFGs in discrete time and show that this game has a closed-form, adapted solutions for finite time horizon games. An infinite time horizon solution is proposed, which has emergent behavior in the solution state based on the normalization of the eigenvalue of the graphon. Results are supported with numerical demonstrations.

Alex Dunyak
HEC Montréal - Université de Montréal
alex.dunyak@mail.mcgill.ca

MS30

Hilbert Space-Valued LQG Mean Field Games: An Infinite-Dimensional Analysis

Mean field games (MFGs) were originally developed in finite-dimensional spaces. However, there are scenarios where Euclidean spaces do not adequately capture the essence of the problem, such as systems involving time delays. We present a comprehensive study of linear-quadratic (LQ) MFGs in Hilbert spaces, involving N agents with dynamics governed by infinite-dimensional stochastic equations. In this framework, both state and control processes of each agent take values in separable Hilbert spaces. All agents are coupled through the average state of the population which appears in their linear dynamics and quadratic cost functional. Specifically, the dynamics of each agent incorporates an infinite-dimensional noise, namely a Q-Wiener process, and an unbounded operator. The diffusion coefficient of each agent is stochastic involving the state, control, and average state processes. We first study the well-posedness of a system of N coupled semilinear stochastic evolution equations establishing the foundation of MFGs in Hilbert spaces. We then specialize to N-player LQ games described above and study the asymptotic behavior as the number of agents, N, approaches infinity. We develop an infinite-dimensional variant of the Nash Certainty Equivalence principle and characterize a unique Nash equilibrium for the limiting MFG. Finally, we demonstrate the resulting limiting best-response strategies form an ϵ-Nash equilibrium for the N-player game in Hilbert spaces.

Dena Firoozi
HEC Montreal
University of Montreal
dena.firoozi@hec.ca

MS30

Neural Operators Can Efficiently Play Infinite-Dimensional LQ Mean Field Games

The power of neural operators to solve various infinite-dimensional problems has only recently come into focus, especially in the game theory and stochastic control communities. In this talk, we prove that neural operators trained by ERM with finitely many samples can indeed learn the solution operator to a broad class of LQ MFGs in infinite dimensions. Our analysis combines new techniques from optimal control, approximation theory, optimal transport, and learning theory.

Anastasis Kratsios
ETH Zürich
anastasis.kratsios@unibas.ch

Anastasis Kratsios
McMaster University
anastasis.kratsios@unibas.ch

MS30

Pasting Discrete Time Equilibria and Donsker-Type Results for Mean Field Games

In this talk we discuss mean field games in discrete time on general probability spaces. Using dynamic programming and a forward-backward algorithm, we will construct mean field equilibria of multi period models as concatenation of equilibria of one-step games. We will also present results on convergence of discrete time games to continuous time counterparts. The talk is based on a joint work with J. Dianetti, M. Nendel and S. Wang

Ludovic Tangpi
Princeton University, U.S.
ludovic.tangpi@princeton.edu

MS31

Modeling and Control of a Cochlea

TThe cochlea is the sensory organ of the inner ear that converts sound vibrations from the ear drum to electrical impulses that are transmitted to the brain by the auditory nerve. Ill describe a few variations of a basic cochlea model that have been used to describe the basic functioning of the cochlea. The basic model consists of a fluid that surrounds the basilar membrane. Vibrations of the basilar membrane are induced by a pressure field created within the cochlea from vibrations in the middle ear. Ill describe some controllability results based on control inputs from either the oval window or from a small portion of the basilar membrane. When the basilar membrane is modeled as an infinite array of independent oscillators, only approximate controllability holds. If longitudinal tension is included, exact controllabiity holds

Scott Hansen
Iowa State University
Department of Mathematics
shansen@iastate.edu

Scott Hansen
TBA
shansen@iastate.edu

MS31

Null-controllability for Non-autonoumous Degenerate PDEs: A Control-theoretic Approach to Climate Science

Recovering the equilibrium of the "Earth's radiation budget" requires balancing the amount of solar radiation reflected by the amount absorbed by Earths surface. To simulate the interaction of basic climate system parameters on Earth, climatologists Budyko and Sellers independently introduced a classical energy balance model in 1969, which can be rewritten as the following one-dimensional nonlinear degenerate parabolic equation

$$u_t(t,x) - \rho_0 \left(a(x)u_x\right)_x = R_a(t,x,u) - R_e(t,x,u),$$

where $u(t,x)$ is the surface temperature averaged over longitute, $a(x) = 1 - x^2$ ($x = \sin\varphi \in [-1,1]$, with φ being the latitude) and ρ_0 is a positive parameter. In this talk, I will be presenting new results on a non-autonomous degenerate parabolic equation in divergence or in non-divergence form. First, we study the null-controllability for the considered problem under Dirichlet or Neumann boundary conditions. Then, we consider the Robin boundary conditions which is appropriate for modeling the convection occuring at the Earth's surface. Thus, we provide new Carleman estimates for the associated non-autonomous adjoint system under these boundary conditions. This talk is based on joint works with *Genni Fragnelli* (Universit degli Studi di Siena) and *Mohammad Akil* (Universit Polythechniques Hauts-de-France).

Genni Fragnelli
University of Siena
genni.fragnelli@unisi.it

Mohammad Akil
Université Polytechnique Hauts-de-France
mohammad.akil@uphf.fr

Sarah Ismail
University of Bari
sarah.ismail@uniba.it

MS32

Optimal Control of Opinion Dynamics in Evolving Social Media Networks

We present a second-order numerical scheme for solving optimal control problems in opinion dynamics within evolving social media networks. The control framework is formulated using the Lagrange multiplier approach, leading to a coupled forward-backward system. The forward equation, representing the Fokker-Planck dynamics, captures opinion spreading under the influence of dynamic social media contacts and is discretized using an asymptotic preserving scheme. The backward equation, modeled as a Hamilton-Jacobi-Bellman problem, is solved via a semi-Lagrangian scheme that supports large time steps while preserving stability. Coupling between the forward and backward problems is achieved through a gradient descent optimization strategy, ensuring convergence to the optimal control. Numerical experiments demonstrate the schemes second-order accuracy, computational efficiency, and effectiveness in controlling opinion dynamics across various scenarios.

Elisa Calzola
University of Verona
Department of Computer Science
elisa.calzola@univr.it

Giacomo Albi
Università degli Studi di Verona
giacomo.albi@univr.it

MS32

Decentralization and Learning in Mean-Field Control

The solution and complexity of multi-agent control problems rely heavily on the information structure of the control problem. Decentralization, where each agent uses only their local information variables, is a highly desirable property to reduce the necessity for coordination and complexity. However, achieving such decentralization is generally not possible in most multi-agent control problems. The mean-field control formulation, where agents are only "weakly" correlated through a mean-field term, offers a promising modeling framework in which decentralization can be achievable. In particular, the solution of an auxiliary control problem, where one considers the infinite population dynamics, can provide near-optimal decentralized strategies for large population control problems. The main focus of the talk will be on the limitations and varying degrees of decentralization in these scenarios. In the final part of the talk, I will focus on the learning aspect of the problem. I will present model-based learning methods that use linear function approximations for the dynamics and cost functions. We will see that during exploration, coordination may be inevitable, as fully decentralized learning approaches can fail to sufficiently explore and excite the state space.

Ali Kara
Florida State University
akara@fsu.edu

MS32

Numerical Approximation of Second-Order Mean Field Game Partial Differential Inclusions

The Mean Field Game (MFG) system of Partial Differential Equations (PDE), introduced by Lasry & Lions in 2006, models Nash equilibria of large population stochastic differential games of optimal control where the players of the game have unique optimal controls, and the convex Hamiltonian of the underlying optimal control problem is differentiable. In this talk, we introduce a new class of model problems called Mean Field Game Partial Differential Inclusions (MFG PDI), which extend the MFG system of Lasry and Lions to situations where players may have possibly non-unique optimal controls, and the resulting Hamiltonian of the underlying optimal control problem is not required to be differentiable. We prove the existence of unique weak solutions to MFG PDI for a broad class of Hamiltonians that are convex, Lipschitz, but possibly non-differentiable, under a monotonicity condition similar to one considered previously by Lasry & Lions. Moreover, we introduce a class of monotone finite element discretizations of the weak formulation of MFG PDI and present theorems on the strong convergence of the approximations to the value function in the $L^2(H_0^1)$-norm and the strong convergence of the approximations to the density function in $L^p(L^2)$-norms. We conclude the talk with discussion of numerical experiments involving non-smooth solutions.

Yohance Osborne
Durham University
yohance.a.osborne@durham.ac.uk

Iain Smears
University College London

i.smears@ucl.ac.uk

MS32

Temporal-Difference and Q-Learning for Continuous-Time Reinforcement Learning

We develop a model-free algorithm for solving stochastic optimal control problems with unknown dynamics using only discrete-time data. The proposed method directly estimates the optimal Q-function by iterating a projected PhiBE-difference, a temporal-difference analogue tailored to continuous-time settings via a Galerkin projection scheme. While classical approaches often rely on model-based PDEs or discretized Bellman equations, PhiBE-difference learning mitigates sensitivity to reward oscillations and reduces discretization errors. This talk presents the algorithm, establishes its theoretical guarantees including convergence and convergence rates, and illustrates its near-optimal performance through numerical experiments on linear-quadratic regulator (LQR) problems.

Rain Ren
University of California, Los Angeles
USA
ytren@ucla.edu

MS33

Nonlinear Port-Hamiltonian System Identification

Port Hamiltonian systems have received a lot of attention in recent years because of their interesting properties in modeling and control. These structured systems, which are also close to physics, allow for a more generic understanding of the underlying dynamics of physical systems. Especially, in a data-driven context where only data is available, infusing physics into the learned model can help in training and long term predictions. However, data-driven modeling of port-Hamiltonian systems remains an open problem, particularly for nonlinear systems. In this talk, we look at the recent emergence of scientific machine learning techniques for learning port-Hamiltonian systems. More specifically, we compare different architectures for learning port Hamiltonian systems from data and discuss various strategies to enable more efficient training. In addition, we discuss the addition of prior knowledge on the learned model and discuss its impact on the training and accuracy of the model. Finally, we illustrate our results with different examples of physical systems.

Karim Cherifi
Wuppertal University
cherifi@uni-wuppertal.de

Achraf El Messaoudi
Sorbonne university, France
achraf.el_messaoudi@etu.sorbonne-universite.fr

Hannes Gernandt
Fraunhofer IEG, Cottbus, Germany
gernandt@uni-wuppertal.de

Marco Roschkowski
Wuppertal university
roschkowski@uni-wuppertal.de

MS33

Structure-Preserving Splitting Methods for PH-Systems

In this talk, we present high-order splitting methods for linear port-Hamiltonian systems, focusing on preserving their intrinsic structure, particularly the dissipation inequality. Port-Hamiltonian systems are characterized by their ability to describe energy-conserving and dissipative processes, which is essential for the accurate simulation of physical systems. For autonomous systems, we introduce an energy-associated decomposition that exploits the systems energy properties. We present splitting schemes up to order six. In the non-autonomous case, we employ a port-based splitting. This special technique makes it possible to set up methods of arbitrary even order. Both splitting approaches are based on the properties of the commutator. Moreover, we discuss extensions to systems with algebraic constraints. The proposed approaches are validated through theoretical analysis and numerical experiments.

Nicole Marheineke, Marius Mönch
Trier University
marheineke@uni-trier.de, moench@uni-trier.de

MS33

Reduced Order Energy Shaping Control of Large-Scale Linear Port-Hamiltonian Systems

This talk is concerned with reduced-order control design for a class of high dimensional linear port-Hamiltonian systems stemming from the modeling of large-scale systems networks or from the discretization of distributed parameter systems. A class of dynamic controllers synthesized from low-dimensional and reduced-order models of the system are proposed. First, the controller structure and the criteria for asymptotic stability are established for a controller based on the full-order model. Then, using structural invariants, two design methods are proposed and compared: one based on a low-dimensional model of the system and the other on a reduced-order model based on modal truncation. With applications in shape control in mind, the systems equilibrium points are parametrized using the controller parameters. It allows to establish an optimal criterion to minimize the norm of the error between the intended and achievable closed-loop equilibrium configurations. An asymptotic stability margin in terms of the full and low/reduced order models stiffness matrices is provided and related with the closed-loop transient performances. Mindlin plate with specific inputs is used to show how dynamic shape control can be achieved using the proposed approach.

Hector Ramirez
Universidad Técnica Federico Santa María
hector.ramireze@usm.cl

Yann Le Gorrec
FEMTO-ST AS2M, ENSMM
yann.le.gorrec@ens2m.fr

Cristobal Ponce
AC3E, Universidad Técnica Federico Santa María
cristobal.ponces@usm.cl

MS34

Boundary Control for Optimal Data Transport

This work discusses an optimal control design for data transport and exchange via domain boundaries. The mathematical model is governed by the transport equations which are driven by the incompressible velocity fields. The objective is to optimize the density distributions of the data to the desired ones through active control of the velocity for transporting data on a portion of the domain boundaries. We provide a rigorous proof of existence of an optimal control and establish the Gteaux differentiability of the objective functional with respect to the boundary control inputs. Finally, we derive the first-order optimality conditions for solving such an optimal solution using a variational inequality.

Alexander J. Brower, Weiwei Hu, Daniel O. Adu
University of Georgia
Ajb38015@uga.edu, Weiwei.Hu@uga.edu,
daniel.adu@uga.edu

Zhaiming Shen
Georgia Institute of Technology
zshen49@gatech.edu

MS34

Practical Feedback Tracking for Distributed Parameter Systems

Tracking problems are fundamental to control design and analysis. Approaches to the solution of these problems include geometric control, optimal control, adaptive control and new reinforcement learning metods. In the linear case, the dynamic system is defined on a Hilbert state space Z and has the form

$$z_t(t) = Az(t) + Bu(t) + w(t), \quad t > 0, \tag{1}$$

$$z(0) = z_0 \in Z. \tag{2}$$

where $w(t)$ is a disturbance signal and $u(t)$ is the control input. There are measured (sensed) outputs $y_m(t)$ and controlled outputs $y_c(t)$ of the form

$$y_m(t) = Cz(t) + \eta(t) \;\text{ and }\; y_c(t) = Dz(t), \tag{3}$$

respectively. Here, $\eta(t)$ represents sensor noise. In addition, there is a reference signal $r(t)$ that one desires to "track' by the output $y_c = Dz(t)$. Thus, the goal is to find a feedback control of the form $u(t) = K_1 y_m(t) + K_2 r(t)$ to make the tracking error $e(t) = r(t) - y_c(t)$ "small' in some precisely defined metric. In this talk we discuss how specific choices of these metrics, norms on the various spaces and problem formulations impact theoretical issues such as existence of solutions and computational algorithms.

John A. Burns
Virginia Tech
Interdisciplinary Center for Applied Mathematics
jaburns@vt.edu

David S. Gilliam
Texas Tech University
Department of Mathematics and Statistics
david.gilliam@ttu.edu

MS34

Sensor and Filter Design for 1D Pdes Using Computational Geometric Methods

This work uses computational geometry methods via a modification of Centroidal Voronoi Tessellations to partition the spatial distribution of sensors and filter kernels. For the partitioning of a sensor distribution, it is assumed that it represents an ideal sensor with enhanced observability that does not correspond to a realistic sensing device. The modified CVT method approximates the idealized sensor distribution by a network of sensor distributions that describe available sensing devices. For the partitioning of an optimal filter kernel, obtained via Luenberger observer design or Kalman filter design, the CVT method approximates the filter kernel by a network of sensing devices with spatial distributions given by the spatial delta functions. For both cases, the approximation is made feasible via computational geometry methods by modifying the Centroidal Voronoi Tessellations. This modified version of CVT ensures that the ideal sensor distribution is partitioned into cells of equal areas, and a single pointwise sensor is placed in each cell. Once the perfect sensor distribution is approximated, an optimal filter is subsequently designed for the original process resulting in a state estimator using realistic sensing devices. Extensive numerical studies on a parabolic PDE examine the various aspects of the decomposition using single and multiple pointwise sensors.

Michael A. Demetriou
Worcester Polytechnic Institute
mdemetri@wpi.edu

MS34

On Some Control Problems for Quasi-Variational Inequalities of the Second Kind

The talk addresses a class of evolutionary quasi-variational inequalities (QVIs) of the second kind (and control thereof) arising in the models of material science. We formulate a space-time continuous optimal control problem with the QVI as constraint, develop several regularization and approximation procedures, and establish the existence of optimal solutions for the time continuous and space discrete problem.

Carlos Rautenberg
George Mason University
crautenb@gmu.edu

MS35

Multiscale Interface Couplings of Poroelastic Systems and Lumped Hydraulic Circuits

In biomechanics, local phenomena, such as tissue and organ perfusion, are strictly related to the global features of the surrounding blood circulation. We propose a heterogeneous model where a local, accurate, 3D description of tissue perfusion by means of poroelastic equations is coupled with a systemic 0D lumped model of the remainder of the circulation. This represents a multiscale strategy, which couples an initial boundary value problem to be used in a specific tissue region with an initial value problem in the rest of the circulatory system. We present new well-posedness analysis and solution methods for the multiscale model under consideration.

Lorena Bociu
NC State University
Raleigh, NC
lvbociu@ncsu.edu

MS35

On the Value Function for Optimal Control of Semilinear Parabolic Equations

The value function for an infinite horizon tracking type optimal control problem with semilinear parabolic equation is investigated. In view of a possible nonconvexity of the optimal control problem, a local version of the value function is considered. Its differentiability is proved for initial data in a neighborhood around the nominal initial value, provided a second order sufficient optimality condition is fulfilled for the nominal locally optimal control. Based on the differentiability of the value function, a Hamilton-Jacobi-Bellman equation is derived.

Eduardo Casas
Universidad de Cantabria
ETSI Ind y de Telecom
eduardo.casas@unican.es

Karl Kunisch
University of Graz and Radon Institute, Austrian Academy of
Science, Austria
karl.kunisch@uni-graz.at

Fredi Tröltzsch
Techn. University of Berlin
Institute of Mathematics
troeltzsch@math.tu-berlin.de

MS35

A Bilinear Pointwise Tracking Optimal Control Problem for a Semilinear Elliptic PDE

We consider a bilinear control problem with pointwise tracking for a semilinear elliptic PDE: the control variable enters the PDE as a (reaction) coefficient and the cost functional contains point evaluations of the state variable. The latter leads to an adjoint problem with a linear combination of Dirac measures as a forcing term and whose solution has reduced regularity properties. We derive the existence of optimal solutions and analyze first- and necessary and sufficient second-order optimality conditions. We also analyze regularity properties of optimal variables. Finally, we develop a fully discrete scheme based on finite elements and study its convergence and error bounds.

Enrique Otarola
Department of Mathematics
Universidad Tecnica Federico Santa Maria, Chile
enrique.otarola@usm.cl

Daniel Quero, Matias Sasso
Universidad Tecnica Federico Santa Maria
Chile
daniel.quero@alumnos.usm.cl, matias.sasso@sansano.usm.cl

MS35

The Minimum Energy Estimator for a Cubic Wave Equation

The *minimum energy estimator* - also called *Mortensen observer* - was originally designed for the reconstruction of the state of nonlinear finite-dimensional dynamical systems subject to deterministic disturbances based on partial and flawed measurements. In this presentation we propose a generalization to systems governed by PDEs. Using the example of a nonlinear defocusing wave equation we formulate the underlying optimal control problem and formally derive the associated observer. After discussing theoretical results on well-posedness we introduce a spatial discretization of the wave equation inspired by spectral methods. This allows the numerical realization of the observer based on a polynomial approximation of the value function. We conclude with a comparison of the obtained state reconstruction to the well-known *extended Kalman filter*.

Tobias Breiten
Technical University of Berlin
tobias.breiten@tu-berlin.de

Karl Kunisch
University of Graz and Radon Institute, Austrian Academy of
Science, Austria
karl.kunisch@uni-graz.at

Jesper Schröder
RICAM
Linz, Austria
jesper.schroed@gmail.com

MS36

Cybersecurity Problems in Remote State Estimation

Cybersecurity is of paramount importance in modern cyber-physical systems. Such systems often involve remote state estimation, in which sensor data is typically collected locally, and transmitted via networks to a remote location where state estimation and cyberattack detection take place. Cyberattacks come in several different forms, including denial of service, eavesdropping, and false-data injection. With these types of attacks, three relevant research problems are as follows: (i) What attacking patterns attackers would take to bring down normal system operations or cause maximum system performance degradation? (These reveal potential threats or system loopholes.) (ii) How to detect these attacks and mitigate their adverse effects? (iii) How to develop defense countermeasures to improve security of remote state estimation systems? This talk aims at presenting a summary of the current state of research on cybersecurity in remote state estimation problems. The first part reviews optimal designs of false-data injection attacks, denial-of-service (DoS) attacks, and eavesdropping attacks, as well as common defensive measures. The second part elaborates on one optimal design of false-data injection attacks; from the attacker's perspective, a "separate design" unified framework reveals the extent of damage to estimation performance under extreme cases of stealthy attacks, providing a research foundation and guidance for the development of optimal defense measures.

Tongwen Chen
Department of Electrical and Computer Engineering
University of Alberta
tchen@ualberta.ca

MS36

Non-Convex Optimization Approach to Sparse Control Design

This talk presents a novel computational method for sparse control, also known as maximum hands-off control, using non-convex penalty functions such as the minimax concave penalty. The sparse control is formulated as the L0-optimal control problem, which is difficult to directly solve. Conventionally, the L1-norm has been used as a surrogate for the L0 norm to numerically obtain the solution. However, the L1-norm approximation may not always yield sparse control. To overcome this difficulty, we propose non-convex functions such as the minimax concave penalty as a surrogate for the L0 norm. We establish the equivalence of the original and proposed control problems without relying on the normality assumption, which is typically required when approximating the L0 norm with the L1 norm. Furthermore, we present an effective numerical algorithm for the proposed optimal control based on the Alternating Direction Method of Multipliers (ADMM). A design example is shown to illustrate the effectiveness of the proposed method.

Masaaki Nagahara
Graduate School of Advanced Science and Engineering
Hiroshima University
nagahara@ieee.org

Takuya Ikeda
The University of Kitakyushu
t-ikeda@kitakyu-u.ac.jp

MS36

The Power of Contraction in Nonlinear Control: Toward Trustworthy Autonomy for Cyber-Physical Systems

Achieving trustworthy autonomy in cyber-physical systems requires robust methodologies to ensure safety, security, and performance in complex, networked environments. In this talk, we explore the role of contraction theory as a unifying framework for nonlinear control, enabling modular design, optimal performance, and resilience against adversarial conditions, with a focus on the following three key concepts. 1. Contraction properties in nonlinear systems exhibit inherent modularity similar to linear time-varying systems. Applications such as tracking and synchronization hierarchies in nonlinear networked control systems demonstrate how modularity simplifies system analysis and synthesis, ensuring both scalability and robustness. 2. In learning-based control systems, the quality of data directly impacts performance and reliability, while compromised system outputs may fail to capture critical real-world behaviors. We discuss how we optimally facilitate secure data collection to ensure the conformality of contraction properties. 3. Regret-optimality and system-level parameterization are emerging concepts that adapt and enhance classical H-2 and H-infinity norms through achievable system responses. We introduce a new security metric defined by these techniques for improving system resilience in the presence of stealthy adversaries. We also investigate how optimality measured in the security metric can be exponentially enhanced using contraction theory.

Hiroyasu Tsukamoto
Department of Aerospace Engineering, The Grainger College of
University of Illinois Urbana-Champaign
hiroyasu@illinois.edu

MS36

Efficient Control in Cyber-Physical Systems Via Nonlinear Lifting

In this talk, we introduce the nonlinear lifting technique and its application to sampled-data model predictive control, highlighting its critical role in the advancement of cyber-physical systems (CPS). Sampled-data systems form the interface between the physical (continuous) and computational (discrete) domains, underpinning CPS applications such as robotics and smart grids. Traditional control design approaches - discretizing continuous-time controllers or designing controllers for discretized systems - often neglect intersample dynamics, leading to performance degradation such as intersample ripples. In the 1990s, continuous-time lifting was introduced to address these issues, allowing accurate intersample optimization, but it was limited to linear systems and remains underexploited in practice. By extending lifting to nonlinear systems, we can open up new possibilities for achieving higher precision and robustness in sampled-data control, thus addressing the growing complexity of modern CPS. In this talk, we outline the foundations of modern sampled-data control theory and present recent advances in nonlinear lifting, bridging the gap between theory and practical implementation.

Kaoru Yamamoto
Faculty of Information Science and Electrical Engineering
Kyushu University
yamamoto.kaoru.481@m.kyushu-u.ac.jp

Yutaka Yamamoto
Kyoto University
yy@i.kyoto-u.ac.jp

MS37

Learning Tensor Rank for Model Order Reduction

Model order reduction like POD or reduced basis methods aims to capture low rank structure and pattern extraction of the solution manifold that has low Kolmogorov width from key snapshots. We construct a tensor from a collection of solutions on sampled parameters. A reduced basis set is obtained from the low rank reconstruction of the given tensor data. Since low rank reconstruction of tensor data often requires an input of the rank, which is often unknown, we devise a machine learning model to approximate tensor rank. Lastly, we apply our method to problems of control of PDEs with unknown parameters.

David Heson
Mississippi State University
dch376@msstate.edu

MS37

Breaking Symmetry with Data Fusion for Joint Analysis

Data fusion is a valuable tool which enables joint analysis of data from multiple sources. These techniques have been prevalent in bioinformatics, social network analysis and signal processing. In this talk, we will discuss several applications of data fusion in nonlinear and multilinear control systems. We will describe the joint analysis of matrix and tensor decompositions which leads to optimization formulations.

Carmeliza Navasca
Department of Mathematics
University of Alabama at Birmingham
cnavasca@gmail.com

MS37

Large-Scale Tensor Decomposition and Completion for Non-Gaussian Data

Many applications in signal processing, machine learning, and control theory involve structured high-dimensional data that is **non-Gaussian** in naturesuch as binary measurements, event counts, or categorical outcomes. Classical tensor decomposition methods typically rely on Gaussian noise models, limiting their applicability to such data. Existing approaches for large-scale non-Gaussian tensor decomposition are often restricted to **first-order (gradient-based)** methods, which can struggle with accuracy and convergence. In this talk, we present a general framework for **scalable and accurate tensor decomposition** under **non-Gaussian statistical models**, with a focus of this talk on **Poisson** and **Bernoulli** (binary) data. By formulating the decomposition objective via **maximum likelihood estimation (MLE)** based on the appropriate likelihood, we derive loss functions that faithfully reflect the data-generating process. We show how these objectives can be solved efficiently by exploiting **second-order derivative information**, enabling accurate estimation of **CP** or **Tucker** factors in large-scale problems.

Navjot Singh
University of Illinois Urbana-Champaign
navjot2@illinois.edu

Edgar Solomonik
University of Illinois at Urbana-Champaign
solomon2@illinois.edu

MS38

Risk-Aware Control Theory with Application to Mean-Field Coupled Subsystems

The control systems field traditionally has focused on analysis and design in the average case or in the worst case. However, there is a fascinating paradigm at their intersection called risk-aware control theory, which considers the spectrum of possibilities between the average case and the worst case. The flexibility and generality offered by risk-aware control theory has broad significance because control systems often require an awareness of rare, harmful possibilities without being overly cautious, and different applications have different needs and preferences about managing uncertainty. Major early players in this area include David Jacobson (1970s) and Peter Whittle (1980s-1990s). There have been many exciting developments since those times, motivated by advances in finance and operations research in the early 2000s. In this talk, I will present an overview of risk-aware control theory, including a brief history, along with recent work on risk-aware, social optimal control of mean-field coupled, linear-quadratic subsystems.

Margaret P. Chapman
University of Toronto
mchapman@ece.utoronto.ca

MS38

Linear Quadratic Mean Field Games with Quantile-Dependent Cost Coefficients

This paper studies a class of linear quadratic mean field games where the coefficients of quadratic cost functions depend on both the mean and the variance of the populations state distribution through its quantile function. Such a formulation allows for modelling agents that are sensitive to not only the population average but also the population variance. The corresponding mean field game equilibrium is identified, which involves solving two coupled differential equations: one is a Riccati equation and the other the variance evolution equation. Furthermore, the conditions for the existence and uniqueness of the mean field equilibrium are established. Finally, numerical results are presented to illustrate the behavior of two coupled differential equations and the performance of the mean field game solution. Joint work with Roland P. Malhame

Shuang Gao
Polytechnique Montreal
Université dIngénierie
shuang.gao@polymtl.ca

MS38

Hamilton-Jacobi Equations and Mean-Field Games for Robust Generative Modeling

This talk explores the versatility of Hamilton-Jacobi (HJ) equations and mean-field games (MFGs) as a unifying framework for analyzing, designing, and ensuring the robustness of generative models. By connecting MFG formulations to major classes of flow- and diffusion-based generative modelsincluding continuous-time normalizing flows, score-based models, and Wasserstein gradient flowswe show how different choices of particle dynamics and cost functions naturally lead to these models. The mathematical structure of MFGs, based on forward-backward nonlinear PDEs, offers new insights into the design and performance of generative algorithms. For instance, it enables the development of faster, more data-efficient score-based models, robust normalizing flows for learning low-dimensional manifold-supported distributions, and new analyses of diffusion models using nonlinear PDE tools. Another focus of the talk is uncertainty quantification (UQ) and robustness in generative modeling. Using a new Wasserstein uncertainty propagation theorem, we establish that score-based generative models are provably robust to the multiple sources of error in their practical implementation. The regularity theory of HJ equations within the MFG framework underpins this robustness, offering both theoretical guarantees and practical insights into the stability of generative algorithms.

Markos A. Katsoulakis
University of Massachusetts, Amherst
Dept of Mathematics and Statistics
markos@math.umass.edu

MS38

Solvability and Stabilizability of Mean Field LQG Games in Finite Population

This work is concerned with a new class of mean-field LQG games which involve a finite number of agents. Necessary and sufficient conditions are obtained for the existence of the decentralized open-loop Nash equilibrium in terms of non-standard forwardbackward stochastic differential equations (FBSDEs). Furthermore, the open-loop solvability for any initial states is shown to be equivalent to the wellposedness of two differential Riccati equations, which implies the closed-loop solvability. Instead of the asymptotic Nash equilibrium in classical mean-field games, the set of decentralized strategies is shown to be a Nash equilibrium. For stabilizability problem, necessary and sufficient conditions are obtained for stabilizability of general mean field systems by employing two differential Riccati inequalities, respectively.

Bing-Chang Wang
Shandong University

bcwang@sdu.edu.cn

MS39

Feedback Control Design for Mixing in Incompressible Flows

This work is concerned with nonlinear feedback control design for the problem of fluid mixing in incompressible flows. The feedback laws are constructed based on the ideas of instantaneous control. The major challenge is encountered in the analysis of the asymptotic behavior of the closed-loop systems, due to the absence of diffusion in the transport equation together with its nonlinear coupling with the flow equations. To address these issues, we first establish the decay properties of the velocity, which in turn help obtain the estimates on scalar mixing and its long-time behavior. Finally, mixed continuous Galerkin (CG) and discontinuous Galerkin (DG) methods are employed to discretize the closed-loop system. Numerical experiments are conducted to demonstrate our ideas and compare the effectiveness of different feedback laws.

Weiwei Hu
University of Georgia
Weiwei.Hu@uga.edu

Carlos Rautenberg
George Mason University
crautenb@gmu.edu

Xiaoming Zheng
Mathematics Department
Central Michigan University
zheng1x@cmich.edu

MS39

Dynamic Stabilization of Two-String Systems with Dynamical Interior Mass

This work investigates the stabilization of a two-string system coupled through a single dynamical interior mass, offering refined results and novel insights into the interplay between boundary damping, higher-order nodal damping (associated with angular velocity), and lower-order nodal damping (associated with tip velocity). Our analysis shows that exponential stability is unconditionally achieved when boundary damping is combined with higher-order nodal damping. In contrast, lower-order nodal damping, even when supplemented by boundary damping, yields only polynomial stability with a decay rate of 1/t. In the special case where only boundary damping is present, our findings are consistent with the foundational work [11], which established strongbut not exponentialstability. Moreover, our results recover and reconfirm the sharp decay rate of 1/t previously obtained, thus validating the optimality of this rate under such damping configurations. In the absence of boundary damping, we demonstrate that higher-order nodal damping alone can still guarantee exponential stability, provided a resonance-avoiding condition involving specific geometric and material parameters is satisfied. Conversely, lower-order nodal damping without boundary feedback yields at most a polynomial decay with rate 1/t. [11]:S. Hansen and E. Zuazua. Exact controllability and stabilization of a vibrating string with an interior point mass. 1995.

Ibtissam Issa
University of L'Aquila
ibtissam.issa@univaq.it

MS39

A Decomposition Technique for Trust-Region Algorithms in Integer Optimal Control with Total Variation

We propose a globally convergent, coordinate descent-inspired trust-region algorithm that allows subproblem solutions restricted a partition of the domain. The restricted trust-region subproblems induce a modification of the control variable on a subdomain only. Under a subdomain overlap condition, we prove that first-order optimality is equivalent to first-order optimality per subdomain. We prove sufficient decrease on a single subdomain. We utilize this to prove convergence of our algorithm, which operates via greedy subdomain selection. Finally, our method demonstrates the capacity to accelerate large PDE-constrained integer control problems.

Paul Manns
Mathematik
TU Dortmund
paul.manns@tu-dortmund.de

MS40

What Is Observable from Wall-Pressure Measurements in High-Speed Boundary Layers?

In transitional high-speed flow, wall-pressure sensors are often used to detect boundary-layer instability waves and to measure their amplitude. Using these limited observations, data assimilation (DA) can enable reconstruction of the entire flow field. However, the success of DA depends on what is observable from the sensor. We introduce the notion of the sensor domain of dependence (DoD), which is defined as the space spanned by perturbations that can influence the sensor signal at the measurement time. As such, this domain depends on the placement of the sensor, and changes qualitatively when the wall-pressure probe is placed within an attached or separated boundary layer. These ideas will be explained in detail, with aid of examples of high-speed transitional boundary layers over flat-plate and cone-flare geometries. In the latter case, the presence of the corner shock and separation bubble qualitatively modifies the domain of dependence of the wall-pressure probe and has important implication on the accuracy of data assimilation.

Tamer Zaki, Curtis Haas, Qi Wang
Johns Hopkins University
t.zaki@jhu.edu, chaas5@jhu.edu, qiwang065@gmail.com

MS40

Stable Error Dynamics for Estimation Using the Extended Kalman Filter

The full state of most systems cannot be measured. Observer design is an important tool for estimating the state from available measurements. For linear systems, both finite- and infinite-dimensional, the Kalman filter provides an estimate with minimum-variance on the error, if certain assumptions on the noise are satisfied. It can also be regarded as a minimum energy filter for linear systems. The extended Kalman filter is one type of extension to nonlinear systems. It is widely used in applications. The extended Kalman filter is non-optimal but it is key that the error dynamics are stable. More precisely, that the error should converge to zero in the absence of disturbances, and be bounded when disturbances are present. Previous results for stability of error dynamics rely on uniform observability of the system. Furthermore, these results apply only to finite-dimensional systems. Many finite-dimensional systems and almost all infinite-dimensional systems fail to be uniformly observable. We show that the equations for the extended Kalman filter are well-posed for semilinear infinite-dimensional systems. Furthermore, we prove local stability of the error dynamics under an assumption of detectability. The assumptions are milder than previously used. This is joint work with Sepideh Afshar and Fabian Germ.

Kirsten Morris
Dept. of Applied Mathematics
University of Waterloo
kmorris@uwaterloo.ca

Sepideh Afshar
Harvard Medical School
safshar1@mgh.harvard.edu

Fabian Germ
TU Delft
fabian.germ@yahoo.com

MS40

Applying Classical Data Assimilation Strategies to Compressible Flows with Shock Waves A Study

An exploratory study of sequential and variational DA methods to essentially one-dimensional propagation of shock waves in a compressible gas will be presented. The nonlinear hyperbolic character of the underlying differential equations presents limitations in adequacy of information as well as offers new opportunities which exploit physics. Emphasis is on reconstructing system state at a given time or its initial conditions, using a time sequence of measurements, either of the full system or of quantities such as local static pressure.

Ramakanth Munipalli
Edwards Air Force Base
Air Force Research Laboratory
ramakanth.munipalli@us.af.mil

Ayaboe K. Edoh
ERC, Inc. (AFRL)
ayaboe.edoh@jacobs.com

Tomas Houba, Eric West, Matthew Harvazinski
AFRL
tomas.houba.1.ctr@us.af.mil, eric.west.17.ctr@us.af.mil, matthew.harvazinski.1@spaceforce.mil

MS40

Information Worth and Assimilation of Binary Data

Many sensors report feature data, e.g., shock locations and level curves, in a binary form. In doing so, a sensor converts a continuous state variable into a positive or negative reading. Estimation of the state and parameters of the system from binary observations is challenging due to at least two reasons. First, binary observations' information content is lower than their continuous counterparts, which hinders the system's observability and identifiability. Second, the discrete nature of binary observations poses a challenge to variational data assimilation methods. We show that a dynamic system with a continuous forward model and observation operators is almost surely non-identifiable under binary observations and establish a metric to quantify the degree of non-identifiability of the system. We supplement this theoretical result with numerical experiments, which demonstrate that binary observations contain valuable information for parameter estimation. We propose two variational approaches to parameter estimation from binary observations: constrained optimization and constraint-free optimization. We apply our algorithms to analyze in-host virus dynamics and immune response to COVID-19.

Apoorv Srivastava
Stanford University
apoorv1@stanford.edu

Wei Kang
Naval Postgraduate School
wkang@nps.edu

Daniel Tartakovski
Department of Energy Resources Engineering
Stanford University
tartakovsky@stanford.edu

MS41

Integrated Semigroups for Abstract Dissipative-Hamiltonian Daes

The solvability for infinite dimensional abstract dissipative Hamiltonian DAEs possessing a resolvent index is studied. In particular, the concept of integrated semigroups is used to analyze and represent the solutions of such DAEs. Afterwards, this knowledge is used to determine solutions of the inhomogeneous case.

Mehmet-Emin Erbay
University of Wuppertal
erbay@uni-wuppertal.de

Birgit Jacob
University of Wuppertal, Germany
bjacob@uni-wuppertal.de

Timo Reis
Ilmenau University of Technology
timo.reis@tu-ilmenau.de

MS41

H-infinity Control for a Class of Boundary Controlled Infinite-Dimensional Port-Hamiltonian Systems

A solution to the suboptimal H-infinity control problem is given for a class of hyperbolic partial differential equations (PDEs) that may be viewed as infinite-dimensional port-Hamiltonian systems under appropriate assumptions. The first result of this contribution shows that the considered class of PDEs admits an equivalent representation as an infinite-dimensional discrete-time system. Taking advantage of this, we show that it is equivalent to solve the suboptimal H-infinity control problem for a finite-dimensional discrete-time system whose matrices are derived from the PDEs. After computing the solution to this much simpler problem, the solution to the original problem can be deduced easily. In particular, the optimal compensator solution to the suboptimal H-infinity control problem is governed by a set of hyperbolic PDEs, actuated and observed at the boundary. Moreover, the closed-loop system is governed by a set of PDEs that are of the same form as the original system. We illustrate our results with a boundary controlled and boundary observed vibrating string.

Anthony Hastir
Wuppertal university
hastir@uni-wuppertal.de

Birgit Jacob
University of Wuppertal, Germany
bjacob@uni-wuppertal.de

Hans Zwart
Department of Applied Mathematics
University of Twente
h.j.zwart@utwente.nl

MS41

Uniformly Exponentially Stable Structure-preserving Approximation of Boundary-damped Anisotropic Waves

The exponential stability of partial differential equation systems is related to relevant properties from a control point of view, such as the stability margin, exact controllability, and observability. Consequently, the uniform conservation of the exponential decay rate by numerical approximations model allows the preservation of these properties independently of mesh size. Similarly, controllers and estimators designed from uniformly exponentially stable approximation models will perform as desired when implemented on the original partial differential equation system. Unfortunately, not all spatial discretization methods preserve exponential stability uniformly for any application. An additional constraint is imposed for numerical approximations of distributed-parameters port-Hamiltonian systems, i.e., the preservation of the dynamics structure that describes the energy flux within the system. In this talk, we will discuss about a uniformly exponentially stable mixed-finite discretization method for a class of anisotropic distributed-parameters port-Hamiltonian systems and its application to linear quadratic control design.

Luis A. Mora
University of Waterloo
lmora@uwaterloo.ca

Kirsten Morris
Dept. of Applied Mathematics
University of Waterloo
kmorris@uwaterloo.ca

David C. Del Rey Fernandez
University of Waterloo
Department of Applied Mathematics
dcdelrey@gmail.com

Anita Gjestelan
Dep. of Applied Math.
University of Waterloo
agjesteland@uwaterloo.ca

MS41

BIBO Stability of Port-Hamiltonian Systems

Port-Hamiltonian systems (pHS) provide a useful tool for modelling physical systems such as e.g. flexible beams within mechanical systems. In this contribution we consider the question of when a distributed port-Hamiltonian system is bounded-input bounded-output (BIBO) stable, continuing recent research on subtleties of this classical notion for infinite-dimensional systems. Analysing and utilizing the special structure of the transfer function of this system class, we provide sufficient conditions for BIBO stability for a sub-class of pHS.

Alexander Wierzba
University of Wuppertal
a.a.wierzba@utwente.nl

Felix L. Schwenninger
University of Twente
f.l.schwenninger@utwente.nl

MS42

Optimal Domain Shape Design for Uniform Temperature Distribution

In this talk, we will discuss recent advancements in shape optimization problems involving non-isothermal fluids. Our focus will be on designing an optimal two-dimensional domain to achieve the most uniform possible temperature distribution within it. The geometric framework we introduce allows us to demostrate the well-posedness of the Boussinesq system, which serves as a constraint for each admissible domain. Moreover, we will show that the solution exhibits higher regularity on the deformable portion of the boundary, a crucial requirement for the subsequent analysis. Additionally, we will present results on the existence of an optimal domain and derive a first-order optimality condition for the problem. Lastly, we will present some numerical experiments.

Andrea Ceretani
University of Buenos Aires - CONICET
aceretani@dm.uba.ar

MS42

Optimization and Control of a Model of Sandpile Accumulation

In this talk we consider the optimization and perturbation of parameters of a stationary model of sandpile accumulation. The mathematical model consists in a minimization problem on non-standard spaces of Borel measures with (possibly) more regular divergences. Existence results are determined by means of set convergence results for Banach spaces of vector-valued measures. We develop approximation results via regularization of the total variation seminorm. We finalize the talk with numerical tests.

Nicholas Chisholm
Dept. of Mathematical Sciences
George Mason University

nchishol@gmu.edu

MS42

Reduced Order Modeling for Kinetic Models and Applications

Efficient simulation of parameterized differential equations is critical for optimal design, control, and inversion in science and engineering. Many queries for high-fidelity solutions are computationally expensive, necessitating reduced-order modeling to construct efficient surrogate solvers. This work focuses on kinetic models, specifically a time-dependent Fokker-Planck equation and a stationary Boltzmann (-BGK) model, and their model reduction strategies. We explore classical reduced basis methods for the Boltzmann model. The reduced solvers, combined with constrained optimization procedures, are used to infer model parameters in collision kernels. For the Fokker-Planck equation, we leverage optimal transport to transform the original solution space into the Wasserstein tangent space to address the convection-dominant feature, and apply skeleton decomposition to select basis directly from the feature matrix so that it preserves the optimal transport structure in the tangent space. Because of the intrinsic structure of their solutions, both models require the design of structure-preserving (e.g., positivity) reduction strategies.

Jingwei Hu
Department of Applied Mathematics
University of Washington
hujw@uw.edu

Fengyan Li
Rensselaer Polytechnic Institute
lif@rpi.edu

Zhaiming Shen
Georgia Institute of Technology
zshen49@gatech.edu

Shanyin Tong
Columbia University
st3503@columbia.edu

Yunan Yang
Cornell University
yunan.yang@cornell.edu

Jiajia Yu
Duke University
jiajia.yu@duke.edu

MS42

Control Design for Fluid Mixing Based on Optimal Transport

We investigate the mixing dynamics of a passive scalar field advected by a divergence-free velocity field with the free-slip boundary condition. This mixing process is governed by a purely transport equation. Drawing inspiration from optimal transport theory, we introduce a control design aimed at achieving a specified level of mixing in the passive scalar field. In our design, the velocity field (the "control') is assumed to be generated by a finite set of divergence-free flows, with the cellular flow serving as a representative example. We derive the first-order necessary conditions for optimality and implement the optimization algorithm using augmented Lagrangian methods. The associated partial differential equations are numerically solved using spline methods. Numerical experiments demonstrating the mixing results are presented.

Hao-Ning Wu
Dept. of Mathematics
University of Georgia
hnwu@uga.edu

MS43

Quantum Coherent and Measurement Feedback Control Based on Atoms Coupled with a Semi-Infinite Waveguide

In this talk, we demonstrate an application of quantum feedback control in creating desired states for atomic and photonic systems utilizing a semi-infinite waveguide coupled with multiple two-level atoms. In this approach, an initially excited atom can emit one photon into the waveguide, and the photon can be either reflected by the terminal mirror of the waveguide or other atoms, establishing various feedback loops through the coherent interactions between the atom and photon. When there are no more than two excitations in the waveguide quantum electrodynamics (QED) system, the evolution of quantum states can be effectively elucidated through the lens of random graph theory. However, this process is influenced by the environment. We propose that the environment-induced dynamics in the coherent feedback loop can be eliminated by measurement-based feedback control or coherent drives. Consequently, in the atom-waveguide interactions in open quantum systems, measurement-based feedback has the potential to modulate the quantum steady states. Additionally, the homodyne detection noise during the measurement process can induce errors upon quantum states, which can be influenced by the coherent feedback parameter designs.

Haijin Ding
LSS CentraleSupélec
dhj17@tsinghua.org.cn

MS44

Controllability and Inverse Problems for Hyperbolic Systems with Interfaces

We study controllability properties and coefficient inverse problems the wave equation with discontinuous principal coefficient

$$\partial_t^2 u - div(\gamma(x,t)\nabla u) + p(x)u = h$$

posed in $\Omega \times (0,T)$, where $\Omega \subset \mathbb{R}^n$ is a given domain and $\gamma(\cdot,t) \in L^\infty(\Omega)$ is regular in each one of the subdomains $\Omega_1 = \Omega_1(t)$ and $\Omega_2 = \Omega_2(t)$, which satisfy

$$\Omega_1 \cap \Omega_2 = \emptyset \quad \text{and} \quad \overline{\Omega} = \overline{\Omega}_1 \cup \overline{\Omega}_2.$$

The set $\Gamma_* := \overline{\Omega_1} \cap \overline{\Omega_2}$ is the interface. In the case of γ independent of t, the system is equivalent to a transmission system coupled by *transmission conditions* only depending on space. We study the inverse problem of recovering $p \in L^\infty(\Omega)$ using Carleman estimates with a weight function specially adapted to the geometry of the interface. We also consider the case of γ depending on both space and time, where even the well-posedness of the system may not be fulfilled. We study the problems of determining conditions to have well-posedness and also controllability.

Alberto Mercado Saucedo

Universidad tecnica Federico Santa Maria
alberto.mercado@usm.cl

MS44

Boundary Null Controllability of a Class of 2-d Degenerate Parabolic PDEs

In this talk, we present new results related to the boundary null controllability of some degenerate parabolic equations posed on a square domain, presenting the first study of boundary controllability for such equations in multidimensional settings. The proof combines two classical techniques: the method of moments and the Lebeau-Robbiano strategy. A key novelty of this work lies in analyzing a boundary control localized on a subset of the boundary where degeneracy occurs. Furthermore, we establish a Kalman rank condition to characterize the boundary controllability for coupled degenerate systems fully. The results are extended to N-dimensional domains, and we give some other potential extensions to motivate further research in this area.

Luz de Teresa
Universidad Nacional Autónoma de México, Mexico
ldeteresa@im.unam.mx

Subrata Majumdar, Víctor Hernández-Santamaría
Universidad Nacional Autónoma de México
subrata.majumdar@im.unam.mx, victor.santamaria@im.unam.mx

MS45

Finite-Difference Least Square Method for Solving Hamilton-Jacobi Equations Using Neural Networks

In recent years, advancements in deep learning and new optimisation algorithms have motivated the use of artificial neural networks to solve non-linear problems in high-dimensional setups. One of the crucial steps during the implementation of any deep learning method is the choice of the loss functional, which is used to train the neural network parameters, typically through a gradient-based method. In this talk, I will consider the approximation of the viscosity solution for Hamilton-Jacobi equations by means of an artificial neural network. I will discuss the choice of the loss functional, which should be such that any critical point approximates the viscosity solution. I will present some recent results concerning loss functionals involving a consistent and monotone numerical Hamiltonian of Lax-Friedrichs type. Using the numerical diffusion built in the numerical Hamiltonian, we are able to prove that any critical point solves the associated finite-difference problem and, therefore, approximates the viscosity solution. I will also present a method in which the numerical diffusion of the numerical scheme is decreased during the training, allowing for approximations with less numerical diffusion.

Carlos Esteve-Yague
Universidad de Alicante
c.esteve@ua.es

Richard Tsai
Department of Mathematics
University of Texas, Austin
ytsai@math.utexas.edu

MS45

Occasionally Observed Piecewise-Deterministic Markov Processes

Piecewise-deterministic Markov processes (PDMPs) are a broad class of non-diffusive stochastic process. They are useful in a wide range of modeling and control applications, such as mitigating the economic impacts of natural disasters, managing a failure prone manufacturing systems, or controlling a vehicle navigating hazardous terrain. In this talk, we focus on the optimal control of what we call "mode-switching" PDMPs, which may be in one of a finite number of stochastically switching operating modes, each with its own deterministic dynamics. Furthermore, we consider the setting in which the true operating mode is not always known, but the planner instead receives occasional exact observations of its value. We develop an efficient scheme for estimating the likely operating mode between the time of observations and derive governing Hamilton-Jacobi-Bellman PDEs for the resulting optimal control problem. We illustrate our method via numerical experiments based on an evader minimizing exposure to surveillance from randomly switching sources and the other based on a Mars rover that may accumulate unobservable damage while navigating hazardous terrain.

Marissa Gee
Center for Applied Mathematics
Cornell University
mag433@cornell.edu

MS45

Monotone Inclusion Methods for a Class of Second-Order Non-Potential Mean-Field Games

We propose a monotone splitting algorithm for solving a class of second-order non-potential mean-field games. Following [Achdou, Capuzzo-Dolcetta, Mean Field Games: Numerical Methods, SINUM (2010)], we introduce a finite-difference scheme and observe that the scheme represents first-order optimality conditions for a primal-dual pair of monotone inclusions. Based on this observation, we prove that the finite-difference system obtains a solution that can be provably recovered by an extension of the celebrated primal-dual hybrid gradient (PDHG) algorithm.

Levon Nurbekyan
Department of Mathematics
Emory University
levon.nurbekyan@emory.edu

Yat Tin Chow, Siting Liu
University of California, Riverside
yattinc@ucr.edu, sitingl@ucr.edu

MS45

Noise and Disorder in a Network for Sensing Extremely Low Electric Fields

Over the past years, we have exploited the bistability features that are commonly found in many individual sensors to develop a network-based approach to model, design, and fabricate extremely sensitive magnetic- and electric-field sensors capable of resolving field changes as low as 150pT and 100 fAmps, respectively. Higher sensitivity is achieved by exploiting the symmetry of the network to create infinite-period bifurcations that render the ensuing oscillations highly sensitive to symmetry-breaking effects from external signals. In this talk, we discuss the effects of noise on the response of a network-based electric-field sensor as well as the effects of parameter disorder, which appear naturally due to material imperfections and noise. The results show that Signal-to-Noise Ratio (SNR) increases sharply near the onset of the infinite-period bifurcation, and they increase further as the coupling strength in the network increases past the threshold that leads to oscillatory behavior. Overall, the SNR indicates that the negative effects of highly contaminated signals are well-mitigated by the sensitivity response of the system. In addition, computer simulations show the network-based system to be robust enough to disorder in system parameters, while the deviations from the nominal parameter values form regions where the oscillations persist. Noise has a smoothing effects over the boundaries of these regions.

Antonio Palacios
San Diego State University
apalacios@sdsu.edu

MS46

Higher-order Lie Bracket Approximation and Averaging of Control-affine Systems with Application to Extremum Seeking

This paper provides a rigorous derivation for what is known in the literature as the Lie bracket approximation of control-affine systems in a more general and sequential framework for higher-orders. In fact, by using chronological calculus, we show that said Lie bracket approximations can be derived, and considered, as higher-order averaging terms. Hence, the theory provided in this paper unifies both averaging and approximation theories of control-affine systems. In particular, the Lie bracket approximation of order (n+1) turns out to be a higher-order averaging of order (n). The derivation and formulation provided in this paper can be directly reduced to the first and second-order Lie bracket approximations available in the literature. However, we do not need to make many of the unproven assumptions provided in the literature and show that they are in fact natural corollaries from our work. Moreover, we use our results to show that important and useful information about control-affine extremum seeking systems can be obtained and used for significant performance improvement, including a faster convergence rate influenced by higher-order derivatives. We provide multiple numerical simulations to demonstrate both the conceptual elements of this work as well as the significance of our results on extremum seeking with comparison against the literature.

Sameh Eisa, Sameh Eisa
University of Cincinnati
eisash@ucmail.uc.edu, eisash@ucmail.uc.edu

MS46

Extremum Seeking for Controlled Vibrational Stabilization of Mechanical Systems: A Variation-of-Constant Averaging Approach Inspired by Flapping Insects Mechanics

This work presents a novel control-affine extremum seeking control (ESC) approach for the vibrational stabilization of a class of mechanical systems. Both the ESC approach and the class of mechanical systems considered in this paper are inspired by a recent work that succeed in characterizing the challenging hovering phenomenon of flapping insects as a natural ESC system. We test the introduced ESC approach on some classical mechanical systems, namely a mass-spring system and an inverted pendulum system. We also provide a novel, first-of-its-kind, application of the introduced ESC by achieving a model-free source-seeking of a flapping system.

Ahmed Elgohary, Sameh Eisa, Sameh Eisa
University of Cincinnati
elgohaam@mail.uc.edu, eisash@ucmail.uc.edu, eisash@ucmail.uc.edu

MS46

Rigid Body Estimation-based Morse-Lyapunov Tracking Control on the Special Euclidean Group and its Tangent Bundle with Application to Cislunar Spacecraft

This work studies on-manifold estimation and estimation-based tracking control for rigid body motion. A Morse-Lyapunov control law compatible with the dynamic formulation of the special Euclidean group SE(3) and its tangent bundle TSE(3) is presented to allow for tracking control of a rigid-body spacecraft. Analysis on the rigid body motion group allows for simultaneous tracking control both rigid body position and orientation. This control law is then extended to an estimation-based form, leveraging a square-root modified unscented Kalman filter on SE(3) and TSE(3) that has been presented in the speakers previous work. Following the development of the control law and the square-root modified unscented Kalman filter, the stability of the closed loop is investigated through use of the Lyapunov direct method to prove theoretical convergence of the true dynamic states to desired dynamic states. Then, the efficacy of the control law is demonstrated through application to a spacecraft tracking some desired orbit in the cislunar region. Rigid body motion in the cislunar region is of special interest in industry, despite challenges in modeling dynamic behavior posed by the inherent coupling of translational and rotational motions. These challenges are accounted for through the proposed nonlinear estimation and control methodology on the Lie group of rigid body motion through use of the equations of the circular restricted full three body problem.

Herman Gunter, Marco Fagetti, Morad Nazari
Embry-Riddle Aeronautical University
gunterh1@my.erau.edu, fagettim@my.erau.edu, nazarim@erau.edu

MS46

Nonlinear State and Parameter Estimation in Rigid Body Motion Groups: Theory andSpace Applications

This presentation highlights advancements in state and parameter estimation for rigid bodies, addressing challenges in modeling and dynamics under nonlinear and uncertain conditions. Using the geometric framework of the special Euclidean group SE(3) and its tangent bundle TSE(3), we propose robust and singularity-free formulations to estimate key parameters such as mass, center of mass, and moments of inertia. These methodologies employ both joint and dual estimation techniques, enabling accurate characterization of systems with invariant or time-varying properties. Applications include spacecraft equipped with robotic manipulators and vehicles with sloshing liquid propellants. The proposed estimation methods are validated through numerical simulations, showcasing their precision and computational efficiency. By enabling estimation-based control, these methods have the potential to enhance the reliability and robustness of space missions, including on-orbit servicing and propellant management, among other critical applications.

Morad Nazari, Marco Fagetti, Herman Gunter, Carla Cabero Del Hierro
Embry-Riddle Aeronautical University
nazarim@erau.edu, fagettim@my.erau.edu, gunterh1@my.erau.edu, caberodc@my.erau.edu

Matthew Wittal
NASA KSC and Embry-Riddle Aeronautical University
matthew.m.wittal@nasa.gov

Jeffrey Smith
Deep Space Logistics, NASA Kennedy Space Center
jeffrey.d.smith@nasa.gov

MT1

Partial Differential-Algebraic Equations: Dissipativity and Controller Design

Ala' Alalabi
NC State University
alaawaddah93@gmail.com

MT1

Analysis and Control of Partial Differential-Algebraic Equations

Dynamical models of multi-physical systems are often described by coupled partial differential equations (PDEs) and ordinary differential equations (ODEs) combined with conservation laws. This framework naturally leads to partial differential-algebraic equations (PDAEs), which form the core of this mini-tutorial. We provide an overview of recent advances in the solvability and control of PDAEs within Hilbert spaces. In the first part, we introduce the physical modeling of electrical circuits, a context that naturally gives rise to differential-algebraic equations (DAEs). We then summarize the main results regarding the solvability and control of DAEs in finite-dimensional spaces. This includes the discussion of the index, the Weierstra-Kronecker form as well as results on feedback stabilization and linear quadratic optimal control. The second part explores recent findings on the existence and uniqueness of mild, weak, and classical solutions for PDAEs and a brief discussion of index concepts and Weierstra-Kronecker forms for PDAEs. Finally, the third part of this mini-tutorial focuses on the controller design for PDAEs. In particular, the extension of optimal control theory for PDEs to linear PDAEs is presented. Also, boundary stabilization of a special class of PDAEs, namely coupled parabolic-elliptic systems, is discussed.

Hannes Gernandt
Fraunhofer IEG, Cottbus, Germany
gernandt@uni-wuppertal.de

MT2

Explicit Methods for the Control and the Estimation of Systems Modeled by Partial Differential Equations

The presentation would compare and contrast backstepping and LQR-nLnQr on some simple problems.. I want to keep the presentation as simple as possible for pedagogical reasons. It would present four examples. I have chosen simple problems similar to those that you have already worked on.

Arthur J. Krener
Naval Postgraduate School
Department of Applied Mathematics
ajkrener@nps.edu

MT3

Stochastic Approximation and Learning

Aditya Mahajan
McGill University
aditya.mahajan@mcgill.ca

PP1

Neural Networks Based Modeling and Robust Control of Suspended Cable Robots

Cable-Driven Parallel Robots (CDPRs) use cables for spatial movement, offering advantages like a broad workspace, fast and precise motion, heavy load capability, low maintenance costs, and adaptability to complex environments. Despite these benefits, CDPRs present scientific and technological challenges, as the dynamic behavior involves nonlinear differential equations where control laws must take into account constraints on cable tension permanently, both to keep them taut and to avoid their breakage, while ensuring trajectory tracking. Various approaches like PID, state feedback or fuzzy logic controllers were developed for fully constrained CDPR. However, challenges arise with suspended cable robots due to load swinging, necessitating specialized control strategies. In this article, we investigate the modeling and control problem of four-cable suspended robots during the movement of a platform carrying a given load. The approach is based on constructing neural networks for learning and reinforcement learning based control to ensure smooth trajectory tracking without oscillations. The advantage of this approach lies in its robustness across various configurations and diverse unknown loads. A preliminary analysis of convergence conditions, related to the reward function, is established. The results obtained are illustrated through numerical simulations demonstrating the performance of this approach.

Mohamed Boutayeb
University of Lorraine
mohamed.boutyeb@univ-lorraine.fr

Amal Bouazza
International University of Rabat - Morocco
bouazzaamal400@gmail.com

Dominique Martinez
Aix-Marseille University, CNRS-ISM - France
dominique.martinez@univ-amu.fr

Mustapha Oudani
International University of Rabat - Morocco

mustapha.oudani@uir.ac.ma

PP1

A Decomposition-Based Approach to Optimal Control of Partially Observed Lti Systems

A systematic framework for stabilization and optimal control of linear systems in partially observed environments is provided. The goal is to minimize a performance function incorporating both the system state trajectory and the control input costs over specified time horizons. Linear Time-Invariant (LTI) systems are considered with two types of outputs: a measurable output for feedback control and another directly linked to the cost of the regulated states, without imposing stability or detectability conditions. A state-space based three-step decomposition method is introduced based on the controllability, information observability, and cost observability properties of the LTI system. This decomposition facilitates the determination of candidate optimal feedback gains and the values of their performance functions by establishing conditions under which Linear Quadratic Regulator (LQR) techniques can be effectively applied. A holistic view of the regulatory problem is offered which bridges the gap between this matrix-based approach and the geometric approach introduced by Wonham in “Linear Multivariable Control: A Geometric Approach,’ 1985. While the geometric formulation does not allow direct selection of the solution with the least accumulated cost and is hindered by numerical limitations in computing specific geometric spaces, the matrix-based method overcomes these deficiencies. The planned next step is a comparative analysis with H-infinity control methods.

Reihaneh Ghoroghchian
Mcgill University
reihaneh.ghoroghchian@mail.mcgill.ca

Peter Caines, Aditya Mahajan
McGill University
peter.caines@mcgill.ca, aditya.mahajan@mcgill.ca

PP1

Mean Field Games with Clearing Condition and Stochastic Coefficients

We present a class of linear-quadratic mean field games with common noise, where the agents are interacting through a clearing condition. Moreover, all model parameters of agents are allowed to be random. We propose a new approach to address such problems and derive an explicit optimal strategy for a representative agent in the limiting case where the number of agents, N, goes to infinity. Finally, we prove the ϵ-Nash property for the obtained strategies when applied to the original N-player game.

Onesime Hounkpe
HEC Montreal
onesime.hounkpe@hec.ca

Dena Firoozi
HEC Montreal
University of Montreal
dena.firoozi@hec.ca

Shuang Gao
Polytechnique Montreal
Université dIngénierie
shuang.gao@polymtl.ca

PP1

Reinforcement Learning Based Secured Control Design for Nonlinear Cyber Physical Systems Against Multiple Cyber-Attacks

Cyber-physical systems(CPS) are the new generation of dynamical systems, characterized by a profound interaction between cyberspace and the physical world. CPS integrates the different elements from different theories including distributed controls, sensor networks, cybernetics, and so on. Also, incorporating cyber components in human CPS brings up serious security concerns, as they can be vulnerable to cyber-attacks. Thus, it is essential to safeguard the system from potential attackers. Concerning the aforementioned factors, this work aims to interpret the mathematical framework and analyze the stability of the considered CPS. The state space formulation of nonlinear autonomous dynamical systems is considered to describe the mathematical formulation of CPS. To ease the analysis, Takagi-Sugeno fuzzy modelling approach is used to linearize the nonlinear CPS along with its membership functions. Further, due to the multiple attacks from attackers or hackers, CPS becomes unstable. To solve this issue, a robust feedback control is implemented to stabilize and secure the protocol against such attacks for the considered CPS. Furthermore, reinforcement learning based on the actor-critic technique is used for learning the optimal parameters. Further, the required stabilization conditions are developed in the form of linear matrix inequalities with the help of Lyapunov stability theory. Finally, numerical example is used to show the effectiveness of the proposed method.

Keerthana Nanjundan
Research Scholar
Anna University Regional Campus Coimbatore
keerthanananjundan99@gmail.com

PP1

Robust Resilient Control for Uncertain Pde Systems with External Disturbances

This work addresses the stochastic stability analysis for the parabolic partial differential equation systems with the presence of unknown external disturbances and uncertainties by designing a robust nonfragile controller. Then, by embedding passivity performance into the Lyapunov stability theory and Ito’s formula, sufficient conditions are presented to attenuate the effect of disturbances. Consequently, the gain matrices are precisely computed such that the system remains stochastically stable. Finally, theoretical findings are validated through numerical simulation.

Aarthi Subramanian
B
Anna University Regional Campus Coimbatore
aarthi15.au@gmail.com

PP1

Attack Resilient Observer Based Bipartite Synchronization of Switched Reaction-Diffusion Neural Networks

This work focuses on developing an attack-resilient observer-based nonfragile control to address the problems of state estimation and bipartite synchronization of switched reaction-diffusion neural networks that are vulnerable to cyberattacks, gain perturbations, and time delays. Interestingly, the concept of directed signed graphs is utilized to effectively model the interrelationship between node cooperation and competition in the examined network. Initially, the sensor network responsible for gathering system measurements considers the potential influence of stochastic cyberattacks to enhance the resiliency and Bernoulli distribution aids in governing the stochastic aspect of these attacks. Moreover, an attack-resilient observer is devised to address the limitations of measuring neuron states and through the amalgamation of insights from the built observer, a non-fragile controller is crafted to accomplish the desired synchronization. Herein, taking gain perturbations into account improves the controller's resilience. Moreover, by formulating appropriate Lyapunov-Krasovskii functionals, a suite of relevant criteria expressed through linear matrix inequalities is established with triple integral terms and using the Kronecker product to guarantee the bipartite synchronization of the constructed network model. Ultimately, simulation results will be supplied to underscore the capability and relevance of the developed theoretical outcomes.

Elayabharath V T
Bharathiar University
Bharathiar University
elayabharathvt@gmail.com

Sakthivel R
Bharathiar University
krsakthivel@buc.edu.in

PP1

Optimal Trajectory Planning with Collision Avoidance for Autonomous Vehicle Maneuvering

To perform autonomous driving maneuvers, such as parallel or perpendicular parking, a vehicle requires continual speed and steering adjustments to follow a generated path. In consequence, the path's quality is a limiting factor of the vehicle maneuver's performance. While most path planning approaches include finding a collision-free route, optimal trajectory planning involves solving the best transition from initial to final states, minimizing the action over all paths permitted by a kinematic model. Here we propose a novel method based on sequential convex optimization, which permits flexible and efficient optimal trajectory generation. The objective is to achieve the fastest time, shortest distance, and fewest number of path segments to satisfy motion requirements, while avoiding sensor blindspots. In our approach, vehicle kinematics are represented by a discretized Dubins model. To avoid collisions, each waypoint is constrained by linear inequalities representing closest distance of obstacles to a polygon specifying the vehicle's extent. To promote smooth and valid trajectories, the solved kinematic state and control variables are constrained and regularized by penalty terms in the model's cost function, which enforces physical restrictions including limits for steering angle, acceleration and speed. In this paper, we analyze trajectories obtained for several parking scenarios. Results demonstrate efficient and collision-free motion generated by the proposed technique.

Jason Zalev
Magna International Inc.
jason.zalev@magna.com