MTNS 2022

12-16 September 2022 | Bayreuth | Germany

UNIVERSITÄT BAYREUTH

The 25th International Symposium on Mathematical Theory of Networks and Systems

Conference Programme

MTNS 2022 is co-sponsored by

IFAC INTERNATIONAL FEDERATION OF AUTOMATIC CONTROL

Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

OBERFRANKEN STIFTUNG

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Welcome to MTNS 2022 from the General Chair

Dear MTNS 2022 participants,

It is my great pleasure to welcome all of you to the 25th International Symposium on Mathematical Theory of Networks and Systems – MTNS 2022 – in Bayreuth, Germany.

After two years of postponed, cancelled and virtual conferences, I am very glad that finally the Systems and Control Community is able to come together again in person. Almost 320 participants will meet on site and more than 50 speakers will, in addition, participate remotely.

Besides providing an excellent technical programme, which is described in the welcome address of the programme co-chairs, below, MTNS 2022 offers many different ways to interact informally during breaks, receptions, the conference dinner, and the traditional Wednesday afternoon excursions. We thus hope to create an environment that fosters the casual and unexpected encounters between scientists from different sub-disciplines in our field, which are so important for creating scientific progress beyond the beaten tracks.

I hope that you all enjoy this week of excellent plenary and semi-plenary presentations, exciting sessions, informative mini courses, and lots of fruitful meetings, and wish a great conference to all of us.

Lars Grüne, General Chair, MTNS 2022

Welcome from the Programme co-Chairs

Dear valued participant,

The 25th International Symposium on Mathematical Theory of Networks and Systems (MTNS 2022) carries on the long-lasting and extremely successful tradition of bringing together researchers and practitioners from different mathematical disciplines. This can be easily inferred by the high number of 336 talks in the scientific programme; not yet including the two mini courses and the pre-conference workshop dedicated to Arjan van der Schaft's retirement.

On the one hand, the conference programme reflects recent trends in the theory of networks and systems, e.g.,

- algebraic and geometric approaches in coding,
- Hamilton-Jacobi equations and mean-field games, or
- the close relationships between dissipativity and the turnpike property.

Further topics of current interest are the interplay between learning and systems theory, see, e.g., the plenary talks by Claudio de Persis on data-driven control and by Weinan E on the relation between deep learning and (optimal) control and various invited sessions on this topic. Another example are port-Hamiltonian systems, see, e.g. the mini-course on infinite-dimensional port-Hamiltonian systems.

On the other hand, the programme features traditional core topics of MTNS, e.g., coding or infinite-dimensional systems theory with its connections to both operator theory and partial differential equations. This is nicely illustrated and highlighted by George Weiss' and Luz de Teresa's plenary talks, which point to advanced topics like hierarchical control or (Lax-Phillips) semigroups for nonlinear systems. Other key themes of the MTNS are networked (control) systems, see, e.g., the plenary talk by Maria Elena Valcher on opinion dynamics for a more abstract, mathematical perspective on multi-agent systems.

In addition, more classical talks and sessions on numerics, adaptive control, stabilisation and safety (barrier functions and hybrid feedback solutions), multi-dimensional systems, measure differential equations (see, e.g. the mini course devoted to this topic), quantum control and algorithmic trading are covered.

We thank the Steering Committee, the Programme Committee members, the editors, and the external reviewers who worked hard to put together an exciting programme of (semi-)plenary, mini-courses, invited and contributed talks.

We hope you will enjoy the MTNS 2022 in Bayreuth with inspiring talks and discussions in an environment full of culture, history, and Bavarian hospitality.

Birgit Jacob and Karl Worthmann, Programme co-Chairs, MTNS 2022

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Yutaka Yamamoto (Japan)
Eva Zerz (Germany)

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, The Netherlands
2016: Minneapolis, Minnesota, USA
2018: Hong Kong, China
2020: Cambridge, UK (postponed to 2024)

Lunch menu at the Mensa during MTNS 2022:

Menu: Kitchen, Frischraum

STUDENTEN WERK

Monday, 12.09.2022

main course:	Stud.	Serv.	Gues.	Spec.
vegetable spaghetti (2, 3, 14, 16, 18, f, i, a1)	€ 2,40	€ 3,00	€ 3,70	€ 2,60
Crispy cauliflower and cheese patty served on Mediterranean grilled veggies (1, 2, 3, 14, 17, 18, c, g, l, a1, h4)	€ 2,70	€ 3,30	€ 4,00	€ 2,90
Chop suey with mie noodles (1, 2, 4, 14, 15, 18, f, k, a1)	€ 4,00	€ 4,60	€ 5,30	€ 4,20

Tuesday, 13.09.2022

main course:	Stud.	Serv.	Gues.	Spec.
Aubergine curry with chickpea rice (1, 2, 3, 14, 16, 18, f)	€ 2,40	€ 3,00	€ 3,70	€ 2,60
Spinach spätzle with young vegetables over tomato and rosemary potpourri (1, 14, c, g, i, a1)	€ 3,00	€ 3,60	€ 4,30	€ 3,20
?Hellas? gyros roll with tzatziki (14, g, i, a1)	€ 3,50	€ 4,10	€ 4,80	€ 3,70

Wednesday, 14.09.2022

main course:	Stud.	Serv.	Gues.	Spec.
Vegan Kaiserschmarrn with apple sauce (1, 3, 8, 14, 16, 18, a1, h1)	€ 2,40	€ 3,00	€ 3,70	€ 2,60
Mini spring rolls with vegetables and fragrant rice (1, 2, 4, 14, 17, 18, f, i, j, a1)	€ 3,00	€ 3,60	€ 4,30	€ 3,20
Beefsteak with fresh herbs, mango-avocado cream and bell pepper and rocket leaves salad (1, 3, 14, 16, g, k, a1)	€ 4,00	€ 4,60	€ 5,30	€ 4,20

Thursday, 15.09.2022

main course:	Stud.	Serv.	Gues.	Spec.
Cuban-style rice and beans (1, 2, 3, 14, 17, 18, i)	€ 2,40	€ 3,00	€ 3,70	€ 2,60
Fine porcini mushroom dumplings with Italian hard cheese on creamed vegetables (2, 14, 15, 18, c, f, g, i, a1, a3)	€ 2,70	€ 3,30	€ 4,00	€ 2,90
Lasagne bolognese (1, 14, c, g, i, a1)	€ 3,50	€ 4,10	€ 4,80	€ 3,70

Friday, 16.09.2022

main course:	Stud.	Serv.	Gues.	Spec.
Ham and pasta with tomato sauce (1, 2, 3, 8, 14, 16, 18, c, g, i, a1)	€ 2,40	€ 3,00	€ 3,70	€ 2,60
Parsnip curry with corinader pesto and fragrant rice (1, 2, 14, 17, 18, f, g, i, a1, h4)	€ 2,70	€ 3,30	€ 4,00	€ 2,90
Baked trout fillet with remoulade sauce (1, 2, 3, 5, 9, 14, 15, 17, 18, a, c, d, f, i, j, l, a1, a3)	€ 4,00	€ 4,60	€ 5,30	€ 4,20

Legend

Changes reserved

- Pork
- beef
- Lamb
- game
- Poultry
- fish
- Shellfish
- sustainably fished
- vegetarian
- Animal-derived
- vegan
- Mensa-Vital a brand of the Studentenwerke
- homemade
- regional
- Kräuterküche

1) with colouring agent 2) with preserving agent 3) with antioxidant 4) with flavour enhancer 5) sulphured 6) blackened 7) waxed 8) with phosphate 9) with sweetener 10) contains a source of phenylalanine 11) may have a laxative effect if consumed in excess 12) contains caffeine 13) contains quinine 14) with acidifier 15) with thickener 16) Stabiliser 17) with alcohol 18) Acidity regulator a1) Wheat gluten a2) Rye gluten a3) Barley gluten a4) Oat gluten a5) Spelt gluten h1) Almonds h2) Hazelnuts h3) Walnuts h4) Cashew nuts h5) Pecan nuts h6) Brazil nuts h7) Pistachios h8) Macadamia nuts a) Cereals containing gluten b) Crustaceans and derived products c) Eggs and derived products d) Fish and derived products e) Peanuts and derived products f) Soya beans and derived products g) Milk and derived products h) Nuts i) Celery and derived products j) Mustard and derived products k) Sesame seeds and derived products l) Sulphur dioxide and sulphites m) Lupin beans and derived products n) Molluscs and derived products

Useful Information:

(maps can be found on the last pages of this book, further information can be found on the MTNS 2022 web site https://www.mtns2022.uni-bayreuth.de)

Conference Buildings: All conference activities take place in the building **NW II**, except for the morning plenary talks, which are held in the **Audimax**.

Talks: The slots for the talks in the parallel sessions are 25 minutes. In order to allow for enough time for questions and change of speakers, please make sure that your talk is **no longer than 20 minutes**. Please make sure to upload your slides to the presentation laptop before the start of your session. Technical assistance will be present in the lecture rooms 20 minutes before the start of the session. We strongly encourage the use of the presentation laptops provided in the rooms. Speakers who absolutely must use their own laptop should inform the technical staff in the lecture room in advance. In hybrid sessions, it is not possible to use own laptops.

Coffee Stands: There are two coffee stands in the main conference building NW II, which are open during the designated coffee breaks and during the lunch breaks.

Lunch: All participants have received five lunch tickets with their registration. Lunch is held in the Mensa (University Restaurant). The menu can be found on the left.

Registration Desk: The registration desk is located near the entrance of the lecture hall H18. It will be open on Monday from 10:00 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 BayernWLAN are available everywhere on the Campus.

Transportation: If you do not like to walk from your hotel to the university, the public **bus lines 304 and 306** run every 10 minutes between the Central Bus Station (ZOH, bus stop L) and the University Campus. The **bus line 316** runs every 30 minutes from the Train Station to the University Campus (except during lunch time).

Tickets can be bought from the driver (cash only), at the vending machines at the ZOH or at the Train Station (cash or card) or via the VGN app, which you can download for iOS and Android devices. A single ride is 2.10€ for a paper ticket or 1.80€ in the VGN app. If you plan to use the bus more than once, you can obtain a discounted ticket for four rides (“Viererkarte”, 7.20€) or a pass for seven days (“MobiCard 7 Tage”, 15.20€).

In the morning, additional **MTNS shuttle buses** depart from Luitpoldplatz at 8:30, i.e., just in time for the plenary talks. The buses depart near the “Sparkasse”, on the opposite side of the road and carry the sign **MTNS**.

Please note that wearing a **face mask** is mandatory on public transport in Germany!

Social Programme:

(maps can be found on the last pages of this book, further information can be found on the MTNS 2022 web site https://www.mtns2022.uni-bayreuth.de)

Welcome Reception: The welcome reception takes place on Sunday before the conference, 11 September, from 18:30 until 21:00, in the Evangelisches Zentrum in Richard-Wagner-Strasse 24 in the town centre. Drinks and snacks will be served.

Conference Dinner: The conference dinner will be held on Thursday, 15 September, from 19:00 until late at the Herzogkeller, Hindenburgstrasse 9, a few minutes walk from the town centre or via bus line 306 direction "Roter Hügel" to bus stop "Fröbelstrasse".

Farewell Reception: The farewell reception takes place on Friday, 16 September, after the last talks of the conference in the main conference building NW II. Drinks and snacks will be served.

Excursions on Wednesday Afternoon: Traditionally, there are no talks at MTNS on Wednesday afternoon. Instead, we have arranged three different excursions. Remaining and returned tickets will be available at the conference desk until Wednesday.

Excursion 1: Guided City Walk and Guided Tour through Wagner's Festival Opera House

Excursion 2: Guided Tour through Hermitage Gardens and Palace

Excursion 3: Hiking Tour in Fränkische Schweiz

Please see https://www.mtns2022.uni-bayreuth.de/en/social-prog or your excursion ticket for more information on the excursions.

Bayreuth Baroque Festival: Although not an official part of the MTNS programme, the Bayreuth Baroque Opera Festival takes place during the week of the MTNS. It features opera performances and concerts, some of them in the world heritage site of the Margravial Opera House. This is one of the few occasions in each year for visiting a performance in this world famous baroque opera theatre – some remaining tickets may still be available, see https://www.bayreuthbaroque.de/en/ for details.
Due to the Baroque Festival, the time for tours of the Margravial Opera House is limited during the MTNS week. Detailed information can be found on https://www.bayreuth-wilhelmine.de/deutsch/tourist/Opernhaus_Schliesszeiten.pdf.

Monday, 12 September 2022

Opening: 8:50-9:00, Audimax

Plenary	Session	Session/ Semi Plenary	Session/ Semi Plenary	Session/ Semi Plenary	Session	Session	Session	Session
09:00-10:00 MoP_Audimax Audimax Plenary: Maria Elena Valcher								
	10:30-13:00 MoAM_H16 H 16 Matrix Variables and Matrix Inequalities - I (Hybrid Session)	10:30-13:00 MoAM_H17 H 17 Hybrid Systems: Lyapunov Theory and Controller Design (Hybrid Session)	10:30-13:00 MoAM_H18 H 18 Applications of Coding Theory in Security (Hybrid Session)	10:30-13:00 MoAM_H19 H 19 Learning-Based Methods in Control - I (Hybrid Session)	10:30-13:00 MoAM_H20 H 20 Future Trends in MPC - I	10:30-13:00 MoAM_S70 S 70 Systems Theory: Analysis, Applications, and Methods	10:30-13:00 MoAM_S80 S 80 Distributed Parameter Systems I	10:30-13:00 MoAM_S82 S 82 Modeling and Control of Network Systems (Hybrid Session)
		14:00-15:00 MoSP_H17 H 17 Semi Plenary: Roland Herzog	14:00-15:00 MoSP_H18 H 18 Semi Plenary: Christopher M. Kellett	14:00-15:00 MoSP_H19 H 19 Semi Plenary: Yann Le Gorrec				
	15:30-18:00 MoPM_H16 H 16 Matrix Variables and Matrix Inequalities - II (Hybrid Session)	15:30-18:00 MoPM_H17 H 17 Dissipativity Theory I: Dissipativity and Optimal Control (Hybrid Session)	15:30-18:00 MoPM_H18 H 18 Algebraic Theory of Block and Convolutional Codes (Hybrid Session)	15:30-18:00 MoPM_H19 H 19 Learning-Based Methods in Control - II (Hybrid Session)	15:30-18:00 MoPM_H20 H 20 Future Trends in MPC - II	15:30-18:00 MoPM_S70 S 70 Hybrid and Switched Systems	15:30-18:00 MoPM_S80 S 80 Distributed Parameter Systems II	15:30-18:00 MoPM_S82 S 82 Networked Control Systems - I (Hybrid Session)

Tuesday, 13 September 2022

Plenary	Session	Session/ Semi Plenary	Session	Session/ Semi Plenary	Session/ Semi Plenary	Session	Session
09:00-10:00 TuP_Audimax Audimax Plenary: Weinan E							
	10:30-13:00 TuAM_H16 H 16 Algebraic and Geometric Approaches to Systems Structure and Control - I (Hybrid Session)	10:30-13:00 TuAM_H17 H 17 Dissipativity Theory II: Stability Analysis (Hybrid Session)	10:30-13:00 TuAM_H18 H 18 Data-Driven Agent-Based Modeling (Hybrid Session)	10:30-13:00 TuAM_H19 H 19 Learning-Based Methods in Control - III (Hybrid Session)	10:30-13:00 TuAM_S70 S 70 Adaptive Control	10:30-13:00 TuAM_S80 S 80 Infinite-Dimensional Input-To-State Stability	10:30-13:00 TuAM_S82 S 82 Hamilton-Jacobi Equations and Mean Field Games - I (Hybrid Session)
		14:00-15:00 TuSP_H17 H 17 Semi Plenary: Sanne Ter Horst	14:00-15:00 TuSP_H18 H 18 Semi Plenary: Achim Ilchmann	14:00-15:00 TuSP_H19 H 19 Semi Plenary: Claudia Schillings			
	15:30-18:00 TuPM_H16 H 16 Algebraic and Geometric Approaches to Systems Structure and Control - II (Hybrid Session)	15:30-18:00 TuPM_H17 H 17 Dissipativity Theory III: Structure (Hybrid Session)	15:30-18:00 TuPM_H18 H 18 Network Coding (Hybrid Session)	15:30-18:00 TuPM_H19 H 19 Adaptive Control under Input or Output Constraints (Hybrid Session)	15:30-18:00 TuPM_S70 S 70 Control and Optimization of Energy Networks	15:30-18:00 TuPM_S80 S 80 Infinite-Dimensional Systems Theory	15:30-18:00 TuPM_S82 S 82 Hamilton-Jacobi Equations and Mean Field Games - II (Hybrid Session)

Wednesday, 14 September 2022

Plenary	Mini Course	Session	Session	Session	Session	Session	Session
09:00-10:00 WeP_Audimax Audimax Plenary: Claudio De Persis							
	10:30-13:00 WeAM_H16 H 16 Mini Course: Measure Differential Equations	10:30-13:00 WeAM_H17 H 17 Dissipativity Theory IV: Nonlinear Systems (Hybrid Session)	10:30-13:00 WeAM_H18 H 18 Codes and Geometry (Hybrid Session)	10:30-13:00 WeAM_H19 H 19 Lifting Techniques for Data-Driven Modeling and Control (Hybrid Session)	10:30-13:00 WeAM_H20 H 20 Turnpike Phenomenon for Optimal Control Problems	10:30-13:00 WeAM_S80 S 80 Distributed Parameter Systems III	10:30-13:00 WeAM_S82 S 82 Control in and Around Human-Computer Interaction (Hybrid Session)

Thursday, 15 September 2022

Plenary	Session	Mini Course/ Session/ Semi Plenary	Session/ Semi-Plenary	Session/ Semi Plenary	Session	Session	Session	Session
09:00-10:00 ThP_Audimax Audimax Plenary: Luz De Teresa								
	10:30-13:00 ThAM_H16 H 16 Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations - I (Hybrid Session)	10:30-13:00 ThAM_H17 H 17 Mini Course: Infinite-Dimensional Port-Hamiltonian Systems	10:30-13:00 ThAM_H18 H 18 Data-Based Learning and Control Theory - I	10:30-13:00 ThAM_H19 H 19 Optimal Transport in Networks and Systems (Hybrid Session)				
		14:00-15:00 ThSP_H17 H 17 Semi Plenary: Jacquelien M.A. Scherpen	14:00-15:00 ThSP_H18 H 18 Semi Plenary: Anna-Lena Horlemann	14:00-15:00 ThSP_H19 H 19 Semi Plenary: Na Li				
	15:30-18:00 ThPM_H16 H 16 Circuit Synthesis - I: Signals, Systems, and Circuits (Hybrid Session)	15:30-18:00 ThPM_H17 H 17 Structure-Preserving Discretization of Dynamical Systems - I (Hybrid Session)	15:30-18:00 ThPM_H18 H 18 Data-Based Learning and Control Theory - II	15:30-18:00 ThPM_H19 H 19 Data-Driven Methods for Reduced-Order Modelling and Control - I	15:30-18:00 ThPM_H20 H 20 Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations - II	15:30-18:00 ThPM_S70 S 70 Nonlinear Systems	15:30-18:00 ThPM_S80 S 80 Infinite-Dimensional Port-Hamiltonian Systems	15:30-18:00 ThPM_S82 S 82 Hamilton-Jacobi Equations and Mean Field Games - III (Hybrid Session)

Conference Dinner: 19:00-late, Herzogkeller

Friday, 16 September 2022

Plenary	Session	Session/ Semi Plenary	Session/ Semi Plenary	Session/ Semi Plenary	Session	Session	Session	Session
09:00-10:00 FrP_Audimax Audimax Plenary: George Weiss								
	10:30-13:00 FrAM_H16 H 16 Circuit Synthesis - II: Network Synthesis (Hybrid Session)	10:30-13:00 FrAM_H17 H 17 Structure-Preserving Discretization of Dynamical Systems - II (Hybrid Session)	10:30-13:00 FrAM_H18 H 18 Quantum Control (Hybrid Session)	10:30-13:00 FrAM_H19 H 19 Data-Driven Methods for Reduced-Order Modelling and Control - II	10:30-13:00 FrAM_H20 H 20 Moment Problems, Convex Algebraic Geometry, and Semidefinite Relaxations - III	10:30-13:00 FrAM_S70 S 70 Networked Control Systems - II	10:30-13:00 FrAM_S80 S 80 Model Predictive Control	10:30-13:00 FrAM_S82 S 82 Hamilton-Jacobi Equations and Mean Field Games - IV (Hybrid Session)
		14:00-15:00 FrSP_H17 H 17 Semi Plenary: Masaaki Nagahara	14:00-15:00 FrSP_H18 H 18 Semi Plenary: Boris Houska	14:00-15:00 FrSP_H19 H 19 Semi Plenary: Dante Kalise				
	15:30-18:00 FrPM_H16 H 16 Advances in Algorithmic Trading (Hybrid Session)	15:30-18:00 FrPM_H17 H 17 Structure-Preserving Discretization of Dynamical Systems - III (Hybrid Session)	15:30-18:00 FrPM_H18 H 18 Systems Theory and Geometry (Hybrid Session)	15:30-18:00 FrPM_H19 H 19 Data-Driven Sensing, Modeling, and Control (Hybrid Session)	15:30-18:00 FrPM_H20 H 20 Operator-Theoretic Methods and Linear Systems Theory	15:30-18:00 FrPM_S70 S 70 Networked Control Systems - III	15:30-18:00 FrPM_S80 S 80 Estimation and Filtering	15:30-18:00 FrPM_S82 S 82 Hamilton-Jacobi Equations and Mean Field Games - V (Hybrid Session)

Farewell Reception: 17:30-19:30, Foyer NW II buildung

Some morning sessions end at 12:10 or at 12:35 and some afternoon sessions end at 17:10 or at 17:35.

Plenary Speakers and Talks

Maria Elena Valcher (University of Padova, Italy)

Opinion dynamics models: A mathematical abstraction of individuals' behaviours and interactions

(plenary talk, Monday 9:00, Audimax)

Abstract. The talk will focus on the main mechanisms influencing opinion dynamics, like homophily, mutual appraisal, and bounded confidence. Some classic opinion dynamics models, as well as some recent ones, will be presented. Interesting open problems as well as promising research directions will be proposed.

Short biography. M. Elena Valcher (Ph.D., 1995) is a Professor of Control Theory at the University of Padova since 2005.

She is an IEEE Fellow since 2012, a member of IFAC Technical Board since 2017 and the Italian Representative in EUCA since 2017. She is currently the co-General Chair (together with Andrea Serrani) of the 2022 IEEE Conference on Decision and Control.
She was the 2015 President of the IEEE Control Systems Society. She is the (founding) Editor-in-Chief of the *IEEE Control Systems Letters* (2017-), and she served as AE in several Editorial Boards, including *IEEE Trans. Automatic Control*, *Systems Control Letters*, *Automatica*, *SIAM J. Control Optimization* and *IEEE Access* (2014-2019). She is the author of more than 90 journal papers, and approximately 110 conference papers.

Her current research interest include multi-agent systems, social networks, positive systems, and Boolean control networks.

Weinan E (Peking University, China and Princeton University, NJ, USA)

Deep Learning and Optimal Control

(plenary talk, Tuesday 9:00, Audimax)

Abstract. There is a close analogy between deep learning and optimal control. This analogy can be exploited to develop deep learning-based algorithms for optimal control, and optimal control-based algorithms for deep learning. I will discuss the progress made along these directions.

Short biography. Weinan E is a professor at Peking University and in the Department of Mathematics and Program in Applied and Computational Mathematics at Princeton University. He got his Ph.D. from UCLA in 1989 and afterwards held visiting positions at NYU and the Institute for Advanced Study. He was on the faculty of the Courant Institute from 1994 to 1999 before moving to Princeton.

Weinan E was awarded the ICIAM Collatz Prize in 2003, the SIAM Kleinman Prize in 2009 and the SIAM von Karman Prize in 2014, the SIAM-ETH Peter Henrici Prize in 2019. He is a member of the

Chinese Academy of Sciences, a fellow of SIAM, AMS and IOP. Weinan E has been an invited speaker at ICM, ICIAM as well as the AMS National Meeting. He has also been an invited speaker at APS, ACS, AIChe annual meetings and the American Conference of Theoretical Chemistry.

Weinan E's main research interest is numerical algorithms, machine learning and multi-scale modeling, with applications to chemistry, material sciences and fluid mechanics. In recent years, he has also developed an interest in control theory.

Claudio De Persis (University of Groningen, The Netherlands)

On data-driven control

(plenary talk, Wednesday 9:00, Audimax)

Abstract. We present a technique to design controllers from data for systems whose model is imprecisely known. The technique is based on collecting measurements of low complexity from the systems and using them for the synthesis of controllers, which is reduced to the solution of data-dependent semidefinite programs. The method provides stability certificates in the presence of perturbations on the dataset.

Short biography. Claudio De Persis is a professor with the Engineering and Technology Institute (ENTEG), Faculty of Science and Engineering, University of Groningen, the Netherlands, since 2011. He is also affiliated with the Jan Willems Center for Systems and Control. He received the Laurea and Ph.D. degrees in engineering in 1996 and 2000 both from the University of Rome "La Sapienza", Rome, Italy, and held positions at the University of Twente, the University of Rome "La Sapienza", Washington University, St. Louis, MO, USA, and Yale University, New Haven, CT, USA.

He was an Editor of the International *Journal of Robust and Nonlinear Control* (2006-2013), an Associate Editor of the *IEEE Transactions on Control Systems Technology* (2010-2015), the *IEEE Transactions on Automatic Control* (2012-2015), *Automatica* (2013-2021) and the *IEEE Control Systems Letters* (2017-2021).

His main research interest is in automatic control, and his recent research focuses on data-driven control and learning for control.

Luz de Teresa (National Autonomous University of Mexico, Mexico City, Mexico)

Some results on hierarchical control for parabolic equations

(plenary talk, Thursday 9:00, Audimax)

Abstract. In classical control theory, we usually have a state equation or system and just one control, with the mission of achieving a predetermined goal. Sometimes, the goal is to minimize a cost function in a prescribed family of admissible controls; this is the optimal control viewpoint. A more interesting situation arises when several (in general, conflictive or contradictory) objectives are considered. This may happen, for example, if the cost function is the sum of several terms and it is not clear how to average. It can also be expectable to have more than one control acting on the equation.
In this talk, we present an overview of the known results on this subject for the heat equation. We will recall the results of Araruna and collaborators where hierarchic exact controllability results were established for linear and semilinear heat equations. In this research, and in the seminal papers by J.-L. Lions, the main idea is to work with one primary control (the leader) and one or several secondary controls (the followers). For each possible leader, the associated followers try to minimize a functional (or reach equilibrium if there is more than one cost objective function). Then, the leader is chosen such that the associated state satisfies a final time constraint. We will present the recent result with E. Fernández-Cara et al., where we accomplish optimal control and controllability tasks with a hierarchy of controls. This time, however, the controllability goal will be commended to the follower, while the choice of the leader will be subject to an optimal control problem. It will be seen that this makes the problem more difficult to handle (essentially because we must work all the time in a very restrictive class of leader controls).

Short biography. Luz de Teresa did her undergraduate studies in mathematics at the Faculty of Sciences of the UNAM (National Autonomous University of Mexico). She obtained her professional degree in April 1990. With a grant from the DGAPA-UNAM, she received a Ph.D. in Applied Mathematics at the Complutense University of Madrid. She entered as a researcher at the Institute of Mathematics of the UNAM in April 1995, where she continues to work. She collaborates with mathematicians and engineers from Mexico, France, Spain, Chile, Brazil, the United States, Italy, Romania and Argentina.

So far she has 49 research articles published in highly recognized journals. These works have received more than 700 citations. She also works in the field of teaching and training of young researchers and students, as well as in terms of the design and development of national and international research projects, and the organization of numerous relevant academic events. She is currently a member of the UNAM Governing Board and was president of the Mexican Mathematical Society (SMM) for the 2018-2020 period. Finally, Dr. de Teresa is a member of various editorial committees in international journals.

The central theme of Prof. de Teresa's works is the control of coupled parabolic equations and related problems.

George Weiss (Tel Aviv University, Israel)

Lax-Phillips semigroups for nonlinear systems

(plenary talk, Friday 9:00, Audimax)

Abstract. We briefly recall the basics about Lax-Phillips semigroups for well-posed linear systems, and the definition of well-posed nonlinear systems via nonlinear Lax Phillips semigroups. Then we concentrate on two results concerning well-posed nonlinear systems:

We investigate a special class of nonlinear systems that are obtained by modifying the second order differential equation that is part of the description of conservative linear systems "out of thin air" introduced by M. Tucsnak and G. Weiss in 2003. The differential equation contains a nonlinear damping term that is maximal monotone and possibly set-valued. We show that this new class of nonlinear systems is incrementally scattering passive (hence well-posed). Our approach uses the theory of maximal monotone operators and the Crandall-Pazy theorem about nonlinear contraction semigroups, which we apply to the Lax-Phillips semigroup of the system.

We investigate the class of incrementally scattering passive nonlinear systems, as defined in some earlier papers of ours. We show that these can be defined by a differential inclusion and a formula defining the current output in term of the current state and the current input. Our approach uses the theory of maximal monotone operators.

The talk is based on joint work with Shantanu Singh.

Short biography. George Weiss is professor of control engineering in the School of EE, Tel Aviv University. He received the M.Eng. degree in control engineering from the Polytechnic Institute of Bucharest, Romania, in 1981, and the Ph.D. degree in applied mathematics from Weizmann Institute, Rehovot, Israel, in 1989. He has been with Brown University, Providence, RI, USA, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, Ben-Gurion University, Beer Sheva, Israel, University of Exeter, Exeter, UK, and Imperial College London, UK.

He is a co-author, with M. Tucsnak, of the book "*Observation and Control for Operator Semigroups*", Birkhäuser, 2009, and leading research projects for the European Commission and for the Israeli Ministry of Energy.

His research interests include distributed parameter systems, operator semigroups, passive and conservative systems (linear and nonlinear), power electronics, the stability of power grids, repetitive control, sampled data systems, and wind-driven power generators.

Semi-Plenary Speakers and Talks

Roland Herzog (University of Heidelberg, Germany)

The role of the metric in numerical linear algebra and optimization (semi-plenary talk, Monday 14:00, H17)

Abstract. Many algorithms in everyday use implicitly employ the Euclidean inner product of the underlying space. While this is convenient and user-friendly on the one hand, it also turns out that the Euclidean metric may not be the one yielding the best performance of the respective algorithm. In this talk we revisit the role of the metric in a number of well-known algorithms in numerical linear algebra and optimization, and demonstrate the potential of user-defined metrics in each case.

Short biography. Roland Herzog has been Professor for Scientific Computing and Optimization at the Interdisciplinary Center for Scientific Computing of the University of Heidelberg, Germany, since 2021. Before that, he held positions at the Technische Universität Chemnitz, Germany, at RICAM in Linz, Austria, at the Karl Franzens University Graz, Austria, where he obtained his Habilitation in 2008, and at the University of Bayreuth, Germany, where he obtained his Ph.D. in 2003. He also held a visiting position at the University of British Columbia, Vancouver, Canada.

Prof. Herzog is Editorial board member for *Advances in Discrete and Continuous Models*, *SMAI Journal of Computational Mathematics*, *SIAM Journal on Control and Optimization*, *SIAM Journal on Numerical Analysis*, *Journal of Optimization Theory and Applications*, *Electronic Transactions on Numerical Analysis*, *OPTPDE Problem Collection*, and *Optimization Methods and Software*.

His research interests lie in the area of optimal control and optimization with partial differential equations.

Christopher M. Kellett (Australian National University, Canberra, Australia)

Discontinuous Feedbacks for Stabilization and Combined Stabilization and Safety (semi-plenary talk, Monday 14:00, H18)

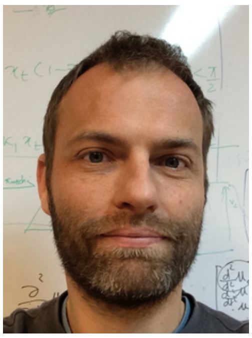
Abstract. It has long been known that asymptotic controllability of a nonlinear system to a desired equilibrium or target set require discontinuous controllers for feedback stabilization, which, in turn, is equivalent to the existence of a nonsmooth control Lyapunov function. More recently, results combining stabilization and safety, captured by so-called barrier functions, have been proposed. This also gives rise to the need for discontinuous feedback controllers, though for slightly different reasons. In this talk, we summarise these results and present a hybrid feedback solution to the combined stabilization and safety problem for a non-trivial class of systems.

Short biography. Christopher M. Kellett received the B.Sc. degree in electrical engineering and mathematics from the University of California, Riverside, and the M.Sc. and Ph.D. degrees in electrical and computer engineering from the University of California, Santa Barbara in 1997, 2000, and 2002, respectively. Chris has held research positions with the Centre Automatique et Systèmes at École des Mines de Paris, Paris, France; the University of Melbourne; and the Hamilton Institute at National University of Ireland, Maynooth. From 2006 until 2020 he was with the University of Newcastle, Australia. Since February 2020 he has been the Director of the School of Engineering at the Australian National University.

Chris is a Senior Editor for the *IEEE Transactions on Automatic Control* and an Associate Editor for *Mathematics of Control, Signals and Systems*. He has previously served on the editorial boards for *IEEE CSS Letters* and the *European Journal on Control*. He has been the recipient of an Australian Research Council Future Fellowship (2011-2015), an Alexander von Humboldt Research Fellowship (2012-2013), the 2012 IET Control Theory and its Applications Premium Award, and the inaugural IFAC Foundation Award (2017).

His research interests are broadly in the area of systems and control theory and applications, with specific emphases on stability and robustness properties for nonlinear systems.

Yann Le Gorrec (National Engineering Institute in Mechanics and Microtechnologies "ENSMM", Besançon, France)



Control design for distributed parameter systems – the port Hamiltonian approach (semi-plenary talk, Monday 14:00, H19)

Abstract. This talk is concerned with the control of distributed parameter systems defined on a 1D spatial domain using the port Hamiltonian framework. We consider two different cases: when actuators and sensors are located within the spatial domain and when the actuator is situated at the boundary of the spatial domain, leading to a boundary control system (BCS). In the first case we show how dynamic extensions and structural invariants can be used to change the internal properties of the system when the system is fully actuated, and how it can be done in an approximate way when the system is actuated using piecewise continuous actuators stemming from the use of patches. Asymptotic stability is achieved using damping injection. In the boundary-controlled case we show how the closed loop energy function can be partially shaped, modifying the minimum and a part of the shape of this function and how damping injection can be used to guarantee asymptotic convergence. We end with some some extensions of the proposed results to irreversible thermodynamic systems.

Short biography. Yann Le Gorrec is full Professor at National Engineering Institute in Mechanics and Microtechnologies of Besançon, France. He is the director of the AS2M department of the FEMTO-ST institute. His current field of research is the control of nonlinear systems and Distributed Parameter Systems with an application to smart material based actuators, micro systems, irreversible thermodynamic systems and fluid structure interactions by using the port Hamiltonian framework.

He has co-authored more than 220 publications (among which more than 60 journal papers and 30 invited plenary talks) and has been the coordinator of numerous collaborative research projects. He is an Associate Editor for *IEEE Transactions on Automatic Control* and *Systems and Control Letters*.

He has been the chair of the IEEE Technical Committee DPS from 2016 to 2019 and is currently the chair of the IFAC TC 2.6 on Distributed Parameter Systems and member of IFAC TC2.1 Control Design, TC2.3 Control of Nonlinear Systems , and TC2.6 Distributed Parameter Systems.

Sanne ter Horst (North-West University, Potchefstroom, South Africa)

Convex invertible cones and Nevanlinna-Pick interpolation

(semi-plenary talk, Tuesday 14:00, H17)

Abstract. Nevanlinna-Pick interpolation developed from a topic in classical complex analysis to a useful tool for solving various problems in control theory and electrical engineering. Over the years many extensions of the original problem were considered, including extensions to different function spaces, nonstationary problems, several variable settings and interpolation with matrix and operator points. In this talk we discuss a variation on Nevanlinna-Pick interpolation for positive real odd functions evaluated in real matrix points. This problem was studied by Cohen and Lewkowicz using convex invertible cones and the Lyapunov order, making interesting connections with stability theory. The solution requires an analysis of linear matrix maps using representations that go back to work of R.D. Hill from the 1970s and focusses, in particular, on the question when positive linear matrix maps are completely positive. If time permits, some possible extensions to multidimensional systems will briefly be discussed.

Short biography. Sanne ter Horst received his Ph.D. in Mathematics (operator theory) at the VU Amsterdam in the Netherlands in 2007. During his Ph.D. studies he received a training in system and control theory from the Dutch Institute of Systems and Control. After a postdoctoral fellowship at Virginia Tech and assistant professor positions at Utrecht University and Radboud University Nijmegen, he moved to South Africa where he is now a full professor in mathematics at North-West University.

He is currently an associate editor at *Quaestiones Mathematicae* and *Complex Analysis and Operator Theory*, where he manages the Linear Operators and Linear Systems section, and has been on the council of the South African Mathematical Society since 2013 in various portfolios.

The focus of his research is on operator theory and matrix analysis methods with applications in system and control theory. More specifically, he has recently worked on metric constrained interpolation, infinite dimensional systems, structured systems and control problems, noncommutative multidimensional systems, and inverse problems.

Achim Ilchmann (Technische Universität Ilmenau, Germany)

Funnel control – history and perspectives

(semi-plenary talk, Tuesday 14:00, H18)

Abstract. The control objective in funnel control is output feedback control such that the norm of the error $e(t)$ of the closed-loop system remains inside a prespecified funnel with boundary $\psi(t)$, i.e. $\|e(t)\| < \psi(t)$ for all $t > 0$. In other words, prescribed transient behaviour as well as asymptotic accuracy is achieved.

Typical features of funnel control are:

- Simplicity of the feedback law. The feedback does not invoke any identification scheme, but is – for example in the relative degree one case – a time-varying error feedback of the form $u(t) = -1 / (1 - \psi(t) \|e(t)\|)\, e(t)$, $e(t) := y(t) - y_{ref}(t)$, where $y_{ref}(\cdot)$ denotes a sufficiently smooth bounded signal with bounded derivative. Note that the gain $k(t) = -1 / (1 - \psi(t) \|e(t)\|)$ is large if, and only if, the error is close to the funnel boundary.
- Funnel control is feasible for a whole class of input-output systems. These classes are described by structural assumptions the systems have to satisfy.

After two decades of high-gain adaptive control, funnel control was introduced in 2002. First results were on linear, single-input, single-output, time-invariant systems with relative degree one and being minimum phase. From then on feasibility of funnel control was shown for other system classes such as multi-input, multi-output, nonlinear, infinite dimensional, perturbed systems, unknown control directions – provided they have stable zero dynamics and satisfy certain assumptions on the high-frequency gain. A particular challenge was to show feasibility for systems with higher relative degree, and to design a funnel controllers for systems described by partial differential equations. Funnel control was applied to various applications such as control in chemical reactor models, industrial servo-systems, wind turbine systems, electrical circuits, to name but a few. Recently, funnel control has been investigated in combination with model predictive control and applied to magnetic levitation systems.

Short biography. Achim Ilchmann obtained the Ph.D. in Mathematics in 1987 at the Universität Bremen, supervised by Professor Diederich Hinrichsen, and received his Habilitation in 1993 from the Universität Hamburg. From 1996 until 2000 he was Lecturer and Reader in Applied Mathematics at the Dept. of Mathematics of the University of Exeter, UK. Since 2000 he holds a Chair in Mathematics at the Institut für Mathematik of the Technische Universität Ilmenau, Germany.

Professor Ilchmann supervised 10 Ph.D. students and published 100 refereed journal papers, 3 books on mathematics, and 2 books on baroque architecture. Since 2003 he is the principle organizer of the annual Elgersburg Workshop on Mathematical Systems Theory.

His research interests include time-varying linear systems, adaptive control of nonlinear systems, and differential-algebraic equations.

Claudia Schillings (Free University Berlin, Germany)

A General Framework for Machine Learning-based Optimization Under Uncertainty

(semi-plenary talk, Tuesday 14:00, H19)

Abstract. Approaches to decision making and learning mainly rely on optimization techniques to achieve "best" values for parameters and decision variables. In most practical settings, however, the optimization takes place in the presence of uncertainty about model correctness, data relevance, and numerous other factors that influence the resulting solutions. For complex processes modeled by nonlinear ordinary and partial differential equations, the incorporation of these uncertainties typically results in high or even infinite dimensional problems in terms of the uncertain parameters as well as the optimization variables, which in many cases are not solvable with current state of the art methods. One promising potential remedy to this issue lies in the approximation of the forward problems using novel techniques arising in uncertainty quantification and machine learning.
We propose in this talk a general framework for machine learning based optimization under uncertainty and inverse problems. Our approach replaces the complex forward model by a surrogate, e.g. a neural network, which is learned simultaneously in a one-shot sense when estimating the unknown parameters from data or solving the optimal control problem. By establishing a link to the Bayesian approach, an algorithmic framework is developed which ensures the feasibility of the parameter estimate / control w.r. to the forward model.
This is joint work with Philipp Guth (U Mannheim) and Simon Weissmann (U Heidelberg).

Short biography. Claudia Schillings is Professor in Numerical Analysis of stochastic and deterministic PDEs at the Institute for Mathematics, FU Berlin. Claudia Schillings received her Ph.D. degree from the Department of Mathematics, University of Trier (Germany) in 2011. After two and half years of postdoctoral activity at ETH Zurich (Switzerland) and two years at the University of Warwick (UK), she was visiting professor at the Humboldt University Berlin (Germany) in 2015-2016, professor at the University of Mannheim in 2017-2022 and then moved to Berlin.

Jacquelien M. A. Scherpen (University of Groningen, The Netherlands)

Extended (differential) balancing for model reduction of linear and nonlinear dynamical systems

(semi-plenary talk, Thursday 14:00, H17)

Abstract. In this talk, we will develop extended balancing and its structure preservation possibilities for linear systems, as well as extended balancing theory for nonlinear systems in the contraction framework. For the latter, we introduce the concept of the extended differential observability Gramian and inverse of the extended differential controllability Gramian for nonlinear dynamical systems and show their correspondence with generalized differential Gramians. We also provide how extended (differential) balancing can be utilized for model reduction to get a smaller apriori error bound in comparison with generalized (differential balancing). We will focus on preserving the structure of a port-Hamiltonian system with help of extended balancing in both the linear and nonlinear systems setting.

Short biography. Jacquelien Scherpen received her MSc and PhD M.Sc. and Ph.D. degrees in 1990 and 1994 from the University of Twente, the Netherlands. She then joined Delft University of Technology and moved in 2006 to the University of Groningen as a professor in Systems and Control Engineering at the Engineering and Technology institute Groningen (ENTEG), Faculty of Science and Engineering at the University of Groningen, the Netherlands. From 2013 til 2019 she was scientific director of ENTEG. She is currently director of the Groningen Engineering Center, and Captain of Science of the Dutch top sector High Tech Systems and Materials (HTSM). Jacquelien has held various visiting research positions, such as at the University of Tokyo, and Kyoto University, Japan, Université de Compiegne, and SUPÉLEC, Gif-sur-Yvette, France, and Old Dominion University, VA, USA.

Jacquelien has been and is at the editorial board of a few international journals among which the *IEEE Transactions on Automatic Control*, and the *International Journal of Robust and Nonlinear Control*. She received the 2017-2020 Automatica Best Paper Prize. In 2019 she received a royal distinction and is appointed Knight in the Order of the Netherlands Lion, and she is a fellow of IEEE. She has been active at the International Federation of Automatic Control (IFAC), and is currently member of the IFAC council. She is a member of the Board of Governors of the IEEE Control Systems Society, and was chair of the IEEE CSS standing committee on Women in Control in 2020. From 2020 to 2021 she is president of the European Control Association (EUCA).

Her current research interests include model reduction methods for networks, nonlinear model reduction methods, nonlinear control methods, modeling and control of physical systems with applications to electrical circuits, electromechanical systems, mechanical systems, smart energy networks and distributed optimal control applications to smart grids.

Anna-Lena Horlemann-Trautmann (University of St. Gallen, Switzerland)

The densities of good codes in various metric spaces

(semi-plenary talk, Thursday 14:00, H18)

Abstract. The densities of codes with certain properties have always been of interest in classical coding theory, in particular to understand how many of such codes exist and how likely a random code will have the prescribed properties. Further applications of density results of codes appear in code-based cryptography, where it is important that the set of codes with a certain property is large enough to outgo brute force attacks. In this talk we will present various density results for optimal or close-to-optimal codes in different metric spaces with different types of linearity. In particular, we will show when optimal codes in the Hamming, rank and sum-rank metric are dense and when they are sparse.

Short biography. Anna-Lena Horlemann-Trautmann received the Diploma degree in mathematics from the University of Bochum, Germany, in 2007 and the Ph.D. degree in mathematics from the University of Zurich, Switzerland, in 2013. From 2013 until 2015 she was a research fellow at the Department of Electrical and Electronic Engineering at the University of Melbourne and at the Department of Electrical and Computer Systems Engineering at Monash University, both in Melbourne, Australia. She was a Postdoctoral fellow at the EPF Lausanne, Switzerland, from 2015 until 2017, before becoming an assistant professor for mathematics and information technology at the University of St. Gallen in Switzerland. Since 2021 she is an associate professor at the School of Computer Science at the University of St. Gallen.

Professor Horlemann-Trautmann is a member of the Editorial Board of *Advances in Mathematics of Communication* and an Associate Editor for the *IEEE Transactions on Information Theory*.

Her research interests lie in Algebraic Coding Theory and post-quantum cryptography.

Na Li (Harvard University, Cambridge, MA, USA)

Learning decentralized policies in Multiagent Systems: How to learn efficiently and what are the learned policies? (semi-plenary talk, Thursday 14:00, H19)

Abstract. Multiagent reinforcement learning has received a growing interest with various problem settings and applications. We will first present our recent work in learning decentralized policies in networked multiagent systems under a cooperative setting. Specifically, we propose a policy gradient-based method that exploits the network structure and finds a local, decentralized policy that is a close approximation of a first-order stationary point of the global objective with complexity that scales with the local state-action space size. Motivated by the question of characterizing the performance of the stationary points, we look into the case where states could be shared among agents but agents still need to take actions following decentralized policies. We show that even when agents have identical interests, the first-order stationary points are only corresponding to Nash equilibria. This observation naturally leads to the use of the stochastic game framework to characterize the performance of policy gradients for decentralized policies in multiagent MDP systems. We will present some of our recent findings on both the local and global geometry of stochastic games.

Short biography. Na Li is a Gordon McKay professor in Electrical Engineering and Applied Mathematics at Harvard University. She received her B.S. degree in Mathematics from Zhejiang University in 2007 and Ph.D. degree in Control and Dynamical systems from California Institute of Technology in 2013. She was a postdoctoral associate at the Massachusetts Institute of Technology 2013-2014. Her research lies in the control, learning, and optimization of networked systems, including theory development, algorithm design, and applications to cyber-physical societal systems.

She received NSF career award (2016), AFSOR Young Investigator Award (2017), ONR Young Investigator Award (2019), Donald P. Eckman Award (2019), McDonald Mentoring Award (2020), along with some other awards.

Masaaki Nagahara (The University of Kitakyushu, Japan)

Compressed sensing and maximum hands-off control

(semi-plenary talk, Friday 14:00, H17)

Abstract. Compressed sensing has been actively researched in the field of signal processing and machine learning. More recently, the method has been applied to control problems. In this talk, we will briefly review compressed sensing for vectors, and then introduce the maximum hands-off control for continuous-time systems, which aims at finding the sparsest control under control constraints.

Short biography. Masaaki Nagahara received the bachelor's degree in engineering from Kobe University in 1998, and the master's degree and the doctoral degree in informatics from Kyoto University in 2000 and 2003, respectively. He is currently a Full Professor with the Institute of Environmental Science and Technology, The University of Kitakyushu. He has been a visiting professor with Indian Institute of Technology (IIT) Bombay since 2017, and IIT Guwahati since 2020.

He received the Transition to Practice Award in 2012 and the George S. Axelby Outstanding Paper Award in 2018 from IEEE Control Systems Society. He also received the Young Authors Award in 1999, Best Paper Award in 2012, Best Book Authors Award in 2016, and SICE Control Division Research Award (Kimura Award) in 2020 from SICE, and the Best Tutorial Paper Award in 2014 from IEICE Communications Society. He is a senior member of IEEE, and a member of SICE, ISCIE, IEICE, JSME, and RSJ.

His research interests include control theory, machine learning, and signal processing.

Boris Houska (ShanghaiTech University, China)

Global Optimal Control: Opportunities and Challenges

(semi-plenary talk, Friday 14:00, H18)

Abstract. Optimal control theory, algorithms, and software for analyzing and computing local solutions of linear and nonlinear optimal control problems have reached a high level of maturity, finding their way into industry. In the context of many applications, locally optimal control inputs can be computed within the milli- and microsecond range. This is in sharp contrast to the development of algorithms for locating global minimizers of non-convex optimal control problems, which is hindered by several key issues, including the overall complexity of generic optimal control problems and their curse of dimensionality. This talk reviews and discusses recent solutions that address these rather fundamental challenges including novel types of Branch & Lift methods as well as modern Koopman-Pontryagin operator based lifting methods for global optimal control. Various numerical experiments will be used to illustrate the effectiveness of these approaches. The talk concludes with an assessment of the state of the art and highlights important avenues for future research.

Short biography. Boris Houska is an associate professor at the School of Information Science and Technology at ShanghaiTech University. He received a diploma in mathematics and physics from the University of Heidelberg in 2007, and a Ph.D. in Electrical Engineering from KU Leuven in 2011. From

2012 to 2013 he was a postdoctoral researcher at the Centre for Process Systems Engineering at Imperial College London. Subsequently, from 2013-14, he has worked as a research faculty member at Shanghai Jiao Tong University. Moreover, he has held visiting professor positions at the Freiburg Institute for Advanced Studies as well as at the Institute for Microsystems Engineering at the University of Freiburg (both in 2014) and various shorter academic visiting appointments, e.g., at UC Berkeley during Winter 2017 and Imperial College London during Summer 2018.

Boris Houska has been recipient of awards including ICCOPT Best Paper Prize for a Young Researcher in Continuous Optimization (Finalist, Top 3), a Marie-Curie Fellowship for the project Next Generation Algorithms for Robust and Global Optimization of Dynamic Systems, as well as a ShanghaiTech Excellent Professor Award from ShanghaiTech University. His paper on "*ACADO Toolkit — An open source framework for automatic control and dynamic optimization*" has been listed as highly cited paper by Web of Science.

His research interests include numerical optimization and optimal control, set-based robust and global optimization, as well as fast model predictive control algorithms.

Dante Kalise (Imperial College London, UK)

High-dimensional approximation of Hamilton-Jacobi-Bellman PDEs in deterministic optimal control: architectures, algorithms, and applications

(semi-plenary talk, Friday 14:00, H19)

Abstract. Optimal feedback synthesis for nonlinear dynamics -a fundamental problem in optimal control- is enabled by solving fully nonlinear Hamilton-Jacobi-Bellman type PDEs arising in dynamic programming. While our theoretical understanding of dynamic programming and HJB PDEs has seen a remarkable development over the last decades, the numerical approximation of HJB-based feedback laws has remained largely an open problem due to the curse of dimensionality. More precisely, the associated HJB PDE must be solved over the state space of the dynamics, which is extremely high-dimensional in applications such as distributed parameter systems or agent-based models.
In this talk we will review recent approaches regarding the effective numerical approximation of very high-dimensional HJB PDEs. We will explore modern scientific computing methods based on tensor decompositions of the value function of the control problem, and the construction of data-driven schemes in supervised and semi-supervised learning environments. We will highlight some novel research directions at the intersection of control theory, scientific computing, and statistical machine learning.

Short biography. Dante Kalise is Senior Lecturer in Computational Optimisation and Control at the Department of Mathematics, Imperial College London, since 2021. He received B.Sc. and M.Sc. degrees (2008) from the Federico Santa María Technical University in Valparaíso, Chile, and a Ph.D. (2012) from the University of Bergen, Norway. Before joining Imperial, he was Assistant Professor in Applied Mathematics at the University of Nottingham, and held research positions at RICAM Linz, and at La Sapienza University of Rome.

He serves as Associate Editor of *Mathematics of Control, Signals, and Systems*, and of *Advances in Continuous and Discrete Models*.

Dr. Kalise's research interests lie at the interface between scientific computing, optimal control, and PDEs. His current research is centered around the analysis and design of computational methods for the solution of high-dimensional Hamilton-Jacobi-Bellman PDEs and applications in nonlinear feedback control for PDE dynamics and agent-based models across scales.

Mini Courses

Mini-course on Measure Differential Equations: Modeling and Numerical Solution, Wednesday, 10:00-13:00, H16

Organizers:

- Benoît Bonnet (LAAS-CNRS Univ. Toulouse, FR)
- Didier Henrion (LAAS-CNRS Univ. Toulouse, FR and Czech Tech. Univ. Prague, CZ)
- Swann Marx (L2N-CNRS Univ. Nantes, FR)
- Francesco Rossi (Univ. Padova, Italy)

Abstract: This mini-course proposal focuses on numerical methods for solving differential equations on measures, with applications in optimization and control, as well as modeling multi-scale multi-agent systems. Covered material include the moment sums of squares hierarchy and Eulerian schemes.

Keywords: Measure differential equations; Numerical methods; Optimization; Control; Multi-scale modeling; Crowd modeling.

Mini-course schedule:

- **Modeling**
  We describe the optimization and control problems that can be modelled in terms of partial differential equations (PDEs) on probability measures. We present the main existing wellposedness theories which are based on optimal mass transportation, establish the correspondence between non-linear ordinary differential equations (ODEs) and linear transport PDEs, and discuss some of the recent progresses made in this area of the literature. We also present a large number of domains in which measure differential dynamics have been successfully applied, e.g. multi-anticipative road traffic, crowd dynamics, collective behavior in animal groups, supply chains, age-structured populations.

- **Solving**
  We introduce some numerical methods for solving measure PDEs. On the one hand, we describe briefly the moment sums of squares a.k.a. Lasserre hierarchy, originally introduced for polynomial optimization, and later on extended to optimal control of ODEs and more recently to numerical computation of non-linear PDEs. On the other hand, we describe Euler schemes for measure differential equations with non-local terms. The idea is to discretize the measure into a grid, and to let it evolve following some adapted ODE. Convergence is based on optimal transportation strategies that provide a metric tool (the Wasserstein distance) for the study of measure dynamics.

Confirmed speakers:

- Nastassia Pouradier-Duteil (Inria Paris) - Continuum limits of collective dynamics with time-varying weights
- Benoît Bonnet (LAAS-CNRS Toulouse) - Differential inclusions in measure spaces
- Claudia Totzeck (Univ. Wuppertal) - Optimization methods for multi-agent systems
- Didier Henrion (LAAS-CNRS Toulouse) - Tutorial on the moment-SOS aka Lasserre hierarchy
- Swann Marx (LS2N-CNRS Nantes) - Conservation laws solved with the Lasserre hierarchy and the Christoffel-Darboux polynomial

Mini-course on Infinite-dimensional port-Hamiltonian systems
Thursday, 10:00-13:00, H17

Organizers:

- Birgit Jacob (Universität Wuppertal, Germany)
- Timo Reis (TU Ilmenau, Germany)

The theory of port-Hamiltonian systems provides a geometric modelling framework for systems of various physical domains, such as mechanics, electrodynamics and thermodynamics. This approach has its roots in analytical mechanics and starts from the principle of least action, and proceeds, via the Euler-Lagrange equations and the Legendre transform, towards the Hamiltonian equations of motion. This class is further closed under network interconnection. That is, coupling of port-Hamiltonian systems again leads to a port-Hamiltonian system, whence it further allows to describe multi-physical systems, i.e., systems obtained by interaction of several physical domains. The port-Hamiltonian approach further allows the qualitative solution behavior, since it provides an energy balance. Modelling of port-Hamiltonian dynamics may result in various different types of equations, such as ordinary differential equations, differential-algebraic equations, partial differential-algebraic equations and partial differential equations. The latter two types can be reformulated as infinite-dimensional systems, which results in a need for a wide theory of infinite-dimensional port-Hamiltonian systems.

The aim of this mini-course is to give a tutorial on the theory and practice of infinite-dimensional port-Hamiltonian systems. We will provide basics of modelling, analysis and numerics for this class.

In particular, we will treat the following questions in the course:

- What are practical examples of infinite-dimensional port-Hamiltonian systems?
- How is modelling of physical systems by infinite-dimensional port-Hamiltonian systems been done?
- What is known about analysis of infinite-dimensional port-Hamiltonian systems?
- What are appropriate numerical tools for infinite-dimensional port-Hamiltonian systems?
- What are open problems for infinite-dimensional port-Hamiltonian systems?

Confirmed speakers:

- Timo Reis – From finite to infinite-dimensional systems
- Bernhard Maschke – Boundary port-Hamiltonian systems
- Hans Zwart – Analysis for boundary port-Hamiltonian systems
- Paul Kotyczka – From infinite to finite-dimensional systems
- Birgit Jacob – Further results and open problems

Technical Programme

Sessions, Speakers, Titles, and Abstracts

Technical Program for Monday September 12, 2022

MoP_Audimax Audimax

Plenary: Maria Elena Valcher (Plenary Session)

Chair: Worthmann, Karl — TU Ilmenau

09:00-10:00 MoP_Audimax.1

Opinion Dynamics Models: A Mathematical Abstraction of Individuals' Behaviours and Interactions, pp. 1-1

Valcher, Maria Elena — Universita' Di Padova

The talk will focus on the main mechanisms influencing opinion dynamics, like homophily, mutual appraisal, and bounded confidence. Some classic opinion dynamics models, as well as some recent ones, will be presented. Interesting open problems as well as promising research directions will be proposed.

MoAM_H16 H 16

Matrix Variables and Matrix Inequalities - I (Hybrid Session) (Invited Session)

Chair: Ball, Joseph — Virginia Tech

Co-Chair: Pascoe, James Eldred — University of Florida

Organizer: Pascoe, James Eldred — University of Florida

Organizer: Helton, J. William — Univ. of California at San Diego

Organizer: Klep, Igor — University of Ljubljana

10:30-10:55 MoAM_H16.1

Linear-Matrix-Inequality Criteria for Various Notions of Stability/performance (I), pp. 2-5

Ball, Joseph — Virginia Tech

Bolotnikov, Vladimir — College of William and Mary

We review Linear-Matrix-Inequality criteria for various notions of stability and performance for discrete-time autonomous (state/output) linear systems. Here we discuss analogues of all these ideas for a certain class of time-varying discrete-time, state/output linear systems, where output-stability requires that the Z-transform of the output sequence be in a weighted Bergman space over the unit disk rather than in the usual Hardy space over the unit disk.

10:55-11:20 MoAM_H16.2

Positivity Is Undecidable in Tensor Products of Free Algebras (I), pp. 6-6

Slofstra, William — University of Waterloo

Zhao, Yuming — University of Waterloo

This is an extended abstract of a paper ``Positivity is undecidable in tensor products of free algebras'' which is currently in preparation. In quantum information, we are interested in tensor products of free algebras and related algebras, since these tensor products model spatially separated subsystems with entanglement. The recent MIP*=RE result shows that it is undecidable to determine whether an element in the tensor product of two free group algebras is positive in all finite-dimensional representations. This shows that this tensor product is not RFD, resolving the Connes embedding problem. In this work, we show that these tensor products are also not archimedean-closed, by showing that it is undecidable to determine if an element of the tensor product is positive. The result also holds for tensor products of related algebras, like algebra of *-polynomials or the group algebra of a free product of abelian groups.

11:20-11:45 MoAM_H16.3

Existence of Best Low Rank Approximations for Positive Definite Tensors (I), pp. 7-8

Evert, Eric — KU Leuven

De Lathauwer, Lieven — Katholieke Universiteit Leuven

The best low rank tensor approximation problem occurs in a wide variety of applications; however, this problem is strictly speaking not well posed. Indeed, best low rank tensor approximations can fail to exist. In the case that a best low rank approximation fails to exist, computing a near optimal low rank approximation is highly numerically ill-conditioned.

In this talk we will consider the best low rank approximation problem for the special class of tensors which are positive definite. We will show that the set of low rank tensors that are positive definite is relatively closed as a subset of the set of tensors that are positive definite. Using this fact, we will provide a deterministic bound for the existence of a best low rank approximation of a positive definite tensor. We will illustrate through numerical experiments that our bound is highly predictive of numerical errors when attempting to compute a best low rank approximation of a measured tensor.

11:45-12:10 MoAM_H16.4

Separating Invariants for Matrix Tuples up to Similarity (I), pp. 9-9

Volcic, Jurij — Drexel University

The talk considers evaluations of linear matrix pencils on matrix tuples. It is shown that ranks of linear matrix pencils constitute a collection of separating invariants for simultaneous similarity of matrix tuples. Variants of this property for other classical symmetries are discussed, and the relation between rank inequalities and orbit closure membership is addressed.

12:10-12:35 MoAM_H16.5

Noncommutative Nullstellensatz and Perfect Games (I), pp. 10-12

Bene Watts, Adam — University of Waterloo

Klep, Igor — University of Ljubljana

Helton, J. William — Univ. of California at San Diego

The foundations of classical Algebraic Geometry and Real Algebraic Geometry are the Nullstellensatz and Positivstellensatz. Over the last two decades the basic analogous theorems for matrix and operator theory (noncommutative variables) have emerged. This paper concerns commuting operator strategies for nonlocal games, recalls NC Nullstellensatz which are helpful, extends these, and applies them to a very broad collection of games.

The main results of this procedure are two characterizations, based on Nullstellensatz, which apply to games with perfect commuting operator strategies. The first applies to all games and reduces the question of whether or not a game has a perfect commuting operator strategy to a question involving left ideals and sums of squares. Previously, Paulsen and others translated the study of perfect synchronous games to problems entirely involving a $*$-algebra. The characterization we present is analogous, but works for all games. The second characterization is based on a new Nullstellensatz we derive in this paper. It applies to a class of games we call torically determined games, special cases of which are XOR and linear system games. For these games we show the question of whether or not a game has a perfect commuting operator strategy reduces to instances of the subgroup membership problem.

MoAM_H17 H 17

Hybrid Systems: Lyapunov Theory and Controller Design (Hybrid Session) (Invited Session)

Chair: Braun, Philipp — The Australian National University

Co-Chair: Zaccarian, Luca — LAAS-CNRS and University of Trento

Organizer: Braun, Philipp — The Australian National University

Organizer: Zaccarian, Luca — LAAS-CNRS and University of Trento

10:30-10:55 MoAM_H17.1

A Mayer Form for Finite Horizon Hybrid Optimal Control Problems (I), pp. 13-14

Sanfelice, Ricardo | University of California Santa Cruz
Altin, Berk | University of California, Santa Cruz

We consider finite horizon optimal control problems for hybrid plants that are modeled as hybrid equations. To determine key properties of the problem, such as existence and regularity of the optimal cost, we formulate a Mayer form that is tailored to hybrid systems. Within the setting of nominally outer well-posed hybrid plants, and under mild (and standard) regularity conditions, establishing existence of optimal solutions and nice (upper semicontinuous and continuous) dependence of the optimal cost is enabled by the proposed Mayer form. The advantage of the proposed approach is that it does not require additional properties that are typically required in the literature, such as assumptions on the continuous dynamics or that the terminal cost is a control Lyapunov function on the terminal constraint set. The proposed new form is illustrated in examples.

10:55-11:20 MoAM_H17.2

Event-Triggered Observer Design of Nonlinear Systems with Multiple Sensor Nodes (I), pp. 15-18

Petri, Elena | Université De Lorraine
Postoyan, Romain | CRAN, CNRS, Université De Lorraine
Astolfi, Daniele | CNRS - Univ Lyon 1
Nesic, Dragan | Univ of Melbourne
Heemels, Maurice | Eindhoven University of Technology

We investigate the scenario where a perturbed nonlinear system communicates its output measurements to a remote observer via a network. The sensors are grouped into N nodes and each of these nodes decides when its measured data is transmitted over the network independently. Given a (continuous-time) observer, we present an approach to design local (dynamic) transmission policies to obtain accurate state estimates, while only sporadically using the communication network. We prove a practical convergence property to the origin for the estimation error and we show there exists a uniform strictly positive minimum inter-event time for each local triggering rule under mild conditions on the plant. The analysis relies on hybrid Lyapunov tools. The efficiency of the proposed techniques is illustrated on a numerical case study of a flexible robotic arm.

11:20-11:45 MoAM_H17.3

On the Joint Spectral Radius of Shuffled Switched Linear Systems (I), pp. 19-21

Aazan, Georges | Université Paris-Saclay
Girard, Antoine | CNRS
Greco, Luca | CentraleSupélec
Mason, Paolo | L2S CentraleSupélec, CNRS

We present and develop tools to analyze stability properties of discrete-time switched linear systems driven by shuffled switching signals. A switching signal is said to be shuffled if all modes of the system are activated infinitely often. We establish a notion of joint spectral radius related to these systems: the shuffled joint spectral radius (SJSR) which intuitively measures the impact of shuffling on the decay rate of the system's state. We show how this quantity relates to stability properties of such systems. Specifically, from the SJSR, we can build a lower bound on the minimal shuffling rate in order to stabilize an unstable system. Then, we present several methods to approximate the SJSR, mainly by computing lower and upper bounds using Lyapunov methods and some automata theoretic techniques.

11:45-12:10 MoAM_H17.4

Reset Control Analysis and Design for Hybrid Lur'e Dynamical Systems (I), pp. 22-25

Djorge, Agustina | INTEC-CONICET-UNL
Queinnec, Isabelle | LAAS-CNRS
Tarbouriech, Sophie | LAAS-CNRS
Zaccarian, Luca | LAAS-CNRS and University of Trento

We introduce a new class of hybrid Lur'e dynamical systems where a sector nonlinearity may affect both the continuous-time evolution and the reset map acting on suitable closed-loop states, under a time-regularization mechanism ensuring dwell time of solutions. For this class of systems we characterize Lyapunov-based exponential stability conditions exploiting homogeneity of the closed loop. In particular, we show that, with quadratic Lyapunov certificates these conditions can be cast as linear matrix inequalities. We then focus on the control design problem, where both the feedback gains acting on the continuous evolution and the reset action must be designed, in addition to the sets where such resets are triggered, expressed by sign-indefinite quadratic forms. For this control design problem we also show that the synthesis can be performed by solving a set of linear matrix inequalities.

12:10-12:35 MoAM_H17.5

Global Synchronization of a Tree-Like Network of Kuramoto Oscillators (I), pp. 26-29

Mariano, Simone | CRAN, CNRS, Université De Lorraine
Bertollo, Riccardo | Università Degli Studi Di Trento
Postoyan, Romain | CRAN, CNRS, Université De Lorraine
Zaccarian, Luca | LAAS-CNRS and University of Trento

Abstract: We study tree-like networks of leaderless Kuramoto-like non-identical oscillators having time-varying natural frequencies taking values in a compact set. We interconnect the oscillators via a novel class of hybrid coupling rules inducing uniform global practical asymptotic stability of the synchronization set, thereby ensuring global uniform convergence. Moreover, we show that the synchronization set is uniformly globally finite-time stable whenever the coupling function is discontinuous at the origin. Numerical simulation results illustrate the advantage of the proposed model with respect to non-uniform behavior typically found with classical Kuramoto models.

12:35-13:00 MoAM_H17.6

Orchestrating Front and Rear Sensors for Global Stabilization of Unicycles (I), pp. 30-33

Ballaben, Riccardo | University of Trento
Braun, Philipp | The Australian National University
Zaccarian, Luca | LAAS-CNRS and University of Trento

We consider mobile robots described through unicycle dynamics equipped with range sensors and cameras, one in the front and one in the back providing measurements of the distance and misalignment to a target. We derive locally asymptotically stabilizing control laws driving the robot to the target position and orientation. The local control laws are combined into a hybrid global stabilizer, switching between control laws relying on the measurements from the front and rear sensors. Using Lyapunov arguments in the local setting as well as in the hybrid systems formulation, we prove global asymptotic stability of the target set for the hybrid closed-loop system. The results are illustrated on numerical examples.

MoAM_H18 H 18

Applications of Coding Theory in Security (Hybrid Session)
(Invited Session)

Chair: Weger, Violetta | Technical University of Munich
Co-Chair: Wachter-Zeh, Antonia | Technical University of Munich
Organizer: Weger, Violetta | Technical University of Munich
Organizer: Wachter-Zeh, Antonia | Technical University of Munich

10:30-10:55 MoAM_H18.1

Code-Based Digital Signatures: State of the Art and Open

Challenges (I), pp. 34-37

Baldi, Marco — Università Politecnica Delle Marche

The problem of decoding a random-like linear block code is recognized as one of the most important mathematical problems that apparently will remain hard even with the availability of solvers based on quantum computers. This motivates an increasing interest in code-based cryptography as a solution for the design of post-quantum cryptographic primitives. However, while several robust and efficient code-based systems exist for asymmetric encryption and key exchange, mostly stemming from the McEliece and Niederreiter original cryptosystems, devising robust and efficient code-based signature schemes is a far more challenging task. This work provides an overview of past and current approaches to the problem of designing secure and practical code-based signature schemes following two main directions: adapting the McEliece and Niederreiter schemes to the digital signature setting following the classical hash-and-sign approach or deriving digital signatures from code-based identification schemes through suitable transformations.

10:55-11:20 MoAM_H18.2

Towards a Reduction of the Public-Key Size of a Gabidulin Codes Based Encryption Scheme (I), pp. 38-40

Loidreau, PIerre — DGA and IRMAR, Univ Rennes

We exhibit a way to reduce the public-key size of a rank metric based public-key cryptosystem. This approach does not use a structural property of the code but exhibit some particular generator matrices that have a quasi-cyclic like structure.

11:20-11:45 MoAM_H18.3

Fast Kötter–Nielsen–Høholdt Interpolation Over Skew Polynomial Rings (I), pp. 41-46

Bartz, Hannes — German Aerospace Center (DLR)

Jerkovits, Thomas — German Aerospace Center (DLR)

Rosenkilde, Johan — GitHub

Skew polynomials are a class of non-commutative polynomials that have several applications in computer science, coding theory and cryptography. In particular, skew polynomials can be used to construct and decode evaluation codes in several metrics, like e.g. the Hamming, rank, sum-rank and skew metric. We propose a fast divide-and-conquer variant of the Kötter–Nielsen–Høholdt (KNH) interpolation algorithm: it inputs a list of linear functionals on skew polynomial vectors, and outputs a reduced Gröbner basis of their kernel intersection. This can be used to solve the interpolation step of interpolation-based decoding of (interleaved) Gabidulin, linearized Reed—Solomon and skew Reed—Solomon codes efficiently, which have various applications in coding theory and code-based quantum-resistant cryptography.

11:45-12:10 MoAM_H18.4

Recent Advances in Decoding General Lee Metric Codes (I), pp. 47-49

Bariffi, Jessica — German Aerospace Center (DLR)

Khathuria, Karan — University of Tartu

Weger, Violetta — Technical University of Munich

The prospect and demand of using the Lee metric to construct public-key encryption schemes and digital signature schemes have immensely grown in recent times. This leads the researchers to ask about the hardness of decoding a general Lee metric code. In this work, we answer this question by showing that the syndrome decoding problem over the Lee metric is NP-complete. Moreover, we will quantify the computational hardness of the syndrome decoding problem with respect to the best-known ISD algorithms.

12:10-12:35 MoAM_H18.5

Efficient Description of Some Classes of Codes Using Group Algebras (I), pp. 50-55

Chimal-Dzul, Henry — University of Zurich

Gassner, Niklas — University of Zurich

Rosenthal, Joachim — University of Zurich

Schnyder, Reto — University of Zurich

Circulant matrices are an important tool widely used in coding theory and cryptography. A circulant matrix is a square matrix whose rows are the cyclic shifts of the first row. It can be efficiently stored in memory because it is fully specified by its first row. The ring of n ×n circulant matrices can be identified with F[x]/(x n − 1). In consequence, the strong algebraic structure of the ring F[x]/(x n − 1) can be used to study properties of the collection of all n × n circulant matrices. The ring F[x]/(x n − 1) is a special case of a group algebra and elements of any finite dimensional group algebra can be represented with square matrices which are specified by a single column. In this paper we study this representation and prove that it is an injective Hamming weight preserving homomorphism of F-algebras and classify it in the case where the underlying group is abelian. Our work is motivated by the desire to generalize the BIKE cryptosystem (a contender in the NIST competition to get a new post-quantum standard for asymmetric cryptography). Group algebras can be used to design similar cryptosystems or, more generally, to construct low density or moderate density parity-check matrices for codes.

12:35-13:00 MoAM_H18.6

Observer Attack on Stream Ciphers, pp. 56-61

Anantharaman, Ramachandran — Indian Institute of Technology, Bombay

Sule, Virendra — Indian Institute of Technology Bombay

This paper proposes an application of a new observer theory for non-linear systems developed previously to solve the Cryptanalysis problem of a special class of pseudorandom generators which are commonly used in Cryptography. The Cryptanalysis problem addressed here is that of the recovery of internal state of the non-linear dynamic stream generator from the output stream. The proposed methodology is termed as emph{observability attack}. It is also shown that for a special class of generators, the computations are of complexity $O(D^4)$ in pre-computation and of $O(D)$ for online computation, where $D = sum_{i=0}^{d} {n choose i}$ for this class of stream generators with n states and d the degree of the output function. The attack is technically applicable over general finite fields as well as most dynamic systems arising from models of stream ciphers and appropriate bounds on computation are estimated. From these complexity bounds, it follows that this attack is feasible in realistic cases and gives important estimates of time and memory resources required for Cryptanalysis of a class of stream ciphers.

MoAM_H19 H 19

Learning-Based Methods in Control - I (Hybrid Session)
(Invited Session)

Chair: Kang, Wei — Naval Postgraduate School

Co-Chair: Gong, Qi — University of California, Santa Cruz

Organizer: Kang, Wei — Naval Postgraduate School

Organizer: Gong, Qi — University of California, Santa Cruz

Organizer: Nakamura-Zimmerer, Tenavi — University of California, Santa Cruz

10:30-10:55 MoAM_H19.1

Compositional Features and Neural Network Complexity in Deep Learning (I), pp. 62-65

Kang, Wei — Naval Postgraduate School

Gong, Qi — University of California, Santa Cruz

In this study, we explore the relationship between the complexity of neural networks and the internal compositional structure of the function to be approximated. The results shed light on the reason why using neural network approximation helps to avoid the curse of dimensionality (COD). In Section 2, we discuss the challenge of

COD in feedback control. In Section 3, we introduce four compositional features that determine the complexity and error upper bound of neural network approximation for dynamical and control systems. In Section 4, several examples are given to illustrate the widely observed phenomenon in science and engineering that complicated functions are formed by the composition of simple ones.

10:55-11:20 MoAM_H19.2

Linear Quadratic Control from an Optimization Viewpoint (I), pp. 66-67

Tang, Yujie	Harvard University
Li, Yingying	University of Illinois Urbana-Champaign
Zheng, Yang	University of California San Diego
Zhang, Runyu	Harvard University
Li, Na (Lina)	SEAS Harvard

We investigate model-free reinforcement learning of linear quadratic control from an optimization viewpoint. In the first part, we consider distributed reinforcement learning of decentralized linear quadratic control, where we propose a zeroth-order distributed policy optimization algorithm, analyze its performance, and point out some limitations of the theoretical guarantees. The second part is on the optimization landscape analysis of the LQG problem, where we study 1) the connectivity of the set of stabilizing controllers, and 2) the structural properties of stationary points of the LQG cost function.

11:20-11:45 MoAM_H19.3

On Neural Network Architectures for Solving High Dimensional Hamilton-Jacobi Equations Arising in Optimal Control (I), pp. 68-71

Jerome Darbon, Jerome	Brown University
Dower, Peter M.	University of Melbourne
Meng, Tingwei	Brown University

We propose new mathematical connections between Hamilton-Jacobi (HJ) partial differential equations (PDEs) with initial data and neural network architectures. Specifically, we prove that some classes of neural networks correspond to representation formulas of HJ PDE solutions whose Hamiltonians and initial data are obtained from the parameters or the activation functions of the neural networks. These results do not require any learning stage. In addition these results do not rely on universal approximation properties of neural networks; rather, our results show that some classes of neural network architectures naturally encode the physics contained in some HJ PDEs. Our results naturally yield efficient neural network-based methods for evaluating solutions of some HJ PDEs in high dimension without using grids or numerical approximations.

11:45-12:10 MoAM_H19.4

Approximation Theory for Deep Learning in Time Series Analysis (I), pp. 72-75

Jiang, Haotian	National University of Singapore
Li, Zhong	Peking University
Li, Qianxiao	National University of SIngapore

This extended abstract summarizes a series of recent works on the approximations theory of deep learning methods for time series modelling and analysis. The primary aim is to develop the mathematical foundations for modelling sequential relationships with neural networks, which guides the practical implementation and design of such architectures. In particular, we place on concrete mathematical footing on when and how certain architectures (recurrent neural networks, encoder-decoder structures, dilated convolutions, etc) can adapt to corresponding data structures in the temporal relationships to be learned (memory, rank, sparsity, etc). These form the first step towards principled neural network architecture design and selection for practical machine learning of temporal relationships.

MoAM_H20 H 20

Future Trends in MPC - I (Invited Session)

Chair: Cannon, Mark	University of Oxford
Co-Chair: Schulze Darup, Moritz	TU Dortmund University
Organizer: Schulze Darup, Moritz	TU Dortmund University
Organizer: Cannon, Mark	University of Oxford

10:30-10:55 MoAM_H20.1

New Results in Multiobjective Model Predictive Control (I), pp. 76-78

Eichfelder, Gabriele	Technische Universität Ilmenau
Gruene, Lars	Univ of Bayreuth
Krügel, Lisa	University of Bayreuth
Schießl, Jonas	University of Bayreuth

In model predictive control, it is a natural idea that not only one but multiple objectives have to be optimized. This leads to the formulation of a multiobjective optimal control problem (MO OCP). In this talk we introduce a multiobjective MPC algorithm, which yields on the one hand performance estimates for all considered objective functions and on the other hand stability results of the closed-loop solution. To this end, we build on the results in Zavala and Flores-Tlacuahuac (2012); Grüne and Stieler (2019) and introduce a simplified version of the algorithm presented in Grüne and Stieler (2019). Compared to Grüne and Stieler (2019), we allow for more general MO OCPs than in Grüne and Stieler (2019) and get rid of restrictive assumption on the existence of stabilizing stage and termi- nal costs in all cost components. Compared to Zavala and Flores-Tlacuahuac (2012), we obtain rigorous performance estimate for the MPC closed loop.

10:55-11:20 MoAM_H20.2

On the Stabilizing Properties of Nonlinear MPC with Arbitrary Positive Definite Cost Functions (I), pp. 79-82

Lazar, Mircea	Eindhoven Univ. of Technology

Recently, a unifying approach to the stability analysis of nonlinear model predictive controllers (MPC) with arbitrary positive definite cost functions has been presented based on dissipativity theory. We have established that regardless of the choice of the positive definite cost function, the resulting value function always satisfies a dissipation inequality. This led to less conservative stability conditions for nonlinear MPC that do not require monotonic decrease of the optimal cost function along closed-loop trajectories. In this extended abstract we recall these results and we analyze recursive feasibility, which has not yet been addressed. To this end we use a control contractive terminal set and an adaptive prediction horizon, without adding a terminal cost.

11:20-11:45 MoAM_H20.3

Discounted Economic MPC without Terminal Conditions for Periodic Optimal Behavior (I), pp. 83-86

Schwenkel, Lukas	University of Stuttgart
Hadorn, Alexander	Universität Stuttgart
Muller, Matthias A.	Leibniz University Hannover
Allgower, Frank	University of Stuttgart

In this work, we study economic model predictive control (MPC) in situations where the optimal operating behavior is periodic. In such a setting, the performance of a plain economic MPC scheme without terminal conditions can generally be far from optimal even with arbitrarily long prediction horizons. Whereas there are modified economic MPC schemes that guarantee optimal performance, all of them are based on prior knowledge of the optimal period length or of the optimal periodic orbit itself. In contrast to these approaches, we propose to achieve optimality by multiplying the stage cost by a linear discount factor. This modification is not only easy to implement but also independent of any system- or cost-specific properties, making the scheme robust against online changes therein. Under standard dissipativity and controllability assumptions, we can prove that the resulting linearly discounted economic MPC without terminal conditions achieves optimal

asymptotic average performance up to an error that vanishes with growing prediction horizons. Moreover, we can guarantee practical asymptotic stability of the optimal periodic orbit under slightly stronger assumptions.

11:45-12:10	MoAM_H20.4

SNMPC: A Matlab Toolbox for Computing Stabilizing Terminal Costs and Sets (I), pp. 87-92

Eyuboglu, Mert	Eindhoven University of Technology
Lazar, Mircea	Eindhoven Univ. of Technology

This paper presents a Matlab toolbox that implements methods for computing stabilizing terminal costs and sets for nonlinear model predictive control (NMPC). Given a discrete-time nonlinear model provided by the user, the toolbox computes quadratic/ellipsoidal terminal costs/sets and local control laws for the following options: (i) cyclically time-varying or standard terminal ingredients; (ii) first or quasi-second order Taylor approximation of the dynamics; (iii) linear or nonlinear local control laws. The YALMIP toolbox and the MOSEK solver are used for solving linear matrix inequalities and the IPOPT solver (with global search) is used for nonlinear programming. Simulation of the resulting stabilizing NMPC algorithms is provided using the CasADi toolbox.

12:10-12:35	MoAM_H20.5

Robust Adaptive Model Predictive Control with Persistent Excitation Conditions (I), pp. 93-96

Lu, Xiaonan	University of Oxford
Cannon, Mark	University of Oxford

For constrained linear systems with bounded disturbances and parametric uncertainty, we propose a robust adaptive Model Predictive Control scheme with online parameter estimation. Constraints enforcing persistent excitation in closed loop operation are introduced to ensure asymptotic parameter convergence. The algorithm requires the online solution of a convex optimisation problem, satisfies constraints robustly, and ensures recursive feasibility and input-to-state stability. Almost sure convergence to the actual system parameters is obtained under mild conditions on stabilisability and the tightness of disturbance bounds.

MoAM_S70	S 70
Systems Theory: Analysis, Applications, and Methods (Regular Session)	
Chair: Aubin-Frankowski, Pierre-Cyril	INRIA
Co-Chair: Rüffer, Björn	Faculty of Civil Engineering

10:30-10:55	MoAM_S70.1

Stability of Solutions for Controlled Nonlinear Systems under Perturbation of State Constraints, pp. 97-99

Aubin-Frankowski, Pierre-Cyril	INRIA

This paper tackles the problem of nonlinear systems, with sublinear growth but unbounded control, under perturbation of some time-varying state constraints. It is shown that, given a trajectory to be approximated, one can find a neighboring one that lies in the interior of the constraints, and which can be made arbitrarily close to the reference trajectory both in L^infty-distance and L^2-control cost. This result is an important tool to prove the convergence of approximation schemes of state constraints based on interior solutions and is applicable to control-affine systems.

10:55-11:20	MoAM_S70.2

Viability and Invariance of Systems on Metric Spaces, pp. 100-103

Badreddine, Zeinab	CNRS and Sorbonne Université
Frankowska, Helene	CNRS and Sorbonne Université

In some applied models (as for instance of flocking or of the crowd control) it is more natural to deal with elements of a metric space (as for instance a family of subsets of a vector space endowed with the Hausdorff metric) rather than with vectors of a normed vector space. We consider a generalized control system on a metric space and investigate necessary and sufficient conditions for viability and invariance of proper subsets, describing state constraints. As examples of application we study controlled continuity equations on the metric space of probability measures, endowed with the Wasserstein distance, and controlled morphological systems on the space of nonempty compact subsets of the Euclidean space endowed with the Hausdorff metric. We also provide sufficient conditions for the existence and uniqueness of contingent solutions to the Hamilton-Jacobi-Bellman equation on a proper metric space.

11:20-11:45	MoAM_S70.3

A Mathematical Model for Depression, pp. 104-107

Rüffer, Björn	Faculty of Civil Engineering

A basic dynamical model for (clinical) depression is proposed that describes the time evolution of two coupled states: a depression symptom and the memory of past symptoms. The model consists of a system of two coupled first order differential equations with unit coefficients that qualitatively captures different courses of illness.

12:10-12:35	MoAM_S70.5

Performance Estimation of First-Order Methods on Quadratic Functions, pp. 108-111

Bousselmi, Nizar	UCLouvain
Hendrickx, Julien M.	UCLouvain
Glineur, François	Université Catholique De Louvain

We are interested in determining the worst performance exhibited by a given first-order optimization method on the class of quadratic functions. Thanks to the Performance Estimation Problem (PEP) methodology, it is possible to compute the exact worst-case performance of a first-order optimization method on a given class of functions. Since it has been introduced, PEP can be solved for a large number of classes. We extend the PEP framework to the class of quadratic functions. We apply it to analyze the difference of performance of the gradient method between convex quadratic and general smooth convex functions.

MoAM_S80	S 80
Distributed Parameter Systems I (Invited Session)	
Chair: Katz, Rami	Tel Aviv University
Co-Chair: Morris, Kirsten A.	Univ. of Waterloo
Organizer: Demetriou, Michael A.	Worcester Polytechnic Institute
Organizer: Morris, Kirsten A.	Univ. of Waterloo

10:30-10:55	MoAM_S80.1

Global Boundary Stabilization of a Semilinear Heat Equation Via Finite-Dimensional Nonlinear Observers (I), pp. 112-115

Katz, Rami	Tel Aviv University
Fridman, Emilia	Tel-Aviv Univ

We study global finite-dimensional observer-based stabilization of a 1D heat equation with a known globally Lipschitz semilinearity in the state variable. We consider Neumann actuation and point measurement. Using dynamic extension and modal decomposition we derive nonlinear ODEs for the modes of the state. We then design a finite-dimensional nonlinear Luenberger observer, which takes into account the known semilinearity. The proposed controller is based on this observer. Our Lypunov H^1-stability analysis leads to LMIs, which are feasible for a large enough observer dimension and small enough Lipschitz constant.

10:55-11:20	MoAM_S80.2

Damping-Robustness of Various 1-D Wave PDEs under Boundary Feedback Control (I), pp. 116-121

Karafyllis, Iasson	National Technical University of Athens
Krstic, Miroslav	Univ. of California at San Diego

This paper is devoted to the study of the robustness properties of the 1-D wave equation for an elastic vibrating string under four different damping mechanisms that are usually neglected in the study of the wave equation: (i) friction with the surrounding medium of the string (or viscous damping), (ii) thermoelastic phenomena (or thermal damping), (iii) internal friction of the string (or Kelvin-Voigt damping), and (iv) friction at the free end of the string (the so-called passive damper). The passive damper is also the simplest boundary feedback law that guarantees exponential stability for the string. We study robustness with respect to distributed inputs and boundary disturbances in the context of Input-to-State Stability (ISS). By constructing appropriate ISS Lyapunov functionals, we prove the ISS property expressed in various spatial norms.

11:20-11:45 MoAM_S80.3

Computational Methods for Uniform Ensemble Reachability, pp. 122-125

Schoenlein, Michael — University of Passau

We consider reachability properties of families of parameter-dependent linear systems, where the inputs are restricted to be independent of the parameter. If for every family of parameter-dependent target states and every neighborhood of it there is an input such that the zero state can be steered simultaneously into the given neighborhood the parameter-dependent system is called ensemble reachable. Recently, a lot of effort has been spent on the derivation of necessary and sufficient conditions for ensemble reachability. Here we tackle the subsequent question how to determine a suitable input if the target family and the neighborhood is given. We present two methods for discrete-time linear systems which are based on complex approximation theory. We will also point out that one of the polynomial techniques can also be applied to certain continuous-time systems.

11:45-12:10 MoAM_S80.4

Revisiting Stability of Positive Linear Discrete-Time Systems, pp. 126-131

Glück, Jochen — University of Wuppertal

Mironchenko, Andrii — University of Passau

We prove small-gain type criteria of exponential stability for positive linear discrete-time systems in ordered Banach spaces that have a normal and generating positive cone. Such criteria play an important role in the finite-dimensional systems theory but are rather unexplored in the infinite-dimensional setting, yet. Furthermore, we show that our stability criteria can be considerably strengthened if the cone has non-empty interior or if the operator inducing the discrete-time system is quasi-compact.

12:10-12:35 MoAM_S80.5

On Internally K-Positive Linear Time-Invariant System Operators, pp. 132-135

Grussler, Christian — Technion - Israel Institute of Technology

B. Burghi, Thiago — University of Cambridge

Sojoudi, Somayeh — UC Berkeley

Variation diminishment -- the reduction in the number of sign changes and local extrema in a signal -- is an intrinsic system property that lies at the heart of positive systems theory and over- and undershooting analysis in controlled systems. While, for general system operators, this property is difficult to verify, we show that it can be readily verified for the controllability and observability operators of finite-dimensional linear time-invariant systems under an internal k-positivity assumption. This complements earlier results on verifying this property for Hankel and Toeplitz operators, and establishes a bridge to internally positive systems theory. Our results provide a new framework for upper bounding the number of over- and undershoots in step responses, as well as a new realization theory of externally positive systems.

MoAM_S82 S 82

Modeling and Control of Network Systems (Hybrid Session)
(Invited Session)

Chair: Jayawardhana, Bayu — University of Groningen

Organizer: Pasumarthy, Ramkrishna — IIT Madras

Organizer: Narasimhan, Sridharakumar — Indian Institute of Technology, Madras

Organizer: Bhatt, Nirav — Indian Institute of Technology Madras

10:30-10:55 MoAM_S82.1

Measures of Modal Controllability for Network Dynamical Systems (I), pp. 136-139

Gokhale, Anand — Indian Institute of Technology Madras

Srighakollapu, Manikya Valli — Indian Institute of Technology Madras

Pasumarthy, Ramkrishna — IIT Madras

The quantification of controllability has gained renewed interest in the context of large, complex network dynamical systems. In some application areas such as computational neuroscience, there is a large interest in modal controllability, which describes the ability of an input to control the modes of a system. In case of a linear system, the modes of the system are given by the left eigenvectors associated with the system matrix. In this work, we identify mode specific and gross metrics for modal controllability for discrete linear time invariant systems. Our metrics are based on energy requirements to move along a given mode and find applications in problems involving selection of driver nodes for minimizing control effort along particular modes of the network. We conclude by studying the properties of the metrics.

10:55-11:20 MoAM_S82.2

Persistent Homology-Based Resilience Enhancement (I), pp. 140-143

Gunjal, Revati — Veermata Jijabai Technological Institute, Mumbai, India

Syed, Shadab Nayyer — Veermata Jijabai Technological Institute, Mumbai, India

Raphel, Mariya — Veermata Jijabai Technological Institute

Pandey, Abhishek — Veermata Jijabai Technological Institute, Mumbai

Wagh, Sushma — VJTI, Mumbai University

Kazi, Faruk — VJTI Mumbai

Singh, Navdeep — Veermata Jijabi Technological Institute

The adverse effect of increasing penetration of distributed energy resources has resulted in increased vulnerabilities to resilience, defined as the ability of the grid to preserve the original properties under disruptive scenarios which were unforeseen in the traditional power grid. Hence it necessitates the development of accurate and reliable resilience metrics to have deeper insight under any disturbance resulting in modification of structural properties. Especially, considering the critical role of local structure and its inherent underlying geometry makes the impact analysis more challenging. In view of this, the proposed Persistent homologybased resilience enhancement (PHRE) technique utilizes the concept of Topological Data Analysis, particularly Betti numbers (identifying the most vulnerable buses) and persistent homology, extracting the longer-lasting topological features of the graphs through the network filtration at various spatial resolutions characterizing the structural functionality of the network. The proposed PHRE technique is validated using a benchmark system.

11:20-11:45 MoAM_S82.3

Kron Reduction of Open Chemical Reaction Network: Zero-Moment Matching and a Priori Error Bound Via Generalized Gramian (I), pp. 144-146

Prawira Negara, Mohamad Agung — University of Groningen

Burohman, Azka Muji — University of Groningen

Jayawardhana, Bayu — University of Groningen

We propose a Kron-based model reduction method for open chemical reaction networks with constant inflow and proportional outflow, which guarantees the preservation of network structures and interlacing property of the reduced-order model. We further show that the proposed Kron-based model reduction method achieves zero-moment matching for nonlinear systems. Lastly, for single-species single-substrate open chemical reaction networks, we present a Gramian-based approach to optimally select the removed nodes and provide the corresponding a priori error bound.

11:45-12:10 MoAM_S82.4

A Priori Parameter Identifiability in Complex Reaction Networks (I), pp. 147-150

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

Differential algebra-based theory and software have been widely used to study the {em a priori} structural identifiability of nonlinear systems. This technique however fails to provide definitive answers for complex reaction networks which involve several reactions and species. In this work, for reaction systems following mass action kinetics, using the theory of reaction extents, we show that identifiability can be ascertained by determining the rank of a matrix. Further, we show that for systems involving most bi-molecular reactions, the parameters are guaranteed to be identifiable, if R (where $R=$ number of independent reactions) species that satisfy a rank condition are measured.

12:10-12:35 MoAM_S82.5

Verification and Rectification of Error in Topology of Conserved Networks (I), pp. 151-156

Pappu, Satya Jayadev	Indian Institute of Technology, Madras
Bawa, Arsh	Indian Institute of Technology Madras
Bhatt, Nirav	Indian Institute of Technology Madras

The knowledge of the underlying topology is essential for understanding and manipulating power grids, water distribution networks, and biological networks. At times, the topology may be reported (or recorded) erroneously, mostly owing to human mistakes in reporting. The networks can be represented as a graph in which entities are represented as nodes and interactions among nodes as edges. This work focuses on the study of a specific type of error in topology that occurs when the incidence of an edge in the network is incorrectly reported. We propose a methodology to detect, isolate, and rectify this type of error using a single noisy measurement of flows along all the edges of a conserved network. We first show that this type of error generates specific error signatures, which enables error diagnosis when the data is noise-free. An approach based on a series of statistical tests is developed to handle noisy data for online error detection and rectification. Simulation studies are performed to test the robustness of the proposed methodology.

12:35-13:00 MoAM_S82.6

Spectral Theory of Koopman Operator for the Analysis of Network Dynamical Systems (I), pp. 157-158

Vaidya, Umesh	Clemson University

The solution to the Hamilton Jacobi equation plays a central role in various problems in system theory, including dissipative theory. In particular, the storage function verifying the dissipative property of the input-output control system can be obtained as a solution to the Hamilton Jacobi equation. The dissipative theory provides a systematic and scalable approach for the stability verification of network control systems. We establish a connection between the spectral theory of the Koopman operator and the Hamilton Jacobi equation. In particular, the solution to the Hamilton Jacobi equation can be constructed using the eigenfunctions of the Hamiltonian system associated with the Hamilton Jacobi equation. This connection between the HJ solution, Koopman spectrum, on the one hand, and the dissipative theory, network system, on the other hand, allows us to discover spectral Koopman theory for the stability analysis of large scale network system.

MoSP_H17 H 17

Semi Plenary: Roland Herzog (Plenary Session)

Chair: Ball, Joseph	Virginia Tech

14:00-15:00 MoSP_H17.1

The Role of the Metric in Numerical Linear Algebra and Optimization, pp. 159-159

Herzog, Roland	Heidelberg University

Many algorithms in everyday use implicitly employ the Euclidean inner product of the underlying space. While this is convenient and user-friendly on the one hand, it also turns out that the Euclidean metric may not be the one yielding the best performance of the respective algorithm. In this talk we revisit the role of the metric in a number of well- known algorithms in numerical linear algebra and optimization, and demonstrate the potential of user-defined metrics in each case.

MoSP_H18 H 18

Semi Plenary: Christopher M. Kellett (Plenary Session)

Chair: Sepulchre, Rodolphe J.	University of Cambridge

14:00-15:00 MoSP_H18.1

Discontinuous Feedbacks for Stabilization and Combined Stabilization and Safety, pp. 160-160

Kellett, Christopher M.	The Australian National University

It has long been known that asymptotic controllability of a nonlinear system to a desired equilibrium or target set require discontinuous controllers for feedback stabilization, which, in turn, is equivalent to the existence of a nonsmooth control Lyapunov function. More recently, results combining stabilization and safety, captured by so-called barrier functions, have been proposed. This also gives rise to the need for discontinuous feedback controllers, though for slightly different reasons. In this talk, we summarise these results and present a hybrid feedback solution to the combined stabilization and safety problem for a non-trivial class of systems.

MoSP_H19 H 19

Semi Plenary: Yann Le Gorrec (Plenary Session)

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

14:00-15:00 MoSP_H19.1

Control Design for Distributed Parameter Systems – the Port Hamiltonian Approach, pp. 161-161

Le Gorrec, Yann	FEMTO-ST, ENSMM

This talk is concerned with the control of distributed parameter systems defined on a 1D spatial domain using the port Hamiltonian framework. We consider two different cases: when actuators and sensors are located within the spatial domain and when the actuator is situated at the boundary of the spatial domain, leading to a boundary control system (BCS). In the first case we show how dynamic extensions and structural invariants can be used to change the internal properties of the system when the system is fully actuated, and how it can be done in an approximate way when the system is actuated using piecewise continuous actuators stemming from the use of patches. Asymptotic stability is achieved using damping injection. In the boundary-controlled case we show how the closed loop energy function can be partially shaped, modifying the minimum and a part of the shape of this function and how damping injection can be used to guarantee asymptotic convergence. We end with some some extensions of the proposed results to irreversible thermodynamic systems.

MoPM_H16	H 16
Matrix Variables and Matrix Inequalities - II (Hybrid Session) (Invited Session)	
Chair: Pascoe, James Eldred	University of Florida
Co-Chair: Vinnikov, Victor	Ben Gurion University of the Negev
Organizer: Pascoe, James Eldred	University of Florida
Organizer: Helton, J. William	Univ. of California at San Diego
Organizer: Klep, Igor	University of Ljubljana

15:30-15:55 MoPM_H16.1

Interpolating Matrices (I), pp. 162-164

Dayan, Alberto — Norwegian University of Science and Technology

We extend Carleson interpolation Theorem to sequences of matrices (of eventually unbounded dimensions) with spectra in the unit disc. As for the multi-variable case, we see how an analogous of the Pick property enjoyed by the NC (non commutative) Drury-Arveson space allows one to characterize interpolating sequences on the NC unit ball in terms of some Riesz system-type conditions on NC kernels. We discuss examples, and some possible directions for some future research in the topic.

15:55-16:20 MoPM_H16.2

Realization of Matrix Monotone and Matrix Convex Functions (I), pp. 165-167

Tully-Doyle, Ryan — California Polytechnic State University

A fundamental result of Löwner gives that a real-valued function is matrix monotone if and only if it extends to an analytic function with a rather rigid structure. Löwner's student Kraus essentially showed that functions that are matrix convex are analytic functions with a similarly rigid form.

We consider recent work in the realization theory of matrix monotone and matrix convex functions that generalize the classical results to the setting of noncommutative function theory. We also discuss continuation results for such realizations. Further topics include partially matrix convex functions and plurisubharmonic functions.

16:20-16:45 MoPM_H16.3

A Hankel Realization for Noncommutative Rational Functions Around a Matrix Point (I), pp. 168-170

Porat, Motke — Ben Gurion Univeristy of the Negev

Vinnikov, Victor — Ben Gurion University of the Negev

It is well known that noncommutative (nc) rational functions regular at the origin admit a good realization (or linearization) theory. This is very useful both conceptually and for a variety of applications since it often essentially reduces the study of these rational functions to a study of linear pencils.By translation the method can be applied to nc rational functions that are regular at some scalar point, but not beyond.

In this talk we discuss the realization problem for nc rational functions regular at an arbitrary given matrix point using the nc difference--differential calculus and the general Taylor--Taylor series of nc function theory and provide a solution which is the analogue of the classical Hankel realization.

16:45-17:10 MoPM_H16.4

Noncommutative Optimal Polynomial Approximants (I), pp. 171-173

Augat, Meric — Washington University in St. Louis

The study of Optimal Polynomial Approximants (OPAs) in weighted Dirichlet-type spaces has seen a great deal of success in the past decade. In more than one variable, not as much is known, and the failure of the famous Shanks Conjectur shows that there may be issues with the typical Drury-Arveson approach. A remediation is to recast the multivariable into the noncommutative setting where the deficiencies of the Drury-Arveson space are not found. This paper outlines the introductory ideas behind noncommutative Optimal Polynomial Approximants, as well as a couple of tangible conjectures and potential approaches inspired by classical techniques in the freely noncommutative setting.

17:10-17:35 MoPM_H16.5

Completing an Operator Matrix and the Free Joint Numerical Radius (I), pp. 174-176

Dela Rosa, Kennett L. — University of the Philippines Diliman

Woerdeman, Hugo J. — Drexel Univ

Ando's classical characterization of the unit ball in the numerical radius norm was generalized by Farenick, Kavruk, and Paulsen using the free joint numerical radius of a tuple of Hilbert space operators (X1, ..., Xm). In particular, the characterization leads to a positive definite completion problem. In this paper, we study various aspects of Ando's result in this generalized setting. Among other things, this leads to the study of finding a positive definite solution L to a certain matrix equation, which may be viewed as a fixxed point equation. Once such a fixed point is identified, the desired positive definite completion is easily obtained. Along the way we derive other related results including basic properties of the free joint numerical radius and an easy way to determine the free joint numerical radius of a tuple of generalized permutations. Finally, we present some open problems.

MoPM_H17	H 17
Dissipativity Theory I: Dissipativity and Optimal Control (Hybrid Session) (Invited Session)	
Chair: Gruene, Lars	Univ of Bayreuth
Co-Chair: Hughes, Timothy H.	University of Exeter
Organizer: Gruene, Lars	Univ of Bayreuth
Organizer: Hughes, Timothy H.	University of Exeter
Organizer: van der Schaft, Arjan J.	Univ. of Groningen

15:30-15:55 MoPM_H17.1

Dissipativity in Infinite-Horizon Optimal Control: Willems' 1971 Paper Revisited (I), pp. 177-182

Faulwasser, Timm — TU Dortmund University

Kellett, Christopher M. — The Australian National University

Jan Willems introduced the system-theoretic notion of dissipativity in his foundational two-part paper which appeared in the Archive of Rational Mechanics and Analysis in 1972. Even earlier, in a likewise pivotal 1971 IEEE Transactions on Automatic Control paper, he investigated infinite-horizon least-squares optimal control and the algebraic Riccati equation from a dissipativity point of view. This note revisits infinite-horizon optimal control leveraging strict dissipativity. We discuss the interplay between dissipativity and stability properties in continuous-time infinite-horizon problems without assuming linear dynamics or quadratic cost functions. Finally, we compare our recent results from Faulwasser and Kellett (2021) to the original findings of Willems (1971).

15:55-16:20 MoPM_H17.2

Optimal Control of Thermodynamic Port-Hamiltonian Systems (I), pp. 183-188

Maschke, Bernhard — Univ Claude Bernard of Lyon

Philipp, Friedrich — Technische Universität Ilmenau

Schaller, Manuel — Technische Universität Ilmenau

Worthmann, Karl — TU Ilmenau

Faulwasser, Timm — TU Dortmund University

We consider the problem of minimizing the entropy, energy, or exergy production for state transitions of irreversible port-Hamiltonian systems subject to control constraints. Via a dissipativity-based analysis we show that optimal solutions exhibit the manifold turnpike phenomenon with respect to the manifold of thermodynamic equilibria. We illustrate our analytical findings via numerical results for a heat exchanger.

16:20-16:45 MoPM_H17.3

Why Does Strict Dissipativity Help in Model Predictive Control? (I), pp. 189-192

Gruene, Lars — Univ of Bayreuth

During the last couple of years the theory of why and when Model Predictive Control (MPC) generates stable, feasible and near optimal closed-loop solutions has significantly matured. In this talk we give a survey about the contribution of the dissipativity concept in this line of research.

16:45-17:10 MoPM_H17.4

On the Optimal Control of Lossless Electrical Networks (I), pp. 193-196

Pates, Richard — Lund University

Electrical networks constructed out of resistors (R), inductors (L), capacitors (C), transformers (T), and gyrators (G) are used throughout engineering and the applied sciences to model physical processes. Synthesising RLCTG networks for control purposes is also important, since in a number application domains the corresponding controllers can be implemented without an energy source. We show that if a process can be modelled by an LCTG network, a controller that maximises robustness with respect to normalised coprime factor perturbations can be synthesised by a decentralised resistive network. The results are illustrated on an example centred on the iterative solution to constrained least squares problems.

17:10-17:35 MoPM_H17.5

On Discrete-Time Optimal Control and the Related Bounded Real and Positive Real Lemmas (I), pp. 197-199

Branford, Edward Hugh — University of Exeter

Hughes, Timothy H. — University of Exeter

We extend the classical discrete-time bounded real lemma to the general case of systems that need not be controllable or observable, and its relationship to the related discrete-time optimal control problem. In the talk accompanying this extended abstract, we will further discuss the analogies in discrete time to the recent continuous time development of an assumption free theory of linear passive and non-expansive systems that draws on the behavioral framework of Jan Willems and collaborators.

17:35-18:00 MoPM_H17.6

On Representations of Port-Hamiltonian DAE Systems, pp. 200-202

Mehrmann, Volker — Technische Universität Berlin

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

Port-Hamiltonian DAE systems are discussed that are the composition of a Dirac structure and a Lagrangian subspace, where the latter is generalizing the Hamiltonian function expressing energy storage. The algebraic constraints in such systems are correspondingly divided into Dirac and Lagrange algebraic constraints. The relations between different representations of the same port-Hamiltonian DAE system are discussed.

MoPM_H18 H 18

Algebraic Theory of Block and Convolutional Codes (Hybrid Session) (Invited Session)

Chair: Lieb, Julia — University of Zurich

Co-Chair: Napp, Diego — University of Alicante

Organizer: Lieb, Julia — University of Zurich

Organizer: Napp, Diego — University of Alicante

15:30-15:55 MoPM_H18.1

Security Considerations about a McEliece Cryptosystem with a Convolutional Encoder (I), pp. 203-206

Almeida, Paulo — University of Aveiro

Beltrá Vidal, Miguel — University of Alicante

Napp, Diego — University of Alicante

Sebastião, Cláudia — Universidade De Aveiro

We present a new variant of the McEliece cryptosystem that possesses several interesting properties, including a reduction of the public key for a given security level. In contrast to the classical McEliece cryptosystems, where block codes are used, we propose the use of a convolutional encoder to be part of the public key. The secret key is constituted by a Generalized Reed-Solomon code and two Laurent polynomial matrices that contain large parts that are generated completely at random. In this setting the message is a sequence of messages instead of a single block message and the errors are added randomly throughout the sequence. We analyse its security against ISD attacks in the first instants and when the whole message is transmitted, as well as against structural attacks.

15:55-16:20 MoPM_H18.2

Combinatorial Tools for the Study of Flag Codes (I), pp. 207-210

Alonso-González, Clementa — University of Alicante

Navarro-Pérez, Miguel Ángel — University of Alacant

In network coding, a flag code is a collection of flags, that is, sequences of nested subspaces of a vector space over a finite field. If the sequence of subspace dimensions is complete, we speak about full flag codes. In this work we present some combinatorial tools coming from the classical theory of partitions that can be naturally associated with full flag codes in order to extract relevant information about them. In particular, we state a combinatorial characterization of those full flag codes that attain the maximum possible distance.

16:20-16:45 MoPM_H18.3

Matrices for Quasi-Cyclic Codes Over Extension Fields Obtained from Gröbner Basis (I), pp. 211-216

Chimal-Dzul, Henry — University of Zurich

Lieb, Julia — University of Zurich

Rosenthal, Joachim — University of Zurich

Quasi-cyclic codes over finite fields are an important class of linear block codes. A fundamental problem in the theory of these codes is to describe their algebraic structure. In this paper it is shown that every quasi-cyclic code is the subfield code and the trace code of a quasi-cyclic code over an extension field. The latter is defined by a parity check matrix obtained from a spectral analysis of a reduced Gröbner basis of the former. Moreover, it is shown that the quasi-cyclic code over the extension field and the one under consideration have the same length, dimension and minimum Hamming distance. Furthermore, we show that under certain conditions it is possible to construct a generator matrix of the quasi-cyclic code over the extension field using similar techniques to construct its parity check matrix. We illustrate that this construction is attainable for some good quasi-cyclic low density parity check codes like the [155,64,20] binary Tanner code.

16:45-17:10 MoPM_H18.4

Genetic Algorithms with Permutation-Based Representation for Computing the Distance of Linear Codes (I), pp. 217-220

Pegalajar Cuéllar, Manolo — Universidad De Granada

Gómez Torrecillas, José — Universidad De Granada

Lobillo, F. Javier — Universidad De Granada

Navarro Garulo, Gabriel — Universidad De Granada

Finding the minimum distance of linear codes is an NP-hard problem. Traditionally, this computation has been addressed by means of the design of algorithms that find, by a clever exhaustive search, a linear combination of some generating matrix rows that provides a codeword with minimum weight. Therefore, as the dimension of the code or the size of the underlying finite field increase, so it does exponentially the run time. In this work, we prove that, given a generating matrix, there exists a column permutation which leads to a reduced row echelon form containing a row whose weight is the code distance. This result enables the use of permutations as representation scheme, in contrast to the usual discrete representation, which makes the search of the optimum polynomial time dependent from the base field. In particular, we have implemented genetic and CHC algorithms using this representation as a proof of concept. Experimental results have been carried out employing codes over fields with two and eight elements, which suggests that evolutionary algorithms with our proposed permutation encoding are competitive with regard to existing methods in the literature. As a by-product, we have found and amended some inaccuracies in the Magma Computational Algebra System concerning the stored distances of some linear codes.

17:10-17:35	MoPM_H18.5

On Rank Metric Convolutional Codes and Concatenated Codes (I), pp. 221-224

Napp, Diego	University of Alicante
Pinto, Raquel	University of Aveiro
Vela, Carlos	University of Aveiro

In the recent history of the theory of network coding the multi-shot network coding has been prove as a good alternative for the classical one-shot network theory which is managed by using block codes. To perform communications in this multi-shot context we have, among others, rank-metric convolutional codes and concatenated codes (using a convolutional code as an outer code and a rank-metric code as inner code). In this work we analyse their performance over the rank deficiency channel (described by Gilbert-Elliot channel model) in terms of the correction capabilities and the complexity of the two decoding schemes.

17:35-18:00	MoPM_H18.6

A Number Theoretic Approach to Cycles in LDPC Codes, pp. 225-230

Lieb, Julia	University of Zurich
Tinani, Simran	University of Zurich

LDPC codes constructed from permutation matrices have recently attracted the interest of many researchers. A crucial point when dealing with such codes is trying to avoid cycles of short length in the associated Tanner graph, i.e. obtaining a possibly large girth. In this paper, we provide a framework to obtain constructions of such codes. We relate criteria for the existence of cycles of a certain length with some number-theoretic concepts, in particular with the so-called Sidon sets. In this way we obtain examples of LDPC codes with a certain girth. Finally, we extend our constructions to also obtain irregular LDPC codes.

MoPM_H19	H 19
Learning-Based Methods in Control - II (Hybrid Session) (Invited Session)	
Chair: Gong, Qi	University of California, Santa Cruz
Co-Chair: Nakamura-Zimmerer, Tenavi	University of California, Santa Cruz
Organizer: Kang, Wei	Naval Postgraduate School
Organizer: Gong, Qi	University of California, Santa Cruz
Organizer: Nakamura-Zimmerer, Tenavi	University of California, Santa Cruz

15:30-15:55	MoPM_H19.1

An Overview of NASA's Learn-To-Fly Concept (I), pp. 231-234

Snyder, Steven	NASA

Learn-to-Fly is a framework for incorporating learning methods into the development cycle of new aircraft. This paper provides an overview of the concept and summarizes some results from previous test campaigns. It will also discuss some perceived benefits of Learn-to-Fly and improvements to the procedure for more practical and widespread use. Ongoing efforts are needed to continue to develop the necessary underlying technologies for integration into this framework.

15:55-16:20	MoPM_H19.2

Accelerating Wound Healing with Feedback Control: A Data-Driven Approach (I), pp. 235-238

Gomez, Marcella	University of California at Santa Cruz

Controlling biological systems presents challenges not typically dealt with in traditional control theoretic approaches but also gives way to leniences not traditionally tolerated. Here, we present a holistic view to this new research area and current developments integrating various data-driven approaches for modeling and control.

16:20-16:45	MoPM_H19.3

Gradient Play in Stochastic Games: Stationary Points and Local Geometry (I), pp. 239-244

Zhang, Runyu	Harvard University
Ren, Zhaolin	Harvard University
Li, Na (Lina)	SEAS Harvard

We study the stationary points and local geometry of gradient play for stochastic games (SGs), where each agent tries to maximize its own total discounted reward by making decisions independently based on current state information which is shared between agents. Policies are directly parameterized by the probability of choosing a certain action at a given state. We show that Nash equilibria (NEs) and first-order stationary policies are equivalent in this setting by establishing a gradient domination condition for SGs. We characterize the structure of strict NEs and show that gradient play locally converges to strict NEs within finite steps. Further, for a subclass of SGs called Markov potential games, we prove that strict NEs are local maxima of the total potential function, thus locally stable under gradient play, and fully-mixed NEs are strict saddle points, thus unstable under gradient play.

16:45-17:10	MoPM_H19.4

Machine Learning Enhanced Algorithm for Optimal Landing Problem (I), pp. 245-248

Zang, Yaohua	Zhejiang University
Long, Jihao	Princeton University
Zhang, Xuanxi	Peking University
Hu, Wei	Princeton University
E, Weinan	Peking University
Han, Jiequn	Flatiron Institute

We study the optimal landing problem for aerial vehicles under (1) a fixed landing time horizon or (2) the minimum time horizon. Both problems can be framed into solving the corresponding two-point boundary value problems. However, solving the boundary value problem in numerics is challenging, primarily due to the lack of good initial conditions. We present a space-marching scheme combined with machine learning techniques to provide good initial conditions for the boundary value problem solver. The algorithm greatly improves the solver's performance by increasing the success rate and reducing the computation time.

MoPM_H20	H 20
Future Trends in MPC - II (Invited Session)	
Chair: Schulze Darup, Moritz	TU Dortmund University
Co-Chair: Cannon, Mark	University of Oxford
Organizer: Schulze Darup, Moritz	TU Dortmund University
Organizer: Cannon, Mark	University of Oxford

15:30-15:55	MoPM_H20.1

Safe Corridor Learning for Model Predictive Path Following Control (I), pp. 249-254

Pfefferkorn, Maik — Otto-Von-Guericke University Magdeburg
Holzmann, Philipp — Otto Von Guericke University Magdeburg
Matschek, Janine — Otto-Von-Guericke-Universität Magdeburg
Findeisen, Rolf — TU Darmstadt

Safe collision-free operation of autonomous systems, such as mobile robots in crowded, uncertain, only partially known environments, is challenging. We propose learning a collision-free corridor from demonstration via heteroscedastic Gaussian processes. We incorporate available deterministic obstacle information in the learning procedure to derive safety guarantees for the corridor. The learned passage is utilized in a model predictive path planning controller that steers the system safely through the environment. The achievable results are underlined in simulations considering a mobile robot.

15:55-16:20 MoPM_H20.2

On the Exact Neural Approximations of MPC Laws (I), pp. 255-258

Fabiani, Filippo — University of Oxford
Goulart, Paul J. — University of Oxford

In this extended abstract we present a general procedure to quantify the performance of rectified linear unit (ReLU) neural network (NN) controllers that preserve the desirable properties of a designed model predictive control (MPC) scheme. First, by quantifying the approximation error between NN and MPC state-to-input mappings, we establish suitable conditions involving the worst-case error and the Lipschitz constant that guarantee the stability of the closed-loop system. Then, we develop an offline, mixed-integer (MI) optimization-based method to compute those quantities exactly, thus providing an analytical tool to certify the stability and performance of a ReLU-based approximation of an MPC control law.

16:20-16:45 MoPM_H20.3

A Note on Explicit Data-Driven (M)PC (I), pp. 259-262

Klädtke, Manuel — TU Dortmund University
Teichrib, Dieter — Technische Universität Dortmund
Schlüter, Nils — TU Dortmund University
Schulze Darup, Moritz — TU Dortmund University

We show that the explicit solution of a data-driven predictive control scheme for deterministic LTI systems may not be as intractable as previously assumed. By comparing the structure of resulting parametric quadratic programs for the data-driven and classical model-based formulation, we analyze similarities and redundancies that ultimately lead to related structures of the respective explicit solutions. More precisely, some observations indicate a one-to-one relationship of these solutions that will be explored in future work. We illustrate this result by a thorough analysis of a simple example.

16:45-17:10 MoPM_H20.4

A Novel Constraint Tightening Approach for Robust Data-Driven Predictive Control (I), pp. 263-266

Klöppelt, Christian — Leibniz University Hannover
Berberich, Julian — University of Stuttgart
Allgower, Frank — University of Stuttgart
Muller, Matthias A. — Leibniz University Hannover

We present a data-driven predictive control scheme for the stabilization of unknown LTI systems subject to process disturbances. The scheme uses Willems' lemma for the prediction of future system trajectories and can be set up using only a priori measured input-output data of the disturbed system and an upper bound on its order. The main contribution is the introduction of a novel constraint tightening, which purely based on data guarantees closed-loop constraint satisfaction and recursive feasibility, even in the presence of process disturbances. Furthermore, a pre-stabilizing controller can be integrated into the scheme which ensures applicability for unstable systems.

17:10-17:35 MoPM_H20.5

Robust Fundamental Lemma for Data-Driven Control (I), pp. 267-270

Coulson, Jeremy — ETH Zürich
van Waarde, Henk J. — University of Groningen
Dorfler, Florian — Swiss Federal Institute of Technology (ETH) Zurich

The fundamental lemma by Willems and coauthors facilitates a parameterization of all trajectories of a linear time-invariant system in terms of a single, measured one. This result plays an important role in data-driven simulation and control. Under the hood, the fundamental lemma works by applying a persistently exciting input to the system. This ensures that the Hankel matrix of resulting input/output data has the "right" rank, meaning that its columns span the entire subspace of trajectories. However, such binary rank conditions are known to be fragile in the sense that a small additive noise could already cause the Hankel matrix to have full rank. Therefore, in this extended abstract we present a robust version of the fundamental lemma. The idea behind the approach is to guarantee certain lower bounds on the singular values of the data Hankel matrix, rather than mere rank conditions. This is achieved by designing the inputs of the experiment such that the minimum singular value of a deeper input Hankel matrix is sufficiently large. This inspires a new quantitative and robust notion of persistency of excitation. The relevance of the result for data-driven control will also be highlighted through comparing the predictive control performance for varying degrees of persistently exciting data.

MoPM_S70 S 70

Hybrid and Switched Systems (Regular Session)

Chair: Dashkovskiy, Sergey — University of Würzburg
Co-Chair: Collins, Pieter — Maastricht University

15:30-15:55 MoPM_S70.1

Construction of a Lyapunov Function for Linear Coupled Impulsive Systems, pp. 271-274

Atamas, Ivan — Julius-Maximilians-Universität Würzburg
Dashkovskiy, Sergey — University of Würzburg
Slyn'ko, Vitaliy — S.P. Timoshenko Institute of Mechanics of NAS of Ukraine

This article proposes an approach to constructing the Lyapunov function for a linear coupled impulsive system consisting of two time-invariant subsystems. In this case, in contrast to various variants of small-gain stability conditions for coupled systems, the presence of the asymptotic stability property of independent subsystems is not assumed. To analyze the asymptotic stability of a coupled system, the direct Lyapunov method is used in combination with the discretization method. The periodic case and the case when the Floquet theory is not applicable at all are considered separately. The main results are illustrated with examples.

15:55-16:20 MoPM_S70.2

Computability of the Behaviour of Impacting Systems Beyond Zeno Times, pp. 275-280

Collins, Pieter — Maastricht University
Konecny, Michal — Aston University

Mathematical models of hybrid systems may exhibit Zeno behaviour, in which infinitely many discrete events occur in a finite time interval. Although this may be considered physically unrealistic, since Zeno behaviour is useful in modelling real-world systems, it is important for computational tools to be able to handle it. In particular, verification tools should use a well-defined semantics under which the Zeno behaviour is effectively and rigorously computable. In this paper, we give a semantics for systems with events similar to mechanical impacts and show that

computation of the behaviour is possible, even beyond the Zeno time. If we allow perturbations outside this class of impacting systems, then it may not be possible to handle Zeno behaviour in a realistic way.

16:20-16:45 MoPM_S70.3

Lyapunov Techniques for Impulsive Systems, pp. 281-286

Dashkovskiy, Sergey — University of Würzburg
Slyn'ko, Vitaliy — S.P. Timoshenko Institute of Mechanics of NAS of Ukraine

We recall two recently published approaches to study stability properties of nonlinear infinite dimensional impulsive systems and apply them to finite and infinite dimensional systems. Both approaches cover the case, when discrete and continuous dynamics are not stable simultaneously. We illustrate these approaches by means of several examples. In particular we demonstrate that our approaches can be used in situations where the existing results cannot be applied. In particular, we will derive sufficient conditions for the ISS property of a linear and spatially non-homogeneous parabolic system with impulsive actions.

16:45-17:10 MoPM_S70.4

A Time-Varying Approach for Model Reduction of Singular Linear Switched Systems in Discrete Time, pp. 287-290

Hossain, Md Sumon — University of Groningen
Sutrisno, Sutrisno — University of Groningen
Trenn, Stephan — University of Groningen

We propose a model reduction approach for singular linear switched systems in discrete time with a fixed mode sequence based on a balanced truncation reduction method for linear time-varying discrete-time systems. The key idea is to use the one-step map to find an equivalent time-varying system with an identical input-output behavior, and then adapt available balance truncation methods for (discrete) time-varying systems. The proposed method is illustrated with a low-dimensional academic example.

17:10-17:35 MoPM_S70.5

Linear Quadratic Optimal Control of Switched Differential Algebraic Equations, pp. 291-294

Wijnbergen, Paul — University of Groningen
Trenn, Stephan — University of Groningen

In this abstract the finite horizon linear quadratic optimal control problem with constraints on the terminal state for switched differential algebraic equations is considered. Furthermore, we seek for an optimal solution that is impulse-free. In order to solve the problem, a non standard finite horizon problem for non-switched DAEs is considered. Necessary and sufficient conditions on the initial value for solvability of this non standard problem are stated. Based on these results a sequence of subspaces can be defined which lead to necessary and sufficient conditions for solvability of the finite horizon optimal control problem for switched DAEs.

17:35-18:00 MoPM_S70.6

A Finite Lyapunov Matrix-Based Stability Criterion Via Piecewise Linear Approximation, pp. 295-297

Alexandrova, Irina — Saint Petersburg State University

Recently, a number of Lyapunov matrix-based necessary and sufficient stability tests which require a finite set of operations to be verified were presented for linear time-invariant time delay systems, see Egorov et al. (2017), Gomez et al. (2019) and Bajodek et al. (2021). Motivated by those works, in this contribution we revisit the early paper Medvedeva & Zhabko (2015) and develop the idea presented there to construct a necessary and sufficient finite stability test for a single-delay system as well. The approach relies on a simple piecewise linear approximation of the arguments of Lyapunov--Krasovskii functionals based on the Lyapunov matrix, and shows its competitiveness at least in the case of small delays.

MoPM_S80 S 80

Distributed Parameter Systems II (Invited Session)

Chair: Morris, Kirsten A. — Univ. of Waterloo
Co-Chair: Kalise, Dante — Imperial College London
Organizer: Demetriou, Michael A. — Worcester Polytechnic Institute
Organizer: Morris, Kirsten A. — Univ. of Waterloo

15:30-15:55 MoPM_S80.1

Control of Large-Scale Delayed Networks: DDEs, DDFs and PIEs (I), pp. 298-303

Peet, Matthew M — Arizona State University
Shivakumar, Sachin — Arizona State University

Delay-Differential Equations (DDEs) are the most common representation for systems with delay. However, the DDE representation has limitations. In network models with delay, the delayed channels are typically low-dimensional and accounting for this heterogeneity is challenging in the DDE framework. In addition, DDEs cannot be used to model difference equations. In this paper, we examine alternative representations for networked systems with delay and provide formulae for conversion between representations. First, we examine the Differential-Difference (DDF) formulation which allows us to represent the low-dimensional nature of delayed information. Next, we consider the coupled ODE-PDE framework and extend this to the recently developed Partial-Integral Equation (PIE) representation. The PIE framework has the advantage that it allows the H infinity-optimal estimation and control problems to be solved efficiently using the recently developed software package PIETOOLS. In each case, we consider a very general class of networks, specifically accounting for four sources of delay - state delay, input delay, output delay, and process delay. Finally, we use a scalable network model of temperature control to show that the use of the DDF/PIE formulation allows for optimal control of a network with 40 users, 80 states, 40 delays, 40 inputs, and 40 disturbances.

15:55-16:20 MoPM_S80.2

Extended Kalman Filter Based Observer Design for Semilinear Infinite-Dimensional Systems (I), pp. 304-307

Afshar, Sepideh — Harvard Medical School
Germ, Fabian — University of Edinburgh
Morris, Kirsten A. — Univ. of Waterloo

A semilinear infinite-dimensional system with a disturbance input is considered. The observation is modelled by an affine linear map with a different disturbance. An observer, based on the extended Kalman filter (EKF), is constructed and its well-posedness is proven under mild conditions. Moreover, local exponential stability of the error dynamics is shown. Thus, if the error in the initial condition is small enough, the estimation error converges to zero. This is a first generalization of the EKF to infinite-dimensional systems. Since only detectability, not observability, is assumed, this result is new even for finite-dimensional systems. An implementation is provided for a magnetic drug-delivery system and numerical results support the effectiveness of the observer.

16:20-16:45 MoPM_S80.3

Supervised Learning for Kinetic Consensus Control (I), pp. 308-313

Albi, Giacomo — University of Verona
Bicego, Sara — Imperial College London
Kalise, Dante — Imperial College London

In this paper, how to successfully and efficiently condition a target population of agents towards consensus is discussed. To overcome the curse of dimensionality, the mean field formulation of the consensus control problem is considered. Although such formulation is designed to be independent of the number of agents, it is feasible to solve only for moderate intrinsic dimensions of the agents space. For this reason, the solution is approached by means of a Boltzmann procedure, i.e. quasi-invariant limit of controlled binary interactions as approximation of the mean field PDE. The need for an efficient solver for the binary interaction control problem

motivates the use of a supervised learning approach to encode a binary feedback map to be sampled at a very high rate. A gradient augmented feedforward neural network for the Value function of the binary control problem is considered and compared with direct approximation of the feedback law.

16:45-17:10	MoPM_S80.4

Constructive Method for Boundary Control of Stochastic 1D Parabolic PDEs (I), pp. 314-319

Wang, Pengfei	Harbin Institute of Technology
Katz, Rami	Tel Aviv University
Fridman, Emilia	Tel-Aviv Univ

Recently, qualitative methods for finite-dimensional boundary state-feedback control were introduced for stochastic 1D parabolic PDEs. In this paper, we present constructive and efficient design conditions for state-feedback control of stochastic 1D heat equations driven by a nonlinear multiplicative noise. We consider the Neumann actuation and apply modal decomposition with either trigonometric or polynomial dynamic extension. The controller design employs a finite number of comparatively unstable modes. We provide mean-square L^2 stability analysis of the full-order closed-loop system, where we employ It^{o}'s formula, leading to linear matrix inequality (LMI) conditions for finding the controller gain and as large as possible noise intensity for the mean-square stabilizability. We prove that the LMIs are always feasible for small enough noise intensity. We further show that in the case of linear multiplicative noise, the system is stabilizable for noise intensities that guarantee the stabilizability of the stochastic finite-dimensional part of the closed-loop system. Numerical simulations illustrate the efficiency of our method.

MoPM_S82	S 82
Networked Control Systems - I (Hybrid Session) (Regular Session)	
Chair: Tegling, Emma	Lund University
Co-Chair: Ito, Hiroshi	Kyushu Institute of Technology

15:30-15:55	MoPM_S82.1

On Scale Fragilities in Localized Consensus, pp. 320-323

Tegling, Emma	Lund University

We consider the prototypical networked control problem of distributed consensus in networks of agents with integrator dynamics of order two or higher (n>=2). We assume all feedback to be localized in the sense that each agent has a bounded number of neighbors and consider a scaling of the network through the addition of agents. We show that standard consensus algorithms that rely on relative state feedback and fixed gains can be subject to scale fragilities, meaning that stability is lost as the network grows. For high-order agents (n>=3), we prove that no consensus algorithm is what we term scalably stable. That is, while a given algorithm may allow a small network to converge, it causes instability if the network grows beyond a certain finite size. This holds in families of network graphs whose algebraic connectivity, that is, the smallest non-zero Laplacian eigenvalue, is decreasing towards zero in network size (equivalently, non-expanding graphs). For second-order consensus (n = 2), we prove that the same scale fragility applies to classes of directed graphs that have a complex Laplacian eigenvalue approaching the origin (e.g. directed ring graphs). We derive algebraic conditions for the affected graphs, and discuss how the consensus algorithm can be modified to retrieve scalable stability.

15:55-16:20	MoPM_S82.2

Lower Bound Performance for Averaging Algorithms in Open Multi-Agent Systems, pp. 324-326

Monnoyer de Galland de Carnières, Charles	Université Catholique De Louvain
Hendrickx, Julien M.	UCLouvain

We derive fundamental limitations on the performance that can be achieved by intrinsic averaging algorithms in open multi-agent systems, which are systems subject to random arrivals and departures of agents. Each agent holds an intrinsic value, and their objective is to collaboratively estimate the average of the values of the agents presently in the system. We provide a lower bound on the expected Mean Square Error for such algorithms where we assume that the size of the system remains constant. Our derivation is based on the error obtained with an algorithm that achieves optimal performance under a set of restrictions on the way agents obtain information about one another. This error represents a lower bound on the error obtained with any other algorithm that can be implemented under the same restrictions. This approach is then applied to derive lower bounds on the performance of the well-known Gossip algorithm by considering restrictions that allow implementing it.

16:20-16:45	MoPM_S82.3

Resource Allocation in Open Multi-Agent Systems: An Online Optimization Approach, pp. 327-330

Monnoyer de Galland de Carnières, Charles	Université Catholique De Louvain
Vizuete, Renato	CentraleSupélec
Hendrickx, Julien M.	UCLouvain
Frasca, Paolo	CNRS, GIPSA-Lab, Grenoble
Panteley, Elena V.	CNRS, ITMO

The resource allocation problem consists in the optimal distribution of a budget between a group of agents. We consider a version of this optimization problem in open systems where agents can be replaced, resulting in variations of the budget and the total cost function to be minimized. We analyze the performance of the Random Coordinate Descent algorithm (RCD) in that setting using natural performance indexes which are related to those used in online optimization. We show that, in a simple setting, both the accumulated error obtained from using the RCD as compared to the optimal solution and the accumulated gain obtained from using the RCD instead of not collaborating grow linearly with the number of iterations considered for the computation, so that in expectation an error cannot be avoided, but remains bounded.

16:45-17:10	MoPM_S82.4

Dynamic Consensus of Nonlinear Oscillators under Weak Coupling, pp. 331-334

Lazri, Anes	PARIS SACLAY
Panteley, Elena V.	CNRS, ITMO
Loria, Antonio	CNRS

Dynamic consensus is a property of networked systems that pertains to the case in which all the interconnected systems synchronise their motions and a collective behaviour arises. If the coupling strength is large such behaviour may be modelled by a single system, but if it is weak, the behaviour is best modelled by a reduced-order network. For networks of homogeneous Stuart-Landau oscillators under weak coupling, we characterise the dimension and dynamics of such reduced-order network in function of the coupling strength.

17:10-17:35	MoPM_S82.5

Semi-Global Input-To-State Stabilization of SIQR Model with Isolation, Outing Regulation, and Vaccination in Staircase Form, pp. 335-340

Ito, Hiroshi	Kyushu Institute of Technology

This paper proposes staircase-like feedback laws for control of human infectious diseases based on the SIQR model in the situation where vaccine administration alone cannot be sufficient. The control inputs consisting of isolation, contact regulation, and vaccination are designed to achieve input-to-state stability (ISS) with respect to uncertainty that includes perturbation of immigrants and newborns. The designed controller is semi-global so that the ISS guarantee can be obtained on an arbitrary large compact set in the state space. To accomplish the practical control implementation, this paper qualifies a simple separable function as a control Lyapunov function.

17:35-18:00	MoPM_S82.6

Multi-Modal Behaviours in Network SIR Model, pp. 341-344

Alutto, Martina	Politecnico Di Torino
Cianfanelli, Leonardo	Politecnico Di Torino
Como, Giacomo	Politecnico Di Torino
Fagnani, Fabio	Politecnico Di Torino

We study the dynamical behaviour of the SIR network model at individual nodes. In two particular cases of a network consisting of only two nodes, we show how this behaviour differs from the epidemic outbreak and monotonic decreasing trend that occur in the homogeneous case. The first case deals with a network in which contact is only direct from one node to another, while the second treats a network with all contacts equal to one. The result shown for this scenario remains true by continuity for all those networks sufficiently close in parameter space.

TuP_Audimax	Audimax
Plenary: Weinan E (Plenary Session)	
Chair: Rantzer, Anders	Lund Univ

09:00-10:00	TuP_Audimax.1

Deep Learning and Optimal Control, pp. 345-350

E, Weinan	Peking University

There is a close analogy between deep learning and optimal control. This analogy can be exploited to develop deep learning-based algorithms for optimal control, and optimal control-based algorithms for deep learning. I will discuss the progress made along these directions.

TuAM_H16	H 16
Algebraic and Geometric Approaches to Systems Structure and Control - I (Hybrid Session) (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

10:30-10:55	TuAM_H16.1

Feasible Initial Conditions for 2D Discrete State-Space Systems (I), pp. 351-355

Pereira, Ricardo	University of Aveiro
Rocha, Paula	Univ of Porto

The aim of this contribution is to characterize the set of feasible initial conditions on a diagonal line in order to compute the solutions of a 2D discrete state-space system (defined over Z^2) on a half-plane of the 2D grid. This characterization is given in terms of the system matrices for the state updating.

10:55-11:20	TuAM_H16.2

Transforming Interconnected Systems and Ladder Circuits into Implicit 2D Models (I), pp. 356-361

Bachelier, Olivier	University of Poitiers
Cluzeau, Thomas	Université De Limoges

In this paper, we consider two classes of spatially interconnected systems (including ladder circuits) modelled as mixed discrete-continuous linear 2D systems. Within the algebraic analysis approach to linear systems theory, we prove that these systems can always be transformed into equivalent implicit Roesser models. Moreover we show that ladder circuits can also be transformed into equivalent implicit Fornasini-Marchesini models. An advantage of our results compared to previous ones obtained through the zero coprime system equivalence approach is that the dimension of the state vector of the equivalent Roesser (or Fornasini-Marchesini) models is significantly smaller.

11:20-11:45	TuAM_H16.3

Algorithms for Specifying Initial Data for Discrete Autonomous nD Systems (I), pp. 362-367

Mukherjee, Mousumi	Technical University of Kaiserslautern, Germany
Bajcinca, Naim	University of Kaiserslautern
Pal, Debasattam	Indian Institute of Technology Bombay

For nD systems, initial data is obtained by specifying trajectories on special subsets of the domain, known as characteristic sets. In this paper, we consider a special class of systems that admits a union of a coordinate sublattice and finitely many parallel translates of it as a characteristic set; we call such systems as strongly relevant systems. Using the discrete Noether's normalization lemma, every discrete autonomous nD system can be transformed to a strongly relevant system. For a strongly relevant system, the set of allowable initial conditions, obtained by restricting trajectories on the characteristic set, is characterized. We then provide an implementable algorithm, based on Groebner basis, for obtaining a representation of the set of allowable initial conditions. Once such a representation is obtained, important deductions, such as, arbitrary assignability of initial data can be easily made.

11:45-12:10	TuAM_H16.4

Application of Generalized Functions in Optimal Control, pp. 368-371

Verriest, Erik I.	Georgia Inst. of Tech

A new spin is given on the classical optimal control problem with piecewise differentiable dynamics and performance index with respect to the state variables. While in each domain of differentiability, the necessary conditions for optimality are easily established, their interpretation at the boundaries between domains is not well-understood. In this paper we show that in order to make sense of the Euler-Lagrange equation at this interface one needs to transcend the classical theory of Schwartz distributions and make suitable extensions to allow for the questionable behavior of impulses multiplied by discontinuities, and the notion of partial derivatives at a discontinuity. Such a theory has been developed, in the Colombeau, Oberguggenberger and Rosinger theory of Generalized Functions in 1990, going back to ideas from Nonstandard Analysis (NSA). We develop an alternative NSA based approach applicable to impulsive dynamics and optimal control.

TuAM_H17	H 17
Dissipativity Theory II: Stability Analysis (Hybrid Session) (Invited Session)	
Chair: Hughes, Timothy H.	University of Exeter
Co-Chair: van der Schaft, Arjan J.	Univ. of Groningen
Organizer: Gruene, Lars	Univ of Bayreuth
Organizer: Hughes, Timothy H.	University of Exeter
Organizer: van der Schaft, Arjan J.	Univ. of Groningen

10:30-10:55	TuAM_H17.1

Compositional Stability Criteria Based on Cyclically Neutral Supply Conditions (I), pp. 372-377

Lazar, Mircea	Eindhoven Univ. of Technology

In this paper we consider stability of large scale interconnected nonlinear systems that satisfy a strict dissipativity property in terms of local storage and supply functions. Existing compositional stability criteria certify global stability by constructing a global Lyapunov function as the (weighted) sum of local storage functions. We generalize these results by unifying spatial composition, i.e., (weighted) sum of local supply functions is neutral, with temporal composition, i.e., (weighted) sum of supply functions over a time cycle is neutral. Two benchmark examples illustrate the benefits of the developed compositional stability criteria in terms of reducing conservatism and constrained distributed stabilization.

10:55-11:20	TuAM_H17.2

Dissipativity, Convexity and Tight O'Shea-Zames-Falb Multipliers for Safety Guarantees (I), pp. 378-383

Scherer, Carsten W.	Department of Mathematics, University of Stuttgart

We develop a novel convex parametrization of integral quadratic constraints with a terminal cost for subdifferentials of convex functions, involving general O'Shea-Zames-Falb multipliers. We show the benefit of our results for the reduction of conservatism of existing techniques, and sketch applications to the analysis of optimization algorithms or the stability analysis of neural network controllers. The development is prepared by providing a novel link between the convex integrability of a multivariable mapping and dissipativity theory.

11:20-11:45	TuAM_H17.3

Small-Gain Conditions for Robust Stability of Nonlinear Infinite Networks (I), pp. 384-387

Mironchenko, Andrii	University of Passau
Glück, Jochen	University of Wuppertal

We prove that a network of input-to-state stable infinite-dimensional systems is input-to-state stable, provided that the gain operator of the network satisfies the monotone limit property. This property is equivalent to the strong small-gain condition in the case of finite networks. We prove our small-gain theorem for a very general class of networks, including networks of nonlinear partial and delay differential equations. It also recovers the classical nonlinear small-gain theorems for finitely many finite-dimensional systems as a special case.

11:45-12:10 TuAM_H17.4

Analyzing Feedback Interconnections of Maximal Monotone Systems Using Dissipativity Approach (I), pp. 388-393

Tanwani, Aneel	LAAS -- CNRS, Université De Toulouse
Brogliato, Bernard	UR Rhone-Alpes

We consider feedback interconnections of two dynamical systems in feedback configuration. The dynamics of individual systems are modeled by a differential inclusion, and the corresponding set-valued mapping is (anti-) maximal monotone with respect to the state of the system for each fixed value of the external signal that defines the interconnection. We provide conditions on these mappings under which the dynamics of the resulting interconnected system are (anti-) maximal monotone. An interpretation of our main results is provided: firstly, by considering dynamical systems defined by the subgradient of a saddle function, and secondly, by considering an interconnection of incrementally passive systems. In the same spirit, when we associate more structure to the individual systems by considering linear complementarity systems, we allow for more flexibility in describing the interconnections and derive more specific sufficient conditions in terms of system matrices that result in the overall system being described by a maximal monotone operator.

TuAM_H18 H 18

Data-Driven Agent-Based Modeling (Hybrid Session) (Invited Session)

Chair: Koltai, Peter	Freie Universität Berlin
Co-Chair: Maggioni, Mauro	Johns Hopkins University
Organizer: Koltai, Peter	Freie Universität Berlin

10:30-10:55 TuAM_H18.1

Learning Interaction Variables and Kernels from Observations of Agent-Based Systems (I), pp. 394-399

Feng, Jinchao	Johns Hopkins University
Maggioni, Mauro	Johns Hopkins University
Martin, Patrick	Johns Hopkins University
Zhong, Ming	Texas A&M University

Dynamical systems across many disciplines, including Physics and Biology are modeled as interacting particles or agents, with interaction rules that depend on the states of pairs of agents, but in fact may truly depend only on a very small number of variables (e.g. pairwise distances, pairwise differences of phases, etc...). These relatively simple interaction rules still can determine complex emergent behaviors (clustering, flocking, swarming, etc.) in so-called self organization dynamics. We propose a learning technique that, given observations of states and corresponding derivatives along trajectories of the agents, it estimates both the variables upon which the interaction kernel depends, and the interaction kernel itself. This yields an effective dimension reduction which avoids the curse of dimensionality from the high-dimensional observation data (states and corresponding derivatives of all the agents). We demonstrate the learning capability of our method to a variety of first-order interacting systems.

10:55-11:20 TuAM_H18.2

Discovering Collective Variable Dynamics of Agent-Based Models (I), pp. 400-403

Lücke, Marvin	Zuse Institute Berlin

Analytical approximations of the macroscopic behavior of agent-based models (e.g. via mean-field theory) often introduce a significant error, especially in the transient phase. For an example model called continuous-time noisy voter model, we use two data-driven approaches to learn the evolution of collective variables instead. The first approach utilizes the SINDy method to approximate the macroscopic dynamics without prior knowledge, but has proven itself to be not particularly robust. The second approach employs an informed learning strategy which includes knowledge about the agent-based model. Both approaches exhibit a considerably smaller error than the conventional analytical approximation.

11:20-11:45 TuAM_H18.3

Data-Driven Coarse-Graining of Agent-Based Models through Stochastic Differential Equations (I), pp. 404-407

Azmat, Asima	Siemens AG, Munich
Wang, Kaili	Technical University of Munich, Department of Informatics
Dietrich, Felix	Technical University of Munich

Macroscopic, coarse descriptions of microscopic, agent-based dynamical systems are useful for tasks such as optimization, bifurcation analysis, and control. Once suitable coarse variables are defined, their dynamics can be either derived analytically or approximated in a data-driven fashion. For many agent-based systems, this coarse-graining procedure requires appropriate closure terms or stochastic elements on the macroscopic scale to summarize degrees of freedom of the agents. In this contribution, we identify effective stochastic differential equations (SDE) for coarse observables of agent-based simulations. These SDE then act as surrogate models on the macroscopic scale. We approximate the drift and diffusivity functions for these SDE through neural networks. Based on earlier work, the loss function is inspired by the structure of established stochastic numerical integrators, in particular Euler-Maruyama and Milstein schemes. We consider cases where the coarse collective observables are known in advance, and where they must be found with data-driven methods. We demonstrate the feasibility on data from an egress simulation of pedestrians in two-dimensional continuous space (with the crowd simulation software Vadere).

11:45-12:10 TuAM_H18.4

Modeling the Economic Effects of the Covid-19 Pandemic in a Data-Driven Agent-Based Framework (I), pp. 408-410

Pichler, Anton	Complexity Science Hub

We introduce a dynamic disequilibrium agent-based model(ABM) that was used to forecast the economics of the Covid-19 pandemic. This model was designed to understand the upstream and downstream propagation of the industry-specific demand and supply shocks caused by Covid-19, which were exceptional in their severity, suddenness and heterogeneity across industries. We used this model to forecast sectoral and aggregate economic activity for the United Kingdom during the early phase of the pandemic. This work demonstrates that an out of equilibrium model calibrated against national accounting data can serve as a useful real time policy evaluation and forecasting tool. We further extend this modeling framework to a large-scale,data-driven ABM of the New York metropolitan area that simulates both, epidemic and economic outcomes across industries, occupations, and income levels. This coupled epidemic-economic model is designed to address the potential tradeoff between economy and health which has been a key issue faced by policymakers. Our results show that lockdown policies affect different social groups very heterogeneously in terms of income and infections.

TuAM_H19 H 19

Learning-Based Methods in Control - III (Hybrid Session) (Invited Session)

Chair: Nakamura-Zimmerer, Tenavi — University of California, Santa Cruz

Co-Chair: Kang, Wei — Naval Postgraduate School

Organizer: Kang, Wei — Naval Postgraduate School

Organizer: Gong, Qi — University of California, Santa Cruz

Organizer: Nakamura-Zimmerer, Tenavi — University of California, Santa Cruz

10:30-10:55 TuAM_H19.1

Neural Network Optimal Feedback Control with Guaranteed Local Stability (I), pp. 411-414

Nakamura-Zimmerer, Tenavi — University of California, Santa Cruz

Gong, Qi — University of California, Santa Cruz

Recent work has demonstrated the potential of applying supervised learning to train neural networks which approximate optimal feedback laws. In this talk, we show that some neural networks with good test accuracy can fail to even locally stabilize the dynamics. To address this challenge, we propose some novel neural network architectures which guarantee local asymptotic stability while still closely approximating optimal feedback laws on large domains.

10:55-11:20 TuAM_H19.2

Curse-Of-Dimensionality-Free Computation of Control Lyapunov Functions Using Neural Networks (I), pp. 415-418

Gruene, Lars — Univ of Bayreuth

Sperl, Mario — University of Bayreuth

Numerical methods for computing control Lyapunov functions often suffer from the so-called curse of dimensionality, i.e., an exponential growth of the numerical effort in the state dimension. It is known that deep neural networks can approximate compositional functions without suffering from this curse of dimensionality. In this talk, we extend the results for computing Lyapunov functions presented in [Grüne, L. (2021). Computing Lyapunov functions using deep neural networks. Journal of Computational Dynamics, 8(2), 131–152] to the case of control Lyapunov functions. To this end, we discuss the use of methods from nonlinear control theory that yield the existence of a compositional control Lyapunov function. Moreover, we develop a suitable network architecture and a training algorithm for an efficient approximation of such a control Lyapunov function.

11:20-11:45 TuAM_H19.3

Data-Driven Initialization of Deep Learning Solvers for Hamilton-Jacobi-Bellman PDEs (I), pp. 419-424

Borovykh, Anastasia — University of Warwick

Kalise, Dante — Imperial College London

Laignelet, Alexis — Imperial College London

Parpas, Panos — Imperial College London

A deep learning approach for the approximation of the Hamilton-Jacobi-Bellman partial differential equation (HJB PDE) associated to the Nonlinear Quadratic Regulator (NLQR) problem. A state-dependent Riccati equation control law is first used to generate a gradient-augmented synthetic dataset for supervised learning. The resulting model becomes a warm start for the minimization of a loss function based on the residual of the HJB PDE. The combination of supervised learning and residual minimization avoids spurious solutions and mitigate the data inefficiency of a supervised learning-only approach. Numerical tests validate the different advantages of the proposed methodology.

11:45-12:10 TuAM_H19.4

Learning Optimal Feedback Laws for Nonlinear Control Systems (I), pp. 425-427

Walter, Daniel — Humboldt-Universität Zu Berlin

Kunisch, Karl — University Graz

A learning approach for optimal feedback gains for nonlinear continuous time control systems is proposed and analysed. Numerical results demonstrate the feasibilty of the approach, which allows to obtain suboptimal feedback gains, without focusing on directly solving the underlying Hamilton Jacobi Belman equation.

TuAM_S70 S 70

Adaptive Control (Regular Session)

Chair: Lanza, Lukas — University of Paderborn

Co-Chair: Kjellqvist, Olle — Lund University

10:30-10:55 TuAM_S70.1

Funnel Control of Linear Systems under Output Measurement Losses, pp. 428-431

Lanza, Lukas — University of Paderborn

Berger, Thomas — Universität Paderborn

We consider tracking control of linear minimum phase systems with known arbitrary relative degree which are subject to possible output measurement losses. We provide a control law which guarantees the evolution of the tracking error within a (shifted) prescribed performance funnel whenever the output signal is available. The result requires a maximal duration of measurement losses and a minimal time of measurement availability, which both strongly depend on the internal dynamics of the system, and are derived explicitly.

10:55-11:20 TuAM_S70.2

Robust Output-Feedback Adaptive Control of Finite Sets of Linear Systems, pp. 432-435

Kjellqvist, Olle — Lund University

This paper concerns the problem of bounded l2-gain adaptive control with noisy measurements for linear time-invariant systems with uncertain parameters belonging to a finite set. We show that it is necessary and sufficient to consider observer-based control with a multiple-observer structure consisting of one H-infinity-observer paired with a model fitness metric per candidate model.

11:20-11:45 TuAM_S70.3

Input-Constrained Funnel Control of Nonlinear Systems, pp. 436-439

Berger, Thomas — Universität Paderborn

We consider tracking control for uncertain nonlinear multi-input, multi-output systems modelled by functional differential equations, in the presence of input constraints. The objective is to guarantee the evolution of the tracking error within a performance funnel with prescribed asymptotic shape. We design a novel funnel controller which, in order to satisfy the input constraints, contains a dynamic component which widens the funnel boundary whenever the input saturation is active. This design is model-free, of low-complexity and extends earlier funnel control approaches.

11:45-12:10 TuAM_S70.4

A Formal Power Series Approach to Multiplicative Dynamic and Static Output Feedback, pp. 440-445

Guggilam, Subbarao Venkatesh — Old Dominion University

The goal of the paper is two-fold. The first of which is to derive an explicit formula to compute the generating series of a closed-loop system when a plant, given in a Chen-Fliess series description is in multiplicative output feedback connection with another system given in Chen-Fliess series description. In addition, the multiplicative dynamic output feedback connection has a natural interpretation as a transformation group acting on the plant. The second of the two-part goal of this paper is same as the first part albeit when the Chen-Fliess series in the feedback is replaced by a memoryless map, so called multiplicative static feedback connection.

TuAM_S80	S 80
Infinite-Dimensional Input-To-State Stability (Invited Session)	

Chair: Schwenninger, Felix	University of Twente
Co-Chair: Hosfeld, René	Bergische Universität Wuppertal
Organizer: Schwenninger, Felix	University of Twente

10:30-10:55 TuAM_S80.1

On Semi-Uniform Input-To-State Stability and Polynomial Input-To-State Stability (I), pp. 446-447

Wakaiki, Masashi — Kobe Univeristy

We introduce the notions of semi-uniform input-to-state stability and polynomial input-to-state stability for infinite-dimensional systems. A characterization of semi-uniform input-to-state stability is developed based on attractivity properties as in the uniform case. We also provide sufficient conditions for linear systems to be polynomially input-to-state stable.

10:55-11:20 TuAM_S80.2

Input-To-State Stability for Unbounded Bilinear Feedback Systems (I), pp. 448-451

Hosfeld, René	Bergische Universität Wuppertal
Jacob, Birgit	Bergische Universität Wuppertal
Schwenninger, Felix	University of Twente
Tucsnak, Marius	University of Bordeaux

We study input-to-state stability (ISS) of systems with a linear control and a bilinear feedback term, depending on the state trajectory itself and the output of the system. Both, the control and the bilinear feedback enter the system through possibly unbounded operators. Further, the observation operator, associated to the output, is also considered to be unbounded. We derive sufficient conditions for a global in time well-posedness result for small initial data as well as sufficient conditions for an ISS-estimate. This extends recent investigations on bilinear systems, where a second control was considered instead of an output. The developed results are applied to a Burgers equation.

11:20-11:45 TuAM_S80.3

A Link between the Backstepping Method and the Sylvester Equation (I), pp. 452-455

Gagnon, Ludovick	INRIA
Hayat, Amaury	Ecole Des Ponts Paristech
Marx, Swann	CNRS
Xiang, Shengquan	EPFL
Zhang, Christophe	INRIA

This talk will be about a general result for the backstepping method. In particular, we will show that, under some classical assumptions in stabilization, there exists a systematic way to define backstepping transformation. Indeed, this transformation is defined as the solution of a Sylvester equation. Existence and uniqueness of this equation are proved for a class of admissible feedback operators. Moreover, the existence of a feedback is obtained thanks to an infinite-dimensional Cauchy matrix. This is a joint work with Ludovick Gagnon, Amaury Hayat, Shengquan Xiang and Christophe Zhang.

11:45-12:10 TuAM_S80.4

L^{infty}-Admissibility for Non-Strongly-Continuous Semigroups (I), pp. 456-459

Kruse, Karsten	Hamburg University of Technology
Schwenninger, Felix	University of Twente

Input-to-state stability is characterised by admissibility for linear systems, governed by strongly continuous semigroups. Yet, in some applications semigroups may fail to be strongly continuous with respect to the norm of the underlying Banach space. Typical examples are given by shift-semigroups and the Gauß-Weierstraß semigroup on spaces of bounded continuous functions as well as dual semigroups. This requires a suitable theory for this general setting within the framework of so-called bi-continuous semigroups, including proper admissibility concepts. Our contribution mainly focuses on non-trivial variants of results from the classical case. For instance, the recently shown fact that the generator of a strongly continuous semigroup is only admissible if it is a bounded operator, fails for bi-continuous semigroups.

TuAM_S82	S 82
Hamilton-Jacobi Equations and Mean Field Games - I (Hybrid Session) (Invited Session)	

Chair: Falcone, Maurizio	SAPIENZA - Universita' Di Roma
Co-Chair: Zidani, Hasnaa	INSA Rouen Normandie
Organizer: Falcone, Maurizio	SAPIENZA - Universita' Di Roma
Organizer: Zidani, Hasnaa	INSA Rouen Normandie

10:30-10:55 TuAM_S82.1

Deterministic Optimal Control Problem onRiemannian Manifolds under Probabilityknowledge of the Initial Condition (I), pp. 460-463

Jean, Frederic	ENSTA ParisTech
Zidani, Hasnaa	INSA Rouen Normandie
Jerhaoui, Othmane	ENSTA PARIS

This paper concerns an optimal control problem on the space of probability measuresover a compact Riemannian manifold. The motivation behind it is to model certain situations where the central planner of a deterministic controlled system has only a probabilistic knowledge of the initial condition. The lack of information here is very specific. In particular, we show that the value function verifies a dynamic programming principle and we prove that it is the unique viscosity solution to a suitable Hamilton Jacobi Bellman equation. The notion of viscosity is defined using test functions that are directionally differentiable in the the space of probability measures.

10:55-11:20 TuAM_S82.2

Constrained Mean Field Games Equilibria As Fixed Point of Random Lifting of Set-Valued Maps (I), pp. 464-469

Capuani, Rossana	University of Tuscia
Marigonda, Antonio	University of Verona

We introduce an abstract framework for the study of general mean field game and mean field control problems. Given a multiagent system, its macroscopic description is provided by a time-depending probability measure, where at every instant of time the measure of a set represents the fraction of (microscopic) agents contained in it. The trajectories available to each of the microscopic agents are affected also by the overall state of the system. By using a suitable concept of random lift of set-valued maps, together with fixed point arguments, we are able to derive properties of the macroscopic description of the system from properties of the set-valued map expressing the admissible trajectories for the microscopical agents. We apply the results in the case in which the admissible trajectories of the agents are the minimizers of a suitable integral functional depending also from the macroscopic evolution of the system.

11:20-11:45 TuAM_S82.3

Constrained Multiagent Dynamical Systems and Hamilton-Jacobi-Bellman Inequalities on the Wasserstein Space (I), pp. 470-471

Quincampoix, Marc — Universite De Bretagne Occidentale

Several optimal control problems in R^d, like systems with uncertainty, control of flock dynamics, or control of multiagent systems, can be naturally formulated in the space of probability measures in $ R^d$. The compatibility of such control systems with a state constraint can be studied by an Hamilton-Jacobi-Bellman equation stated in the Wasserstein space of probability measure. We show that the dynamic is compatible with the constraint when the distance function satisfies the Hamilton Jacobi inequality in a suitable viscosity sense.

11:45-12:10 TuAM_S82.4

A Multilevel Fast-Marching Method, pp. 472-475

Akian, Marianne — INRIA and Ecole Polytechnique
Gaubert, Stephane — INRIA
Liu, Shanqing — Ecole Polytechnique

We introduce a new numerical method to approximate the solutions of a class of static Hamilton-Jacobi-Bellman equations arising from minimum time optimal control problems. We rely on several grid approximations, and look for the optimal trajectories by using the coarse grid approximations to reduce the search space for the optimal trajectories in fine grids. This may be thought of as an infinite dimensional version, for PDE, of the “highway hierarchy” method which has been developed to solve discrete shortest path problems. We obtain, for each level, an approximate value function on a sub-domain of the state space. We show that the sequence obtained in this way does converge to the viscosity solution of the HJB equation. Moreover, the number of arithmetic operations that we need to obtain an error of O(e) is bounded by O(1/e^(2d/(1+b))), to be compared with O(1/e^(2d)) for ordinary grid-based methods. Here b depends on the "stiffness" of the value function around the optimal trajectories. Under a regularity condition on the dynamics, we obtain a bound of O(1/e^((1-b)d)) operations, for b<1, and this bound becomes O(|loge|) for b=1. This allowed us to solve HJB PDE of Eikonal type up to dimension 7.

TuSP_H17	H 17
Semi Plenary: Sanne Ter Horst (Plenary Session)	
Chair: Vinnikov, Victor	Ben Gurion University of the Negev

14:00-15:00	TuSP_H17.1

Convex Invertible Cones and Nevanlinna-Pick Interpolation, pp. 476-483

ter Horst, Sanne — North West University

Nevanlinna-Pick interpolation developed from a topic in classical complex analysis to a useful tool for solving various problems in control theory and electrical engineering. Over the years many extensions of the original problem were considered, including extensions to different function spaces, nonstationary problems, several variable settings and interpolation with matrix and operator points. In this talk we discuss a variation on Nevanlinna-Pick interpolation for positive real odd functions evaluated in real matrix points. This problem was studied by Cohen and Lewkowicz using convex invertible cones and the Lyapunov order, making interesting connections with stability theory. The solution requires an analysis of linear matrix maps using representations that go back to work of R.D. Hill from the 1970s and focusses, in particular, on the question when positive linear matrix maps are completely positive. If time permits, some possible extensions to multidimensional systems will briefly be discussed.

TuSP_H18	H 18
Semi Plenary: Achim Ilchmann (Plenary Session)	
Chair: Allgower, Frank	University of Stuttgart

14:00-15:00	TuSP_H18.1

Funnel Control – History and Perspectives, pp. 484-484

Ilchmann, Achim — Technical Univ Ilmenau

The control objective in funnel control is output feedback control such that the norm of the error e(t) of the closed-loop system remains inside a prespecified funnel with boundary ψ(t), i.e. ‖e(t)‖ < ψ(t) for all t > 0. In other words, prescribed transient behaviour as well as asymptotic accuracy is achieved. Typical features of funnel control are:

- Simplicity of the feedback law. The feedback does not invoke any identification scheme, but is – for example in the relative degree one case – a time-varying error feedback of the form u(t) = − 1 / (1 − ψ(t) ‖e(t)‖) e(t), e(t) := y(t) − yref(t), where yref(·) denotes a sufficiently smooth bounded signal with bounded derivative. Note that the gain k(t) = − 1 / (1 − ψ(t) ‖e(t)‖) is large if, and only if, the error is close to the funnel boundary.

- Funnel control is feasible for a whole class of input-output systems. These classes are described by structural assumptions the systems have to satisfy.

After two decades of high-gain adaptive control, funnel control was introduced in 2002. First results were on linear, single-input, single-output, time-invariant systems with relative degree one and being minimum phase. From then on feasibility of funnel control was shown for other system classes such as multi-input, multi-output, nonlinear, infinite dimensional, perturbed systems, unknown control directions – provided they have stable zero dynamics and satisfy certain assumptions on the high-frequency gain. A particular challenge was to show feasibility for systems with higher relative degree, and to design a funnel controllers for systems described by partial differential equations. Funnel control was applied to various applications such as control in chemical reactor models, industrial servo-systems, wind turbine systems, electrical circuits, to name but a few. Recently, funnel control has been investigated in combination with model predictive control and applied to magnetic levitation systems.

TuSP_H19	H 19
Semi Plenary: Claudia Schillings (Plenary Session)	
Chair: Kang, Wei	Naval Postgraduate School

14:00-15:00	TuSP_H19.1

A General Framework for Machine Learning-Based Optimization under Uncertainty, pp. 485-485

Schillings, Claudia — Free University of Berlin

Approaches to decision making and learning mainly rely on optimization techniques to achieve “best” values for parameters and decision variables. In most practical settings, however, the optimization takes place in the presence of uncertainty about model correctness, data relevance, and numerous other factors that influence the resulting solutions. For complex processes modeled by nonlinear ordinary and partial differential equations, the incorporation of these uncertainties typically results in high or even infinite dimensional problems in terms of the uncertain parameters as well as the optimization variables, which in many cases are not solvable with current state of the art methods. One promising potential remedy to this issue lies in the approximation of the forward problems using novel techniques arising in uncertainty quantification and machine learning. We propose in this talk a general framework for machine learning based optimization under uncertainty and inverse problems. Our approach replaces the complex forward model by a surrogate, e.g. a neural network, which is learned simultaneously in a one-shot sense when estimating the unknown parameters from data or solving the optimal control problem. By establishing a link to the Bayesian approach, an algorithmic framework is developed which ensures the feasibility of the parameter estimate / control w.r.t. to the forward model. This is joint work with Philipp Guth (U Mannheim) and Simon Weissmann (U Heidelberg).

TuPM_H16	H 16
Algebraic and Geometric Approaches to Systems Structure and Control - II (Hybrid Session) (Invited Session)	
Chair: Zerz, Eva	RWTH Aachen University
Co-Chair: Quadrat, Alban	Inria Paris
Organizer: Quadrat, Alban	Inria Paris
Organizer: Zerz, Eva	RWTH Aachen University

15:30-15:55	TuPM_H16.1

Lie Algebraic Analysis of Exponential Stability of Switched DAEs (I), pp. 486-491

Harivanam, Phani — Indian Institute of Technology Bombay
Pal, Debasattam — Indian Institute of Technology Bombay

In this paper, we prove a Lie algebraic criterion for stability of switched differential algebraic equations (DAEs). We show that if the Lie algebra generated by the differential flows associated with the DAE subsystems of an impulse free switched DAE with descriptor matrices that share a common kernel can be decomposed into the solvable ideal and a compact Lie algebra, then the switched DAE is globally uniformly exponentially stable. Furthermore, we show that the proposed Lie algebraic result completely generalizes an existing result in the literature. We also present a conjecture regarding the stability of switched DAEs.

15:55-16:20	TuPM_H16.2

Flatness of Networks of Two Synaptically Coupled Excitatory-Inhibitory Neural Modules (I), pp. 492-497

Nicolau, Florentina	Ensea Cergy
Mounier, Hugues	Laboratoire Des Signaux Et Systèmes, Université Paris Saclay, Ce

In this paper, we consider networks of two synaptically coupled excitatory-inhibitory neural modules. It has been shown that the connection strengths may slowly vary with respect to time and that they can actually be considered as inputs of the network. The problem that we are studying is which connection strengths should be modified (in other words, which connection strengths should be considered as inputs), in order to achieve flatness for the resulting control system. Flatness of the control network depends on the number of inputs and, for all possible values of the number of connection strengths acting as controls, we identify and geometrically describe all flat configurations of the system. In particular, for each case we study whether there are interactions between the two subnetworks or between the excitatory and inhibitory populations that are not allowed (translating into zero connection strengths) or, on the contrary, that necessarily have to take place (translating into nonzero connection strengths), and provide a geometric characterization of each case.

16:20-16:45	TuPM_H16.3

On D-Collision-Free Dynamical Systems (I), pp. 498-500

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

This extended abstract presents several recent results and generalizations that have been obtained in the theory of collision-freeness studied in Zerz and Herty (2019). A nonlinear ODE system x'(t)=f(x(t)) is called collision-free if the solution to the initial value problem with x(0)=x^0 has distinct components for all times t whenever the initial state x^0 has distinct components. This is an important structural property of particle systems. Here, we address the case where the state of the i-th particle has d components x_{ik}, and a collision occurs if there exist t and distinct i,j such that x_{ik}(t)=x_{jk}(t) for all k in {1,...,d}.

16:45-17:10	TuPM_H16.4

Padé Approximation and Hypergeometric Functions: A Missing Link with the Spectrum of Delay-Differential Equations (I), pp. 501-506

Boussaada, Islam	Laboratoire Des Signaux Et Systemes (L2S)
Mazanti, Guilherme	Inria & CentraleSupélec
Niculescu, Silviu-Iulian	Laboratory of Signals and Systems (L2S)

It is well known that rational approximation theory involves degenerate hypergeometric functions and, in particular, the Padé approximation of the exponential function is closely related to Kummer hypergeometric functions. Recently, in the context of the study of the exponential stability of the trivial solution of delay-differential equations, a new link between the degenerate hypergeometric function and the zeros distribution of the characteristic function associated with linear delay-differential equations was emphasized. Such a link allowed the characterization of a property of time-delay systems known as *multiplicity-induced-dominancy (MID)*, which opened a new direction in designing low-complexity controllers for time-delay systems by using a partial pole placement idea. Thanks to their relations to hypergeometric functions, we explore in this paper links between the spectrum of delay-differential equations and Padé approximations of the exponential function. This note exploits and further comments recent results from [I. Boussaada, G. Mazanti and S-I. Niculescu. 2022, Comptes Rendus. Mathématique] and [I. Boussaada, G. Mazanti and S-I. Niculescu. 2022, Bulletin des Sciences Mathématiques].

17:10-17:35	TuPM_H16.5

An Integro-Differential Operator Approach to Linear Differential Systems (I), pp. 507-512

Quadrat, Alban	Inria Paris

In this paper, we initiate a new algebraic analysis approach to linear differential systems based on rings of integro-differential operators. Within this algebraic analysis approach, we first interpret the method of variations of constants as an operator identity. Using this result, we show that the module associated with a state-space representation of a linear system is the same as the one associated with its standard convolution representation. This finitely presented module over the ring of integro-differential operators is proved to be stably free. Finally, we show how the reachability property can be expressed within this algebraic analysis approach.

17:35-18:00	TuPM_H16.6

Variations on Fermat-Steiner-Torricelli, pp. 513-518

Verriest, Erik I.	Georgia Inst. of Tech

We reconsider a classic geometric problem and find some interesting generalizations and applications. The problem in question is Fermat's problem, where for a given triangle, ABC, on finds the point, T, such that the sum of the distances from T to the vertices is minimal. This point T is called the Torricelli point. We generalize the problem to finding this Torricelli point for an arbitrary collection of points in $mathbb{R}^2$ and make connections with the study of linkages. %2D and 3D. We determine the symmetries that leave T invariant. % and solve an associated minimal sensitivity problem. We then propose a balancing problem: Migrate a given set of points minimally so that the Torricelli-point coincides with the origin, and analyze some variants under different objectives and constraints. We illustrate the relevance in foraging and applications in swarm configurations where minimum distance or minimal average communication delay may be important.

TuPM_H17	H 17
Dissipativity Theory III: Structure (Hybrid Session) (Invited Session)	
Chair: Gruene, Lars	Univ of Bayreuth
Co-Chair: van der Schaft, Arjan J.	Univ. of Groningen
Organizer: Gruene, Lars	Univ of Bayreuth
Organizer: Hughes, Timothy H.	University of Exeter
Organizer: van der Schaft, Arjan J.	Univ. of Groningen

15:30-15:55	TuPM_H17.1

Data-Driven Dissipativity Analysis of Linear Systems (I), pp. 519-522

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

The concept of dissipativity is a cornerstone of systems and control theory. Typically, dissipativity properties are verified by resorting to a mathematical model of the system under consideration. In this extended abstract, we aim at assessing dissipativity by computing storage functions for linear systems directly from measured data. As our main contributions, we provide conditions under which dissipativity can be ascertained from a finite collection of noisy data samples. Different noise models will be considered that can capture

a variety of situations, including the cases that the data samples are noise-free, the energy of the noise is bounded, or the individual noise samples are bounded. All of our conditions are phrased in terms of data-based linear matrix inequalities, which can be readily solved using existing software packages.

15:55-16:20	TuPM_H17.2

The Differences between Port-Hamiltonian, Passive and Positive Real Descriptor Systems (I), pp. 523-525

Cherifi, Karim	TU Berlin
Gernandt, Hannes	TU Berlin
Hinsen, Dorothea	TU Berlin

For linear time-invariant descriptor systems it is well known that port-Hamiltonian systems are passive and that passive systems are positive real. In our contribution we study under which assumptions also the converse implications hold. We also study the relationship between passivity, KYP inequalities and a finite required supply.

16:20-16:45	TuPM_H17.3

Lossless Trajectories of Singularly Passive Systems (I), pp. 526-531

Bhawal, Chayan	Indian Institute of Technology Guwahati
Pal, Debasattam	Indian Institute of Technology Bombay
Belur, Madhu	Indian Institute of Technology Bombay

Lossless trajectories of a passive system are the trajectories that satisfy the dissipation inequality with equality. In other words, for a suitable input-state-output representation, these are trajectories for which the rate of change of stored energy is equal to the power supplied to the system. In this paper, we present a method to design feedback control strategies that restrict the trajectories of a passive system to its lossless trajectories. In particular, we deal with passive systems that do not admit an Algebraic Riccati Equation (ARE) arising from the dissipation inequality; we call such systems singularly passive systems. We show that suitably designed PD feedback controllers help us restrict the trajectories of the system to its lossless trajectories. The design method of the controller is linked to the LMI arising from the KYP Lemma corresponding to a passive system.

16:45-17:10	TuPM_H17.4

Dissipation Inequalities and Sum-Of-Squares Programming for Reachability Analysis (I), pp. 532-535

Yin, He	University of California, Berkeley
Seiler, Peter	Univ. of Michigan
Arcak, Murat	UC Berkeley

This abstract summarizes our recent results on reachability analysis using dissipation inequalities. We first outline a method to outer-approximate forward reachable sets (FRS) on finite horizons for uncertain polynomial systems. This method makes use of time-dependent polynomial storage functions that satisfy appropriate dissipation inequalities that account for L2 disturbances, uncertain parameters, and perturbations characterized by time-domain, integral quadratic constraints (IQC). By introducing IQCs to reachability analysis, we now allow for various types of uncertainty, including unmodeled dynamics.We next discuss backward reachable sets (BRS), and decompose control synthesis process into two steps: first we construct storage functions whose sublevel sets are used for BRS estimation, and then we compute control laws using these storage functions through quadratic programs (QP). In a separate result we simultaneously compute an under-approximation to the BRS, as well as an explicit control law in order to incorporate input saturation limits. These methods make use of the generalized S-procedure and Sum-of-Squares techniques to derive algorithms with the goal of finding the tightest approximation to the reachable sets.

17:10-17:35	TuPM_H17.5

Output Consensus Control for Linear Port-Hamiltonian Systems, pp. 536-541

Feng, Shuai	University of Groningen
Kawano, Yu	Hiroshima University
Cucuzzella, Michele	University of Pavia
Scherpen, Jacquelien M.A.	University of Groningen

In this paper, we study output consensus of coupled linear port-Hamiltonian systems on graphs in the presence of constant disturbances, where couplings are allowed to be both static and dynamic. Utilizing port-Hamiltonian structures, we present dynamic controllers achieving output consensus where the consensus values are determined by the disturbances. Finally, the utility of the proposed controller is illustrated by applying it to current sharing of DC microgrids.

17:35-18:00	TuPM_H17.6

Angle-Based Formation Control for a Class of Underlying Triangulated Laman Graphs, pp. 542-545

Li, Ningbo	University of Groningen
Borja, Pablo	TU Delft
van der Schaft, Arjan J.	Univ. of Groningen
Scherpen, Jacquelien M.A.	University of Groningen

This extended abstract proposes a passivity-based approach using bearing and velocity information for an angle-based formation control with a class of underlying triangulated Laman graphs. The controller is designed using virtual couplings on the relative measurements related to the edges. The different embedding of the graph is mapped by the measurement Jacobian, which is calculated by the time-evolution of the measurement. Furthermore, to avoid unavailable distance measurements in the control law, an estimator is designed based on the port-Hamiltonian theory using bearing and velocity measurements. The stability analysis of the closed-loop system is provided and simulations are performed to illustrate the effectiveness of the approach.

TuPM_H18	H 18
Network Coding (Hybrid Session) (Invited Session)	
Chair: Alfarano, Gianira	University of Zurich
Co-Chair: Neri, Alessandro	Max-Planck-Institute for Mathematics in the Sciences
Organizer: Alfarano, Gianira	University of Zurich
Organizer: Neri, Alessandro	Max-Planck-Institute for Mathematics in the Sciences

15:30-15:55	TuPM_H18.1

Evasive Subspaces and Rank-Metric Codes (I), pp. 546-549

Marino, Giuseppe	University of Naples "Federico II"

We investigate the connections between rank-metric codes and evasive ${mathbb F}_q$-subspaces of ${mathbb F}_{q^m}^k$. We show how the parameters of a rank-metric code are related to special geometric properties of the associated evasive subspace and construct new MRD-codes.

15:55-16:20	TuPM_H18.2

Multilayer Crisscross Error and Erasure Correction (I), pp. 550-553

Martínez-Peñas, Umberto	University of Valladolid

In this work, the multi-cover metric is introduced. It is defined as a Cartesian product of classical cover metrics. A Singleton bound is given and maximum multi-cover distance (MMCD) codes are defined. Puncturing and shortening of linear MMCD codes are studied. It is shown that the dual of a linear MMCD code is not necessarily MMCD, and those satisfying this duality condition are defined as dually MMCD codes. Finally, constructions of dually MMCD codes are given, which also include some new linear codes attaining the Singleton bound for the classical cover metric and classical crisscross error correction.

16:20-16:45	TuPM_H18.3

Network Decoding against Restricted Adversaries (I), pp. 554-559

Beemer, Allison	University of Wisconsin-Eau Claire
Kilic, Altan Berdan	Eindhoven University of Technology
Ravagnani, Alberto	Eindhoven University of Technology

We initiate the study of the one-shot capacity of communication (coded) networks with an adversary having access only to a proper subset of the network edges. We introduce the Diamond Network as a minimal example to show that known cut-set bounds are not sharp in general, and that their non-sharpness comes precisely from restricting the action of the adversary to a region of the network. We give a capacity-achieving scheme for the Diamond Network that implements an adversary detection strategy. We also show that linear network coding does not suffice in general to achieve capacity, proving a strong separation result between the one-shot capacity and its linear version. We then give a sufficient condition for tightness of the Singleton Cut-Set Bound in a family of two-level networks. Finally, we discuss how the presence of nodes that do not allow local encoding and decoding does or does not affect the one-shot capacity.

16:45-17:10	TuPM_H18.4

Evaluation Subspace Codes and Convolutional Codes (I), pp. 560-562

Rosenthal, Joachim	University of Zurich

A constant dimension subspace code can be viewed geometrically as a subset of the Grassmann variety defined over a finite field.

There exist few algebraic constructions for constant dimension subspace codes. A major technique is the 'lifting technique' of a rank metric code with a good distance. For rank metric codes exist several good algebraic constructions. First and for most one should mention the technique of constructing Gabidulin codes which can be seen as the image of a linear space of linearized functions under an evaluation map. The technique of constructing Gabidulin codes naturally generalizes the construction of AG-codes such as Reed-Solomon codes and more general geometric Goppa codes.

To our knowledge no similar constructions of subspace codes using evaluation maps is known.

In this talk we will show how convolutional codes give raise in a natural way to constant dimension subspace codes. Using the evaluation over some extension field it is possible to achieve subspace codes with maximal possible distance.

17:10-17:35	TuPM_H18.5

Flag Code Constructions Via Group Actions (I), pp. 563-566

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

In the context of Network Coding, flag codes can be seen as an extension of constant dimension codes. In this case, the codewords are sequences of nested subspaces (flags) of a finite dimensional vector space over a finite field. As with constant dimension codes, a particularly interesting way of constructing flag codes is through group actions, which produces codes with an orbital structure. The aim of this note is to present two specific constructions of flag codes having maximum distance through the action of Singer groups. To this end, we will make use of the transitive action of these groups on lines and hyperplanes.

17:35-18:00	TuPM_H18.6

Algebraic and Geometrical Aspects of Cyclic Subspace Codes (I), pp. 567-570

Zullo, Ferdinando	Università Degli Studi Della Campania "Luigi Vanvitelli"

Cyclic subspace codes gained a lot of attention especially because they may be used in random network coding for correction of errors and erasures. Roth, Raviv and Tamo in 2018 established a connection between cyclic subspace codes (with certain parameters) and Sidon spaces, introduced by Bachoc, Serra and Zémor in 2017 in relation with the linear analogue of Vosper's Theorem. This connection allowed Roth, Raviv and Tamo to construct large classes of cyclic subspace codes with one or more orbits. In this abstract we will consider an extension of the notion of Sidon space, which turns out to be related to cyclic subspace codes with more than one orbit. Moreover, we will also use the geometry of linear sets to provide some bounds on the parameters of a cyclic subspace code.

TuPM_H19	H 19
Adaptive Control under Input or Output Constraints (Hybrid Session) (Invited Session)	
Chair: Berger, Thomas	Universität Paderborn
Co-Chair: Trenn, Stephan	University of Groningen
Organizer: Berger, Thomas	Universität Paderborn
Organizer: Trenn, Stephan	University of Groningen

15:30-15:55	TuPM_H19.1

Distributed Control Barrier Function-Based Control Scheme for Multi-Agent Systems under a Collective Constraint (I), pp. 571-574

Tan, Xiao	KTH Royal Institute of Technology
Dimarogonas, Dimos V.	KTH Royal Institute of Technology

In this work, we consider multi-agent systems (MAS) operating under a collective constraint, i.e., a constraint that involves the collective states of MAS, using control barrier function (CBF) technique. CBF-based control design usually consists of designing a task-achieving controller, and modifying it minimally in a quadratic program (QP) to satisfy the state constraint. Despite its success for single-agent systems, most existing CBF-based control designs for MAS are either centralized or sub-optimal. Our proposed distributed CBF-based control scheme guarantees that the optimal to the QP control signals are obtained in finite time, and the collective constraint is satisfied for all time. The result is valid for a large class of MAS (linear or nonlinear, homogeneous or heterogeneous), underlying tasks (consensus, formation, coverage, etc), and collective constraints. We also analyze another scheme with some comparative remarks. Several numerical examples are shown.

15:55-16:20	TuPM_H19.2

Prescribed Performance Regulation in the Presence of Unknown Time-Varying Delays (I), pp. 575-580

Bikas, Lampros	Aristotle University of Thessaloniki
Rovithakis, George	Aristotle University of Thessaloniki

We design a state-feedback controller to impose prescribed performance attributes on the output stabilization error for uncertain nonlinear systems, in the presence of unknown time-varying delays appearing both to the state and control input signals, provided that an upper bound on those delays is known. The proposed controller achieves pre-specified minimum convergence rate and maximum steady-state error, and keeps bounded all signals in the closed-loop. We proved that the error is confined strictly within a delayed version of the constructed performance envelope. Nevertheless, the maximum value of the output error at steady state remains unaltered, exactly as pre-specified by the constructed performance functions. Furthermore, the controller does not incorporate knowledge regarding the nonlinearities of the controlled system, and is of low-complexity in the sense that no hard calculations (analytic or numerical) are required to produce the control signal. Simulation results validate the theoretical findings.

16:20-16:45	TuPM_H19.3

Flat Outputs for Funnel Control of Non-Minimum-Phase Systems (I), pp. 581-582

Reis, Timo	Technische Universität Ilmenau
Berger, Thomas	Universität Paderborn

We consider adaptive ouput feedback tracking control of linear time-invariant systems which are not necessarily minimum phase. The zero dynamics is split into a stable and an unstable part, we show that a flat output of the unstable part can contribute to the design of a funnel controller of the system. More precisely, we consider an auxiliary output based of the "true output" of the system and the flat output of the unstable part of the zero dynamics. The funnel controller is designed for this auxiliary output, and the consequences for the true output are discussed.

16:45-17:10 TuPM_H19.4

Funnel Control with Internal Model and Anti-Windup for Input-Saturated Mechatronic Systems (I), pp. 583-586

Hackl, Christoph M. — Technical Univ of Munich

Funnel control (FC) in combination with internal model (IM) achieves asymptotic tracking but feasibility of IM-FC in presence of input saturation (if e.g. a feasibility condition is satisfied) is unclear. Here, both aspects are brought together to obtain a closed-loop system comprising of funnel controller, serial interconnection of internal model with anti-windup and input-saturated high-gain stabilizable system which achieves prescribed transient and asymptotic accuracy if a feasibility conditions is satisfied (Hackl, 2017, Chapter 10). It will be illustrated that in presence of actuator saturation, funnel control with internal model but without anti-windup might exhibit integrator windup deteriorating control performance and resulting in instability of the closed-loop system. The theory of funnel control of input-saturated systems will be extended to allow for the application of funnel control with internal model to input-saturated systems by introducing an anti-windup strategy called conditional integration. The proposed approach is implemented and illustrated for a simple relative-degree-two system.

17:10-17:35 TuPM_H19.5

A High-Gain Adaptive Control Design with Output Constraint (I), pp. 587-589

Liu, Yong-Hua — Guangdong University of Technology
Chen, Zhong-Qiu — School of Automation, Guangdong University of Technology
Su, Chun-Yi — Concordia Univ

This paper presents a novel high-gain adaptive control approach for stabilization of unknown minimum-phase linear systems with output constraints. The proposed approach unites the high-gain adaptive control technique and the tool of barrier function to guarantee the output constraint, without resorting to a priori knowledge of the system matrices. Simulation results performed on a numerical example is illustrated to testify the effectiveness of the developd controller.

17:35-18:00 TuPM_H19.6

Funnel Control by Induced Contraction (I), pp. 590-595

Lee, Jin Gyu — Imperial College London
B. Burghi, Thiago — University of Cambridge

This note explores a property of the internal dynamics that is essential for the functioning of classical funnel control. We relax the property of internal dynamics bounded-input bounded-output (BIBO) stability by concentrating on a narrower class of output reference trajectories. Our ideas have a connection with the recently introduced concept of induced contraction, which is motivated by the phenomenon of noise-induced synchronization in neuronal oscillators. We remark that, contrary to previous works, we only have to modify the class of admissible output reference trajectories to handle non-minimum phase systems. We also propose a way (specific to nonlinear systems) to choose an output reference trajectory (possibly under output constraints) for classical funnel control to work for a certain class of unknown systems.

TuPM_S70	S 70
Control and Optimization of Energy Networks (Invited Session)	
Chair: Faulwasser, Timm	TU Dortmund University
Co-Chair: Goettlich, Simone	University of Mannheim
Organizer: Goettlich, Simone	University of Mannheim
Organizer: Faulwasser, Timm	TU Dortmund University

15:30-15:55 TuPM_S70.1

Essentially Decentralized Interior Point Methods for Optimization in Energy Networks (I), pp. 596-599

Engelmann, Alexander — TU Dortmund University
Kaupmann, Michael — TU Dortmund University
Faulwasser, Timm — TU Dortmund University

This note discusses an essentially decentralized interior point method, which is well suited for optimization problems arising in energy networks. Advantages of the proposed method are guaranteed and fast local convergence for problems with non-convex constraints. Moreover, our method exhibits a small communication footprint and it achieves a comparably high solution accuracy with a limited number of iterations. Furthermore, the local subproblems are of low computational complexity. We illustrate the performance of the proposed method on an optimal power flow problem with 708 buses.

15:55-16:20 TuPM_S70.2

Max-p Optimal Boundary Control of Gas Flow (I), pp. 600-603

Gugat, Martin — Friedrich-Alexander-Universität Erlangen-Nürnberg
Schuster, Michael — Friedrich-Alexander Universität Erlangen-Nürnberg

In the transition to renewable energy sources, hydrogen will potentially play an important role for energy storage. The efficient transport of this gas is possible via pipelines. An understanding of the possibilities to control the gas flow in pipelines is one of the main building blocks towards the optimal use of gas.

For the operation of gas transport networks, it is important to take into account the randomness of the consumers' demand, where often information on the probability distribution is available. Hence in an efficient optimal control model the corresponding probability should be included and the optimal control should be such that the state that is generated by the optimal control satisfies given state constraints with large probability. We comment on the modelling of gas pipeline flow and the problems of optimal nodal control with random demand, where the aim of the optimization is to determine controls that generate states that satisfy given pressure bounds with large probability. We include the H2-norm of the control as control cost, since this avoids large pressure fluctuations which are harmful in the transport of hydrogen since they can cause embrittlement of the pipeline metal.

16:20-16:45 TuPM_S70.3

Stochastic Optimal Control for Nonlinear Damped Serial Network Dynamics (I), pp. 604-607

Goettlich, Simone — University of Mannheim
Schillinger, Thomas — University of Mannheim

We present a stochastic optimal control problem for a serial network. The dynamics of the network are governed by transport equations with a special emphasis on the nonlinear damping function. The demand profile at the network sink is modeled by a stochastic differential equation. An explicit optimal inflow into the network is determined and numerical simulations are presented to show the effects for different choices of the nonlinear damping.

16:45-17:10 TuPM_S70.4

Nonlinear and Divergent Responses of Fluctuation-Driven Systems (I), pp. 608-613

Thümler, Moritz — TU Dresden
Schröder, Malte — TU Dresden
Timme, Marc — TU Dresden, Chair for Network Dynamics

Most network dynamical systems are out of equilibrium and externally driven by fluctuations. Linear response theory generically characterizes systems responses to such fluctuations for small driving amplitudes yet cannot capture response properties that are either due to strong driving or intrinsically nonlinear. For oscillationdriven systems, we here report average response offsets that scale quadratically with asymptotically small amplitudes. At some critical driving amplitude, responses cease to stay close to a given operating point and may diverge. Standard response theory fails to predict these amplitudes even at arbitrarily high orders. We propose a new method for predicting critical amplitudes based on an integral self-consistency condition that captures the full nonlinear system dynamics. We illustrate our approach for a minimal one-dimensional model and capture the nonlinear shift of voltages in the phase, frequency and voltage dynamics of AC power grid networks. Our approach may help to quantitatively predict intrinsically nonlinear response dynamics as well as bifurcations emerging at large driving amplitudes in non-autonomous dynamical systems.

17:10-17:35 TuPM_S70.5

Distributed Stochastic Control of Incentive for Bike-Sharing Systems, pp. 614-619

Shigemi, Kazuhide — The University of Tokyo
Tsumura, Koji — The University of Tokyo

In the past decade, bike-sharing system has attracted significant attention as eco-friendly and healthy system of transportation. However, rebalancing the number of bicycles parked at port stations in networks is a serious challenge to provide comfortable service for users. One method to rebalance bicycles is by incentivizing users to rent or return their bicycles to appropriate port stations. In this paper, we first introduce a mathematical model to describe the dynamics of the number of parked bicycles, in which the behavior of incentivized users is stochastic. Then, we propose a distributed stochastic feedback-control law of the incentive, based on the idea of the quantized gossip algorithm to rebalance bicycles at all port stations in a network. We prove the convergence around the references in a probabilistic manner and discuss the results.

17:35-18:00 TuPM_S70.6

Guaranteeing a Minimum Distance to Infeasibility in DC Power Grids with Constant-Power Loads, pp. 620-623

Jeeninga, Mark — Politecnico Di Torino

This paper is concerned with the feasibility of the power flow in DC power power grids with constant power loads. Necessary and sufficient matrix inequalities are derived that guarantee a minimal p-norm distance between a configuration of power demands and the infeasibility boundary in the space of power demands. The (non)convexity of these matrix inequalities is studied subsequently.

TuPM_S80 S 80

Infinite-Dimensional Systems Theory (Regular Session)

Chair: Yamamoto, Yutaka — Kyoto University
Co-Chair: Sepulchre, Rodolphe J. — University of Cambridge

15:30-15:55 TuPM_S80.1

Optimal Control of Parabolic Equations -- a Spectral Calculus Based Approach, pp. 624-625

Lazar, Martin — University of Dubrovnik
Grubisic, Luka — University of Zagreb, Faculty of Science
Nakić, Ivica — University of Zagreb
Tautenhahn, Martin — Universität Leipzig

Recent theoretical and numerical results on a constrained optimal control problem of Bolza type for a class of parabolic equations obtained by the authors are presented. We study the case when the cost functional is quadratic and comprises the norm of a control and the distance of the system trajectory from the desired evolution profile, the constraint is imposed on the final state that should be steered within a prescribed distance to a given target and the control enters the system through the initial condition.The theoretical results provide a formula for the optimal control and the numerical algorithm is based on efficient rational Krylov approximation techniques.

15:55-16:20 TuPM_S80.2

Splitting Algorithms and Circuit Analysis, pp. 626-629

Chaffey, Thomas Lawrence — University of Cambridge
Das, Amritam — Eindhoven University of Technology
Sepulchre, Rodolphe J. — University of Cambridge

The splitting algorithms of monotone operator theory find zeros of sums of relations. This corresponds to solving series or parallel one-port electrical circuits, or the negative feedback interconnection of two subsystems. One-port circuits with series and parallel interconnections, or block diagrams with multiple forward and return paths, give rise to current-voltage relations consisting of nested sums and inverses. In this extended abstract, we present new splitting algorithms specially suited to these structures, for interconnections of monotone and antimonotone relations.

16:20-16:45 TuPM_S80.3

Characterization and Computation of the Strong H2 Norm for Delay Differential Algebraic Systems, pp. 630-632

Michiels, Wim — KU Leuven
Gomez, Marco Antonio — Universidad De Guanajuato
Mattenet, Sébastien Maurice — Université Catholique De Louvain
De Iuliis, Vittorio — Università Degli Studi Dell'Aquila
Jungers, Raphaël M. — Université Catholique De Louvain

The H2 norm of an exponentially stable system described by Delay Differential Algebraic Equations (DDAEs) might be infinite, due to the existence of hidden feedthrough terms and it might become infinite as a result of infinitesimal changes to the delay parameters. We first introduce the notion of strong H2 norm of semi-explicit DDAEs, a robustified measure that takes into account delay perturbations, and we analyze its properties. Next, we discuss necessary and sufficient finiteness criteria for the strong H2 norm in terms of a frequency sweeping test over a hypercube, and in terms of a finite number of equalities involving multi-dimensional powers of a finite set of matrices. Finally, we show that if the H2 norm of the DDAE is finite, it is possible to construct an exponentially stable neutral delay-differential equation which has the same transfer matrix as the DDAE, without any need for differentiation of inputs or outputs. This connected with a neutral system enables the framework of Lyapunov matrices for computing the H2 norm.

16:45-17:10 TuPM_S80.4

Bezout Identity in Pseudorational Transfer Functions, pp. 633-636

Yamamoto, Yutaka — Kyoto University
Bonnet, Catherine — Inria Saclay-Ile-De-France

Coprime factorizations of transfer functions play various important roles, e.g., minimality of realizations, stabilizability of systems, etc. This paper studies the Bezout condition over the ring E'(R-) of distributions of compact support and the ring M(R-) of measures with compact support. These spaces are known to play crucial roles in minimality of state space representations and controllability of behaviors. We give a detailed review of the results obtained thus far, as well as discussions on a new attempt of deriving general results from that for measures. It is clarified that there is a technical gap in generalizing the result for M(R-) to that for E'(R-). A detailed study of a concrete example is given.

17:10-17:35 TuPM_S80.5

A Ball-Marsden-Slemrod Type Result for Semi-Linear Equations with Analytic Semigroups, pp. 637-642

Dirr, Gunther — University of Wurzburg

We extend a well-known non-controllability result of Ball, Marsden, and Slemrod on infinite-dimensional bilinear systems (with bounded control term) to control-affine semi-linear systems whose linear part generates an analytic semigroup and whose control term is possibly unbounded as well. Here control inputs are assumed to lie in some suitable Lp-space, p > 1. The result allows an application to PDEs whose control terms include not only the state but also lower oder derivatives compared to the uncontrolled leading linear part. The proof relies on an abstract compactness principle for parameter dependent fixed point maps.

17:35-18:00	TuPM_S80.6

Nonlinear Discrete-Time Systems with Inputs in Banach Spaces, pp. 643-648

Bachmann, Patrick — Julius-Maximilians-Universität Würzburg
Dashkovskiy, Sergey — University of Würzburg
Schroll, Andreas — Julius-Maximilians-Universität Würzburg

In this paper we study ISS-like properties of infinite dimensional discrete time systems and compare them with their continuous time counterparts available in the literature. New characterizations of such properties are derived in this work. We discuss differences between discrete and continuous time systems in view of their robust stability and demonstrate the corresponding properties by means of examples.

TuPM_S82	S 82

Hamilton-Jacobi Equations and Mean Field Games - II (Hybrid Session) (Invited Session)

Chair: Gao, Shuang — McGill University
Co-Chair: Falcone, Maurizio — SAPIENZA - Universita' Di Roma
Organizer: Falcone, Maurizio — SAPIENZA - Universita' Di Roma
Organizer: Zidani, Hasnaa — INSA Rouen Normandie

15:30-15:55	TuPM_S82.1

Mean Field Games on the Acceleration with State Constraints (I), pp. 649-652

Achdou, Yves — University of Paris Cité
Mannucci, Paola — University of Padova
Marchi, Claudio — University of Padova
Tchou, Nicoletta — IRMAR-Université De Rennes 1

We consider deterministic mean field games in which the agents control their acceleration and are constrained to remain in a region of R^n. We study relaxed equilibria in the Lagrangian setting; they are described by a probability measure on trajectories. The main results of the paper concern the existence of relaxed equilibria under suitable assumptions. The fact that the optimal trajectories of the related optimal control problem solved by the agents do not form a compact set brings a difficulty in the proof of existence. The proof also requires closed graph properties of the map which associates to initial conditions the set of optimal trajectories.

15:55-16:20	TuPM_S82.2

A Fundamental Solution Concept for a Family of State Constrained Regulator Problems (I), pp. 653-658

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

A family of continuous-time regulator problems, subject to linear time-varying dynamics and convex state constraints, is parameterized with respect to a space of semiconcave terminal costs. By embedding the state constraints into an extended real-valued running cost, a family of relaxations is employed to develop a min-plus convolution-based fundamental solution concept for the family of regulator problems. A representation of the fundamental solution concept is provided in terms of solutions of associated differential Riccati and related equations, and possible avenues for efficient numerical computation are explored.

16:20-16:45	TuPM_S82.3

First Order Mean Field Games on Networks (I), pp. 659-660

Achdou, Yves — University of Paris Cité
Marchi, Claudio — University of Padova
Paola, Mannucci — University of Padova
Tchou, Nicoletta — IRMAR-Université De Rennes 1

We study deterministic Mean Field Games with finite horizon in which the state space of the players is a network. In these games, the generic agent can control its dynamics: inside each edge, it can choose its velocity (which coincides with its control) and it can also choose, when it arrives at a vertex, the edge in which it enters. It will pay a cost which is formed by a running cost and a terminal cost; both these costs depend on the trajectory that it has chosen and on the evolution of the distribution of all agents. On the other hand, its position cannot affect the distribution of the whole population. As in the Lagrangian approach, we introduce a relaxed notion of Mean Field Games equilibria which relies on probability measures on trajectories on the network instead of probability measures on the network. Our main result is to establish the existence of such Mean Field equilibria.

With such an equilibrium at hand, we can introduce the value function and we prove that this function is a generalized solution to the associated first order Hamilton-Jacobi problem on the network.

16:45-17:10	TuPM_S82.4

Time--Depenent Hamilton--Jacobi Equations on Networks (I), pp. 661-662

Siconolfi, Antonio — Rome University La Sapienza

The purpose of this presentation is to study the well posedness of a time–dependent Hamilton–Jacobi equation, coupled with suitable additional conditions, posed on a network. We consider a connected network Γ embedded in R N with a finite number of arcs γ, which are regular simple curves parametrized in [0, 1], linking points of RN called vertices, which make up a set we denote by V. We define a Hamiltonian on Γ as a collection of Hamiltonians Hγ : [0, 1] × R → R, indexed by arcs, with the crucial feature that Hamiltonians associated to arcs possessing different support, are totally unrelated.

17:10-17:35	TuPM_S82.5

Stationary Cost Nodes in Infinite Horizon LQG-GMFGs, pp. 663-668

Foguen Tchuendom, Rinel — McGill University
Gao, Shuang — McGill University
Caines, Peter E. — McGill Univ

An analysis of infinite horizon linear quadratic Gaussian (LQG) Mean Field Games is given within the general framework of Graphon Mean Field Games (GMFG) on dense infinite graphs (or networks) introduced in Caines and Huang (2018). For a class of LQG-GMFGs, analytical expressions are derived for the infinite horizon Nash values at the nodes of the infinite graph. Furthermore, under specific conditions on the network and the initial population means, it is shown that the nodes with strict local maximal infinite network degree are also nodes with strict local minimal cost at equilibrium.

WeP_Audimax	Audimax
Plenary: Claudio De Persis (Plenary Session)	
Chair: Ohta, Yoshito	Kyoto University

09:00-10:00	WeP_Audimax.1

On Data-Driven Control, pp. 669-669

De Persis, Claudio — University of Groningen

We present a technique to design controllers from data for systems whose model is imprecisely known. The technique is based on collecting measurements of low complexity from the systems and using them for the synthesis of controllers, which is reduced to the solution of data-dependent semidefinite programs. The method provides stability certificates in the presence of perturbations on the dataset.

WeAM_H16	H 16
Mini Course: Measure Differential Equations (Invited Session)	
Chair: Henrion, Didier	LAAS-CNRS, Univ. Toulouse
Co-Chair: Bonnet, Benoit	LAAS CNRS

10:30-13:00	WeAM_H16.7

Mini Course on Measure Differential Equations, pp. 670-670

Bonnet, Benoit	LAAS CNRS
Henrion, Didier	LAAS-CNRS, Univ. Toulouse
Marx, Swann	CNRS
Rossi, Francesco	Università Degli Studi Di Padova

Mini Course on Measure differential equations: modeling and numerical solution organised by Benoît Bonnet, Didier Henrion, Swann Marx, and Francesco Rossi This mini-course focuses on numerical methods for solving differential equations on measures, with applications in optimization and control, as well as modeling multi-scale multi-agent systems. Covered material include the moment sums of squares hierarchy and Eulerian schemes.

Part one - modeling: In the first part of the mini-course we describe the optimization and control problems that can be modelled in terms of partial differential equations (PDEs) on probability measures. We present the main existing wellposedness theories which are based on optimal mass transportation, establish the correspondence between non-linear ordinary differential equations (ODEs) and linear transport PDEs, and discuss some of the recent progresses made in this area of the literature. We also present a large number of domains in which measure differential dynamics have been successfully applied, e.g. multi-anticipative road traffic, crowd dynamics, collective behavior in animal groups, supply chains, age-structured populations.

Part two - solving: In the second part of the mini-course we introduce some numerical methods for solving measure PDEs. On the one hand, we describe briefly the moment sums of squares a.k.a. Lasserre hierarchy, originally introduced for polynomial optimization, and later on extended to optimal control of ODEs and more recently to numerical computation of non-linear PDEs. On the other hand, we describe Euler schemes for measure differential equations with non-local terms. The idea is to discretize the measure into a grid, and to let it evolve following some adapted ODE. Convergence is based on optimal transportation strategies that provide a metric tool (the Wasserstein distance) for the study of measure dynamics.

Confirmed speakers:

Nastassia Pouradier-Duteil - continuum limits of collective dynamics with time-varying weights Benoît Bonnet - differential inclusions in measure spaces Claudia Totzeck - optimization methods for multi-agent systems Didier Henrion - tutorial on the moment-SOS aka Lasserre hierarchy Swann Marx - conservation laws solved with the Lasserre hierarchy and the Christoffel-Darboux polynomial

WeAM_H17	H 17
Dissipativity Theory IV: Nonlinear Systems (Hybrid Session) (Invited Session)	
Chair: Hughes, Timothy H.	University of Exeter
Co-Chair: van der Schaft, Arjan J.	Univ. of Groningen
Organizer: Gruene, Lars	Univ of Bayreuth
Organizer: Hughes, Timothy H.	University of Exeter
Organizer: van der Schaft, Arjan J.	Univ. of Groningen

10:30-10:55	WeAM_H17.1

On the Incremental Form of Dissipativity (I), pp. 671-675

Sepulchre, Rodolphe J.	University of Cambridge
Chaffey, Thomas Lawrence	University of Cambridge
Forni, Fulvio	University of Cambridge

Following the seminal work of Zames, the input-output theory of the 70s acknowledged that incremental properties (e.g. incremental gain) are the relevant quantities to study in nonlinear feedback system analysis. Yet, non-incremental analysis has dominated the use of dissipativity theory in nonlinear control from the 80s. Results connecting dissipativity theory and incremental analysis are scattered and progress has been limited. This abstract investigates whether this theoretical gap is of fundamental nature and considers new avenues to circumvent it.

10:55-11:20	WeAM_H17.2

On Shifted Passivity of Multi-Producer Heating Networks with Storage (I), pp. 676-679

Machado Martinez, Juan Eduardo	University of Groningen
Cucuzzella, Michele	University of Pavia
Scherpen, Jacquelien M.A.	University of Groningen

We present a nonlinear ODE-based thermo-hydraulic model of a district heating system with multiple heat producers, consumers and storage devices. We analyze the conditions under which the hydraulic and thermal subsystems of the model exhibit shifted passivity properties. For the hydraulic subsystem, our claims on passivity draw on the monotonicity of the vector field associated with the district heating system's flow dynamics, which mainly codifies viscous friction effects on the system's pressures. For the temperature dynamics, we propose a storage function based on the ectropy function of a thermodynamic system, recently used in the passivity analysis of heat exchanger networks.

11:20-11:45	WeAM_H17.3

Energy Shaping, Interconnection and Entropy Assignment of Boundary Controlled Irreversible Port-Hamiltonioan Systems: The Heat Equation (I), pp. 680-682

Le Gorrec, Yann	FEMTO-ST, ENSMM
Mora, Luis A.	University of Waterloo
Ramirez, Hector	Universidad Federico Santa Maria

In this extended abstract we show, on the one dimensional (1D) heat equation example, how Boundary Controlled Irreversible Port Hamiltonian Systems (BC-IPHS) formulations and systems thermodynamic fundamental properties can be used for control design purposes.

11:45-12:10	WeAM_H17.4

Energy Conversion and Dissipativity (I), pp. 683-685

van der Schaft, Arjan J.	Univ. of Groningen
Jeltsema, Dimitri	HAN University of Applied Sciences

The Second Law of thermodynamics implies that no thermodynamic system with a single heat source at constant temperature can convert heat into mechanical work in a repeatable manner. First, we note that this is equivalent to cyclo-passivity at the mechanical port of the thermodynamic system which is constrained by constant temperature at the thermal port. Second, we address the general system-theoretic question which physical systems with two power ports share this property, called one-port cyclo-passivity. Recently, sufficient conditions for one-port cyclo-passivity have been obtained, based on the structure of the interconnection matrix in the port-Hamiltonian formulation. We elaborate on these conditions and provide some extensions. Next we focus on control strategies which go beyond the classical Carnot cycle in order to convert energy in case of one-port cyclo-passivity, and apply this to a number of multiphysics systems.

WeAM_H18	H 18
Codes and Geometry (Hybrid Session) (Invited Session)	
Chair: Kiermaier, Michael	Universität Bayreuth
Co-Chair: Greferath, Marcus	University College Dublin
Organizer: Kiermaier, Michael	Universität Bayreuth
Organizer: Wassermann, Alfred	University of Bayreuth
Organizer: Kurz, Sascha	University of Bayreuth

10:30-10:55	WeAM_H18.1

Extremality of Codes in the Lee Metric (I), pp. 686-689

Byrne, Eimear	University College Dublin
Weger, Violetta	Technical University of Munich

We investigate Singleton-like bounds in the Lee metric and characterize extremal codes. We then focus on Plotkin-like bounds in the Lee metric and present a new bound that extends and refines a previously known bound, which it out-performs in the case of non-free codes. We then compute the density of codes that meet this bound. Finally, we fill a gap in the characterization of Lee-equidistant codes.

10:55-11:20	WeAM_H18.2

On Cameron-Liebler Sets of K-Spaces in Finite Projective Spaces (Part I) (I), pp. 690-693

De Beule, Jan	Vrije Universiteit Brussel

Cameron-Liebler sets of lines in a finite 3-dimensional space PG(3,q) originate from the study by Cameron and Liebler in 1982 of groups of collineations with equally many orbits on the points and the lines of PG(3,q). These objects have some interesting equivalent characterizations, and are examples of Boolean functions of degree one and completely regular codes. In this talk, we focus on these objects from a geometric perspective, and report on several existence and non-existence results, including a recent so-called modular equality for the parameter of Cameron-Liebler sets of k-spaces in finite n-dimensional projective spaces.

11:20-11:45	WeAM_H18.3

On Cameron-Liebler Sets of k-Spaces in Finite Projective Spaces (Part II) (I), pp. 694-697

Mannaert, Jonathan	Vrije Universiteit Brussel

Cameron-Liebler sets of lines in a finite 3-dimensional space $mathrm{PG}(3,q)$ originate from the study by Cameron and Liebler in 1982 of groups of collineations with equally many orbits on the points and the lines of $mathrm{PG}(3,q)$. These objects have some interesting equivalent characterizations, and are examples of Boolean functions of degree one. In this talk, we focus on these objects and their generalisation from a geometric perspective, and report on several existence and non-existence results, including a lower bound on the existence of the parameter x (besides trivial examples).

11:45-12:10	WeAM_H18.4

Group Testing with Error-Correction Capability for General Pandemics (I), pp. 698-701

Greferath, Marcus	University College Dublin
Roessing, Cornelia	Austrian Embassy

Based on a recently presented approach to non-adaptive group testing in terms of residuated pairs on Boolean lattices, we extend our investigation into group testing to the noisy case.

In this context, several concepts and techniques from traditional Coding Theory over finite fields need to be adapted and refined. We will touch a variety of relevant notions and concepts and provide some first sporadic examples of error-correcting group testing schemes.

The possible applications are diverse and reach from simple search of defective items in production chains to mass testing under pandemic conditions.

12:10-12:35	WeAM_H18.5

Binary Linear [7, 3] Codes As Codewords of a Putative 2-Analog of the Fano Plane (I), pp. 702-706

Honold, Thomas	ZJU-UIUC Institute, Zhejiang University

The aim of this paper is to explore a possible route to the construction, or to a non-existence proof, of a 2-analog of the Fano Plane by viewing its codewords as binary linear [7,3] codes.

12:35-13:00	WeAM_H18.6

Designing and Combining Designs (I), pp. 707-709

Pavcevic, Mario Osvin	University of Zagreb, Faculty of Electrical Engineering and Comp
Tabak, Kristijan	Rochester Institute of Technology, Zagreb Campus

The fact that further constructions often don't bring breakthrough results motivates us to combine designs to be particles of other combinatorial structures. One of them are mosaics of designs, where instead of having a matrix presenting incidences of a design, one might fill the matrix with incidences of more than one design. Another way of combining designs are design cubes. They can be thought of as 3-dimensional incidence 0-1 matrices, such that each 2-dimensional incidence submatrix satisfies the properties of a design. In this paper we shall be concentrated on designing and combining t-designs although we are aware of the fact that the ideas presented here might work and be interesting for other sorts of combinatorial designs.

WeAM_H19	H 19
Lifting Techniques for Data-Driven Modeling and Control (Hybrid Session) (Invited Session)	
Chair: Rosenfeld, Joel	University of South Florida
Organizer: Kamalapurkar, Rushikesh	Oklahoma State University
Organizer: Rosenfeld, Joel	University of South Florida

10:30-10:55	WeAM_H19.1

Carlemen Linearization of Nonlinear Systems and Their Convergent Finite-Section Approximations (I), pp. 710-713

Amini, Arash	Lehigh University
Zheng, Cong	University of Central Florida
Sun, Qiyu	University of Central Florida
Motee, Nader	Lehigh University

In his 1932 paper, Carleman proposes a linearization method to transform a given finite-dimensional nonlinear system that is defined by an analytic function into an equivalent infinite-dimensional linear system with (usually) unbounded operators. Finite truncation of the transformed system has been used to study dynamical properties, learning, and control of such nonlinear systems. One of the important problems in this context is to quantify the effectiveness of such finitely truncated models. In this paper, we provide explicit error bounds and prove that the trajectory of the truncated system stays close to that of the original nonlinear system over a quantifiable time interval. This is particularly important in several applications, including Model Predictive Control, to choose proper truncation lengths for a given sampling period and employ the resulting truncated system as a good approximation of the nonlinear system.

10:55-11:20 WeAM_H19.2

Learning Stochastic Nonlinear Dynamical Systems with Embedded Latent Transfer Operator (I), pp. 714-716

Kawahara, Yoshinobu — Kyushu University

We consider an operator-based latent Markov representation of a stochastic nonlinear dynamical system, where the stochastic evolution of the corresponding latent state embedded in a reproducing kernel Hilbert space is described with a transfer operator, and develop a spectral method to learn this representation based on the theory of stochastic realization.

11:20-11:45 WeAM_H19.3

Theoretical Foundations for the Dynamic Mode Decomposition of High Order Dynamical Systems (I), pp. 717-720

Rosenfeld, Joel — University of South Florida

Kamalapurkar, Rushikesh — Oklahoma State University

Russo, Benjamin — Oak Ridge National Laboratory

Conventionally, data driven identification and control problems for higher order dynamical systems are solved by augmenting the system state by the derivatives of the output to formulate first order dynamical systems in higher dimensions. However, solution of the augmented problem typically requires knowledge of the full augmented state, which requires numerical differentiation of the original output, frequently resulting in noisy signals. This manuscript develops the theory necessary for a direct analysis of higher order dynamical systems using higher order Liouville operators. Fundamental to this theoretical development is the introduction of signal valued RKHSs and new operators posed over these spaces. Ultimately, it is observed that despite the added abstractions, the necessary computations are remarkably similar to that of first order DMD methods using occupation kernels.

11:45-12:10 WeAM_H19.4

Kernelized Active Subspaces (I), pp. 721-724

Russo, Benjamin — Oak Ridge National Laboratory

Rosenfeld, Joel — University of South Florida

Given a function over a potentially high dimensional domain, the active subspace method seeks an affine subspace inside which the functions changes the most on average. This is done by finding the eigenvectors of a covariance matrix incorporating gradient information. In a similar vein, the active manifold method finds a manifold M and if information on f is recovered along M then f can be recovered on the connected component of a level set touching M. An inherent limitation of the Active subspace technique is that it only considers affine subspaces (which may still be high dimensional). Inspired by methods in occupation kernel dynamic mode decomposition, we develop a notion of active subspace taking place in a Hilbert space which contains sufficient complexity to describe highly nonlinear level sets. In this learning problem, only function values along trajectories following the gradient direction of the function are required to determine this decomposition.

12:10-12:35 WeAM_H19.5

An Occupation Kernel Approach to Optimal Control (I), pp. 725-728

Kamalapurkar, Rushikesh — Oklahoma State University

Rosenfeld, Joel — University of South Florida

In this effort, a novel operator theoretic framework is developed for data-driven solution of optimal control problems. The developed methods focus on the use of trajectories (i.e., time-series) as the fundamental unit of data for the resolution of optimal control problems in dynamical systems. Trajectory information in the dynamical systems is embedded in a reproducing kernel Hilbert space (RKHS) through what are called occupation kernels. The occupation kernels are tied to the dynamics of the system through the densely defined Liouville operator. The pairing of Liouville operators and occupation kernels allows for lifting of nonlinear finite-dimensional optimal control problems into the space of infinite-dimensional linear programs over RKHSs.

WeAM_H20 H 20

Turnpike Phenomenon for Optimal Control Problems (Invited Session)

Chair: Lazar, Martin — University of Dubrovnik

Co-Chair: Gugat, Martin — Friedrich-Alexander-Universität Erlangen-Nürnberg

Organizer: Gugat, Martin — Friedrich-Alexander-Universität Erlangen-Nürnberg

Organizer: Lazar, Martin — University of Dubrovnik

10:30-10:55 WeAM_H20.1

A Turnpike Result for Optimal Boundary Control of Gas Pipeline Flow (I), pp. 729-732

Gugat, Martin — Friedrich-Alexander-Universität Erlangen-Nürnberg

Herty, Michael — Rwth Aachen

The operation of gas pipeline networks leads to problems of optimal boundary control for systems governed by the isothermal Euler equations. In this contribution we consider a problem of optimal Dirichlet control with an objective function of integral type that is given as the sum of a tracking term for a desired stationary state and the corresponding control cost that is also given by a time-integral. We study the well-posedness and exact controllability properties of the system. We study regular solutions that generate a field of non-intersecting characteristic curves without rarefaction fan. We present an integral turnpike result and a result about the turnpike phenomenon with interior decay for such an optimal control problem where the control cost is given by the H2-norm.

10:55-11:20 WeAM_H20.2

Turnpike Behaviour for Systems That Are Partially Uncontrollable (I), pp. 733-734

Lazar, Martin — University of Dubrovnik

Gugat, Martin — Friedrich-Alexander-Universität Erlangen-Nürnberg

We analyse the turnpike properties for a general, linear-quadratic (LQ) optimal control problem. We assume that the system under consideration is governed by an infinite-dimensional differential equation with a generator A of a strongly continuous semi-group. The objective function is the sum of a control cost and a tracking term for an observation of the state.

The novelty of the results is twofold. Firstly, it obtains positive turnpike results for systems that are (partially) uncontrollable. Secondly, it provides turnpike results for optimal averaged control associated to a family of problems that depend on a random parameter, which is the first turnpike type result that extends the averaged controllability approach to optimal control problems. In both cases, the results do not require assumptions on stabilizability and detectability, which are most commonly used in the study of turnpike phenomena.

Examples supporting the theoretical findings will be presented as well.

11:20-11:45 WeAM_H20.3

Local Turnpike Analysis for Discrete Time Discounted Optimal Control (I), pp. 735-737

Gruene, Lars — Univ of Bayreuth

Krügel, Lisa — University of Bayreuth

Recent results in the literature have provided connections between the turnpike property, near optimality of closed- loop solutions, and strict dissipativity. In this talk, based on the recent paper Grüne and Krügel (2021) (to which we refer for all proofs), we consider optimal control problems with discounted stage cost. In contrast to non-discounted optimal control problems, it is more likely that several asymptotically stable optimal equilibria coexist. Due to the discounting and transition cost from a local to the global equilibrium, it may be more favourable staying in a local equilibrium than moving to the global “cheaper” equilibrium. In this talk, we propose a local notion of dis- counted strict dissipativity and a local turnpike property, both depending on the discount factor. Using these concepts, we investigate the local behaviour of (near-)optimal trajectories and develop conditions on the discount factor to ensure convergence to a local asymptotically stable optimal equilibrium.

11:45-12:10	WeAM_H20.4

Average Turnpike Property (I), pp. 738-741

Hernandez, Martin	Friedrich-Alexander-Universität Erlangen-Nürnberg
Zamorano, Sebastián	Universidad De Santiago De Chile
Lecaros, Rodrigo	Universidad Técnica Federico Santa María

This paper studies the integral turnpike and turnpike in the average for a class of random ordinary differential equations. We prove that, under suitable assumptions on the matrices that define the system, the optimal solutions for an optimal distributed control tracking problem remain, in an average sense, sufficiently close to the associated random stationary optimal solution for most of the time horizon.

WeAM_S80	S 80
Distributed Parameter Systems III (Invited Session)	
Chair: Kitsos, Constantinos	Tel Aviv University
Co-Chair: Morris, Kirsten A.	Univ. of Waterloo
Organizer: Demetriou, Michael A.	Worcester Polytechnic Institute
Organizer: Morris, Kirsten A.	Univ. of Waterloo

10:30-10:55	WeAM_S80.1

Indirect Optimal Control of Advection-Diffusion Fields through Distributed Robotic Swarms (I), pp. 742-747

Sinigaglia, Carlo	Politecnico Di Milano
Manzoni, Andrea	Politecnico Di Milano
Braghin, Francesco	Politecnico Di Milano
Berman, Spring	Arizona State University

In this paper, we consider the problem of optimally guiding a large-scale swarm of underwater vehicles that is tasked with the indirect control of an advection-diffusion environmental field. The microscopic vehicle dynamics are governed by a stochastic differential equation with drift. The drift terms model the self-propelled velocity of the vehicle and the velocity field of the currents. In the mean-field setting, the macroscopic vehicle dynamics are governed by a Kolmogorov forward equation in the form of a linear parabolic advection-diffusion equation. The environmental field is governed by an advection-diffusion equation in which the advection term is defined by the fluid velocity field. The vehicles are equipped with on-board actuators that enable the swarm to act as a distributed source in the environmental field, modulated by a scalar control parameter that determines the local source intensity. In this setting, we formulate an optimal control problem to compute the vehicle velocity and actuator intensity fields that drive the environmental field to a desired distribution within a specified amount of time. After proving an existence result for the solution of the optimal control problem, we discretize and solve the problem using the Finite Element Method (FEM). Finally, we show through numerical simulations the effectiveness of our control strategy in regulating the environmental field to zero or to a desired distribution in the presence of a double-gyre flow field.

10:55-11:20	WeAM_S80.2

A Mixed Continuous-Discrete Approach to Fast Charging of Li-Ion Batteries While Maximizing Lifetime (I), pp. 748-753

Berliner, Marc D.	Massachusetts Institute of Technology
Cogswell, Daniel A.	Massachusetts Institute of Technology
Bazant, Martin Z.	Massachusetts Institute of Technology
Braatz, Richard D.	Massachusetts Institute of Technology

In this article, we derive physics-based operating modes based on degradative governing equations, which are used to ensure safe use and minimal degradation during long-term cycling. The fast-charging protocols are efficiently and deterministically simulated using a mixed continuous-discrete (aka hybrid) approach to fast charging. This simultaneously solves the battery system of equations and the constraint-based control problem. The approach is evaluated using a Porous Electrode Theory-based model that includes solid-electrolyte interface (SEI) capacity fade. Three physics-based charging protocols are compared to a conventional constant current-constant voltage (CC-CV) protocol. Given identical levels of capacity fade after 500 cycles, the physics-based protocols uniformly reach a greater charge capacity compared to CC-CV after charging for 10 and 15 minutes. The computational cost of simulating physics-based charging protocols is only about 30% greater than the CC-CV method. The fast charging framework is easily extendable to other battery models, irrespective of model complexity.

11:20-11:45	WeAM_S80.3

Sparsity Enforcing Convex Relaxation of D-Optimal Sensor Selection for Parameter Estimation of Distributed Parameter Systems (I), pp. 754-757

Ucinski, Dariusz	University of Zielona Gora

Owing to the wide availability of efficient convex optimization algorithms, convex relaxation of optimum sensor selection problems has gained in popularity. Generally, however, there is a performance gap between the optimal solution of the original combinatorial problem and the heuristic solution of the respective relaxed continuous problem. This gap can be small in many cases, but there is no guarantee that this is always the case. That is why the D-optimality criterion is often extended by addition of some kind of sparsity-enforcing penalty term. Unfortunately, the problem convexity is then lost and the question of how to control the influence of this penalty so as not to excessively deteriorate the optimal relaxed solution remains open. This work proposes an alternative problem formulation, in which the sparsity-promoting term is directly minimized subject to the constraint that the D-efficiency of the sensor selection is no less than a given threshold. This offers direct control of the degree of optimality of the produced solution. An efficient computational scheme based on the majorization-minimization algorithm is proposed, which reduces to solving a sequence of low-dimensional convex optimization problems via generalized simplicial decomposition. A numerical example illustrating the effectiveness of the proposed approach is also reported.

11:45-12:10	WeAM_S80.4

Strict Dissipativity for Generalized Linear-Quadratic Problems in Infinite Dimensions (I), pp. 758-763

Philipp, Friedrich	Technische Universität Ilmenau
Schaller, Manuel	Technische Universität Ilmenau
Gruene, Lars	Univ of Bayreuth

We analyze strict dissipativity of generalized linear quadratic optimal control problems on Hilbert spaces. Here, the term ``generalized'' refers to cost functions containing both quadratic and linear terms. We characterize strict pre-dissipativity with a quadratic storage function via coercivity of a particular Lyapunov-like quadratic form. Further, we show that under an additional algebraic assumption, strict pre-dissipativity can be strengthened to strict dissipativity. Last, we relate the obtained characterizations of dissipativity with exponential detectability.

12:10-12:35	WeAM_S80.5

Internal Stabilization of an Underactuated Linear Parabolic System Via Modal Decomposition (I), pp. 764-769

Kitsos, Constantinos	Tel Aviv University
Fridman, Emilia	Tel-Aviv Univ

This work concerns the internal stabilization of underactuated linear systems of m heat equations in cascade, where the control is placed internally in the first equation only and the diffusion coefficients are distinct. Combining the modal decomposition

method with a recently introduced state transformation approach for observation problems, a proportional-type stabilizing control is given explicitly. It is based on a transformation for the ODE system corresponding to the comparatively unstable modes into a target one, where calculation of the stabilization law is independent of the arbitrarily large number of them and it is achieved by solving generalized Sylvester equations recursively. This provides a finite-dimensional counterpart of a recently introduced infinite-dimensional one, which led to Lyapunov stabilization. The present approach answers to the problem of stabilization with actuators not appearing in all the states and when boundary control results do not apply.

WeAM_S82	S 82
Control in and Around Human-Computer Interaction (Hybrid Session) (Invited Session)	
Co-Chair: Fleig, Arthur	University of Bayreuth
Organizer: Fleig, Arthur	University of Bayreuth
Organizer: Fischer, Florian	University of Bayreuth
Organizer: Faisal, Ahmed Aldo	Imperial College London

10:30-10:55	WeAM_S82.1

Content Rendering for Acoustic Levitation Displays Via Optimal Path Following (I), pp. 770-773

Paneva, Viktorija	University of Bayreuth
Fleig, Arthur	University of Bayreuth
Martinez Plasencia, Diego	University College London
Faulwasser, Timm	TU Dortmund University
Müller, Jörg	University of Bayreuth

Recently, volumetric displays based on acoustic levitation have demonstrated the capability to produce mid-air content using the Persistence of Vision (PoV) effect. In these displays, acoustic traps are used to rapidly move a small levitated particle along a prescribed path. This note is based on our recent work OptiTrap (Paneva et al., 2022), the first structured numerical approach for computing trap positions and timings via optimal control to produce feasible and (nearly) time-optimal trajectories that reveal generic levitated graphics. While previously, feasible trap trajectories needed to be tuned manually for each shape and levitator, relying on trial and error, OptiTrap automates this process by allowing for a systematic exploration of the range of contents that a given levitation display can render. This represents a crucial milestone for future content authoring tools for acoustic levitation displays and advances volumetric displays closer toward real-world applications.

10:55-11:20	WeAM_S82.2

Understanding the Variability of Pointing Tasks with Event-Driven Intermittent Control (I), pp. 774-779

Alvarez Martin, Jose Alberto	University of Glasgow
Doublein, Thomas	University of Glasgow
Gollee, Henrik	Univ of Glasgow
Müller, Jörg	University of Bayreuth
Murray-Smith, Roderick	University of Glasgow

Event-driven Intermittent control (IC) has been used as a framework to explain relevant aspects of human movement. The events, which are generated by states crossing predefined thresholds, give rise to state trajectories that mimic those of a continuous controller, by only using feedback information at event times. Here we present the results of using an optimisation approach to identify the parameters of an intermittent controller from experimental data, where users performed one dimensional mouse movements in a reciprocal pointing task. The results show that IC is able to reproduce both, the dynamical features and the variability of the pointing task across participants. We then introduce probabilistic elements in the IC framework in the form of Gaussian processes as an additional method to represent human movement variability.

11:20-11:45	WeAM_S82.3

Simulating Mid-Air Interaction Trajectories Via Model Predictive Control (I), pp. 780-783

Klar, Markus	University of Bayreuth
Fischer, Florian	University of Bayreuth
Fleig, Arthur	University of Bayreuth
Bachinski, Miroslav	Bayreuth University
Müller, Jörg	University of Bayreuth

We investigate the ability of Model Predictive Control (MPC) to generate human-like movements during interaction with mid-air user interfaces, i.e., pointing in virtual or augmented reality, using a state-of-the-art biomechanical model. The model is partly a black box implemented in the MuJoCo physics engine, requiring either gradient-free optimization algorithms or gradient approximation. This makes it even more important to choose the objective function or the MPC horizon length wisely. We introduce three objective functions suggested in the literature and identify optimal cost weights such that the simulated trajectories best match real ones obtained from motion capturing, i.e., we tackle an inverse optimal control problem. For the best performing objective function, we then analyze the effects of the horizon length and of the cost weights. This model-based approach enables the analysis of interaction techniques, e.g., in terms of ergonomics and effort, without the need for extensive user studies.

11:45-12:10	WeAM_S82.4

Online Parameter Tracking in Human Reaching Adaptation and Control (I), pp. 784-787

Crevecoeur, Frederic	Université Catholique De Louvain

Recent experiments have suggested that the nervous system adapted feedback control strategies during an ongoing, perturbed movement. These findings raised the possibility that a function of motor adaptation could be to complement feedback control online, but this idea had not been tested with biologically realistic properties of the human motor system, considering in particular the non-linear limb dynamics and the presence of transmission delays in the neural feedback loop. This study addresses this question by showing that online adaptive control is indeed feasible in a simplified nonlinear model of the human arm, featuring a delay of 60ms as observed in experiments. It is shown that online adaptation can reduce the impact of non-linear effects arising due to limb dynamics within a single movement. Strikingly, the directions that most benefited from online adaptation correlated with known directional biases characterising the distribution of reaching representations in the primate's brain. Further, it is demonstrated that, for some movement directions, it is possible to learn to produce relatively straight hand paths with end-point errors comparable with human performance within tens of trials. These simulation results provide support to the hypothesis that a function of adaptation in the human sensorimotor system is to compensate online for unmodelled disturbances arising in novel or non-linear environments.

12:10-12:35	WeAM_S82.5

3D Cues for Human Control of Target Acquisition in Auditory Augmented Reality (I), pp. 788-791

Dadamis, Konstantinos	University of Glasgow, School of Computing Science
Williamson, John H.	University of Glasgow, School of Computing Science
Murray-Smith, Roderick	University of Glasgow

We compare the effectiveness of different auditory cues for attracting attention to spatial targets around a mobile user, using a commercial 3D audio headset instrumented with GPS and inertial sensors. We compare two approaches to spatial audio feedback with a baseline case that only provides `on target' feedback: 1. hints as single sounds played from a 3D location and 2. frequency modulation of inter-pulse gaps based on proximity. We illustrate the difference in user control behaviour created by the different forms of feedback with phase plots. Single 3D sound hints provided the best improvement over the baseline case of no hint. Frequency modulation of pulses performed more poorly for larger targets. The choice of sound has a significant effect on targeting performance and there is a significant trade-off between efficient targeting and aesthetically-pleasing audio.

ThP_Audimax Audimax

Plenary: Luz De Teresa (Plenary Session)

Chair: Jacob, Birgit — Bergische Universität Wuppertal

09:00-10:00 ThP_Audimax.1

Some Results on Hierarchical Control for Parabolic Equations, pp. 792-792

de Teresa, Luz — Universidad Nacional Autónoma De México

In classical control theory, we usually have a state equation or system and just one control, with the mission of achieving a predetermined goal. Sometimes, the goal is to minimize a cost function in a prescribed family of admissible controls; this is the optimal control viewpoint. A more interesting situation arises when several (in general, conflictive or contradictory) objectives are considered. This may happen, for example, if the cost function is the sum of several terms and it is not clear how to average. It can also be expectable to have more than one control acting on the equation. In this talk, we present an overview of the known results on this subject for the heat equation. We will recall the results of Araruna and collaborators where hierarchic exact controllability results were established for linear and semilinear heat equations. In this research, and in the seminal papers by J.-L. Lions, the main idea is to work with one primary control (the leader) and one or several secondary controls (the followers). For each possible leader, the associated followers try to minimize a functional (or reach equilibrium if there is more than one cost objective function). Then, the leader is chosen such that the associated state satisfies a final time constraint. We will present the recent result with E. Fernández-Cara et al., where we accomplish optimal control and controllability tasks with a hierarchy of controls. This time, however, the controllability goal will be commended to the follower, while the choice of the leader will be subject to an optimal control problem. It will be seen that this makes the problem more difficult to handle (essentially because we must work all the time in a very restrictive class of leader controls).

ThAM_H16 H 16

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

Chair: Infusino, Maria — University of Cagliari

Co-Chair: Henrion, Didier — LAAS-CNRS, Univ. Toulouse

Organizer: Henrion, Didier — LAAS-CNRS, Univ. Toulouse

Organizer: Infusino, Maria — University of Cagliari

Organizer: Kuhlmann, Salma — University of Konstanz

Organizer: Vinnikov, Victor — Ben Gurion University of the Negev

10:30-10:55 ThAM_H16.1

Globally Positive Trace Polynomials (I), pp. 793-793

Volcic, Jurij — Drexel University

A trace polynomial is a polynomial in noncommuting variables and traces of their products. It is positive if its evaluations on all symmetric matrices, or more generally, self-adjoint operators from tracial von Neumann algebras, attain only positive semidefinite values. A Positivstellensatz for positive univariate trace polynomials is presented, and a characterization of trace-positive multivariate noncommutative polynomials is discussed.

10:55-11:20 ThAM_H16.2

Spectrahedral Shadows and Completely Positive Maps on Real Closed Fields (I), pp. 794-795

Kummer, Mario — TU Dresden

We provide a new characterization of spectrahedral shadows. We use this to show that the cone of copositive matrices of size at least five is not a spectrahedral shadow, a convex semialgebraic set that resisted the efforts of Scheiderer (2018). This is a joint work with Manuel Bodirsky and Andreas Thom.

11:20-11:45 ThAM_H16.3

Commutative and Non-Commutative Polynomial Optimization in Quantum Optimal Control (I), pp. 796-798

Marecek, Jakub — Czech Technical University

Vala, Jiri — IBM Research

Quantum optimal control has numerous important applications, ranging from magnetic resonance imagining to laser control of chemical reactions and quantum computing. There are two major challenges: non-commutativity inherent in quantum systems and non-convexity of quantum optimal control problems involving more than three quantum levels. Here, under mild assumptions, we present the first globally convergent methods for quantum optimal control. We address the non-commutativity of the control Hamiltonian at different times by the use of Magnus expansion. To tackle the non-convexity, we employ non-commutative polynomial optimisation and non-commutative geometry. Our results also demonstrate that the use of Magnus expansion expands the reachable set for Hamiltonians that are not operator controllable. Further, we show that for any fixed precision, there exists an efficiently-solvable convexification of the Magnus-expanded polynomial functionals in the control signal. Quantum optimal control is hence approximable to any fixed precision in a model of computing, wherein one arithmetic operation with two real numbers can be performed within one unit of time that has been introduced by Blum, Shub, and Smale.

11:45-12:10 ThAM_H16.4

The Truncated Moment Problem for Unital Commutative R-Algebras (I), pp. 799-802

Curto, Raul — University of Iowa

Ghasemi, Mehdi — University of Saskatchewan

Infusino, Maria — University of Cagliari

Kuhlmann, Salma — University of Konstanz

Let A be a unital commutative R-algebra, K a closed subset of the character space of A, and B a linear subspace of A. For a linear functional L:B --> R, we investigate conditions under which L admits an integral representation with respect to a positive Radon measure supported in K. When A is equipped with a submultiplicative seminorm, we employ techniques from the theory of positive extensions of linear functionals to prove a criterion for the existence of such an integral representation for L. When no topology is prescribed on A, we identify suitable assumptions on A, K, B and L which allow us to construct a seminormed structure on A, so as to exploit our previous result to get an integral representation for L. Our main theorems allow us to extend some well-known results on the Classical Truncated Moment Problem, the Truncated Moment Problem for point processes, and the Subnormal Completion Problem for 2-variable weighted shifts. We also analyze the relationship between the Full and the Truncated Moment Problem in our general setting; we obtain a suitable generalization of Stochel's Theorem which readily applies to Full Moment Problems for localized algebras.

12:10-12:35 ThAM_H16.5

On a Solution of the Multidimensional Truncated Matrix-Valued Moment Problem (I), pp. 803-804

Kimsey, David — Newcastle University

Trachana, Matina — Cardiff University

We will consider the multidimensional truncated $p times p$ Hermitian matrix-valued moment problem. We will prove a characterisation of truncated $p times p$ Hermitian matrix-valued multisequence with a minimal positive semidefinite matrix-valued representing measure via the existence of a flat extension, i.e., a rank preserving extension of a multivariate Hankel matrix (built from the given truncated matrix-valued multisequence). Moreover, the support of the representing measure can be computed via the intersecting zeros of the determinants of matrix-valued polynomials which describe the flat extension. We will also use a matricial generalisation of Tchakaloff's theorem due to the first author together with the above result to prove a characterisation of truncated matrix-valued multisequences which have a representing measure. When $p = 1$, our result recovers the celebrated flat extension theorem of Curto and Fialkow. The bivariate quadratic matrix-valued problem will be explored in detail.

ThAM_H17	H 17
Mini Course: Infinite-Dimensional Port-Hamiltonian Systems (Invited Session)	
Chair: Reis, Timo	Technische Universität Ilmenau
Co-Chair: Jacob, Birgit	Bergische Universität Wuppertal

10:30-13:00	ThAM_H17.7

Mini Course: Infinite-Dimensional Port-Hamiltonian Systems, pp. 805-805

Reis, Timo	Technische Universität Ilmenau
Jacob, Birgit	Bergische Universität Wuppertal
Zwart, Hans	University of Twente
Kotyczka, Paul	Technical University of Munich
Maschke, Bernhard	Univ Claude Bernard of Lyon

Mini Course on Infinite-dimensional port-Hamiltonian systems organised by Birgit Jacob and Timo Reis. The theory of port-Hamiltonian systems provides a geometric modelling framework for systems of various physical domains, such as mechanics, electrodynamics and thermodynamics. This approach has its roots in analytical mechanics and starts from the principle of least action, and proceeds, via the Euler-Lagrange equations and the Legendre transform, towards the Hamiltonian equations of motion. This class is further closed under network interconnection. That is, coupling of port-Hamiltonian systems again leads to a port-Hamiltonian system, whence it further allows to describe multi-physical systems, i.e., systems obtained by interaction of several physical domains. The port-Hamiltonian approach further allows the qualitative solution behavior, since it provides an energy balance. Modelling of port-Hamiltonian dynamics may result in various different types of equations, such as ordinary differential equations, differential-algebraic equations, partial differential-algebraic equations and partial differential equations. The latter two types can be reformulated as infinite-dimensional systems, which results in a need for a wide theory of infinite-dimensional port-Hamiltonian systems.

The aim of this mini-course is to give a tutorial on the theory and practice of infinite-dimensional port-Hamiltonian systems. We will provide basics of modelling, analysis and numerics for this class. In particular, we will treat the following questions in the course:

What are practical examples of infinite-dimensional port-Hamiltonian systems? How is modelling of physical systems by infinite-dimensional port-Hamiltonian systems been done? What is known about analysis of infinite-dimensional port-Hamiltonian systems? What are appropriate numerical tools for infinite-dimensional port-Hamiltonian systems? What are open problems for infinite-dimensional port-Hamiltonian systems?

ThAM_H18	H 18
Data-Based Learning and Control Theory - I (Invited Session)	
Chair: Camlibel, Kanat	University of Groningen
Organizer: Camlibel, Kanat	University of Groningen
Organizer: Trentelman, Harry L.	Univ. of Groningen

10:30-10:55	ThAM_H18.1

A Constructive Proof of the Fundamental Lemma for Data-Driven Representation of LTI Systems (I), pp. 806-807

Markovsky, Ivan	Vrije Universiteit Brussel
Prieto-Araujo, Eduardo	CITCEA-UPC
Dorfler, Florian	Swiss Federal Institute of Technology (ETH) Zurich

The existing proofs of the fundamental lemma (J.C. Willems, et al. Control Lett., 54(4), 325-329, 2005) use arguments by contradiction and do not give insight into the assumptions of controllability and persistency of excitation of the input. We present an alternative constructive proof that reduces the required persistency of excitation and characterizes the nongeneric cases in which the extra persistency of excitation beyond the time horizon is needed.

10:55-11:20	ThAM_H18.2

Towards a Stochastic Fundamental Lemma for LTI Systems (I), pp. 808-811

Faulwasser, Timm	TU Dortmund University
Pan, Guanru	TU Dortmund University
Ou, Ruchuan	TU Dortmund University

Jan Willems and co-authors introduced the characterization of finite-time behaviors of linear systems via the image of Hankel matrices already in 2005. The increasing popularity and research interest of data-driven control techniques has catalyzed the use of this result – which is commonly known as Willems' fundamental lemma – for predictive control and beyond. In this note, we recap recent results on a stochastic extension of the fundamental lemma from~ Pan et al., 2021. Specifically, we leverage the framework of polynomial chaos expansions to derive a computationally tractable stochastic extension of the fundamental lemma.

11:20-11:45	ThAM_H18.3

The Untold Story of System Identification (I), pp. 812-815

Camlibel, Kanat	University of Groningen
Rapisarda, Paolo	Univ. of Southampton

We state necessary and sufficient conditions for one finite length input-output trajectory to determine uniquely (modulo state-space isomorphisms) a minimal linear, deterministic input-state-output system, given an upper bound on the state dimension.

11:45-12:10	ThAM_H18.4

Informativity Conditions for Data-Driven Control Based on Input-State Data and Polyhedral Cross-Covariance Noise Bounds (I), pp. 816-821

Steentjes, Tom Robert Vince	Eindhoven University of Technology
Lazar, Mircea	Eindhoven Univ. of Technology
Van den Hof, Paul M.J.	Eindhoven University of Technology

Modeling and control of dynamical systems rely on measured data, which contains information about the system. Finite data measurements typically lead to a set of system models that are unfalsified, i.e., that explain the data. The problem of data-informativity for stabilization or control with quadratic performance is concerned with the existence of a controller that stabilizes all unfalsified systems or achieves a desired quadratic performance. Recent results in the literature provide informativity conditions for control based on input-state data and ellipsoidal noise bounds, such as energy or magnitude bounds. In this paper, we consider informativity of input-state data for control where noise bounds are defined through the cross-covariance of the noise with respect to an instrumental variable; bounds that were introduced originally as a noise characterization in parameter bounding identification. The considered cross-covariance bounds are defined by a finite number of hyperplanes, which induce a (possibly unbounded) polyhedral set of unfalsified systems. We provide informativity conditions for input-state data with polyhedral cross-covariance bounds for stabilization and H-2/H-infinity control through vertex/half-space representations of the polyhedral set of unfalsified systems.

12:10-12:35	ThAM_H18.5

Maximum Entropy Optimal Density Control of Discrete-Time Linear Systems, pp. 822-825

Ito, Kaito	Kyoto University
Kashima, Kenji	Kyoto University

Entropy regularization, or a maximum entropy method for optimal control has attracted much attention especially in reinforcement learning due to its many advantages such as a natural exploration strategy and robustness against disturbances. Nevertheless, for safety-critical applications, it is crucial to suppress state uncertainty due to the stochasticity of high-entropy control policies and dynamics to an acceptable level. To achieve this, we consider the problem of steering a state distribution of a deterministic discrete-time linear system to a specified one at final time with entropy-regularized minimum energy control. We show that this problem boils down to solving coupled Lyapunov equations. Based on this, we derive the existence, uniqueness, and explicit form of the optimal policy.

ThAM_H19	H 19
Optimal Transport in Networks and Systems (Hybrid Session) (Invited Session)	
Co-Chair: Taghvaei, Amirhossein	University of Washington Seattle
Organizer: Chen, Yongxin	Georgia Institute of Technology
Organizer: Georgiou, Tryphon T.	Univ. of California, Irvine
Organizer: Pavon, Michele	Università Di Padova
Organizer: Taghvaei, Amirhossein	University of Washington Seattle

10:30-10:55 ThAM_H19.1

Schrödinger Bridges on Trees and Multi-Marginal Optimal Transport (I), pp. 826-829

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

Recently, there has been a large interest in the theory of optimal transport and its connections to the Schrödinger bridge problem. In this work we generalize some of these results to multi-marginal optimal transport problems when the cost function decouples according to a tree structure. In particular, the entropy regularized multi-marginal optimal transport problem can be seen as a Schrödinger bridge problem on the same tree. Moreover, based on this, we extend efficient algorithms for the bi-marginal problem to the multi-marginal setting where the cost function decouples according to a tree structure. Such problems appear in several applications of interest such as barycenter and tracking problems. A common approach for solving these problems is by utilizing pairwise regularization. However, we show that the multi-marginal regularization introduces less diffusion which is favorable in many applications.

10:55-11:20 ThAM_H19.2

Optimality vs Stability Trade-Off in Ensemble Kalman Filters (I), pp. 830-835

Taghvaei, Amirhossein — University of Washington Seattle
Mehta, Prashant G. — Univ. of Illinois at Urbana-Champaign
Georgiou, Tryphon T. — Univ. of California, Irvine

This paper is concerned with optimality and stability analysis of a family of ensemble Kalman filter (EnKF) algorithms. EnKF is commonly used as an alternative to the Kalman filter for high-dimensional problems, where storing the covariance matrix is computationally expensive. The algorithm consists of an ensemble of interacting particles driven by a feedback control law. The control law is designed such that, in the linear Gaussian setting and asymptotic limit of infinitely many particles, the mean and covariance of the particles follow the exact mean and covariance of the Kalman filter. The problem of finding a control law that is exact does not have a unique solution, reminiscent of the problem of finding a transport map between two distributions. A unique control law can be identified by introducing control cost functions, that are motivated by the optimal transportation problem or Schr"odinger bridge problem. The objective of this paper is to study the relationship between optimality and long-term stability of a family of exact control laws. Remarkably, the control law that is optimal in the optimal transportation sense leads to an EnKF algorithm that is not stable.

11:20-11:45 ThAM_H19.3

Lossy Schroedinger Bridges: The Most Likely Transport between Unbalanced Marginals (I), pp. 836-839

Chen, Yongxin — Georgia Institute of Technology
Georgiou, Tryphon T. — Univ. of California, Irvine
Pavon, Michele — Università Di Padova

The problem to reconcile observed marginal distributions with a given prior was posed by E. Schro ̈dinger in 1932/32, and is now known as the Schroo ̈dinger Bridge Problem. It represents a stochastic counterpart of the Optimal Mass Transport (OMT). In either setting, the problem to interpolate between “unbalanced” marginals has been approached by introducing source/sink terms into the transport equations, in an adhoc manner, chiefly driven by applications in image registration. In the present work we developed a formalism to interpolate between “unbalanced” marginals in the original spirit of E. Schro ̈dinger, seeking the most likely transport of particles that may vanish along their path between given end points in time. In this, we develop a Schro ̈dinger system of equations that accounts for losses, by allowing particles to “jump” into a coffin state according to a suitable probabilistic law. The solution of the Schro ̈dinger system allows constructing a stochastic evolution that reconciles the given unbalanced marginals.

11:45-12:10 ThAM_H19.4

A Distributed Algorithm for Measure-Valued Optimization with Additive Objective (I), pp. 840-843

Nodozi, Iman — University of California, Santa Cruz
Halder, Abhishek — University of California Santa Cruz

We propose a distributed nonparametric algorithm for solving measure-valued optimization problems with additive objectives. Such problems arise in several contexts in stochastic learning and control including Langevin sampling from an unnormalized prior, mean field neural network learning and Wasserstein gradient flows. The proposed algorithm comprises a two-layer alternating direction method of multipliers (ADMM). The outer-layer ADMM generalizes the Euclidean consensus ADMM to the Wasserstein consensus ADMM, and to its entropy-regularized version Sinkhorn consensus ADMM. The inner-layer ADMM turns out to be a specific instance of the standard Euclidean ADMM. The overall algorithm realizes operator splitting for gradient flows in the manifold of probability measures.

12:10-12:35 ThAM_H19.5

Data-Driven Approximation of the Perron-Frobenius Operator Using the Wasserstein Metric (I), pp. 844-849

Karimi, Amirhossein — University of California, Irvine
Georgiou, Tryphon T. — Univ. of California, Irvine

This manuscript introduces a regression-type formulation for approximating the Perron-Frobenius Operator by relying on distributional snapshots of data. These snapshots may represent densities of particles. The Wasserstein metric is leveraged to define a suitable functional optimization in the space of distributions. The formulation allows seeking suitable dynamics so as to interpolate the distributional flow in function space. A first-order necessary condition for optimality is derived and utilized to construct a gradient flow approximating algorithm. The framework is exemplified with numerical simulations.

ThSP_H17	H 17
Semi Plenary: Jacquelien M.A. Scherpen (Plenary Session)	
Chair: Maschke, Bernhard	Univ Claude Bernard of Lyon

14:00-15:00 ThSP_H17.1

Extended (differential) Balancing for Model Reduction of Linear and Nonlinear Dynamical Systems, pp. 850-850

Scherpen, Jacquelien M.A. University of Groningen

In this talk, we will develop extended balancing and its structure preservation possibilities for linear systems, as well as extended balancing theory for nonlinear systems in the contraction framework. For the latter, we introduce the concept of the extended differential observability Gramian and inverse of the extended differential controllability Gramian for nonlinear dynamical systems and show their correspondence with generalized differential Gramians. We also provide how extended (differential) balancing can be utilized for model reduction to get a smaller apriori error bound in comparison with generalized (differential balancing). We will focus on preserving the structure of a port-Hamiltonian system with help of extended balancing in both the linear and nonlinear systems setting.

ThSP_H18 H 18

Semi Plenary: Anna-Lena Horlemann (Plenary Session)

Chair: Rosenthal, Joachim University of Zurich

14:00-15:00 ThSP_H18.1

The Densities of Good Codes in Various Metric Spaces, pp. 851-851

Horlemann, Anna-Lena University of St. Gallen

The densities of codes with certain properties have always been of interest in classical coding theory, in particular to understand how many of such codes exist and how likely a random code will have the prescribed properties. Further applications of density results of codes appear in code-based cryptography, where it is important that the set of codes with a certain property is large enough to outgo brute force attacks. In this talk we will present various density results for optimal or close-to-optimal codes in different metric spaces with different types of linearity. In particular, we will show when optimal codes in the Hamming, rank and sum-rank metric are dense and when they are sparse.

ThSP_H19 H 19

Semi Plenary: Na Li (Plenary Session)

Chair: Sugie, Toshiharu Kyoto University

14:00-15:00 ThSP_H19.1

Learning Decentralized Policies in Multiagent Systems: How to Learn Efficiently and What Are the Learned Policies?, pp. 852-852

Li, Na (Lina) SEAS Harvard

Multiagent reinforcement learning has received a growing interest with various problem settings and applications. We will first present our recent work in learning decentralized policies in networked multiagent systems under a cooperative setting. Specifically, we propose a policy gradient-based method that exploits the network structure and finds a local, decentralized policy that is a close approximation of a first-order stationary point of the global objective with complexity that scales with the local state-action space size. Motivated by the question of characterizing the performance of the stationary points, we look into the case where states could be shared among agents but agents still need to take actions following decentralized policies. We show that even when agents have identical interests, the first-order stationary points are only corresponding to Nash equilibria. This observation naturally leads to the use of the stochastic game framework to characterize the performance of policy gradients for decentralized policies in multiagent MDP systems. We will present some of our recent findings on both the local and global geometry of stochastic games.

ThPM_H16 H 16

Circuit Synthesis - I: Signals, Systems, and Circuits (Hybrid Session) (Invited Session)

Chair: Trenn, Stephan University of Groningen

Co-Chair: Smith, Malcolm C. University of Cambridge

Organizer: Smith, Malcolm C. University of Cambridge

Organizer: Hughes, Timothy H. University of Exeter

15:30-15:55 ThPM_H16.1

Moment Based Parametrization of Higher Order Stochastic Models (I), pp. 853-856

Dewilde, Patrick TUM Institute of Advanced Study

The paper reports results on the modeling of related stochastic variables, based on a finite fully ordered sequence of higher order moments (or correlations), and using mutually independent parameters that characterize all solutions that interpolate the given (or measured) data. The results are obtained by determining properties of the hierarchical generalized Hankel matrix of the moments. A system theoretic approach is used to derive the results. It appears that an extension of the related Hamburger-Jacobi orthogonal polynomials to the multivariate case does not suffice to yield a parametrization, but a further reduction of the recursive Cholesky factorization of the moment matrix does.

15:55-16:20 ThPM_H16.2

Sampling Formulae in Reproducing Kernel Hilbert Spaces (I), pp. 857-858

Dym, Harry Weizmann Institute

The classical sampling formula associated with the names of Shannon, Whittaker, Nyquist and Kotelnikov, will be exhibited as a special case of a general sampling formula in the setting of reproducing kernel Hilbert spaces of entire functions due to Louis de Branges. Other applications of these spaces and generalizations to spaces of vector valued entire functions will also be discussed briefly.

16:20-16:45 ThPM_H16.3

The Laplace Transform and Inconsistent Initial Values (I), pp. 859-862

Trenn, Stephan University of Groningen

Switches in electrical circuits may lead to Dirac impulses in the solution; a real world example utilizing this effect is the spark plug. Treating these Dirac impulses in a mathematically rigorous way is surprisingly challenging. This is in particular true for arguments made in the frequency domain in connection with the Laplace transform. A survey will be given on how inconsistent initials values have been treated in the past and how these approaches can be justified in view of the now available solution theory based on piecewise-smooth distributions.

16:45-17:10 ThPM_H16.4

Structure of Feedback-Loops through Positive Real Odd Functions (I), pp. 863-865

Lewkowicz, Izchak Ben-Gurion University

Positive real Odd rational functions, PO, (a.k.a. Foster or Lossless) correspond to the driving point immittance of reactive, i.e L-C, circuits. We here show that through PO functions one can model a feedback-loop connection (irrespective of the nature of each block). This suggests a research problem: Extend one of the classical scalar circuits synthesis schemes like Brune, Darlington, Bott-Duffin or Foster to the realm of possibly elaborate network of feedback loops. A challenge here is that the respective PO functions are of several non-commuting variables.

17:10-17:35 ThPM_H16.5

On Computing the H2 Norm Using the Polynomial Diophantine Equation (I), pp. 866-869

Hughes, Timothy H. University of Exeter

Willetts, Gareth Haydn University of Exeter

An explicit algorithm will be presented for computing the H2 norm of a single input single output system from the coefficients in its transfer function. The algorithm follows directly from Cauchy's residue theorem, and the most computationally intensive step involves solving a polynomial Diophantine equation. This can be efficiently solved using subresultant sequences in a fraction-free variant of the extended Euclidean algorithm. The coefficients in these subresultant sequences correspond to the Hurwitz determinants, whereby a stability test can be obtained alongside computing the H2 norm with little additional computational effort. Implementations of the algorithm symbolically, in exact arithmetic, and in floating-point arithmetic will be presented. The accompanying talk will demonstrate an example application on the design of passive train suspension systems that optimise passenger comfort. The example will demonstrate the algorithm's greater robustness and computational efficiency relative to H2 norm algorithms requiring the computation of the controllability or observability Gramians. The more general application of the techniques to the realisation of optimal lumped-parameter networks will also be discussed.

ThPM_H17	H 17
Structure-Preserving Discretization of Dynamical Systems - I (Hybrid Session) (Invited Session)	
Chair: Flaßkamp, Kathrin	Saarland University
Co-Chair: Kotyczka, Paul	Technical University of Munich
Organizer: Flaßkamp, Kathrin	Saarland University
Organizer: Kotyczka, Paul	Technical University of Munich
Organizer: Ober-Blöbaum, Sina	Paderborn University

15:30-15:55 ThPM_H17.1

Input Parametrizations and Their Numerical Implementation in Structure-Preserving Optimal Control (I), pp. 870-873

Herrmann-Wicklmayr, Markus	Saarland University
Flaßkamp, Kathrin	Saarland University

Motivated by the advantages of structure-preserving integration for applications ranging from molecular dynamics to astrodynamics, geometric integration has been brought into optimal control in the past two decades. Advantages over conventional methods have been shown in biomechanics, robotics, automotive applications, and space mission design. The implicit midpoint method, that is a member of the class of symplectic (partitioned) Runge-Kutta methods but also possess a variational derivation and thus is symmetry-preserving, is widely used due to its many favorable properties. In particular, efficient computations can be achieved by coarse discretizations of state and control signals, since structure preservation does not have to be ensured by small step sizes, as it is the case in conventional methods. Then, specific input parametrizations become an issue when implementing optimized signals in control architectures. We show numerical studies for piecewise linear control signals used inenergy optimal control problems.

15:55-16:20 ThPM_H17.2

Redundant Coordinates and Generalized Momentum Maps in the Optimal Control of Constrained Mechanical Systems (I), pp. 874-875

Schneider, Simeon	Karlsruhe Institute of Technology
Betsch, Peter	Karlsruhe Institute of Technology

The optimal control of mechanical systems satisfies an optimal control version of Noether's theorem. Accordingly, there exist generalized momentum maps on the level of the optimal control problem which are conserved if the system has symmetry. For constrained mechanical systems different approaches to define the necessary optimality conditions are known. These approaches will be compared with respect to their capability to preserve the generalized momentum maps. In addition to that, a discretization approach will be proposed which is capable to preserve the generalized momentum maps.

16:20-16:45 ThPM_H17.3

Structure-Preserving Integrators for Dissipative Systems Based on Reversible-Irreversible Splitting (I), pp. 876-879

Shang, Xiaocheng	University of Birmingham
Öttinger, Hans Christian	ETH Zürich

We study the optimal design of numerical integrators for dissipative systems, for which there exists an underlying thermodynamic structure known as GENERIC (General Equation for the NonEquilibrium Reversible-Irreversible Coupling). We present a frame-work to construct structure-preserving integrators by splitting the system into reversible and irreversible dynamics. The reversible part, which is often degenerate and reduces to a Hamiltonian form on its symplectic leaves, is solved by using a symplectic method (e.g., Verlet) with degenerate variables being left unchanged, for which an associated modified Hamiltonian (and subsequently a modified energy) in the form of a series expansion can be obtained by using backward error analysis. The modified energy is then used to construct a modified friction matrix associated with the irreversible part in such a way that a modified degeneracy condition is satisfied. The modified irreversible dynamics can be further solved by an explicit midpoint method if not exactly solvable. Our findings are verified by various numerical experiments, demonstrating the superiority of structure-preserving integrators over alternative schemes in terms of not only the accuracy control of both energy conservation and entropy production but also the preservation of the conformal symplectic structure in the case of linearly damped systems.

16:45-17:10 ThPM_H17.4

EPHS: A Port-Hamiltonian Modelling Language (I), pp. 880-885

Lohmayer, Markus	Friedrich-Alexander-Universität Erlangen-Nürnberg
Leyendecker, Sigrid	Friedrich-Alexander-Universität, Germany

A prevalent theme throughout science and engineering is the ongoing paradigm shift from isolated systems to open and interconnected systems. Port-Hamiltonian theory developed as a synthesis of geometric mechanics and network theory. The possibility to model complex multiphysical systems via interconnection of simpler components is often advertised as one of its most attractive features. The development of a port-Hamiltonian modelling language however remains a topic which has not been sufficiently addressed. We report on recent progress towards the formalization and implementation of a modelling language for exergetic port-Hamiltonian systems. Its diagrammatic syntax is the operad of undirected wiring diagrams with an interpretation akin to bond graphs. Together with a port-Hamiltonian semantics defined as an operad functor, this enables a modular and hierarchical approach to model specification.

17:10-17:35 ThPM_H17.5

Port-Hamiltonian FE Models for Filaments (I), pp. 886-891

Thoma, Tobias	Technical University of Munich
Kotyczka, Paul	Technical University of Munich

In this article, we present the port-Hamiltonian representation, the structure preserving discretization and the resulting finite-dimensional state space model of one-dimensional filaments based on a mixed finite element formulation. Due to the fact that the equations of motion of a filamentous body are based on the theory of geometrically nonlinear mechanical systems, the port-Hamiltonian formulation is expressed by means of its co-energy (effort) variables. The resulting port-Hamiltonian state space model features a quadratic Hamiltonian and the nonlinearity is reflected in the state dependence of its interconnection matrix. Numerical experiments generated with FEniCS illustrate the properties of the resulting finite element models.

ThPM_H18	H 18
Data-Based Learning and Control Theory - II (Invited Session)	
Chair: Trentelman, Harry L.	Univ. of Groningen
Co-Chair: Camlibel, Kanat	University of Groningen
Organizer: Camlibel, Kanat	University of Groningen
Organizer: Trentelman, Harry	Univ. of Groningen

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15:30-15:55 ThPM_H18.1

The Role of Systems Theory in Control Oriented Learning (I), pp. 892-895

Sznaier, Mario	Northeastern University
Olshevsky, Alex	Boston University
Sontag, Eduardo	Northeastern University

This talk discusses the role that systems theory plays in unveiling fundamental limitations of learning algorithms and architectures when used to control a dynamical system, and in suggesting strategies for overcoming these limitations. As an example, a feedforward neural network cannot stabilize a double integrator using output feedback. Similarly, a recurrent NN with differentiable activation functions that stabilizes a non-strongly stabilizable system must be itself open loop unstable, a fact that has profound implications for training with noisy, finite data. A potential solution to this problem, motivated by results on stabilization with periodic control, is the use of neural nets with periodic resets, showing that indeed systems theoretic analysis is instrumental in developing architectures capable of controlling certain classes of unstable systems. The talk will finish by arguing that when the goal is to learn control oriented models, the loss function should reflect closed loop, rather than open loop model performance, a fact that can be accomplished by using gap-metric motivated loss functions.

15:55-16:20 ThPM_H18.2

A Behavioral Approach to Data-Driven Control Using Noisy Input-Output Data (I), pp. 896-899

van Waarde, Henk J.	University of Groningen
Camlibel, Kanat	University of Groningen
Trentelman, Harry L.	Univ. of Groningen
Eising, Jaap	University of Groningen

In this extended abstract we consider input-output systems described by higher order difference equations, also called autoregressive systems. We assume that we have input-output data obtained from an underlying true, but unknown, system. The problems we then consider is to determine on the basis of these data whether this unknown system is stable. We also deal with the problem of determining whether a stabilizing controller exists, and, if so, to determine one using only the data. In order to tackle these problems we heavily rely on methods from the behavioral approach to systems and control, in particular the notion of quadratic difference form.

16:20-16:45 ThPM_H18.3

Data-Driven MPC of Descriptor Systems: A Case Study for Power Networks (I), pp. 900-905

Schmitz, Philipp	TU Ilmenau
Engelmann, Alexander	TU Dortmund University
Faulwasser, Timm	TU Dortmund University
Worthmann, Karl	TU Ilmenau

Recently, data-driven predictive control of linear systems has received wide-spread research attention. It hinges on the fundamental lemma by Willems et al. In a previous paper, we have shown how this framework can be applied to predictive control of linear time-invariant descriptor systems. In the present paper, we present a case study wherein we apply data-driven predictive control to a discrete-time descriptor model obtained by discretization of the power-swing equations for a nine-bus system. Our results show the efficacy of the proposed control scheme and they underpin the prospect of the data-driven framework for control of descriptor systems.

16:45-17:10 ThPM_H18.4

Data-Driven Distributed MPC of Dynamically Coupled Linear Systems (I), pp. 906-911

Koehler, Matthias	University of Stuttgart
Berberich, Julian	University of Stuttgart
Muller, Matthias A.	Leibniz University Hannover
Allgower, Frank	University of Stuttgart

In this paper, we present a data-driven distributed model predictive control (MPC) scheme to stabilise the origin of dynamically coupled discrete-time linear systems subject to decoupled input constraints. The local optimisation problems solved by the subsystems rely on a distributed adaptation of the Fundamental Lemma by Willems et al., allowing to parametrise system trajectories using only measured input-output data without explicit model knowledge. For the local predictions, the subsystems rely on communicated assumed trajectories of neighbours. Each subsystem guarantees a small deviation from these trajectories via a consistency constraint. We provide a theoretical analysis of the resulting non-iterative distributed MPC scheme, including proofs of recursive feasibility and (practical) stability. Finally, the approach is successfully applied to a numerical example.

17:10-17:35 ThPM_H18.5

Learning Stability Guarantees for Data-Driven Constrained Switching Linear Systems (I), pp. 912-915

Banse, Adrien	UCLouvain
Wang, Zheming	Université Catholique De Louvain
Jungers, Raphaël M.	Université Catholique De Louvain

We consider stability analysis of constrained switching linear systems in which the dynamics is unknown and whose switching signal is constrained by an automaton. We propose a data-driven Lyapunov framework for providing probabilistic stability guarantees based on data harvested from observations of the system. By generalizing previous results on arbitrary switching linear systems, we show that, by sampling a finite number of observations, we are able to construct an approximate Lyapunov function for the underlying system. Moreover, we show that the entropy of the language accepted by the automaton allows to bound the number of samples needed in order to reach some pre-specified accuracy.

ThPM_H19 H 19

Data-Driven Methods for Reduced-Order Modelling and Control - I (Invited Session)

Chair: Breiten, Tobias	Technical University Berlin
Co-Chair: Gosea, Ion Victor	Max Planck Institute for Dynamics of Complex Technical Systems
Organizer: Breiten, Tobias	Technical University Berlin
Organizer: Gosea, Ion Victor	Max Planck Institute for Dynamics of Complex Technical Systems

15:30-15:55 ThPM_H19.1

Data-Driven Approximation and Reduction from Noisy Data in Matrix Pencils Frameworks (I), pp. 916-921

Kergus, Pauline	CNRS
Gosea, Ion Victor	Max Planck Institute for Dynamics of Complex Technical Systems

This work aims at tackling the problem of learning surrogate models from noisy time-domain data by means of matrix pencil-based techniques, namely the Hankel and Loewner frameworks. A data-driven approach to obtain reduced order state-space models from time-domain input-output measurements for linear time-invariant (LTI) systems is proposed. This is accomplished by combining the aforementioned model order reduction (MOR) techniques with the signal matrix model (SMM) approach. The proposed method is illustrated by a numerical example consisting of a high-order building model.

15:55-16:20 ThPM_H19.2

The One-Sided Loewner Framework and Connections to Other Model Reduction Methods Based on Interpolation (I), pp. 922-927

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

Systems

Antoulas, Athanasios C. — Rice Univ

We present an extension of the Loewner framework, an established data-driven reduction, and identification method. This will be referred to as the one-sided Loewner framework since only one set of interpolation conditions are explicitly and exactly matched. For the other set of conditions, approximated interpolation is imposed. We describe how to explicitly characterize new interpolation conditions, derived from the latter set. We also show connections to the iterative AAA algorithm. Typical applications include constructing reduced models from frequency response data measured from systems in electronics or mechanical engineering. We illustrate the application of the main method on a large-scale benchmark example.

16:20-16:45 — ThPM_H19.3

Data-Driven Model Reduction by Moment Matching: One-Shot Moment Approximation through a Swapped Interconnection (I), pp. 928-931

Mao, Junyu — Imperial College London

Scarciotti, Giordano — Imperial College London

In this extended abstract, we present a time-domain data-driven technique for model reduction by moment matching of linear systems. We propose an algorithm, based on the so-called swapped interconnection, that (asymptotically) approximates an arbitrary number of moments of the system from a single time-domain sample. A family of reduced-order models that match the estimated moments is derived. Finally, the use of the proposed algorithm is demonstrated on the problem of model reduction of an atmospheric storm track model.

16:45-17:10 — ThPM_H19.4

Least Squares Moment Matching for Linear and Nonlinear Systems (I), pp. 932-935

Padoan, Alberto — ETH Zurich

The model reduction problem by least squares moment matching is studied. A recent time-domain characterization of least squares moment matching for linear systems is used to define a notion of least squares moment matching for nonlinear systems. Models achieving least squares moment matching are shown to minimize an a priori error bound on the worst case r.m.s. gain of an error system with respect to a given family of signals, thus providing new insights on the linear theory.

17:10-17:35 — ThPM_H19.5

Extended Differential Balancing and Generalized Balancing for Nonlinear Dynamical Systems, pp. 936-939

Sarkar, Arijit — University of Groningen

Scherpen, Jacquelien M.A. — University of Groningen

In this work, we introduced extended differential balancing, which is a model reduction approach for nonlinear dynamical systems in the contraction framework. We utilized the solutions of two time-varying LMIs to arrive at a balanced realization of the associated variational system to perform the truncation of less important states of the original system. One of the main contributions of the work is to show a computationally tractable way of performing model reduction providing tighter aprioiri error bounds in comparison with generalized differential balancing. On the other hand, we introduce generalized controllability function and generalized observability function for continuous-time stable nonlinear systems. We also propose a balanced realization for nonlinear port-Hamiltonian systems in which the generalized energy functions are balanced as well as the Hamiltonian of the corresponding system is in diagonal form. Moreover, the reduced order model obtained by truncation preserves the port-Hamiltonian structure.

ThPM_H20 — H 20

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

Chair: Kuhlmann, Salma — University of Konstanz

Co-Chair: Henrion, Didier — LAAS-CNRS, Univ. Toulouse

Organizer: Henrion, Didier — LAAS-CNRS, Univ. Toulouse

Organizer: Infusino, Maria — University of Cagliari

Organizer: Kuhlmann, Salma — University of Konstanz

Organizer: Vinnikov, Victor — Ben Gurion University of the Negev

15:30-15:55 — ThPM_H20.1

Optimization of Polynomials with Sparsity Encoded in a Few Linear Forms (I), pp. 940-944

Lasserre, Jean B. — CNRS

We consider polynomials of a few linear forms and show how exploit this type of sparsity for optimization on some particular domains like the Euclidean sphere or a polytope. Moreover, a simple procedure allows to detect this form of sparsity and also allows to provide an approximation of any polynomial by such sparse polynomials.

15:55-16:20 — ThPM_H20.2

Real Hyperplane Sections and Linear Series on Algebraic Curves (I), pp. 945-946

Plaumann, Daniel — TU Dortmund University

Given a real algebraic curve in projective space, we study the computational problem of deciding whether there exists a hyperplane meeting the curve in real points only. More generally, given any divisor on such a curve, we may ask whether the corresponding linear series contains an effective divisor with totally real support. This translates into a particular type of parametrized real root counting problem that we wish to solve exactly.

We will focus on examples and some general results and conjectures, based on recent work with Huu Phuoc Le and Dimitri Manevich.

16:20-16:45 — ThPM_H20.3

Hyperbolic Secant Varieties of M-Curves (I), pp. 947-947

Sinn, Rainer — Universität Leipzig

We present recent results joint with Mario Kummer (TU Dresden) on convex hulls of curves. We see a large family of examples where these convex hulls turn out to be hyperbolicity cones. For convex hulls of elliptic curves, we are able to show that these hyperbolicity cones are spectrahedra, generalizing previous results by Henrion and Scheiderer.

16:45-17:10 — ThPM_H20.4

Positive Semidefinite Quadratic Forms on Varieties Defined by Quadratic Forms (I), pp. 948-950

Hess, Sarah Tanja — University of Konstanz

For a fixed number of n+1 (n≥1) variables and even degree 2d (d≥1), the SOS cone of all real forms representable as finite sums of squares (SOS) of half degree d real forms is included in the PSD cone of all positive semidefinite (PSD) real forms. Hilbert (1888) states that both cones coincide if and only if n+1=2, d=1 or (n+1,2d)=(3,4). In this talk, we discuss necessary or sufficient conditions to extend local positive semidefiniteness of real quadratic forms along projective varieties generated by s (s≥0) real quadratic forms. Those conditions allow us to construct an explicit filtration of intermediate cones between the SOS and PSD cone along the Veronese variety. Indeed, the latter is known to be a projective variety finitely induced by real quadratic forms. We analyze this filtration for proper inclusions. In fact, after applying an inductive argument, it suffices to investigate the situation for a truncated subfiltration of the former. A result of Blekherman et al. (2016) on projective varieties of minimal degree permits us to handle the first inclusion in the constructed filtration. Generalizing this observation, we are able to show that the first n+1 cones in the peculiar filtration coincide. Finally, we lay out the situation in the basic non Hilbert case of quaternary quartics by identify exactly two strictly separating intermediate cones in the constructed filtration of the SOS and PSD cone via considerations of real forms based on techniques due to Robinson (1969) and Choi and Lam (1977). This is a work in progress with Salma Kuhlmann und Charu Goel.

17:10-17:35 — ThPM_H20.5

A Tale of Two Cones: Psd vs Sos in Equivariant Situations (I), pp. 951-953

Goel, Charu — IIIT Nagpur
Kuhlmann, Salma — University of Konstanz

The relationship between the cone of positive semidefinite (psd) real forms and its subcone of sums of squares (sos) of forms is of fundamental importance in real algebraic geometry and optimization, and has been studied extensively (see for instance Marshall (2008)). The study of this relationship goes back to the 1888 seminal paper of Hilbert, where he gave a complete characterisation of the pairs $(n,2d)$ for which a psd n-ary $2d$-ic form can be written as sos. In this talk we discuss how this relationship changes under the additional assumptions of invariance on the given forms, i.e. when we consider the induced action of a real finite reflection group on the ring of polynomials. We will see that in equivariant situations Hilbert's classification does not remain true in general and depends on the group action, the degree and the number of variables.

17:35-18:00 — ThPM_H20.6

Semialgebraic Convex Bodies (I), pp. 954-955

Meroni, Chiara — Max Planck Institute for Mathematics in the Sciences

Convex Algebraic Geometry lives at the intersection of Convex Geometry, Optimization, Algebraic Geometry and Real Algebra. Classically, convex geometry has been studied from an analytical point of view. Here, we approach it using tools from real and complex algebraic geometry, with a focus on semialgebraic convex bodies, beyond polytopes.

ThPM_S70 — S 70

Nonlinear Systems (Regular Session)

Chair: Trumpf, Jochen — The Australian National University
Co-Chair: Mirkin, Leonid — Technion—IIT

15:30-15:55 — ThPM_S70.1

Global Solution to an H-Infinity Control Problem for Control-Affine Systems, pp. 956-961

Vladu, Emil — Lund University
Rantzer, Anders — Lund Univ

In this paper, we present a global solution to a nonlinear H-infinity optimal control problem for control-affine systems with an associated potential function. We also give a closed form expression for an optimal controller and demonstrate its potential for sparsity. This paper thus advances a recent result which considers the same problem restricted to systems with symmetric state matrix and nonlinear input matrix. We further apply the main result to obtain a simpler and more intuitive statement for a class of systems capable of modeling nonlinear buffer networks.

15:55-16:20 — ThPM_S70.2

Loop Shaping with Scaled Relative Graphs, pp. 962-965

Chaffey, Thomas Lawrence — University of Cambridge
Forni, Fulvio — University of Cambridge
Sepulchre, Rodolphe J. — University of Cambridge

The Scaled Relative Graph (SRG) is a generalization of the Nyquist diagram that may be plotted for nonlinear operators, and allows nonlinear robustness margins to be defined graphically. This abstract explores techniques for shaping the SRG of an operator in order to maximize these robustness margins.

16:20-16:45 — ThPM_S70.3

A Non-Linear Internal Model Principle for Observers, pp. 966-967

Trumpf, Jochen — The Australian National University
Nüssle, Johannes — -

We show that any asymptotic observer for a non-linear kinematic system on a differentiable manifold contains a full internal model of the plant.

16:45-17:10 — ThPM_S70.4

On the Implementation and Adaptation of a Class of Internal Models, pp. 968-971

Colaneri, Patrizio — Politecnico Di Milano
Incremona, Gian Paolo — Politecnico Di Milano
Marconi, Lorenzo — Univ. Di Bologna
Mirkin, Leonid — Technion—IIT

A recent result in (Incremona et al., 2022) put forward an architecture of internal model based controllers, in which the stabilizer can be fully separated from the internal model. In this paper we propose a parametrized implementation of this controller, which isolates a parameter shaping properties of the exosystem. We show that with this implementation the closed-loop dynamics have an affine dependence on the parameter. As such, the closed-loop system remains stable even under arbitrary variations of the parameter, as long as it remains bounded. We demonstrate that this property is beneficial for adding an adaptation mechanism to adjust parameters of the internal model.

17:10-17:35 — ThPM_S70.5

Normal Forms for X-Flat Two-Input Control-Affine Systems in Dimension Five, pp. 972-977

Nicolau, Florentina — Ensea Cergy
Gstöttner, Conrad — Johannes Kepler University Linz
Respondek, Witold — INSA - Rouen

In this paper, we give normal forms for flat two-input control-affine systems in dimension five that admit a flat output depending on the state only (we call systems with that property x-flat systems). We discuss relations of x-flatness in dimension five with static and dynamic feedback linearization and show that if a system is x-flat it becomes linearizable via at most three prolongations of a suitably chosen control. Therefore x-flat systems in dimension five can be, in general, brought into normal forms generalizing the Brunovsky canonical form. If a system becomes linear via at most two-fold prolongation, the normal forms are structurally similar to the Brunovsky form: they have a special triangular structure consisting of a linear chain and a nonlinear one with at most two nonlinearities. If a system becomes linear via a three-fold prolongation, we obtain not only triangular structures but also a nontriangular one, and face new interesting phenomena.

17:35-18:00 — ThPM_S70.6

Dead-Time Compensation As an Observer-Based Design, pp. 978-981

Mirkin, Leonid — Technion—IIT
Zanutto, Dennis — Politecnico Di Milano

In this note we study discrete-time dead-time compensation from the viewpoint of the observer-based design procedure. We show that the discrete equivalent of the observer-predictor architecture can be derived ab initio via classical state-feedback and observer arguments under mild assumptions. The resulting observer is reduced order and we show that this choice is justifiable even if corresponding state measurement channels are noisy.

ThPM_S80 — S 80

Infinite-Dimensional Port-Hamiltonian Systems (Invited Session)

Chair: Reis, Timo — Technische Universität Ilmenau
Co-Chair: Jacob, Birgit — Bergische Universität Wuppertal
Organizer: Reis, Timo — Technische Universität Ilmenau
Organizer: Jacob, Birgit — Bergische Universität Wuppertal

15:30-15:55 — ThPM_S80.1

Port-Hamiltonian Modeling of Power Networks with Distributed Transmission Lines (I), pp. 982-984

Gernandt, Hannes | TU Berlin
Hinsen, Dorothea | TU Berlin

In this talk we consider power networks consisting of loads and generators which are interconnected via transmission lines. Here we use a distributed model for the transmission lines and provide a port-Hamiltonian formulation as a boundary control system and show the exponential stability and a power-balance equation for classical solutions.

15:55-16:20 ThPM_S80.2

Towards a General Port-Hamiltonian Descriptor Formalism for Multi-Phase Flow Dynamics (I), pp. 985-988

Bansal, Harshit | Eindhoven University of Technology
Schilders, Wilhelmus | TU Eindhoven

Recently, port-Hamiltonian (pH) representations have been developed for multi-phase flow models, such as the Two-Fluid Model and the zero-slip Drift Flux Model (DFM), with non-quadratic Hamiltonian functionals, by eliminating constraints and writing a partial differential-algebraic system as a system with (only) partial differential equations. However, the existing multi-phase modelling framework is not modular enough since mathematical computations have to be performed again for even a small change, say a different governing equation of state, in the model description. Furthermore, a pH representation of the general DFM still does not exist, and the complicated, non-linear models may not always be amenable to the pH model formulation as per the current state-of-the-art. To this end, we make efforts towards developing a general pH descriptor formalism for non-linear multi-phase flow dynamics.

16:20-16:45 ThPM_S80.3

Port-Hamiltonian Modeling of Interacting Particle Systems (I), pp. 989-992

Jacob, Birgit | Bergische Universität Wuppertal
Totzeck, Claudia | Bergische Universität Wuppertal

A port-Hamiltonian formulation of a general class of interacting particle systems and its corresponding mean-field partial-differential equation is discussed. To establish the port-Hamiltonian structure of the interacting particle systems a specific variable transformation is employed. It turns out that an appropriate retransformation of the characteristics corresponding to the mean-field partial differential equation yields again a port-Hamiltonian structure.

16:45-17:10 ThPM_S80.4

Dirac Structure for Spatial Multidimensional Port-Hamiltonian Systems (I), pp. 993-996

Skrepek, Nathanael | TU Freiberg

We regard port-Hamiltonian systems on multidimensional spatial domains. We show that there are multiple (slightly different) Dirac structures assigned to such systems. Moreover, we point out that not every Dirac structure admits well-posedness of the corresponding system.

17:10-17:35 ThPM_S80.5

Port-Hamiltonian System Nodes (I), pp. 997-1000

Philipp, Friedrich | Technische Universität Ilmenau
Reis, Timo | Technische Universität Ilmenau
Schaller, Manuel | Technische Universität Ilmenau

We present a framework to formulate infinite dimensional port-Hamiltonian systems by means of system nodes, which provide a very general and powerful setting for unbounded input and output operators that appear, e.g., in the context of boundary control or observation. One novelty of our approach is that we allow for unbounded and not necessarily coercive Hamiltonian energies. To this end, we construct finite energy spaces to define the port-Hamiltonian dynamics and give an application in case of multiplication operator Hamiltonians where the Hamiltonian density does not need to be positive or bounded. In order to model systems involving differential operators on these finite energy spaces, we show that if the total mass w.r.t. the Hamiltonian density (and its inverse) is finite, one can define a unique weak derivative.

17:35-18:00 ThPM_S80.6

Exponential Decay Rate of Port-Hamiltonian Systems with One Side Boundary Damping (I), pp. 1001-1006

Mora, Luis A. | University of Waterloo
Morris, Kirsten A. | Univ. of Waterloo

The multiplier approach is applied to a class of port-Hamiltonian systems with boundary dissipation to establish exponential decay. The exponential stability of port-Hamiltonian systems has been studied and sufficient conditions obtained. Here the decay rate $Me^{-alpha t}$ is established with M and $alpha$ are in terms of system parameters. This approach is illustrated by several examples, in particular, boundary stabilization of a piezoelectric beam with magnetic effects.

ThPM_S82 S 82

Hamilton-Jacobi Equations and Mean Field Games - III (Hybrid Session) (Invited Session)

Chair: Camilli, Fabio | SAPIENZA - Universita' Di Roma
Co-Chair: Zidani, Hasnaa | INSA Rouen Normandie
Organizer: Falcone, Maurizio | SAPIENZA - Universita' Di Roma
Organizer: Zidani, Hasnaa | INSA Rouen Normandie

15:30-15:55 ThPM_S82.1

A Policy Iteration Method for Mean Field Games (I), pp. 1007-1012

Camilli, Fabio | "Sapienza", Universita' Di Roma

The policy iteration method is a classical algorithm for solving optimal control problems. We introduce a policy iteration method for Mean Field Games systems and we prove, under a classical monotonicity assumption on the coupling cost, the convergence of this procedure to the solution of the problem.

15:55-16:20 ThPM_S82.2

Microscopic Derivation of Traffic Flow Models (I), pp. 1013-1016

Cardaliaguet, Pierre | Université Paris-Dauphine
Forcadel, Nicolas | INSA Rouen Normandie

The goal of this talk is to present a rigorous derivation of a macroscopic traffic flow model with a bifurcation or a local perturbation from a microscopic one. The microscopic model is a simple follow-the-leader with random parameters. The random parameters are used as a statistical description of the road taken by a vehicle and its law of motion. The limit model is a deterministic and scalar Hamilton-Jacobi equation on a network with a flux limiter, the flux-limiter describing how much the bifurcation or the local perturbation slows down the vehicles. The proof of the existence of this flux limiter relies on a concentration inequality and on a delicate derivation of a super-additive inequality.

16:20-16:45 ThPM_S82.3

Deterministic Mean Field Games with Non Coercive Hamiltonian (I), pp. 1017-1018

Mannucci, Paola | University of Padova
Marchi, Claudio | University of Padova
Tchou, Nicoletta | IRMAR-Université De Rennes 1

We study some models of evolutive deterministic mean field games with finite time horizon where the Hamiltonian is not coercive in the gradient term because the dynamic of the generic player has some forbidden directions. We study the existence of weak solutions and their representation by means of relaxed equilibria in the Lagrangian setting which are described by a probability measure on optimal trajectories.

16:45-17:10 ThPM_S82.4

Approximation of Deterministic Mean Field Games with Control-Affine Dynamics (I), pp. 1019-1020

Gianatti, Justina | CIFASIS-CONICET-UNR
Silva Alvarez, Francisco José | Université De Limoges

In this talk we study the numerical approximation of deterministic Mean Field Games where the dynamics of a typical agent is non-linear with respect to the state variable and affine with respect to the control variable. Particular instances of the problem considered here are MFGs with control on the acceleration. Our main result is the convergence of solutions of this approximation towards MFG equilibria.

FrP_Audimax Audimax
Plenary: George Weiss (Plenary Session)

Chair: Reis, Timo — Technische Universität Ilmenau

09:00-10:00 FrP_Audimax.1

Lax-Phillips Semigroups for Nonlinear Systems, pp. 1021-1021

Weiss, George — Tel Aviv University

We briefly recall the basics about Lax-Phillips semigroups for well-posed linear systems, and the definition of well-posed nonlinear systems via nonlinear Lax Phillips semigroups. Then we concentrate on two results concerning well-posed nonlinear systems: We investigate a special class of nonlinear systems that are obtained by modifying the second order differential equation that is part of the description of conservative linear systems "out of thin air" introduced by M. Tucsnak and G. Weiss in 2003. The differential equation contains a nonlinear damping term that is maximal monotone and possibly set- valued. We show that this new class of nonlinear systems is incrementally scattering passive (hence well-posed). Our approach uses the theory of maximal monotone operators and the Crandall-Pazy theorem about nonlinear contraction semigroups, which we apply to the Lax-Phillips semigroup of the system. We investigate the class of incrementally scattering passive nonlinear systems, as defined in some earlier papers of ours. We show that these can be defined by a differential inclusion and a formula defining the current output in term of the current state and the current input. Our approach uses the theory of maximal monotone operators. The talk is based on joint work with Shantanu Singh.

FrAM_H16 H 16
Circuit Synthesis - II: Network Synthesis (Hybrid Session) (Invited Session)

Chair: Hughes, Timothy H. — University of Exeter
Co-Chair: Reis, Timo — Technische Universität Ilmenau
Organizer: Smith, Malcolm C. — University of Cambridge
Organizer: Hughes, Timothy H. — University of Exeter

10:30-10:55 FrAM_H16.1

Systems Theoretic Properties of Linear RLC Circuits (I), pp. 1022-1025

Reis, Timo — Technische Universität Ilmenau

We consider the differential-algebraic systems obtained by modified nodal analysis of linear RLC circuits from a systems theoretic viewpoint. We derive expressions for the set of consistent initial values and show that the properties of controllability at infinity and impulse controllability do not depend on parameter values but rather on the interconnection structure of the circuit. We further present circuit topological criteria for behavioral stabilizability.

10:55-11:20 FrAM_H16.2

Optimum Mechanical Network Identification Methodologies: With and without Mass Elements (I), pp. 1026-1029

Li, Yiyuan — University of Bristol
Zhang, Sara Ying — Shenzhen University
Jiang, Jason Zheng — University of Bristol
Neild, Simon Andrew — Univ of Bristol
Macdonald, John — University of Bristol

Traditional linear passive vibration-absorber networks, such as the tuned mass damper (TMD), often contain springs, dampers, and masses. Recently there has been a growing trend to supplement or replace the masses with inerters. When considering the absorbers without a mass, a structure-immittance approach was proposed to identify possible configurations consisting of springs, dampers, and inerters. This approach can characterise the full class of network layouts with pre-determined numbers of each element type, and also prescribe the allowed value range for each element. More recently, a mass-included passive absorber, the tuned-mass-damper-inerter, was introduced, showing significant performance benefits on vibration suppression. With the aim to further explore the potential of numerous mass-included passive absorber layouts, a more generalised methodology was developed. Using this methodology, a full class of absorber layouts with a mass and a pre-determined number of inerters, dampers, and springs connected in series and parallel can be systematically investigated. A 3-storey building model is used to demonstrate the advantages of the proposed approaches for the cases without and with a mass, where the performance improvements can be up to 21.6% and 65.6%, respectively, compared to the TMD.

11:20-11:45 FrAM_H16.3

Controller Synthesis for an Arbitrary Length of Mass Chain (I), pp. 1030-1033

Yamamoto, Kaoru — Kyushu University

The disturbance suppression problem for a chain of masses is discussed. The particular focus is placed on synthesising mechanical networks between masses that effectively suppress the disturbance propagation along the chain of any length. This study is motivated by the problem of controlling multi-agent systems where agents may leave or join the network. That is, the size of the network may change over time. In this work, we give the explicit expressions of scalar transfer functions from disturbance to an intermass displacement as a function of the number of masses, N, and discuss the methodology of synthesising a controller such that the H^∞ norm is upper bounded by a prescribed value for any N.

11:45-12:10 FrAM_H16.4

Mechanical Realisation of a Lossless Adjustable Two-Port Transformer (I), pp. 1034-1037

Gaudiesius, Lukas — University of Cambridge
Georgiou, Tryphon T. — Univ. of California, Irvine
Houghton, Neil Edward — University of Cambridge
Smith, Malcolm C. — University of Cambridge

This paper continues the work of Georgiou, Jabbari and Smith on lossless adjustable mechanical devices. Defining equations and mechanical constructions of lossless adjustable springs and inerters for translational and rotational devices will be recalled. The role played by the lossless adjustable two-port transformer will be highlighted. A mechanical design will be described for a lossless adjustable rotational two-port transformer involving a double-cone arrangement, movable carriage and a pair of counter-rotating balls.

12:10-12:35 FrAM_H16.5

Nonlinear Mechanical Network-Based Models for Force-Controlling Devices (I), pp. 1038-1040

Li, Yuan — University of Bristol
Liu, Xiaofu — China Agricultural University
Jiang, Jason Zheng — University of Bristol
Titurus, Branislav — University of Bristol
Neild, Simon Andrew — Univ of Bristol

In recent years, network synthesis theory has been successfully applied to vibration absorber design, to identify optimum mechanical networks providing performance improvements. These identified mechanical networks consist of ideal linear modelling elements, such as springs, dampers and inerters. For real-life applications, the essential next step is to transfer these linear mechanical networks into physical absorber designs. There are two major challenges for this step: firstly, in order to achieve practical physical realisations, multidomain physical components (mechanical, hydraulic, pneumatic and electrical) need to be considered; and secondly, nonlinearities and other parasitic properties of physical components must be taken into consideration or potentially be made full use of. To this end, this paper, using a nonlinear mechanical network-based model for a bespoke mechanical-hydraulic device, demonstrates the feasibility of resolving both challenges.

12:35-13:00 FrAM_H16.6

Exhaustive Synthesis of Microwave Circuits with Frequency Dependent Couplings (I), pp. 1041-1044

Olivi, Martine	INRIA
Seyfert, Fabien	INRIA Sophia-Antipolis
Wu, Ke-Li	Chinese University of Hong Kong
Zhang, Yan	Chinese University of Hong Kong

The synthesis of bandpass microwave filters is based on the use of equivalent circuit models made of coupled resonators. These couplings are usually supposed to be independent of the frequency. We present in this paper a circuit model including possibly frequency varying couplings. After presenting some of its properties we consider the associated synthesis problem and show how techniques such as Groebner basis computation and Schur analysis based extraction techniques can be used to solve the latter exhaustively.

FrAM_H17 H 17

Structure-Preserving Discretization of Dynamical Systems - II (Hybrid Session) (Invited Session)

Chair: Kotyczka, Paul	Technical University of Munich
Co-Chair: Flaßkamp, Kathrin	Saarland University
Organizer: Flaßkamp, Kathrin	Saarland University
Organizer: Kotyczka, Paul	Technical University of Munich
Organizer: Ober-Blöbaum, Sina	Paderborn University

10:30-10:55 FrAM_H17.1

Asymptotic Stability and Structure Preserving Discretization for Gas Flow in Networks (I), pp. 1045-1046

Egger, Herbert	Johannes Kepler University Linz, RICAM Linz
Giesselmann, Jan	TU Darmstadt
Kunkel, Teresa	TU Darmstadt
Philippi, Nora	TU Darmstadt

Gas transport in one-dimensional pipe networks can be described as an abstract dissipative Hamiltonian system, for which quantitative stability bounds can be derived by means of relative energy estimates for subsonic flow. This allows to establish convergence to the parabolic limit problem in the practically relevant high friction regime. The stability estimates carry over almost verbatim to a mixed finite element approximations with an implicit Euler time discretization, leading to order optimal convergence rates that are uniform the high friction limit. All results are proven in detail for the flow on a single pipe, but by the port-Hamiltonian formalism, they naturally extend to pipe networks.

10:55-11:20 FrAM_H17.2

From Discrete Modeling to Explicit FE Models for Port-Hamiltonian Systems of Conservation Laws (I), pp. 1047-1052

Kotyczka, Paul	Technical University of Munich
Thoma, Tobias	Technical University of Munich

Mixed finite element (FE) approaches have proven very useful for the structure-preserving discretization of port-Hamiltonian (PH) distributed parameter systems, but non-uniform boundary conditions (BCs) were treated in an implicit manner up to now. We apply our recent approach from structure mechanics, which relies on the weak imposition of both Neumann and Dirichlet BCs based on a suitable variational principle, to the class of PH systems of two conservation laws. We illustrate (a) starting with the integral conservation laws the transition to an exterior calculus representation suitable for FE approximation according to Farle et al. (2013). Based thereon, we show (b) the variational formulation with weakly imposed BCs of both types. We discuss (c) on a simple example on a quadrilateral mesh the structure and the variables of the resulting FE models compared to the equations derived from a direct discrete approach on dual cell complexes. We (d) provide the corresponding FEniCS code for download.

11:20-11:45 FrAM_H17.3

Explicit Structure-Preserving Discretization of Port-Hamiltonian Systems with Mixed Boundary Control (I), pp. 1053-1058

Brugnoli, Andrea	University of Twente
Haine, Ghislain	Institut Superieur De l'Aeronautique Et De L'Espace
Matignon, Denis	ISAE

In this contribution, port-Hamiltonian systems with non-homogeneous mixed boundary conditions are discretized in a structure-preserving fashion by means of the Partitioned FEM. At the discrete level, an explicit pHs is obtained. The general construction relies on a weak imposition of the boundary conditions by means of the Hellinger-Reissner variational principle, as recently proposed in [Thoma et al., 2021]. The case of linear hyperbolic wave-like systems, including the elastodynamic problem and the Maxwell equations in 3D, is then illustrated in detail. A numerical example is worked out on the case of the wave equation.

11:45-12:10 FrAM_H17.4

A Structure-Preserving Finite Element Method for MHD That Preserves Energy, Cross-Helicity, Magnetic Helicity, divB = 0 (I), pp. 1059-1062

Gay-Balmaz, François	Ecole Normale Supérieure De Paris
Gawlik, Evan	University of Hawaii at Manoa

We construct a structure-preserving finite element method and time-stepping scheme for inhomogeneous, incompressible magnetohydrodynamics (MHD). The method preserves energy, cross-helicity (when the fluid density is constant), magnetic helicity, mass, total squared density, pointwise incompressibility, and the constraint div B = 0. to machine precision, both at the spatially and temporally discrete levels.

12:10-12:35 FrAM_H17.5

Structure-Preserving Discretization of Maxwell's Equations As a Port-Hamiltonian System (I), pp. 1063-1068

Haine, Ghislain	Institut Superieur De l'Aeronautique Et De L'Espace
Matignon, Denis	ISAE
Florian, Monteghetti	ISAE

This work demonstrates the discretization of the boundary-controlled Maxwell equations, recast as a port-Hamiltonian system (pHs). After a reminder on the Stokes-Dirac structure associated with the Maxwell system, we introduce different partitioned weak formulations that preserve the pHs structure, and its associated power balance, at the semi- discrete level. These weak formulations are compared through numerical applications to closed non-perfectly conducting cavities and open waveguides under transverse approximation.

FrAM_H18 H 18

Quantum Control (Hybrid Session) (Regular Session)

Chair: Dirr, Gunther	University of Wurzburg
Co-Chair: Elassoudi, Rachida	University of Normandy, INSA Rouen

10:30-10:55 FrAM_H18.1

Exploring the Limits of Open Quantum Dynamics I: Motivation, New Results from Toy Models to Applications, pp. 1069-1072

Schulte-Herbrueggen, Thomas	Technichal Univ Munich (TUM)
Dirr, Gunther	University of Wurzburg
vom Ende, Frederik	Technichal University Munich (TUM)

Which quantum states can be reached by controlling open Markovian n-level quantum systems? Here, we address reachable sets of coherently controllable quantum systems with switchable coupling to a thermal bath of temperature T. --- The core problem reduces to a toy model of studying points in the standard simplex allowing for two types of controls: (i) permutations within the simplex, (ii) contractions by a dissipative semigroup [Dirr et al. (2019)]. By illustration, we put the problem into context and show how toy-model solutions pertain to the reachable set of the original controlled Markovian quantum system. Beyond the case T = 0 (amplitude damping) we present new results for 0 < T < 1 using methods of d-majorisation.

10:55-11:20	FrAM_H18.2

Exploring the Limits of Open Quantum Dynamics II: Gibbs-Preserving Maps from the Perspective of Majorization, pp. 1073-1076

vom Ende, Frederik — Technichal University Munich (TUM)

Motivated by reachability questions in coherently controlled open quantum systems coupled to a thermal bath, as well as recent progress in the field of thermo-/vector-majorization we generalize classical majorization from unital quantum channels to channels with an arbitrary fixed point D of full rank. Such channels preserve some Gibbs-state and thus play an important role in the resource theory of quantum thermodynamics, in particular in thermo-majorization.

Based on this we investigate D-majorization on matrices in terms of its topological and order properties, such as existence of unique maximal and minimal elements, etc. Moreover we characterize D-majorization in the qubit case via the trace norm and elaborate on why this is a challenging task when going beyond two dimensions.

11:20-11:45	FrAM_H18.3

Time Minimal Control of Multi-Level Quantum Systems, pp. 1077-1080

Elassoudi, Rachida — University of Normandy, INSA Rouen
Zibo, Irigo Edouard — INSA Rouen Normandie

We study time minimal control problem for quantum systems whose dynamics are governed by the Bloch equation with interaction. The dynamics of the quantum systems are analyzed as affine control systems on the Bloch ball using parametrizations of the density matrix. The influence of Coulomb energies during a process of population transfer for a quantum system with several energy levels is shown and time minimal trajectories are given.

11:45-12:10	FrAM_H18.4

Noncommutative Real Algebraic Geometry and Quantum Games, pp. 1081-1081

Helton, J. William — Univ. of California at San Diego

The last two decades produced a substantial noncommutative (in the free algebra) real and complex algebraic geometry. The aim of the subject is to develop a systematic theory of equations and inequalities for noncommutative polynomials in operator variables. A problem leading very directly to such equations and inequalities is finding good quantum strategies for games. The talk will focus on quantum games and present recent results done jointly with Adam Bene Watts, Igor Klep, Vern Paulsen, Mousavi, Nezhadi, Russel, and Zehong Zhao.

FrAM_H19	H 19

Data-Driven Methods for Reduced-Order Modelling and Control - II (Invited Session)

Chair: Gosea, Ion Victor — Max Planck Institute for Dynamics of Complex Technical Systems
Co-Chair: Breiten, Tobias — Technical University Berlin
Organizer: Breiten, Tobias — Technical University Berlin
Organizer: Gosea, Ion Victor — Max Planck Institute for Dynamics of Complex Technical Systems

10:30-10:55	FrAM_H19.1

A Data-Driven Formulation for Balanced Truncation of Bilinear Dynamical Systems (I), pp. 1082-1085

Gosea, Ion Victor — Max Planck Institute for Dynamics of Complex Technical Systems
Pontes Duff, Igor — Max Planck Institute for Dynamics of Complex Technical Systems
Gugercin, Serkan — Virginia Tech
Beattie, Christopher A. — Virginia Tech

We describe here a non-intrusive data-driven time-domain formulation of balanced truncation (BT) for bilinear control systems. We build on the recent method of Gosea et al. (2021) that recasts the classic BT method for linear time invariant systems as a data-driven method requiring only evaluations of either transfer function values or impulse responses. We extend the domain of applicability of this non-intrusive data driven method to bilinear systems, arguably the simplest nontrivial class of weakly nonlinear systems.

10:55-11:20	FrAM_H19.2

Reduced-Order Models from Data Via Generalized Balanced Truncation (I), pp. 1086-1089

Burohman, Azka Muji — University of Groningen
Besselink, Bart — University of Groningen
Scherpen, Jacquelien M.A. — University of Groningen
Camlibel, Kanat — University of Groningen

This extended abstract proposes a data-driven model reduction approach on the basis of noisy data. Firstly, the concept of data reduction is introduced. In particular, we show that the set of reduced-order models obtained by applying a Petrov-Galerkin projection to all systems explaining the data characterized in a large-dimensional quadratic matrix inequality (QMI) can again be characterized in a lower-dimensional QMI. Next, we develop a data-driven generalized balanced truncation method that relies on two steps. First, we provide necessary and sufficient conditions such that systems explaining the data have common generalized Gramians. Second, these common generalized Gramians are used to construct projection matrices that allow to characterize a class of reduced-order models via generalized balanced truncation in terms of a lower-dimensional QMI by applying the data reduction concept. Additionally, we present an alternative procedure to compute an a priori error bound.

11:20-11:45	FrAM_H19.3

Convolutional Autoencoders and Clustering for Low-Dimensional Parametrization of Incompressible Flows, pp. 1090-1095

Heiland, Jan — Max Planck Institute for Dynamics of Complex Technical Systems
Kim, Yongho — Max Planck Institute for Dynamics of Complex Technical Systems

The design of controllers for general nonlinear PDE models is a difficult task because of the high dimensionality of the partially discretized equations. It has been observed that the embedding of nonlinear systems into the class of linear parameter varying systems (LPV) gives way to apply linear theory and methods from numerical linear algebra for controller design. The feasibility of the LPV approach hinges on the dimension of the inherent parametrization. In this work we propose and evaluate combinations of convolutional neural networks and clustering algorithms for very low-dimensional parametrizations of incompressible Navier-Stokes equations.

11:45-12:10	FrAM_H19.4

Compatible Snapshot-Based Model Reduction of a Nonlinear Port-Hamiltonian PDE on Networks (I), pp. 1096-

1098

Liljegren-Sailer, Björn	Trier University
Marheineke, Nicole	Trier University

This contribution is on the construction of structure-preserving, online-efficient reduced models for a class of nonlinear partial differential equations on networks, which inherit a port-Hamiltonian structure. The flow problem finds broad application, e.g., in the context of gas distribution networks. We propose a snapshot-based reduction approach that consists of a mixed variational Galerkin approximation combined with quadrature-type complexity reduction. Its main feature is that certain compatibility conditions are assured during the training phase, which make our approach structure-preserving. The resulting reduced models are locally mass conservative and inherit an energy-bound and port-Hamiltonian structure. We demonstrate the applicability and good stability properties of our approach using the example of the Euler equations on networks.

FrAM_H20 H 20

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

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

10:30-10:55 FrAM_H20.1

Moments, Sums of Squares, and Tropicalization (I), pp. 1099-1102

Blekherman, Grigoriy	Georgia Tech
Rincon, Felipe	Queen Mary University of London
Sinn, Rainer	Universität Leipzig
Vinzant, Cynthia	University of Washington
Yu, Josephine	Georgia Tech

The relationship between nonnegative polynomials and sums of squares on semialgebraic set S is one of the central questions in real algebraic geometry. The (convex) dual side of this story is important in analysis, where it is known as the truncated S-moment problem, and it considers the truncated cones of moments which are dual to nonnegative polynomials, and ``pseudo-moments'' which are dual to sums of squares. We bring a new tool for understanding of these classical problems: tropicalization. While extensively studied in complex algebraic geometry, tropicalization is rarely applied to semialgebraic sets. We provide explicit combinatorial descriptions of tropicalizations of the moment and pseudo-moment cones, and demonstrate their usefulness in distinguishing between nonnegative polynomials and sums of squares, proving results limiting the power of sums of squares approximations of nonnegative polynomials. We believe that this just scratches the surface of applications of tropicalization in semi-algebraic geometry.

10:55-11:20 FrAM_H20.2

Signed Tropicalizations of Convex Semialgebraic Sets (I), pp. 1103-1106

Skomra, Mateusz	LAAS-CNRS

We study the signed valuations of convex semialgebraic sets defined over non-Archimedean fields. This is motivated by the efforts to understand the structure of semialgebraic sets that arise in convex optimization, such as the spectrahedra and the hyperbolicity cones. We give a full characterization of regular sets that are obtained as signed tropicalizations of convex semialgebraic sets, and we prove that the signed tropicalizations of hyperbolicity cones have a more restrictive structure. To obtain our results, we combine two recent advances in the area of tropical geometry: the study of signed valuations of general semialgebraic sets and the separation theorems for signed tropical convexities.

11:20-11:45 FrAM_H20.3

On the Computational Complexity of the Moment-SOS Hierarchy for Polynomial Optimization (I), pp. 1107-1110

Gribling, Sander	Université De Paris, CNRS, IRIF
Polak, Sven	Centrum Wiskunde & Informatica (CWI)
Slot, Lucas	Centrum Wiskunde & Informatica (CWI)

The moment-sum-of-squares (moment-sos) hierarchy is one of the most celebrated and widely applied methods for approximating the minimum of an n-variate polynomial over a feasible region defined by polynomial (in)equalities. A key feature of the hierarchy is that it can be formulated as a semidefinite program of size polynomial in the number of variables n. Although this suggests that it may therefore be computed in polynomial time, this is not necessarily the case. Indeed, as O'Donnell and later Raghavendra & Weitz show, there exist examples where the sos-representations used in the hierarchy have exponential bit-complexity. We study the computational complexity of the sos-hierarchy, complementing and expanding upon earlier work of Raghavendra & Weitz. In particular, we establish algebraic and geometric conditions under which polynomial-time computation is possible. As this work is still ongoing, our results should be treated as preliminary.

11:45-12:10 FrAM_H20.4

Combining the SOS and SONC Cones - a Hilbert's 1888 Theorem Analogue and Further Separation Results (I), pp. 1111-1114

Schick, Moritz	University of Konstanz

Studying convex cones inside the cone of positive semidefinite (PSD) polynomials is an important field of research in real algebraic geometry and polynomial optimization. In this work, we combine two such well established cones, which are sums of squares (SOS) and sums of nonnegative circuit polynomials (SONC) and consider PSD polynomials, that decompose into an SOS and a SONC part. We call the resulting set the SOS+SONC cone. For this newly established cone, we prove two separation results. The first one is an analogue to Hilbert's 1888 Theorem for the SOS+SONC cone. The second one shows that whenever the SOS and SONC cones are proper subsets of the PSD cone, they are also proper subsets of the SOS+SONC cone.

12:10-12:35 FrAM_H20.5

Tractable Semidefinite Bounds of Positive Maximal Singular Values (I), pp. 1115-1118

Magron, Victor	CNRS LAAS
Mai, Ngoc Hoang Anh	LAAS-CNRS
Ebihara, Yoshio	Kyushu University
Waki, Hayato	Institute of Mathematics for Industry, Kyushu University

We focus on computing certified upper bounds for the positive maximal singular value (PMSV) of a given matrix.

The PMSV problem boils down to maximizing a quadratic polynomial on the intersection of the unit sphere and the nonnegative orthant. We provide a hierarchy of tractable semidefinite relaxations to approximate the value of the latter polynomial optimization problem as closely as desired. This hierarchy is based on an extension of Polya's representation theorem. Doing so, positive polynomials can be decomposed as weighted sums of squares of s-nomials, where s can be a priori fixed (s=1 corresponds to monomials, s=2 corresponds to binomials, etc.). This in turn allows us to control the size of the resulting semidefinite relaxations.

FrAM_S70	S 70
Networked Control Systems - II (Regular Session)	
Chair: Legat, Antoine	UCLouvain

10:30-10:55 FrAM_S70.1

On Internal Stability of Diffusive-Coupling and the Dangers of Cancel Culture, pp. 1119-1122

Barkai, Gal	Technion—Israel Institute of Technology
Mirkin, Leonid	Technion—IIT
Zelazo, Daniel	Technion - Israel Institute of Technology

We study internal stability in the context of diffusively-coupled control architecture, common in multi-agent systems (e.g. the celebrated consensus protocol). We derive a condition under which the system can be stabilized by no controller from that class. The condition says effectively that diffusively-coupled controllers cannot stabilize agents that share common unstable dynamics, directions included. This class always contains a group of homogeneous unstable agents, like integrators. We argue that the underlying reason is intrinsic cancellations of unstable agent dynamics by such controllers, even static ones, where directional properties play a key role. The intrinsic lack of internal stability explains the notorious behavior of some distributed control protocols when affected by measurement noise or exogenous disturbances.

10:55-11:20 FrAM_S70.2

Caratheodory Solutions to Opinion Dynamics with Topological Interactions and Their Associated Graphs, pp. 1123-1128

Frasca, Paolo	CNRS, GIPSA-Lab, Grenoble
Rossi, Francesco	Università Degli Studi Di Padova

Models of social influence may present discontinuous dynamical rules, which are unavoidable with topological interactions, i.e. when the dynamics is the outcome of interactions with a limited number of nearest neighbors.

Here, we show that classical solutions are not sufficient to describe the resulting dynamics. We first describe the time evolution of the interaction graph associated to Caratheodory solutions, whose properties depend on the dimension of the state space and on the number of considered neighbors. We then prove the existence of Caratheodory solutions for 2-nearest neighbors, via a constructive algorithm.

11:20-11:45 FrAM_S70.3

Reaching Optimal Distributed Estimation through Myopic Self-Confidence Adaptation, pp. 1129-1134

Como, Giacomo	Politecnico Di Torino
Fagnani, Fabio	Politecnico Di Torino
Proskurnikov, Anton V.	Politecnico Di Torino

Consider discrete-time linear distributed averaging dynamics, whereby a finite number of agents in a network start with uncorrelated and unbiased noisy measurements of a common state of the world modeled as a scalar parameter, and iteratively update their estimates following a non-Bayesian learning rule. Specifically, let every agent update her estimate to a convex combination of her own current estimate and those of her neighbors in the network (this procedure is also known as the French-DeGroot model, or the consensus algorithm). As a result of this iterative averaging process, each agent obtains an asymptotic estimate of the state of the world, and the variance of this individual estimate depends on the matrix of weights the agents assign to themselves and to the others. We study a game-theoretic multi-objective optimization problem whereby every agent seeks to choose her self-confidence value in the convex combination in such a way to minimize the variance of her asymptotic estimate of the state of the world. Assuming that the relative influence weights assigned by the agents to their neighbors in the network remain fixed and form an irreducible relative influence matrix, we characterize the Pareto frontier of the problem, as well as the set of Nash equilibria in the resulting game.

11:45-12:10 FrAM_S70.4

Optimal Intervention in Transportation Networks, pp. 1135-1138

Cianfanelli, Leonardo	Politecnico Di Torino
Como, Giacomo	Politecnico Di Torino
Ozdaglar, Asu	MIT
Parise, Francesca	Cornell University

We study a network design problem (NDP) where the planner aims at selecting the optimal single-link intervention in a transportation network to minimize the total congestion. Our first result is to show that the NDP may be formulated in terms of electrical quantities on a related resistor network, in particular in terms of the effective resistance between adjacent nodes. We then suggest an approach to approximate such an effective resistance by performing only local computations, and exploit this approach to design an efficient algorithm to solve the NDP, without recomputing the equilibrium flow after the intervention. We then study the optimality of the proposed procedure for recurrent networks, and provide simulations over relevant networks.

12:10-12:35 FrAM_S70.5

Algebraic and Path-Based Conditions for Local Network Identifiability, pp. 1139-1140

Legat, Antoine	UCLouvain
Hendrickx, Julien M.	UCLouvain

This work focuses on the generic identifiability of dynamical networks with partial excitation and measurement: a set of nodes are interconnected by transfer functions according to a known topology, some nodes are excited, some are measured, and only a part of the transfer functions are known. Our goal is to determine whether the unknown transfer functions can be generically recovered based on the input-output data collected from the excited and measured nodes. Introducing the notion of generic local identifiability, we derive a necessary and sufficient algebraic condition, which can be checked efficiently by rank computation. Another notion, generic decoupled identifiability, allows to reflect on a larger network which decouples excitations and measurements. This yields a necessary path-based condition, and a sufficient one.

12:35-13:00 FrAM_S70.6

Distributed Online Mirror Descent Algorithm with Event Triggered Communication, pp. 1141-1146

Paul, Anik Kumar	Indian Institute of Technology Madras
Mahindrakar, Arun D.	Indian Institute of Technology Madras
Kalaimani, Rachel Kalpana	Indian Institute of Technology Bombay

The paper proposes an algorithm that uses distributed online mirror descent algorithm for solving constrained online optimization problem with event triggered communication. The optimization is over a time horizon and the future objective functions are not apriori known to each agent. In the proposed algorithm, the communication between the agents, that happens in a distributed optimization framework, occurs only when the difference between the current state and the state when the last event has been triggered exceeds a threshold. The performance of the algorithm is analysed using a regret function. We establish a bound on the regret and provide sufficient conditions on the step-size and thresholding error such that the regret is sublinear. We demonstrate the reduction in the number of inter-agent communications using our proposed algorithm for an estimation problem in a dynamic environment.

FrAM_S80	S 80
Model Predictive Control (Regular Session)	
Chair: Berberich, Julian	University of Stuttgart
Co-Chair: Nagahara, Masaaki	The University of Kitakyushu

10:30-10:55 FrAM_S80.1

Towards Funnel MPC for Nonlinear Systems with Relative Degree Two, pp. 1147-1150

Dennstädt, Dario	Tu Ilmenau

Funnel MPC, a novel Model Predictive Control (MPC) scheme, allows guaranteed output tracking of smooth reference signals with prescribed error bounds for nonlinear multi-input multi-output systems. To this end, the stage cost resembles the high-gain idea of funnel control. Without imposing additional output constraints or terminal conditions, the Funnel MPC scheme is initially and recursively feasible for systems with relative degree one and stable internal dynamics. Using an additional funnel for the derivative as a penalty term in the stage cost, these results can be also extended to single-input single-output systems with relative degree two.

10:55-11:20 FrAM_S80.2

Stochastic Model Predictive Control Using Initial State Optimization, pp. 1151-1156

Schlüter, Henning	University of Stuttgart
Allgower, Frank	University of Stuttgart

We propose a stochastic MPC scheme using an optimization over the initial state for the predicted trajectory. Considering linear discrete-time systems under unbounded additive stochastic disturbances subject to chance constraints, we use constraint tightening based on probabilistic reachable sets to design the MPC. The scheme avoids the infeasibility issues arising from unbounded disturbances by including the initial state as a decision variable. We show that the stabilizing control scheme can guarantee constraint satisfaction in closed loop, assuming unimodal disturbances. In addition to illustrating these guarantees, the numerical example indicates further advantages of optimizing over the initial state for the transient behavior.

11:20-11:45 FrAM_S80.3

Targeted Harmonic Exploration with Application to Robust Dual Control, pp. 1157-1160

Venkatasubramanian, Janani	University of Stuttgart
Köhler, Johannes	ETH Zurich
Berberich, Julian	University of Stuttgart
Allgower, Frank	University of Stuttgart

We present a novel targeted exploration strategy for the application of robust dual control. Unlike common greedy random exploration strategies considered in the related dual control literature, we introduce a targeted strategy in which the exploration inputs are a linear combination of sinusoids whose amplitudes are optimized based on an exploration criterion. Specifically, we leverage recent results on persistence of excitation using spectral lines to show how a (high probability) lower bound on the resultant persistence of excitation of the exploration data can be established. These results can be used to provide a priori lower bounds on the remaining model uncertainty after exploration. Given this exploration strategy and the corresponding uncertainty bounds, tools from robust control and gain-scheduling can be used to design a robust dual controller.

11:45-12:10 FrAM_S80.4

Discrete-Time Hands-Off Feedback Control with Real-Time Optimization, pp. 1161-1164

Nagahara, Masaaki	The University of Kitakyushu
Quevedo, Daniel	Queensland University of Technology (QUT)
Schulze Darup, Moritz	TU Dortmund University

In this paper, we discuss hands-off feedback control of discrete-time linear time-invariant systems based on receding horizon control. Hands-off control, also known as sparse control, is a control that has a long time duration over which the control action is exactly zero whilst satisfying control objectives. To obtain the maximum hands-off control, the L1-norm optimization is adopted. For a model predictive control formulation, we need to numerically solve the L1 optimization with equality/inequality constraints. Although fast iterative algorithms are known to solve the optimization problem, they will often not be fast enough for control systems that need real-time computation. To obtain the control values in real time, we propose to stop the iteration for the L1 optimization after just one step. We prove that this strategy leads to practical stability of the closed-loop, provided the systems are open-loop stable. Simulation results show the effectiveness of the proposed method.

12:10-12:35 FrAM_S80.5

Explicit Model Predictive Control for PDEs: The Case of a Heat Equation, pp. 1165-1170

Dubljevic, Stevan	Unversity of Alberta
Humaloja, Jukka-Pekka	Tampere University
Kurula, Mikael	Åbo Akademi University

Explicit model predictive control design is carefully developed for discrete-time linear plants on Hilbert spaces, and we highlight the role of the so-called Slater condition in the reliable explicit solution of the MPC optimization. We then proceed to present an explicit MPC algorithm that accounts for the stabilization and input constraints satisfaction. We do structure preserving temporal discretization of the infinite-dimensional parabolic PDE system by application of the Cayley transformation. The salient feature of explicit MPC design is the realization of the region-free approach in explicit MPC design with identification of active constraint sets to realize optimal stabilization and constraints satisfaction. Finally, the resulting design is illustrated by the application to the PDE model given by an unstable heat equation with boundary actuation and Neumann boundary conditions. The example demonstrates simultaneous stabilization and input constraints satisfaction on the one hand, and on the ability to deal with a relatively high plant dimension and a long optimization horizon on the other hand.

FrAM_S82 S 82

Hamilton-Jacobi Equations and Mean Field Games - IV (Hybrid Session) (Invited Session)

Co-Chair: Zidani, Hasnaa	INSA Rouen Normandie
Organizer: Falcone, Maurizio	SAPIENZA - Universita' Di Roma
Organizer: Zidani, Hasnaa	INSA Rouen Normandie

10:30-10:55 FrAM_S82.1

Tropical Numerical Methods for Solving Stochastic Control Problems (I), pp. 1171-1174

Akian, Marianne	INRIA and Ecole Polytechnique
Chancelier, Jean-Philippe	ENPC
Pascal, Luz	Queensland University of Technology
Tran, Benoit	FGV EMAp

We consider Dynamic programming equations associated to discrete time stochastic control problems with continuous state space, which arise in particular from monotone time discretizations of Hamilton-Jacobi-Bellman equations. We develop and study several numerical algorithms for solving such equations, combining tropical numerical methods and stochastic dual dynamic programming methods. We also compare these algorithms with the point based methods for solving Partially Observable Markov Decision Processes (POMDP).

10:55-11:20 FrAM_S82.2

A Semi-Lagrangian Scheme for Hamilton-Jacobi-Bellman Equations with Oblique Derivatives Boundary Conditions (I), pp. 1175-1176

Carlini, Elisabetta	Sapienza Universita' Di Roma
Calzola, Elisa	Università Di Verona
Dupuis, Xavier	University of Bourgogne
Silva Alvarez, Francisco José	Université De Limoges

We investigate in this work a fully-discrete semi-Lagrangian approximation of second order possibly degenerate Hamilton-Jacobi-Bellman (HJB) equations on a bounded domain with oblique derivatives boundary conditions. These equations appear naturally in the study of optimal control of diffusion processes with oblique reflection at the boundary of the domain.

The proposed scheme is shown to satisfy a consistency type property, it is monotone and stable. Our main result is the convergence of the numerical solution towards the unique viscosity solution of the HJB equation. The convergence result holds under the same asymptotic relation between the time and space discretization steps as in the classical setting for semi-Lagrangian schemes on unbounded domains. We present some numerical results, in dimensions one and two, on unstructured meshes, that confirm the numerical convergence of the scheme.

11:20-11:45	FrAM_S82.3

Route Planning and Hybrid Games for Multiple Players (I), pp. 1177-1178

Cacace, Simone	Università Degli Studi Roma Tre
Ferretti, Roberto	Roma Tre University
Festa, Adriano	Politecnico of Turin

We investigate the modelling of sailing races as hybrid stochastic games, either with zero or nonzero sum, where the first case is typical of match races and the second of fleet races. In particular, we provide models of growing complexity and dimension, study the optimal strategies in various racing situations and devise some fast and/or reduced memory implementation.

11:45-12:10	FrAM_S82.4

Separation of Nonlinearity and Stochasticity in Nonlinear Diffusion Control Problems (I), pp. 1179-1182

McEneaney, William	Univ of California, San Diego
Dower, Peter M.	University of Melbourne
Wang, Tao	University of California San Diego

A class of nonlinear, stochastic staticization control problems (including minimization problems with smooth, convex, coercive payoffs) driven by diffusion dynamics with constant diffusion coefficient is considered. The nonlinearities are addressed through staticization-based duality. The second-order Hamilton-Jacobi partial differential equations (HJ PDEs) are converted into associated control problems with higher-dimensional states. In these problems, one component of the state propagates by deterministic, nonlinear dynamics, while the other component is a scaled Brownian motion. These components interact only through a bilinear terminal cost. This structure will be exploited to generate an efficient solution approach.

FrSP_H17	H 17
Semi Plenary: Masaaki Nagahara (Plenary Session)	
Chair: Yamamoto, Yutaka	Kyoto University

14:00-15:00	FrSP_H17.1

Compressed Sensing and Maximum Hands-Off Control, pp. 1183-1190

Nagahara, Masaaki	The University of Kitakyushu

In this paper, we review the basics of compressed sensing and introduce its application to optimal control, called the maximum hands-off control. First, we present the mathematical formulation of compressed sensing and show a heuristic approach to the problem using the l1 norm with efficient numerical algorithms. Then, we introduce the maximum hands-off control, the sparsest control, or the L0 optimal control. We show mathematical properties of the maximum hands-off control, such as the equivalence between the L0 and L1 optimal controls, necessary conditions, and the existence. We also show the time discretization method to numerically compute the maximum hands-off control. Finally, we showcase some extensions of the maximum hands-off control.

FrSP_H18	H 18
Semi Plenary: Boris Houska (Plenary Session)	
Chair: Zidani, Hasnaa	INSA Rouen Normandie

14:00-15:00	FrSP_H18.1

Global Optimal Control: Opportunities and Challenges, pp. 1191-1191

Houska, Boris	ShanghaiTech University

Optimal control theory, algorithms, and software for analyzing and computing local solutions of linear and nonlinear optimal control problems have reached a high level of maturity, finding their way into industry. In the context of many applications, locally optimal control inputs can be computed within the milli- and microsecond range. This is in sharp contrast to the development of algorithms for locating global minimizers of non- convex optimal control problems, which is hindered by several key issues, including the overall complexity of generic optimal control problems and their curse of dimensionality. This talk reviews and discusses recent solutions that address these rather fundamental challenges including novel types of Branch & Lift methods as well as modern Koopman-Pontryagin operator based lifting methods for global optimal control. Various numerical experiments will be used to illustrate the effectiveness of these approaches. The talk concludes with an assessment of the state of the art and highlights important avenues for future research.

FrSP_H19	H 19
Semi Plenary: Dante Kalise (Plenary Session)	
Chair: Gruene, Lars	Univ of Bayreuth

14:00-15:00	FrSP_H19.1

High-Dimensional Approximation of Hamilton-Jacobi-Bellman PDEs in Deterministic Optimal Control: Architectures, Algorithms, and Applications, pp. 1192-1192

Kalise, Dante	Imperial College London

Optimal feedback synthesis for nonlinear dynamics -a fundamental problem in optimal control- is enabled by solving fully nonlinear Hamilton-Jacobi-Bellman type PDEs arising in dynamic programming. While our theoretical understanding of dynamic programming and HJB PDEs has seen a remarkable development over the last decades, the numerical approximation of HJB-based feedback laws has remained largely an open problem due to the curse of dimensionality. More precisely, the associated HJB PDE must be solved over the state space of the dynamics, which is extremely high-dimensional in applications such as distributed parameter systems or agent-based models. In this talk we will review recent approaches regarding the effective numerical approximation of very high-dimensional HJB PDEs. We will explore modern scienti fic computing methods based on tensor decompositions of the value function of the control problem, and the construction of data-driven schemes in supervised and semi-supervised learning environments. We will highlight some novel research directions at the intersection of control theory, scientific computing, and statistical machine learning.

FrPM_H16	H 16
Advances in Algorithmic Trading (Hybrid Session) (Invited Session)	
Chair: Barmish, Bobby	Boston University
Co-Chair: Baumann, Michael Heinrich	Universität Bayreuth
Organizer: Baumann, Michael Heinrich	Universität Bayreuth
Organizer: Barmish, Bobby	Boston University

15:30-15:55	FrPM_H16.1

Continuous Hedging Strategy for Power Market Using Financial Instruments on Electricity Price and Weather (I), pp. 1193-1196

Yamada, Yuji	University of Tsukuba
Matsumoto, Takuji	Kanazawa University

In this study, we develop a quantitative strategy for controlling cash-flow fluctuations of power utilities in electricity trading market using adequate financial instruments. In particular, we focus on hedging of thermal power generations and provide mixed positions of derivatives and forwards in a flexible manner, where we apply nonparametric regression techniques to find optimal payoff structure of derivatives and/or optimal units of forward contracts with fine granularity. An empirical backtest is conducted to illustrate our proposed hedging strategy.

Keywords: Forward contracts, derivatives, thermal power generators, hedging, nonparametric regressions.

15:55-16:20 FrPM_H16.2

On Data-Driven Log-Optimal Portfolio: A Sliding Window Approach (I), pp. 1197-1202

Wang, Pei Ting — National Tsing Hua University
Hsieh, Chung-Han — National Tsing Hua University

In this paper, we propose an online data-driven sliding window approach to solve a log-optimal portfolio problem. In contrast to many of the existing papers, this approach leads to a trading strategy with time-varying portfolio weights rather than fixed constant weights. We show, by conducting various empirical studies, that the approach possesses a superior trading performance to the classical log-optimal portfolio in the sense of having a higher cumulative rate of returns.

16:20-16:45 FrPM_H16.3

Signature-Based Models in Finance: Theory and Calibration (I), pp. 1203-1206

Cuchiero, Christa — University of Vienna
Gazzani, Guido — University of Vienna
Sara, Svaluto-Ferro — University of Verona

Signature methods represent a non-parametric way for extracting characteristic features from time series data which is essential in machine learning tasks. This explains why these techniques become more and more popular in econometrics and mathematical finance. Indeed, signature based approaches allow for data-driven and thus more robust model selection mechanisms, while first principles like no arbitrage can still be easily guaranteed.

Here we focus on financial models whose dynamics are described by linear functions of the (time-extended) signature of a primary underlying process, which can range from a (market-inferred) Brownian motion to a general multidimensional tractable stochastic process. The framework is universal in the sense that any classical model can be approximated arbitrarily well and that the model characteristics can be learned from all sources of available data by simple methods. In view of option pricing and calibration, key quantities that need to be computed in these models are the expected value or Fourier Laplace transform of the signature of the primary underlying process. Surprisingly this can be achieved via techniques from affine and polynomial processes. These formulas can then be used in the calibration procedure to option prices, while calibration to time series data just reduces to a simple regression.

16:45-17:10 FrPM_H16.4

On the Risks of Feedback-Trading (I), pp. 1207-1209

Baumann, Michael Heinrich — Universität Bayreuth

It has been shown in the literature that for certain trading strategies based on control techniques, namely for the so-called simultaneously long short strategies under relatively weak market assumptions in continuous time, the so-called robust positive expectation property holds. This means that for such strategies, if the assumptions are fulfilled, in expectation positive profits can be proven. Of course, arguments such as trading costs or trading constraints can be used when discussing these unexpected results. But there are also risks inherent in the strategies themselves, such as short-selling risks, discretization risks, or momenta. In this talk, we will present these risks and show how they can possibly be controlled.

17:10-17:35 FrPM_H16.5

Future Control Community Papers on Algorithmic Trading Should Pay More Attention to Backtesting (I), pp. 1210-1212

Barmish, Bobby — Boston University

The takeoff point for this work is the emerging body of literature which addresses algorithmic trading in the framework of feedback control systems. In this setting, the buying and selling of equities period is governed by the action of a controller, using past history, to determine the time-varying investment level. Almost all of the papers to date begin with a underlying mathematical model structure for the stock-price dynamics and "theoretical" performance is studied. In many cases, the parameters of the price model are not assumed to be known in advance; they are estimated over time from the realized price path. In the literature, we also see many variations on this theme. For example, the investment-level controller may have no explicit reliance on an assumed price model and instead are updated by performance variables such as account market value or gains and losses over time. Subsequently, the authors of papers along these lines demonstrate the performance of their trading algorithms using various criteria. Given this context, we draw attention to use of the word "should" in the title. This is intentional because this short paper is an opinion piece; it does not contain new results. Instead, arguments are given that the control community will be well served if future papers devote greater attention to backtesting and standardization of benchmark data sets. It is argued that this will enable the results of one researcher to more easily be compared against those of another and increase the impact of control-theoretic papers on researchers and practitioners outside the control field. While it is true that a number of the control-inspired papers to date already include some backtest results, the use of widely varying data sets makes evaluation of worthiness of their "controller recipes" difficult or impossible.

FrPM_H17 H 17

Structure-Preserving Discretization of Dynamical Systems - III (Hybrid Session) (Invited Session)

Chair: Flaßkamp, Kathrin — Saarland University
Co-Chair: Kotyczka, Paul — Technical University of Munich
Organizer: Flaßkamp, Kathrin — Saarland University
Organizer: Kotyczka, Paul — Technical University of Munich
Organizer: Ober-Blöbaum, Sina — Paderborn University

15:30-15:55 FrPM_H17.1

Learning Hamiltonian Systems and Symmetries (I), pp. 1213-1216

Dierkes, Eva — University of Bremen
Offen, Christian — Paderborn University
Ober-Blöbaum, Sina — Paderborn University
Flaßkamp, Kathrin — Saarland University

During the last years, Hamiltonian neural networks (HNN) have been introduced to incorporate prior physical knowledge when learning dynamical systems. Hereby, the symplectic system structure is preserved despite the data-driven modeling approach. However, preserving symmetries requires additional attention. In this research, we enhance the HNN with a Lie algebra framework to detect and embed symmetries in the neural network. This approach allows to simultaneously learn the symmetry group action and the total energy of the system.

15:55-16:20 FrPM_H17.2

Learning and Numerical Integration of Lagrangian Systems (I), pp. 1217-1220

Offen, Christian — Paderborn University
Ober-Blöbaum, Sina — Paderborn University

Hamilton's principle is one of the most fundamental principle in physics. Incorporating the principle into data-driven models of dynamical systems guarantees that motions share important qualitative properties with the real system, such as energy or momentum conservation. To learn Lagrangian dynamics, we propose to learn inverse modified Lagrangians related to variational integrators instead of attempting to learn an exact Lagrangian, as is typically done in the literature. The key advantage is that inverse modified Lagrangians can be learned from snapshots of position

data of observed trajectories directly without approximating velocities or acceleration data. This is beneficial when snapshot times are large. Moreover, when inverse modified Lagrangians are integrated using a variational method, discretisation errors are compensated for. Therefore, large step-sizes can be used while maintaining high accuracy and tiny energy errors.

16:20-16:45	FrPM_H17.3

Dissipativity in Analysis of Neural Networks, pp. 1221-1224

Grönqvist, Johan	Lund University
Rantzer, Anders	Lund Univ

Building on the strong connection between dissipativity theory and Integral Quadratic Constraints, we show how feedback loops involving neural networks can be analysed computationally with respect to both stability and robustness. A basic building block is the ReLU (Rectified Linear Unit) nonlinearity and we present both old and new dissipation inequalities that are useful for its analysis.

16:45-17:10	FrPM_H17.4

Decomposition of Additive LMIs with Applications in Distributed Analysis of Interconnected LTI Systems, pp. 1225-1230

Jokic, Andrej	Faculty of Mechanical Engineering and Naval Architecture, Univer
Nakić, Ivica	University of Zagreb

In this paper we present a simple technique which can be systematically used to obtain non-conservative decomposition for a class of linear matrix inequalities (LMIs) with an additive structure. By non-conservative decomposition we mean a suitable replacement of an additive LMI with a set of equivalent inequalities which are coupled by common variables. The results are applied on several stability/dissipativity analysis problems to produce analysis LMIs suitable for distributed computation.

17:10-17:35	FrPM_H17.5

Hollow Matrices and Stabilization by Noise, pp. 1231-1234

Damm, Tobias	TU Kaiserslautern
Fassbender, Heike	TU Braunschweig

We consider orthogonal transformations of arbitrary square matrices to a form where all diagonal entries are equal. In our main results we treat the simultaneous transformation of two matrices and the symplectic orthogonal transformation of one matrix. A relation to the joint real numerical range is worked out, efficient numerical algorithms are developed and applications to stabilization by rotation and by noise are presented.

FrPM_H18	H 18
Systems Theory and Geometry (Hybrid Session) (Regular Session)	
Chair: Collins, Pieter	Maastricht University

15:30-15:55	FrPM_H18.1

Optimization Flows Landing on the Stiefel Manifold, pp. 1235-1240

Gao, Bin	University of Münster
Vary, Simon	UCLouvain
Ablin, Pierre	CNRS, Université Paris-Dauphine, PSL University
Absil, Pierre-Antoine	Universite Catholique De Louvain

We study a continuous-time system that solves optimization problems over the set of orthonormal matrices, which is also known as the Stiefel manifold. The resulting optimization flow follows a path that is not always on the manifold but asymptotically lands on the manifold. We introduce a generalized Stiefel manifold to which we extend the canonical metric of the Stiefel manifold. We show that the vector field of the proposed flow can be interpreted as the sum of a Riemannian gradient on a generalized Stiefel manifold and a normal vector. Moreover, we prove that the proposed flow globally converges to the set of critical points, and any local minimum and isolated critical point is asymptotically stable.

15:55-16:20	FrPM_H18.2

Hypergraph Based Distributed Quadratic Optimization, pp. 1241-1244

Papastaikoudis, Ioannis	University of Cambridge
Li, Mengmou	University of Cambridge
Lestas, Ioannis	University of Cambridge,

We study a dual decomposition algorithm for a distributed optimization problem with a communication structure corresponding to a hypergraph. We prove that in the case of quadratic objective functions the respective discrete-time dynamical system of a modified dual decomposition algorithm that makes use of the Hessians of the objective functions converges in only one iteration.

16:20-16:45	FrPM_H18.3

Matrix Pontryagin Principle Approach to Controllability Metrics Maximization under Sparsity Constraints, pp. 1245-1248

Ohtsuka, Tomofumi	Kyoto University
Ikeda, Takuya	The University of Kitakyushu
Kashima, Kenji	Kyoto University

Controllability maximization problem under sparsity constraints is a node selection problem that selects inputs that are effective for control in order to minimize the energy to control for desired state. In this paper we discuss the equivalence between the sparsity constrained controllability metrics maximization problems and their convex relaxation. The proof is based on the matrix-valued Pontryagin maximum principle applied to the controllability Lyapunov differential equation.

16:45-17:10	FrPM_H18.4

Polarization of Multi-Agent Gradient Flows Over Hypersurfaces, pp. 1249-1252

Mi, La	University of Luxembourg
Goncalves, Jorge M.	University of Luxembourg
Markdahl, Johan	University of Luxembourg

Multi-agent systems are known to exhibit stable emergent behaviors, including polarization, over R^n or highly symmetric nonlinear spaces. In this article, we eschew linearity and symmetry of the underlying spaces, and study the stability of polarized equilibria of multi-agent gradient flows evolving on general hypermanifolds. The agents attract or repel each other according to the partition of the communication graph that is connected but otherwise arbitrary. The hypersurfaces are outfitted with geometric features styled "dimples" and "pimples" that characterize the absence of flatness. The signs of inter-agent couplings together with these geometric features give rise to stable polarization under various sufficient conditions.

17:10-17:35	FrPM_H18.5

Reduced Control Systems on Symmetric Lie Algebras, pp. 1253-1256

Malvetti, Emanuel	Technical University Munich
Dirr, Gunther	University of Wurzburg
vom Ende, Frederik	Technichal University Munich (TUM)
Schulte-Herbrueggen, Thomas	Technichal Univ Munich (TUM)

For a symmetric Lie algebra **g=k⊕p** we consider a class of bilinear or more general control-affine systems on **p** defined by a drift vector field **X** and control vector fields **adk_i** which gain fast and full control on the adjoint orbits of the corresponding compact group **K**. We show that under quite general assumptions on **X** such a control system is essentially equivalent to a natural reduced system on a maximal Abelian subspace **a⊆p**, and likewise to related differential inclusions defined on **a**.

17:35-18:00	FrPM_H18.6

Monadic Systems, pp. 1257-1262

Collins, Pieter — Maastricht University

In this paper we develop the use of monads, a concept popularised in the functional language Haskell, to provide a general framework for studying control systems with uncertainty. We first develop the theory of monads, notably dependent products and conditioning. We then provide three main applications, namely computing the input-output behaviour, designing observers, and studying compositionality for uncertain systems.

FrPM_H19	H 19
Data-Driven Sensing, Modeling, and Control (Hybrid Session) (Invited Session)	
Chair: Peitz, Sebastian	Paderborn University
Co-Chair: Manohar, Krithika	University of Washington
Organizer: Peitz, Sebastian	Paderborn University
Organizer: Manohar, Krithika	University of Washington

15:30-15:55 — FrPM_H19.1

Spectral Identification of Networks with Generalized Diffusive Coupling (I), pp. 1263-1268

Gulina, Marvyn — University of Namur

Mauroy, Alexandre — University of Namur

Spectral network identification aims at inferring the eigenvalues of the Laplacian matrix of a network from measurement data. This allows to capture global information on the network structure from local measurements at a few number of nodes. In this paper, we consider the spectral network identification problem in the generalized setting of a vector-valued diffusive coupling. The feasibility of this problem is investigated and theoretical results on the properties of the associated generalized eigenvalue problem are obtained. Finally, we propose a numerical method to solve the generalized network identification problem, which relies on dynamic mode decomposition and leverages the above theoretical results.

15:55-16:20 — FrPM_H19.2

Data-Driven Approximation of the Koopman Generator on Rich Approximation Spaces (I), pp. 1269-1269

Nüske, Feliks — Max Planck Institute for Dynamics of Complex Technical Systems

In the context of Koopman operator based analysis of dynamical systems, the generator of the Koopman semigroup is of central importance. Models for the Koopman generator can be used, among others, for system identification, coarse graining, and control of the system at hand.

A critical modeling choice is the subspace or dictionary used for Koopman estimation. In this talk, I will present recent advances allowing for the approximation of the generator on reproducing kernel Hilbert spaces (RKHS), and on tensor-structured subspaces by means of low-rank representations. Both approaches allow modelers to employ high-dimensional, or even infinite-dimensional approximation spaces, while controlling the computational effort at the same time. In both cases, I will discuss the algorithmic realization and computational complexity in detail. I will also discuss recent results on estimating the finite-data estimation error for Koopman generator models.

16:20-16:45 — FrPM_H19.3

A Note on Efficient and Reliable Prediction-Based Control in the Koopman Framework (I), pp. 1270-1273

Schaller, Manuel — Technische Universität Ilmenau

Worthmann, Karl — TU Ilmenau

Philipp, Friedrich — Technische Universität Ilmenau

Peitz, Sebastian — Paderborn University

Nüske, Feliks — Max Planck Institute for Dynamics of Complex Technical Systems

Extended Dynamic Mode Decomposition, embedded in the Koopman framework, is a widely-applied technique to predict the evolution of an observable along the flow of a dynamical (control) system. However, despite its popularity, the error analysis for control systems is still fragmentary. Here, we provide a complete and rigorous analysis of the approximation error for control systems. To this end, the approximation error is split up according to its two sources of error: the finite dictionary size (projection) and the finite amount of i.i.d. data used to generate the surrogate model (estimation). Then, invoking—among others—finite-elements techniques and the Chebyshev inequality, probabilistic error bounds are derived. Finally, we demonstrate the applicability of the novel error bounds in optimal control with state and control constraints.

16:45-17:10 — FrPM_H19.4

Convex Approach to Data-Driven Stochastic Optimal Control Using Linear Operator Theory (I), pp. 1274-1274

Vaidya, Umesh — Clemson University

We provide a data-driven framework for optimal control of a continuous-time stochastic dynamical system. The proposed framework relies on the linear operator theory involving linear Perron-Frobenius (P-F) and Koopman operators. Our first results involving the P-F operator provide a convex formulation to the optimal control problem in the dual space of densities. This convex formulation of the stochastic optimal control problem leads to an infinite-dimensional convex program. The finite-dimensional approximation of the convex program is obtained using a data-driven approximation of the P-F operator. Our second results demonstrate the use of the Koopman operator, which is dual to the P-F operator, for the stochastic optimal control design. We show that the Hamilton Jacobi Bellman (HJB) equation can be expressed using the Koopman operator. We provide an iterative procedure along the lines of a popular policy iteration algorithm based on the data-driven approximation of the Koopman operator for solving the HJB equation. The two formulations, namely the convex formulation involving P-F operator and Koopman based formulation using HJB equation, can be viewed as dual to each other where the duality follows due to the dual nature of P-F and Koopman operators.

17:10-17:35 — FrPM_H19.5

A Fuzzy Derivative Model Approach to Time Series Prediction, pp. 1275-1280

Salgado, Paulo — Utad & Citab

Azevedo Perdicoúlis, T-P — UTAD & ISR-Coimbra

This paper presents a fuzzy systems approach to the prediction of nonlinear time series and dynamical systems, based on a fuzzy model. The underlying mechanism governing a time series is perceived by a modified structure of the fuzzy system in order to capture the time series as well as the information about its successive time derivatives. The prediction task is carried out by a fuzzy predictor based on the extracted rules and by the Taylor ODE solver method. The approach has been applied to a benchmark problem: the Mackey- Glass chaotic time series. Furthermore, comparative studies with other fuzzy and neural network predictors were made and these suggest equal or even better performance of the herein presented approach.

FrPM_H20	H 20
Operator-Theoretic Methods and Linear Systems Theory (Invited Session)	
Chair: Ball, Joseph	Virginia Tech
Co-Chair: Vinnikov, Victor	Ben Gurion University of the Negev
Organizer: Ball, Joseph	Virginia Tech
Organizer: Vinnikov, Victor	Ben Gurion University of the Negev

15:30-15:55 — FrPM_H20.1

Controllability and Observability of Poset-Causal Systems (I), pp. 1281-1284

ter Horst, Sanne — North West University

Jakkie, Jacobus — North-West University

Concepts of controllability and observability have been de fined for a class of decentralized systems known as coordinated linear systems. The classical duality result does not extend to these systems. In the present paper, we generalize these notions of controllability and observability to poset-causal systems. We introduce the dual system associated with a poset-causal system and extend the classical duality result using this notion of a dual system.

15:55-16:20 — FrPM_H20.2

A Hankel Realization for Discrete-Time Overdetermined Systems (I), pp. 1285-1287

Ball, Joseph — Virginia Tech

Vinnikov, Victor — Ben Gurion University of the Negev

We consider overdetermined multidimensional discrete-time systems where the evolution of the whole state vector is given by several update equations in several linearly independent directions. Such systems are overdetermined and we assume that they come equipped with compatibility difference equations for the input and output signals. As a consequence of these compatibility equations frequency domain analysis leads to function theory on a certain algebraic curve rather than to function theory in several complex variables. More precisely, the transfer function of the system is (under certain assumptions) a meromorphic bundle map on a compact Riemann surface.

In this talk we will discuss the corresponding realization problem and provide a solution which is the higher genus analogue of the classical Hankel realization.

16:20-16:45 — FrPM_H20.3

Realization Formulas for Involutions of Matrix-Valued Positive Real Odd Functions (I), pp. 1288-1291

van der Merwe, Alma — University of the Witwatersrand

ter Horst, Sanne — North West University

In a seminal paper Foster showed that the impedances of lumped electrical circuits generated by inductances and capacitors are positive real odd functions (PRO for short). For multi-port electrical systems built from inductances and capacitors one obtains matrix-valued PRO functions, denoted PRO_m in the case of m by m matrix functions. Like PRO, the class of matrix functions PRO_m is also a convex invertible cone, i.e., a convex cone closed under inversion (in the form of involution). Given a minimal, Weierstrass descriptor realization for a function in PRO_m, we explicitly compute a minimal, Weierstrass descriptor realization for its involution, and through these formulas one can analyse the zero-pole structure of the function.

16:45-17:10 — FrPM_H20.4

Realizations of Passive Systems Are Inter-Related (I), pp. 1292-1293

Lewkowicz, Izchak — Ben-Gurion University

There are four families of passive linear systems, described by: Positive Real, Bounded real, Discrete-time Positive real and Discrete-time Bounded real functions. We show that by using Quadratic Matrix Inequalities, starting with the state-space realization of one of the four families, the other three may be obtained through prescribed Linear Fractional Transformations.

17:10-17:35 — FrPM_H20.5

The Twofold Ellis-Gohberg Inverse Problem for Rational Matrix Functions (I), pp. 1294-1296

ter Horst, Sanne — North West University

Kaashoek, Marinus — Department of Mathematics, Vrije Universiteit, Amsterdam

Van Schagen, Frederik — Vrije Universiteit Amsterdam

In recent years various papers appeared that concentrate on inverse problems associated with work of Ellis and Gohberg on orthogonal matrix Wiener functions. Here we study such an inverse problem restricting to rational matrix functions on the real line. The functions used in stating the problem are assumed to be given by minimal state space realizations, and the necessary and sufficient solution criterion as well as the formulas for the solution presented here are described in terms of the matrices of the state space realizations along with solutions to certain Lyapunov equations associated with the data.

FrPM_S70 — S 70

Networked Control Systems - III (Regular Session)

Chair: Rolf, Hermann Folke Johann — Kiel University

Co-Chair: Jeeninga, Mark — Politecnico Di Torino

15:30-15:55 — FrPM_S70.1

Aggregating Distributed Energy Resources for Grid Flexibility Services: A Distributed Game Theoretic Approach, pp. 1297-1300

Chen, Xiupeng — University of Groningen

Scherpen, Jacquelien M.A. — University of Groningen

Monshizadeh, Nima — Universiy of Groningen

We propose a novel fully decentralized energy management scheme for aggregating distributed energy resources for grid flexibility services in wholesale electricity market. We model this problem as a multi-leader-multi-follower noncooperative game. Then a fully distributed algorithm in discrete-time is proposed to solve the problem and find the Nash Equilibrium(NE). In this algorithm, each aggregator only needs to exchange its estimate of the aggregate and an auxiliary variable with its neighbours. This scheme shows the scalability and efficiency in aggregating flexibility services from a large number of prosumers.

15:55-16:20 — FrPM_S70.2

On Evolutionary Population Games on Community Networks with Dynamic Densities, pp. 1301-1304

Govaert, Alain — Lund University

Zino, Lorenzo — University of Groningen

Tegling, Emma — Lund University

We deal with evolutionary game-theoretic learning processes for population games on networks with dynamically evolving communities. Specifically, we propose a novel framework in which a deterministic, continuous-time replicator equation on a community network is coupled with a closed migration process between the communities, in turn governed by an environmental feedback mechanism resulting in co-evolutionary dynamics. Through a rigorous analysis of the system of differential equations obtained, we characterize the equilibria of the coupled dynamical system. Moreover, for a class of population games ---matrix games--- a Lyapunov argument is used to establish an evolutionary folk theorem that guarantees convergence to the evolutionary stable states of the game. Numerical simulations are provided to illustrate and corroborate our theoretical findings.

16:20-16:45 — FrPM_S70.3

Nash Equilibria of the Pay-As-Bid Auction with K-Lipschitz Supply Functions, pp. 1305-1308

Vanelli, Martina — Politecnico Di Torino

Como, Giacomo — Politecnico Di Torino

Fagnani, Fabio — Politecnico Di Torino

We model a system made of n asymmetric firms participating in a market in which each firm chooses as its strategy a supply function relating its quantity to its price. Such strategy (Supply function equilibrium) is a generalization of models where firms can either set a fixed quantity (Cournot model) or set a fixed price (Bertrand model). Our goal is to study the payas-bid auction in this setting. Under the assumption of K-Lipschitz supply functions, we were capable of determining existence and characterization of Nash equilibria of the game.

16:45-17:10 — FrPM_S70.4

Game-Theoretic Control of Markov Chains: Two Applications, pp. 1309-1312

Li, Yuke — Peking University
Luo, Yun — Westlake University
Yu, Changbin (Brad) — Australian National University

This extended abstract presents two network games applied to problems in the context of security -- robotic surveillance and agents' mutual influences on communication networks. The analysis depends on a method we termed as ``control of Markov chains.'' In these two games, agents' strategy can be regarded as designing a Markov chain. And we study the existence and properties of pure strategy Nash equilibria in different scenarios. The main advantage of the games is that the payoff functions for the agents will be properties derived from a Markov chain itself, such as the stationary distribution. Lastly, we discuss the possibilities of extending the analysis.

17:10-17:35 FrPM_S70.5

Braess' Paradox for Power Flow Feasibility in DC Power Grids with Constant-Power Loads, pp. 1313-1316

Jeeninga, Mark — Politecnico Di Torino

This paper studies the power flow feasibility of DC power grids with constant-power loads. We introduce and motivate the concept of Braess' paradox for power flow feasibility, and show that this phenomenon can occur in most practical power grids with at least two source nodes.

17:35-18:00 FrPM_S70.6

Bifurcation Analysis of Coupled Andronov-Hopf Oscillators: A Geometric Approach, pp. 1317-1322

Rolf, Hermann Folke Johann — Kiel University
Meurer, Thomas — Kiel University

The bifurcation behaviors of coupled Andronov-Hopf oscillators is analyzed. For this, an analytic solution of the bifurcation point of two linear, static coupled Andronov-Hopf oscillators is provided. This solution is rearranged so that the bifurcation can be interpreted geometrically by maximizing the area of an triangle defined by the system parameters. This geometric interpretation serves as the basis to address a network of linear, static coupled Andronov-Hopf oscillators, where a rather simple solution for the bifurcation point can be determined depending on a simple tree topology. With this, implications about the synchronization of this class of networks can be deduced.

FrPM_S80 S 80

Estimation and Filtering (Regular Session)

Chair: Yamamoto, Yutaka — Kyoto University
Co-Chair: Tanwani, Aneel — LAAS -- CNRS, Université De Toulouse

15:30-15:55 FrPM_S80.1

On Error Analysis of a Closed-Loop Subspace Model Identification Method, pp. 1323-1326

Oku, Hiroshi — Osaka Institute of Technology
Ikeda, Kenji — Tokushima University

This article is a resubmission of the full paper that was accepted for the presentation at the MTNS 2020. This article reports error analysis and asymptotic variance of a closed-loop subspace model identification method for a system described with the output-error state-space representation. For details, since the procedure of the identification method includes the QR factorization of stacked data Hankel matrices, this study investigates asymptotic properties of block entries of the triangular matrix obtained from the QR factorization. The set of the block entries is separated into two components, namely, the signal-based component and the noise-based component. The contributions are to derive asymptotic properties of both components and to obtain the asymptotic covariance matrix of the vectorization of the noise-based component.

15:55-16:20 FrPM_S80.2

Sparse System Identification with Kernel Regularization, pp. 1327-1329

Nagahara, Masaaki — The University of Kitakyushu
Fujimoto, Yusuke — The University of Kitakyushu
Yamamoto, Yutaka — Kyoto University

In this article, we propose a novel system identification method for stable and sparse linear time-invariant systems. We adopt kernel-based regularization to take a priori information, such as the decay rate, of the target system into account. For promoting sparsity, we introduce the minimax concave penalty function, which is known to promote sparser results than the standard L1 penalty. The estimation problem is shown to be reduced to a convex optimization problem, which can be efficiently solved by the forward-backward algorithm. We show a numerical example of delayed FIR (finite impulse response) system identification to illustrate the effectiveness of the proposed method.

16:20-16:45 FrPM_S80.3

Reinforced Likelihood Box Particle Filter, pp. 1330-1333

Lu, Quoc Hung — LAAS-CNRS
Fergani, Soheib — LAAS-CNRS
Jauberthie, Carine — LAAS-CNRS

This paper is concerned with the development of a general scheme for box particle filtering, in which the likelihood computation is shown to be the most crucial step for the estimation strategy. An overview on Box Particle Filters and discussions about from assumptions used in the literature to the filters performance evaluation approach are in the scope of the paper. From this, we aim to produce a filter taking advantages from strong aspects of various existing box particle filters. A class of nonlinear L^2 functions is concerned. Also, a comparative study via an illustration example to highlight the efficiency of the proposed method is investigated.

16:45-17:10 FrPM_S80.4

A Deterministic Least Squares Approach for Simultaneous Input and State Estimation, pp. 1334-1337

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

This paper considers a deterministic estimation problem to find the input and state of a linear dynamical system which minimise a weighted integral squared error between the resulting output and the measured output. A completion of squares approach is used to find the unique optimum in terms of the solution of a Riccati differential equation. The optimal estimate is obtained from a two-stage procedure that is reminiscent of the Kalman filter. The first stage is an end-of-interval estimator for the finite horizon which may be solved in real time as the horizon length increases. The second stage computes the unique optimum over a fixed horizon by a backwards integration over the horizon. A related tracking problem is solved in an analogous manner. Making use of the solution to both the estimation and tracking problems a constrained estimation problem is solved which shows that the Riccati equation solution has a least squares interpretation that is analogous to the meaning of the covariance matrix in stochastic filtering. The paper shows that the estimation and tracking problems considered here include the Kalman filter and the linear quadratic regulator as special cases.

17:10-17:35 FrPM_S80.5

Error Bounds for Locally Optimal Distributed Filters Over Random Graphs, pp. 1338-1341

Tanwani, Aneel — LAAS -- CNRS, Université De Toulouse

In this extended abstract, we consider the problem of analyzing the performance of distributed filters for continuous-time linear stochastic systems under certain information constraints. We associate an undirected and connected graph with the measurements of the system, where the nodes have access to partial measurements in continuous time. Each node executes a locally optimally filter based on the available measurements. In addition, a node communicates its estimate to a neighbor at some

randomly drawn discrete time instants, and these activation times of the graph edges are governed by independent Poisson counters. When a node gets some information from its neighbor, it resets its state using a convex combination of the available information. Consequently, each node implements a filtering algorithm in the form of a stochastic hybrid system. We derive bounds on expected value of error covariance for each node, and show that they converge to a common value for each node if the mean sampling rates for communication between nodes are large enough.

17:35-18:00	FrPM_S80.6

Robust Luenberger Filters for Stochastic State-Multiplicative Systems, pp. 1342-1344

Gershon, Eli	Holon Institute of Technology

Linear, continuous-time systems with state-multiplicative noise are considered. The problem of H_infty Luenberger filtering for either deterministic norm-bounded or polytopic-type uncertain systems are solved via a simple LMI(s) condition. An illustrative example is given that demonstrates the tractability of our solution method in the robust uncertain case.

FrPM_S82 S 82

Hamilton-Jacobi Equations and Mean Field Games - V (Hybrid Session) (Invited Session)

Chair: Zidani, Hasnaa	INSA Rouen Normandie
Co-Chair: Falcone, Maurizio	SAPIENZA - Universita' Di Roma
Organizer: Falcone, Maurizio	SAPIENZA - Universita' Di Roma
Organizer: Zidani, Hasnaa	INSA Rouen Normandie

15:30-15:55	FrPM_S82.1

Neural Networks Approximations for State Constrained Deterministic Control (I), pp. 1345-1346

Bokanowski, Olivier	Université Paris-Diderot (Paris 7)
Warin, Xavier	EDF R&D, Paris
Prost, Averil	INSA of Rouen

We propose new neural networks algorithms for the approximation of deterministic optimal control problems with maximum running cost. This problem is motivated by the approximation of general optimal control problems in the presence of state constraints. This problem is also related to Hamilton-Jacobi-Bellman equations with an obstacle term. Difficulties arise in particular because of the non-smoothness of the value to be approximated, and appropriate solutions are studied to deal with this specific issue. Numerical examples are given on front propagation problems in the presence of an obstacle, for average dimensions $2leq dleq 8$.

15:55-16:20	FrPM_S82.2

Efficient Algorithms for Certain High-Dimensional Optimal Control Problems Based on Novel Hopf-Type and Lax-Oleinik-Type Representation Formulas (I), pp. 1347-1350

Jerome Darbon, Jerome	Brown University
Chen, Paula	Brown University
Meng, Tingwei	Brown University

Solving high-dimensional optimal control problems and their corresponding Hamilton-Jacobi partial differential equations is an important but challenging problem. In particular, handling optimal control problems with state-dependent running costs or constraints on the control presents an additional challenge. We present two representation formulas: one is a Hopf-type representation formula for solving a class of optimal control problems with certain non-smooth state-dependent running costs, and the other is a Lax-Oleinik-type representation formula for solving a class of optimal control problems with certain control constraints. Based on these formulas, we propose efficient algorithms that overcome the curse of dimensionality. As such, our proposed methods have the potential to serve as a building block for solving more complicated high-dimensional optimal control problems in real-time.

16:20-16:45	FrPM_S82.3

Risk Averse Optimization with Tensor Decompositions (I), pp. 1351-1353

Dolgov, Sergey	University of Bath

We develop a new algorithm named TTRISK to solve high-dimensional risk-averse optimization problems governed by differential equations (ODEs and/or PDEs) under uncertainty. As an example, we focus on the so-called Conditional Value at Risk (CVaR), but the approach is equally applicable to other coherent risk measures. Both the full and reduced space formulations are considered. The algorithm is based on low rank tensor approximations of random fields discretized using stochastic collocation. To avoid non-smoothness of the objective function underpinning the CVaR, we propose an adaptive strategy to select the width parameter of the smoothed CVaR to balance the smoothing and tensor approximation errors. Moreover, unbiased Monte Carlo CVaR estimate can be computed by using the smoothed CVaR as a control variate. To accelerate the computations, we introduce an efficient preconditioner for the KKT system in the full space formulation.The numerical experiments demonstrate that the proposed method enables accurate CVaR optimization constrained by large-scale discretized systems. In particular, the first example consists of an elliptic PDE with random coefficients as constraints. The second example is motivated by a realistic application to devise a lockdown plan for United Kingdom under COVID-19. The results indicate that the risk-averse framework is feasible with the tensor approximations under tens of random variables.

This is an extended abstract for a talk based on https://arxiv.org/abs/2111.05180

16:45-17:10	FrPM_S82.4

Optimizing Semilinear Representations for State-Dependent Riccati Equation-Based Feedback Control (I), pp. 1354-1359

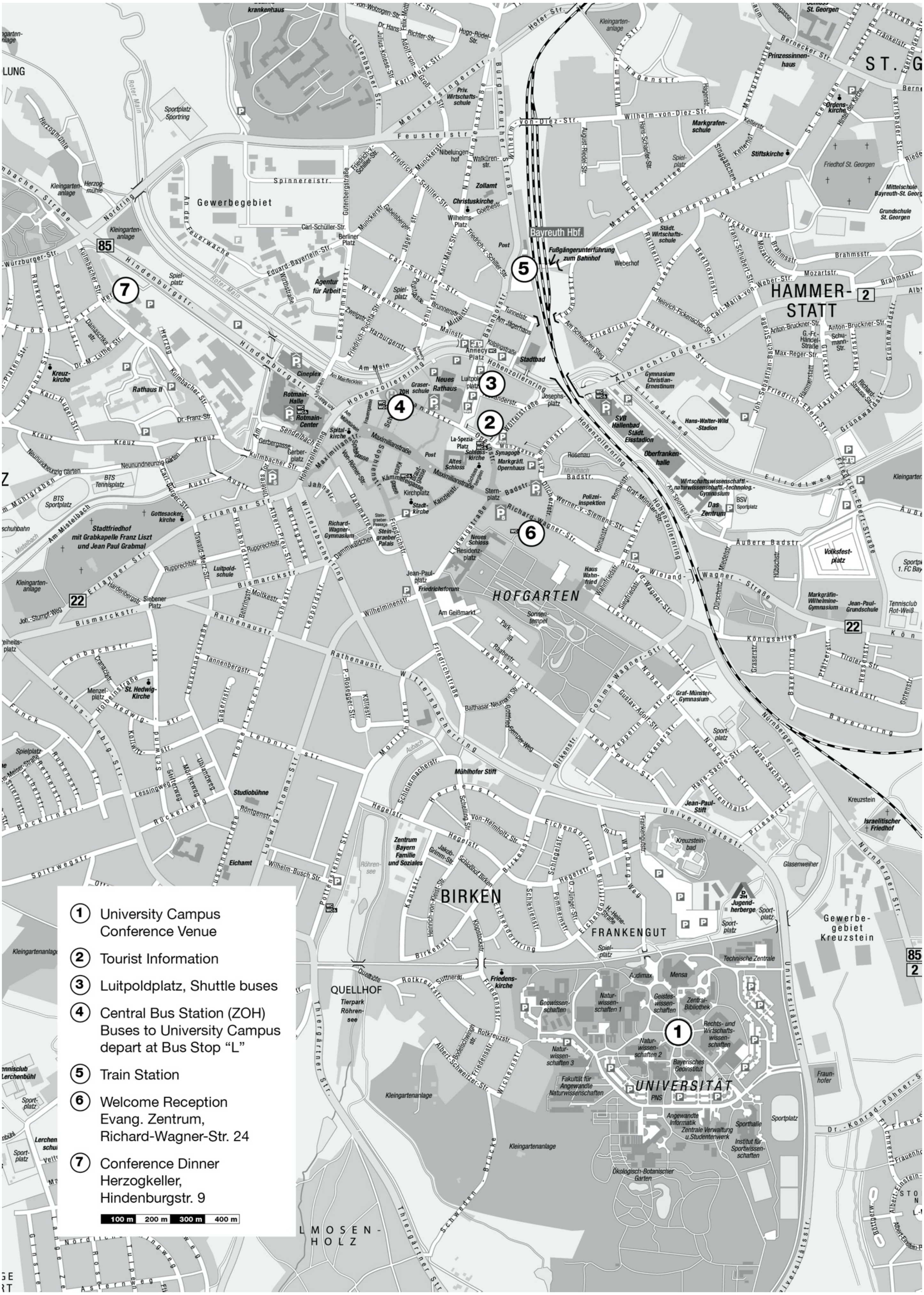
Dolgov, Sergey	University of Bath
Kalise, Dante	Imperial College London
Saluzzi, Luca	Imperial College London

An optimized variant of the State Dependent Riccati Equations (SDREs) approach for nonlinear optimal feedback stabilization is presented. The proposed method is based on the construction of equivalent semilinear representations associated to the dynamics and their affine combination. The optimal combination is chosen to minimize the discrepancy between the SDRE control and the optimal feedback law stemming from the solution of the corresponding Hamilton Jacobi Bellman (HJB) equation. Numerical experiments assess effectiveness of the method in terms of stability of the closed-loop with near-to-optimal performance.

Technical Programme

Author Index

MTNS 2022 Author Index


1 University Campus Conference Venue
2 Tourist Information
3 Luitpoldplatz, Shuttle buses
4 Central Bus Station (ZOH) Buses to University Campus depart at Bus Stop "L"
5 Train Station
6 Welcome Reception Evang. Zentrum, Richard-Wagner-Str. 24
7 Conference Dinner Herzogkeller, Hindenburgstr. 9
100 m
200 m
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BIRKEN
FRANKENGUT
QUELLHOF
UNIVERSITÄT
Bayreuth Hbf.
Gewerbegebiet


Plenary Talks
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Mensa
Lunch
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(all bus lines)
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GW II
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RW II
BGI
MTNS 2022 Main Building
(semi plenaries, parallel sessions, coffee breaks)
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NW III
FAN-A
FAN-B
FAN-C
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(pick up location for taxis)
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BZKG
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Limnolog. Station
B-Geb.
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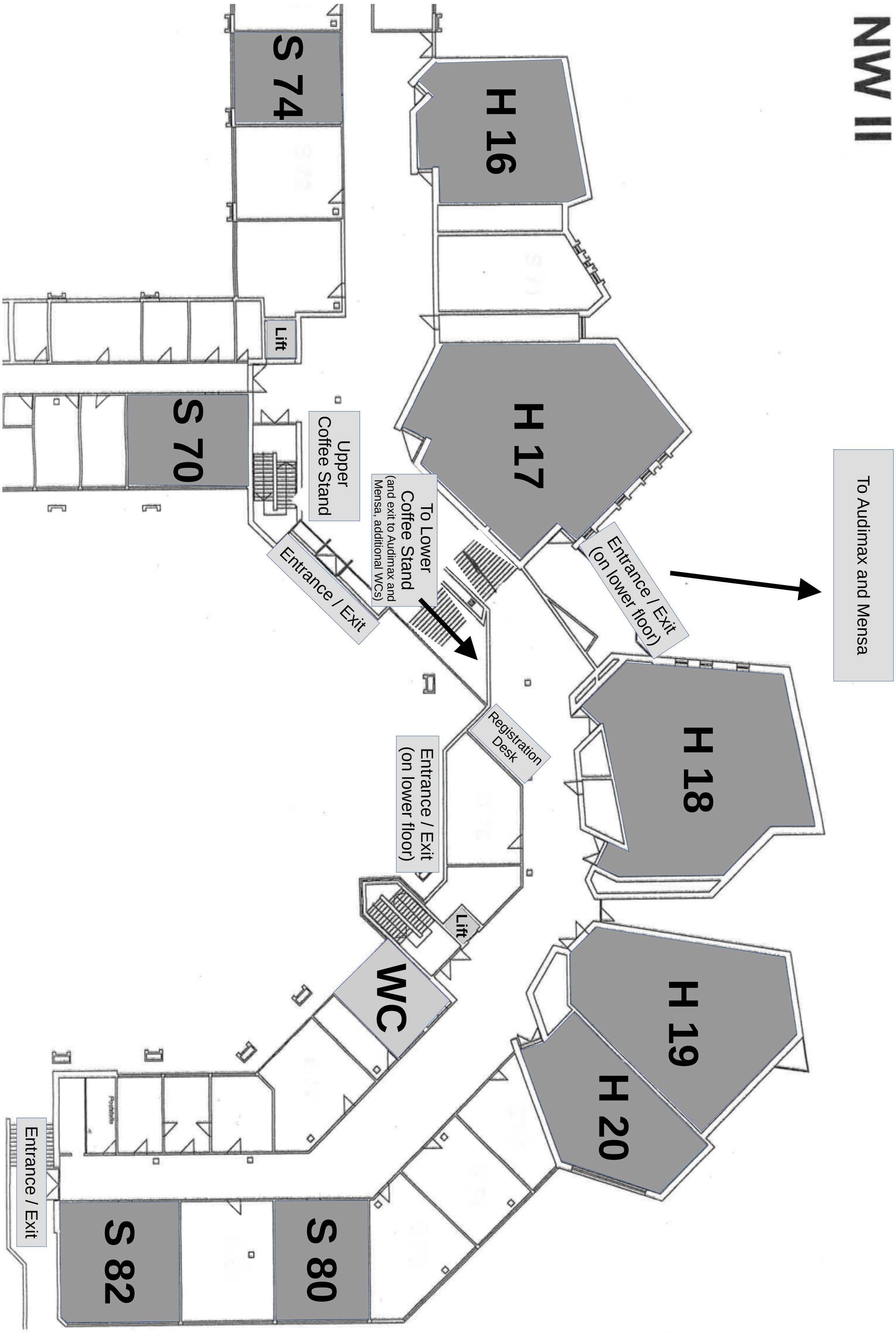
Geowissenschaften
Uni-Verwaltung
Screen
Universitätsstraße
Universitätsstraße 30


NW II
S 74
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Lift
S 70
Upper Coffee Stand
H 17
To Lower Coffee Stand (and exit to Audimax and Mensa, additional WCs)
Entrance / Exit
Entrance / Exit (on lower floor)
To Audimax and Mensa
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Entrance / Exit (on lower floor)
Lift
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