UNIVERSITY OF CAMBRIDGE

MTNS 2024

26th International Symposium on Mathematical Theory of Networks and Systems

19 - 23 August, Cambridge, UK

www.mtns2024.eng.cam.ac.uk

IFAC INTERNATIONAL FEDERATION OF AUTOMATIC CONTROL

Welcome to MTNS 2024 from the General Chair

Dear MTNS 2024 participants,

It is a great pleasure to welcome you to Cambridge for the 26th International Symposium on Mathematical Theory of Networks and Systems.

MTNS 2024 takes its traditional form of a five day meeting with a free afternoon on Wednesday, allowing plenty of time for interaction and technical discussions, as well as relaxation and enjoyment of the City, University and Colleges. Opening and closing receptions will be in Gonville and Caius and St John's Colleges, and the banquet on Thursday will be shared between the Halls of Trinity and St John's Colleges. A special exhibition on Newton, Maxwell and other luminaries has been arranged for MTNS participants on Wednesday afternoon in the Wren Library of Trinity College.

It is hoped that participants will be able to enjoy at least some of the famous attractions of Cambridge such as its many museums e.g. the Fitzwilliam, the Cambridge Shakespeare Festival with three different plays being performed in College Gardens, and punting on the river along the famous 'Backs' or to Grantchester and the Orchard Tea Garden for the more adventurous.

Above all, I hope that the conference will be a memorable scientific occasion not least for its excellent presentations, exciting sessions, and mini courses, but also for the new scientific friendships and collaborations, and fresh ideas, which will be sparked by the meeting.

Malcolm Smith
General Chair
MTNS 2024

Welcome to MTNS 2024 from the Programme Chair

Dear valued participant,

We are so pleased to see MTNS finally happening in person in Cambridge, with a rich and diverse programme in the best tradition of the conference. It was a hard decision to first postpone and then cancel MTNS 2020, but finally seeing you all in person in Cambridge feels like a fantastic reward.

The 26th International Symposium on Mathematical Theory of Networks and Systems (MTNS 2024) carries on the successful tradition of bringing together researchers and practitioners from different mathematical disciplines around the classical and yet lively concept of Networks and Systems.

The programme includes a total of 4 plenary talks, 12 semi-plenary talks, 285 contributed talks, 20 invited sessions, 6 mini-courses, and a special session dedicated to the memory and scientific legacy of Allen Tannenbaum. Four of the mini-courses will be presented by (semi)-plenary speakers as a complement to their (semi)-plenary talk.

The topics feature the traditional strong areas of the conference (operator theory, optimization in finite and infinite-dimensional spaces, geometry, algebra) as well as their connection to themes of current strong interest such as learning, optimal transport, stochastic control and stochastic modelling, and large-scale physical and biological networks. In the tradition of MTNS, the programme also includes a plenary talk in mathematics, this year on the topic of probability in the continuum by Fields medalist Wendelin Werner.

As always, the quality of the programme primarily relies on the hard work of many volunteers. In addition to authors and speakers, we thank the Steering Committee, the programme Committee members, the editors, and the external reviewers for their essential contribution to the quality of the programme.

We hope you will enjoy the MTNS 2024 and benefit from the unique cultural and intellectual environment of Cambridge to stimulate lively and inspiring discussions, leading to many novel research ideas to bring back home.

Rodolphe Sepulchre
Programme Chair
MTNS 2024

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MTNS History:

1973: College Park, Maryland, USA
1975: Montreal, Canada
1977: Lubbock, Texas, USA
1979: Delft, the Netherlands
1981: Santa Monica, California, USA
1983: Beer Sheva, Israel
1985: Stockholm, Sweden,
1987: Phoenix, Arizona, USA
1989: Amsterdam, the Netherlands
1991: Kobe, Japan
1993: Regensburg, Germany
1996: St. Louis, Missouri, USA
1998: Padova, Italy
2000: Perpignan, France
2002: Notre Dame, Indiana, USA
2004: Leuven, Belgium
2006: Kyoto, Japan
2008: Blacksburg, Virginia, USA
2010: Budapest, Hungary
2012: Melbourne, Australia
2014: Groningen, Netherlands
2016: Minneapolis, USA
2018: Hong Kong
2020: Cambridge, UK (cancelled)
2022: Bayreuth, Germany

Useful Information:

(Maps can be found on the last pages of this booklet, further information can be found on the MTNS 2024 website https://mtns2024.eng.cam.ac.uk/)

Conference Venue

The conference will be held in Lecture Block, the Little Hall and the Lady Mitchell Hall at the Sidgwick Site on Sidgwick Avenue in the University of Cambridge. Technical sessions will take place in Lecture Rooms 1-6. Lecture Rooms 7-9 are quiet rooms available for the use of MTNS participants.
TOPOLOGICAL NOTE: there is no landing connecting the North and South sides of the building on the second floor – hence the shortest path between LR4 and LR5 involves stairs.

Information for Speakers

It is recommended that speakers upload their presentations onto the computer provided before the start of the session, rather than using their own laptops. Slots are 25 minutes so please aim to speak for 20 minutes to allow time for questions and handover to the next speaker.

Registration Desk

The registration desk is located in the entrance of the Lady Mitchell Hall. It will be open on Monday from 08:15 until 16:00 and on Tuesday to Friday from 10:00 until 10:30 (morning coffee break) and from 12:30 until 14:00 (lunch break).

Wifi

Eduroam and the free UniOfCam-Guest are available at the Sidgwick Site.

Local Transportation

The Sidgwick Site can be reached with the U2 (and also U1) Whippet buses which run every 30 mins approximately on routes in the city. You can get a £2.00 ticket from the driver. They take either cash or card.

Refreshments

Coffee and tea will be served from 10.00 – 10.30 and 15.00 – 15.30 in the marquee each day except Wednesday afternoon.
Lunch is not provided as part of the registration. There are two lunch venues at the Sidgwick Site: the Buttery (adjacent to the Lady Mitchell Hall) and the ARC café (Alison Richard Building). Opening times at Harvey’s Coffee House (Harvey Court) TBC.

Social Programme:

Conference Events

Welcome Reception. Monday 19th August, 18.30 – 19.30.
Opening drinks reception in the Old Courts of Gonville and Caius College.

Wren Library Exhibition, Trinity College. Wednesday 21st August, 14.30 – 17.30.
Private exhibition for MTNS delegates with material on display from Newton, Maxwell, Rutherford, the Braggs, Hardy, Ramanujan, Hodgkin and Huxley.

Organ Concert, Trinity College Chapel. Thursday 22nd August, 18.00 – 18.30.
The Trinity College Chapel Organ has pipes dating back to Isaac Newton's time. Alongside the musical entertainment Malcolm will give some brief remarks about the historic instrument with a demonstration!

Banquet pre-dinner drinks (all conference attendees). Trinity College, Wren Cloisters. Thursday 22nd August, 18.40 – 19.25.

Banquet. Trinity College Hall and St John's College Hall. Thursday 22nd August, 19.30 – late.

Farewell Reception. The "Backs" of St John's College. Friday 23rd August, 18.00 – 19.30.

Other Events and Attractions

Cambridge Shakespeare Festival. Every night at 7.30 pm except Sundays.
The Merry Wives of Windsor (St John's College Gardens), Richard II (Trinity College Gardens) and A Midsummer Night's Dream (King's College Gardens). Tickets online.

Punting on the River Cam. Hire your own punt or book a chauffeured punt tour.

The Orchard Tea Garden, Grantchester. Famous from Edwardian times from the patronage of Rupert Brooke, Virginia Woolf, Bertrand Russell, Ludwig Wittgenstein, E.M. Forster, John Maynard Keynes and others. About 45 minutes' walk from the Sidgwick Site.

King's College Chapel. View the famous fan vaulted ceiling and the Adoration of the Magi by Rubens. Well worth the entrance price.

The Fitzwilliam Museum. Open Tuesday-Saturday: 10.00-17.00. Free admission.

MTNS 2024 Technical Program Monday August 19, 2024

Opening: 8:50-9:00, Lady Mitchell Hall

Plenary	Mini-course	Session	Session	Session/Semi Plenary	Session	Session	Mini-course/Session
09:00-10:00 MoP_LMH Lady Mitchell Hall Architectural Questions in Distributed Systems and Controls							
	10:30-13:00 MoAM_LH Little Hall Dynamics and Control in Spatiotemporal Systems (I)	10:30-13:00 MoAM_LR1 LR1 Operator Theoretic Methods in Systems Theory	10:30-13:00 MoAM_LR2 LR2 System Identification	10:30-13:00 MoAM_LR3 LR 3 Recent Progress in Ensemble Control	10:30-13:00 MoAM_LR4 LR4 Nonlinear Control	10:30-13:00 MoAM_LR5 LR5 Optimization : Theory and Algorithms	10:30-13:00 MoAM_LR6 LR6 Extended Dynamic Mode Decomposition in the Koopman Framework
14:00-15:00 MoSP_LMH Lady Mitchell Hall Semi-Plenary: Enhancing Kalman Filtering with Backpropagation: Theory and Examples	**14:00-15:00 MoSP_LH Little Hall Semi-Plenary: Robustness and Resilience of Dynamical Networks in Nature**			**14:00-15:00 MoSP_LR3 LR 3 Semi-Plenary: Port-Hamiltonian Systems: Modelling and Analysis**			
	15:30-18:00 MoPM_LH Little Hall Dynamics and Control of Spatio-Temporal Systems (II)	15:30-18:00 MoPM_LR1 LR1 Control of Distributed Parameter Systems	15:30-18:00 MoPM_LR2 Modelling and Dynamical Aspects of Biological Systems	15:30-18:00 MoPM_LR3 LR 3 Group-Affine Systems and Invariant Filtering	15:30-18:00 MoPM_LR4 LR4 Optimal Control and Learning	15:30-18:00 MoPM_LR5 LR5 Analysis of Networks and Graphs	15:30-18:00 MoPM_LR6 LR6 Learning and Optimization in Stochastic Systems and Control (I)

Welcome Reception: 18.30 – 19.30, Gonville and Caius College

MTNS 2024 Technical Program Tuesday August 20, 2024

Plenary	Semi-plenary/ session	Session	Session	Session / Semi-plenary	Session	Session	Session
09:00-10:00 TuP_LMH Lady Mitchell Hall Plenary : AI and Optimization through a Geometric Lens							
	10:30-13:00 TuAM_LH Little Hall Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations (I)	10:30-13:00 TuAM_LR1 LR1 Optimal and H-Infty Control	10:30-13:00 TuAM_LR2 LR2 Structure-Preserving Methods in Simulation, Control, and Learning of Dynamical Systems	10:30-13:00 TuAM_LR3 LR 3 System Phase and Its Integration with System Gain	10:30-13:00 TuAM_LR4 LR4 Operator Theoretic Methods in Identification and Control	10:30-13:00 TuAM_LR5 LR5 Networks and Transportation Systems	10:30-13:00 TuAM_LR6 LR6 Learning and Optimization in Stochastic Systems and Control (II)
14:00-15:00 TuSP_LMH Lady Mitchell Hall Semi-Plenary: Any-Dimensional Optimization	**14:00-15:00 TuSP_LH Little Hall Semi-Plenary: Closed Loop Neurophysiology**			**14:00-15:00 TuSP_LR3 LR 3 Semi-Plenary: The Ubiquity and Applications of Lie Groups**			
15:30-18:00 TuPM_LMH Lady Mitchell Hall A Gentle Introduction to Representation Stability: Fundamentals and Applications	15:30-18:00 TuPM_LH Little Hall Feedback Control Systems	15:30-18:00 TuPM_LR1 LR1 Optimal Control	15:30-18:00 TuPM_LR2 LR2 Learning and Surrogate Modeling of Port-Hamiltonian Systems	15:30-18:00 TuPM_LR3 LR 3 Mechanical Network Synthesis	15:30-18:00 TuPM_LR4 LR4 Delay Systems	15:30-18:00 TuPM_LR5 LR5 Hybrid Systems	15:30-18:00 TuPM_LR6 LR6 Learning and Optimization in Stochastic Systems and Control (III)
18:10-19:00 TuE_LMH Lady Mitchell Hall A Life in Science and Engineering: The Legacy of Allen Tannenbaum							

MTNS 2024 Technical Program Wednesday August 21, 2024

Plenary	Mini Course	Session	Session	Session	Session	Session	Session
09:00-10:00 WeP_LMH Lady Mitchell Hall Plenary: A Network View of Wind Farm Modeling and Control							
	10:30-13:00 WeAM_LH LH Stochastic Safety	10:30-13:00 WeAM_LR1 LR1 Nonlinear Systems and Control	10:30-13:00 WeAM_LR2 LR2 Data-Driven Reduced-Order Modeling and Learning of Dynamical Systems: Some New Insights into the Future	10:30-13:00 WeAM_LR3 LR3 Port-Hamiltonian Systems	10:30-13:00 WeAM_LR4 LR4 Solution of Hamilton-Jacobi Equations	10:30-13:00 WeAM_LR5 LR5 Mathematical Theory of Networks and Circuits	10:30-13:00 WeAM_LR6 LR6 Learning and Optimization in Stochastic Systems and Control (IV)

MTNS 2024 Technical Program Thursday August 22, 2024

Plenary	Session / Semi-plenary	Session	Session	Session/Semi Plenary	Session	Session	Session
09:00-10:00 ThP_LMH Lady Mitchell Hall About Probability in the Continuum							
	10:30-13:00 ThAM_LH Little Hall Theory of Control Architectures	10:30-13:00 ThAM_LR1 LR1 Algebraic Coding Theory and Applications (I)	10:30-13:00 ThAM_LR2 LR2 Optimization in Operator Variables (I)	10:30-13:00 ThAM_LR3 LR3 Optimal Transport: Theory and Applications in Networks and Systems (I)	10:30-13:00 ThAM_LR4 LR4 Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations (II)	10:30-13:00 ThAM_LR5 LR5 Riemannian Methods in Optimization and Systems Theory (I)	10:30-13:00 ThAM_LR6 LR6 Learning and Optimization in Stochastic Systems and Control (V)
14:00-15:00 ThSP_LMH Lady Mitchell Hall Semi-Plenary: Towards Data-Driven Nonlinear Filtering Algorithms	**14:00-15:00 ThSP_LH Little Hall Semi-Plenary: Nanoscale Control Theory**			**14:00-15:00 ThSP_LR3 LR3 Semi-Plenary: Infinite Dimensional Analysis, Hida White Noise Space and Applications to Linear Systems with Random Coefficients**			
		15:30-17:10 ThPM_LR1 LR1 Algebraic Coding Theory and Applications (II)	15:30-17:10 ThPM_LR2 LR2 Optimization in Operator Variables(II)	15:30-17:10 ThPM_LR3 LR3 Optimal Transport: Theory and Applications in Networks and Systems (II)	15:30-17:10 ThPM_LR4 LR4 Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations (III)	15:30-17:10 ThPM_LR5 LR5 Riemannian Methods in Optimization and Systems Theory (II)	15:30-17:10 ThPM_LR6 LR6 Partial Differential Algebraic Equations

Conference Dinner: 19:00-late, Trinity College Hall and St John's College Hall.

MTNS 2024 Technical Program Friday August 23, 2024

Plenary	Session / Semi-plenary	Session	Session	Session/Semi Plenary	Session	Session	Session
	10:00-12:30 FrAM_LH Little Hall Control across Scales	10:00-12:30 FrAM_LR1 LR1 Stochastic Modeling and Stochastic Systems Theory	10:00-12:30 FrAM_LR2 LR2 Reinforcement Learning and Information Theory	10:00-12:30 FrAM_LR3 LR3 Issues in Networked Consensus Control	10:00-12:30 FrAM_LR4 LR4 Infinite Dimensional Analysis (I)	10:00-12:30 FrAM_LR5 LR5 Algebraic and Geometric Approaches to Systems Structure and Control (I)	10:00-12:30 FrAM_LR6 LR6 Geometry in Optimization and Learning (I)
14:00-15:00 FrSP_LMH Lady Mitchell Hall Semi-Plenary: Stochastic Diffusions for Control, Learning, and Inference	**14:00-15:00 FrSP_LH Little Hall Semi-Plenary: Optimization-Based Control under Uncertainty: Guarantees, Performance & Computation**			**14:00-15:00 FrSP_LR3 LR3 Semi-Plenary: When Is a Time-Delay System Stable and Stabilizable? a Third-Eye View**			
	15:30-17:35 FrPM_LH Little Hall Algebraic Systems Theory	15:30-17:35 FrPM_LR1 Stability	15:30-17:35 FrPM_LR2 Quantum Control		15:30-17:35 FrPM_LR4 LR4 Infinite Dimensional Analysis (II)	15:30-17:35 FrPM_LR5 LR5 Algebraic and Geometric Approaches to Systems Structure and Control (II)	15:30-17:35 FrPM_LR6 LR6 Geometry in Optimization and Learning (II)

Farewell Reception, 18.00 – 19.30. The “Backs” of St John’s College.

Plenary/Semi-Plenary Lectures:

Bassam Bamieh (UC Santa Barbara)

Title: Architectural Questions in Distributed Systems and Controls

Abstract: In the design and control of large-scale distributed systems, architectural considerations are arguably some of the most important ones. These include local versus global feedback in multi-agent systems, sensor and actuator placement in distributed control of PDEs, how far should sensor information travel in distributed controller architectures, the structure and realizations of distributed controllers, and many other related issues. Many of these questions have significant implications for plant and system co-design, which are perhaps even more important than controller design itself. We survey some of these questions using specific case studies to point out the role of optimal and robust control in determining limits of performance, which in turn inform controller and system architecture motifs. The case studies will evoke more questions than answers, indicating the need for a more developed theory of systems and controls architecture.

Bio: Bassam Bamieh is Professor of Mechanical Engineering at the University of California at Santa Barbara (UCSB). He received his B.Sc. degree in Electrical Engineering and Physics from Valparaiso University (Valparaiso, IN) in 1983, and his M.Sc. and PhD degrees in Electrical and Computer Engineering from Rice University in 1986 and 1992 respectively. Prior to joining UCSB in 1998, he was an Assistant Professor in the Department of Electrical and Computer Engineering and the Coordinated Science Laboratory at the University of Illinois at Urbana-Champaign (1991-98). His research interests are in the fundamentals of Controls and Dynamical Systems, as well as the applications of systems and feedback techniques in several physical and engineering systems. These areas include Robust and Optimal Control, distributed and networked control and dynamical systems, shear flow transition and turbulence, quantum control, and thermoacoustics. His recognitions include the IEEE Control Systems Society G. S. Axelby Outstanding Paper Award (twice), an AACC Hugo Schuck Best Paper Award, and a National Science Foundation CAREER award. He is a Fellow of the International Federation of Automatic Control (IFAC), and a Fellow of the IEEE.

Dennice Gayme (Johns Hopkins University)

Title: A network view of wind farm modeling and control

Abstract: Wind farms comprise a network of dynamical systems coupled through interactions with the turbulent atmospheric boundary layer (ABL). The ABL dynamics govern the velocity field that enters the farm as well as the turbulent mixing that regenerates energy for extraction at downstream rows, thereby playing a fundamental role in wind farm power production.

Understanding the dynamic interactions between turbines, wind farms, and the ABL is therefore critical for improving wind farm performance. This talk introduces a suite of models that leverage ABL information to provide improved models of both static and dynamic conditions in the wind farm. An example of such a dynamic model in a control setting provides a case study wherein turbines are viewed as actuators that adjust the flow field to collectively produce more efficient power tracking performance.

Bio: Dennice F. Gayme is a Professor in Mechanical Engineering at Johns Hopkins University. She received her B. Eng. & Society in Mechanical Engineering from McMaster University in 1997, an M.S. in Mechanical Engineering from the University of California at Berkeley in 1998, and her Ph.D. in Control and Dynamical Systems from the California Institute of Technology in 2010. Her research interests are in modeling, analysis and control of spatially distributed and large-scale networked systems, such as wind farms, wall-bounded shear flows, and power systems. She was a recipient of a JHU Catalyst Award in 2015, ONR Young Investigator and NSF CAREER awards in 2017, a Whiting School of Engineering Johns Hopkins Alumni Association Excellence in Teaching Award in 2020, and the Turbulence and Shear Flow Phenomena (TSFP12) Nobuhide Kasagi Award in 2022. She is a fellow of the American Physical Society (APS), serves as a Member-At-Large in the Executive Committee of the APS Division of Fluid Dynamics (APS/DFD), and is the Standing Co-Chair of the Women in Control Committee of the Control Systems Society (CSS) of the IEEE.

Suvrit Sra (TU Munich & MIT)

Title: AI and optimization through a geometric lens

Abstract: Geometry arises in a myriad ways across the sciences, and quite naturally also within AI and optimization. In this talk I wish to share with you examples where geometry helps us understand problems in machine learning, optimization, and sampling. For instance, when sampling from densities supported on a manifold, understanding geometry and the impact of curvature are crucial; surprisingly, progress on geometric sampling theory helps us understand certain generalization properties of SGD for deep-learning! Another fascinating viewpoint afforded by geometry is in non-convex optimization: geometry can either help us make training algorithms more practical for deep learning, it can reveal tractability despite non-convexity (e.g., via geodesic convexity), or it can simply help us understand important ideas better (e.g., eigenvectors, LLM training and inference, etc.)

My hope is to offer the audience insights into geometric thinking, and to share with them some new tools that can help us make progress on modeling, algorithms, and applications. To make my discussion concrete, I will recall a few foundational results arising from our research, provide several examples, and note some open problems.

Bio: Suvrit Sra is an Alexander von Humboldt Professor of Artificial Intelligence at the Technical University of Munich (TUM), and an Associate Professor in the EECS Department at MIT, where he is also a member of the Laboratory for Information and Decision Systems (LIDS) and the Institute for Data, Systems, and Society (IDSS). He obtained his PhD in Computer Science from the University of Texas at Austin. Before TUM & MIT, he was a Senior Research Scientist at the Max Planck Institute for Intelligent Systems, Tübingen, Germany. He has held visiting positions at UC Berkeley (EECS) and Carnegie Mellon University (Machine Learning Department) during 2013-2014. His research bridges mathematical topics such as differential geometry, matrix analysis, convex analysis, probability theory, and optimization with machine learning. He founded the OPT (Optimization for Machine Learning) series of workshops, held from OPT2008–2017 at the NeurIPS (erstwhile NIPS) conference. He has co-edited a book with the same name (MIT Press, 2011). He is a co-founder and the Chief Scientist of Pendulum, a global, AI-driven logistics startup.

Wendelin Werner (University of Cambridge)

Title: About Probability in the Continuum

Abstract: The usual way to think about randomness is to start from the discrete world, where one tosses a finite collection of random variables. When the randomness is in fact “spread” in a fairly natural way over space, then in some cases, rather complex and interesting random geometric physically relevant structures with some surprising features can emerge. The aim of this talk is to illustrate this using some specific examples that arose in recent works.

Bio: Wendelin Werner is Rouse Ball Professor of Mathematics and Royal Society Research Professor at the University of Cambridge. Prior to that, he was Professor at University Paris-Sud from 1997 to 2013 and at ETH Zürich from 2013 to 2023. He has received a number of awards for his research in Probability Theory and related topics, including the Fields Medal in 2006.

Daniel Alpay (Chapman University)

Title: Infinite dimensional analysis, Hida white noise space and applications to linear systems with random coefficients

Abstract: Infinite dimensional analysis is at the crossroad of the theory of positive definite kernels, stochastic processes, complex analysis, and topological vector spaces. It has numerous applications, with connections to second quantization, stochastic linear systems, models for stochastic processes and their derivatives. In the talk we will survey some of these connections, focusing on links with the theory of linear systems. A non-commutative version of the theory will also be presented.

Bio: Daniel Alpay was born in Paris (France) and has a double formation of electrical engineer (Telecom Paris) and theoretical mathematics (Weizmann Institute, Rehovot, Israel). His research interests are in hypercomplex analysis, operator theory, stochastic processes (in particular in the setting of infinite dimensional analysis) and mathematical physics. He wrote a number of research books and more than 320 papers. Building on his research, he wrote two exercises books on complex analysis and his book entitled "Exercises in applied mathematics, with a view toward information theory, machine learning, wavelets and statistical physics" just appeared. He was a chaired professor at Ben-Gurion University (Beer-Sheva, Israel) and is now Professor at Chapman University (Orange, California), where he holds the Foster G. and Mary McGaw Professorship in Mathematical Sciences.

Ravi Banavar (IIT Bombay)

Title: The Ubiquity and Applications of Lie Groups

Abstract: The comfort zone of most engineers is the Euclidean space. Most applications of the past century have relied on tools from the repository of this space – transforms, projections, norms and inner products. However, the intrinsic nature of many problems in engineering is not in this setting. Therefore, solutions that have been proposed in an Euclidean setting are necessary "local" and hence termed "coordinate-dependant." This weakness has beckoned new paradigms. Not stepping too far away from the comfort zone of Euclidean space, we encounter Lie Groups. The umbilical connection of a Lie group to a Lie algebra (a vector space) brings in familiarity in terms of many tools commonly employed in Euclidean space. In this talk I shall present preliminary machinery for Lie groups, and four domains of applications – multiagent control, consensus, optimal control and observer design.

Bio: Ravi N. Banavar is currently an Institute Chair Professor in Systems and Control Engineering at IIT Bombay. He received his B.Tech. in Mechanical Engineering from IIT Madras (1986), his Masters (Mechanical, 1988) and Ph.D. (Aerospace, 1992) degrees from Clemson University and the University of Texas at Austin, respectively. He had a brief teaching stint at UCLA during 1991–92, soon after which he joined the Systems and Control Engineering group at IIT Bombay in early 1993. From 2009 onwards, during his tenure as the Convener of the group, the strength of the group grew from 5 to 9 members, with academic strengths in nonlinear control, switched systems, optimization, geometric mechanics, formation and cooperative control, robotics and adaptive control. He has spent a few sabbatical breaks at UCLA (Los Angeles), IISc (Bangalore) and LSS (Supelec, France.) His research interests are broadly in the field of geometric mechanics, nonlinear and optimal control, with applications to electromechanical and aerospace engineering problems. He is an Associate Editor of the Elsevier journal, Systems and Control Letters, on the Editorial Advisory Board of the Taylor and Francis publication, The International Journal of Control, and a Technical Associate Editor of the IEEE Control Systems Society magazine.

Silvère Bonnabel (Mines-Paris Tech)

Title: Enhancing Kalman Filtering with Backpropagation: Theory and Examples

Abstract: The Kalman filter (KF) and its nonlinear extension (EKF) are a cornerstone in estimating the state of a dynamical system from noisy measurements, crucial for many real-world applications. However, the accuracy of those filters, whether used in a probabilistic setting or as observers, hinge on precise tuning of various parameters. The sensitivity equations, developed by Gupta and Mehra in 1974 for maximum likelihood parameter estimation, allow for computation of the effect of small variations in these parameters on the KF estimates and its internal variables. By leveraging the gradient backpropagation method, a key technique in neural networks, we introduce a much more numerically efficient method to analytically compute these derivatives for the KF and the EKF. Their applicability is also extended beyond traditional maximum likelihood estimation.
We illustrate the potential of these novel sensitivity equations through several applications: fault detection, where gradient-based insights detect structured spurious measurements; adaptive filtering, where an EKF combined with a shallow neural network, that dynamically adapts its noise parameters at all times, allows for localization of a car over hours using only inertial measurements; and active sensing, where gradients of the EKF's covariance matrix with respect to the control inputs allow for computation of trajectories that optimize the information gathered by sensors, demonstrated with real experiments.

Bio: Silvère Bonnabel is a professor at Mines Paris PSL, Paris Sciences et Lettres Research University. His research lie in the intersection of control theory, robotics, and learning. He received his doctoral degree in Mathematics and Control from Mines Paris in 2007. He was an Invited Fellow at the University of Cambridge in 2017, and at INRIA Paris in 2022. Dr. Bonnabel was awarded the IEEE - SEE Glavieux prize in 2015, the Automatica Paper Prize in 2020, the European Control Award in 2021, and the Prix IMT Espoir from the French Academy of Sciences in 2022. He currently serves as an Associate Editor for IEEE Control Systems.

Venkat Chandresakaran (Caltech)

Title: Any-dimensional optimization

Abstract: Optimization problems in many applications arise naturally as sequences indexed by dimension. In extremal combinatorics and information theory, sequences of problems are indexed by graph size or number of channel uses, and it is of interest to obtain bounds on the optimal values of all problems in a sequence or on the limiting value. In other domains such as inverse problems and combinatorial optimization, the objective is to design tractable relaxations that are compatible across dimension in various ways depending on the application.

We present a systematic treatment of sequences of convex programs by explicitly considering relations between problem instances of different dimensions. We show that such sequences are often described in a manner that makes their instantiation in every dimension obvious. Such 'free' descriptions arise from a recently identified phenomenon in algebraic topology called representation stability.

Our framework yields two types of consequences. First, we show that certain sequences of invariant convex programs that are commonly seen in applications can be solved using a number of operations that is independent of dimension. Second, we present new approaches to design convex relaxations from data – in our setting, input-output training data are provided for problem instances of low dimension and we derive a sequence of convex relaxations that can be employed for problems in any dimension, including those not in the training set.

Bio: Venkat Chandrasekaran is on the faculty at Caltech, where he is Tomiyasu Professor of Computing and Mathematical Sciences and of Electrical Engineering. He received a Ph.D. in Electrical Engineering and Computer Science from MIT (2011) and undergraduate degrees in Mathematics and in Electrical and Computer Engineering from Rice University (2005). He has received several awards including the Jin-Au Kong Prize for his dissertation in Electrical Engineering at MIT (2012), the Sloan Research Fellowship in Mathematics (2016), and the INFORMS Optimization Society Prize for Young Researchers (2016). His research interests lie in optimization and the information sciences.

Jie Chen (City University of Hong Kong)

Title: When is a Time-Delay System Stable and Stabilizable? A Third-Eye View

Abstract: Time delays are a prevailing scene in natural and engineered systems. While a recurring subject in classical studies, modern interconnected networks are especially prone and indeed, are vulnerable to long and variable delays; systems and networks in this category are many, ranging from communication networks, sensor networks, cyber-physical systems, to biological systems. A time-delay system may or may not be stable for different lengths of delay, and further, may or may not be stabilized under a conventional feedback mechanism. When will then a delay system be stable or unstable, and for what values of delay? When can an unstable delay system be stabilized? What range of delay can a feedback system tolerate to maintain stability? Fundamental questions of this kind have long eluded engineers and mathematicians alike, yet ceaselessly invite new thoughts and solutions. In this talk I shall present a nontraditional perspective on the stability and stabilization of time-delay systems, wherein we attempt to develop tools and techniques that answer to the questions alluded to above, seeking to provide exact and efficient computational solutions to stability and stabilization problems of time-delay systems. We develop in full an operator-theoretic approach that departs from both the classical algebraic and the omnipresent LMI solution approaches, notable for both its conceptual appeal and its computational efficiency. Preceding this development we shall also develop the necessary mathematical foundation centered at operator perturbation series, which characterize the analytical and asymptotic properties of eigenvalues of matrix-valued functions or operators. Extensions to contemporary topics such as networked control and multi-agent systems may also be addressed.

Bio: Jie Chen holds the appointment of Chair Professor with the Department of Electrical Engineering, City University of Hong Kong, Hong Kong, China. Prior to joining City University, he was with The University of California, Riverside, California from 1994 to 2014, where he served as Professor and Chair for the Department of Electrical Engineering. He has also held guest positions and visiting appointments with institutions in Australia, Chile, China, France, Germany, Japan, and Sweden. His main research interests are in the areas of linear multivariable systems theory, system identification, robust control, optimization, time-delay systems, networked control, and multi-agent systems. He presently serves on the editorial boards of International Journal of Robust and Nonlinear Control, and SIAM Journal on Control and Optimization. He routinely serves on program and organizing committees of international conferences, most recently as the General Chair of the 3rd IEEE Conference on Control Technology and Applications, and the International Program Committee Chair of the 16th IFAC Workshop on Time Delay Systems. He is a Fellow of IEEE, Fellow of AAAS, Fellow of IFAC, Fellow of SIAM and a Yangtze Scholar/Chair Professor of China.

Yongxin Chen (Georgia Tech)

Title: Stochastic Diffusions for Control, Learning, and Inference

Abstract: Diffusion processes refer to a class of stochastic processes driven by Brownian motion. They have been widely used in various applications, ranging from engineering to science to finance. In this talk, I will discuss my experiences with diffusion and how this powerful tool has shaped my research programs. I will go over several research projects in the area of control, inference, and machine learning, where we have extensively utilized tools from diffusion processes. In particular, I will present our research on three topics: i) covariance control in which we aim to regulate the uncertainties of a dynamic system; ii) diffusion models for generative modeling in machine learning; iii) and Monte Carlo Markov chain sampling for general inference tasks.

Bio: Yongxin Chen is an Associate Professor in the School of Aerospace Engineering at Georgia Institute of Technology. He has served on the faculty at Iowa State University (2017-2018). Prior to that, he spent one year (2016-2017) at the Memorial Sloan Kettering Cancer Center (MSKCC) as a postdoctoral fellow. He received his BSc from Shanghai Jiao Tong University in 2011, and Ph.D. from University of Minnesota in 2016. He is an awardee of the best Paper Award of IEEE Transactions on Automatic Control in 2017 and the best paper prize of SIAM Journal on Control and Optimization in 2023. He received the NSF Faculty Early Career Development Program (CAREER) Award in 2020, the Simons-Berkeley Research Fellowship in 2021, the A.V. Balakrishnana Award in 2021 and the Donald P. Eckman Award for outstanding young engineer in the field of automatic control in 2022. His current research interests are in the areas of control, machine learning, and robotics. He enjoys developing new algorithms and theoretical frameworks for real world applications.

Jean-Charles Delvenne (UCLouvain)

Title: Nanoscale control theory

Abstract: Modelling and design of interconnected nanoscale systems, such as electronic circuits or biochemical networks, call for a rewriting of the rulebook of control theory. In order to agree with fundamental laws of nature, such as microscopic reversibility and ubiquitous thermal noise, one must merge dissipative systems theory on the one hand, with stochastic thermodynamics on the other hand.

An overarching theme is the trade-off between dissipation and various objective functions such as precision or speed. We introduce and illustrate those trade-offs on a range of systems, from molecular motors to ultra-low-power electronic memories.

Bio: Jean-Charles Delvenne received the M. Eng. degree (2002) and a Ph.D. (2005) in Applied Mathematics from Université catholique de Louvain, Louvain-la-Neuve, Belgium. After positions at the California Institute of Technology, the Imperial College London, and the University of Namur, he has been Professor of Applied Mathematics at Université catholique de Louvain, Louvain-la-Neuve, Belgium since 2010.

His research interests include networked dynamical systems, statistical physics, information theory, complex networks and data science. His works have found applications in neurosciences, biochemistry, social sciences, geography, biophysics and electronics.

Giulia Giordano (University of Trento)

Title: Robustness and resilience of dynamical networks in nature

Abstract: Biological, ecological and epidemiological systems can be seen as dynamical networks, namely dynamical systems that are naturally endowed with an underlying network structure, because they are composed of several subsystems that interact according to an interconnection topology. Despite their large scale and complexity, natural systems are often able to preserve fundamental properties and qualitative behaviours even in the presence of huge perturbations and uncertainties, both intrinsic and extrinsic. We look for the source of the extraordinary robustness that often characterises systems in nature, by identifying properties and emerging behaviours that exclusively depend on the system structure (the graph topology along with qualitative information), regardless of parameter values. We focus on the parameter-free assessment of important properties, such as the stability of equilibria and the sign of steady-state input-output influences, thus allowing structural model falsification and structural comparison of alternative mechanisms proposed to explain the same phenomenon. Finally, we discuss the limitations of structural methodologies, which may be overcome by integrating and complementing them with probabilistic approaches, and we propose definitions of resilience that complement the notion of robustness and can be effectively applied to biological models.

Bio: Giulia Giordano leads the Dynamical Networks and Systems Biology group at the Department of Industrial Engineering, University of Trento, Italy. She received the B.Sc. and M.Sc. degrees summa cum laude, and the Ph.D. degree with honours in Systems and Control Theory, from the University of Udine, Italy. She was a Research Fellow at Lund University, Sweden, from 2016 to 2017, and an Assistant Professor at the Delft University of Technology, The Netherlands, from 2017 to 2019. Giulia serves as an Associate Editor for the IEEE Control Systems Letters and for Automatica. She was selected as Outstanding Reviewer by the IEEE Transactions on Automatic Control in 2016 and by the Annals of Internal Medicine in 2020, and as the Outstanding Associate Editor of the IEEE Control Systems Letters in 2021. Giulia received the EECI Ph.D. Award 2016, the NAHS Best Paper Prize 2017, and the SIAM Activity Group on Control and Systems Theory Prize 2021 for "significant contributions to the development of innovative methodologies for the structural analysis of networked control systems and their applications to biological networks". Her main research interests include the analysis and the control of dynamical networks, with applications especially to biology and epidemiology.

Birgit Jacob (University of Wuppertal)

Title: Port-Hamiltonian Systems: Modelling and Analysis

Abstract: The port-Hamiltonian system formulation combines several traditions from mechanics, system modelling and control. One of these is port-based modelling, in which complex systems can be represented by the interconnection of simpler blocks. By using energy as a common language for the connection, this approach enables the modelling of systems belonging to different physical domains (mechanical, electrical, thermal, …). In particular, we model interacting particle systems as port-Hamiltonian systems and investigate analytical properties of a class of port-Hamiltonian systems on a one-dimensional spatial domain.

Bio: Birgit Jacob received the M.Sc. degree in mathematics from the University of Dortmund, Germany, in 1992 and the Ph.D. degree in mathematics from the University of Bremen, Germany, in 1995. She held postdoctoral and Professor positions at the Universities of Twente, Leeds and Paderborn, and at the TU Berlin, and TU Delft. Since 2010, she has been with the University of Wuppertal, Germany, where she is a Full Professor in analysis. From 2012-2016, she has been the Vice Dean of the Faculty of Mathematics and Natural Sciences. She is the coordinator of the EU MSCA Doctoral Network ModConflex. Her current research interests include the area of infinite-dimensional systems and operator theory, particularly well-posed linear systems and port-Hamiltonian systems.

Timothy O'Leary (University of Cambridge)

Title: Closed loop neurophysiology

Abstract: The nervous system is the epitome of a dynamic network, operating in tight feedback with the environment. Due to the closed loop relationship between neural activity and behaviour, it is difficult to establish whether a signal in the brain drives a behavioural outcome or merely reports it, and it is even harder to manipulate brain activity in a systematic way. As a result, much of what we know about nervous system function is correlative, and most of the technology we have for manipulating the brain works despite its dynamics rather than in tandem with them.

In this talk I will highlight two aspects of our recent attempts to study nervous systems in closed loop with data driven models. First, I will describe brain-machine interfaces (BMI) we developed to understand how abstract representations of the environment are used by rodents to navigate virtual environments. I will show how the neural code can be surprisingly simple in some brain areas, enabling robust decoding with no learning required by the animal. I will also show how adaptive properties in other neural circuits can make them extremely sensitive to coupling via brain-machine interfaces, to the extent that the code itself may reconfigure completely during BMI use. In the second part of the talk, I will describe our efforts to use tools from system identification to constrict data-driven predictive models of neural activity. We focus on the dynamics of small central pattern generating circuits that control movement. The internal dynamics of these circuits is extremely rich, and this presents an obstacle to building predictive, data driven models with "the right level" of detail. I will describe work we are doing to build such models and ultimately use them to control the activity of living neural circuits in real time.

Bio: Timothy O'Leary's research interests lie at the intersection between physiology, neural computation and feedback control. Originally trained as a pure mathematician, he dropped out of a PhD in hyperbolic geometry to retrain as an experimental physiologist. After obtaining his doctorate from the University of Edinburgh in 2009, he pursued a mixture of theoretical and experimental research on homeostasis, neural circuit dynamics and neuromodulation. From 2012-2016 he worked with Prof Eve Marder in Brandeis University, USA, where he developed theory that reconciles nervous system variability with reliable function. For this work he was awarded the Gruber International Prize in 2014. In 2016 he embarked on mission to try to bring together control engineers and neuroscientists, forming an ERC-funded research group in the University of Cambridge. In 2017 he became a HFSP Young Investigator, leading an international collaboration between his group and experimentalists in the Weizmann Institute of Science and Harvard Medical School to attempt to understand how navigational information is represented in the brain. This has led to recent insights in how memories can be formed and maintained in the absence of stable synaptic connections, how neural circuit size influences learning performance, and how neural signals can be decoded to control movement in real time. He was elected a FENS-Kavli Fellow in 2021 and serves as a reviewing editor for The Journal of Neuroscience.

Amirhossein Taghvaei (University of Washington)

Title: Towards data-driven nonlinear filtering algorithms

Abstract: In this talk, I present a new variational formulation of the Bayes' law, that will be used for construction of a new family of nonlinear filtering algorithms. The variational formulation is based on the optimal-transportation (OT) theory, and aims at approximating the Brenier Optimal transport map from the prior to the posterior distribution, as a solution to a stochastic optimization problem. Unlike sequential importance resampling (SIR) particle filters, the OT formulation does not require the analytical form of the likelihood. Moreover, it allows us to harness the approximation power of neural networks to model complex and multi-modal distributions and employ stochastic optimization algorithms to enhance scalability. I present error analysis and numerical results that illustrate the performance of the algorithm in comparison with the SIR particle filters, and present an extension of the algorithm that is model-free and only requires recorded data from the state and observation processes.

Bio: Amirhossein Taghaei is an Assistant Professor in the William E. Boeing Department of Aeronautics and Astronautics at University of Washington Seattle. Prior to that, he was a Postdoctoral Scholar at the University of California Irvine in Prof. Tryphon Georgiou's research lab. He received his Ph.D. degree in Mechanical Science and Engineering and the M.S. degree in Mathematics from University of Illinois at Urbana-Champaign. His current research involves nonlinear filtering, computational optimal transport, and stochastic thermodynamics.

Melanie Zeilinger (ETH Zürich)

Title: Optimization-based Control under Uncertainty: Guarantees, performance & computation

Abstract: Increasing requirements on modern complex control systems amplify the challenging tradeoff between performance gains and safety concerns. Optimization-based control has a long history of providing rigorous control-theoretic guarantees, particularly for ensuring the satisfaction of critical safety constraints. Its popularity has recently surged due to its potential as a flexible framework for safe learning-based control. While a variety of methods are available to address model uncertainty, the context of learning and complex systems has emphasized the need for improved uncertainty handling to reduce conservativeness while maintaining strong controller guarantees.

The talk will begin with a holistic discussion of uncertainties arising in an optimization-based controller, ranging from model to numerical uncertainty. I will then discuss both the improved treatment of model uncertainty and concepts to reduce uncertainty through learning and data-driven techniques. The results will be accompanied by efficient computational methods, which are critical to enabling these advancements in practice.

Bio: Melanie Zeilinger is an Associate Professor at the Department of Mechanical and Process Engineering at ETH Zurich, where she is leading the Intelligent Control Systems. She received the diploma in Engineering Cybernetics from the University of Stuttgart in Germany in 2006 and the Ph.D. degree in Electrical Engineering from ETH Zurich in 2011. From 2011 to 2012 she was a postdoctoral fellow at the École Polytechnique Fédérale de Lausanne (EPFL), Switzerland. From 2012 to 2015 she was a Postdoctoral Researcher and Marie Curie fellow in a joint program with the University of California at Berkeley, USA, and the Max Planck Institute for Intelligent Systems in Tuebingen, Germany. From 2018 to 2019 she was a professor at the University of Freiburg, Germany. Her awards include the ETH medal for her PhD thesis, an SNF Professorship, the Golden Owl for exceptional teaching at ETH Zurich 2022 and the European Control Award 2023. Her research interests include learning-based control with applications to robotics and biomedical systems.

Special Memorial Plenary Session

A Life in Science and Engineering: The Legacy of Allen Tannenbaum

Organisers: Yongxin Chen (Georgia Tech) and Tryphon Georgiou (UC Irvine)

Aim:

The special session will overview a most remarkable path in Science and Engineering by Allen Tannenbaum, a towering figure in the field of Mathematical Systems Theory, Robust Control, Image Processing, Optimal Mass Transport and Biomedical Applications, who departed on December 28, 2023. We will highlight some of his most important contributions that underscore the broad spectrum and impact of his work, from the structure of systems to robust control, analytic function theory, partial differential equations and group invariance for applications in image analysis, optimal mass transport on continuous/discrete spaces and on the non-commutative/quantum setting, on the structure of networks focusing on gene regulatory networks, and on a wide range of biomedical applications targeting cancer.

Program:

Chairs.
Malcolm Smith (Cambridge) and Tryphon Georgiou (UC Irvine)

Speakers:
1. Tryphon Georgiou (UC Irvine)
2. Yongxin Chen (Georgia Tech)
3. Hitay Özbay (Bilkent)
4. Yutaka Yamamoto (Kyoto)

Mini Courses

Mini-course: Dynamics and Control in Spatiotemporal Systems

Bassam Bamieh
University of California at Santa Barbara, USA.

Aim:

This minicourse is intended to present a mutually-related set of techniques aimed at understanding collective dynamics and control/estimation architectures in spatially distributed systems. Relations between temporal and spatial scales play an important role in analysis of dynamical phenomena that emerge in such systems. Optimal spatiotemporal control problems also exhibit spatiotemporal scales that determine fundamental performance limitations, as well as architectural features in distributed control and estimation problems. The minicourse aims at a tutorial introduction to this set of techniques, as well as case study demonstrations of their use in specific areas from networked systems, biology, and fluid dynamics.

Program:

Part I will be primarily (though not exclusively) centered on architectural questions in analysis and design of spatially distributed control and estimation problems for both networked as well as continuum systems described by PDEs, as well as structured robustness analysis.

1. Overview: Spatiotemporal Systems in Discrete and Continuum Space
   Bassam Bamieh, University of California at Santa Barbara, USA
2. Controller Architectures: Tradeoffs Between Performance and Structure
   Mihailo Jovanovic, University of Southern California, USA
3. Optimal Distributed Control with Spatial Constraints
   Emily Jensen, University of Colorado, Boulder, USA
4. Information Passing in the Spatially Distributed Kalman Filter
   Juncal Arbelaiz, Princeton University, USA
5. Mean-Square Stability Analysis with Distributed Stochastic Uncertainty
   Maurice Filo, ETH-Zürich, Switzerland.

Part II will present applications in a several settings. Those include networked and vehicular formation control, the mammalian cochlea as a distributed sensor network, and problems from fluid dynamics involving shear-flow transition and turbulence as well control in wind farms.

1. Stability and Fragility in the Mammalian Cochlea
   Maurice Filo, ETH-Zürich, Switzerland.
2. Control of Densities in Wasserstein Space
   Max Emerick, University of California at Santa Barbara, USA.
3. Dynamics and Control of Transitional and Turbulent Fluid Flows
   Mihailo Jovanovic, University of Southern California, USA.
4. Input-Output Analysis Based Tools for Turbulence and Transition
   Dennice Gayme, Johns Hopkins University, USA.

Mini course on extended dynamic mode decomposition in the Koopman framework

Friedrich Philipp and Karl Worthmann
Optimization-based Control Group, Technische Universität Ilmenau, Germany

Aim:
In this mini course, we provide a tutorial on the theory and practice of extended dynamic mode decomposition (EDMD) in the Koopman framework. We cover the basics of modelling, spectral information, and control for this data-driven technique. Hereby, we emphasize the algorithm design including convergence guarantees and error bounds. The mini course encompasses the following topics and questions:

- Brief self-contained recap of EDMD and the underlying Koopman theory
- Data-driven surrogate models based on EDMD: algorithms and use cases
- Finite-data bounds on the approximation error resulting from projection and estimation
- Spectral analysis in view of chaotic and stable long-term behaviour
- Convergence guarantees for algorithms to approximate the spectrum
- What is the benefit of reprojections to ensure consistent predictors?
- Kernel EDMD, Koopman invariance and uniform error bounds
- Why is convex and polynomial optimization key for the stability analysis?
- Extensions to control systems: proportional error bounds and closed-loop stability
- What are open problems?

The mini course will be accessible to everyone with basic knowledge on systems theory and differential equations. Furthermore, the mini course nicely fits to Parts II and IV of the invited session *Learning and optimization in stochastic systems and control,* organized by Lars Grüne and Karl Worthmann.

Program:

1 Koopman operator theory and its applications (40 minutes)
Stefan Klus, Heriot-Watt University, Edinburgh, UK.
Introduction to the Koopman operator framework and its use for the analysis and prediction of nonlinear dynamical systems. We will introduce data-driven methods for the approximation of the Koopman operator such as DMD and EDMD and present simple guiding examples as well as applications in molecular dynamics and fluid dynamics.
2. Error bounds for EDMD and its kernel-based variants (35 minutes)
Manuel Schaller, Technische Universität Chemnitz, Germany.
Bounds on the approximation error stemming from projection and estimation. Further, we introduce kernel EDMD, discuss the role of Koopman invariance of the underlying RKHS, and present uniform error bounds.
3. Data-driven computation of spectral properties of Koopman operators
Matthew J. Colbrook, University of Cambridge, UK.
We propose data-driven algorithms to compute spectral information of Koopman operators from trajectory data with convergence guarantees. Further, we discuss the boundaries and classifications of what is achievable in Koopman learning.
4. EDMD-based (predictive) closed-loop control with guarantees
Karl Worthmann, Technische Universität Ilmenau, Germany.
We present extensions of EDMD to control systems and derive novel proportional bounds on the approximation error to rigorously ensure closed-loop stability of EDMD-based (predictive) control schemes.
5. Data-driven system analysis: Polynomial optimization meets Koopman
Giovanni Fantuzzi, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany.
In this talk, we combine EDMD with polynomial optimization techniques to analyze dynamical systems directly from measured data, bypassing the need for model identification.

Mini-course on Group-affine systems and invariant filtering

Silvère Bonnabel
Mines Paris PSL, PSL Research University, Paris, France.

Aim:

In the field of state estimation, systems may broadly be divided into linear and nonlinear systems. In the linear case, the Kalman filter "solves" the problem of state estimation in many regards, see Kalman and Bucy (1961). The case of nonlinear dynamical systems, though, is much more difficult, although admittedly numerous results do exist, see e.g., Khalil (1992). If we focus on aerospace engineering (and robotics), that prompted early implementations and developments of Kalman filtering, and we want to improve on the widespread extended Kalman filter (EKF), we immediately run into two (related) main troubles. First, we have a problem of representation. Indeed, the configuration space of a rigid body fixed at a point is given by the underlying manifold of the rotation (Lie) group SO(3). Then, the equations governing the motion of a rigid body in space are nonlinear.

The presence of those two issues of a different nature, and their intrication, might have created some confusion in the past. By studying dynamical systems "on Lie groups" and observers or filters "on Lie groups", it is unclear whether one is alluding to a representation issue to accommodate the state variable, or whether one is leveraging the rich structure of Lie groups to attack the nonlinearity of the dynamics, and that of the observations (the output map). The latter is what drives the work that we will present in this mini-course: Group affine systems are a class of dynamical systems on Lie groups that can be viewed as "linear" in some sense, as they essentially mimic linear systems by replacing addition with group multiplication.

A mathematical theory of group affine systems on Lie groups could seem meaningless if there were no applications. For systems defined on the basic groups SO(3), or SE(3), the theory encompasses left-invariant or right-invariant or mixed invariant systems, that were previously exploited in the field of invariant observers, complementary filters, or attitude observers, e.g., Mahony et al. (2005); Bonnabel et al. (2008); Martin and Salaun (2008), and had actually laid the foundations for such a theory. Those early observers on Lie groups were an enabling technology for the first generation of mini-drones back in the mid 2000s. It turns out though, that much more complex systems fall into the scope of the theory.

Moving from SE(3) to its extension SEk(d), introduced in Barrau (2015) and in particular SE2(3), introduced in Barrau and Bonnabel (2017), one may prove many systems in robotics and navigation have the group affine structure, beyond invariant ones. The invariant extended Kalman filter (IEKF) is a state observer which builds upon this mathematical framework, and possesses many properties of the linear Kalman filter, albeit not optimal. It was rapidly adopted and implemented in a high-end industrial product, see Barrau and Bonnabel (2018), and allowed for numerous recent successes in robotics, see e.g., Wu et al. (2017); Heo and Park (2018); Hartley et al. (2019); Cohen et al. (2020); Van Der Laan et al. (2020); de Araujo et al. (2023).

Program:
The course will be divided into 4 slots:

1. General introduction, motivating applications, relation to the literature.
2. Reminders on SO(3), SE(3), left-invariant systems. Introduction of their extension SEk(d).
3. Group affine systems on SEk(d), main properties.
4. The Invariant extended Kalman filter and its properties.

A Gentle Introduction to Representation Stability: Fundamentals and Applications

Eitan Levin∗, Mateo Diaz †, and Venkat Chandrasekaran∗
∗Department of Computing and Mathematical Sciences, Caltech, Pasadena, CA 91125, USA.
†Department of Applied Mathematics and Statistics, Johns Hopkins University, Baltimore, MD 21218, USA.

Aim:
Representation stability is a newly discovered phenomenon that describes how certain invariants in sequences of group representations stabilize as their size or complexity increases. This arguably abstract concept has recently found applications in learning and optimization. While the literature on this topic tends to be technical in nature, this mini-course aims to provide a user-friendly introduction to these concepts, making them accessible to a wider audience. Through a series of talks, we plan to introduce participants to the fundamental ideas of representation stability: consistent sequences, finite generation, and freely-described objects. Once the foundational knowledge is established, we'll explore its practical applications, specifically focusing on neural networks and symmetric convex programs. This approach aims to bridge the gap between theoretical intricacies and practical utility.

This mini-course is a companion to the semi-plenary that will be given by Venkat Chandrasekaran.

Intended audience:

This mini-course targets a diverse audience, including graduate students, researchers, and professionals in mathematics, physics, and engineering. No prior knowledge of the topics is assumed, making it an ideal introduction for those curious about representation theory, representation stability, and their applications to optimization
and machine learning.

Program:

The mini-course spans one block with five 25-minute slots.

Slot 1: Introduction to Representation Theory (Eitan Levin).
Essentials of representation theory, exploring the foundational principles of groups and group actions.

Slot 2: Invariance, equivariance, and tensors (Mateo Diaz)
Critical concepts of invariance and equivariance, cornerstones in understanding how mathematical objects can change or preserve their structure in response to transformations.

Slot 3: Exploring Representation Stability (Eitan Levin)
In this slot, we delve into a recently-identified phenomenon called representation stability that lays the groundwork for our any-dimensional learning framework.

Slot 4: Applications to Learning (Mateo Diaz)
This slot introduces an innovative application of representation stability to learning problems, specifically in the development of equivariant neural networks.

Slot 5: Applications to Optimization (Eitan Levin/Mateo Diaz)
In the final slot, we address a surprising phenomenon observed across various applications of convex optimization: the emergence of programs with constant size complexity, regardless of the initial problem scale.

Mini-course on Stochastic Safety

Manuela L. Bujorianu ∗ Rafal Wisniewski ∗∗
∗ Department of Computer Science, University College London, UK
∗∗ Section of Automation & Control, Aalborg University, Denmark

Aim:

The primary purpose of this minicourse is to introduce the participants to stochastic safety. That is a method for computing the probability that a system hits an unsafe state before reaching the goal. It is related to the subject of constrained optimisation, specifically to safe dynamic programming. The lectures will gently introduce the participants to the subject of safety. Firstly, we will define stochastic safety, where the primary object of interest is a stochastic process. Subsequently, we will discuss numeric algorithms for computing safety. To this end, we will use semi-definite and linear programming. We will present examples of how to apply these numerical optimisation tools to compute safety. The final slot of the course will focus on specializing in Markov decision processes. Here, we will demonstrate methods to identify optimal strategies while adhering to safety constraints. The course will be accompanied by papers and slides/handouts.

Program:

The course consists of 3 lectures each of 40 minutes followed by 10 minutes of questions and discussions.

Lecture 1
- *Martingales and martingale inequalities*
- *Strong p-safety and weak p-safety*
- *Super martingale characterization of barrier certificates*
- *Generators of Markov processes and examples*

Lecture 2
- *Main theorem of strong p-safety*
- *Computation of strong p-safety with the sum of squares programming*
- *Computation of weak p-safety with the moment method*

Lecture 3
- *Evolution equation of the Markov chains*
- *Dynamic programming with a stopping time*
- *Strong p-safety for Markov chains*
- *On-line learning of safety function*

Mini-course: Infinite Dimensional Analysis

Daniel Alpay
Chapman University, California, USA.

Aim:

Infinite dimensional analysis is a domain at the crossroads of:
(1) Positive definite kernels (for building probability spaces via the Bochner-Minlos theorem, and as covariance functions of second order stochastic processes; Loeve theorem).
(2) The theory of stochastic processes (for instance, fractional Brownian motion). This is one of the main applications of infinite dimensional analysis. Various models can be built, in spaces where differentiation is allowed; this makes various technical arguments (for instance for stochastic integration) much easier.
(3) Reproducing kernel Hilbert spaces (for instance the Fock space and its various extensions and generalizations). The construction of the Fock space and the second quantization allow to make links with quantum mechanics and Feynman integrals.
(4) Topological vector spaces, and in particular Frechet nuclear spaces and their dual spaces, and Gelfand triples (to model derivatives of stochastic processes such as the Brownian motion, the white noise, (Brownian motion has no derivative in the probabilistic sense ...).
(5) Positive operators from a topological vector space into its anti-dual, or conversely.
(6) Complex analysis, possibly in an infinite number of variables.

Applications include stochastic processes and stochastic PDEs, models for the brain in life sciences, and economics (for instance to solve the stochastic Black-Scholes equation).

Intended audience:

This mini-course targets a diverse audience, including graduate students, researchers, and professionals in mathematics, physics, and engineering. No prior knowledge of the topics is assumed, making it an ideal introduction for those curious about representation theory, representation stability, and their applications to optimization and machine learning.

Program:

The course will be divided into four distinct blocks:

Lecture 1: Background: Positive definite kernels. Bochner theorem. Schwartz functions and tempered distributions. The Bochner-Minlos theorem.

Lecture 2: White noise space and models for stochastic processes: Construction of the white noise space. The Fock space and the Wick product. The Hermite transform.

Lecture 3: Stochastic test functions and stochastic distributions: Kondratiev's spaces of stochastic test functions and stochastic distributions, and derivatives of stochastic processes. V age inequality. Strong algebras.

Lecture 4: The free setting: The counterpart of the above in the free probability setting. We present in particular a construction of non-commutative white noise.

Technical Programme

Sessions, Speakers, Titles, and Abstracts

MoP_LMH	Lady Mitchell Hall
Architectural Questions in Distributed Systems and Controls (Plenary Session)	
Chair: Glover, Keith	Univ. of Cambridge

09:00-10:00	MoP_LMH.1

Plenary: Architectural Questions in Distributed Systems and Controls

Bamieh, Bassam — Univ. of California at Santa Barbara

MoAM_LH	Little Hall
Dynamics and Control in Spatiotemporal Systems (I) (Mini Course)	
Chair: Bamieh, Bassam	Univ. of California at Santa Barbara
Co-Chair: Arbelaiz, Juncal	Princeton University

10:30-10:55	MoAM_LH.1

Dynamics and Control in Spatiotemporal Systems

Bamieh, Bassam — Univ. of California at Santa Barbara

MoAM_LR1	LR1
Operator Theoretic Methods in Systems Theory (Regular Session)	
Chair: Wirth, Fabian	University of Passau
Co-Chair: Patil, Deepak	Indian Institute of Technology Delhi

10:30-10:55	MoAM_LR1.1

Minimum Time Consensus of Multi-Agent System under Fuel Constraints

Rautela, Akansha — Indian Institute of Technology Delhi
Patil, Deepak — Indian Institute of Technology Delhi
Mulla, Ameer — Indian Institute of Technology Dharwad
Kar, Indra Narayan — Indian Institute of Technology, Delhi

This work addresses the problem of finding a consensus point in the state space for a multi-agent system that is comprised of N identical double integrator agents. It is assumed that each agent operates under constrained control input (i.e., $|u_i(t)| leq 1$ $forall i = 1, hdots N$). Further, a fixed fuel budget is also assumed i.e., the total amount of cumulative input that can be expended is limited by $int_0^{t_f}|u(t)|dt le beta$. First, the attainable set $mathcal{A}(t_f,mathbf{x}_0,beta)$ at time t_f, which is the set of all states that an agent can attain starting from initial conditions $mathbf{x}_0$ under the fuel budget constraints at time t is computed for every agent. This attainable set is shown to be a convex set for all t_fge0. Then the minimum time to consensus is the minimum time $bar{t}_f$ at which attainable sets of all agents intersect, and the consensus point is the point of intersection. A closed-form expression for the minimum time consensus point is provided for the case of three agents. Then, using Helly's theorem, the intersection will be non-empty at a time when all the $Mycomb[N]{3}$ triplets of agents have non-empty intersection. The computation of minimum time consensus for all $Mycomb[N]{3}$ triplets is performed independently and can be distributed among all the N agents. Finally, the overall minimum time to consensus is given by the triplet that has the highest minimum time to consensus. Further, the intersection of all the attainable sets of this triplet gives the minimum time consensus point for all N agents.

10:55-11:20	MoAM_LR1.2

On Pointwise Hölder Continuity of the Joint Spectral Radius

Epperlein, Jeremias — Universität Passau
Wirth, Fabian — University of Passau

We show that the joint spectral radius is pointwise Hölder continuous. This extends results from classical perturbation theory of single matrices to the setting of compact sets of matrices. The results are new for reducible matrix sets, as Lipschitz continuity of the joint spectral radius restricted to irreducible matrix sets was already shown by the second author in Wirth (2002).

11:20-11:45	MoAM_LR1.3

A Cantor-Kantorovich Metric between Markov Decision Processes with Application to Transfer Learning

Banse, Adrien — UCLouvain
Renganathan, Venkatraman — Lund University
Jungers, Raphaël M. — Université Catholique De Louvain

We extend the notion of Cantor-Kantorovich distance between Markov chains introduced by Banse et al. (2023) in the context of Markov Decision Processes (MDPs). The proposed metric is well-defined and can be efficiently approximated given a finite horizon. Then, we provide numerical evidences that the latter metric can lead to interesting applications in the field of reinforcement learning. In particular, we show that it could be used for forecasting the performance of transfer learning algorithms.

11:45-12:10	MoAM_LR1.4

Splitting Algorithms for Nonlinear RLC Circuits

Shahhosseini, Amir — KU Leuven
Chaffey, Thomas Lawrence — University of Cambridge
Sepulchre, Rodolphe J. — University of Cambridge

Splitting algorithms are well established in large-scale convex optimization problems reformulated as zero finding of monotone operators. We explore such algorithms in solving nonlinear circuits represented as port interconnections of monotone or mixed-monotone elements. For circuits made of linear capacitors and inductors with nonlinear resistive elements, we propose that the splitting of the circuit between its LTI lossless passive component and its static resistive component is attractive both for physical and algorithmic reasons. We illustrate this splitting on the well-known FitzHugh-Nagumo circuit model, a paradigmatic example of a spiking neuron.

12:10-12:35	MoAM_LR1.5

A Hill-Pick Matrix Criterion for Matrix-Point Nevanlinna-Pick Interpolation in the Right Half-Plane

ter Horst, Sanne — North West University
van der Merwe, Alma — University of the Witwatersrand

Cohen & Lewkowicz (2007, 2009) considered a variation on Nevanlinna-Pick interpolation in the class of positive real odd functions, denoted PRO, with real matrix point interpolation conditions, that is, for real matrices A,B, the question is to determine when there exists a function f in PRO such that f(A)=B. They introduced the Lyapunov order, and showed that Lyapunov domination of A by B is a necessary condition for existence of a solution, claiming that, under certain regularity conditions, this Lyapunov domination together with B being in the double commutant of A is also sufficient. Under an additional condition, called "suboptimality", this claim was proved by Ter Horst & Van der Merwe (2022c). In this talk we give more detail on how the Lyapunov order can be determined provided that B is in the double commutant of A in terms of a Hill-Pick matrix criterion. The results are based on the work of Ter Horst & Van der Merwe (2022b).

MoAM_LR2	LR2
System Identification (Regular Session)	
Chair: Ohta, Yoshito	Kyoto University
Co-Chair: Hendrickx, Julien M.	UCLouvain

10:30-10:55	MoAM_LR2.1

Relaxation of Large-Scale Network Inference to Many Small-Scale Networks

Teng, Basi	University of Cambridge
Zhao, Yuxuan	Huazhong University of Science and Technology
Yuan, Ye	Huazhong University of Science and Technology
Goncalves, Jorge	University of Luxembourg

This work addresses the challenge of reconstructing large-scale networks by leveraging network collapse algorithms. Traditional inference methods struggle with scalability, making large-scale inference computationally demanding. For sparse networks, such as those encountered in biology, instead of tackling the large-scale network directly, we propose to relax the problem by solving many small-scale network reconstructions to significantly reduce computational costs and improve performance. Our approach is centred on three key objectives: the first two assume network identifiability, while the third, practical in nature, does not. First, we aim to demonstrate that our method outperforms conventional algorithms in accuracy and computational efficiency by reconstructing large-scale networks and comparing performance metrics. Second, we explore relaxations to our algorithm to significantly minimize computational efforts without sacrificing too much accuracy. Given the nature of our method, we can efficiently infer non-existing links which are the vast majority in sparse networks, and streamline the overall reconstruction process. Third, we address the issue of non-identifiable networks, common in fields like gene regulatory networks, where experimental constraints limit identifiability. By integrating regularization techniques and prior network knowledge, we aim to enhance the identifiability and accuracy of large-scale network reconstructions. Overall, our work will contribute to a scalable, efficient framework for large-scale network reconstruction, offering significant advancements in understanding complex systems.

10:55-11:20 MoAM_LR2.2

Data Informativity of Continuous-Time Systems by Sampling Using Linear Functionals

Ohta, Yoshito	Kyoto University

This paper discusses the data informativity for continuous-time system identification. We extract a finite number of data samples from continuous-time signals using linear functionals and decide whether the data is informative for determining system matrices uniquely. We examine how and when the sampled data preserves the information of continuous-time signals enough to identify the system.

11:20-11:45 MoAM_LR2.3

Towards a Representer Theorem for Identification of Passive Systems

Shali, Brayan	University of Groningen
Sepulchre, Rodolphe J.	University of Cambridge
van Waarde, Henk J.	University of Groningen

A major problem in system identification is the incorporation of prior knowledge about the physical properties of the given system, such as stability, positivity and passivity. In this extended abstract, we present first steps towards tackling this problem for passive systems. In particular, using ideas from the theory of reproducing kernel Hilbert spaces, we solve the problem of identifying a nonnegative input-output operator from data consisting of input-output trajectories of the system. We prove a representer theorem for this problem in the case where the input space is finite-dimensional. This provides a computationally tractable solution, which we show can be obtained by solving an associated semidefinite program.

11:45-12:10 MoAM_LR2.4

Identification of Nonlinear Networks in Continuous Time

Anantharaman, Ramachandran	University of Namur
Vizuete, Renato	UCLouvain
Hendrickx, Julien M.	UCLouvain
Mauroy, Alexandre	University of Namur

We propose a method for the identification of nonlinear networks in continuous time. In this preliminary work, we focus on paths and trees and we prove that the measurement of the sinks is necessary and sufficient for the identification of the network. Then, based on the measurement of higher order derivatives, we introduce a method for the identification that allow us to recover the nonlinear functions located in the edges of the network. Finally, we provide an insight about the practical implementation of the identification method using the Koopman operator.

12:10-12:35 MoAM_LR2.5

Simultaneous Input and State Estimation for Systems with Arbitrary Inherent Delay

Gakis, Grigorios	University of Cambridge
Smith, Malcolm C.	University of Cambridge

This extended abstract presents a filtering and smoothing algorithm for left invertible systems of any inherent delay. The approach places no assumption on the exogenous input so that the state and input estimation are on an equal footing. The form of the derived recursions closely resembles that of the Kalman filter and smoother. The filtering algorithm is a generalisation of existing literature which has focused on systems with an inherent delay of zero or one. Conditions for the convergence of the filter are also presented and consist of a controllability condition and a minimum phase condition. The algorithm is illustrated for the simple system of a mass with a force input and a position sensor, which has an inherent delay of two.

MoAM_LR3 LR 3

Recent Progress in Ensemble Control (Invited Session)

Chair: Schoenlein, Michael	Bauhaus-Universität Weimar
Co-Chair: Dirr, Gunther	University of Wurzburg
Organizer: Schoenlein, Michael	Bauhaus-Universität Weimar
Organizer: Dirr, Gunther	University of Wurzburg

10:30-10:55 MoAM_LR3.1

Ensemble Controllability of Parabolic Type Equations (I)

Danhane, Baparou	INP-Toulouse
Loheac, Jerome	Université De Lorraine / CNRS

We extend the concept of ensemble controllability introduced in 2009 by Jr-Shin Li and Navin Khaneja to a class of linear partial differential equation. More precisely, we consider some abstract parabolic equation, where the system depends on some unknown parameter which is assumed to belong to a compact interval. We investigate the possibility of approximatively reaching (in L^2-norm) any target state from any initial state, with an open loop control. Here the initial and target states might depend on the unknown parameter, but the control is assumed to be parameter independent.

10:55-11:20 MoAM_LR3.2

Output Controllability of Parameter Dependent Systems with Parameter Independent Open-Loop Controls (I)

Danhane, Baparou	INP-Toulouse
Loheac, Jerome	Université De Lorraine / CNRS
Jungers, Marc	CNRS - Université De Lorraine

In this article, we aim to present an extension of the concept of ensemble controllability often considered in the context of state variable in the output frame. More precisely, we consider the linear system $\dot{x}(t, \theta) = A(\theta)x(t, \theta) + B(\theta)u(t)$ coupled with an output variable $y(t, \theta) = C(\theta)x(t, \theta)$ where A, B and C are continuous matrices with respect to the constant parameter θ. Given any continuous initial state datum $\theta \to x0(\theta)$ and any continuous output function $\theta \to y1(\theta)$, we investigate the existence of a θ-independent open-loop control u such that x0 is steered, in finite time, arbitrarily closed to y1 for the uniform norm.

11:20-11:45 MoAM_LR3.3

Structural Average Controllability of Single-Input Linear Ensemble Systems (I)

Gharesifard, Bahman — University of California, Los Angeles

Chen, Xudong — Washington University in St. Louis

This extended abstract reports on a complete characterization of the sparsity patterns that are structurally averaged controllable for the class of single-input linear time-invariant ensemble control systems.

11:45-12:10 MoAM_LR3.4

Ensemble Feedback Methods for Families of Linear Systems (I)

Schoenlein, Michael — Bauhaus-Universität Weimar

Wirth, Fabian — University of Passau

Ensemble control is a rather new research area of control theory which is concerned with a whole parameter-dependent family of systems instead of a single one. Here, the major challenge is to achieve classical control task simultaneously, i.e. for the entire ensemble via controls that are independent of the system parameter. Thus the topic of ensemble control is located at the crossroad of finite- and infinite-dimensional control theory, operator theory and approximation theory. From a mathematical point of view, this intimate interplay of various disciplines is expected to lead to deep results with impact far beyond control theory.

The problem of simultaneous stabilization of parameterized families of linear systems falls into this setting. In this context, parameter-dependent pole-shifting has been addressed in the 1980s and 1990s. We note that the contributions used rather different methods. On the one hand, in Hautus, Sontag and Wang used the algebraic theory of systems over rings. On the other hand, for the simultaneous stabilization problem a frequency domain approach using function theoretic methods was proposed by various authors. For details and more references we refer to the comprehensive monograph of Blondel. In this work, we will use tools from functional analysis and approximation theory to study the possibilities and limits of ensemble feedback methods for families of one-parameter families of linear systems.

12:10-12:35 MoAM_LR3.5

Ensemble Control Beyond Banach Spaces (I)

Dirr, Gunther — University of Wurzburg

Schoenlein, Michael — Bauhaus-Universität Weimar

In recent years ensemble control has become a very active and growing research area of mathematical control theory. Attention turned to the field particularly due to its wide range of applications to systems which consist of huge number of identical subsystems: In biology, for instance, one could think of a flock of birds or a swarms of fish. In robotics or engineering, certain motion control problems for platoons (formations) of vehicles, satellites or robots fall into the class of ensemble control. Here we focus on so-called linear ensembles, i.e. we concentrate on (finite dimensional) linear systems which depend on some additional parameter.

The aim of this work is to present new results in ensemble control, where the underlying function spaces do not support a canonical Banach space structure, such as the set of smooth functions or continuous functions over an unbounded domain. Both examples carrying a natural Fréchet space structure prepared the framework of our studies. We pursue a generalization of ensemble control results which have been established for Banach spaces. For this purpose, we resort to an infinite dimensional version of the Kalman rank condition – first shown by Triggiani for linear systems over Banach spaces. We will extended this result to Fréchet spaces.

12:35-13:00 MoAM_LR3.6

Ensemble Control of N-Level Systems Via Combined Adiabatic and Rotating Wave Approximations (I)

Liang, Ruikang — Sorbonne University

Boscain, Ugo V. — DR2, CNRS, CMAP, Ecole Polytechnique

Robin, Rémi — PSL Université

Sigalotti, Mario — Inria

In this work, we explore the ensemble control problem of n-level quantum systems with unknown parameters. Under a suitable frequency conditions, we justify the application in cascade of the rotating wave approximation and the adiabatic approximation. This enables the construction of a real-valued control law that realizes population inversion between two arbitrary eigenstates. Illustrative numerical examples are given for further insight.

MoAM_LR4 LR4

Nonlinear Control (Regular Session)

Chair: Yamamoto, Kaoru — Kyushu University

Co-Chair: Rantzer, Anders — Lund Univ

10:30-10:55 MoAM_LR4.1

Dissipativity and Passivity for Sampled-Data Control Systems

Yamamoto, Kaoru — Kyushu University

Yamamoto, Yutaka — Kyoto University

This short note discusses the correspondence of disspativity and passivity between a continuous-time system and its sampled-data discrete-time system. It is well known that strictly proper discrete-time systems cannot be passive, and hence inheritance of such a property is not entirely trivial. We will show that employing the nonlinear lifting such dissipativity/passivity properties are naturally inherited to the discretized systems, and hence pertinent stability properties as well. Following our previous work on nonlinear lifting cite{YYKYIFAC2023}, we proceed to define dissipativity and passivity notions for continuous-time systems and their respective discrete-time counterparts. We show that such notions are naturally preserved under lifting. We will further proceed to prove a correspondence of a positive-real properties for continuous-time and discrete-time counterparts. In particular, a Kalman-Yakubovich-Popov lemma for lifted system is proved.

10:55-11:20 MoAM_LR4.2

Decentralized and Asymptotically Optimal PI Control of Systems with Nonlinear Control Couplings

Agner, Felix — Lund University

Rantzer, Anders — Lund Univ

In this abstract we investigate multi-agent systems which are coupled by a class of nonlinear functions in their control mapping. In addition, these agents are subject to saturating control inputs. We consider a control strategy based on proportional integral control with anti-windup which is fully decentralized in both design and actuation. Additionally, the controller is designed without explicit parameterization of the nonlinear interconnection. We ultimately show that this strategy not only globally stabilizes the system, but asymptotically minimizes a weighted 1-norm of stationary control errors.

11:20-11:45 MoAM_LR4.3

Pattern Recognition Tools for Output-Based Classification of Synchronised Kuramoto States

ALanazi, Faizah — University of Exeter

Mueller, Markus — University of Exeter

Townley, Stuart — Univ. of Exeter

Kuramoto oscillators are known to exhibit multiple synchrony where the states of individual oscillators synchronise in groups. We present a method for output-based classification of synchronised states in networks of Kuramoto oscillators using an artificial neural network for pattern recognition. Outputs of synchronised states are represented by spectrograms, in other words ``fingerprint'', on which an artificial neural network of stacked autoencoders is then trained to classify these fingerprints and thus the different types of synchrony. We illustrate the approach for a Kuramoto model with $N=4$ oscillators which exhibits synchrony of five types. We provide performance metrics for learning and training data which demonstrat that the approach reaches high levels of reliability.

11:45-12:10 MoAM_LR4.4

Predicting Stochastic State Transitions in Autonomous Nonlinear Bistable Systems

Van Brandt, Léopold — Université Catholique De Louvain
Delvenne, Jean-Charles — UCLouvain

Bistable autonomous systems can be found in many areas of science. When the intrinsic noise intensity is large, these systems exhibits stochastic transitions from one metastable steady state to another. In electronic bistable memories, these transitions are failures, usually simulated in a Monte-Carlo fashion at a high CPU-time price. Existing analytical approaches, relying on near-stable-steady-state approximation of the nonlinear system dynamics to estimate the mean transition time, have turned out inaccurate. From a unidimensional stochastic model of overdamped autonomous system, we propose an extended Eyring-Kramers closed-form formula accounting for both nonlinear drift and state-dependent white noise variance. Rigorously derived from stochastic calculus in an another paper, numerical trials confirm a remarkable accuracy.

12:10-12:35 MoAM_LR4.5

Real-Time Simulation for a Digital Twin to Realize Exact Human Gait

Li, Chi-Ying — National Taiwan University
Tsai, I-Haur — National Taipei University of Technology
Tou, Tzu-Hsiang — National Taiwan University University of Science and Technology
Yen, Jia-Yush — National Taiwan University of Science and Technology
Hsu, Wei-Li — National Taiwan University
Tsao, Tsu-Chin — University of California Los Angeles

This paper proposes a digital twin concept to mimic the exact human gait. Mimicking human locomotion is useful in orthopedics for biomechanical study and patient assessment. It is also useful in designing an exoskeleton gait controller to determine the required joint forces and ensure safe operation. The exact mimicking of human gait is not as straightforward as it appears. Notice that the digital twin is not free to direct its own movement for balancing but has to mimic the joint movements of the human twin. Achieving the same balance under these constraints becomes a challenging task. This research records the human gait data through a Vicon motion-capture system. The real-time motion data uses an iSen inertia measurement unit (IMU) data analysis kit. This research first uses the OpenSim package to compute human motion and the corresponding joint forces. We then built a ten-degrees-of-freedom biped model in SimScape with the same biological data as the test subject for the digital twin. The biped model executes recorded joint movements to mimic the subject's gait. Although the data records the balanced motion of the test subject, the biped will fall without additional treatment. This research then used a modified cart table model with ankle torque input to save computing effort and allow real-time digital twin simulation. The simulation model can mimic human motion and maintain balance with proper control tuning. One can then use the digital twin for the biomechanical analysis of its human twin and the balancing trend of the corresponding gait.

12:35-13:00 MoAM_LR4.6

Effects of Time Delay on the Resonance Frequency of Andronov-Hopf Bifurcations in Neuromorphic Devices

Rolf, Hermann Folke Johann — Karlsruhe Institute of Technology
Kumar, Rakesh — Karlsruhe Institute of Technology (KIT)
Meurer, Thomas — Karlsruhe Institute of Technology (KIT)

Tunability is the property that the resonance frequency of an oscillator can be controlled to some degree. Subsequently, the tunability enhancements by introducing delayed feedback are discussed in detail. This is done by analyzing the bifurcation of the normal form of the super-critical Andronov-Hopf bifurcation with delayed feedback. For this analysis, it is assumed that the damping, the feedback, and the delay can be assigned arbitrarily. If the delay is assumed to be the bifurcation parameter, infinitely many Andronov-Hopf bifurcation emerge under certain conditions on the feedback and the damping. In addition to the bifurcations, the resonance frequency of this particular oscillator becomes tunable in terms of the damping and delayed feedback, such that the resonance frequency can be increased and decreased by assigning the parameters accordingly.

MoAM_LR5 LR5

Optimization : Theory and Algorithms (Regular Session)

Chair: Karlsson, Johan — Royal Institute of Technology (KTH)
Co-Chair: Ringh, Axel — Chalmers University of Technology and University of Gothenburg

10:30-10:55 MoAM_LR5.1

A Schrödinger Bridge Framework for Estimating Pollution Spread in Water Networks

Mascherpa, Michele — KTH Kungliga Tekniska Högskolan
Haasler, Isabel — EPFL
Ahlgren, Bengt — RISE
Karlsson, Johan — Royal Institute of Technology (KTH)

We address the problem of estimating the spread of pollution in a water network given measurements from a set of sensors. By modeling water flow as a Markov chain, we introduce states based on water quantities in specific areas (e.g., pipes). Then we seek the most likely flow of the pollution given the expected water flow and the sensors observations. This is a large-scale optimization problem that can be formulated as a Schrödinger bridge problem with partial information, linked to an entropy-regularized multimarginal optimal transport problem. The software EPANET is used for testing the performance of the methodology.

10:55-11:20 MoAM_LR5.2

Martingale Optimal Transport for Robust Pricing of Financial Derivatives

Engström, Linn — KTH Royal Institute of Technology
Källblad, Sigrid — KTH Royal Institute of Technology
Karlsson, Johan — Royal Institute of Technology (KTH)

We introduce a framework for efficiently solving a class of multi-marginal martingale optimal transport problems. The motivation for doing so originates from mathematical finance, since the robust pricing of many path dependent derivatives belong to this problem class. One example of such a derivative is the lookback option. Our method combines entropic regularisation with Newton's method and the exploitation of sparse structures inherent in the problem, which allows for efficient computation of optimal solutions using a generalisation of Sinkhorn's algorithm. By doing so, we are able to solve problems with a large number of marginals. We demonstrate the utility of the method by applying it on a problem where the optimal solution is known analytically.

11:20-11:45 MoAM_LR5.3

A Cool and Greedy Bouncy Particle Method for Piecewise

Deterministic Optimisation

Molin, Vincent — Chalmers University of Technology

Ringh, Axel — Chalmers University of Technology and University of Gothenburg

Schauer, Moritz — Chalmers University of Technology and University of Gothenburg

Sharma, Akash — Chalmers University of Technology

In this work we explore the connection between sampling and optimisation by modifying existing Bayesian inference methods based on piecewise deterministic Markov processes. Starting from the Bouncy Particle Sampler, we combine a continuous time simulated annealing formulation with additional mode-seeking behaviour by biasing the exploration towards modes of the cost function. We demonstrate the algorithm with numerical experiments on neural network training.

11:45-12:10 — MoAM_LR5.4

On the Optimal Communication Weights in Distributed Optimization Algorithms

Colla, Sébastien — UCLouvain

Hendrickx, Julien M. — UCLouvain

We establish that in distributed optimization, the prevalent strategy of minimizing the second-largest eigenvalue modulus (SLEM) of the averaging matrix for selecting communication weights, while optimal for existing theoretical worst-case performance bounds, is generally not optimal regarding the exact worst-case performance of the algorithms. This exact performance can be computed using the Performance Estimation Problem (PEP) approach. We thus rely on PEP to formulate an optimization problem that determines the optimal communication weights for a distributed optimization algorithm deployed on a specified undirected graph. Our results show that the optimal weights can outperform the weights minimizing the second-largest eigenvalue modulus (SLEM) of the averaging matrix. This suggests that the SLEM is not the best characterization of weighted network performance for decentralized optimization. Additionally, we explore and compare alternative heuristics for weight selection in distributed optimization.

MoAM_LR6 — LR6

Extended Dynamic Mode Decomposition in the Koopman Framework (Mini Course)

Chair: Philipp, Friedrich — Technische Universität Ilmenau

Co-Chair: Worthmann, Karl — TU Ilmenau

10:30-10:55 — MoAM_LR6.1

Extended Dynamic Mode Decomposition in the Koopman Framework

Philipp, Friedrich — Technische Universität Ilmenau

Worthmann, Karl — TU Ilmenau

MoSP_LMH — Lady Mitchell Hall

Semi-Plenary: Enhancing Kalman Filtering with Backpropagation: Theory and Examples (Plenary Session)

Chair: Trumpf, Jochen — The Australian National University

14:00-15:00 — MoSP_LMH.1

Semi-Plenary: Enhancing Kalman Filtering with Backpropagation: Theory and Examples

Bonnabel, Silvere — Mines ParisTech

MoSP_LH — Little Hall

Semi-Plenary: Robustness and Resilience of Dynamical Networks in Nature (Plenary Session)

Co-Chair: van Schuppen, Jan H. — Van Schuppen Control Research

14:00-15:00 — MoSP_LH.1

Semi-Plenary: Robustness and Resilience of Dynamical Networks in Nature

Giordano, Giulia — Università degli Studi di Trento

MoSP_LR3 — LR 3

Semi-Plenary: Port-Hamiltonian Systems: Modelling and Analysis (Plenary Session)

Chair: Morris, Kirsten A. — Univ. of Waterloo

Co-Chair: van der Schaft, Arjan J. — Univ. of Groningen

14:00-15:00 — MoSP_LR3.1

Semi-Plenary: Port-Hamiltonian Systems: Modelling and Analysis

Jacob, Birgit — Bergische Universität Wuppertal

MoPM_LH — Little Hall

Dynamics and Control in Spatiotemporal Systems (II) (Mini Course)

Chair: Bamieh, Bassam — Univ. of California at Santa Barbara

Co-Chair: Arbelaiz, Juncal — Princeton University

15:30-18:00 — MoPM_LH.1

Dynamics and Control in Spatiotemporal Systems

Bamieh, Bassam — Univ. of California at Santa Barbara

MoPM_LR1 — LR1

Control of Distributed Parameter Systems (Regular Session)

Chair: Paunonen, Lassi — Tampere University

Co-Chair: Selivanov, Anton — The University of Sheffield

15:30-15:55 — MoPM_LR1.1

Boundary Control of the Semilinear Heat Equation Via Residue Separation

Selivanov, Anton — The University of Sheffield

Wang, Pengfei — Tel-Aviv University

Fridman, Emilia — Tel-Aviv Univ

We propose a simple method of designing a finite-dimensional state-feedback boundary controller that exponentially stabilizes the semilinear heat equation. It is common to design such controllers by performing modal decomposition, truncating highly damped modes, and designing a controller for a finite number of dominating modes. This may lead to the spillover phenomenon: the ignored modes can have an unexpected deteriorating effect on the overall system performance. In this paper, we provide a new method of accounting for these modes. The main idea is to treat the control input as a disturbance in the truncated modes, find the corresponding L2 gains, and take their sum into account when designing a controller for the dominating modes. We show that this idea leads to a natural bound on the number of the dominating modes and improves the admissible Lipschitz constant compared to the recent direct Lyapunov approach that relied on Young's inequality.

15:55-16:20 — MoPM_LR1.2

Energy Decay Estimates for the Transmission Schrödinger/wave Equation with Distributed Damping

Salah-Eddine, Rebiai — University of Batna 2

Moumen, Latifa — University of Batna 2

This paper is devoted to the long-time behavior of the transmission Schrödinger/wave equation with distributed damping. The damping acts through one of the equation only and its effect is transmitted to the other equation through the boundary coupling.

When the damping acts through the wave equation, we show that the system energy decays exponentially. The proof is based on a result due to Prüss which states that the semigroup is exponentially stable if and only if the imaginary axis belongs to the resolvent set and the resolvent operator is uniformly bounded on the imaginary axis. On the other hand, when the damping acts through the Schrödinger equation, it is shown that the system is not exponentially stable. Using a result of Borichev and Tomilov on the resolvent characterization of polynomially stable semigroups, we prove under some assumptions on the geometry of the spatial domain that the system energy has a polynomial decay rate.

16:20-16:45	MoPM_LR1.3

H-Infinity-Optimal Estimator Synthesis for Linear 2D PDEs Using Convex Optimization

Jagt, Declan S	Arizona State University
Peet, Matthew M	Arizona State University

Any suitably well-posed PDE in two spatial dimensions can be represented as a Partial Integral Equation (PIE) -- with system dynamics parameterized using Partial Integral (PI) operators. Furthermore, L_2-gain analysis of PDEs with a PIE representation can be posed as a linear operator inequality, which can be solved using convex optimization. In this paper, these results are used to derive a convex-optimization-based test for constructing an *H-infinity*-optimal estimator for 2D PDEs. In particular, a PIE representation is first derived for arbitrary well-posed 2D PDEs with sensor measurements along boundaries of the domain. An associated Luenberger-type estimator is then parameterized using a PI operator *L* as the observer gain. Next, it is shown that an upper bound on the *H-infinity*-norm of the error dynamics for the estimator can be minimized by solving a linear operator inequality on PI operator variables. Finally, an analytical formula for inversion of a sub-class of 2D PI operators is derived and used to reconstruct the Luenberger gain *L*. Results are implemented in the PIETOOLS software suite -- applying the methodology and simulating the estimator for an unstable 2D heat equation.

16:45-17:10	MoPM_LR1.4

Boundary Control Port-Hamiltonian Systems with Power and Energy Ports

van der Schaft, Arjan J.	Univ. of Groningen
Maschke, Bernhard	Univ Claude Bernard of Lyon

In the original definition of boundary control port-Hamiltonian systems, see van der Schaft & Maschke(2002), the boundary variables are originating from formally skew-adjoint differential operators, leading to Stokes-Dirac structures. In this Extended Abstract, based on the recent paper Maschke & Van der Schaft(2023), instead boundary variables are discussed that arise from Hamiltonian functionals defined by formally self-adjoint differential operators, leading to Stokes-Lagrange structures. In contrast to the boundary variables of Stokes-Dirac structures their product does not have dimension of power, but instead of energy.

17:10-17:35	MoPM_LR1.5

Polynomial Stability of Coupled Waves with Weak Indirect Damping

Kosonen, Jasper	Tampere University
Paunonen, Lassi	Tampere University
Vanspranghe, Nicolas	Tampere University

We study the stability properties of coupled one-dimensional wave equations with indirect damping. We employ methods based on observability estimates for the undamped system to prove polynomial stability and rational energy decay for the classical solutions of the coupled systems. We present our results for two different kinds of indirect damping -- viscous damping and weak damping.

MoPM_LR2

Modelling and Dynamical Aspects of Biological Systems (Invited Session)

Chair: Giordano, Giulia	Università Degli Studi Di Trento
Co-Chair: Jozsa, Monika	University of Cambridge
Organizer: Rao, Shodhan	Ghent University Global Campus
Organizer: Bhatt, Nirav	Indian Institute of Technology Madras
Organizer: Jayawardhana, Bayu	University of Groningen
Organizer: Giordano, Giulia	Università Degli Studi Di Trento

15:30-15:55	MoPM_LR2.1

Dynamics of Forced and Unforced Metapopulation Models with Anti-Symmetric Lotka-Volterra Systems (I)

Anish, Anju Susan	Ghent University Global Campus
De Baets, Bernard	Ghent University
Rao, Shodhan	Ghent University Global Campus

The central idea of this work is to study the existence of a unique coexistence equilibrium of a metapopulation model with Lotka-Volterra prey-predator dynamics governing the species interactions in discrete habitat patches and analyze its stability properties. We establish that a forced system obtained by introducing a specific feedback law to an unforced balanced metapopulation model with rock-paper-scissor dynamics governing the intra-patch interactions can be reformulated as a two-species metapopulation model with prey-predator dynamics. We show that if the unforced metapopulation model has a unique coexistence equilibrium, then with specific initial conditions the associated forced metapopulation model will also admit the same equilibrium, which moreover is asymptotically stable.

15:55-16:20	MoPM_LR2.2

Stability Analysis of an SIR Model with General Transmission Rates (I)

Rao, Shodhan	Ghent University Global Campus
Gasparyan, Manvel	University of Montpellier and CNRS

We consider an SIR infection model with a general nonlinear transmission rate from the compartment of susceptible population (S) to the compartment of infected population (I). We assume that there is an infection-free equilibrium associated with the model, which pertains to the state at which there is no infection. We assume certain reasonable properties on the transmission function and the rates of birth, death and recovery of the population in compartments S and I. We then give a set of sufficient conditions under which the infection-free equilibrium is globally asymptotically stable. Next, we assume the existence of an endemic equilibrium, which represents a state at which the compartment I is not empty. We then provide other biologically reasonable conditions that guarantee its global asymptotic stability. The proof of global asymptotic stability of the endemic equilibrium is based on the construction of a Lyapunov function which is a generalization of the standard Lyapunov function for the Lotka-Volterra prey-predator system. We finally illustrate our results via simulation of a certain SIR model that obeys all the conditions considered in the work.

16:20-16:45	MoPM_LR2.3

Bridging Robustness and Resilience for Dynamical Systems in Nature (I)

Proverbio, Daniele	University of Trento
Katz, Rami	University of Trento
Giordano, Giulia	Università Degli Studi Di Trento

Biological systems have evolved to maintain properties that are crucial for survival. Robustness and resilience are associated with a system's ability to preserve its functions despite uncertainties, fluctuations and perturbations, both intrinsic and extrinsic. However, due to the multidisciplinary nature of the research topic, numerous competing definitions of these concepts coexist and often lack a rigorous control-theoretic formulation. Here, we consider a family of ODE systems consisting of stochastic perturbations of a nominal deterministic system and we introduce possible formal definitions of resilience of such a family of systems aimed at probabilistically quantifying its ability to preserve a prescribed attractor. We show that our proposed definitions generalise the notion of probabilistic robustness, and we demonstrate their efficacy when applied to widely used models in biology.

16:45-17:10	MoPM_LR2.4

Sparse Identification of Chemical Reaction Networks from Concentration-Time Series (I)

Bhatt, Nirav	Indian Institute of Technology Madras
Jayawardhana, Bayu	University of Groningen

Chemical reaction networks play an important role in understanding of biological and chemical processes. Models of chemical reaction networks are useful for analysis, optimization and control of these systems. This work deals with identification of chemical reaction networks from concentration-time series data by combining concepts of sparse identification and reaction coordinates in CRNs. It will be shown that the identification of CRNs is equivalent to identifying algebraic reaction invariant relationships and differential equations of a subset of chemical species in CRNs. The work will then exploit this property of CRNs to overcome challenges associated with applying Sparse Identification of Nonlinear Systems (SINDy) algorithm in the literature. A novel algorithm, SINDy-CRN, will be proposed by combining SINDy algorithm and the properties of CRNs and will be illustrated on a simulation example

17:10-17:35	MoPM_LR2.5

A Priori Parameter Identifiability of Enzymatic Reaction Networks (I)

Sreenath, Ragini	Indian Institute of Technology Madras
Narasimhan, Sridharakumar	Indian Institute of Technology, Madras
Bhatt, Nirav	Indian Institute of Technology Madras

A priori parameter identifiability analysis is a first step towards building a reliable and robust model of biochemical reaction networks. Differential algebra-based approaches are widely used to study the a priori structural identifiability of nonlinear systems. However, these approaches fail to yield any results in complex reaction networks. Recently, Varghese et al, IFAC-paper Online, 2018, have shown that the input-output map can be computed by proposing a linear transformation of the system equations for chemical reaction networks. Subsequently, the identifiability of reaction networks can be studied using this input-output map. In this work, we investigate this input-output map for establishing the conditions for global identifiability of enzymatic reaction networks arising in systems biology. Furthermore, we derive the reparameterized form of kinetic parameters that can be uniquely identified for enzymatic kinetic models. We illustrate the results using several common enzymatic kinetic rate expressions in systems biology.

17:35-18:00	MoPM_LR2.6

What Linearisation Tells Us about the Number of Modes in a Biochemical Switch

Jozsa, Monika	University of Cambridge
Donchev, Tihol Ivanov	University of Cambridge
Sepulchre, Rodolphe J.	University of Cambridge
O'Leary, Timothy	University of Cambridge

MoPM_LR3	LR 3
Group-Affine Systems and Invariant Filtering (Mini Course)	
Chair: Bonnabel, Silvere	Mines ParisTech
Co-Chair: Mostajeran, Cyrus S.	University of Cambridge

15:30-15:55	MoPM_LR3.1

Group-Affine Systems and Invariant Filtering

Bonnabel, Silvere	Mines ParisTech

MoPM_LR4	LR4
Optimal Control and Learning (Regular Session)	
Chair: Ortega, Juan-Pablo	Nanyang Technological University
Co-Chair: Gashi, Bujar	The University of Liverpool

15:30-15:55	MoPM_LR4.1

Learning Optimal Dispatching Policies for Queueing Systems

Bencherki, Fethi	Lund University
Rantzer, Anders	Lund Univ

This work presents a dual controller that learns the optimal server in a multi-server queueing system in the presence of disturbance. We formulate an optimization problem of linear cost, linear dynamics for the queueing system model and an equality constraint on the dispatcher policy. A model-free data-driven Riccati equation is constructed, based on which the policy update and the policy evaluation are conducted. Convergence of the estimated Q-factor to the true one is discussed.

15:55-16:20	MoPM_LR4.2

Optimal Investment in a Market with Borrowing, the CIR Interest Rate Model, and the Heston Volatility Model

Alasmi, Nuha	University of Liverpool
Gashi, Bujar	The University of Liverpool

We consider the optimal investment problem with power utility from terminal wealth in a market with borrowing, the CIR interest rate model, and the Heston volatility model. This is an optimal stochastic control problem with nonlinear system dynamics due to the higher interest rate for borrowing than lending, and the square-root nonlinearities from the CIR and Heston models. By utilising a certain a piece-wise completion of squares method, the unique explicit closed-form solution to this problem is obtained as a linear state-feedback control, the gain of which can have up to three different regimes.

16:20-16:45	MoPM_LR4.3

Digital Twins for Optimal Decision-Making

Anand, Akhil	Norwegian University of Science and Technology (NTNU)
Gros, Sebastien	NTNU

Digital Twins could support decision-making in autonomous systems by predicting the future behavior of the system in silico. However, the specific conditions on constructing a Digital Twin to facilitate optimal decision-making remains unclear. This paper investigates this question and outlines formal conditions for constructing a Digital Twin that supports optimal decision-making for autonomous systems.

16:45-17:10	MoPM_LR4.4

Optimal Cell Growth under Periodic Environment

Innerarity Imizcoz, Javier	Université Côte D'Azur
Djema, Walid	INRIA
Mairet, Francis	Ifremer
Gouze, Jean-Luc	INRIA

We study the optimization of resource allocation in bacteria evolving in periodic environments. We use a dynamical model of the metabolism of these microorganisms with a control variable representing the allocation of protein precursors. We mathematically define the objective of maximizing the long-term growth of a given cell. We carry out a theoretical analysis of the resulting dynamical optimal control problem (DOCP), which we complete with a numerical resolution of its solution. Then we examine the effects of period and amplitude of the external forcing.

17:10-17:35	MoPM_LR4.5

Heuristic Search for Linear Optimal Control

Ohlin, David	Lund University

Rantzer, Anders | Lund Univ
Tegling, Emma | Lund University

This work extends previous results in infinite-horizon optimal control of positive linear systems to the case of network routing problems. We demonstrate the equivalence between Stochastic Shortest Path (SSP) problems and optimal control of a certain class of linear systems. This is used to construct a heuristic search framework for this class of linear systems inspired by existing methods for SSPs. More fundamentally, the results allow for analysis of the conditions for explicit solutions to the Bellman equation, utilized by heuristic search methods.

17:35-18:00 MoPM_LR4.6

Nature-Inspired Dynamic Control of the Pursuit-Evasion System

Zhou, Panpan | KTH Royal Institute of Technology
Hu, Xiaoming | KTH Royal Institute of Technology

The Pursuit-evasion problem is captivating and pervasive topic that has gained significant attention from research communities of mathematics and engineering. Originating from animals' hunting behaviours observed in nature, wherein the pursuer and evader typically represent predator and prey, respectively, this concept has found application in various domains. In the artificial world, these roles can be embodied by robotic vehicles. The algorithms developed to address this challenge have far-reaching implications, spanning diverse fields such as military operations, where they inform the planning of maneuvers and tactics, robotics, facilitating search and rescue missions, and game theory, particularly in scenarios involving multiple players with conflicting objectives. Moreover, they find utility in network security, sports, and athletics, where strategic movements are employed to outmaneuver opponents, as well as in the realm of autonomous vehicles, aiding in navigation and obstacle avoidance, among numerous other applications. Generally, a pursuer runs faster than its target evader, for instance, the cheetah exemplifies the epitome of such cursorial pursuit. Consequently, the evader's strategy becomes crucial for its survival. Notably, a slower evader often possesses superior agility, enabling it to execute rapid maneuvers with a smaller turning radius, especially when operating at lower speeds. Thus, the evader can employ quick-turning tactics to evade capture, mirroring the evasive behaviors observed in nature. It is vital for an evader to design an escape strategy that leverages such advantage for survival. This raises several intriguing questions: How can we effectively model the behaviors, particularly the quick-turning maneuvers, of both predators and prey during hunts? What strategies can an evader employ to outmaneuver a faster pursuer? To what extent does the velocity advantage determine a pursuer's ability to capture an evader? What are the primary factors influencing whether an evader successfully escapes or not? Given initial conditions, including positions and velocities, what is the likelihood of capture or escape? In natural settings, multiple predators or prey often engage in coordinated hunt

MoPM_LR5 LR5

Analysis of Networks and Graphs (Regular Session)

Chair: Jauberthie, Carine | LAAS-CNRS

15:30-15:55 MoPM_LR5.1

Integer Transformation of Boolean Networks and Its Topological Implications

Bensussen, Antonio | Departamento De Control Automático, Cinvestav-IPN
Alvarez-Buylla, Elena R. | Institute of Ecology and National Autonomous University of Mexic
Martínez-García, Juan Carlos | Centro De Investigación Y De Estudios Avanzados Del I.P.N

Studying large-scale Boolean networks is of interest for several areas of biology. One of the simplest ways to approach this type of systems is by implementing iterative synchronous update schemes. However, the complexity of such approach grows exponentially depending on the number of nodes included in the network, being almost impossible to characterize the complete topology of networks with more than 35 nodes. Consequently, in this paper we developed an algebraic method equivalent to the synchronous update scheme able to characterize the entire topology of Boolean networks. To do this, we explored the properties of transforming n-dimensional discrete non parameterised Boolean systems into relations defined in integers, which can be visualized in the Cartesian plane. This visualization makes then easy to explore in a systematic manner the topology of the attractor landscape. Finally, we show examples of how to implement this method for topological analysis, which opens new possibilities for modeling large Boolean networks for biology and other areas of knowledge.

15:55-16:20 MoPM_LR5.2

Statistical Methods to Evaluate Discrete Boolean Mathematical Models from Systems Biology Experimental Data Sets

Bensussen, Antonio | Departamento De Control Automático, Cinvestav-IPN
Arciniega-Gonzalez, J. Arturo Arciniega-González | Osgrado En Ciencias Biomédicas & C3, UNAM, México
Pacheco-Marín, Rosario | CONAHCYT, México & C3-UNAM, México
Alvarez-Buylla, Elena R. | Institute of Ecology and National Autonomous University of Mexic
Martínez-García, Juan Carlos | Centro De Investigación Y De Estudios Avanzados Del I.P.N

Discrete Boolean models offer qualitative insights into gene regulatory networks, enhancing understanding of cellular phenotypes. Despite lacking quantitative parameters, their reliability stems from data derived through systematic reviews and databases supported by experimental validation. Unlike other mathematical models, they don't employ statistical tests for intrinsic validity, making it challenging to establish their utility in interpreting experimental data. In this paper, we propose two statistical procedures to validate different description levels obtained from Boolean models, addressing simulated mutations and stationary states. These methods provide guidelines for integrating data from massive sequencing techniques, such as RNA-seq.

16:20-16:45 MoPM_LR5.3

Graphons and the H-Property

Belabbas, Mohamed Ali | University of Illinois, Urbana-Champaign
Chen, Xudong | Washington University in St. Louis

A graphon satisfies the H-property if graphs sampled from it contain a Hamiltonian decomposition almost surely, which in turn implies that the corresponding network topologies are, e.g., structurally stable and structurally ensemble controllable. In recent papers, we have exhibited a set of conditions that is essentially necessary and sufficient for the H-property to hold for the finite-dimensional class of step-graphons. The extension to the infinite-dimensional case of general graphons was hindered by the fact that said conditions relied on objects that do not admit immediate extensions to the infinite-dimensional case. We outline here our approach to bypass this difficulty and state conditions that guarantee that the H-property holds for general graphons.

16:45-17:10 MoPM_LR5.4

Sparse Factorization of the Square All-Ones Matrix of Arbitrary Order

Uribe, Cesar | Rice University
Nguyen, Edward Duc Hien | Rice University
Ying, Bicheng | Google Inc
Jiang, Xin | Lehigh University

17:10-17:35	MoPM_LR5.5

Low-Complexity Convergence Rate Bound for Push-Sum Algorithms on Transitive Graphs

Gerencsér, Balázs	HUN-REN Alfréd Rényi Institute of Mathematics
Kornyik, Miklós	HUN-REN Alfréd Rényi Institute of Mathematics

The objective of the work is to establish an upper bound for the almost sure convergence rate for a class of push-sum algorithms, with the goal of extending applicability of recent works of the authors on convenient performance guarantees which have low complexity to be accessed.

The result complements previous work by Gerencsér (2023) on general computable rate bound, Gerencsér and Gerencsér (2022) providing an exact, but often less accessible description, and extends Gerencsér and Kornyik (2024) discussing low-complexity bounds for synchronous gossip dynamics on transitive graphs.

Numerical results confirm the speedup without deteriorating the performance of the computable bound, for a graph on 120 vertices the runtime drops 3 orders of magnitude.

17:35-18:00	MoPM_LR5.6

Analysis of Set-Membership Algebraic Detectability Based on Algebra Tools

Jauberthie, Carine	LAAS-CNRS
Verdière, Nathalie	Université Du Havre
Orange, Sébastien	University of Le Havre

Fault-diagnosis approach consists in verifying in a first part the detectability property; this last one is the capacity to detect the occurrence of faults in a system. In this work, a fault means an abnormal parameter value. The second part of fault-diagnosis approach consists in estimating the time-occurrence and values of faults. Fault-diagnosis approach based on the modeling of complex systems subject to uncertainties (perturbations, noises for example) is a task awkward. In the stochastic framework, the uncertainties are often described through probability distribution function while in set-membership framework, the uncertainties are assumed to be bounded in a connected set but otherwise unknown. The representation provided by the set-membership framework makes possible to provide fewer assumptions on the (random) variables (such as independence) and dealing with nonlinearities is easier. But the modelization by probability distribution functions provides a more accurate information than a set enclosing its support. This is why, in the proposed work, the two frameworks are combined: the model uncertainties (parameters) are supposed to be bounded and the measurement noise is supposed gaussian. This work presents, in the first part, an original approach for assessing multiple fault detectability of nonlinear parametrized dynamical models with bounded uncertainties. The second part consists in considering measurement noise modeled by probability density functions. The proposed method is based on computer algebra algorithms, such as the Rosenfeld–Groebner algorithm which permits to eliminate the unknown variables of the model. From the outputs of this algorithm, precomputed algebraic expressions characterizing the presence of faults can be obtained. Input and output measurements permit to estimate these expressions and then to detect and isolate multiple faults acting on the system. This approach is applied on a coupled water-tank model and highlights the potential of the suggested approach.

MoPM_LR6	LR6

Learning and Optimization in Stochastic Systems and Control (I) (Invited Session)

Chair: Gruene, Lars	Univ of Bayreuth
Co-Chair: Worthmann, Karl	TU Ilmenau
Organizer: Gruene, Lars	Univ of Bayreuth
Organizer: Worthmann, Karl	TU Ilmenau

15:30-15:55	MoPM_LR6.1

The Shortest Experiment for Linear System Identification (I)

Camlibel, Kanat	University of Groningen
van Waarde, Henk J.	University of Groningen
Rapisarda, Paolo	Univ. of Southampton

This extended abstract is concerned with the following problem: given an upper bound of the state-space dimension and lag of a linear time-invariant system, design a sequence of inputs so that the system dynamics can be recovered from the resulting input-output data. As our main result we propose an online experiment design method, meaning that the selection of the inputs is iterative, and guided by data samples collected in the past. We show that this approach leads to the shortest possible experiments for linear system identification.

15:55-16:20	MoPM_LR6.2

A Stochastic Fundamental Lemma with Reduced Data Requirements (I)

Ou, Ruchuan	Hamburg University of Technology
Pan, Guanru	Hamburg University of Technology
Faulwasser, Timm	Hamburg University of Technology

Recently, the fundamental lemma by Willems et. al has been extended towards stochastic LTI systems subject to process disturbances. Using the stochastic fundamental lemma requires previously recorded data of inputs, outputs and disturbances. In this paper, we exploit causality concepts of stochastic control to propose a variant of the stochastic fundamental lemma that does not require past disturbance data. Our developments rely on polynomial chaos expansions and on the knowledge of the disturbance distribution. Similar to our previous results, the proposed variant of the fundamental lemma allows to predict future input-output trajectories of stochastic LTI systems.

16:20-16:45	MoPM_LR6.3

Data-Driven Distributionally Robust MPC Via Semi-Infinite Semidefinite Programming with Application to Financial Models (I)

Das, Souvik	Indian Institute of Technology, Bombay
Ganguly, Siddhartha	IIT Bombay
Aravind, Ashwin	Indian Institute of Technology Bombay
Chatterjee, Debasish	Indian Institute of Technology, Bombay

This article introduces a novel distributionally robust model predictive control (DRMPC) algorithm for a specific class of controlled dynamical systems where the disturbance multiplies the state and control variables. These classes of systems arise in mathematical finance, where the paradigm of distributionally robust optimization (DRO) fits perfectly, and this serves as the primary motivation for this work. We recast the optimal control problem (OCP) as a semidefinite program with an infinite number of constraints, making the ensuing optimization problem a semi-infinite semidefinite program (SI-SDP). To numerically solve the SI-SDP, we advance the approach established in Das et al. (2022) in the context of convex SIPs (cSIPs) to SI-SDPs and subsequently, solve the DRMPC problem. A numerical example is provided to show the effectiveness of the algorithm.

16:45-17:10	MoPM_LR6.4

Geometrically Robust Least Squares through Manifold Optimization (I)

Coulson, Jeremy	University of Wisconsin-Madison
Padoan, Alberto	ETH Zurich
Mostajeran, Cyrus S.	University of Cambridge

This paper presents a methodology for solving a geometrically robust least squares problem, which arises in various applications

where the model is subject to geometric constraints. The problem is formulated as a minimax optimization problem on a product manifold, where one variable is constrained to a ball describing uncertainty. To handle the constraint, an exact penalty method is applied. A first-order gradient descent ascent algorithm is proposed to solve the problem, and its convergence properties are illustrated by an example. The proposed method offers a robust approach to solving a wide range of problems arising in signal processing and data-driven control.

17:10-17:35	MoPM_LR6.5

Towards a Unifying Framework for Data-Driven Predictive Control with Quadratic Regularization (I)

Klädtke, Manuel	TU Dortmund University
Schulze Darup, Moritz	TU Dortmund University

Data-driven predictive control (DPC) has recently gained popularity as an alternative to model predictive control (MPC). Amidst the surge in proposed DPC frameworks, upon closer inspection, many of these frameworks are more closely related (or perhaps even equivalent) to each other than it may first appear. We argue for a more formal characterization of these relationships so that results can be freely transferred from one framework to another, rather than being uniquely attributed to a particular framework. We demonstrate this idea by examining the connection between gamma-DDPC and the original DeePC formulation.

17:35-18:00	MoPM_LR6.6

The Perspective of Kernel Regression on Willems' Fundamental Lemma (I)

Molodchyk, Oleksii	TU Dortmund University
Faulwasser, Timm	Hamburg University of Technology

Generalizations and variations of the fundamental lemma by Willems et al. are an active topic of recent research. In this note, we explore and formalize the links between kernel regression and some known nonlinear extensions of the fundamental lemma. Applying a transformation to the usual linear equation in Hankel matrices, we arrive at an alternative implicit representation of the system trajectories while keeping the requirements on persistency of excitation. We show that the new representation is equivalent to the solution of a specific kernel regression problem. We explore the possible structures of the underlying kernel as well as the system classes to which they correspond.

TuP_LMH	Lady Mitchell Hall

Plenary : AI and Optimization through a Geometric Lens (Plenary Session)

Chair: Sepulchre, Rodolphe J.	University of Cambridge
Co-Chair: Fawzi, Hamza	University of Cambridge

09:00-10:00	TuP_LMH.1

Plenary: AI and Optimization through a Geometric Lens

Sra, Suvrit	MIT

TuAM_LH	Little Hall

Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations (I) (Invited Session)

Chair: Henrion, Didier	LAAS-CNRS, Univ. Toulouse
Organizer: Vinnikov, Victor	Ben Gurion University of the Negev
Organizer: Henrion, Didier	LAAS-CNRS, Univ. Toulouse
Organizer: Infusino, Maria	University of Cagliari
Organizer: Kuhlmann, Salma	University of Konstanz

10:30-10:55	TuAM_LH.1

Analysis and Control of Input-Affine Systems Using Parameterized Robust Counterparts (I)

Miller, Jared	ETH Zurich
Sznaier, Mario	Northeastern University

Generically nonconvex tasks such as optimal control, peak estimation, and reachable set estimation can be posed as infinite-dimensional but convex LPs in terms of auxiliary functions. The computational bottleneck when discretizing these programs involve the universal quantification jointly over time, state, and input (e.g., Lie derivative nonpositivity in continuous-time). Decomposition techniques to reduce dimensionality can be applied to simplify the complexity of discretization (e.g., sum-of-squares, gridding, sampling). This work extends prior work treating continuous-time input-affine dynamics under vertex or box constraints on inputs by considering continuous-time or discrete-time systems under semidefinite-representable uncertainty. The disturbance variables are eliminated using parameterized robust counterparts without introducing conservatism under mild compactness and regularity conditions. Effectiveness is demonstrated on data-driven peak-estimation of a discrete-time dynamical system.

10:55-11:20	TuAM_LH.2

Peak Estimation of Nonnegative Models Using Signomial Optimization (I)

Miller, Jared	ETH Zurich
Dressler, Mareike	University of New South Wales (UNSW Sydney)
Murray, Riley	Sandia National Laboratory
Wallington, Kevin	ETH Zurich
Smith, Roy S.	Swiss Federal Institute of Technology (ETH)

Peak estimation involves bounding extreme values of state functions along system trajectories, such as finding the maximum current draw on a transmission line, or the maximum speed obtained by an aircraft. The nonconvex but finite-dimensional peak estimation problem (in terms of optimizing over the initial condition and stopping time) can be lifted into a primal-dual pair of infinite-dimensional linear programs in auxiliary functions/occupation measures. Under mild assumptions, this lifting provides an exact reformulation.

This work focuses on the setting where the dynamics and auxiliary function are chosen to be signomials (linear combinations of exponentials with possibly non-integer exponents). The infinite-dimensional linear constraints are truncated into sum-of-arithmetic-geometric-exponential nonnegativity certificates, which can be represented by relative entropy or dual-power-cone expressions. Our method is applicable to problems in chemical reaction networks, in which the generalized mass action kinetics can be transformed into signomial dynamics under a logarithmic mapping.

11:20-11:45	TuAM_LH.3

An Intrinsic Characterization of Moment Functionals in the Compact Case (I)

Infusino, Maria	University of Cagliari
Kuhlmann, Salma	University of Konstanz
Kuna, Tobias	University of L'Aquila
Michalski, Patrick	Universität Konstanz

We consider the question of whether a linear functional L on an unital commutative real algebra A can be represented as integral w.r.t. a compactly supported Radon measure on the character space of A? We present a characterization in terms of growth conditions on $(L(a^n))_n$. We compare our result with characterizations in terms of non-negativity conditions of L on Archimedean quadratic modules, and continuity conditions of L w.r.t. submultiplicative seminorms on A. We show that these conditions are directly mutually equivalent and we will relate each of these conditions to a different technique solving the moment problem.The main novelty is that we also establish an exact characterization of the compact support of the representing Radon measure purely in terms of L, instead of just a containment. See M. Infusino, S. Kuhlmann, T. Kuna, P. Michalski, {it An Intrinsic Characterization of Moment Functionals in the Compact Case}, International Mathematics Research Notices, textbf{2023}, 3, %pp. 2281–2303 (2023) for details and further results.

11:45-12:10 TuAM_LH.4

Geometry of Exactness of Moment-SOS Relaxations for Polynomial Optimization (I)

Henrion, Didier — LAAS-CNRS, Univ. Toulouse

The moment-SOS (sum of squares) hierarchy is a powerful approach for solving globally non-convex polynomial optimization problems (POPs) at the price of solving a family of convex semidefinite optimization problems (called moment-SOS relaxations) of increasing size, controlled by an integer, the relaxation order. We say that a relaxation of a given order is exact if solving the relaxation actually solves the POP globally. In this note, we study the geometry of the exactness cone, defined as the set of polynomial objective functions for which the relaxation is exact. Generalizing previous foundational work on quadratic optimization on real varieties, we prove by elementary arguments that the exactness cones are unions of semidefinite representable cones monotonically embedded for increasing relaxation order.

TuAM_LR1 LR1

Optimal and H-Infty Control (Regular Session)

Chair: Mirkin, Leonid — Technion—IIT

Co-Chair: Gashi, Bujar — The University of Liverpool

10:30-10:55 TuAM_LR1.1

Optimization with Adaptive Window, Multi-Start and Comparative Fusion: A Novel Approach to Enhanced Iterative Stereo-Matching

Xue, Yao — Pennsylvania State University
Jiang, Caoyang — HypeVR
Zheng, Yue'er — Affiliated Eye Hospital of Wenzhou Medical University
Armaou, Antonios — The Pennsylvania State Univ

This paper introduces innovative modules and algorithms designed for optimizing stereo-matching models through the implementation of a hierarchical iterative searching mechanism. The proposed model architecture comprises three pivotal elements: a multi-start mechanism featuring a global matching module that initializes match searching under both zero-initialized and globally-matched conditions; a confidence-based fusion block that assesses intermediate results from each start and conducts pixel-wise fusion based on confidence scores; an adaptive search window module that dynamically adjusts search dilation for each pixel before every search iteration, effectively balancing search speed and accuracy across diverse scenarios. These modules and components significantly enhance the robustness and efficiency of stereo-matching models in optimization, particularly in addressing complex scenes and large disparaties. Importantly, these modules can be seamlessly adapted to other depth estimation models with similar iterative matching architectures, offering substantial contributions to the research community.

10:55-11:20 TuAM_LR1.2

Kalman Filtering of Riesz-Spectral Systems by Spectral Factorization

Hastir, Anthony — University of Wuppertal
Mohet, Judicaël — University of Namur
Winkin, Joseph J. — University of Namur (UNamur)

The problem of optimal state estimation via deterministic Kalman filtering in the frequency domain is considered for a class of single-output Riesz-spectral systems on specific Hilbert state spaces. It is reported that the spectral factorization problem can be solved by symmetric extraction of poles and zeros, which leads to a tractable computational method in order to calculate the optimal output injection in the Kalman filter problem for such systems. The results and methods turn out to be applicable to the class of Sturm-Liouville operators with pointwise measurement.

11:20-11:45 TuAM_LR1.3

Optimal Regularized Transport with Incomplete Marginals Information

Pathan, Aayan Masood — New York University Abu Dhabi - NYUAD
Pavon, Michele — Università Di Padova

We study regularized optimal mass transport over networks in the important situation where the initial and final goods distribution is only known on a subset of the state space. We show that, in spite of the meager information, it is possible to characterize the most likely flow on the given network. As an important by-product, we get the most likely initial and final marginals on the whole state space.

11:45-12:10 TuAM_LR1.4

Solution Analysis of H∞ /H2 Control Formulations Based on Chain-Scattering Description Approach

Tsai, Mi-Ching — National Cheng Kung Univ
Zhou, Yan-Qi — National Cheng Kung University
Tsai, Bo-Cheng — National Cheng Kung University
Ubadigha, Chinweze Ukachukwu — National Cheng Kung University
Chang, Chi-Yang — National Cheng-Kung University

This paper employs the chain-scattering description two-port framework to identify the relationship between the feedback closed-loop poles of a standard control configuration (SCC) system and the spectral zeros of the off-diagonal (P12 and P21 respectively) SCC plant matrix in H∞/H2 control design. By leveraging the symmetric nature of the coprime factorization techniques, the resulting closed-loop poles for H∞ control solutions for a sufficiently large γ are found to approach the spectral zeros of P12 and P21 respectively and will become the same as that of the H2 optimal control solution. This identified property provides an easy technique for determining the closed-loop poles from a designed SCC plant prior to solving the H∞/H2 controller so that an effective SCC plant construction via weighting function selection can be implemented for robust control realization. The main contributions of this paper include the identification, proof and formulation of the identified property from two specific design problems, which play a crucial role in obtaining H∞/H2 control solutions. Two lemmas that disclose this feature are presented for both H2 optimal control and H∞ sub-optimal control solutions. Using MATLAB/Control Toolbox, an illustrated example is given to verify the identified property.

12:10-12:35 TuAM_LR1.5

Robust Control of Linear Stochastic Systems with Affine Plus Integral State Feedback

Gashi, Bujar — The University of Liverpool
Hua, Haochen — Hohai University

We introduce a generalisation to the finite-horizon mixed H_2/H_infty control method for linear stochastic systems with additive noise by considering {it affine plus integral} state-feedback controls and disturbances instead of the more common ones in a linear state-feedback form. This in particular permits achieving robust performance with respect to a wider class of disturbances and an improved tracking performance. The solution to this problem is obtained in an explicit-closed form by the completion of squares method, and the controller gains are expressed in terms of solutions to coupled Riccati and linear ordinary differential equations.

12:35-13:00 TuAM_LR1.6

Discrete-Time Performance Guaranteeing H_infty Event-Triggered Control

Mi, La — University of Luxembourg
Mirkin, Leonid — Technion—IIT

We study event-triggered control for discrete-time systems with the H_infty (induced ell_2) performance measure. We construct event-triggered controllers generating sampling intervals no smaller than those of the optimal time-triggered controller under the same H_infty performance bound $gamma$. The design philosophy is based on a parametrization of discrete, possibly nonlinear and time-varying, $gamma$-suboptimal controllers and triggering events via the Q parameter that renders the parametrization sampled-data. We characterize through the associated difference Riccati equation a class of signals that causes our event-triggered controllers to generate the optimal time-triggered sampling pattern.

TuAM_LR2 LR2

Structure-Preserving Methods in Simulation, Control, and Learning of Dynamical Systems (Invited Session)

Chair: Othmane, Amine	Saarland University, Saarbrücken, Germany
Co-Chair: Ober-Blöbaum, Sina	Paderborn University
Organizer: Flasskamp, Kathrin	Saarland University, Germany
Organizer: Maslovskaya, Sofya	Paderborn University
Organizer: Ober-Blöbaum, Sina	Paderborn University
Organizer: Othmane, Amine	Saarland University, Saarbrücken, Germany

10:30-10:55 TuAM_LR2.1

Learning Splitting and Composition Methods (I)

Lockyer, Henry	University of Bath
Kreusser, Lisa	University of Bath
Mueller, Eike	University of Bath
Singh, Pranav	University of Bath

Splitting and composition methods are ubiquitous in the solution of ordinary and partial differential equations since it is often easier to solve the differential equation under separate flows. This may be due to the availability of exact solutions under sub-flows or due to their efficient approximations that exploit, for instance, the favourable structure, sparsity, or smaller spectral radius of the resulting numerical linear algebra problems. Traditionally, splitting and composition methods have been derived using analytic and algebraic techniques. This normally means truncated Taylor series or its Lie algebraic analogue – the Baker–Campbell– Hausdorff formula. Very high order splitting and composition methods have been derived in this way, which achieve high accuracy for small time-steps, and have exact or near conservation of physical properties such as mass, unitarity, and energy. However, in many applications of practical interest a moderate accuracy is acceptable while the limited computational resources necessitate the use of larger time-steps. For these large time-steps, the asymptotically derived high-order splittings typically fail to achieve adequate accuracy. In contrast, machine learning approaches for solving differential equation are often efficient, but come with no convergence guarantees, and often do not conserve physical properties such as energy. In this work we outline a hybrid approach for designing machine learned splitting and composition methods that work effectively for large time steps, and have provable convergence and conservation guarantees.

10:55-11:20 TuAM_LR2.2

Neural Networks Enhanced Integrators for Systems Defined by Ordinary Differential Equations (I)

Othmane, Amine	Saarland University, Saarbrücken, Germany
Flasskamp, Kathrin	Saarland University, Germany

Many applications require numerical solutions to differential equations for a large number of initial conditions and/or system parameters. For example, the analysis of fatigue effects and lifetime prediction of technological systems such as wind energy converters (WECs) often requires a comparison of design site conditions with real site conditions by simulating models of WECs for a large number of different conditions. This contribution evaluates the effectiveness of neural network (NN) enhanced integrators. NNs learn the integration errors, the approximation of which are then used as an additive correction term for the numerical schemes. The resulting integrators are compared with well-established methods in numerical studies, with a particular focus on computational requirements. The analytical properties will be addressed in terms of local errors. Classical Runge-Kutta methods and symplectic integrators are considered.

11:20-11:45 TuAM_LR2.3

Sampling Deep Operator Networks (I)

Burak, Iryna	Technical University of Munich
Dietrich, Felix	Technical University of Munich

Operators on function spaces are a versatile tool to describe maps between functions. An example of this is a map from the initial condition of a partial differential equation (PDE) to the solution at a final time. A popular choice to encode operators for this task is a Deep Operator Network (DeepONet), a model that approximates an operator by simultaneously learning two sub-networks. DeepONets are usually optimized iteratively on large datasets to find the optimal internal network parameters. A recently introduced algorithm from our group allows the numerical construction of neural network parameters by sampling from a data-dependent probability distribution. Here, we apply this idea to POD DeepONet parameter sampling, a variation of the original model. We demonstrate the approach on solutions to Burgers' equation and show that our sampling method can achieve comparable accuracy while being orders of magnitude faster in training than the iteratively trained model.

11:45-12:10 TuAM_LR2.4

Quantum Simulation of Highly-Oscillatory Many-Body Hamiltonians for Near-Term Devices (I)

Chen, Guannan	University of Bath
Foroozandeh, Mohammadali	University of Oxford
Budd, Chris	University of Bath
Singh, Pranav	University of Bath

We develop a fourth-order Magnus expansion based quantum algorithm for the simulation of many-body problems involving two-level quantum systems with time-dependent Hamiltonians, H(t). A major hurdle in the utilization of the Magnus expansion is the appearance of a commutator term which leads to prohibitively long circuits. We present a technique for eliminating this commutator and find that a single time-step of the resulting algorithm is only marginally costlier than that required for time-stepping with a time-independent Hamiltonian making the proposed algorithm a suitable candidate for simulation of time-dependent Hamiltonians on near-term quantum devices. The significance of this problem to computational quantum chemistry and physics, the suspected exponential difficulty for classical computers, and the demonstrably linear growth in terms of number of qubits required, makes Hamiltonian simulation problems for many-body systems an important class of candidates for demonstrating quantum advantage.

12:10-12:35 TuAM_LR2.5

Symplectic Methods in Deep Learning (I)

Maslovskaya, Sofya	Paderborn University
Ober-Blöbaum, Sina	Paderborn University

Deep learning is widely used in tasks including image recognition and generation, in learning dynamical systems from data and many more. It is important to construct learning architectures with theoretical guarantees to permit safety in the applications. There has been considerable progress in this direction lately. In particular, symplectic networks were shown to have the non vanishing gradient property, essential for numerical stability. On the other hand, architectures based on higher order numerical methods were shown to be efficient in many tasks where the learned function has an underlying dynamical structure. In this work we construct symplectic networks based on higher order explicit methods with non vanishing gradient property and test their efficiency on various examples.

12:35-13:00	TuAM_LR2.6

Data-Driven Model Reduction for Soft Robots Via Lagrangian Operator Inference (I)

Sharma, Harsh	University of California San Diego
Adibnazari, Iman	University of California San Diego
Cervera-Torralba, Jacobo	University of California San Diego
Tolley, Michael	University of California San Diego
Kramer, Boris	University of California San Diego

Data-driven model reduction methods provide a nonintrusive way of constructing computationally efficient surrogates of high-fidelity models for real-time control of soft robots. This work leverages the Lagrangian nature of the model equations to derive structure-preserving linear reduced-order models via Lagrangian Operator Inference and compares their performance with prominent linear model reduction techniques through an anguilliform swimming soft robot model example with 231,336 degrees of freedom. The case studies demonstrate that preserving the underlying Lagrangian structure leads to learned models with higher predictive accuracy and robustness to unseen inputs.

TuAM_LR3	LR 3

System Phase and Its Integration with System Gain (Invited Session)

Chair: Qiu, Li	Hong Kong Univ. of Sci. & Tech
Co-Chair: Chen, Wei	Peking University
Organizer: Zhang, Ding	Hong Kong University of Science and Technology
Organizer: Chen, Wei	Peking University
Organizer: Qiu, Li	Hong Kong Univ. of Sci. & Tech

10:30-10:55	TuAM_LR3.1

Synchronization of Multi-Agent Network Using Phase Alignment (I)

Wang, Dan	KTH Royal Institute of Technology
Chen, Wei	Peking University
Qiu, Li	Hong Kong Univ. of Sci. & Tech
Johansson, Karl H.	KTH Royal Institute of Technology

This paper investigates the synthesis problem for synchronization of heterogeneous multi-agent systems, which aims at characterizing the allowable diversities among the agents for which a uniform controller can be designed to achieve synchronization. We introduce a matrix phase alignment principle and employ it to solve the simultaneous stabilization problem of a collection of semi-stable systems. By applying this result, we elucidate the allowable diversity in terms of phase alignment of the residue matrices of the agents at their persistent modes. Moreover, when the problem is solvable, a controller design method is provided.

10:55-11:20	TuAM_LR3.2

On Dissipativity Characterization of Phase of Multivariable LTI Systems (I)

Yang, Xiaokan	Peking University
Li, Junhui	Peking University
Chen, Wei	Peking University

By virtue of the well-known KYP lemma, there is a dissipativity characterization of the system gain (positive realness, respectively) for multivariable linear time-invariant (LTI) systems. Recently, a new notion of system phase for multivariable LTI systems was defined. In this extended abstract, we shed light on the dissipativity characterization of the phase and establish its connections to optimal control problems. The results not only share similarity with the understandings of gain and positive realness, but also exhibit conceptual differences due to the asymmetry of phase properties. Furthermore, the results pave the road for a comprehensive study of phase theory in time domain.

11:20-11:45	TuAM_LR3.3

Scalable Phase Preservation in N-Port Networks with Diverse Connectivity Schemes (I)

Chen, Jianqi	Nanjing University
Chen, Wei	Peking University
Chen, Chao	KU Leuven
Qiu, Li	Hong Kong Univ. of Sci. & Tech

This study explores the frequency-wise phases of linear time-invariant networks with n-ports, utilizing recently defined phases of complex matrices. These phase descriptions provide a quantitative measure of the widely recognized concept of passivity in networks. Furthermore, the study investigates a comprehensive set of matrix operations induced by all conceivable n-port network connections. A scalable phase-preserving criterion is formulated, allowing for effective determination of the phase range of the integrated network. This analysis maintains scalability by relying solely on the phase properties of individual subnetworks under the considered matrix operations.

11:45-12:10	TuAM_LR3.4

Mixed Singular Value and Phase Majorization Inequalities for Accretive Matrices and Operators (I)

Liu, Yuwen	Dalian University of Technology
Qiu, Li	Hong Kong Univ. of Sci. & Tech

The understanding of singular values of matrices and operators is rather mutual and has been applied widely in science and engineering. In recent years, some studies have begun to focus on the phases of matrices and operators. The purpose of our research is to explore the `mixed' singular value and phase properties of matrices and operators. We establish a series of mixed singular value and phase majorization inequalities for a class of accretive matrices and operators. One occasion where the results can be applied is the study of the impedance matrices induced by connections of two n-port networks.

12:10-12:35	TuAM_LR3.5

Sectored-Disk Problems and Robust Stability under Mixed Gain and Phase Uncertainty (I)

Liang, Jiajin	Hong Kong University of Science and Technology
Zhao, Di	Tongji University
Qiu, Li	Hong Kong Univ. of Sci. & Tech

In this presentation, we first review the historical matrix small gain theorem and the recent matrix small phase theorem. Then we propose and study a matrix sectored-disk problem in which we wish to determine the invertibility of a matrix with mixed gain and phase uncertainty. The matrix sectored-disk problem can then be carried on to the robust feedback stability problem for multiple-input-multiple-output (MIMO) linear time-invariant (LTI) systems involving sectored-disk uncertainty, namely, dynamic uncertainty subject to simultaneous gain and phase constraints. This problem is thereby called an LTI system sectored-disk problem.

12:35-13:00	TuAM_LR3.6

On Robustness against Phase and Gain Type Uncertainty (I)

Ringh, Axel	Chalmers University of Technology and University of Gothenburg
Mao, Xin	Hong Kong University of Science and Technology
Chen, Wei	Peking University
Qiu, Li	Hong Kong Univ. of Sci. & Tech
Khong, Sei Zhen	-

The search for multipliers for guaranteeing robust stability of a feedback interconnection is a common theme in the control theory literature, and under mild conditions the existence of a multiplier is a both necessary and sufficient condition for robust stability. Here, we further develop this and show that if the feedback is robustly stable against certain structured uncertainties, then there always exists a multiplier that takes a corresponding form. More precisely, robust stability against certain gain-type perturbations implies that there exists a multiplier that is of phase-type. Analogously, robust stability against certain phase-type perturbations implies that there exists a gain-type multiplier. The results are meaningfully instructive in the search for a valid multiplier for establishing robust closed-loop stability, and cover the well-known small-gain and the recent small-phase theorems.

TuAM_LR4	LR4
Operator Theoretic Methods in Identification and Control (Invited Session)	

Chair: Kamalapurkar, Rushikesh	Oklahoma State University
Co-Chair: Rosenfeld, Joel	University of South Florida
Organizer: Kamalapurkar, Rushikesh	Oklahoma State University
Organizer: Rosenfeld, Joel	University of South Florida

10:30-10:55 TuAM_LR4.1

Operator Approximations for Inverse Problems (I)

Rosenfeld, Joel	University of South Florida
Russo, Benjamin	Riverside Research Institute
Kamalapurkar, Rushikesh	Oklahoma State University

This manuscript presents a framework for resolving inverse problems through the use of operator approximations over vector valued RKHSs. This generalizes Koopman based methods for data driven methods in dynamical systems, and three examples of this framework are presented.

10:55-11:20 TuAM_LR4.2

Weighted Composition Operators for Learning Nonlinear Dynamics (I)

Russo, Benjamin	Riverside Research Institute
Messenger, Daniel	CU Boulder
Bortz, David	University of Colorado-Boulder
Rosenfeld, Joel	University of South Florida

Operator theoretic methods in dynamical system have been dominated by the use of Koopman operators and their continuous time counterparts, such as Koopman Generators and Liouville Operators. The advantage gained from their use primarily stems from the ability to extract subspaces and eigenfunctions within a space of observables that are invariant with respect to the Koopman operator over that space. When this occurs, a dynamic mode decomposition of the systems state provides a linear model for the dynamical system.

Not all Koopman operators have eigenfunctions that may be exploited in this manner. However, the framework can still be leveraged for approximations using other operators. In this setting, we present a different operator for the study of dynamical systems, the weighted composition operator. These operators are compact for a wide range of dynamics and spaces, and through their interactions with occupation kernels and vector valued kernels, they admit an estimation of the underlying dynamics.

This manuscript presents a new algorithm for the data driven study of dynamical systems from data, and also provides two numerical experiments where convergence is achieved as a proof of concept.

11:20-11:45 TuAM_LR4.3

A Dual Approach to Observer Design for Nonlinear Systems (I)

Mohet, Judicaël	University of Namur
Mauroy, Alexandre	University of Namur
Winkin, Joseph J.	University of Namur (UNamur)

A novel approach is reported for the observer design of nonlinear systems based on a Koopman operator framework. Using the adjoint of the Liouville operator (or Koopman generator), we define a dual Koopman system on a reproducing kernel Hilbert space, which is associated with a nonlinear dynamics. For a given class of dynamics, we build a Luenberger observer that estimates the state of the (linear) Koopman dual system. Then, the (infinite dimensional) estimated state yields an estimation of the (finite dimensional) state of the nonlinear dynamics. Moreover, we introduce new concepts of observability and detectability for the dual Koopman system, which are shown to be equivalent to observability and detectability of the finite dimensional nonlinear system, and we characterize them in terms of spectral properties.

11:45-12:10 TuAM_LR4.4

On Convergent Dynamic Mode Decomposition and Its Equivalence with Occupation Kernel Regression (I)

Abudia, Moad	Oklahoma State University
Kamalapurkar, Rushikesh	Oklahoma State University
Rosenfeld, Joel	University of South Florida

This paper presents a new technique for norm-convergent dynamic mode decomposition of deterministic systems. The developed method utilizes recent results on singular dynamic mode decomposition where it is shown that by appropriate selection of domain and range Hilbert spaces, the Liouville operator (also known as the Koopman generator) can be made to be compact. In this paper, it is shown that by selecting appropriate collections of finite basis functions in the domain and the range, a novel finite-rank representation of the Liouville operator may be obtained. It is also shown that the model resulting from dynamic mode decomposition of the finite-rank representation is closely related to regularized regression using the so-called occupation kernels as basis functions.

TuAM_LR5	LR5
Networks and Transportation Systems (Regular Session)	

Chair: Su, Lanlan	University of Sheffield
Co-Chair: Lestas, Ioannis	University of Cambridge,

10:30-10:55 TuAM_LR5.1

On Output Consensus of Heterogeneous Dynamical Networks

Su, Yongkang	University of Sheffield
Su, Lanlan	University of Sheffield
Khong, Sei Zhen	-

This work is concerned with interconnected networks with non-identical subsystems. We investigate the output consensus of the network where the dynamics are subject to external disturbance and/or reference input. For a network of output-feedback passive subsystems, we first introduce an index that characterises the gap between a pair of adjacent subsystems by the difference of their input-output trajectories. The set of these indices quantifies the level of heterogeneity of the networks. We then provide a condition in terms of the level of heterogeneity and the connectivity of the networks for ensuring the output consensus of the interconnected network.

11:20-11:45 TuAM_LR5.3

Frequency Control and Power Sharing for Combined Heat and Power Networks with Heat Pump Participation

Qin, Xin	University of Cambridge
Lestas, Ioannis	University of Cambridge,

This study considers the problem of using district heating systems as ancillary services for primary frequency control in power networks. We propose a novel power sharing scheme for heating networks that ensures an optimal power allocation among the different heat sources, without having a prior knowledge of the disturbances. We also show that the stability of the combined heat and power network is maintained when this control scheme is used. Simulations demonstrate the benefits the proposed scheme can provide.

11:45-12:10	TuAM_LR5.4

Information Design in Bayesian Routing Games

Ambrogio, Alexia	Politecnico Di Torino
Cianfanelli, Leonardo	Politecnico Di Torino
Como, Giacomo	Politecnico Di Torino

We study an information design problem in transportation networks when users are strategic and the network state is uncertain. An omniscient planner observes the network state and discloses information to the users to minimize the expected travel time at the equilibrium. Since public signals are known to be inefficient in achieving optimality, we focus on private signals. We formulate and analyze the problem for arbitrary network topologies and delay functions. Then, we focus on networks with an arbitrary number of parallel links and affine delay functions, and provide sufficient and necessary conditions for optimality.

12:10-12:35	TuAM_LR5.5

Continuous and Discrete Operation of Potential Flow Networks with Dissimilar Sink Potentials

Das, Tarak	Indian Institute of Technology, Madras
Kurian, Varghese	University of Delaware
Narasimhan, Sridharakumar	Indian Institute of Technology, Madras

Nodal demand satisfaction in potential flow networks often requires a scheduled manipulation of edge resistances. The actuators used to implement the resistance variations can broadly be classified into (i) discrete (edge fully OPEN or CLOSED) and (ii) continuous (continuously vary edge resistance). Previously, we presented theoretical bounds on the ratio of time required to transport a given quantum of material with either type of actuators assuming that that all sinks are at the same potential. In the present work, we extend the results to a class of networks with demand nodes at different potentials. Based on our findings, we conjecture that the bounds remain the same irrespective of whether the sinks are at the same potentials or not.

12:35-13:00	TuAM_LR5.6

Sensitivity Over the Infinite Lattice

Mi, La	University of Luxembourg
Pates, Richard	Lund University

It is known that in a growing string network of homogeneous agents, there are fundamental limitations on the local feedback control capability to regulate non-local dynamics over larger spacial range. In this note, we study this problem in the infinite (2D) lattice by deriving one of the sensitivity functions in the infinite sensitivity matrix. The analytical solution is obtained by employing spacial discrete Fourier transform. The result may shed light on practical control problems in large-scale finite lattices, as the finite lattice sensitivity function is expected to converge point-wise to the infinite one in the sense of H_2.

TuAM_LR6	LR6

Learning and Optimization in Stochastic Systems and Control (II) (Invited Session)

Chair: Gruene, Lars	Univ of Bayreuth
Co-Chair: Worthmann, Karl	TU Ilmenau
Organizer: Gruene, Lars	Univ of Bayreuth
Organizer: Worthmann, Karl	TU Ilmenau

10:30-10:55	TuAM_LR6.1

Statistical Proper Orthogonal Decomposition for Model Reduction in Feedback Control (I)

Dolgov, Sergey	University of Bath
Kalise, Dante	Imperial College London
Saluzzi, Luca	Scuola Normale Superiore

The Hamilton-Jacobi-Bellman (HJB) equation is a challenging first-order fully nonlinear PDE cast over $mathbb{R}^d$, where d can be arbitrarily large, and thus intractable through conventional grid based methods. In this context we propose to approximate the value function together with its gradient in a data-driven approach, learning a surrogate model for the value function via adaptive sampling of the solution of the HJB. The value function is represented in Functional Tensor Train format and it has been successfully applied to optimal control problems up to dimension 100. However, the dimension of the value function is still that of the state space, leading to a very large number of unknowns in the approximation ansatz and training data. A possible way to tackle this problem is given by the application of Proper Orthogonal Decomposition techniques. In contrast to existing techniques, we propose a Statistical Proper Orthogonal Decomposition (SPOD) which takes into account controlled trajectories treating boundary conditions and initial conditions as random variables. The corresponding reduced basis is chosen to minimize the empirical risk for the controlled solution and we will show its application to the vorticity stabilization of the 2D Navier-Stokes equations.

10:55-11:20	TuAM_LR6.2

Dynamic Programming in Probability Spaces Via Optimal Transport and Its Application to Multi-Agent Systems (I)

Lanzetti, Nicolas	ETH Zürich
Terpin, Antonio	ETH Zürich
Dorfler, Florian	Swiss Federal Institute of Technology (ETH) Zurich

Motivated by multi-agent systems, we study discrete-time finite-horizon optimal control problems in probability spaces, whereby the state of the system is a probability measure. We show that, in many instances, the solution of dynamic programming in probability spaces results from two ingredients: (i) the solution of dynamic programming in the “ground space” (i.e., the space on which the probability measures live) and (ii) the solution of an optimal transport problem. From a multi-agent control perspective, a separation principle holds: The ”low-level control of the agents of the fleet” (how to reach the destination?) and “fleet-level control” (who goes where?) are decoupled. This extended abstract is based on our recent paper (Terpin, Lanzetti, and Dörfler, 2023).

11:20-11:45	TuAM_LR6.3

On Koopman-Based Feedback Design with Stability Guarantees (I)

Strässer, Robin	University of Stuttgart
Schaller, Manuel	Technische Universität Ilmenau
Worthmann, Karl	TU Ilmenau
Berberich, Julian	University of Stuttgart
Allgower, Frank	University of Stuttgart

We present a state-feedback design method ensuring exponential stability for nonlinear systems using measurement data only. Our approach combines Koopman theory and robust control to explicitly account for approximation errors due to finitely many data samples. The proposed controller design is framed as a semidefinite program in terms of linear matrix inequalities, allowing for an efficient solution. Finally, we demonstrate the efficacy of the proposed feedback design procedure in a numerical example.

11:45-12:10	TuAM_LR6.4

Towards Nonlinear and Data-Driven Stochastic Optimal Control Via PDE-Constrained Optimization (I)

Houska, Boris	ShanghaiTech University
Schaller, Manuel	Technische Universität Ilmenau
Worthmann, Karl	TU Ilmenau

We propose to analyze and solve stochastic nonlinear optimal control problems by formulating them as convex optimization problems subject to a partial differential equation (PDE). Such PDE based formulations do not only enable us to analyze global minimizers but also to apply modern operator-based learning methods. We outline on how such a framework can be used for the development of effective data-driven nonlinear optimal control algorithms.

12:10-12:35 TuAM_LR6.5

Model Order Reduction for the TASEP Master Equation (I)

Pioch, Kilian — University of Bayreuth
Kriecherbauer, Thomas — University of Bayreuth
Margaliot, Michael — Tel Aviv University
Gruene, Lars — Univ of Bayreuth

The totally asymmetric simple exclusion process (TASEP) is a stochastic model for the unidirectional dynamics of interacting particles on a 1D-lattice that is much used in systems biology and statistical physics. Its master equation describes the evolution of the probability distribution on the state space. The size of the master equation grows exponentially with the length of the lattice. It is known that the complexity of the system may be reduced using mean field approximations. We provide a rigorous derivation and a stochastic interpretation of these approximations and present numerical results on their accuracy for a number of relevant cases.

TuSP_LMH Lady Mitchell Hall

Semi-Plenary: Any-Dimensional Optimization (Plenary Session)

Chair: Rantzer, Anders — Lund Univ
Co-Chair: Helton, J. William — Univ. of California at San Diego

14:00-15:00 TuSP_LMH.1

Semi-Plenary: Any-Dimensional Optimization

Chandresakaran, Venkat — Caltech

TuSP_LH Little Hall

Semi-Plenary: Closed Loop Neurophysiology (Plenary Session)

Chair: Doyle, John C. — California Inst. of Tech
Co-Chair: Giordano, Giulia — Università Degli Studi Di Trento

14:00-15:00 TuSP_LH.1

Semi-Plenary: Closed Loop Neurophysiology

O'Leary, Timothy — University of Cambridge

TuSP_LR3 LR 3

Semi-Plenary: The Ubiquity and Applications of Lie Groups (Plenary Session)

Chair: Forni, Fulvio — University of Cambridge
Co-Chair: Bonnabel, Silvere — Mines ParisTech

14:00-15:00 TuSP_LR3.1

Semi-Plenary: The Ubiquity and Applications of Lie Groups

Banavar, Ravi — Indian Institute of Technology

TuPM_LMH Lady Mitchell Hall

A Gentle Introduction to Representation Stability: Fundamentals and Applications (Mini Course)

Chair: Chandrasekaran, Venkat — Massachusetts Institute of Technology
Co-Chair: Diaz, Mateo — Johns Hopkins University,

15:30-15:55 TuPM_LMH.1

A Gentle Introduction to Representation Stability: Fundamentals and Applications

Levin, Eitan — Caltech
Diaz, Mateo — Johns Hopkins University,
Chandrasekaran, Venkat — Massachusetts Institute of Technology

TuPM_LH Little Hall

Feedback Control Systems (Regular Session)

Chair: ter Horst, Sanne — North West University
Co-Chair: Forni, Fulvio — University of Cambridge

15:30-15:55 TuPM_LH.1

Magnitude-Feedback Control: A Study on Integrator Stabilization

Hansson, Jonas — Lund University
Kjellqvist, Olle — Lund University

We consider feedback stabilization of the discrete-time integrator restricted to magnitude feedback. This prototype problem captures the complexities of controlling systems with even non-linearities near their extremum points. This challenge is present in diverse problems such as wood chip refiner control, inverted pendulum systems based on height measurements, and antenna alignment utilizing signal power. Although effective adaptive controllers exist for these systems, it is not yet known if there is any stabilizing solution that is causal, linear, and time-invariant. This has led to the conjecture that no such controller exists. In this note, we present a first attempt at validating the conjecture by proving a partial result. In particular, our results show that the system is not strongly stabilizable.

15:55-16:20 TuPM_LH.2

Strategies for the Output Feedback Case of H2-Optimal Control for Poset-Causal Systems

ter Horst, Sanne — North West University
Zeelie, Jacobus — North-West University

The $mathcal{H}_2$ optimal control problem has been solved for simple sub-classes of poset-causal systems such as the two player problem, but the methods used there do not seem to extend easily to broader sub-classes of poset-causal systems. In this talk we consider the challenges of extending results to more intricate sub-classes of poset causal systems. Furthermore we present several strategies for constructing feasible structured controllers for $mathcal{H}_2$ optimal control problem for general poset-causal systems, taking various optimality considerations into account along the way.

16:20-16:45 TuPM_LH.3

Stable Virtual Reference Feedback Tuning with Passive iFIR Controllers

Wang, Zixing — University of Cambridge
Forni, Fulvio — University of Cambridge

We consider a new class of passive iFIR controllers. These are the parallel of an integrator and a finite impulse response filter. A data-driven design method based on virtual reference feedback tuning is illustrated, which does not require any model of the plant nor large datasets. Passivity is achieved via constrained optimization. iFIRs are more expressive than proportional-integral-derivative (PID) controllers but retain their features and simplicity of use. The approach is illustrated with a compliant mechanical system.

16:45-17:10 TuPM_LH.4

A Self Triggered Control Strategy for Disturbance Decoupling

Das, Sayar — Enphase Solar Energy Pvt Ltd
Patil, Deepak — Indian Institute of Technology Delhi

We consider a classical problem of decoupling the output of a linear time-invariant system from the disturbances. It is well known that if certain decoupling conditions are met, there exists a linear state-feedback control that decouples the output from the disturbance. However, the control law obtained for disturbance decoupling in continuous time is usually implemented digitally leading to ineffective decoupling. Typically, one redesigns the decoupling control considering a discrete-time linear system obtained by using a sample and hold mechanism for control with uniform sampling. In contrast, here, we develop a self-triggered control strategy that ensures that the norm of the output of the system under the disturbance input remains bounded within a specified tolerance for all time. Furthermore, a heuristic procedure is provided to increase the time between successive triggers, thus reducing the number of triggers.

17:10-17:35 TuPM_LH.5

Towards Robust Funnel Model Predictive Control for Higher Order Systems

Dennstädt, Dario — Universität Paderborn

The novel model-based controller funnel MPC allows for output tracking of smooth reference signals within prescribed error bounds for nonlinear multi-input multi-output systems with stable internal dynamics. Recently, a combination of this MPC algorithm with the model-free high-gain adaptive funnel control was proposed to make the former robust against disturbances, uncertainties, and structural model-plant mismatches. In this work we propose a generalization of this robust funnel MPC scheme to higher order systems that may encompass nonlinear time delays and potentially infinite dimensional internal dynamics.

17:35-18:00 TuPM_LH.6

On Derivative-Free Sample-And-Hold Control with Prescribed Performance

Lanza, Lukas — Technische Universität Ilmenau

A feedback controller is proposed to perform output reference tracking with prescribed performance for nonlinear continuous-time systems of relative degree two. The controller is of sampled-data type, i.e., measurements are available only at sampling times - a typical situation in real systems when sensors are involved. Furthermore, only output information is available, i.e., neither the full state nor derivatives can be used for feedback. A sufficient uniform sampling rate is derived and the control consists of piecewise constant signals on the sampling intervals, i.e., zero-order hold. Feasibility of the controller and satisfaction of the control objective are rigorously proven. The controller is illustrated by a numerical example.

TuPM_LR1 — LR1

Optimal Control (Regular Session)

Chair: Jacob, Birgit — Bergische Universität Wuppertal
Co-Chair: Jones, Morgan — The University of Sheffield

15:30-15:55 TuPM_LR1.1

LQ-Optimal Control for a Class of Boundary Controlled Hyperbolic PDEs

Hastir, Anthony — University of Wuppertal
Jacob, Birgit — Bergische Universität Wuppertal
Zwart, Hans — University of Twente

Linear-Quadratic (LQ) optimal controls are computed for a class of linear infinite-dimensional hyperbolic partial differential equations (PDEs), with inputs and outputs at the boundary of the spatial domain. After converting the continuous-time system into an equivalent discrete-time system, the optimal control problem is solved in discrete-time and its solution is then interpreted in continuous-time.

15:55-16:20 TuPM_LR1.2

A Minimax Optimal Controller for Positive Systems

Gurpegui, Alba — Lund University
Tegling, Emma — Lund University
Rantzer, Anders — Lund Univ

We present an explicit solution to the discrete-time Bellman equation for minimax optimal control of positive systems under unconstrained disturbances. The primary contribution of our result relies on deducing a bound for the disturbance penalty, which characterizes the existence of a finite solution to the problem class. Moreover, this constraint on the disturbance penalty reveals that, in scenarios where a solution is feasible, the problem converges to its equivalent minimization problem in the absence of disturbances.

16:20-16:45 TuPM_LR1.3

Model Predictive Bang-Bang Controller Synthesis Via Approximate Value Functions

Jones, Morgan — The University of Sheffield
Nie, Yuanbo — University of Sheffield
Peet, Matthew M — Arizona State University

In this paper, we propose a novel method for addressing Optimal Control Problems (OCPs) with input-affine dynamics and cost functions. This approach adopts a Model Predictive Control (MPC) strategy, wherein a controller is synthesized to handle an approximated OCP within a finite time horizon. Upon reaching this horizon, the controller is re-calibrated to tackle another approximation of the OCP, with the approximation updated based on the final state and time information. To tackle each OCP instance, all non-polynomial terms are Taylor-expanded about the current time and state and the resulting Hamilton-Jacobi-Bellman (HJB) PDE is solved via Sum-of-Squares (SOS) programming, providing us with an approximate polynomial value function that can be used to synthesize a bang-bang controller.

16:45-17:10 TuPM_LR1.4

Nonlinear Sampled-Data Control: Optimal Robust Inter-Sample Tracking

Hammer, Jacob — Univ. of Florida

The design and implementation of optimal robust controllers to optimize inter-sample tracking in nonlinear sampled-data control systems is considered. Optimal robust controllers that minimize inter-sample tracking errors are shown to exist for a very broad family of nonlinear systems that includes most systems of practical interest. A relatively simple technique for the design and implementation of such controllers is presented. Results apply to most nonlinear systems of practical interest.

17:10-17:35 TuPM_LR1.5

An Inverse Optimal Control Interpretation of Augmented Distributed Optimisation Algorithms

Hallinan, Liam — University of Cambridge
Lestas, Ioannis — University of Cambridge,

Distributed optimisation algorithms are used in a wide variety of problems where the goal is for a set of agents in a network to solve a network-wide optimisation problem via decentralised update rules. Here, we use inverse optimal control to show that a broad class of augmented primal-dual distributed optimisation algorithms can be viewed as the optimal solution to a network-wide optimal control problem, thus providing a performance metric for such methods.

17:35-18:00 TuPM_LR1.6

Indefinite Optimal Stochastic Regulator for a Class of Nonlinear Stochastic Systems

Algoulity, Mashael — University of Tabuk
Gashi, Bujar — The University of Liverpool

We consider an indefinite optimal regulator problem for a class of nonlinear stochastic systems with a square-root nonlinearity, random and possibly unbounded coefficients, and the quadratic-linear criterion with weight matrices being indefinite in general. This represents a certain nonlinear generalisation of the indefinite stochastic linear-quadratic control with random coefficients. All solutions to this problem are obtained in an explicit closed-form as an affine state-feedback control the coefficients of which are determined by the solution pairs of certain backward stochastic differential equations with algebraic equality and inequality constraints.

TuPM_LR2	LR2
Learning and Surrogate Modeling of Port-Hamiltonian Systems (Invited Session)	

Chair: Schaller, Manuel	Technische Universität Ilmenau
Co-Chair: Totzeck, Claudia	Bergische Universität Wuppertal
Organizer: Schaller, Manuel	Technische Universität Ilmenau
Organizer: Totzeck, Claudia	Bergische Universität Wuppertal

15:30-15:55 TuPM_LR2.1

Structure-Preserving Model Reduction of Port-Hamiltonian Systems by Optimization (I)

Schwerdtner, Paul	New York University
Voigt, Matthias	UniDistance Suisse

We discuss a new framework for structure-preserving model reduction of port-Hamiltonian systems based on optimization. Using frequency response samples, that can either be obtained from transfer function evaluations or measurements, we define an objective functional that measures the error between the given data and corresponding data that is generated by a reduced-order model with a prescribed structure. This functional can be minimized by gradient-based optimization to find a port-Hamiltonian model of prescribed order that explains the given data best and typically leads to small H-infinity errors due to its construction. We will also discuss extensions of the framework, e.g., to model reduction of descriptor systems or H-infinity control and to systems with other structures.

15:55-16:20 TuPM_LR2.2

Lumped Parameter Port-Hamiltonian Modeling and Order Reduction of Flexible Structures (I)

Sarkar, Arijit	University of Groningen
Dirksz, Daniel A.	Philips
Scherpen, Jacquelien M.A.	University of Groningen

In this work, we consider a scalable lumped-parameter model of the flexible structure in the port-Hamiltonian framework. We then propose a structure-preserving model reduction approach in the contraction framework. The contraction framework facilitates performing model reduction not around an equilibrium point, but rather along a trajectory of the system. As the interconnection matrix and the dissipation matrix are constant for the discretized model, the variational system provides the flexibility to preserve the port-Hamiltonian structure for the reduced-order model along a trajectory.

16:20-16:45 TuPM_LR2.3

Structure-Preserving Calibration of Linear Port-Hamiltonian Systems in Time Domain (I)

Totzeck, Claudia	Bergische Universität Wuppertal

We discuss a calibration approach for port-Hamiltonian systems that was recently introduced in Guenther, Jacob, Totzeck (2023). The method exploits that the defining matrices of linear port-Hamiltonian systems are elements of manifolds embedded in respective Euclidean vector spaces. The matrix structure, for example positive definiteness or skew-symmetry, is preserved in each step of the gradient-based algorithm. Numerical results illustrate the feasibility and robustness of the approach.

16:45-17:10 TuPM_LR2.4

Stabilisation of Stochastic Single-File Dynamics Using Port-Hamiltonian Systems (I)

Ackermann, Julia	University of Wuppertal
Ehrhardt, Matthias	Bergische Universität Wuppertal
Kruse, Thomas	University of Wuppertal
Tordeux, Antoine	University of Wuppertal

This study revisits a recently proposed symmetric port-Hamiltonian single-file model in one dimension. The uniform streaming solutions are stable in the deterministic model. However, the introduction of white noise into the dynamics causes the model to exhibit divergence. In response, we add a relaxation term that draws the agents' speed to a desired constant speed and plays the role of the input in the port-Hamiltonian framework. Our results show that this relaxation term effectively stabilises the dynamics even in the presence of stochastic noise.

17:10-17:35 TuPM_LR2.5

Structure-Preserving Model Reduction for Port-Hamiltonian Systems Based on Special Classes of Nonlinear Manifolds (I)

Schulze, Philipp	Technische Universität Berlin

In general model order reduction techniques may lead to unstable reduced-order models, even if the corresponding full-order model is stable. One possibility for ensuring stability preservation is given by the preservation of a port-Hamiltonian structure which often implies stability. While there are many structure-preserving techniques in the context of linear subspace techniques, in this talk we focus on approaches involving nonlinear manifolds and demonstrate how to achieve structure preservation. To this end, we consider two classes of nonlinear manifolds and present corresponding structure-preserving model reduction techniques. At the end of the talk, we illustrate both approaches by means of a transport-dominated numerical test case.

17:35-18:00 TuPM_LR2.6

Stability-Certified Learning of Control Systems with Quadratic Nonlinearities (I)

Pontes Duff, Igor	Max Planck Institute for Dynamics of Complex Technical Systems
Goyal, Pawan	Max Planck Institute for Dynamics of Compelx Technical Systems
Benner, Peter	Max Planck Institute for Dynamics of Complex Technical Systems

This work primarily focuses on an operator inference methodology aimed at constructing low-dimensional dynamical models based on a priori hypotheses about their structure, often informed by established physics or expert insights. Stability is a fundamental attribute of dynamical systems, yet it is not always assured in models derived through inference. Our main objective is to develop a method that facilitates the inference of quadratic control dynamical systems with inherent stability guarantees. To this aim, we investigate the stability characteristics of control systems with energy-preserving nonlinearities, thereby identifying conditions under which such systems are bounded-input bounded-state stable. These insights are subsequently applied to the learning process, yielding inferred models that are inherently stable by design. The efficacy of our proposed framework is demonstrated through a couple of numerical examples.

TuPM_LR3	LR 3
Mechanical Network Synthesis (Regular Session)	

Chair: Pates, Richard	Lund University
Co-Chair: Wang, Fu-Cheng	National Taiwan Univ

15:30-15:55 TuPM_LR3.1

Concepts for a Rotary Fluid Inerter

Unwin, Alasdair Thomas Rossiter	University of Cambridge
Smith, Malcolm C.	University of Cambridge

This paper explores concepts to construct rotary fluid inerters, i.e. passive mechanical one-port (two terminal) devices such that the equal and opposite torque applied is proportional to the relative angular acceleration between them. Embodiments with unlimited and limited travel will be described. Their potential as robust integrated devices, and the use of parallel cavities to enhance their performance will also be considered.

15:55-16:20 TuPM_LR3.2

Bifurcations in Latch-Mediated Spring Actuation (LaMSA) Systems

Srinivasan, Vittal — Purdue University
Hyun, Nak-seung P. — Purdue University

In nature, different species of smaller animals produce ultra-fast movements to aid in their locomotion or protect themselves against predators. These ultra-fast impulsive motions are possible, as often times, there exist a small latch in the organism that could hold the potential energy in the system, and once released, generate an impulsive motion. These type of systems are classified as Latch Mediated Spring Actuated (LaMSA) systems, a multi-dimensional, multi-mode hybrid system that switches between a latched and an unlatched state. The LaMSA mechanism has been studied extensively in the field of biology and is observed in a wide range of animal species, such as the mantis shrimp, grasshoppers, and trap-jaw ants. In recent years, research has been done in mathematically modeling the LaMSA behavior with physical implementations of the mechanism. A significant focus is given to mimicking the physiological behavior of the species and following an end-to-end trajectory of impulsive motion. This paper introduces a foundational analysis of the theoretical dynamics of the contact latch-based LaMSA mechanism. The authors answer the question on what makes these small-scale systems impulsive, with a focus on the intrinsic properties of the system using bifurcations. Necessary and sufficient conditions are derived for the existence of the saddle fixed points. The authors propose a mathematical explanation for mediating the latch when a saddle node exists, and the impulsive behavior after the bifurcation happens.

16:20-16:45 — TuPM_LR3.3

Network Representations of the Inerter by Two-Port Matrix Framework

Tsai, I-Haur — National Taipei University of Technology
Chang, Chi-Yang — National Cheng-Kung University
Yan, Wei-Mon — National Taipei University of Technology
Yen, Jia-Yush — National Taiwan University of Science and Technology
Wang, Fu-Cheng — National Taiwan University

This paper proposes two-port network representations for the inerter. The inerter is a genuine mechanical two-port element analogous to the capacitor in electrical networks in the force-current analogy. Its prominent advantages and unique mechanical characteristics have garnered widespread attention. This paper proposes two-port network representations of the inerter. For example, considering the rack-pinion inerter, we derive its corresponding block diagrams and two-port networks. Finally, we apply linear fractional transformations to derive their equivalent inertances.

16:45-17:10 — TuPM_LR3.4

H2 and H-Infinity Optimal Control of Mass-Spring Systems

Lindberg, Johan — Lund University
Pates, Richard — Lund University

In this paper we provide optimal H2 and H-infinity controllers for an interesting class of mass-spring systems under no damping and uniform damping. The H2 optimal controller for the undamped and uniformly damped system are themselves passive damped mass-spring systems. This means that the controllers can be built from physical components and without an energy source. The H-infinity optimal control of the undamped mass-spring system is decentralized linear feedback. The types of systems that are investigated have an interesting interpretation in the AC frequency control of electrical power systems.

17:10-17:35 — TuPM_LR3.5

From Network Synthesis to Absorber Synthesis: A Multidomain Design Methodology

Nar, Emily — University of Bristol
Li, Yuan — University of Bristol
Jiang, Jason Zheng — University of Bristol
Titurus, Branislav — University of Bristol
Neild, Simon Andrew — Univ of Bristol

Passive vibration absorbers are employed in a wide range of engineering applications. Modern absorbers often incorporate physical components from various domains, including mechanical, hydraulic, pneumatic, and electrical. Research has shown that these multidomain absorbers offer broader functionalities compared to those limited to a single domain. Traditional design approaches for vibration absorbers typically involve making specific modifications to existing designs. While these approaches can enhance performance, they are limited in scope, addressing only a narrow range of design variation around the conventional device. Consequently, numerous absorber design possibilities remain unexplored, leaving their potentials locked.

Network synthesis, originally developed for electrical engineering problems, offers the opportunity to identify optimal absorber properties in network representation. Such properties are represented using a mechanical network configuration consisting of stiffness, damping and inertance elements. By employing network synthesis techniques, alternative absorber properties can be obtained which theoretically outperform traditional designs. However, such properties have not yet been translated into practical application due to two unresolved questions: 1) What is the network configuration of the conventional absorber? The existing network-synthesis design approach constructs network possibilities without considering any links to the existing absorber design. Therefore, there is no guarantee that the identified optimal network configuration can be physically realised. 2) How can the optimal network configuration be realised considering physical components from multiple domains? The existing network-synthesis approach focuses on a single-domain (i.e., mechanical) representation. This means the diversified functionalities of components from other domains cannot be systematically exploited.

This paper addresses these two key questions by developing a novel bi-directional multidomain synthesis technique. Using this technique, a vibration-absorber design methodology is proposed, which can construct an optimal vibration absorber considering physical components from multiple domains.

17:35-18:00 — TuPM_LR3.6

Physics-Informed Network Synthesis Approach for Designing Vibration Suppression Systems

Liao, Zichen — University of Bristol
Qu, Cenxiao — University of Bristol
Wang, Zixiao — University of Bristol
Li, Yuan — University of Bristol
Graham, Mark — University of Bristol
Hill, Tom — University of Bristol
Jiang, Jason Zheng — University of Bristol

Network synthesis offers a systematic way for identifying optimal passive vibration suppression systems (VSSs). The conventional approach uses linear element properties to synthesize optimised impedances. However, the elements' parasitic effects can cause discrepancies between the ideal and actual behaviours of a network, potentially leading to oversight of the true optimal network configuration. To address this issue, this paper introduces a physics-informed approach for VSS design that considers parasitic effects early in the optimal network identification stage. The approach's efficacy is demonstrated through a case study, applying it to determine the optimal configuration of a hydraulic shock absorber for passenger cars.

TuPM_LR4 — LR4

Delay Systems (Regular Session)

Chair: Cantoni, Michael — University of Melbourne
Co-Chair: Michiels, Wim — KU Leuven

15:30-15:55 — TuPM_LR4.1

Funnel Control in the Presence of Delays

Berger, Thomas — Universität Paderborn
Hachmeister, Jan — Universität Paderborn

We propose a new funnel control algorithm for output tracking with prescribed performance of the tracking error for a class of nonlinear multi-input, multi-output systems in the presence of input and state measurement delays. The controller does not require a precise knowledge of the system parameters and is of low complexity. The approach presented here fixes an error in the control design presented in a recent work on the same topic.

15:55-16:20 — TuPM_LR4.2

On Perturbation Gain Bounds for Asynchronous Sampled-Data Links

Cantoni, Michael — University of Melbourne

From an input-output perspective, an asynchronous sampled-data link is an uncertain time-varying saw-tooth delay. It is well-known that the L2 gain of the corresponding integrator weighted perturbation of the ideal unity gain link is bounded by the maximum delay. A new parametrization of this uncertain perturbation is proposed in terms of the minimum delay increase between zero-order hold output updates, in addition to the maximum delay parameter. It is shown that a perturbation gain bound smaller than the maximum delay is possible over a narrow region of the parameter space; specifically, where the minimum delay increase is a sufficiently large fraction of the maximum delay. Outside this narrow region the maximum delay bound is less conservative.

16:20-16:45 — TuPM_LR4.3

Control Semiflows and Chain Controllability for Linear Delay Systems

Colonius, Fritz — Univ of Augsburg

A continuous affine semiflow is introduced describing linear control systems with delays in the state and control and with bounded control range. The state of the semiflow includes the control function. It is proved that there exists a unique chain control set which corresponds to the chain recurrent set of the semiflow. The semiflow can be lifted to a linear semiflow on an infinite dimensional vector bundle with chain transitive base flow. A decomposition into exponentially separated subbundles is provided by a recent generalization of Selgrade's theorem.

16:45-17:10 — TuPM_LR4.4

Sampled-Data Finite-Dimensional Boundary Control for 1-D Burgers' Equation

Pan, Lina — Beijing Institute of Technology
Wang, Pengfei — Tel-Aviv University
Fridman, Emilia — Tel-Aviv Univ

In this paper, we are concerned with the regional exponential stabilization of a 1-D Burgers' equation under Neumann actuation via a modal decomposition method and dynamic extension. We consider a sampled-data finite-dimensional boundary control, which is implemented via a generalized hold device. We use Wirtinger-based piecewise continuous-time Lyapunov functional to compensate sampling of the finite-dimensional state, and provide the H^1-stability analysis for the full-order closed-loop system. Given a decay rate, we provide the efficient linear matrix inequality (LMI) conditions for finding the controller dimension and gain, as well as a bound on the domain of attraction. We prove that for some fixed upper bounds on the initial value and sampling intervals, the feasibility of LMIs for some N (dimension of the controller) implies their feasibility for $N+1$. Numerical example illustrates the efficiency of the proposed method.

17:10-17:35 — TuPM_LR4.5

Characterizations of Input-To-State Stability for Time-Delay Systems

Mironchenko, Andrii — University of Klagenfurt
Wirth, Fabian — University of Passau
Chaillet, Antoine — CentraleSupelec - IUF
Brivadis, Lucas — Université Paris-Saclay, CNRS, CentraleSupélec

For nonlinear time-delay systems, characterizations of input-to-state stability (ISS) are investigated. While general ISS superposition theorems for infinite-dimensional systems can be applied in this context, the criteria provided by such theorems are unnecessarily demanding. It is shown that for time-delay systems relaxed characterizations can be obtained. While recovering some ISS characterizations known for ordinary differential equations, we also highlight specific obstructions posed by time-delay systems. In particular, the boundedness of finite-time reachability sets becomes a central property in this context. As it turns out this assumption cannot be relaxed in a meaningful sense. With this assumption, however, several uniformity properties may be derived for time-delay systems.

17:35-18:00 — TuPM_LR4.6

On the Notion of Filtered Spectral Abscissa of Continuous-Time Delay-Difference Equations

Michiels, Wim — KU Leuven

For feedback control systems where the closed-loop system description is governed by linear delay-differential equations of neutral type, the achieved stability may be fragile, in the sense of being sensitive to infinitesimal perturbations to parameters in the system model or arbitrarily small errors in the implementation of the controller. A natural approach to resolve this problem of ill-posedness and to break down the underlying instability mechanisms, rooted in characteristic roots moving from the left plane to the right one via the point at infinity, consists of including a low-pass filter in the control loop, provided its inclusion is stability preserving. The addition of a low-pass filter essentially boils down to a ``regularization'' of delay-difference equations and delay equations of neutral type in terms of parametrized delay equations of retarded type, where the parameter corresponds to the filter's cut-off frequency. In my talk, the stability properties of these parametrized delay equations are analyzed in a general, multi-delay setting, with focus on the transition to the original delay-difference or neutral equation. It is illustrated that the spectral abscissa may be discontinuous at the transition. Conditions for preservation of stability in terms of a novel robustified stability indicator called filtered spectral abscissa are presented, for which mathematical characterizations and a computationally tractable expression are provided. The potential of the results in the controller design of systems described by hyperbolic PDEs, relying on integral transformations, is also discussed.

TuPM_LR5 — LR5

Hybrid Systems (Regular Session)

Chair: Briat, Corentin — FHNW

15:30-15:55 — TuPM_LR5.1

Local Stabilization of Networked Linear Systems with Decentralized Switching Controllers

Khodja, Ghania — Centrale Lille Institut
Fiter, Christophe — Université De Lille
Hetel, Laurentiu — CNRS
Floquet, Thierry — CNRS
Michiels, Wim — KU Leuven

In this paper, we consider the decentralized control design problem for a particular case of networked switched affine systems. The considered network consists of interconnected (identical) linear systems with the controlled input switching among a finite set of values. We address a challenging case where the network can be only locally stabilized. Scalable Lyapunov based conditions are proposed for designing such decentralized controllers. The derived conditions (theoretical and linear matrix inequalities) do not depend on the number of subsystems. Ellipsoidal estimates of the domain of attraction are given.

15:55-16:20 — TuPM_LR5.2

Robust Performance for Switched Systems with Constrained Switching and Its Application to Weakly Hard Real-Time Control Systems

Lang, Simon	University of Stuttgart, Institute for Systems Theory and Automa
Seidel, Marc	University of Stuttgart
Allgower, Frank	University of Stuttgart

We consider robust controller synthesis for switched systems with graph-constrained switching with respect to quadratic performance criteria. The presented methods are based on dissipativity arguments and can be used to handle switched systems affected by a broad range of uncertainties and switching input-/output-dimension. Moreover, we show how the results can be applied to weakly hard real-time control systems – a system class naturally appearing in networked and real-time control.

16:20-16:45 TuPM_LR5.3

Stability Analysis of Nonlinear Systems Over Switching Networks Using Singularly Perturbed Hybrid Systems Framework

Tanwani, Aneel	LAAS -- CNRS, Université De Toulouse
Shim, Hyungbo	Seoul National University
Teel, Andrew R.	Univ. of California at Santa Barbara

To analyze the stability of a network of agents described by nonlinear oscillators which only exchange information about their position with some of its neighbors from time to time, we consider a theoretical framework of singularly perturbed hybrid systems. We describe such systems as an interconnection of two hybrid subsystems, a timer which triggers the jumps, and some discrete variables to determine the index of the jump maps. The flow equations of these variables are singularly perturbed differential equations, and in particular, smaller value of the singular perturbation parameter leads to increase in the frequency of the jump instants. For the limiting value of this parameter, we consider a decomposition which comprises a quasi-steady-state system modeled by a differential equation without any jumps, and a boundary-layer system described by purely discrete dynamics. Under appropriate stability assumptions on the quasi-steady-state system and the boundary-layer system, we derive results showing practical stability of a compact attractor when the information exchange between the agents occurs frequently often.

16:45-17:10 TuPM_LR5.4

Stability Analysis of Impulsive Linear Time-Invariant Infinite-Dimensional Systems

Briat, Corentin	ETH-Zurich
Ferrante, Francesco	Università Degli Studi Di Perugia
Prieur, Christophe	CNRS

We consider here the uniform exponential stability analysis of linear time-invariant infinite dimensional impulsive systems defined on a Hilbert space X. Such systems have been the subject of previous works such as [1]. We combine ideas from hybrid systems theory [2,3] and infinite-dimensional systems [4–6] to produce operator-based stability conditions, which can be analytically or numerically checked using off- the-shelf tools. We extend the general results to address the stability of such systems subject to periodic impulse sequences and sequences satisfying a minimum dwell-time condition.

17:10-17:35 TuPM_LR5.5

Input-To-State Stability of Nonlinear Impulsive Systems with Hybrid Impulses

Kumar, Rakesh	Karlsruhe Institute of Technology (KIT)
Feketa, Petro	Victoria University of Wellington
Meurer, Thomas	Karlsruhe Institute of Technology (KIT)

This note investigates input-to-state stability (ISS) of nonlinear impulsive systems with hybrid impulses. Such systems contain a time-dependent jump map that can generate both stabilizing and destabilizing impulsive jumps. To cope with the two-fold effect of impulses within a single impulse time sequence, we use the concept of average impulsive gain. We provide novel sufficient conditions for ISS in terms of exponential ISS-Lyapunov function equipped with average impulsive gain and appropriate dwell-time condition. Contrary to the existing results we do not impose severe restrictions on impulsive gains, like periodicity or a finite number of different gains. Finally, we demonstrate effectiveness of our results by concluding ISS for a system whose ISS property cannot be verified by any other result available in the literature.

17:35-18:00 TuPM_LR5.6

Hybrid Predictor-Corrector Numerical Schemes: Lambda-Tracking, Sampled-Data Observers and Data Assimilation

Mousa, Aisha	Exeter University
Das, Saptarshi	University of Exeter
Townley, Stuart	Univ. of Exeter

This paper considers hybrid ODE solvers for process dynamics constructed by combining standard numerical schemes with standard observers. Specifically, we combine the first order Euler scheme with a Luenberger observer. The key ideas are to take advantage of available process output information and to switch from the numerical scheme to the process output-driven observer when the numerical scheme alone would produce inadequate results. Within this setup, two tasks emerge: How do we choose the observer gain? How do you choose the step size in the numerical scheme? Underpinning our approach is a λ tracking-based sampled-data observer that invokes a λ dead zone. This λ tracking observer adaptively determines the observer gain and the numerical step size. The resulting adaptive hybrid algorithm is a time-stepping numerical scheme. Using a sampled-data observer allows for process measurements to be only available at some discrete times, whilst adaptive tuning allows the gains and sampling times to adjust automatically to each other – rather than both being subject to design. Results are illustrated with examples of simulation.

TuPM_LR6 LR6

Learning and Optimization in Stochastic Systems and Control (III) (Invited Session)

Chair: Gruene, Lars	Univ of Bayreuth
Co-Chair: Worthmann, Karl	TU Ilmenau
Organizer: Gruene, Lars	Univ of Bayreuth
Organizer: Worthmann, Karl	TU Ilmenau

15:30-15:55 TuPM_LR6.1

Distributional Uncertainty Propagation Via Optimal Transport (I)

Aolaritei, Liviu	ETH Zurich
Lanzetti, Nicolas	ETH Zürich
Dorfler, Florian	Swiss Federal Institute of Technology (ETH) Zurich
Chen, Hongruyu	Automatic Control Lab, ETH Zurich

This paper addresses the limitations of standard uncertainty models, i.e., robust (norm-bounded) and stochastic (one fixed distribution, e.g., Gaussian), and proposes to model uncertainty via Optimal Transport (OT) ambiguity sets. These constitute a very rich uncertainty model, which enjoys many desirable geometrical, statistical, and computational properties, and which: (1) naturally generalizes both robust and stochastic models, and (2) captures many additional real-world uncertainty phenomena (e.g., black swan events). Our contributions show that OT ambiguity sets are also analytically tractable: they propagate easily and intuitively through linear (possibly corrupted by additive or multiplicative stochastic noise) maps, and the result of the propagation is again an OT ambiguity set or can be tightly upper bounded by one. In the context of dynamical systems, our results allow us to consider multiple sources of uncertainty (e.g., initial condition, additive noise, multiplicative noise) and to capture in closed-form, via an OT ambiguity set, the resulting uncertainty in the state at any future time.

15:55-16:20	TuPM_LR6.2

Reinforcement Learning for Docking Maneuvers with Prescribed Performance (I)

Gottschalk, Simon	Universität Der Bundeswehr München
Lanza, Lukas	Technische Universität Ilmenau
Worthmann, Karl	TU Ilmenau
Lux-Gottschalk, Kerstin	Eindhoven University of Technology

We propose a two-component data-driven controller to safely perform docking maneuvers for satellites. Reinforcement Learning is used to deduce an optimal control policy based on measurement data. To safeguard the learning phase, an additional feedback law is implemented in the control unit, which guarantees the evolution of the system within predefined performance bounds. We define safe and safety-critical areas to train the feedback controller based on actual measurements. To avoid chattering, a dwell-time activation scheme is implemented. We provide numerical evidence for the performance of the proposed controller for a satellite docking maneuver with collision avoidance.

16:20-16:45	TuPM_LR6.3

Generalized Synchronizations and Learning with Reservoir Systems (I)

Grigoryeva, Lyudmila	University of St. Gallen
Hart, Allen	University of Exeter
Ortega, Juan-Pablo	Nanyang Technological University

This talk shows that the celebrated Embedding Theorem of Takens is a particular case of a much more general statement according to which, randomly generated lin- ear state-space representations of generic observations of an invertible dynamical system carry in their wake an embedding of the phase space dynamics into the chosen Euclidean state space. This embedding coincides with a natural generalized synchronization that arises in this setup and that yields a topological conjugacy between the state-space dynamics driven by the generic observations of the dynamical system and the dynamical system itself. This result provides additional tools for the representation, learning, and analysis of chaotic attractors and sheds additional light on the reservoir computing phenomenon in the context of recurrent neural networks.

16:45-17:10	TuPM_LR6.4

Reservoir Kernels and Volterra Series (I)

Gonon, Lukas	Imperial College London
Grigoryeva, Lyudmila	University of St. Gallen
Ortega, Juan-Pablo	Nanyang Technological University

17:10-17:35	TuPM_LR6.5

Convergence Analysis of Ensemble Filters for Linear Stochastic Systems with Poisson-Sampled Observations (I)

Tanwani, Aneel	LAAS -- CNRS, Université De Toulouse
Yufereva, Olga	Krasovskii Institute of Mathematics and Mechanics

For continuous-time linear stochastic dynamical systems driven by Wiener processes, we consider the problem of designing ensemble filters when the observation process is randomly sampled. We propose a continuous-discrete McKean--Vlasov type diffusion process with additive Gaussian noise in observation model, which is used to describe the evolution of the individual particles in the ensemble. These particles are coupled through the empirical covariance and require less computations for implementation than the optimal ones based on solving Riccati differential equations. Using appropriate analysis tools, we show that the empirical mean and the sample covariance of the ensemble filter converges to the mean and covariance of the optimal filter if the mean sampling rate of the observation process is sufficiently large and as the number of particles tends to infinity.

17:35-18:00	TuPM_LR6.6

Risk-Neutral Limit of Adaptive Importance Sampling of Random Stopping Times (I)

Hartmann, Carsten	Brandenburgische Technische Universität Cottbus-Senftenberg
Jöster, Annika	Brandenburgische Technische Universität Cottbus-Senftenberg

We discuss importance sampling of exit problems that involve unbounded stopping times; examples are mean first passage times, transition rates or committor probabilities in molecular dynamics. The naive application of variance minimization techniques can lead to pathologies here, including proposal measures that are not absolutely continuous to the reference measure or importance sampling estimators that formally have zero variance, but that produce infinitely long trajectories. We illustrate these issues with simple examples and discuss a possible solution that is based on a risk-sensitive optimal control framework of importance sampling.

TuE_LMH	Lady Mitchell Hall

A Life in Science and Engineering: The Legacy of Allen Tannenbaum (Invited Session)

Chair: Smith, Malcolm C.	University of Cambridge
Co-Chair: Georgiou, Tryphon T.	Univ. of California, Irvine
Organizer: Chen, Yongxin	Georgia Institute of Technology
Organizer: Georgiou, Tryphon T.	Univ. of California, Irvine

18:10-19:00	TuE_LMH.1

A Life in Science and Engineering: The Legacy of Allen Tannenbaum

Chen, Yongxin	Georgia Institute of Technology
Georgiou, Tryphon T.	Univ. of California, Irvine

WeP_LMH	Lady Mitchell Hall

Plenary: A Network View of Wind Farm Modeling and Control (Plenary Session)

Chair: Jovanovic, Mihailo	University of Southern California
Co-Chair: Verriest, Erik I.	Georgia Inst. of Tech

09:00-10:00	WeP_LMH.1

Plenary: A Network View of Wind Farm Modeling and Control

Gayme, Dennice	Johns Hopkins University

WeAM_LH	LH

Stochastic Safety (Mini Course)

Chair: Bujorianu, Luminita-Manuela	University College London
Co-Chair: Wisniewski, Rafal	Aalborg University

10:30-10:55	WeAM_LH.1

Stochastic Safety

Bujorianu, Luminita-Manuela	University College London
Wisniewski, Rafal	Aalborg University

WeAM_LR1	LR1

Nonlinear Systems and Control (Regular Session)

Chair: Chen, Chao	KU Leuven
Co-Chair: Carrasco, Joaquin	University of Manchester

10:30-10:55	WeAM_LR1.1

Reciprocity of Input-State-Output Systems: From Linear to Nonlinear

van der Schaft, Arjan J. — Univ. of Groningen

Based on van der Schaft(2024), this paper aims at extending to the nonlinear case the theory of reciprocal linear systems as developed in Willems(1972).

10:55-11:20	WeAM_LR1.2

Discrete-Time Negative Imaginary Systems from ZOH Sampling

Shi, Kanghong — The Australian National University

Petersen, Ian R — The Australian National University

Vladimirov, Igor — Australian National University

A new definition of discrete-time negative imaginary (NI) systems is provided. This definition characterizes the dissipative property of a zero-order hold sampled continuous-time NI system. Under some assumptions, asymptotic stability can be guaranteed for the closed-loop interconnection of an NI system and an output strictly negative imaginary system, with one of them having a one step advance. In the case of linear systems, we also provide necessary and sufficient frequency-domain and LMI conditions under which the definition is satisfied. Also provided is a simple DC gain condition for the stability results in the linear case.

11:20-11:45	WeAM_LR1.3

On the Stability of Networked Nonlinear Negative Imaginary Systems with Applications to Electrical Power Systems

Chen, Yijun — The University of Sydney

Shi, Kanghong — The Australian National University

Petersen, Ian R — The Australian National University

Ratnam, Elizabeth Louise — The Australian National University

In this paper, we propose employing battery-based feedback control and nonlinear negative imaginary (NI) systems theory to reduce the need for such expansion. By formulating a novel Lur'e-Postnikov-like Lyapunov function, stability results are presented for the feedback interconnection of two single nonlinear NI systems, while output feedback consensus results are established for the feedback interconnection of two networked nonlinear NI systems based on a network topology. This theoretical framework underpins our design of battery-based control in power transmission systems. We demonstrate that the power grid can be gradually transitioned into the proposed NI systems, one transmission line at a time.

11:45-12:10	WeAM_LR1.4

Modelling and Analysis of Networks of Memristors and Capacitors

Huijzer, Anne-Men — University of Groningen

van der Schaft, Arjan J. — Univ. of Groningen

Besselink, Bart — University of Groningen

Motivated by neuromorphic computing applications, this work considers electrical circuits comprising memristors and capacitors, connected to external sources. We derive a model describing the dynamic behaviour of such a circuit and show that, for given initial conditions and a fixed input signal, the voltages across the memristors converge towards zero, implying that the conductance values of the memristors converge to a fixed value.

12:10-12:35	WeAM_LR1.5

On the Scaled Relative Graph Separation for Feedback Incremental Stability

Chen, Chao — KU Leuven

Khong, Sei Zhen — -

Sepulchre, Rodolphe J. — University of Cambridge

We present incremental stability analysis of nonlinear feedback systems based on the recent notion of scaled relative graph (SRG). The essence of our proposed analysis is that the separation of SRGs of two open-loop systems on the complex plane implies closed-loop incremental stability. The main result generalizes the existing SRG separation theorem for stable open-loop systems which was based on a critical assumption of a chordal property. By comparison, our analysis allows possibly unstable open-loop systems and does not require the chordal assumption. Moreover, an L2e-counterpart to an SRG, referred to as a hard SRG, is proposed in parallel, based upon which we recover the existing incremental passivity theorem.

12:35-13:00	WeAM_LR1.6

Input/output Continuity of Stable Lurye Systems Revisited

Heath, William — Bangor University

Carrasco, Joaquin — University of Manchester

Dynamic multipliers can be used to establish the input/output stability of a Lurye system but there exist examples in the literature where Lipschitz continuity is lost. In this extended abstract we discuss what properties dynamic multipliers still guarantee and the implications for practical applications. Several questions remain open: not least whether the existing examples also imply loss of continuity.

WeAM_LR2	LR2

Data-Driven Reduced-Order Modeling and Learning of Dynamical Systems: Some New Insights into the Future
(Invited Session)

Chair: Gosea, Ion Victor — Max Planck Institute for Dynamics of Complex Technical Systems

Organizer: Gosea, Ion Victor — Max Planck Institute for Dynamics of Complex Technical Systems

Organizer: Unger, Benjamin — University of Stuttgart

10:30-10:55	WeAM_LR2.1

A Non-Intrusive Data-Based Reformulation of a Hybrid Projection-Based Model Reduction Method (I)

Gosea, Ion Victor — Max Planck Institute for Dynamics of Complex Technical Systems

Gugercin, Serkan — Virginia Tech

Beattie, Christopher A. — Virginia Tech

We present a novel data-driven reformulation of iterative SVD-rational Krylov algorithm (ISRK), in its original formulation a Petrov-Galerkin (two-sided) projection-based iterative method for model reduction combining rational Krylov subspace (on one side) with Gramian/SVD based subspaces (on the other side). We show that at each step of ISRK, we do not necessarily require access to the original system matrices, but only to input/output data. In this context, data represent samples of the system's transfer function, evaluated at particular values (frequencies). Numerical examples illustrate the efficiency of the new data-driven formulation.

10:55-11:20	WeAM_LR2.2

Representation and Evolution of Linear Systems in Learning Complex Time Series (I)

Yu, Annan — Cornell University

Nigmetov, Arnur — Lawrence Berkeley National Laboratory

Morozov, Dmitriy — Lawrence Berkeley National Laboratory

Mahoney, Michael — University of California, Berkeley

Erichson, Benjamin — International Computer Science Institute

A state-space model (SSM) uses linear, time-invariant (LTI) systems to model complicated time series data, such as weather and language. Given a training dataset, one applies a gradient-based algorithm to train an SSM in the frequency domain. To make training efficient, one leverages a simplified (e.g., diagonal) structure of the state matrices in the LTI systems. The latent states need to be meaningful; hence, the LTI systems are often initialized by a particular class of matrices called the HiPPO matrices, which store the Legendre coefficients of the input into the state vector. Unfortunately, such matrices cannot be stably diagonalized. While earlier solutions propose to modify the initial HiPPO matrices, the modification leads to a non-smooth transfer function that causes instability in the frequency domain. In this work, we propose an alternative solution by approximately diagonalizing the original HiPPO matrices in a backward stable way. This method results in a robust model that performs better than the earlier ones on many large test datasets. Additionally, we monitor the evolution of the LTI systems throughout training. We make observations about the change in the transfer functions in different parts of the frequency space, which demonstrate how an SSM is trained and suggest possible future improvements in the model. We conclude by providing a new research direction of SSMs through the lens of the Hankel singular values, which leads to a more robust parameterization scheme of an LTI system using its Hankel operator.

11:20-11:45	WeAM_LR2.3

Model Reduction on Manifolds: A Differential Geometric Framework (I)

Buchfink, Patrick	University of Twente
Glas, Silke	University of Twente
Haasdonk, Bernard	University of Stuttgart
Unger, Benjamin	University of Stuttgart

Classical linear-subspace model reduction (MOR) techniques are widely used whenever speed-ups of parametric problems or real-time evaluations are needed. However, when the underlying problem at hand admits slowly decaying Kolmogorov n-widths, resulting reduced-order models of low-dimension can yield inaccurate results. To overcome this difficulty, MOR on manifolds has been introduced which uses nonlinear projections. In this talk, we provide a unifying geometric framework for MOR on manifolds, which allows us to geometrically understand and unify existing MOR techniques. Moreover, this includes structure-preserving MOR techniques for, e.g., Hamiltonian and Lagrangian systems.

11:45-12:10	WeAM_LR2.4

Frequency-Domain Identification of Discrete-Time Systems Using Sum-Of-Rational Optimization (I)

Abdalmoaty, Mohamed Rasheed Hilmy	ETH Zurich
Miller, Jared	ETH Zurich
Yin, Mingzhou	ETH Zurich
Smith, Roy S.	Swiss Federal Institute of Technology (ETH)

Frequency-domain system identification of SISO linear systems using least squares can be cast as sum-of-rational optimization problem. Prediction error methods based on thissum-of-rational least-squares objective suffer from nonconvexities, and may become stuck in local minima. Our work uses the sum-of-squares hierarchies of semidefinite programs based on the sum-of-rationals framework of (Bugarin, Henrion, Lasserre 2016) to find a convergent sequences of lower-bounds to the optimal mean-squared error. If the semidefinite program's solution satisfies a rank condition, we can recover plants that are global optima for the mean squared error. The method can be extended towards identification in continuous-time and in closed-loop.

12:10-12:35	WeAM_LR2.5

Learning Stable Dynamical Systems from Data Using Constrained Operator Inference (I)

Benner, Peter	Max Planck Institute for Dynamics of Complex Technical Systems
Goyal, Pawan	Max Planck Institute for Dynamics of Compelx Technical Systems
Pontes Duff, Igor	Max Planck Institute for Dynamics of Complex Technical Systems

We study the problem of identifying linear and nonlinear systems from data. In particular, we discuss the inference of models with certified stability properties. This includes asymptotic stability for linear systems as well as Lyapunov stability for nonlinear systems with quadratic nonlinearity. Moreover, we also study the identification of free dynamics for systems with trapping regions.

12:35-13:00	WeAM_LR2.6

An Extension of the AAA Algorithm for Fitting Stable MIMO Systems from Data (I)

Bradde, Tommaso	Politecnico Di Torino
Grivet Talocia, Stefano	Politecnico Di Torino
Gosea, Ion Victor	Max Planck Institute for Dynamics of Complex Technical Systems

This work introduces an approach for generating guaranteed stable reduced-order linear time-invariant (LTI) models in a completely automated, data-driven, and efficient manner. The presented method is based on the AAA algorithm for rational fitting of scalar transfer functions. We propose a computationally efficient multi-input multi-output extension of the AAA algorithm, and we combine the resulting algorithm with a post-processing stability enforcement step that is formulated in terms of a small convex problem. A numerical example from electronics engineering attests to the method's effectiveness.

WeAM_LR3	LR3
Port-Hamiltonian Systems (Regular Session)	
Chair: Kurula, Mikael	Åbo Akademi University

10:30-10:55	WeAM_LR3.1

Energy-Based Tracking Methods for Classes of Electromechanical Systems

Javanmardi, Najmeh	Groningen University
Borja, Pablo	University of Plymouth
Scherpen, Jacquelien M.A.	University of Groningen

This extended abstract suggests control approaches for the trajectory-tracking problem in two classes of weakly coupled electromechanical systems. To this end, we formulate these systems within the port-Hamiltonian framework. Then, the notion of a contractive port-Hamiltonian system is used to develop tracking control approaches. These methods, derived from the Interconnection and Damping Assignment Passivity Based Control approach, eliminate the need to solve partial differential equations and use coordinate transformations. We also investigate the effect of coupled damping on the transient performance of the closed-loop system. The applicability of the proposed approaches is shown through simulations in two electromechanical applications.

10:55-11:20	WeAM_LR3.2

Implicit Lyapunov Control of Multi-Control Hamiltonian Systems in Degenerate Cases

Cong, Shuang	University of Science and Technology of China
Meng, Fangfang	Department of Automation, University of Science and Technology O

In closed quantum systems, if controlled systems are not strongly regular or there exists at least one eigenstate that is directly uncoupled to the target state, then such systems control will become degenerate cases. This paper proposes a quantum control method designed by an implicit Lyapunov function to transfer states of the quantum systems in these two degenerate cases, especially the method proposed is suitable for multi-control Hamiltonian systems. The state distance is selected as the Lyapunov function in this paper. Numerical simulation experiments on a 4-level system are done, and the experiment results indicate the effectiveness of the implicit Lyapunov control method proposed for degenerate cases and multi-control Hamiltonians.

11:20-11:45 WeAM_LR3.3

On Stokes-Lagrange and Stokes-Dirac Representations for 1D Distributed Port-Hamiltonian Systems

Bendimerad-Hohl, Antoine, Amine	ISAE Supaero
Matignon, Denis	ISAE
Haine, Ghislain	Institut Superieur De l'Aeronautique Et De L'Espace
Lefevre, Laurent	Univ. Grenoble Alpes

Port-Hamiltonian systems were recently extended to include implicitly defined energy and energy ports thanks to a (Stokes-)Lagrange subspace. Here, we study the equivalent port-Hamiltonian representations of two systems with damping, written using either a classical Hamiltonian or a Stokes-Lagrange subspace. Then, we study the Timoshenko beam and Euler-Bernoulli models, the latter being the flow-constrained version of the former, and show how they can be written using either a Stokes-Dirac or Stokes-Lagrange subspace related by a transformation operator. Finally, it is proven that these transformations commute with the flow-constraint projection operator.

11:45-12:10 WeAM_LR3.4

Solvability of Time-Varying Continuous-Time Systems on Hilbert Spaces: The Port-Hamiltonian Case

Kurula, Mikael	Åbo Akademi University

Very recently, Jacob and Laasri obtained strong results on the solvability and well-posedness of infinite-dimensional time-varying linear port-Hamiltonian systems with boundary control and boundary observation. In this paper, we complement their results by giving a relatively non-technical discussion on the solvability of linear, infinite-dimensional time-varying linear systems not necessarily of boundary control type. The presentation is an overview of two recent papers by the author. The focus is on port-Hamiltonian systems and the theory is illustrated on a system with a delay component in the state dynamics.

12:10-12:35 WeAM_LR3.5

Towards BIBO Stability of Port-Hamiltonian Systems

Schwenninger, Felix	University of Twente
Wierzba, Alexander	University of Twente

Port-Hamiltonian systems (pHS) provide a useful tool for modelling physical systems such as e.g. flexible beams within mechanical systems. We study 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 the transfer function of this system class, we provide sufficient conditions for BIBO stability for a sub-class of pHS.

12:35-13:00 WeAM_LR3.6

On the Exact Linearization of Minimally Underactuated Configuration Flat Lagrangian Systems in Generalized State Representation

Hartl, Georg	Johannes Kepler University Linz
Gstöttner, Conrad	Johannes Kepler University Linz
Kolar, Bernd	Johannes Kepler University Linz
Schöberl, Markus	Johannes Kepler University of Linz

In this paper, we examine the exact linearization of configuration flat Lagrangian control systems in generalized state representation with p degrees of freedom and p−1 control inputs by quasi-static feedback of its generalized state. We formally introduce generalized Lagrangian control systems, which are obtained when configuration variables are considered as inputs instead of forces. This work presents all possible lengths of integrator chains achieved by an exact linearization with a quasi-static feedback law of the generalized state that allows for rest-to-rest transitions. We show that such feedback laws can be systematically derived without using Brunovský states.

WeAM_LR4 LR4

Solution of Hamilton-Jacobi Equations (Invited Session)

Chair: McEneaney, William	Univ of California, San Diego
Co-Chair: Kaise, Hidehiro	Kumamoto University
Organizer: McEneaney, William	Univ of California, San Diego
Organizer: Dower, Peter M.	University of Melbourne

10:30-10:55 WeAM_LR4.1

Solution of Hamilton-Jacobi Equations (I)

McEneaney, William	Univ of California, San Diego
Dower, Peter M.	University of Melbourne
Zheng, Yifei	University of California San Diego

A finite-horizon nonlinear optimal control problem is considered. Stat-quad duality is used to generate an equivalent problem with linear dynamics and running cost that is quadratic in state with an additional term that is nonlinear in newly introduced control state variables. The new problem form is used to obtain a representation of the value function in terms of staticization over a set of quadratic functions, where the coefficients of the quadratic functions consist of the solutions to certain ODEs. A novel numerical method is indicated for solution of the resulting staticization problem; the method leverages the low dimensionality of nonlinearity. An example is included.

10:55-11:20 WeAM_LR4.2

Leveraging Hamilton-Jacobi PDEs for Certain Scientific Machine Learning Problems (I)

Chen, Paula	Naval Air Warfare Center Weapons Division
Meng, Tingwei	Brown University
Zou, Zongren	Brown University
Jerome Darbon, Jerome	Brown University
Karniadakis, George	Brown University

We establish a novel theoretical connection between optimization problems arising in scientific machine learning (SciML) and generalized Hopf formulas, which represent the solution to certain Hamilton-Jacobi partial differential equations (HJ PDEs). Namely, we show that solving certain regularized learning problems is equivalent to solving an optimal control problem and its associated HJ PDE. We leverage these connections to design new efficient training approaches for SciML based on existing HJ PDE solvers. As a first exploration of these connections, we consider linear regression problems and develop a new Riccati-based methodology, which demonstrates potential computational and memory advantages over conventional learning approaches.

11:20-11:45 WeAM_LR4.3

Approximations of Differential Games in Fractional Order Systems Governed by Caputo Differential Equations (I)

Kaise, Hidehiro	Kumamoto University

We consider approximations of differential games in fractional order systems governed by Caputo differential equations. It is known that value functionals of past state trajectories are characterized as viscosity solutions of the Isaacs partial differential equations (PDEs) defined on that trajectory space. Motivated by the Euler approximation method of Caputo differential equations, we propose discrete-time approximations of the differential games. Using stability-type arguments of viscosity solutions with the generators of the path-dependent dynamic programming operators, we show that the discrete-time approximations converge to a viscosity solution of the Isaacs PDEs on the trajectory space as the size of the time-discretization goes to 0.

11:45-12:10 WeAM_LR4.4

Escape Rate Games (I)

Akian, Marianne — Inria and CMAP, Ecole Polytechnique
Gaubert, Stephane — INRIA
Marchesini, Loic — CMAP, Ecole Polytechnique and Inria

We consider a new class of repeated zero-sum games in which the payoff of one player is the escape rate of a dynamical system which evolves according to a nonexpansive nonlinear operator depending on the actions of both players. Considering order preserving finite dimensional linear operators over the positive cone endowed with Hilbert's projective (hemi-)metric, we recover the matrix multiplication games, introduced by Asarin et al., which generalize the joint spectral radius of sets of nonnegative matrices and arise in some population dynamics problems (growth maximization and minimization). We establish a two-player version of Mañé's lemma characterizing the value of the game in terms of a nonlinear eigenproblem. This generalizes to the two-player case the characterization of joint spectral radii in terms of extremals norms. This also allows us to show the existence of optimal strategies of both players.

12:10-12:35 WeAM_LR4.5

Local Upper and Lower Bounds for a Class of Constrained Optimal Control Problems (I)

Liu, Vincent — University of Melbourne
Dower, Peter M. — University of Melbourne
Manzie, Chris — The University of Melbourne

Although numerical schemes exist for approximating the value of an optimal control problem, the curse-of-dimensionality limits their application in practice. In this paper, super- and subsolutions of a Hamilton-Jacobi equation are used to characterise upper and lower bounds of a corresponding value function that hold locally over sublevel, superlevel, or 'thick' level sets of the bounding functions. In reachability analysis, these bounds may facilitate the tractable computation of inner and outer approximations of reachable sets. The value of Mayer problems for time-varying, continuous-time nonlinear systems with input constraints are considered.

WeAM_LR5 LR5

Mathematical Theory of Networks and Circuits (Regular Session)

Chair: Delvenne, Jean-Charles — UCLouvain
Co-Chair: Chaffey, Thomas Lawrence — University of Cambridge

10:30-10:55 WeAM_LR5.1

Analysis of a Nearly-Linear Time Laplacian Solver

Heneffe, Christophe — UCLouvain
Remacle, Jean-François — UCLouvain
Delvenne, Jean-Charles — UCLouvain

We implement and analyze the linear systems solver created by Koutis, Miller and Peng which allows to solve Lx = b, where L is the Laplacian of a weighted, undirected graph with n nodes and m edges, in almost-linear time O(mlogn). We obtain that the solver is close to theoretical performances, running in almost-linear time. However, it has a large hidden constant, which makes it noncompetitive against methods with higher asymptotic complexity in most test cases. When applied to solving discretized partial differential equations, we observe that The KMP solver is better than Conjugate Gradient.

10:55-11:20 WeAM_LR5.2

Optimal Topology for Minimal Laplacian Energy

Lu, Susie — Stanford OHS
Liu, Ji — Stony Brook University

This extended abstract characterizes the graphical properties of an optimal topology with minimal Laplacian energy under the constraint of fixed numbers of vertices and edges, and devises an algorithm to construct such connected optimal graphs.

11:20-11:45 WeAM_LR5.3

Verification of Compositional Frameworks in Coq

Collins, Pieter — Maastricht University
Bastiaan, Laarakker — Universiteit Van Amsterdam
Sindorf, Sacha — Universiteit Maastricht

In this paper we aim to verify in Coq basic properties of compositional behavioural frameworks for dynamic systems. We analyse systems by their external behaviour rather than a state space model, and use the parallel composition operator to build complex systems from simpler subsystems. It is important that the composition is well-defined and avoids undesirable behaviour such as deadlocks. To ensure the our framework is correct, we formulate and prove the results in the proof assistant Coq. We consider discrete-time deterministic systems and timed-event systems, with a view to eventually proving results on a framework for hybrid systems.

11:45-12:10 WeAM_LR5.4

Circuit Realizations of Equilibrium Neural Networks

Chaffey, Thomas Lawrence — University of Cambridge

It is shown that the port behavior of a resistor–diode network corresponds to the solution of a monotone deep equilibrium network (a neural network in the limit of infinite depth), giving a parsimonious construction of a neural network in analog hardware.

12:10-12:35 WeAM_LR5.5

Well-Posedness of Non-Autonomous Transport Equation on Metric Graphs

Budde, Christian — University of the Free State
Kramar Fijavz, Marjeta — University of Ljubljana

We consider transport processes on metric graphs with time-dependent velocities and show that, under continuity assumption of the velocity coefficients, the corresponding non-autonomous abstract Cauchy problem is well-posed by means of evolution families and evolution semigroups.

WeAM_LR6 LR6

Learning and Optimization in Stochastic Systems and Control (IV) (Invited Session)

Chair: Gruene, Lars — Univ of Bayreuth
Co-Chair: Worthmann, Karl — TU Ilmenau
Organizer: Gruene, Lars — Univ of Bayreuth
Organizer: Worthmann, Karl — TU Ilmenau

10:30-10:55 WeAM_LR6.1

Approximating Stochastic Koopman Operators (I)

Colbrook, Matthew — University of Cambridge
Li, Qin — University of Wisconsin-Madison
Raut, Ryan — Allen Institute
Townsend, Alex — Cornell

Koopman operators linearize nonlinear dynamics, making their spectral analysis crucial. Dynamic Mode Decomposition (DMD) is a popular method for this, but challenges arise due to the operator's infinite-dimensional action. These include spurious modes and verifying decompositions, especially in stochastic systems where Koopman operators assess observable expectations. Our approach incorporates variance to tackle these issues, using a DMD-like matrix to approximate residual and variance sums. This enables accurate spectral computation for stochastic Koopman operators and introduces variance-pseudospectra for statistical coherence. We validate with convergence results and practical examples, including neural recordings from mice, showcasing new insights beyond standard expectation-based dynamical models.

10:55-11:20 WeAM_LR6.2

Efficient Koopman-Based Modeling with Random Fourier Features (I)

Nüske, Feliks	Max Planck Institute for Dynamics of Complex Technical Systems
Klus, Stefan	Heriot-Watt University

We present an efficient approach to modeling dynamical systems with complex long-time behaviour by approximating the Koopman operator on reproducing kernel Hilbert spaces. To maintain computational efficiency, we employ low-rank approximation techniques based on random Fourier features (RFF). We present effective model validation techniques and illustrate the method's success using molecular dynamics simulation data.

11:20-11:45 WeAM_LR6.3

Error Bounds on Data-Driven Techniques for Learning Dynamics (I)

Philipp, Friedrich	Technische Universität Ilmenau
Schaller, Manuel	Technische Universität Ilmenau
Peitz, Sebastian	Paderborn University
Nüske, Feliks	Max Planck Institute for Dynamics of Complex Technical Systems
Worthmann, Karl	TU Ilmenau

We provide novel probabilistic error bounds on traditional and kernel-based Extended Dynamic Mode Decomposition based on both i.i.d. and ergodic sampling. In addition, we illuminate the RKHS invariance under the Koopman operator of stochastic systems.

11:45-12:10 WeAM_LR6.4

Data-Driven Network Analysis Using Local Delay Embeddings (I)

Klus, Stefan	Heriot-Watt University
Zhu, Hongyu	Raytheon Technologies Research Center

Data-driven methods for the identification of the governing equations of dynamical systems or the computation of reduced surrogate models play an increasingly important role in many application areas such as physics, chemistry, biology, and engineering. Given only measurement or observation data, data-driven modeling techniques allow us to gain important insights into the characteristic properties of a system, without requiring detailed mechanistic models. However, most methods assume that we have access to the full state of the system, which might be too restrictive. We show that it is possible to learn certain global dynamical features from local observations using delay embedding techniques, provided that the system satisfies a localizability condition -- a property that is closely related to the observability and controllability of linear time-invariant systems.

12:10-12:35 WeAM_LR6.5

Partial Observations, Coarse Graining and Equivariance in Koopman Operator Theory for Large-Scale Dynamical Systems (I)

Peitz, Sebastian	Paderborn University
Harder, Hans	Paderborn University
Nüske, Feliks	Max Planck Institute for Dynamics of Complex Technical Systems
Philipp, Friedrich	Technische Universität Ilmenau
Schaller, Manuel	Technische Universität Ilmenau
Worthmann, Karl	TU Ilmenau

The Koopman operator has become an essential tool for data-driven analysis, prediction and control of complex systems, the main reason being the enormous potential of identifying linear function space representations of nonlinear dynamics from measurements. Until now, the situation where for large-scale systems, we (i) only have access to partial observations (i.e., measurements, as is very common for experimental data) or (ii) deliberately perform coarse graining (for efficiency reasons) has not been treated to its full extent. In this paper, we address the pitfall associated with this situation, that the classical EDMD algorithm does not automatically provide a Koopman operator approximation for the underlying system if we do not carefully select the number of observables. Moreover, we show that symmetries in the system dynamics can be carried over to the Koopman operator, which allows us to massively increase the model efficiency. We also briefly draw a connection to domain decomposition techniques for partial differential equations and present numerical evidence using the Kuramoto--Sivashinsky equation.

ThP_LMH Lady Mitchell Hall

About Probability in the Continuum (Plenary Session)

Chair: Smith, Malcolm C.	University of Cambridge
Co-Chair: Bonnabel, Silvere	Mines ParisTech

09:00-10:00 ThP_LMH.1

Plenary: About Probability in the Continuum

Werner, Wendelin	University of Cambridge

ThAM_LH Little Hall

Theory of Control Architectures (Invited Session)

Chair: Matni, Nikolai	University of Pennsylvania
Co-Chair: Doyle, John C.	California Inst. of Tech
Organizer: Matni, Nikolai	University of Pennsylvania
Organizer: Doyle, John C.	California Inst. of Tech

10:30-10:55 ThAM_LH.1

Towards a Theory of Control Architecture (I)

Doyle, John C.	California Inst. of Tech
Ames, Aaron	Caltech
Matni, Nikolai	University of Pennsylvania

We propose a framework for quantitatively reasoning about control architectures that highlights the importance of layered control architectures. Our approach takes an overall synthesis problem and decomposes it into tractable subproblems via suitable relaxations and approximations, with each subproblem assigned to a layer.

10:55-11:20 ThAM_LH.2

Augmented Lagrangian Methods As Layered Control Architectures (I)

Srikanthan, Anusha	University of Pennsylvania
Kumar, Vijay	University of Pennsylvania
Matni, Nikolai	University of Pennsylvania

For optimal control problems that involve planning and following a trajectory, trajectory generators combined with two degree of freedom (2DOF) controllers are a ubiquitously used control architecture that decomposes the problem into a trajectory generation layer and a feedback control layer. However, despite the broad use and practical success of this layered control architecture, it remains a design choice that must be imposed emph{a priori} on the control policy. To address this gap, this paper seeks to initiate a principled study of the design of layered control architectures, with an initial focus on the 2DOF controller. We show that applying the Alternating Direction Method of Multipliers (ADMM) algorithm to solve a strategically rewritten optimal control problem results in solutions that are naturally layered, and composed of a trajectory generation layer and a feedback control layer. Furthermore, these layers are coupled via Lagrange multipliers that ensure dynamic feasibility of the planned trajectory. We instantiate this framework in the context of deterministic and stochastic linear optimal control problems, and show how our approach automatically yields a feedforward/feedback-based control policy that exactly solves the original problem.

11:20-11:45	ThAM_LH.3

How to Talk to Your Robot: Layering Language and Control for Robotic Skills (I)

Ismail, Seif	ETH
Li, Siqi	California Institute of Technology
Zurbrügg, René	ETH Zürich
Amo Alonso, Carmen	California Institute of Technology

The impressive capabilities of Large Language Models (LLMs) have led to various efforts to perform robotic control via natural language commands. The goal is for the motor- control task to be performed accurately, efficiently and safely, while also enjoying the flexibility imparted by LLMs to design and adjust the task through natural language. In this work, we demonstrate how a careful layering of an LLM in combination with a Model Predictive Control (MPC) (Rawlings et al. (2017)) formulation allows for accurate, safe, and flexible robotic control via natural language. As a proof of concept, we conduct extensive experiments in simulation and hardware for a robotic, demonstrating that our proposed architecture successfully executes complex tasks while adhering to safety constraints. The approach presented can be used for different platforms by simply modifying the low-level controller.

11:45-12:10	ThAM_LH.4

Learning Pipeline Architectures for Identification and Control (I)

Anderson, James	Columbia University

We consider two standard learning problems in control: identifying a model from data, i.e., system identification, and model-free control via policy gradient methods. Both problems are well studied and in the LTI and LQR problem setups have well known sample complexity bounds. In this talk we consider a collaborative learning setup where we have two conflicting goals: agents are allowed to collaborate by sharing models learnt from their local data with the objective of producing an aggregate model that performs well for each client. However, we would also like the models to allow for downstream personalization. Thus we need to generalize with an eye on personalization. This talk will highlight various collaboration and communication scenarios for which we have been able to pinpoint the sample complexity benefits/hindrances achieved through collaboration.

12:10-12:35	ThAM_LH.5

Compositional Design of Autonomous Systems: From Hardware Selection to Decision Making (I)

Zardini, Gioele	Massachusetts Institute of Technology

When designing autonomous systems, we need to consider multiple trade-offs at various abstraction levels, and choices of single (hardware and software) components need to be studied jointly. For instance, the design of future mobility solutions (e.g., autonomous vehicles) and the design of the mobility systems they enable are closely coupled. Indeed, knowledge about the intended service of novel mobility solutions would impact their design and deployment process, whilst insights about their technological development could significantly affect transportation policies.

Co-designing autonomous systems is a complex task for at least two reasons. First, the co-design of interconnected systems (e.g., networks of cyber-physical systems) involves the simultaneous choice of components arising from heterogeneous fields, while satisfying systemic constraints and accounting for multiple objectives. Second, components are connected via interactions between different stakeholders. I will present a framework to co-design such systems, leveraging a monotone theory of co-design. The framework will be instantiated in applications in mobility and autonomy. Through various case studies, I will show how the proposed approaches allow one to efficiently answer heterogeneous questions, unifying different modeling techniques and promoting interdisciplinarity, modularity, and compositionality. I will then discuss open challenges for compositional systems design optimization.

ThAM_LR1	LR1
Algebraic Coding Theory and Applications (I) (Invited Session)	
Chair: Lieb, Julia	University of Zurich
Co-Chair: Vela, Carlos	University of Aveiro
Organizer: Lieb, Julia	University of Zurich
Organizer: Vela, Carlos	University of Aveiro

10:30-10:55	ThAM_LR1.1

K-Spread Codes with an Orbital Structure (I)

Climent, Joan-Josep	University of Alicante
Requena, Verónica	University of Alicante
Soler-Escrivà, Xaro	University of Alacant

In this talk we present a way of constructing spreads of Fq^n. They will arise as orbits under the action of an Abelian non-cyclic group. First we construct a family of orbit codes of maximum distance using this group and then we complete each of these codes to achieve a spread of the whole space having an orbital structure.

10:55-11:20	ThAM_LR1.2

Pseudo-MDP Convolutional Codes (I)

Abreu, Zita	University of Aveiro
Lieb, Julia	University of Zurich
Pinto, Raquel	University of Aveiro
Simões, Rita	University of Aveiro

We are going to consider a new construction of convolutional codes and analyze their erasure correction capability. MDP convolutional codes have optimal correction capacity if decoding is done sequentially. However, there are not many constructions of MDP convolutional codes and the existing ones require a large finite field. We will construct new codes by considering an encoder of an MDP convolutional code and repeating a (matrix) coefficient of the encoder. The resulting code, which we call Pseudo-MDP, will be defined over the same field. Although it may not be MDP, it will have a better erasure correction capacity than the original code.

11:20-11:45	ThAM_LR1.3

Convolutional Erasure Codes with Simplex Locality (I)

Kuijper, Margreta	The Universityof Melbourne
Lieb, Julia	University of Zurich
Napp, Diego	University of Alicante

This work provides a continuation of earlier work on simplex distributed storage block codes over extension fields, published at MTNS 2014. We first look at easy repair properties of unit memory tailbiting convolutional codes. We next construct a convolutional code with simplex properties. We explore its easy repair properties for the distributed storage setting, as well as the usage of a sliding window decoder to do the actual easy repair.

11:45-12:10	ThAM_LR1.4

A Repair Scheme of One Erasure for Reed-Muller Codes (I)

López, Hiram H.	Virginia Tech
Matthews, Gretchen L.	Virginia Tech
Valvo, Daniel	Virginia Tech

A distributed storage system stores data over multiple storage nodes. The main goal of an exact repair scheme is to recover the data from a failed node by accessing and downloading information from the rest of the nodes. In a groundbreaking paper, Guruswami and Wootters (2017) developed an exact repair scheme using Reed Solomon codes. In these notes, we extend the repair scheme to the family of Reed-Muller codes.

ThAM_LR2	LR2
Optimization in Operator Variables (I) (Invited Session)	
Chair: Klep, Igor	University of Ljubljana
Co-Chair: Volcic, Jurij	Drexel University
Organizer: Magron, Victor	CNRS LAAS
Organizer: Volcic, Jurij	Drexel University

10:30-10:55	ThAM_LR2.1

SDP Bounds on Quantum Codes (I)

Anglès Munné, Gerard	Uniwersytet Jagielloński
Nemec, Andrew	Duke University
Huber, Felix	University of Bordeaux

This paper provides a semidefinite programming hierarchy based on state polynomial optimization to determine the existence of quantum codes with given parameters. The hierarchy is complete, in the sense that if a $(!(n,K,delta)!)_2$ code does not exist, some level of the hierarchy is infeasible. It is not restricted to stabilizer codes and thus applicable generally. While it is formally dimension-free, we restrict it to qubit codes by making use of quasi-Clifford algebras. From an intermediate level, a quantum Lov'asz bound for self-dual quantum codes is derived. A symmetry reduction of a minor variation of this Lov'asz bound then recovers the quantum Delsarte bound. A second symmetry reduction making use of the Terwilliger algebra leads to semidefinite programming bounds of size $O(n^4)$.

10:55-11:20	ThAM_LR2.2

First-Order Optimality Conditions for Non-Commutative Optimization Problems (I)

Araújo, Mateus	University of Valladolid
Klep, Igor	University of Ljubljana
Garner, Andrew J. P.	IQOQI Vienna, Austrian Academy of Sciences
Vértesi, Tamás	MTA Atommagkutató Intézet (MTA Atomki)
Navascués, Miguel	Austrian Academy of Sciences

11:20-11:45	ThAM_LR2.3

Semidefinite Representability of the Set of Quantum Correlations in the Simplest Bell Scenario (I)

Farkas, Máté	University of York

We study the set of correlations that can be achieved in quantum theory in the simplest Bell scenario---with two inputs and outputs per party---where qubits suffice to obtain extremal correlations. This qubit reduction allows us to cast the problem of maximising a Bell inequality as a polynomial optimisation problem. Using results from polynomial optimisation, we show that for every Bell inequality there exists a finite semidefinite programme that finds its maximum. Furthermore, using a connection to entanglement theory, we show that there exists a single semidefinite programme that finds the maximum of an arbitrary Bell inequality. We further discuss the (distinct) question of the semidefinite representability of the set of quantum correlations in the simplest Bell scenario.

11:45-12:10	ThAM_LR2.4

Solving Moment and Polynomial Optimization Problems on Sobolev Spaces (I)

Henrion, Didier	LAAS-CNRS, Univ. Toulouse
Rudi, Alessandro	Inria Paris

Using standard tools of harmonic analysis, we state and solve the problem of moments for positive measures supported on the unit ball of a Sobolev space of multivariate periodic trigonometric functions. We describe outer and inner semidefinite approximations of the cone of Sobolev moments. They are the basic components of an infinite-dimensional moment-sums of squares hierarchy, allowing to solve numerically non-convex polynomial optimization problems on infinite-dimensional Sobolev spaces, with global convergence guarantees.

ThAM_LR3	LR3
Optimal Transport: Theory and Applications in Networks and Systems (I) (Invited Session)	
Chair: Chen, Yongxin	Georgia Institute of Technology
Co-Chair: Haasler, Isabel	EPFL
Organizer: Chen, Yongxin	Georgia Institute of Technology
Organizer: Georgiou, Tryphon T.	Univ. of California, Irvine
Organizer: Haasler, Isabel	EPFL
Organizer: Karlsson, Johan	Royal Institute of Technology (KTH)
Organizer: Ringh, Axel	Chalmers University of Technology and University of Gothenburg

10:30-10:55	ThAM_LR3.1

Interconnection of Representation Learning and Control of Ensemble Systems by Time-Dependent Optimal Transport (I)

Li, Jr-Shin	Washington University in St. Louis
Shih, Yi-Hsuan	Washington University in St Louis
Zhang, Wei	Washington University in St. Louis

Optimal transport (OT) has gained widespread recognition across various fields, from economics and fluid mechanics, lately, to machine learning. However, its connection with dynamical systems and control and potential to drive applications in these areas has not been fully realized. To fill this gap, we propose an OT-based ensemble control framework, which enables the modeling of the OT process as an ensemble control system and, conversely, the solution to ensemble control problems using OT techniques. Our development is rooted in the concept of treating OT as a time-dependent process by utilizing displacement interpolation. Through this interpretation, we develop a moment kernelization approach to model the OT process as an ensemble system using moment representations. This framework naturally gives rise to a systematic representation learning approach to modeling OT with control systems.

10:55-11:20	ThAM_LR3.2

Space-Time Bridge-Diffusion (I)

Behjoo, Hamidreza	University of Arizona
Chertkov, Michael	University of Arizona

In this study, we introduce a novel method for generating i.i.d. synthetic samples from high-dimensional real-valued probability distributions, defined by Ground Truth (GT) samples. Our approach integrates space-time mixing strategies across temporal and spatial dimensions. The methodology involves three interrelated stochastic processes: (a) linear processes with space-time mixing yielding Gaussian conditional densities, (b) their diffusion bridge analogs conditioned on initial and final states, and (c) nonlinear stochastic processes refined via score-matching techniques. The training regime fine-tunes both nonlinear and potentially linear models to align with GT data. We validate our space-time diffusion bridge approach through numerical experiments.

11:20-11:45	ThAM_LR3.3

Algorithms for Gromov-Wasserstein Barycenters (I)

Beier, Florian	Technische Universität Berlin
Beinert, Robert	Technische Universität Berlin

Steidl, Gabriele — Technische Universität Berlin

Gromov–Wasserstein (GW) transport allows for the matching of objects based on the preservation of their internal geometry, which does not require an embedding in a canonical ambient space. Hence, GW barycenters are perfectly suited for the joint embedding-free matching and interpolation of multiple objects. However, the high computational costs of existing algorithms still makes it challenging when considering larger inputs such as three-dimensional surfaces. In this short note, we consider GW barycenters and their relation to multi-marginal GW transport. These multi-marginal formulations spark two numerical approaches for computing these barycenters which we briefly discuss.

11:45-12:10 — ThAM_LR3.4

Graph-Structured Unbalanced Optimal Transport for Density Control Problems (I)

Ringh, Axel — Chalmers University of Technology and University of Gothenburg
Haasler, Isabel — EPFL
Chen, Yongxin — Georgia Institute of Technology
Karlsson, Johan — Royal Institute of Technology (KTH)

In this work we develop a numerical method for solving a type of convex graph-structured tensor optimization problems. This type of problems can be seen as a generalization of multi-marginal optimal transport problems with graph-structured costs, and appear for instance in unbalanced optimal transport, and nonlinear density control problems, such as multi-species potential mean field games. We develop an efficient algorithm for solving these types of problems, and showcase the flexibility of our method on a density control problem.

ThAM_LR4 — LR4

Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations (II) (Invited Session)

Chair: Dressler, Mareike — University of New South Wales (UNSW Sydney)
Co-Chair: Augier, Nicolas — LAAS, CNRS
Organizer: Vinnikov, Victor — Ben Gurion University of the Negev
Organizer: Henrion, Didier — LAAS-CNRS, Univ. Toulouse
Organizer: Infusino, Maria — University of Cagliari
Organizer: Kuhlmann, Salma — University of Konstanz

10:30-10:55 — ThAM_LR4.1

On the Symmetry Reduction of Optimal Control Problems (I)

Augier, Nicolas — LAAS, CNRS

We address the problem of symmetry reduction of optimal control problems under the action of a finite group from a measure relaxation viewpoint. We propose a method based on the moment-SOS aka Lasserre hierarchy which allows one to significantly reduce the computation time and memory requirements compared to the case without symmetry reduction. We show that the recovery of optimal trajectories boils down to solving a symmetric parametric polynomial system. Then we illustrate our method on the time-optimal inversion of qubits.

10:55-11:20 — ThAM_LR4.2

Degree Bounds for Putinar's Positivstellensatz on the Hypercube (I)

Baldi, Lorenzo — MPI Leipzig
Slot, Lucas — ETH Zurich

The Positivstellensätze of Putinar and Schmüdgen show that any polynomial f positive on a compact semialgebraic set can be represented using sums of squares. Recently, there has been large interest in proving effective versions of these results, namely to show bounds on the required degree of the sums of squares in such representations. These effective Positivstellensätze have direct implications for the convergence rate of the celebrated moment-SOS hierarchy in polynomial optimization. In this work, we restrict to the fundamental case of the hypercube. We show an upper degree bound for Putinar-type representations on the cube of the order O(fmax/fmin), where fmax, fmin are the maximum and minimum of f on the cube, respectively. Previously, specialized results of this kind were available only for Schmüdgen-type representations and not for Putinar-type ones. Complementing this upper degree bound, we show a lower degree bound. This is the first lower bound for Putinar-type representations on a semialgebraic set with nonempty interior described by a standard set of inequalities.

11:20-11:45 — ThAM_LR4.3

The Operator Moment Problem in Finite Sets of R (I)

Curto, Raul — University of Iowa
Ech-charyfy, Abderrazzak — Mohammed V University in Rabat
El Azhar, H. — Chouaib Doukkali University
Zerouali, El Hassan — Mohammed V University in Rabat

We study the connections between operator moment sequences ${mathcal T}=displaystyle(T_n)_{ninmathbf{N}}$ of self-adjoint operators on a complex Hilbert space $mathcal{H}$ and the local moment sequences $langle{mathcal T}x,xrangle = (langle T_nx,xrangle)_{ninmathbf{N}}$ for arbitrary $xin mathcal{H}$. We provide necessary and sufficient conditions for solving the operator moment problem on $mathbf{R}$, and we show that these criteria are automatically valid on compact subsets of $mathbf{R}$. Applications of the compact case are used to study subnormal operator weighted shifts. A Stampfli-type propagation theorem for subnormal operator weighted shifts is also established. In addition, we discuss the validity of Tchakaloff's Theorem for operator moment sequences with compact support. In the case of a recursively generated sequence of self-adjoint operators, necessary and sufficient conditions for an affirmative answer to the operator recursive moment problem are provided, and the support of the associated representing operator-valued measure is described.

11:45-12:10 — ThAM_LR4.4

Optimization of Analytic Functions Over Compact Domains: From Convergence Results to Practical Computations (I)

Safey El Din, Mohab — Sorbonne Univ
Scholten, Georgy — Sorbonne Univ
Trelat, Emmanuel — University Pierre Et Marie Curie (Paris 6)

Let $Cscr$ be a compact subset of RR^{n} and $f: Cscr to RR$ be a emph{real analytic} function assumed to be a Morse function. We consider the problem of computing emph{all} local minimizers. Note that, under our assumptions, there are finitely many such points.

We use the classical model of Turing machines. Since, not all real numbers can be represented in this model (an infinite amount of bits may required to represent them), we assume that the function f is given by an emph{evaluation program} $Gamma$ which takes as input rational points in $Cscrcap QQ^{n}$ considering both the framework where this evaluation program is emph{exact} -- if the image of f can be represented with a finite amount of bits -- or emph{noisy} -- in that case, we assume that the evaluation function takes an additional parameter eta and returns a rational point at distance at most eta to the real point it should compute in the image of f.

Under these assumptions, we design an algorithm which takes as input $Gamma$ (and eta in the noisy model) and a numerical accuracy parameter $epsilon$. With some additional assumptions of probabilistic nature, it outputs finitely many rational points of $Cscrcap QQ^{n}$ such that union of the balls of radius $varepsilon$ centered at these points contains the set of all local minimizers of the function f.

ThAM_LR5 LR5

Riemannian Methods in Optimization and Systems Theory (I) (Invited Session)

Chair: Absil, Pierre-Antoine — UCLouvain
Co-Chair: Olikier, Guillaume — Inria Centre at Université Côte D'Azur
Organizer: Absil, Pierre-Antoine — UCLouvain

10:30-10:55 ThAM_LR5.1

Bounds on Geodesic Distances on the Stiefel Manifold (I)

Mataigne, Simon — UCLouvain
Absil, Pierre-Antoine — UCLouvain
Miolane, Nina — UCSB

We give bounds on the geodesic distances on the Stiefel manifold, derived from new geometric insights. These geodesic distances are induced by a previously proposed one-parameter family of Riemannian metrics, which contains the well-known Euclidean and canonical metrics. We give the best Lipschitz constants between the distances induced by any two members of the family of metrics. Then, we give a lower and an upper bound on the geodesic distance by the Frobenius distance. These bounds aim at improving the performance of minimal geodesic computation algorithms and contribute to advancing the understanding of geodesic distances on the Stiefel manifold and their practical applications.

10:55-11:20 ThAM_LR5.2

Riemannian Optimization for Matrix Nearness Problems (I)

Noferini, Vanni — Aalto University

We give an overview of two recent success stories in solving matrix nearness problems by means of tools in Riemannian optimization, and in particular the Manopt software package. We present performance profiles, obtained utilizing statistical experiments, for these new algorithms, described in (Noferini and Poloni, 2021) and in (Dopico et al., 2023) and aimed at computing distances to Hurwitz stability and to pencil singularity, respectively. Experimentally, the new algorithms displayed superior accuracy and computational efficiency, outperforming competitors.

11:20-11:45 ThAM_LR5.3

Characterization of Optimization Problems That Are Solvable Iteratively with Linear Convergence (I)

Alimisis, Foivos — University of Geneva

In this work, we state a general conjecture on the solvability of optimization problems via algorithms with linear convergence guarantees. We make a first step towards examining its correctness by fully characterizing the problems that are solvable via Riemannian gradient descent with linear convergence.

11:45-12:10 ThAM_LR5.4

Retractions on Closed Sets (I)

Olikier, Guillaume — Inria Centre at Université Côte D'Azur

On a manifold or a closed subset of a Euclidean vector space, a retraction enables to move in the direction of a tangent vector while staying on the set. Retractions are a versatile tool to perform computational tasks such as optimization, interpolation, and numerical integration. This paper studies two known definitions of retraction on a closed subset of a Euclidean vector space, one being weaker than the other. Specifically, it shows that, in the context of constrained optimization, the weaker definition should be preferred as it inherits the main property of the other while being less restrictive.

ThAM_LR6 LR6

Learning and Optimization in Stochastic Systems and Control (V) (Invited Session)

Chair: Gruene, Lars — Univ of Bayreuth
Co-Chair: Worthmann, Karl — TU Ilmenau
Organizer: Gruene, Lars — Univ of Bayreuth
Organizer: Worthmann, Karl — TU Ilmenau

10:30-10:55 ThAM_LR6.1

Safe, Stable, and Explainable Reinforcement Learning (I)

Zanon, Mario — IMT Institute for Advanced Studies Lucca
Gros, Sebastien — NTNU

Reinforcement Learning (RL) is a very successful data-driven approach to optimal control, which, however, typically struggles to provide both explainability and strong guarantees on the behavior of the resulting control scheme, e.g., safety and stability. In contrast, Model Predictive Control (MPC) is a well-established tool for the closed-loop optimal control of complex systems subject to constraints. MPC benefits from a rich theory that allows one to provide strong guarantees about closed-loop behavior. Because of model inaccuracy, however, MPC can fail to deliver satisfactory closed-loop performance. The use of MPC as a function approximator within RL paves the way toward safe and explainable RL but also requires the development of a new theory. In this paper, we will mention some recent theoretical results that make it possible to introduce safety and stability guarantees in RL by using MPC as function approximator. Furthermore, we will discuss further open questions that are the subject of ongoing research.

10:55-11:20 ThAM_LR6.2

Multi-Level Optimal Control with Neural Surrogate Models (I)

Kalise, Dante — Imperial College London
Loayza-Romero, Estefanía — Imperial College London
Morris, Kirsten A. — Univ. of Waterloo
Zhong, Zhengang — Imperial College London

Optimal actuator and control design is studied as a multi-level optimisation problem, where the actuator design is evaluated based on the performance of the associated optimal closed loop. The evaluation of the optimal closed loop for a given actuator realisation is a computationally demanding task, for which the use of a neural network surrogate is proposed. The use of neural network surrogates to replace the lower level of the optimisation hierarchy enables the use of fast gradient-based and gradient-free consensus-based optimisation methods to determine the optimal actuator design. The effectiveness of the proposed surrogate models and optimisation methods is assessed in a test related to optimal actuator location for heat control.

11:20-11:45 ThAM_LR6.3

Dissipativity and Turnpike in Stochastic Optimal Control (I)

Schießl, Jonas — University of Bayreuth
Ou, Ruchuan — TU Dortmund University
Baumann, Michael Heinrich — Universität Bayreuth
Faulwasser, Timm — Hamburg University of Technology
Gruene, Lars — Univ of Bayreuth

Analyzing optimal control problems in deterministic settings has benefitted from the concepts of turnpike and dissipativity. We extend the classic dissipativity notion of Jan C. Willems to stochastic systems, introducing two distinct dissipativity notions based on stationarity concepts in distribution and random variables. We explain the links between these notions and explore their connections to various forms of stochastic turnpike properties. The proposed turnpike properties range from a formulation for random variables via turnpike phenomena in probability and in probability measures to a turnpike property for single moments. Finally, we introduce the generalized linear-quadratic stochastic optimal control problem as an example for which an explicit storage function can be constructed and illustrate our analytical findings by numerical simulations.

11:45-12:10	ThAM_LR6.4

Risk Bounded Nonlinear Robot Motion Planning with Integrated Perception & Control (I)

Renganathan, Venkatraman	Lund University
Safaoui, Sleiman	The University of Texas at Dallas, USA
M Kothari, Aadi	Bastian Solutions
Gravell, Benjamin	University of Texas at Dallas
Shames, Iman	Australian National University
Summers, Tyler	University of Texas at Dallas

Robust autonomy stacks require tight integration of perception, motion planning, and control layers, but these layers often inadequately incorporate inherent perception and prediction uncertainties. Robots with nonlinear dynamics and complex sensing modalities operating in an uncertain environment demand more careful consideration of how uncertainties propagate across stack layers. We propose a framework to integrate perception, motion planning, and control by explicitly incorporating perception and prediction uncertainties into planning so that risks of constraint violation can be mitigated. Specifically, we use a nonlinear model predictive control based steering law coupled with a decorrelation scheme based Unscented Kalman Filter for state and environment estimation to propagate the robot state and environment uncertainties. Subsequently, we use Distributionally Robust (DR) risk constraints to limit the risk in the presence of these uncertainties. Finally, we present a layered autonomy stack consisting of a nonlinear steering-based DR motion planning module and a reference trajectory tracking module. Our numerical experiments with nonlinear robot models and an urban driving simulator show the effectiveness of our proposed approaches.

12:10-12:35	ThAM_LR6.5

Stochastic Optimal Control with Chance Constraints in Complex Systems (I)

Lux-Gottschalk, Kerstin	Eindhoven University of Technology
Goettlich, Simone	University of Mannheim
Kolb, Oliver	University of Mannheim

We consider the optimal control of the inflow into a supply system given an uncertain demand stream. Thereby, the supply system is modeled by a hyperbolic partial differential equation (PDE), more precisely a hyperbolic balance law. A stochastic differential equation is used to describe the uncertain demand. We add chance constraints to enhance supply reliability. We will present the generic procedure from Göttlich et al. (2021) how to come up with a deterministic reformulation of this stochastic optimal control problem. We use well-established deterministic PDE-constrained optimization techniques. We will illustrate our procedure for an energy supply control problem given an uncertain consumer demand.

ThSP_LMH	Lady Mitchell Hall

Semi-Plenary: Towards Data-Driven Nonlinear Filtering Algorithms (Plenary Session)

Chair: Ringh, Axel	Chalmers University of Technology and University of Gothenburg

14:00-15:00	ThSP_LMH.1

Semi-Plenary: Towards Data-Driven Nonlinear Filtering Algorithms

Taghvaei, Amirhossein	University of Washington Seattle

ThSP_LH	Little Hall

Semi-Plenary: Nanoscale Control Theory (Plenary Session)

Chair: Vinnicombe, Glenn	Univ. of Cambridge
Co-Chair: Petersen, Ian R	The Australian National University

14:00-15:00	ThSP_LH.1

Semi-Plenary: Nanoscale Control Theory

Delvenne, Jean-Charles	UCLouvain

ThSP_LR3	LR3

Semi-Plenary: Infinite Dimensional Analysis, Hida White Noise Space and Applications to Linear Systems with Random Coefficients (Plenary Session)

Chair: ter Horst, Sanne	North West University
Co-Chair: Dirr, Gunther	University of Wurzburg

14:00-15:00	ThSP_LR3.1

Semi-Plenary: Infinite Dimensional Analysis, Hida White Noise Space and Applications to Linear Systems with Random Coefficients

Alpay, Daniel	Faculty of Mathematics, Physics, and Computation

ThPM_LR1	LR1

Algebraic Coding Theory and Applications (II) (Invited Session)

Chair: Lieb, Julia	University of Zurich
Co-Chair: Vela, Carlos	University of Aveiro
Organizer: Lieb, Julia	University of Zurich
Organizer: Vela, Carlos	University of Aveiro

15:30-15:55	ThPM_LR1.1

Bounding the Sum of mu-Invariants on Pair Symbol Weights Over Some Irreducible Codes (I)

Can, Mahir Bilen	Tulane University
Ozbudak, Ferruh	Sabanci University

Let ${mathbb F}_q$ be a finite field with $q equiv 3 ; {rm mod} ; 4$. Let w be a primitive element of ${mathbb F}_{q^4}^*$ and let $mathcal{C}(w)$ be the irreducible cyclic code of length $(q^4-1)/(q-1)$ of dimension 4 defined by w. The symbol-pair weight enumerator of $mathcal{C}(w)$ is determined exactly by the invariant $mu(w)$ introduced in cite{ZSO}. The determination of good upper and lower bounds on this invariant remains an open problem. Let W be the set of all primitive elements of ${mathbb F}_{q^4}^*$. In this paper, by using algebraic and arithmetical methods, particularly those from the theory of algebraic curves over finite fields, we derive effective upper and lower bounds on $sum_{w in W} mu(w)$.

15:55-16:20	ThPM_LR1.2

An Approach to Constructing Convolutional Codes with Moderate Density and Quasi-Cyclic Structure (I)

Gassner, Niklas	University of Zurich
Mazumder, Abhinaba	University of Zurich
Rosenthal, Joachim	University of Zurich
Sutton, Abigail	University of Zürich

There exist in the literature two natural generalizations of low density parity check (LDPC) codes: 1) LDPC convolutional codes or sometimes also called spatially coupled LDPC codes which have shown to be able to reach Shannon capacity in a practical way. 2) Moderate density parity check (MDPC) codes which are linear codes possessing a parity check matrix whose row weight is not more than O(√n), still allowing efficient decoding with high probability. MDPC codes became a highly interesting class of block codes for the purpose of doing code- based cryptography. In this paper we study MDPC convolutional codes and some of their basic properties. At the end of the paper we explain how one can construct a new code-based cryptographic system. This new system can be seen as a convolutional version of the famous BIKE system currently evaluated for possible standardization by the National Institute for Standards and Technology (NIST).

16:20-16:45	ThPM_LR1.3

Flag Codes Generated from Constant Dimension Codes (I)

Navarro-Pérez, Miguel Ángel	University of Alacant
Soler-Escrivà, Xaro	University of Alacant

The aim of this note is to study under which conditions a family of constant dimension codes produces flag codes. In that situation, we realise that diferent flag codes can come from the same family of constant dimension codes. Then we give a method to obtain the largest flag code generated by a family of constant dimension codes and we determine in which cases such a family gives exactly one flag code. These notions will be crucial to properly connect the (semi)linear equivalence of flag codes with the (semi)linear equivalence of their projected codes. In addition, this study leads to new results concerning the automorphism group of certain families of flag codes.

ThPM_LR2 LR2

Optimization in Operator Variables(II) (Invited Session)

Chair: Helton, J. William	Univ. of California at San Diego
Co-Chair: Volcic, Jurij	Drexel University
Organizer: Magron, Victor	CNRS LAAS
Organizer: Volcic, Jurij	Drexel University

15:30-15:55 ThPM_LR2.1

Certified Algorithms for Equilibrium States of Local Quantum Hamiltonians (I)

Fawzi, Hamza	University of Cambridge
Fawzi, Omar	INRIA Lyon
Scalet, Samuel	University of Cambridge

15:55-16:20 ThPM_LR2.2

Relaxations and Exact Solutions to Quantum Max Cut Via the Algebraic Structure of Swap Operators (I)

Bene Watts, Adam	University of Waterloo
Chowdhury, Anirban	U Waterloo
Epperly, Aidan	UC Davis
Helton, J. William	Univ. of California at San Diego
Klep, Igor	University of Ljubljana

The Quantum Max Cut (QMC) problem has emerged as a test-problem for designing approximation algorithms for the local Hamiltonian problem in quantum complexity theory. In this talk we attack this problem using the algebraic structure of QMC, specifically the relationship between the quantum max cut Hamiltonian and the representation theory of the symmetric group. We give a new hierarchy of semidefinite programming (SDP) relaxations to QMC by extending non-commutative Sum of Squares optimization techniques. To prove correctness of this hierarchy, we exploit a finite presentation of the algebra generated by qubit swap operators. We also give a polynomial-time algorithm that exactly computes the maximum eigenvalue of the QMC Hamiltonian for graphs that can be “decomposed” as a signed combination of cliques.

16:20-16:45 ThPM_LR2.3

Computing Noise Robustness of Incompatible Quantum Measurements (I)

Bluhm, Andreas	Univ. Grenoble Alpes, CNRS, Grenoble INP

We present a connection between two very different problems: the joint measurability of measurements in quantum information theory and the inclusion problem for free spectrahedra. In particular, joint measurability of a tuple of dichotomic quantum measurements is equivalent to the inclusion of the matrix diamond inside a free spectrahedron defined by the measurements. The same correspondence holds for general quantum measurements and a different free spectrahedron, the matrix jewel. Moreover, the amount of noise necessary to render any tuple of measurements compatible corresponds to the inclusion constants for the respective free spectrahedron. In order to compute the inclusion constants of interest and thereby the noise robustness of measurement incompatibility, we put forward hierarchies of semidefinite programs and demonstrate their usefulness with some examples.

ThPM_LR3 LR3

Optimal Transport: Theory and Applications in Networks and Systems (II) (Invited Session)

Chair: Chen, Yongxin	Georgia Institute of Technology
Co-Chair: Haasler, Isabel	EPFL
Organizer: Chen, Yongxin	Georgia Institute of Technology
Organizer: Georgiou, Tryphon T.	Univ. of California, Irvine
Organizer: Haasler, Isabel	EPFL
Organizer: Karlsson, Johan	Royal Institute of Technology (KTH)
Organizer: Ringh, Axel	Chalmers University of Technology and University of Gothenburg

15:30-15:55 ThPM_LR3.1

Anisotropic Optimal Transport and an Application to Polycrystal Generation (I)

Bourne, David	Heriot-Watt University

The microstructure of metals and foams is often modelled using generalised Voronoi diagrams (Laguerre diagrams or anisotropic power diagrams). The challenge is to generate realistic geometric models with prescribed statistical properties, such as the distribution of the volumes and shapes of the cells. In this work we develop an efficient algorithm for generating anisotropic power diagrams with cells of prescribed volumes. Our approach uses semi-discrete optimal transport theory with an anisotropic cost, combined with a fast GPU implementation using the KeOps library.

15:55-16:20 ThPM_LR3.2

From Mass Transportation to Optimization in the Probability Space (I)

Lanzetti, Nicolas	ETH Zürich
Bolognani, Saverio	ETH Zurich
Dorfler, Florian	Swiss Federal Institute of Technology (ETH) Zurich

Many problems, from distributionally robust optimization to learning biological dynamics, can be cast as optimization problems in the probability space, whereby the decision variable is a probability measure. In this talk, we review some of these problems and present an optimization framework to attack them. Our tools are enabled by the theory of optimal transport and Wasserstein gradient flows, together with more classical calculus of variations. In particular, we present first-order necessary and sufficient conditions for optimality, and we make sense of expressions like ”set the (Wasserstein) gradient to zero” or ”(Wasserstein) gradients are aligned optimality”, widely used for optimization in Euclidean settings. We then demonstrate that these simple and interpretable optimality conditions can be directly leveraged to study many optimization problems in the probability space, both to derive quasi-closed-form solutions (e.g., in a distributionally robust control problem) and to devise numerical algorithms (e.g., in learning population dynamics). This extended abstract is based on our papers (Lanzetti, Bolognani, and Dörfler, 2022; Lanzetti, Terpin, and Dörfler, 2024).

16:20-16:45 ThPM_LR3.3

Group-Sparse Optimal Transport for Spatio-Temporal Estimation (I)

Haasler, Isabel	EPFL
Elvander, Filip	Aalto University

In this work, we consider modeling multi-sensor broad-band signals by means of the concept of a spatio-temporal spectrum, defined on the product space of spatial and frequency domains. In particular, we propose to track the evolution of time-vaying spatio-temporal spectra by means of a group-sparse optimal transport formulation. As we show, this allows us to fuse information across both separate time-instances and across frequency, leading to accurate estimates of the frequency content and location of broad-band signal sources

16:45-17:10	ThPM_LR3.4

Solution of the Probabilistic Lambert's Problem: Optimal Transport Approach (I)

Teter, Alexis	University of California Santa Cruz
Nodozi, Iman	University of California, Santa Cruz
Halder, Abhishek	Iowa State University

The deterministic variant of the Lambert's problem was posed by Lambert in the 18th century and its solution for conic trajectory has been derived by many, including Euler, Lambert, Lagrange, Laplace, Gauss and Legendre. The solution amounts to designing velocity control for steering a spacecraft from a given initial to a given terminal position subject to gravitational potential and flight time constraints. In recent years, a probabilistic variant of the Lambert's problem has received attention in the aerospace community where the endpoint position constraints are softened to endpoint joint probability distributions over the respective positions. Such probabilistic specifications account for the estimation errors, modeling uncertainties, etc. Building on a deterministic optimal control reformulation via analytical mechanics, we show that the probabilistic Lambert's problem is a generalized dynamic optimal mass transport problem where the gravitational potential plays the role of an additive state cost. This allows us to rigorously prove the existence-uniqueness of the solution for the probabilistic Lambert problem both with and without process noise. In the latter case, the problem and its solution correspond to a generalized Schrödinger bridge, much like how classical Schrödinger bridge can be seen as stochastic regularization of the optimal mass transport. We deduce the large deviation principle enjoyed by the Lambertian Schrödinger bridge. Leveraging these newfound connections, we design a computational algorithm to illustrate the nonparametric numerical solution of the probabilistic Lambert's problem.

ThPM_LR4 LR4

Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations (III) (Invited Session)

Chair: Curto, Raul	University of Iowa
Co-Chair: Schick, Moritz	University of Konstanz
Organizer: Vinnikov, Victor	Ben Gurion University of the Negev
Organizer: Henrion, Didier	LAAS-CNRS, Univ. Toulouse
Organizer: Infusino, Maria	University of Cagliari
Organizer: Kuhlmann, Salma	University of Konstanz

15:30-15:55	ThPM_LR4.1

The Lasserre Hierarchy for the Spherical Code Problem (I)

de Laat, David — TU Delft

We compute the second level of the Lasserre hierarchy for the equiangular lines problem with a fixed angle. We show how the resulting semidefinite programs can be analyzed asymptotically in the dimension, and use this to give new linear bounds on the maximum number of equiangular lines with common angle arccos(alpha). We then extend these techniques to compute the second level of the hierarchy for the kissing number problem, and use this to prove that the optimal kissing configuration in 4 dimensions (the D_4 root system) is unique.

15:55-16:20	ThPM_LR4.2

Polynomial Optimization for PDEs and Variational Problems (I)

Fantuzzi, Giovanni — FAU Erlangen-Nuernberg

Polynomial optimization has emerged as powerful tools for the analysis and control of ordinary differential equations. Inspired by this success, extensions to partial differential equations and variational problems have recently been sought. This extended abstract reviews some of these extensions, pointing out similarities and differences between various approaches. Remaining open questions are also identified.

16:20-16:45	ThPM_LR4.3

Quantitative Relation of Particular Subcones of the Cone of Positive Semidefinite Forms (I)

Schick, Moritz — University of Konstanz

Studying subcones of the convex cone of positive semidefinite, real forms in a given number of variables and a given degree is an important topic in Real Algebraic Geometry. The sums of squares cone (SOS) on the one hand, and the sums of nonnegative circuit forms (SONC) on the other hand are two subcones, which are studied extensively in the literature. In addition, the SOS+SONC cone consists of forms that decompose into a sum of an SOS and a SONC form. In this work, we highlight the set theoretic relation between two of the cones, respectively, and present different methods for showing that a given form is not contained in one of the cones.

16:45-17:10	ThPM_LR4.4

Upper Bound Hierarchies for Noncommutative Polynomial Optimization (I)

Klep, Igor	University of Ljubljana
Magron, Victor	CNRS LAAS
Massé, Gaël	Laas-CNRS
Volcic, Jurij	Drexel University

This work focuses on minimizing the eigenvalue of a noncommutative polynomial subject to a finite number of noncommutative polynomial inequality constraints. Based on the Helton-McCullough Positivstellensatz, the noncommutative analog of Lasserre's moment-sum of squares hierarchy provides a sequence of lower bounds converging to the minimal eigenvalue, under mild assumptions on the constraint set. Each lower bound can be obtained by solving a semidefinite program. We derive complementary converging hierarchies of upper bounds. They are noncommutative analogues of the upper bound hierarchies due to Lasserre for minimizing polynomials over compact sets. Each upper bound can be obtained by solving a generalized eigenvalue problem.

ThPM_LR5 LR5

Riemannian Methods in Optimization and Systems Theory (II) (Invited Session)

Chair: Absil, Pierre-Antoine	UCLouvain
Co-Chair: Olikier, Guillaume	Inria Centre at Université Côte D'Azur
Organizer: Absil, Pierre-Antoine	UCLouvain

15:30-15:55	ThPM_LR5.1

Accelerated Gradient Dynamics on Riemannian Manifolds (I)

Natu, Tejas	Saarland University
Castera, Camille	University of Tuebingen
Fadili, Jalal	CNRS-ENSICAEN-Univ. Caen
Ochs, Peter	Saarland University

15:55-16:20	ThPM_LR5.2

TF-IRKA Is Also a Riemannian Gradient Descent Method (I)

Mlinarić, Petar	Virginia Tech
Beattie, Christopher A.	Virginia Tech

Drmac, Zlatko	University of Zagreb
Gugercin, Serkan	Virginia Tech

In our earlier work Mlinarić et al. (2023), we showed that the interpolation-based iterative rational Krylov algorithm (IRKA) for H_2-optimal model reduction can be interpreted as a Riemannian gradient descent method with a fixed step size. Additionally, we found that the Petrov-Galerkin projection framework of IRKA can also be applied with variable step sizes. Transfer function IRKA (TF-IRKA) is a realization-independent, data-driven formulation of IRKA allowing to perform H_2-optimal approximation without needing a state-space formulation and projection. Here we present the equivalent Riemannian gradient descent formulation and interpretation of TF-IRKA and develop on the Loewner framework to support variable step sizes. We show that Riemannian gradient descent can be implemented using only transfer function samples as in the original TF-IRKA. The new Riemannian formulation with step size control guarantees stability of the reduced model. Numerical examples also show that smaller step sizes can mitigate some issues that may arise due to the ill-conditioning of Loewner matrices.

16:20-16:45	ThPM_LR5.3

Optimization on the Fixed-Rank Matrix Manifold: A Quotient Geometric View (I)

Dong, Shuyu	INRIA, Université Paris-Saclay
Gao, Bin	University of Münster
Huang, Wen	Xiamen University
Gallivan, Kyle	Florida State Univ

We study a type of Riemannian gradient descent (RGD) algorithm, designed through Riemannian preconditioning, for optimization on $mathcal{M}_k^{mtimes n}$---the set of $mtimes n$ real matrices with a fixed rank k. Our analysis is based on a quotient geometric view of $mrkk$: by identifying this set with the quotient manifold of a two-term product space $mathbb{R}^{mtimes k}timesmathbb{R}^{ntimes k}$ (matrices with full column ranks), we find an explicit form for the update rule of the RGD algorithm, which leads to a novel approach to analysing their convergence behavior in rank-constrained optimization. We then deduce some interesting properties that reflect how RGD distinguishes from other matrix factorization algorithms such as those based on the Euclidean geometry. We further show that this RGD algorithm is guaranteed to solve matrix sensing and matrix completion problems with linear convergence rate under the restricted positive definiteness property. Numerical experiments on matrix sensing and completion are provided to demonstrate these properties.

16:45-17:10	ThPM_LR5.4

Riemannian Optimization for Robotic Grasping (I)

Marlier, Norman	University of Liege
Louppe, Gilles	University of Liège
Bruls, Olivier	Univ of Liege

Riemannian methods are promising approaches to deal with rotations in robotic applications. In this work, we frame the grasping problem as a Bayesian inference of the posterior distribution given a success metric and an observation of the scene. We determine the grasp pose, which consists in the position and the orientation, by computing the maximum a posteriori with Riemannian gradient descent. While most previous works use Euler angles to represent the rotation part, our work focus on quaternions. We demonstrate the effectiveness of Riemannian optimization by illustrating that optimized trajectories pass through singularities when transformed into Euler angles and by performing a complex robotic grasping task with a high success rate.

ThPM_LR6	LR6
Partial Differential Algebraic Equations (Invited Session)	
Chair: Jacob, Birgit	Bergische Universität Wuppertal
Co-Chair: Morris, Kirsten A.	Univ. of Waterloo
Organizer: Jacob, Birgit	Bergische Universität Wuppertal
Organizer: Morris, Kirsten A.	Univ. of Waterloo

15:30-15:55	ThPM_LR6.1

Linear-Quadratic Optimal Control for Abstract Differential-Algebraic Equations (I)

Gernandt, Hannes	Wuppertal University
Reis, Timo	Technische Universität Ilmenau

In this paper, we extend a classical approach to linear quadratic (LQ) optimal control via Popov operators to abstract linear differential-algebraic equations (ADAEs) in Hilbert spaces. To ensure existence of solutions, we assume that the underlying differential-algebraic equation has index one in the pseudo-resolvent sense. This leads to the existence of a degenerate semigroup that can be used to define a Popov operator for our system. It is shown that under a suitable coercivity assumption for the Popov operator the optimal costs can be described by a bounded Riccati operator and that the optimal control input is of feedback form. Furthermore, we characterize exponential stability of ADAEs which is required to solve the infinite horizon LQ problem.

15:55-16:20	ThPM_LR6.2

On the Weierstraß Form of Infinite Dimensional Differential Algebraic Equations (I)

Erbay, Mehmet E.	University of Wuppertal
Jacob, Birgit	Bergische Universität Wuppertal
Morris, Kirsten A.	Univ. of Waterloo

The existence of a Weierstraß form and the solvability for infinite dimensional differential algebraic equations with a radiality index is studied. In the latter, one makes use of integrated semigroups to determine a subset on which solutions exist and are unique. This gained information is later used for a special case of systems, namely abstract dissipative Hamiltonian differential algebraic equations.

16:20-16:45	ThPM_LR6.3

Finite-Time Linear Quadratic Control for a Class of Partial Differential-Algebraic Equations (PDAEs) (I)

Alalabi, Ala'	University of Waterloo
Morris, Kirsten A.	Univ. of Waterloo

This talk addresses the linear-quadratic optimal control problem for a class of partial differential-algebraic equations. The main objective is to solve an optimization problem on a finite-time horizon. Using calculus of variations, we prove the existence of a unique optimal control that minimizes a quadratic criterion. The optimal control is shown to be in a feedback form. Additionally, a system consisting of a differential Riccati-like equation coupled with an algebraic equation is derived. This system yields the solution to the optimal control problem in feedback form. Numerical simulations are conducted to illustrate application of the theory.

FrAM_LH	Little Hall
Control across Scales (Invited Session)	
Chair: Sepulchre, Rodolphe J.	University of Cambridge
Co-Chair: Bamieh, Bassam	Univ. of California at Santa Barbara
Organizer: Sepulchre, Rodolphe J.	University of Cambridge

10:00-10:25	FrAM_LH.1

A Sparse Implementation of an LQ Regulator Using Back-Substitution (I)

Adlercreutz, Julia	Lund University
Hansson, Anders	Linkoping Univ
Pates, Richard	Lund University

The state-feedback solution of the Linear Quadratic Regulator problem is central to control theory, in both education and research, as well as in practice. Despite its many successes, a weakness of the LQ Regulator is that input-output map of the optimal controller is almost always dense, even when the problem data is sparse. This makes the control difficult to implement in large-scale applications, due to the resulting expensive and complex communication requirements. In this work we demonstrate by example that while this input-output map is dense, the same control law may be efficiently computed using sparsity exploiting tools from linear algebra. This opens the possibility for the sparse implementation of optimal LQ Regulators for some simple applications.

10:25-10:50 FrAM_LH.2

Multi-Scale Models of Physical Systems Originating from Model Reduction and Interconnection (I)

van der Schaft, Arjan J. — Univ. of Groningen

In this paper we consider model reduction by clustering, and show how this leads to spatial layered network and energy storage structures. Furthermore, we consider the Dirac structures that arise from multi-scale power-conserving interconnections in physical network systems and boundary control distributed-parameter systems.

10:50-11:15 FrAM_LH.3

Variation Bounding Systems (I)

Grussler, Christian — Technion - Israel Institute of Technology
Roth, Chaim — Technion -- Israel Institute of Technology

Bounding or diminishing the number of sign changes (variation) or local extrema in a signal is an intrinsic system property in, e.g., low-pass filtering or the over- and undershooting behaviour in the step-response of controlled systems. This work shows how to verify these properties for systems operators of linear time-invariant systems. In particular, by bounding the variation of input and output by an integer k, we will establish that variation bounding provides intermediates between externally positive systems ($k = 0$) and systems that are composed of simple first order lags ($k = infty$). Our results are exemplified for the observability/controllability operator, in which case we can provide new bounds for the number of sign changes in an impulse response and, thus, the number of local extrema in the step response.

11:15-11:40 FrAM_LH.4

Optimal Control on Positive Cones (I)

Pates, Richard — Lund University
Rantzer, Anders — Lund Univ

An optimal control problem on finite-dimensional positive cones is stated. Under a critical assumption on the cone, the corresponding Bellman equation is satisfied by a linear function, which can be computed by convex optimization. A separate theorem relates the assumption to existence of certain minimal elements in the dual cone. Two special cases are derived as examples. The first one, where the positive cone is a set to positive semi-definite matrices, reduces to standard linear quadratic control. The second one, where the positive cone is a polyhedron, reduces to a recent result on optimal control of positive systems.

11:40-12:05 FrAM_LH.5

Excitable Crawling (I)

Arbelaiz, Juncal — Princeton University
Franci, Alessio — University of Liege
Leonard, Naomi Ehrich — Princeton Univ
Sepulchre, Rodolphe J. — University of Cambridge
Bamieh, Bassam — Univ. of California at Santa Barbara

We propose and analyze the suitability of a spiking controller to engineer the locomotion of a soft robotic crawler. Inspired by the FitzHugh-Nagumo model of neural excitability, we design a bistable controller with an electrical flipflop circuit representation capable of generating spikes on-demand when coupled to the passive crawler mechanics. A proprioceptive sensory signal from the crawler mechanics turns bistability of the controller into a rhythmic spiking. The output voltage, in turn, activates the crawler's actuators to generate movement through peristaltic waves. We show through geometric analysis that this control strategy achieves endogenous crawling. The electro-mechanical sensorimotor interconnection provides embodied negative feedback regulation, facilitating minimal controller tuning for locomotion. Dimensional analysis provides insights on the characteristic scales in the crawler's mechanical and electrical dynamics, and how they determine the crawling gait. Adaptive control of the electrical scales to optimally match the mechanical scales can be envisioned to achieve further efficiency, as in homeostatic regulation of neuronal circuits. Our approach can scale up to multiple sensorimotor loops inspired by biological central pattern generators.

FrAM_LR1 LR1

Stochastic Modeling and Stochastic Systems Theory (Regular Session)

Chair: Bujorianu, Luminita-Manuela — University College London

10:00-10:25 FrAM_LR1.1

Stochastic Safety of Hybrid Markov Chains

Bujorianu, Luminita-Manuela — University College London
Wisniewski, Rafal — Aalborg University
Mazumdar, Abhijit — Automation & Control, Aalborg University,

In this paper we study the stochastic safety problem for a class of Markov chains generated by iterated function systems (IFS). These Markov chains represent a mathematical construct that describes the stochastic process of randomly iterating through a set of functions within the IFS. We propose a safety approach, which allows for the characterization of the reachability problem of the IFS through the lens of Markov chains.

10:25-10:50 FrAM_LR1.2

Steering Stochastic Flows on Graphs between Marginals in Space and Time

Eldesoukey, Asmaa — University of California, Irvine
Georgiou, Tryphon T. — Univ. of California, Irvine

We discuss a problem introduced by Erwin Schröndiger in 1931/1932, to reconcile a prior probability law with data on marginal distributions at two points in time. Schrödinger'sinsight was to seek the most likely “posterior law” that is consistent with the given marginals. Later known as Schrödinger's Bridge problem, the eponym problem bestowed inspiration on the theory of large deviations and various topics in uncertainty control. However, a compelling unstudied facet of this program has been to address uncertainty in space and time, modeling the effect of tasks being completed, instead of imposing hard specifications at fixed times, start and finish. We will present recent results that extend Schrödinger's paradigm in such a direction. Our work is developed in the context of Markov chains and random walks on graphs. Specifically, we examine the case where one marginal distribution represents the initial state occupation of a Markov chain, while other marginals represent first-arrival time distributions at absorbing states signifying completion of tasks. We establish that when the prior is Markov, a posterior Markov policy is optimal apropos to a likelihood cost that follows Schrödinger's dictum. We then provide a systematic method to obtain such optimal posterior law by suitably modifying prior transition probabilities. The below expository on which the presentation will be based follows Eldesoukey and Georgiou (2023).

AMS classification: 90B15, 60F10, 60J10

10:50-11:15 FrAM_LR1.3

Revisiting Stochastic Realization Theory Using Functional Itô Calculus

Veeravalli, Tanya	University of Illinois, Urbana-Champaign
Raginsky, Maxim	Univ of Illinois, Urbana-Champaign

This paper considers the problem of constructing finite-dimensional state space realizations for stochastic processes that can be represented as the outputs of a certain type of a causal system driven by a continuous semimartingale input process. The main assumption is that the output process is infinitely differentiable, where the notion of differentiability comes from the functional Itô calculus introduced by Dupire as a causal (nonanticipative) counterpart to Malliavin's stochastic calculus of variations. The proposed approach builds on the ideas of Hijab, who had considered the case of processes driven by a Brownian motion, and makes contact with the realization theory of deterministic systems based on formal power series and Chen-Fliess functional expansions.

11:15-11:40 FrAM_LR1.4

Convergence of the Heterogeneous Deffuant-Weisbuch Model: A Complete Proof and Some Extensions

Chen, Ge	Academy of Mathematics and Systems Science, Chinese Academy of S
Su, Wei	Beijing Jiaotong University
Mei, Wenjun	Peking University
Bullo, Francesco	Univ of California, Santa Barbara

The proof of convergence for the heterogeneous Deffuant-Weisbuch (DW) model in bounded-confidence opinion dynamics is a long-standing open problem. We resolve this problem completely, and generalize the convergence result to high-dimensional DW model with heterogeneous weighting factors.

11:40-12:05 FrAM_LR1.5

Stochasticity in Biomolecular Systems with Sequestration Mechanisms

Biswas, Ayan	University of Delaware
Nieto, Cesar	University of Delaware
Bokes, Pavol	Comenius University
Singh, Abhyudai	University of Delaware

We study how sequestration mechanisms, such as protein binding to decoy sites and the reversible formation of phase-separated condensates, alter the statistics of protein levels. To implement such a type of regulation, we consider simple birth-death processes in which protein molecules can reversibly switch between active (free-molecule) and inactive (sequestered) configurations with arbitrary concentration-dependent rates. When these transition rates depend only on the levels of the inactive protein, we show analytically that the steady-state distribution of the active protein level has Poisson statistics regardless of the details of the sequestration process. When transition rates depend on the active protein, the molecule copy number distribution is non-Poisson. We illustrate this deviation with the example of an enzyme-driven post-translational modification of an active protein into an inactive state, and we confirm the results using both analytical approximations and exact stochastic simulations. In summary, our results characterize the role of sequestration mechanisms in modulating the stochasticity of biochemical processes and identify noise-invariant processes.

FrAM_LR2 LR2

Reinforcement Learning and Information Theory (Regular Session)

Co-Chair: Wisniewski, Rafal	Aalborg University

10:00-10:25 FrAM_LR2.1

A Convolutional Variant of the McEliece Cryptosystem with GRS Codes

Almeida, Paulo	University of Aveiro
Beltrá, Miguel	University of Alicante
Napp, Diego	University of Alicante
Sebastião, Cláudia	Universidade De Aveiro

We propose a new variant of the McEliece cryptosystem. The generator matrix of the secret code is masked with polynomial matrices. The public key is then the generator matrix of a convolutional code. The plaintext is a sequence of vectors and the ciphertext is the corresponding codeword with some errors added through the sequence satisfying some weight restriction that permits to decode efficiently. We propose the use of a Generalized Reed-Solomon code as the secret code and construct the polynomial matrices to obtain a secure scheme. We analyze its security and compare the obtained results with some of the code-based public-key cryptosystems proposed for the NIST post-quantum cryptography standardization project.

10:25-10:50 FrAM_LR2.2

On Principle of Optimality for Safety-Constrained Markov Decision Process and P-Safe Reinforcement Learning

Misra, Rahul	Aalborg University
Wisniewski, Rafal	Aalborg University

We study optimality for the safety-constrained Markov decision process which is the underlying framework for safe reinforcement learning. Specifically, we consider an undiscounted safety-constrained Markov decision process subject to random stopping times. The decision maker's goal is to reach a goal state while avoiding unsafe states with certain probabilistic guarantees. Therefore the underlying Markov chain for any control policy will be Multichain or non-ergodic since by definition there exists a goal set and an unsafe set. Bellman's principle of optimality does not hold for such a safety-constrained Markov decision process in a Multichain setting as highlighted by a counterexample. We resolve the aforementioned counterexample by considering a zero-sum game setting between the policy and the Lagrange multiplier vector. Under suitable assumptions regarding the existence of admissible policy, we propose an off-policy RL algorithm for learning an optimal policy that satisfies the probabilistic safety guarantees. After that, we present the finite time error bound of the proposed RL algorithm. Lastly, we present simulation results of the aforementioned RL algorithm on a robot in a grid world setting.

10:50-11:15 FrAM_LR2.3

State Space Representations of the Roesser Type for Convolutional Layers

Pauli, Patricia	University of Stuttgart
Gramlich, Dennis	RWTH Aachen University
Allgower, Frank	University of Stuttgart

From the perspective of control theory, convolutional layers (of neural networks) are 2-D (or N-D) linear time-invariant dynamical systems. The usual representation of convolutional layers by the convolution kernel corresponds to the representation of a dynamical system by its impulse response. However, many analysis tools from control theory, e.g., involving linear matrix inequalities, require a state space representation. For this reason, we explicitly provide a state space representation of the Roesser type for 2-D convolutional layers with $c_mathrm{in}r_1 + c_mathrm{out}r_2$ states, where $c_mathrm{in}$/$c_mathrm{out}$ is the number of input/output channels of the layer and r_1/r_2 characterizes the width/length of the convolution kernel. This representation is shown to be minimal for $c_mathrm{in} = c_mathrm{out}$. We further construct state space representations for dilated, strided, and N-D convolutions.

11:15-11:40 FrAM_LR2.4

Minimum Data-Rate for Emulating a Linear Feedback System

Scabin Vicinansa, Guilherme	The University of Melbourne
Nair, Girish N.	University of Melbourne

In this work, we ask what the minimum data-rate is for a possibly nonlinear control law acting on a linear system to emulate the closed-loop behavior of a desired linear control law. This result gives an implicit estimate for the information flow in the feedback path of the closed-loop linear system. We formally introduce the notion of emulation and control law, and we present a data-rate theorem. Remarkably, we note that the minimum data-rate varies discontinuously with the parameters of the open and closed-loop systems. This feature is new since the usual data-rate theorem, which only requires stabilization instead of emulation, gives a continuously varying minimum data-rate.

11:40-12:05 FrAM_LR2.5

A Cooperative Dynamic Game Via Hypergraph Distributed Optimization

Papastaikoudis, Ioannis — University of Cambridge
Watson, Jeremy — University of Cambridge
Lestas, Ioannis — University of Cambridge,

We propose a novel cooperative dynamic game with the use of distributed optimization methods. Each coalition has an objective function and the goal of all the coalitions is to optimize the summation of their objectives given the interactions of their agents. The internal interactions are described by a multigraph but we will use directly a stochastic matrix to describe them while the external interactions are described by a hypergraph. The objective functions are quadratic and they encompass information for both types of interactions to highlight their importance in the outcome for the coalitions. The problem is formulated by means of distributed optimization where the actions of the agents at each iteration are the optimum solutions of the sequential optimization problem and the game is evolving by using a tilted matrix mechanism. We show that the optimization problem at each iteration can be solved in one step via a dual decomposition algorithm by exploiting the hypergraph stucture of the optimization problem. For the complete description of the dynamic game we propose a switched dynamical system and we demonstrate its convergence numerically.

FrAM_LR3 LR3

Issues in Networked Consensus Control (Invited Session)

Chair: Wang, Miaomiao — Academy of Math. & Systems Science, CAS
Co-Chair: Chen, Jianqi — Nanjing University
Organizer: Chen, Jianqi — Nanjing University
Organizer: Wang, Miaomiao — Academy of Math. & Systems Science, CAS
Organizer: Yan, Yamin — Nanyang Technological University
Organizer: Chen, Jie — City University of Hong Kong

10:00-10:25 FrAM_LR3.1

Optimizing Robust Stabilizability in Time-Delay Systems Amid Networked Uncertainties (I)

Chen, Jianqi — Nanjing University
Mao, Qi — City University of Hong Kong
Zhao, Di — Tongji University
Chen, Chao — KU Leuven

The study addresses output feedback controller synthesis for networked control systems with both stochastic multiplicative uncertainties and intrinsic channel-wise time delays. Building on the mean-square stability condition obtained, a fundamental necessary and sufficient condition for the mean-square stabilizability is derived. This criterion elucidates that an open-loop unstable time-delay system can achieve mean-square stabilization through output feedback in the presence of networked uncertainties.

10:25-10:50 FrAM_LR3.2

Asymmetric Weights in Decentralised Bidirectional Control: Size-Independent H-Infinity Performance in Vehicle Platoons (I)

Yamamoto, Kaoru — Kyushu University

We study the error amplification in a vehicle platoon employing a bidirectional control strategy. By deriving closed-form expressions for the scalar transfer functions from the lead vehicle's trajectory deviation to the spacing error, considering varying numbers of vehicles in the platoon, we discuss the convergence of the transfer functions to fixed points in a complex plane and the performance of error suppression evaluated by the H-infinity-norm. Our results suggest that symmetric bidirectional control strategies offer advantages in size-independent error suppression performance over asymmetric ones.

10:50-11:15 FrAM_LR3.3

Secure Synchronization of Heterogeneous Pulse-Coupled Oscillators (I)

Yan, Jiaqi — ETH Zurich
Ishii, Hideaki — University of Tokyo
Mo, Yilin — Tsinghua University

This work considers the synchronization of heterogeneous pulse-coupled oscillators (PCOs), where some oscillators might be faulty or malicious. The oscillators interact through identical pulses at discrete instants and evolve continuously with different frequencies otherwise. Despite the presence of misbehaviors, benign oscillators aim to reach synchronization. To achieve this objective, a resilient synchronization protocol is developed in this work by adapting the real-valued mean-subsequence reduced (MSR) algorithm to pulse-based interactions. We establish sufficient conditions on the initial states and graph structure under which resilient synchronization is achieved. Specifically, the normal oscillators can either detect the presence of malicious nodes or synchronize among themselves in the presence of stealthy attacks

11:15-11:40 FrAM_LR3.4

Periodic Event-Triggered Consensus Using Relative-State Measurements: A Hybrid System Approach (I)

Li, Jiang Lin — University of Alberta
Dhullipalla, Mani Hemanth — University of Alberta
Chen, Tongwen — University of Alberta

Often in practical applications, such as coordinated motion of autonomous vehicles, multi-agent systems (MASs) utilize information obtained from sensors to accomplish complex tasks, asynchronously. In this work, we consider the problem of consensus where the agents obtain relative-state measurements, at their own sampling frequencies, and employ a distributed event-triggered protocol to dictate when to update control. For the designed event-triggered protocol, only local intermittent relative-state measurements are utilized, where they are obtained and evaluated only at pre-determined event-monitoring instants; these instants are governed by sampling periods whose bounds are explicitly pre-computed, individually, for each agent. Hence, the designed protocol is inherently asynchronous and avoid Zeno behaviour by construction. To cope with the continuous-time dynamics of the agents and discrete-time sensing and controller updates, the overall MAS is modelled using the hybrid system framework. A numerical example is provided to clearly demonstrate the effectiveness of the designed protocol.

11:40-12:05 FrAM_LR3.5

Exploring the String Stability of Platooning Schemes under Packet Loss on the Leader State Broadcast (I)

Villenas, Felipe — Department of Electrical Engineering, Eindhoven University of Te
Vargas, Francisco J. — Universidad Técnica Federico Santa María
Maass, Alejandro I. — Pontificia Universidad Católica De Chile
Peters, Andrés A. — Universidad Adolfo Ibáñez

This work studies the string stability of a platoon of autonomous vehicles, where the leader broadcasts information to the followers. We assume that the leader's information is susceptible to data loss and examine how this affects the string stability property of the platoon. Two lossy scenarios are considered, both with a suitable data-loss compensation strategy. In the first scenario, all vehicles in the string are subject to the same loss. In the second scenario, transmission, and we assume that the probability of data loss depends on the distance between each vehicle and the leader. We numerically observe that data loss does not seem to impact the string stability of the platoon in the first scenario under consideration. However, in the second scenario, the function governing data loss based on position within the platoon can induce string instability.

12:05-12:30	FrAM_LR3.6

On Connectability in Expanding Plug-And-Play Networks (I)

Wang, Miaomiao	Academy of Math. & Systems Science, CAS
Yan, Yamin	Nanyang Technological University

This work explores the scalability of graph networks through the so-called "plug-and-play" connections, aiming to expand a network by gradually adding nodes with specified connecting degrees. Using a resource allocation approach, we establish a tighter upper bound on the number of connectable nodes under limited connecting capacity. We also show that the bound can be reached through a 'minimum strategy' where added nodes prioritize establishing connections with nodes that have the smallest degrees.

FrAM_LR4	LR4
Infinite Dimensional Analysis (I) (Mini Course)	
Chair: Hastir, Anthony	University of Wuppertal

10:00-10:25	FrAM_LR4.1

INFINITE DIMENSIONAL ANALYSIS (Part 1)

Alpay, Daniel	Faculty of Mathematics, Physics, and Computation

FrAM_LR5	LR5
Algebraic and Geometric Approaches to Systems Structure and Control (I) (Invited Session)	
Chair: Quadrat, Alban	Inria Paris
Co-Chair: Zerz, Eva	RWTH Aachen University
Organizer: Quadrat, Alban	Inria Paris
Organizer: Zerz, Eva	RWTH Aachen University

10:00-10:25	FrAM_LR5.1

Controlled Invariant Varieties for Second Order Polynomial Control Systems (I)

Harms, Melanie	RWTH Aachen University
Zerz, Eva	RWTH Aachen University
Herty, Michael	Rwth Aachen

We investigate controlled invariant varieties for second order input-affine control systems with polynomial nonlinearity. For autonomous, first order systems, a variety V is said to be invariant if any trajectory starting in V remains in V for all times. We discuss how to adapt this notion in the second order case and give conditions to decide whether a variety is invariant for a second order system using symbolic computation. This results serve as a foundation to characterise controlled invariant varieties, i.e., varieties that can be rendered invariant by a polynomial state feedback.

10:25-10:50	FrAM_LR5.2

Linear Dynamical Systems Over Finite Rings (I)

Rohde, Yannic	RWTH Aachen University
Zerz, Eva	RWTH Aachen University

We present the theory of linear systems over various kinds of finite commutative rings. Since these systems are finite, the trajectories have to run into repeating cycles eventually. This periodic behavior is the main interest of this topic. Using an approach similar to Fitting's lemma, a bijective-nilpotent decomposition of the system can be achieved, which in some cases even gives a decomposition of the system matrix. In particular, this allows us, to apply results about invertible system matrices, where all trajectories are purely periodic, to the more general setting. Finally, the algorithmic potential of the theory is discussed.

10:50-11:15	FrAM_LR5.3

An Internal Model Principle for Non-Linear Observers for Repeatable Systems on Manifolds (I)

Trumpf, Jochen	The Australian National University
Nüssle, Johannes	-

Internal model principles provide necessary conditions on the structure of controllers or observers that achieve a certain control or estimation goal. In formulating such principles, care must be taken in clearly defining the properties of the plant under consideration as well as the set of candidate controllers or observers. We introduce a novel system property for non-linear state-space systems on manifolds that we call repeatability and show that this property is implied by the usual notion of controllability but is significantly weaker. In fact, we show that such a system is repeatable if and only if the reachability relation is an equivalence relation. Sontag calls this latter property reversibility. We then show that any asymptotic observer for a repeatable plant contains a full internal model of the plant, as long as the observer has been constructed on a manifold that is a surjective fiber bundle with compact fibers over the plant state manifold. We discuss in what sense the restriction to surjective fiber bundles is necessary and what happens in the case of non-compact fibers. A direct consequence of this result is that the right-hand side of such an observer can be split without loss of generality into a lift of the plant plus a correction term that is zero along lifted plant trajectories. This split might require a modification of the observer equation that does not change the error trajectories; this is the precise meaning of without loss of generality in this context. The result shows that the generalized Luenberger construction for observers is indeed most general in this setting, in the sense that all possible asymptotically stable error behaviors can be achieved by such designs.

11:15-11:40	FrAM_LR5.4

Generalized Functions in the Study of Signals and Systems (I)

Verriest, Erik I.	Georgia Inst. of Tech
Dirr, Gunther	University of Wurzburg
Gray, W. Steven	Old Dominion Univ

We collect three instances where the theory of generalized functions may still make contributions to the study of signals and systems. In the first, a purely algebraic approach is presented for LTI-ODE's, in terms of two operators, D and T, respectively the differentiation operator and the multiplication-by-the-independent-variable operator. This formalism adds simplicity, a duality theory, and nicely generalizes to other classes of operator equations and their solutions. In the second part we extend the classical bilateral Laplace transform to include Bohl functions with support in R by invoking Sato's hyperfunctions. Finally, in the third case we use the Colombeau algebra to allow for products of generalized functions. This is important in the study of (smooth) nonlinear systems driven by impulsive inputs, and hybrid system theory.

11:40-12:05	FrAM_LR5.5

Asymptotical Left Inversion for Single-Input Linear Systems (I)

Jamet, Hugo	INSA Lyon, Université Claude Bernard Lyon 1, Ecole Centrale De L
Di Loreto, Michael	INSA De Lyon
Eberard, Damien	Universite De Lyon, INSA De Lyon

A constructive design of a stable left inverse for single-input linear systems is proposed. Based on structural properties relating left inversion and feasability of input reconstruction, the input observer is realized within the state-space approach, for arbitrary initial condition. While previous design is concerned with a nominal plant, that is with known parameters, we propose in a second step to apply this inversion methodology to a simplified identification problem. Reformulating the unknown parameters as a fictitious unknown input, convergent parameter estimates are retrieved from measurement. The overall methodology is illustrated by simulations.

FrAM_LR6 LR6

Geometry in Optimization and Learning (I) (Invited Session)

Chair: Mostajeran, Cyrus S. — University of Cambridge
Co-Chair: Hauberg, Søren — Technical University of Denmark
Organizer: Mostajeran, Cyrus S. — University of Cambridge

10:00-10:25 FrAM_LR6.1

Geometric Data Fusion for Collaborative Attitude Estimation (I)

Ge, Yixiao — Australian National University
Zamani, Behzad — University of Melbourne
van Goor, Pieter — University of Twente
Trumpf, Jochen — The Australian National University
Mahony, Robert — Australian National University

In this paper, we consider the collaborative attitude estimation problem of a multi-agent system. The agents are equipped with sensors that provide directional measurements and relative attitude measurements. We present a bottom-up approach where each agent runs an extended Kalman filter (EKF) locally using directional measurements and augments this with relative attitude measurements provided by neighbouring agents. The covariance estimates of the relative attitude measurements are geometrically corrected to compensate for relative attitude between the agent that makes the measurement and the agent that uses the measurement before being fused with the local estimate using the convex combination ellipsoid (CCE) method to avoid data incest. Simulations are undertaken to numerically evaluate the performance of the proposed algorithm.

10:25-10:50 FrAM_LR6.2

A Structure-Preserving Kernel Method for Learning Hamiltonian Systems (I)

Yin, Daiying — Nanyang Technological University
Ortega, Juan-Pablo — Nanyang Technological University
Hu, Jianyu — Nanyang Technological University

We present a structure-preserving kernel method for the learning of Hamiltonian systems. In the presentation, we shall start by establishing reproducing properties of differentiable kernels on any subsets of R^{2d}, which enables us to embed the corresponding RKHS into the space of bounded differentiable functions with bounded derivatives. We then study the Hamiltonian learning problem using a kernel ridge regression, we provide an operator-theoretical framework to represent the structure-preserving kernel estimators, and we prove convergence results and error bounds for them. Finally, we present some numerical experiments.

10:50-11:15 FrAM_LR6.3

On the Influence of Reparametrizations in Bayesian Deep Learning (I)

Miani, Marco — Technical University of Denmark
Roy, Hrittik — Technical University of Denmark
Hauberg, Søren — Technical University of Denmark

11:15-11:40 FrAM_LR6.4

Geometric Statistics with Subspace Structure Preservation for SPD Matrices (I)

Mostajeran, Cyrus S. — University of Cambridge
Da Costa, Nathaël — University of Tübingen
Van Goffrier, Graham — University College London
Sepulchre, Rodolphe J. — University of Cambridge

We present a geometric framework for the processing of SPD-valued data that preserves subspace structures and is based on the efficient computation of extreme generalized eigenvalues. This is achieved through the use of the Thompson geometry of the semidefinite cone. We explore a particular geodesic space structure in detail and establish several properties associated with it. Finally, we review a novel inductive mean of SPD matrices based on this geometry.

FrSP_LMH Lady Mitchell Hall

Semi-Plenary: Stochastic Diffusions for Control, Learning, and Inference (Plenary Session)

Chair: Lestas, Ioannis — University of Cambridge,
Co-Chair: Wisniewski, Rafal — Aalborg University

14:00-15:00 FrSP_LMH.1

Semi-Plenary: Stochastic Diffusions for Control, Learning, and Inference

Chen, Yongxin — Georgia Institute of Technology

FrSP_LH Little Hall

Semi-Plenary: Optimization-Based Control under Uncertainty: Guarantees, Performance & Computation (Plenary Session)

Chair: Gruene, Lars — Univ of Bayreuth
Co-Chair: Maciejowski, Jan — University of Cambridge

14:00-15:00 FrSP_LH.1

Semi-Plenary: Optimization-Based Control under Uncertainty: Guarantees, Performance & Computation

Zeilinger, Melanie N. — ETH Zurich

FrSP_LR3 LR3

Semi-Plenary: When Is a Time-Delay System Stable and Stabilizable? a Third-Eye View (Plenary Session)

Chair: Qiu, Li — Hong Kong Univ. of Sci. & Tech
Co-Chair: Fridman, Emilia — Tel-Aviv Univ

14:00-15:00 FrSP_LR3.1

Semi-Plenary: When Is a Time-Delay System Stable and Stabilizable? a Third-Eye View

Chen, Jie — City University of Hong Kong

FrPM_LH Little Hall

Algebraic Systems Theory (Regular Session)

Co-Chair: Guggilam, Subbarao Venkatesh — UiT the Artic Univeristy of Troms\o

15:30-15:55 FrPM_LH.1

Bounds on the Growth Rate of Time-Invariant Switching Max-Min-Plus-Scaling Discrete-Event Systems

van den Boom, Ton J. J. — Delft Univ. of Tech
Markkassery, Sreeshma — Delft University of Technology
De Schutter, Bart — Delft University of Technology

We consider the growth rate of a switching max-min-plus-scaling (S-MMPS) system in a discrete-event framework. We show that an explicit, time-invariant, monotone, and arbitrarily switching MMPS system has a bounded growth rate. Further, we propose a mixed-integer linear programming problem to calculate the estimates of the smallest upper bound and the largest lower bound of the growth rate of an S-MMPS system.

15:55-16:20 FrPM_LH.2

Data Informativity for Identification and Data-Driven Simulation for Scalar Time-Relevant Discrete 2D Systems

Bharti, Aishwarya — IIT Bombay
Pal, Debasattam — Indian Institute of Technology Bombay

For a class of discrete 2D systems, where one of the independent variables partitions the plane into ‘past' and ‘present', called time-relevant 2D systems, we provide a necessary and sufficient condition on the trajectory data to identify the generating system, i.e., we give a necessary and sufficient condition for the data to be informative for identification. Moreover, we provide a data-driven representation of the behaviour and use it to simulate the admissible trajectories for arbitrary intervals using an informative data and initial conditions without identifying the system.

16:20-16:45 FrPM_LH.3

Mass Chain Control Employing Multiple Output Response Decoupling

Wang, Fu-Cheng — National Taiwan University
Lee, Chung-Hsien — National Taiwan University

This paper introduces the multiple output response decoupling (MORD) theorem and applies it to control mass-chain systems. The dynamics of mass-chain systems are coupled, i.e., improving the performance of one mass might compromise those of others. Therefore, we develop the MORD theorem, which allows the modification of all system outputs independently and simultaneously without compromises. Furthermore, controlling a particular mass requires only three actuators on the consecutive masses. Finally, we apply a five-mass system to demonstrate the effectiveness of MORD control for mass-chain system control.

16:45-17:10 FrPM_LH.4

On Structural Non-Commutativity in Affine Feedback of SISO Nonlinear Systems

Guggilam, Subbarao Venkatesh — UiT the Artic Univeristy of Troms\o

The affine feedback connection of SISO nonlinear systems modeled by Chen–Fliess series is shown to be a group action on the plant which is isomorphic to semi-direct product of shuffle and additive group of non-commutative formal power series. The additive and multiplicative feedback loops in an affine feedback connection are thus proven to be structurally non-commutative. A flip in the order of these loops results in a net additive feedback loop.

FrPM_LR1

Stability (Regular Session)

Chair: Damm, Tobias — RPTU Kaiserslautern-Landau
Co-Chair: Wirth, Fabian — University of Passau

15:30-15:55 FrPM_LR1.1

Preservation of Algebraic Stability Domains in Reduced Models

Damm, Tobias — RPTU Kaiserslautern-Landau
Breiten, Tobias — Technical University Berlin

For linear control systems, we study algebraic stability domains, which are defined by polynomial inequalities in the complex plane. Based on a characterization via generalized Lyapunov matrix inequalities, we define a suitable pair of Gramians and a balancing transformation. For special cases, we analyze the preservation of stability domains by balanced truncation.

15:55-16:20 FrPM_LR1.2

On Absolute and Relative Feedback for Scalable Stability of Third-Order Integrator Networks

Jeeninga, Mark — Lund University
Tegling, Emma — Lund University

It is known that designing a scalable controller for multi-agent systems with third- order integrator dynamics is not possible when only relative information is available. We explore what conditions are needed if also absolute feedback is included in the control design. In this note we study how positional absolute feedback, positional relative feedback and velocity relative feedback are restricted by the relative and absolute feedback of velocity and acceleration. Contrary to intuition, this means that introducing too much relative velocity feedback, relative positional feedback or absolute positional feedback may make a controller lose its scalable stability.

16:20-16:45 FrPM_LR1.3

Global Dynamic Feedback Stabilization: To Twist or Not to Twist

Belabbas, Mohamed Ali — University of Illinois, Urbana-Champaign
Ko, Jehyung — University of Illinois Urbana Champaign

We investigate global dynamic feedback stabilization from a topological viewpoint. In particular, we consider the general case of dynamic feedback systems, whereby the total space (which includes the state space of the system and of the controller) is a fibre bundle, and derive conditions on the topology of the bundle that are necessary for various notions of global stabilization to hold. This point of view highlight the importance of distinguishing trivial bundles (think of a cylinder) and twisted bundles (think of a Mobius strip) in the study of global dynamic feedback stabilization, as we show that dynamic feedback defined on a twisted bundle can stabilize systems that dynamic feedback on trivial bundles cannot.

16:45-17:10 FrPM_LR1.4

The Joint Spectral Radius of Principal Submatrices

Epperlein, Jeremias — Universität Passau
Wirth, Fabian — University of Passau

For compact sets of complex matrices it is shown that there always exists a similarity transformation such that in the transformed set all entries of all matrices are bounded in absolute value by the joint spectral radius. The key tool for this is that every extremal norm of a matrix set has an Auerbach basis. The result implies in particular that all diagonal entries, or equivalently all one-dimensional principal submatrices, are upper bounded by the joint spectral radius. It is shown that the corresponding statement for higher dimensional principal submatrices is false. More precisely, there are finite matrix sets, such that for all points in the similarity orbit the joint spectral radii of all higher dimensional principal submatrices are strictly larger than the joint spectral radius of the original matrix set.

17:10-17:35 FrPM_LR1.5

On Redheffer's Lemma for Potentially Nonlinear Controllers and I/O Stability

Mi, La — University of Luxembourg
Mirkin, Leonid — Technion—IIT

Redheffer's lemma is a key result in H-inf control, reducing 4-block problems to equivalent 2-block ones. This note extends its scope to potentially nonlinear controllers and offers an input/output stability analysis, avoiding the need to use realization-dependent Lyapunov stability arguments.

FrPM_LR2

Quantum Control (Regular Session)

Chair: Tsumura, Koji — The University of Tokyo
Co-Chair: Helton, J. William — Univ. of California at San Diego

15:30-15:55 FrPM_LR2.1

Stability on the Robust Dissipative Coding in Quantum System for Thermal Noise

Supithak, Tanathorn — The University of Tokyo

Tsumura, Koji — The University of Tokyo

In this paper, we deal with the stability of the improved quantum coding method based on Markovian dissipative dynamics that is robust against thermal noise. This coding method was proposed by Nishino et al. and the suppression of the effect of thermal noise was demonstrated by numerical simulations, however the mathematical proof was not given. In this paper, we analyze the effect of the thermal noise in this method and mathematically prove that the quantum states converge to a neighborhood around the target code words. The bound of the neighborhood set is also given strictly. We also demonstrate numerical simulations, which confirm the theoretical results.

15:55-16:20 — FrPM_LR2.2

Quantum Mean-Field Filtering and Control

Amini, Nina Hadis — L2S, CentraleSupelec, CNRS

Chalal, Sofiane — CentraleSupélec

Guo, Gaoyue — CentraleSupélec

We consider an interacting quantum particles system undergoing continuous imperfect observations. By transitioning to the MF limit, we study properties in particular the well-posedness of the limit equation describing the evolution of a particle subjected to a MF potential. We illustrate through an example the application of this limit equation in the design of a stabilizing feedback control.

16:20-16:45 — FrPM_LR2.3

Satisfiability Critical Thresholds for Random Quantum 3XOR Games (I)

Helton, J. William — Univ. of California at San Diego

Hughes, Jared A — UC San Diego

Finding quantum strategies for games ultimately boils down to solving systems of equations in matrix unknowns. The talk concerns a particular class of quantum games which have a long tradition for illuminating new phenomena: XOR games. A particular 2 player XOR games, the CHSH game, demonstrated the existence of quantum entanglement, subsequently Tsirelson showed how to compute an optimal quantum strategy for any 2XOR game (a semidefinite program). This talk focuses on a class of three player games called 3XOR games. There has been much recent progress on understanding perfect strategies for 3XOR games and this talk will focus on that.

The work is joint with Adam Bene Watts, Daniel Kane, Igor Klep, and Zehong Zhang.

FrPM_LR4 — LR4

Infinite Dimensional Analysis (II) (Mini Course)

Chair: Alpay, Daniel — Faculty of Mathematics, Physics, and Computation

Co-Chair: Hastir, Anthony — University of Wuppertal

15:30-15:55 — FrPM_LR4.1

Infinite Dimensional Analysis (part II)

Alpay, Daniel — Faculty of Mathematics, Physics, and Computation

16:45-17:10 — FrPM_LR4.4

Toeplitz, Hankel, De Branges and Beyond

Dym, Harry — Weizmann Institute

FrPM_LR5 — LR5

Algebraic and Geometric Approaches to Systems Structure and Control (II) (Invited Session)

Chair: Quadrat, Alban — Inria Paris

Co-Chair: Zerz, Eva — RWTH Aachen University

Organizer: Quadrat, Alban — Inria Paris

Organizer: Zerz, Eva — RWTH Aachen University

15:30-15:55 — FrPM_LR5.1

Feasible Initial Conditions for Quarter-Plane Updating of 2D Fornasini-Marchesini Models (I)

Rocha, Paula — Univ of Porto

Pereira, Ricardo — University of Aveiro

We put forward the basic ideas for solving the following problem. Consider a two- dimensional (2D) system Σ defined over the whole grid Z2 and described by a first order (2D) model of the Fornasini-Marchesini type. Which initial conditions can be assigned on the boundary F of the first (discrete) quadrant (or quarter-plane) Q(0,0) in order to compute the system signals (inputs, local states and outputs) on Q(0,0)? Due to the nature of the updating equations of the Fornasini-Marchesini model, this would not even be a problem if Σ were defined only over the quarter-plane Q(0,0): in that case, both the inputs and the (local) states would be freely assignable on F. However, the requirement that the signal values computed on Q(0,0) correspond to Σ signals, which are necessarily defined over the whole 2D grid makes this problem nontrivial.

15:55-16:20 — FrPM_LR5.2

Towards the Computation of Stabilizing Controllers of Multidimensional Systems (I)

Cluzeau, Thomas — Université De Limoges

Moroz, Guillaume — India Nancy - Grand Est

Quadrat, Alban — Inria Paris

In this paper, we further study the effective computation of stabilizing controllers of multidimensional systems. Within the algebraic analysis approach, the stabilization problem can be characterized by the fact that a certain finitely presented A-module M, naturally associated with the multidimensional system, is projective, where A denotes the ring of multivariate rational functions without poles in the closed complex unit polydisc D^n. This condition can be reduced to the existence of an element s of a polynomial ideal I which has no zero in D^n. According to the Polydisc Nullstellensatz, the latter condition is equivalent to the fact that no complex zero of the elements of I belongs to D^n. If this condition is satisfied, using cyclic resultants and linear programming, we then propose a method to compute such a polynomial s. Finally, using computer algebra methods for effectively handling basic operations on R[s^{-1}]-modules, where R is a polynomial ring, we show how to compute stabilizing controllers.

16:20-16:45 — FrPM_LR5.3

Data-Based Stability Analysis of Strongly Autonomous Discrete nD Systems (I)

Mukherjee, Mousumi — Indian Institute of Engineering Science and Technology

Pal, Debasattam — Indian Institute of Technology Bombay

The aim is to provide data-based conditions for checking stability of strongly autonomous nD systems. It is known that because of the lack of natural ordering of the domain, the problem of defining and studying stability of nD systems is not straightforward. We focus on the following two notions of stability: (i) stability with respect to a given direction, and more generally, (ii) conic stability, that is, stability with respect to subsets of the domain having the structure of a cone. For a strongly autonomous nD system, these two notions of stability have been studied in the literature from a model based perspective. Here, we analyze their data-based counterparts. We assume that the data is noise-free, and that it is measured from a linear system of partial difference equations, with constant real coefficients, having n independent variables. We further assume that the data-generating system is a strongly autonomous nD system, that is, the solution trajectories can be uniquely determined using finite ``initial conditions''. Given a finite set of data, that is, a finite set of multi-indexed sequences, we first define a notion of informativity of nD trajectories. Using informative nD trajectories, we provide data-based tests for checking stability of nD systems with respect to a given direction, and, more generally, for conic stability.

FrPM_LR6	LR6
Geometry in Optimization and Learning (II) (Invited Session)	
Chair: Mostajeran, Cyrus S.	University of Cambridge
Co-Chair: Hauberg, Søren	Technical University of Denmark
Organizer: Mostajeran, Cyrus S.	University of Cambridge

15:30-15:55	FrPM_LR6.1

Invariant Kernels on Homogeneous Spaces (I)

Da Costa, Nathaël	University of Tübingen
Mostajeran, Cyrus S.	University of Cambridge
Ortega, Juan-Pablo	Nanyang Technological University
Said, Salem	CNRS Université Grenoble Alpes

We discuss the theories underlying positive definite and positively decomposable invariant kernels on homogeneous spaces. These provide a path for the application of reproducing kernel Hilbert space and reproducing kernel Krein space methods on non-Euclidean data spaces, respectively.

15:55-16:20	FrPM_LR6.2

Optimal Regularization for a Data Source (I)

Soh, Yong Sheng	National University of Singapore

Regularization techniques are frequently deployed in optimization-based approaches for solving inverse problems. These techniques help to promote certain desired structure in solutions. In this paper, we ask: Given a distribution, what is the optimal regularizer for data drawn from the distribution?

By restricting to regularizers that are positively homogenous, the functions we consider are in one-to-one correspondence with star bodies. We leverage the dual Brunn-Minkowski theory to show that the optimal choice of regularizer can be described as a radial function that serves as a sufficient statistic of the distribution.

16:20-16:45	FrPM_LR6.3

Double-Bracket Quantum Algorithms for Diagonalization (I)

Gluza, Marek	School of Physical and Mathematical Sciences, Nanyang Technological University, 21 Nanyang Link, 637371 Singapore, Republic of S

Technical Programme

Author Index

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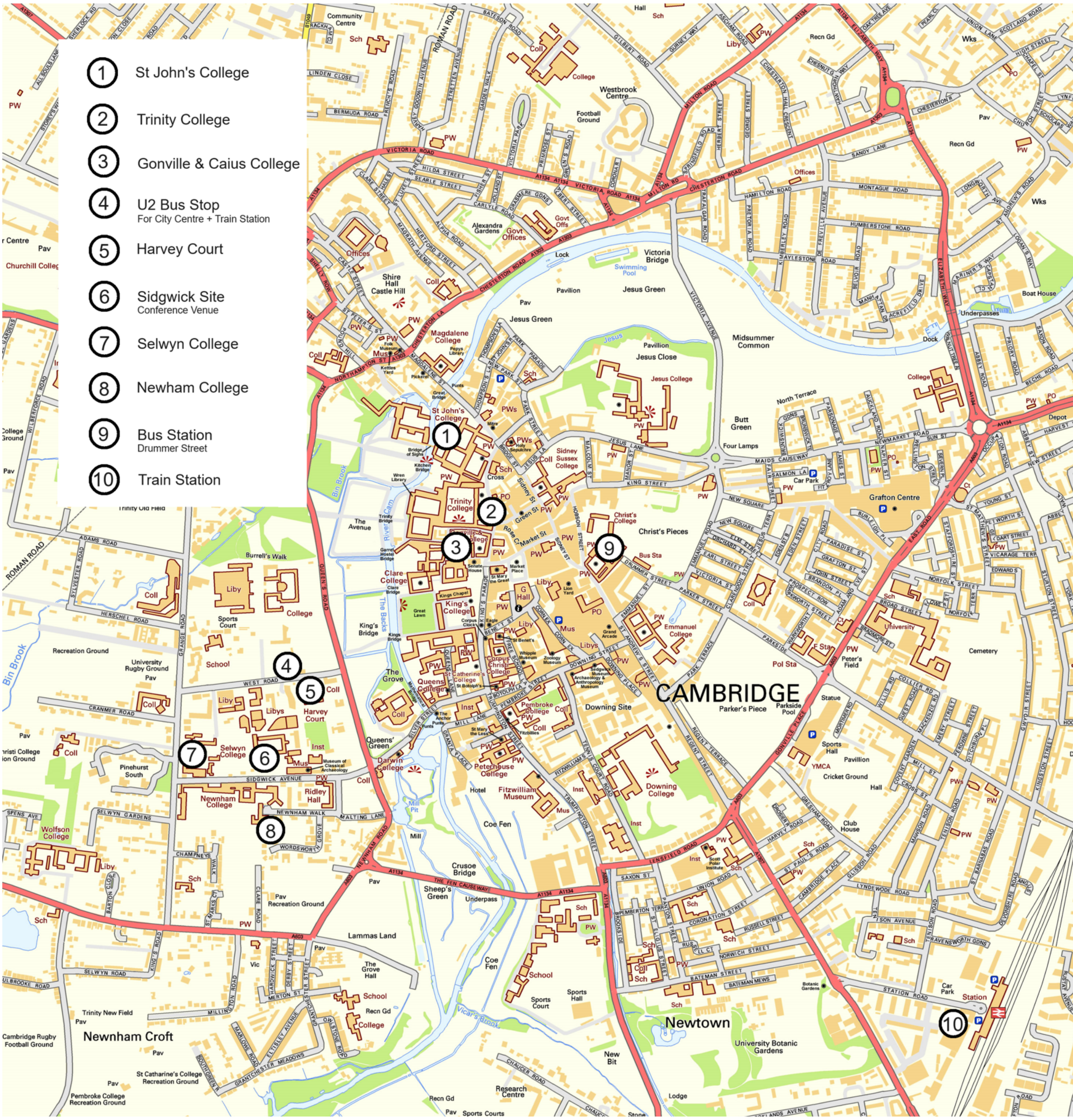
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4 U2 Bus Stop
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Conference Venue
7 Selwyn College
8 Newham College
9 Bus Station
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5 History
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12 Lady Mitchell Hall
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14 Lecture Block
15 Custodian's Lodge

Girton Corner U1
Girton Corner
Thornton Road
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William Gates Building
Bulstrode Gardens
Wilberforce Rd
Storey's Way
Castle St
Phillippa Fawcett Drive
Veterinary School
West Hub
Grange Rd
U1 U2
Playing Fields
Robinson College
West Cambridge
University Rugby Ground
Grange Rd
University Library
Queens' College
Central Cambridge
U2
Selwyn College
Malting Lane
U1
Barton Road
Pembroke St
Fitzwilliam Museum
Mill Road
U1 U2
Station Road
Grange Road
Grantchester Street
Trumpington Rd
Botanic Garden
Cambridge
Newnham
Bateman Street
bus stops towards Biomedical Campus
bus stops towards Eddington & Girton
Bowling Club
Shaftesbury Road
Trumpington Road
Guided Busway
Hills Road Sixth Form College
Cherry Hinton Rd
U2
Homerton College
Hills Rd
The Perse School
Long Road
Long Road Sixth Form
Queen Edith's Way
U1
Outpatients
Puddicombe Way
Royal Papworth Hospital
Cambridge Biomedical Campus
Rosie Hospital
Universal
The University bus for everyone
Jesus Green
Magdalene College
St John's College
Bridge St
Jesus College
Jesus Lane
The Backs
Queens Road
Sidney Sussex College
Trinity College
The Grafton 5 mins
Christ's College
Drummer St bus station
Emmanuel Rd
Gonville & Caius College
Market
King's College
Grand Arcade
Corpus Christi College
Emmanuel College
Parkside
West Rd
St Catharine's College
Downing St
long distance coach stops
Queens' College
Silver St
Pembroke College
Regent St
Parker's Piece
Peterhouse
Downing College
Fitzwilliam Museum
Newnham Rd
Trumpington St