MOPTA 2019

Modeling and Optimization: Theory and Applications

14-16 August '19

http://coral.ie.lehigh.edu/~mopta

Lehigh University

Bethlehem, PA, USA

Program and Abstracts

■ A very warm welcome to MOPTA 2019

Since the year 2000 the Modeling and Optimization: Theory and Applications (MOPTA) conference is an annual event aiming to bring together a diverse group of people from both discrete and continuous optimization, working on both theoretical and applied aspects. The format consists of invited talks from distinguished speakers and selected contributed talks, spread over three days. The conference also features the AIMMS-MOPTA Modeling Competition in which teams of students from all over the world compete to develop innovative solutions for a given real-world problem.

This year, as always, an exceptional group of plenary speakers set the standards of the conference. Our speakers are coming from leading institutions, such as NASA, IBM, and the Konrad Zuse Center in Berlin. Topics range from fundamentals of optimization theory, through applications in energy, health and social sciences, to the latest developments in Quantum Computing optimization. MOPTA 2019 includes a variety of exciting new developments from different optimization areas and special focus streams on optimization in energy, optimization in health, in machine learning, and engineering optimization. These areas bridge continuous, discrete and stochastic optimization.

The conference brings together researchers from both theoretical and applied communities who do not usually have the chance to interact in the framework of a medium-scale event. The conference schedule and the Rausch Business School location are aimed to enhance interaction among the participants during breaks, catered lunches, a cocktail reception and the conference banquet.

■ Directions

Conference Location

The **conference** will take place at:
Lehigh University
RAUCH BUSINESS CENTER
621 TAYLOR STREET
BETHLEHEM, PA 18015 USA

Conference Dinner Location

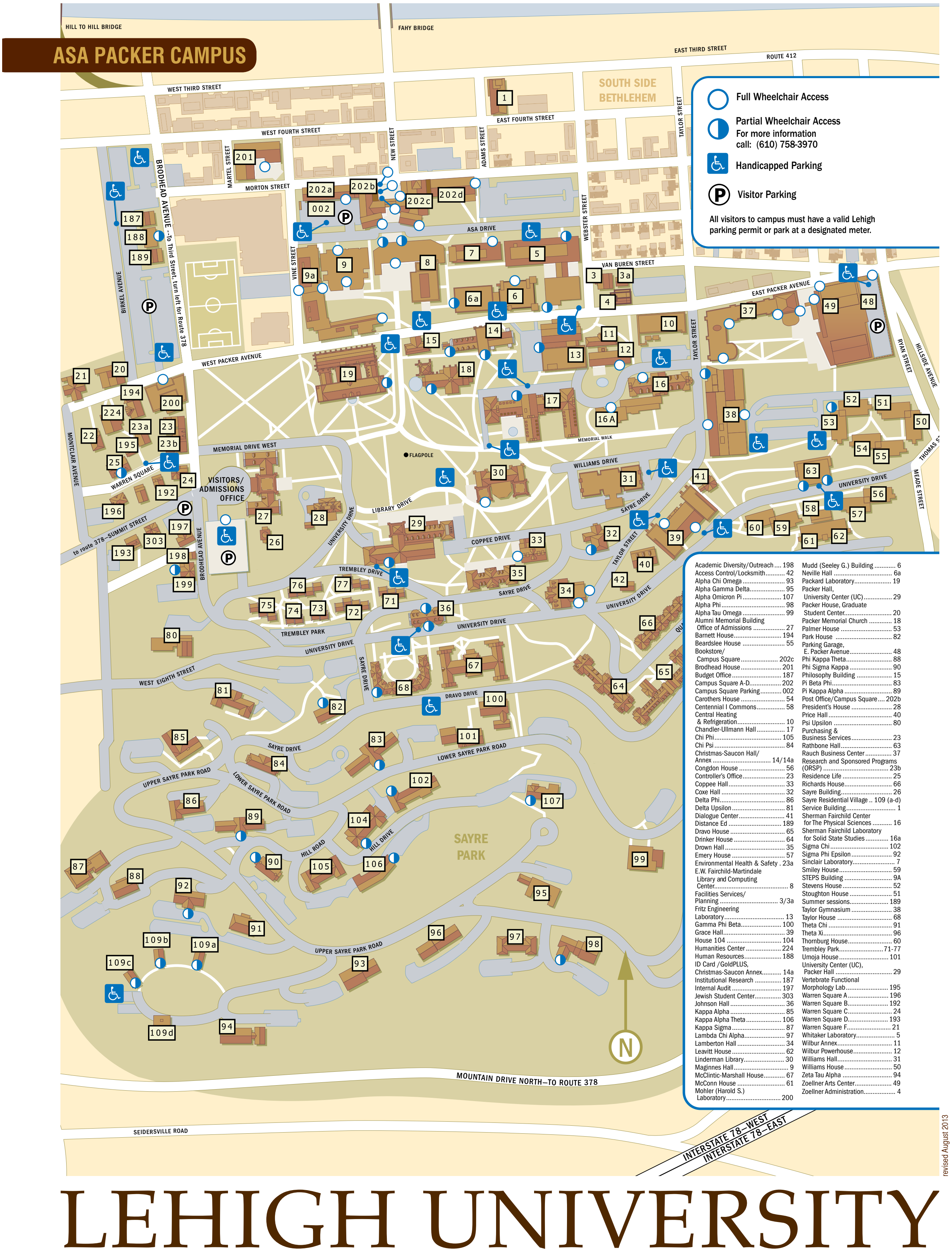
The **Cocktail Reception** is in the
University Center Grace Dining Room, 2nd Floor
29 Trembley Drive, Bethlehem, PA 18015

The **Banquet** is in the
University Center Faculty Lounge
ASA Packer Dining Room, 3rd Floor
29 Trembley Drive, Bethlehem, PA 18015

Graduate Student Social Location

Graduate students attending the Graduate Student Social – Please know that Packer House (see ASA Packer Campus map - Building 20 or Packer House, 217 W Packer Ave, Bethlehem, PA 18015) , where the social is located, is within walking distance of Comfort Suites.
If you need to leave during the conference, please see the registration desk for information about taxis and car services.

■ Maps


ASA PACKER CAMPUS
HILL TO HILL BRIDGE
FAHY BRIDGE
EAST THIRD STREET
ROUTE 412
WEST THIRD STREET
SOUTH SIDE BETHLEHEM
EAST FOURTH STREET
WEST FOURTH STREET
MORTON STREET
ASA DRIVE
VAN BUREN STREET
EAST PACKER AVENUE
WEST PACKER AVENUE
BRODHEAD AVENUE —To Third Street, turn left for Route 378
BIRKEL AVENUE
MONTCLAIR AVENUE
WARREN SQUARE
to route 378—SUMMIT STREET
VISITORS/ ADMISSIONS OFFICE
MEMORIAL DRIVE WEST
FLAGPOLE
MEMORIAL WALK
WILLIAMS DRIVE
LIBRARY DRIVE
COPPEE DRIVE
TREMBLEY DRIVE
TREMBLEY PARK
UNIVERSITY DRIVE
SAYRE DRIVE
WEST EIGHTH STREET
DRAVO DRIVE
LOWER SAYRE PARK ROAD
UPPER SAYRE PARK ROAD
HILL ROAD
HILL DRIVE
SAYRE PARK
MOUNTAIN DRIVE NORTH—TO ROUTE 378
SEIDERSVILLE ROAD
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Handicapped Parking
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All visitors to campus must have a valid Lehigh parking permit or park at a designated meter.
Academic Diversity/Outreach 198
Access Control/Locksmith 42
Alpha Chi Omega 93
Alpha Gamma Delta 95
Alpha Omicron Pi 107
Alpha Phi 98
Alpha Tau Omega 99
Alumni Memorial Building
Office of Admissions 27
Barnett House 194
Beardslee House 55
Bookstore/
Campus Square 202c
Brodhead House 201
Budget Office 187
Campus Square A-D 202
Campus Square Parking 002
Carothers House 54
Centennial I Commons 58
Central Heating
& Refrigeration 10
Chandler-Ullmann Hall 17
Chi Phi 105
Chi Psi 84
Christmas-Saucon Hall/
Annex 14/14a
Congdon House 56
Controller's Office 23
Coppee Hall 33
Coxe Hall 32
Delta Phi 86
Delta Upsilon 81
Dialogue Center 41
Distance Ed 189
Dravo House 65
Drinker House 64
Drown Hall 35
Emery House 57
Environmental Health & Safety . 23a
E.W. Fairchild-Martindale
Library and Computing
Center 8
Facilities Services/
Planning 3/3a
Fritz Engineering
Laboratory 13
Gamma Phi Beta 100
Grace Hall 39
House 104 104
Humanities Center 224
Human Resources 188
ID Card /GoldPLUS,
Christmas-Saucon Annex 14a
Institutional Research 187
Internal Audit 197
Jewish Student Center 303
Johnson Hall 36
Kappa Alpha 85
Kappa Alpha Theta 106
Kappa Sigma 87
Lambda Chi Alpha 97
Lamberton Hall 34
Leavitt House 62
Linderman Library 30
Maginnes Hall 9
McClintic-Marshall House 67
McConn House 61
Mohler (Harold S.)
Laboratory 200
Mudd (Seeley G.) Building 6
Neville Hall 6a
Packard Laboratory 19
Packer Hall,
University Center (UC) 29
Packer House, Graduate
Student Center 20
Packer Memorial Church 18
Palmer House 53
Park House 82
Parking Garage,
E. Packer Avenue 48
Phi Kappa Theta 88
Phi Sigma Kappa 90
Philosophy Building 15
Pi Beta Phi 83
Pi Kappa Alpha 89
Post Office/Campus Square 202b
President's House 28
Price Hall 40
Psi Upsilon 80
Purchasing &
Business Services 23
Rathbone Hall 63
Rauch Business Center 37
Research and Sponsored Programs
(ORSP) 23b
Residence Life 25
Richards House 66
Sayre Building 26
Sayre Residential Village .. 109 (a-d)
Service Building 1
Sherman Fairchild Center
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for Solid State Studies 16a
Sigma Chi 102
Sigma Phi Epsilon 92
Sinclair Laboratory 7
Smiley House 59
STEPS Building 9A
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Summer sessions 189
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Warren Square F 21
Whitaker Laboratory 5
Wilbur Annex 11
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Zoellner Arts Center 49
Zoellner Administration 4
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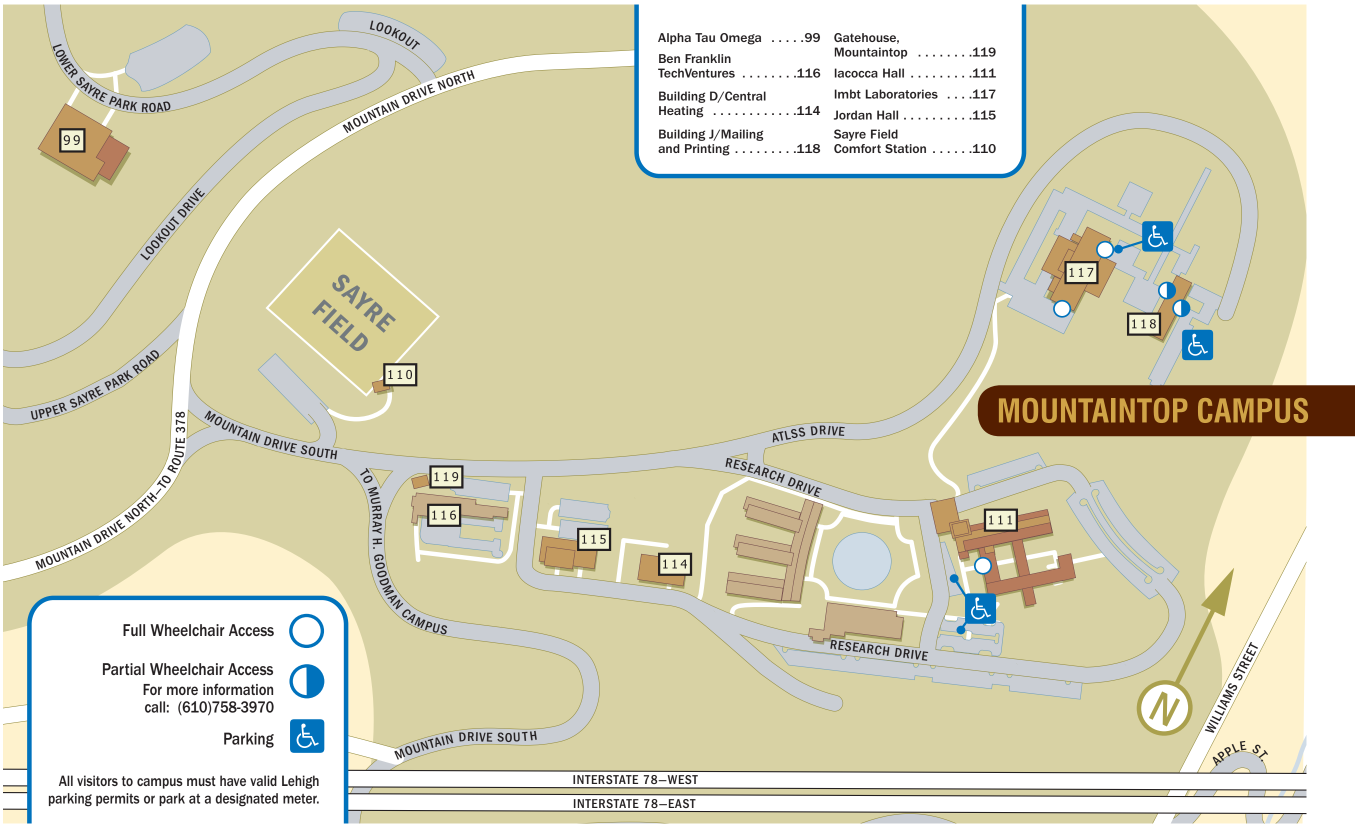
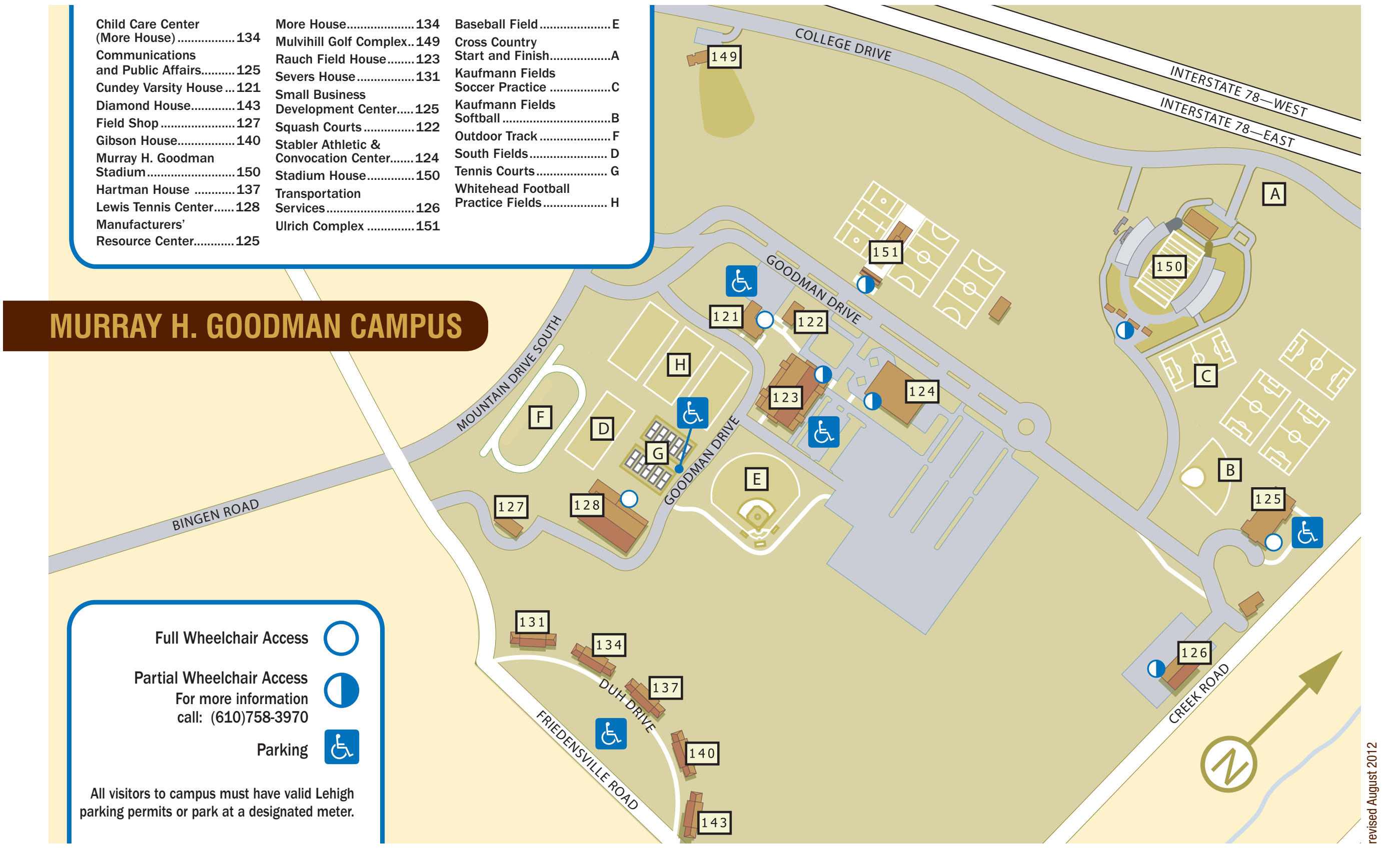
LEHIGH UNIVERSITY

LEHIGH UNIVERSITY CAMPUS MAPS





■ Plenary Talks

Wednesday 09:00–10:00. Natalia Alexandrov

An Optimization Perspective on Trustworthiness and Trust in Autonomous Systems

NASA Langley Research Center

The application domain of the work described in this talk is the near-to-far-future airspace, where the projected density and heterogeneity of autonomous participants, including non-cooperative agents, combine to increase system complexity and uncertainty, with ensuing threats to safety. Given the increased complexity, control of airspace will have to transition to human-machine teams, with ever rising authority of autonomous systems (AS). The growing use of AS leads to a potential paradox: AS are meant to address system uncertainty; however, machine authority and human-machine interactions are themselves major sources of uncertainty in the system. Because trustworthiness and trust are connected to decision making, which, in turn is an optimization problem, subject to expressed and unexpressed constraints, in this presentation we examine the nature of the attendant optimization problems, discuss some approaches to solutions, as well as persistent gaps.

Speaker Biography. Dr. Natalia Alexandrov works at the NASA Langley Research Center. Her interests are in multidisciplinary methods for variable-fidelity modeling, problem synthesis, design optimization (MDO), and control of complex cyber-physical-human systems, including mechanical artifacts and heterogeneous adaptive systems, such as future transportation systems and biological systems; concepts of trust and trustworthiness in systems governed by autonomous computational intelligence and human-machine teams with a high degree of machine autonomy.

Wednesday 12:00–13:00. Tamer Basar

Risk-Sensitive Designs, Robustness, and Stochastic Games

Director, Center for Advanced Study Swanlund Endowed Chair CAS Professor of Electrical and Computer Engineering Professor, Coordinated Science Laboratory & Information Trust Institute
University of Illinois at Urbana-Champaign

basar1@illinois.edu

I will talk about the relationship between risk-averse designs based on exponential loss functions with or without an additional unknown (adversarial) term and a class of stochastic games. This leads to a robustness interpretation for risk-averse decision rules in the general context, through a stochastic dissipation inequality. I will show, in particular, the equivalence between risk-averse linear filter designs and saddle-point solutions of a particular stochastic differential game with asymmetric information for the players. One of the by-products of this analysis is that risk-averse filters for linear signal-measurement models are robust, through a stochastic dissipation inequality, to un-modeled perturbations in both the signal and the measurement processes. Extensions to nonlinear models, problems where there are multiple decision makers with only partially conflicting goals and relationship with mean-field games, and problems where there is an element of deception will also be discussed.

Speaker Biography. Tamer Basar has been with the University of Illinois at Urbana-Champaign since 1981, where he holds the academic positions of Swanlund Endowed Chair; Center for Advanced Study Professor of Electrical and Computer Engineering; Professor, Coordinated Science Laboratory; Professor, Information Trust Institute; and Affiliate Professor, Mechanical Sciences and Engineering. He is also the Director of the Center for Advanced Study. He is a member of the US National Academy of Engineering and the European Academy of Sciences; a Fellow of IEEE, IFAC (International Federation of Automatic Control), and SIAM (Society for Industrial and Applied Mathematics); a past president of the IEEE Control Systems Society (CSS), the founding president of the International Society of Dynamic Games (ISDG), and a past president of the American Automatic Control Council (AACC). He has received several awards and recognitions over the years, including the highest awards of IEEE CSS, IFAC, AACC, and ISDG, the IEEE Control Systems Technical Field Award, and a number of international honorary doctorates and professorships, including chaired professorship at Tsinghua University. He has over 900 publications in systems, control, communications, optimization, networks, and dynamic games, including books on non-cooperative dynamic game theory, robust control, network security, wireless and communication networks, and stochastic networks. He was the Editor-in-Chief of Automatica between 2004 and 2014, and is editor of several book series. His current research interests include stochastic teams, games, and networks; distributed computation and learning; security and trust; energy systems; and cyber-physical systems.

Thursday 09:00–10:00. Antonio Conejo

Operational Equilibria of Electric and Natural Gas Systems with Limited Information Interchange

The Ohio State University

Electric power and natural gas systems are typically operated independently. However, their operations are interrelated due to the proliferation of natural gas-fired generating units. We analyze the independent but interrelated day-ahead operation of the two systems. We use a direct approach to identify operational equilibria involving these two systems, in which the optimality conditions of both electric power and natural gas operational models are gathered and solved jointly. We characterize the equilibria that are obtained under different levels of temporal and spatial granularity in conveying information between the two system operators. Numerical results from the Belgian system are used to examine the impacts of different levels of information interchange on prices and operational cost and decisions in the two systems.

Speaker Biography. Antonio J. Conejo, professor at The Ohio State University, OH, received an M.S. from MIT, and a Ph.D. from the Royal Institute of Technology, Sweden. He has published over 200 papers in refereed journals, and is the author or coauthor of books published by Springer, John Wiley, McGraw-Hill and CRC. He has been the principal investigator of many research projects financed by public agencies and the power industry and has supervised 23 PhD theses. He is an IEEE Fellow and a former Editor-in-Chief of the IEEE Transactions on Power Systems, the flagship journal of the power engineering profession.

Thursday 12:00–13:00. Alexander Shapiro

Distributionally robust and risk averse multistage stochastic programming

Georgia Institute of Technology

We discuss distributionally robust and risk averse approaches to multistage stochastic programming, and the involved concept of time consistency. It turns out that if the respective risk measures are not strictly monotone, then there may exist infinitely many optimal policies which do not satisfy the dynamic programming equations and are not time consistent. This is in a sharp contrast with the risk neutral formulation where all optimal policies are time consistent. As an example we discuss distributionally robust formulations of the inventory models.

Speaker Biography. Alexander Shapiro is a Professor in the School of Industrial and Systems Engineering at Georgia Institute of Technology. He has published more than 140 research articles in peer review journals and is a coauthor of several books. His research is widely cited and he was listed as an ISI Highly Cited Researcher in 2004 (ISI = Institute for Scienti c Information). He was on the editorial board of several professional journals. He was an area editor (Op- timization) of the Operations Research journal and the Editor-in-Chief of the Mathematical Programming, Series A, journal. He gave numerous invited keynote and plenary talks, including invited section talk (sec- tion Control Theory & Optimization) at the International Congress of Mathematicians 2010, Hyderabad, India. In 2013 he was a recipient of the Khachiyan Prize, awarded by the INFORMS Optimization Society, and in 2018 of the Dantzig Prize, award by the Mathematical Optimization Society.

Thursday 16:00–17:00. Giacomo Nannicini

A snapshot of quantum algorithms for optimization

IBM T. J. Watson Research Center

There is much hype surrounding quantum computing and its potential applications for optimization. However, the technical details are often lost in translation. In this (mostly) survey talk I will give an overview of quantum algorithms that could potentially be useful for continuous and discrete optimization. I will discuss benefits and limitations of algorithms for SDP and LP (via faster solution of the Newton linear system, or via the multiplicative weights update method), the quantum approximate optimization algorithm, and hybrid quantum/classical variational methods for combinatorial problems. I will also discuss some fundamental open questions, highlighting what algorithmic limitations need to be overcome for quantum computing to have an impact on the practice of optimization.

Speaker Biography. Giacomo Nannicini is a Research Staff Member in the Theory of Quantum Computing and Information group at the IBM T. J. Watson Research Center. Before joining IBM, he was an assistant professor in the Engineering Systems and Design pillar at the Singapore University of Technology and Design. His main research interest is optimization broadly defined and its applications. Giacomo received several awards, including the 2016 COIN-OR Cup, the 2015 Robert Faure prize, the 2012 Glover-Klingman prize. His algorithms and software are used by one of the largest real-time traffic and mobility information groups in Europe and in IBM Watson Studio.

Friday 09:00–10:00. Boris Mordukhovich

Criticality of Lagrange Multipliers in Conic Programming with Applications to SQP

Wayne State University, Detroit, MI

This talk concerns the study of criticality of Lagrange multipliers in variational systems that have been recognized in both theoretical and numerical aspects of optimization and variational analysis. In contrast to the previous developments dealing with polyhedral KKT systems and the like, we now focus on general nonpolyhedral systems that are associated, in particular, with problems of conic programming. Developing a novel approach, which is mainly based on advanced techniques and tools of second-order variational analysis and generalized differentiation, allows us to overcome principal challenges of nonpolyhedrality and to establish complete characterizations on noncritical multipliers in such settings. We present applications of noncritical multipliers to deriving efficient conditions of the sequential quadratic programming method for general classes of conic programs. Based on joint work with Ebrahim Sarabi (Miami University, Oxford, OH)

Speaker Biography. Boris Mordukhovich was born and educated in the former Soviet Union. He is currently a Distinguished University Professor at Wayne State University. Mordukhovich is an expert in optimization, variational analysis, generalized differentiation, optimal control, and their applications to economics, engineering, behavioral sciences, and other fields. He is the author and a co-author of more than 400 publications including his 2-volume monograph on variational analysis and applications (2006) and the recent book on these topics published in 2018. Mordukhovich is an AMS Fellow, a SIAM Fellow, and a recipient of many international awards and honors including Doctor Honoris Causa degrees from 6 universities worldwide. He was the Founding Editor (2008) and a co-Editor-in-Chief (2009-2014) of Set-Valued and Variational Analysis, and is now is a co-Editor-in-Chief of Applied Analysis and Optimization, and an Associate Editor of many highly ranked journals including SIAM J. Optimization, JOTA, etc. In 2016 he was elected to the Accademia Peloritana dei Pericolanti (Italy). Mordukhovich is in the list of Highly Cited Researchers in Mathematics.

Friday 12:00–13:00. Martin Grötschel

Digital Humanities: Challenges for Optimization?

Berlin-Brandenburg Academy of Sciences and Humanities (BBAW)

Mathematics has "invaded" every branch of the sciences. High quality engineering, management and planning depend, in particular and to a large extent, on optimization and operations research (OR) methodology. For a long time, mathematical modelling and algorithms have played only tiny roles in the support of humanities research. This is slowly changing now. The term Digital Humanities (briefly DH), coined about ten years ago, is used to describe efforts aimed at supporting research (and teaching) in the humanities (and the social sciences) by employing tools and methods from information technology, computer science and mathematics. DH is developing in many directions, but despite some hype and significant media coverage, DH is still in its infancy. The current DH situation resembles the early days of Operations Research (OR), also a field in the interface of many other disciplines. Standard statistical analysis does have a tradition in various branches of the humanities, and the usual IT-tools are frequently employed as well. In my lecture I will address the issue how optimization and OR tools can support DH, i.e., which modeling approaches and solution techniques can be successfully employed in Digital Humanities. I will describe, especially, some of the efforts (still rudimentary) made in this direction at the Berlin-Brandenburg Academy of Sciences and Humanities with a particular focus on linguistics, the edition of manuscripts (of famous scientists such as Leibniz, Alexander von Humboldt, Kant,. . .), and archeology. There is still a long way to go!

Speaker Biography. Martin Grötschel, born in 1948, studied mathematics at U Bochum, received his PhD in economics and habilitation in Operations Research at U Bonn. He was professor of applied mathematics at U Augsburg 1982-1991, professor of information technology at TU Berlin and vice president/president of the Zuse Institute for Information Technology Berlin 1991-2015. Grötschel was the President of the German Mathematical Society (DMV) 1993-1994, Secretary General of the International Mathematical Union (IMU) 2007-2014 and chaired the DFG Research Center Matheon "Mathematics for Key Technologies" 2002-2008. Since October 2015 he has been President of the Berlin Brandenburg Academy of Sciences and Humanities. Grötschel's main areas of research are discrete mathematics, optimization, and operations research with a special focus on the design of practically efficient algorithms for hard combinatorial optimization problems appearing in practice. Cutting plane algorithms for integer programming are among his favorites. The application areas include telecommunications, chip design, energy, production planning and control, logistics, and public transport. He is currently involved in investigating mathematical and IT aspects of the humanities, i.e., in fostering digital humanities. Grötschel's scientific achievements were honored with several distinctions including the Leibniz, the Beckurts, the Dantzig, the Fulkerson, and the John von Neumann Theory Prize. He holds four honorary degrees and is a member of seven scientific academies, including the US National Academy of Engineering. For more details, see http://www.zib.de/groetschel/ http://www.bbaw.de/die-akademie/praesidium-und-gremien/cv-groetschel

■ AIMMS/MOPTA Optimization Modeling Competition 2019

The eleventh AIMMS/MOPTA Optimization Modeling Competition is a result of cooperation between AIMMS and the organizers of the MOPTA conference. Teams of graduate students participated and solved an automated design of assortment problem. The teams were asked to generate a variety of solutions for packing rectangular items in a rectangular container without overlap, in such a way that (i) the value of the assortment, measured by the cumulated surface occupied by the items, is maximized, and (ii) the assortments suggested to the user differ sufficiently to be seen as diverse, according to metrics to be developed.
The teams had to form a mathematical model of the problem, implement it in AIMMS, solve it, create a graphical user interface, and write a 15-page report on the project. Several teams from five countries registered to the competition. The panel of judges (Boris Defourny and Tamás Terlaky from Lehigh University, Mohan Chiriki from AIMMS) selected the following three teams for the final:

Team "ZIB", Mathematical Optimization, Zuse Institute Berlin
Kai Hoppmann, Felix Prause
advised by Thorsten Koch

Team "UCL", Chemical Engineering, University College London
Deemah M. Aljuhani
advised by Lazaros G. Papageorgiou,
Team "Gomory Paper Cuts", Mathematical Sciences, Rensselaer Polytechnic Institute
April Sagan, Dan Kosmas, Jesica Bauer
advised by John Mitchell.

The finalist teams will each give 30-minute presentations (25 minutes for the talk + 5 minutes for questions) on their work on Thursday, August 15th, starting at 10:15am. The winning team will be announced at the conference banquet on Thursday evening.
We thank all the teams for their participation. We believe that it has been a very positive experience for all parties involved in the process.

■ Instructions

For Speakers

- We ask all speakers to be familiar with the time and the location of their stream and talk, as specified in the conference booklet.
- Speakers should arrive at the location of their stream and talk 10 minutes prior to the scheduled start time of the session.
- Upon arrival you will be met by the chair of the session. Please introduce yourself and, if applicable, provide the chair with a copy of your presentation to upload onto the seminar room computer.
- Speakers should adhere to the allotted time slot. Anyone going over this time will be asked to stop by the chair.
- To aid you with the timing of your presentation, the chair will signal when you have 5 minutes and then 1 minute remaining for your presentation.

For Chairs

- Please arrive at the appropriate seminar room 10 minutes before the start of the stream you will be chairing. You should familiarize yourself with the equipment and ensure there are no obvious problems which would prevent the stream from running to schedule.
- In the event of a problem you should immediately seek the help of a local conference organizer.
- Delegates presenting in the stream should also be present in the seminar room 10 minutes before the start of the stream. You should introduce yourself to the speakers. You should discuss is everyone will use the same computer with uploaded presentations or switch computers.
- Your main role will be to ensure that the stream runs to time. Please allow time between talks for the comfort of the audience and to allow for movement between streams, when applicable.
- If a speaker fails to show for their talk, advise the audience to attend a talk in an alternative seminar room. Please, do not move the next talk forward.
- Before each speaker presents, you should introduce them and remind them that you will signal when, first 5 minutes, and then 1 minute, remain.
- Should a speaker go overtime, you must politely but firmly stop their presentation and move on to the next presentation.
- After each talk, thank the speaker, encourage applause, and open the floor to questions.

■ OPTE Special Issue: MOPTA 2019

Submission Due Date: October 30, 2019

Guest Editors:

Tamas Terkay, George N. and Soteria Kledaras '87 Endowed Chair Professor, Industrial and Systems Engineering, Lehigh University, PA USA. ⟨terlaky@lehigh.edu⟩.

Monica G. Cojocaru, Professor of Mathematics, University of Guelph, ON Canada
Senior Visiting Research Fellow, Industrial and Systems Engineering, Lehigh University, PA USA. ⟨mcojocar@uoguelph.ca⟩.

Aim

This call aims at publishing research work that showcases the interactions between Optimization and Engineering to address important current problems in the specific scientific community. The call encourages submissions from speakers at the upcoming MOPTA 2019, specifically original works showcasing the applications of Optimization to areas such as game theory, health and epidemiology, ML/AI, quantum information/computing and energy modelling. Beyond this, the issue **but is open to submissions from any interested authors whose work falls within the areas above.** The call is also **open to all types of papers, including theoretical, applied, and algorithmic articles, as well as articles that combine these features.**

Submission Procedure

Please submit to the **Optimization and Engineering (OPTE)** journal at `http://www.springer.com/mathematics/journal/11081` and select special issue "SI: MOPTA 2019". All submissions must be original and may not be under review by another publication. Interested authors should consult the journal's "Instructions for Authors", at `http://www.springer.com/mathematics/journal/11081`. All submitted papers will be reviewed on a peer review basis.

All inquiries should be directed to the attention of:
M. G. Cojocaru, Guest Editor
Optimization and Engineering (OPTE) journal
⟨mcojocar@uoguelph.ca⟩

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SIAM Representative

Lawrence V. Snyder, Lehigh

Boris Defourny, Lehigh

Ted K. Ralphs

Luis F. Zuluaga, Lehigh

Aberto Lamadrid, Lehigh

Martin Takáč, Lehigh

PROGRAM

08:00–08:50 **Registration and breakfast**

08:50–09:00 **Opening remarks**

09:00–10:00 **Plenary talk** (Wood Dining Room) *Chair: Luis Nunes Vicente*

- **An Optimization Perspective on Trustworthiness and Trust in Autonomous Systems** *Natalia Alexandrov*

10:00–10:15 **Coffee Break**

10:15–11:45 **Predictive disease modeling: Session 1** (Room 91) *Chair: E. Thommes*

1. **Estimating the Cross Immunity Between Drifted Strains of Influenza A/H3N2** *Junling Ma*
2. **Novel compartmental models of infectious disease** *Scott Greenhalgh*
3. **Using a realistic SEIR model to assess the burden of vaccine-preventable diseases in China and design optimal mitigation strategies** *John Glasser*

10:15–11:45 **Games: theory and applications 1** (Room 85) *Chair: M. Cojocaru*

1. **A game-theoretic model for emergency preparedness among NGO's** *Myles Nahirniak*
2. **Generalized Nash games and replicator dynamics** *Monica Cojocaru*
3. **On Decomposition Methods for Generalized Nash Equilibrium Problems** *Tangi Migot*

10:15–11:45 **Energy - II** (Room 271) *Chair: L. A. Roald*

1. **Distribution Electricity Pricing under Uncertainty** *Yury Dvorkin*
2. **Distributionally Robust Chance Constrained Optimal Power Flow Assuming Unimodal Distributions with Misspecified Modes** *Bowen Li*
3. **Risk-Sensitive Economic Dispatch: Theory and Algorithms** *Subhonmesh Bose*

10:15–11:45 **Computational Nonlinear Optimization with Applications** (Room 241) *Chair: G. Fasano*

1. **An Empirical Quantification of the Impact of Choice Constraints on Generalizations of the 0-1 Knapsack Problem using CPLEX** *Yun Lu, Francis Vasko*
2. **Optimization Problems in Space Engineering** *Giorgio Fasano*
3. **A General Lagrange Multipliers Based Approach for Object Packing Applications** *Janos D. Pinter*

11:45–12:00 **Coffee Break**

12:00–13:00 **Plenary talk** (Wood Dining Room) *Chair: Alberto Lamadrid*

- **Risk-Sensitive Designs, Robustness, and Stochastic Games** *Tamer Basar*

13:00–14:00 **Lunch**

14:00–15:30 **Predictive disease modelling 2** (Room 91) *Chair: E. Thommes*

1. **Fitting seasonal influenza epidemic curves to surveillance: Application to the French Sentinelles network** *Edward Thommes*
2. **Impact of influenza vaccine-modified susceptibility and infectivity on the outcomes of immunization** *Kyeongah Nah*
3. **Novel efficient algorithm for risk-set sampling in cohort studies of large administrative health databases** *Salah Mahmud Christiaan Righolt*

14:00–15:30 **Games: theory and applications 2** (Room 85) *Chair: M. Cojocaru*

1. **Decision making of the population under media effects and spread of Influenza** *Safia Athar*
2. **A real-time optimization with warm-start of multiperiod AC optimal power flows** *Youngdae Kim*
3. **Detecting Organ Failure in Motor Vehicle Trauma Patients: A Machine Learning Approach** *Neil Deshmukh*

14:00–15:30 **Energy - III** (Room 271) *Chair: Dan Molzahn*

1. **Computing and Calibrating Prices for Locational Variability in Power Generation and Load** *Bernard Lesieutre*
2. **Stability and robustness of feedback based optimization for the distribution grid** *Marcello Colombino*
3. **Algorithms for Optimal Design and Operation of Networked Microgrids** *Harsha Nagarajan*

14:00–15:30 **Advances in Numerical Optimization 1** (Room 241) *Chair: F. Assous*

1. **Improving an optimization problem by redatuming via a TRAC approach** *Franck Assous*
2. **Modeling Hessian-vector products in nonlinear optimization** *Lili Song*
3. **Adaptive randomized rounding in the big parsimony problem** *Sangho Shim*

15:30–16:00 **Coffee Break**

16:00–17:30 **Health, Data and Optimization** (Room 91) *Chair: S. Sozuer*

1. **The role of pneumonia/influenza in hospital readmissions: Burden and predictive factors via machine learning** *Secil Sozuer*
2. **A further study on the trajectory sensitivity analysis of controlled-prescription opioid epidemic dynamical models** *Getachew Befekadu*
3. **An ABM model of day care center with mobility and infections** *Michael Glazer Monica Cojocaru*

16:00–17:30 **Advances in Numerical Optimization 3** (Room 85) *Chair: M. Takac*

1. **Derivative Approximation of some Model-based Derivative Free Methods** *Liyuan Cao*
2. **Regularized Robust Optimization for Two-Stage Stochastic Programming** *Mingsong Ye*
3. **Quasi-Newton Methods for Deep Learning: Forget the Past, Just Sample** *Martin Takac*

16:00–17:30 **Energy IV** (Room 271) *Chair: Kyri Baker*

1. **Enabling A Stochastic Wholesale Electricity Market Design** *Yury Dvorkin*
2. **Coupling Artificial Neural Networks with Chance Constrained Optimization for Voltage Regulation in Distribution Grids** *Nikolaos Gatsis*
3. **Learning Methods for Distribution System State Estimation** *Ahmed Zamzam*

16:00–17:30 **Optimization and OR** (Room 241) *Chair: T. Terlaky*

1. **The Inmate Transportation Problem and its Application in the PA Department of Corrections** *Anshul Sharma*
2. **On the (near) Optimality of Extended Formulations for Multi-way Cut in Social Networks** *Sangho Shim*
3. **Simulation-Based Optimization of Dynamic Appointment Scheduling Problem with Patient Unpunctuality and Provider Lateness** *Secil Sozuer*

19:00–21:00 **Student Social**

08:00–09:00 **Registration and breakfast**

09:00–10:00 **Plenary talk** (Wood Dining Room) *Chair: Boris Defourny*

- **Operational Equilibria of Electric and Natural Gas Systems with Limited Information Interchange** *Antonio Conejo*

10:00–10:15 **Coffee Break**

10:15–11:45 **Plenary talk** (Wood Dining Room) *Chair: Boris Defourny*

- **Team "ZIB", Mathematical Optimization, Zuse Institute Berlin** *Kai Hoppmann, Felix Prause*
- **Team "UCL", Chemical Engineering, University College London** *Deemah M. Aljuhani*
- **Team "Gomory Paper Cuts", Mathematical Sciences, Rensselaer Polytechnic Institute** *April Sagan, Dan Kosmas, Jesica Bauer*

11:45–12:00 **Coffee Break**

12:00–13:00 **Plenary talk** (Wood Dining Room) *Chair: Lawrence Snyder*

- **Distributionally robust and risk averse multistage stochastic programming** *Alexander Shapiro*

13:00–14:00 **Lunch**

14:00–15:30 **Controlling epidemic and environmental diseases** (Room 91) *Chair: E. Buyuktahtakin Toy*

1. **An Epidemics-Logistics Modeling Framework: Insights into Controlling the Ebola Virus Disease in West Africa** *Esra Buyuktahtakin Toy*
2. **A Multi-Stage Stochastic Programming Approach to Controlling the Ebola Virus Disease with Equity Considerations** *Xuecheng Yin*
3. **Optimizing Search and Control of EAB in Canadian Forests** *Sabah Bushaj*

14:00–15:30 **Nonlinear Optimization Algorithms** (Room 85) *Chair: F. Curtis*

1. **Derivative Approximation of some Model-based Derivative Free Methods** *Liyuan Liyuan*
2. **Optimal Decision Trees for Categorical Data via Integer Programming** *Minhan Li*
3. **Limited-Memory BFGS with Displacement Aggregation** *Baoyu Zhou*

14:00–15:30 **Energy** (Room 271) *Chair: A. Lamadrid*

1. **Convex Restrictions for Optimal Power Flow** *Line A. Roald*
2. **Optimization and control in distribution grids** *Dan Molzahn*
3. **False data injection attack in coordinated natural gas and electricity systems** *Bining Zhao*

14:00–15:30 **Computational nonlinear optimization and applications 2** (Room 241) *Chair: J. Pinter*

1. **Generalized Nonconvex Relaxations to Rank Minimization** *April Sagan*
2. **Nonlinear regularization for solving non-linear inverse problems** *Dimitri Papadimitriou*
3. **Computational Optimization for Nonimaging Solar Concentrators using Generalized Pattern Search** *Christine Hoffman*

15:30–16:00 **Coffee Break**

16:00–17:00 **Plenary talk** (Wood Dining Room) *Chair: Luis Zuluaga*

- **A snapshot of quantum algorithms for optimization** *Giacomo Nannicini*

18:00–19:00 **Cocktail Reception**

19:00–21:00 **Banquet**

08:00–09:00 **Registration and breakfast**

09:00–10:00 **Plenary talk** (Wood Dining Room) *Chair: Monica Cojocaru*

- **Criticality of Lagrange Multipliers in Conic Programming with Applications to SQP** *Boris Mordukhovich*

10:00–10:15 **Coffee Break**

10:15–11:45 **Recent Advances in First-Order Methods for Distributed Optimization** (Room 85) *Chair: C. Uribe*

1. **Achieving Acceleration in Distributed Optimization via Direct Discretization of the Heavy-Ball ODE** *Cesar A. Uribe*
2. **An Efficient Method to find approximate Solutions to Linear and Nonlinear Fractional Differential Equations via Fractional Natural Decomposition Method** *Mahmoud Alrawashdeh*
3. **Recent Innovations for the Projective Splitting Algorithm** *Patrick Johnstone*

10:15–11:45 **Modeling and Optimization in Energy Sector** (Room 271) *Chair: Feng Qiu*

1. **Decomposable Formulation of Transmission Constraints for Decentralized Power Systems Optimization** *Alinson Santos Xavier*
2. **Tight Piecewise Convex Relaxations for Global Optimization of Optimal Power Flow** *Harsha Nagarajan*
3. **Mixed Integer Programming Formulations for the Unit Commitment Problem** *Bernard Knueven*

10:15–11:45 **Application of Discrete Optimization in Structural Design Problems** (Room 241) *Chair: R. Fakhimi*

1. **Warranty of kinematic stability in truss topology design optimization** *Mohammad Shahabsafa*
2. **Solving Large-scale Multi-scenario Truss Sizing Optimization Problem** *Ramin Fakhimi*
3. **A binary expansion method in finding a good lower bound of weight in truss sizing design** *Weiming Lei*

11:45–12:00 **Coffee Break**

12:00–13:00 **Plenary talk** (Wood Dining Room) *Chair: Tamas Telaky*

- **Digital Humanities: Challenges for Optimization?** *Martin Grotschel*

13:00–14:00 **Lunch**

14:00–15:30 **ML/AI and optimization** (Room 91) *Chair: A. Almomani*

1. **Design of neuro-evolutionary model for solving nonlinear singularly perturbed boundary value problems** *Muhammed Syam*
2. **The stochastic multi-gradient algorithm for multi-objective optimization and its application to supervised machine learning** *Suyun Liu*
3. **Different approaches between Pattern Search Algorithm and Particle Swarm Optimization** *Eric Koessler, Ahmad Almomani*

14:00–15:30 **Advances in Numerical Optimization 2** (Room 85) *Chair: B. El Khadir*

1. **Time-Varying Semidefinite Programs** *Bachir El Khadir*
2. **A decoupled first/second-order steps technique for nonconvex optimization** *Clément Royer*
3. **On Local Optimality in Cubic Optimization** *Jeffrey Zhang*

14:00–15:30 **Contributed Talks** (Room 271) *Chair: S. Shim*

1. **A strong formulation for the graph partition problem** *Sangho Shim*
2. **Optimizing Energy Storage Operation via Dual Decomposition** *Bolun Xu*

ABSTRACTS

■ Predictive disease modeling: Session 1

Room: **Room 91** (10:15 - 11:45) Chair: *S. Greenhalgh*

1. Estimating the Cross Immunity Between Drifted Strains of Influenza A/H3N2

Junling Ma[1,*]

[1]University of Victoria; *junlingm@uvic.ca;

Abstract:
To determine the cross-immunity between influenza strains, we design a novel statistical method, which uses a theoretical model and clinical data on attack rates and vaccine efficacy among school children for two seasons after the 1968 A/H3N2 influenza pandemic. This model incorporates the distribution of susceptibility and the dependence of cross-immunity on the antigenic distance of drifted strains. We find that the cross-immunity between an influenza strain and the mutant that causes the next epidemic is 88%. Our method also gives estimates of the vaccine protection against the vaccinating strain, and the basic reproduction number of the 1968 pandemic influenza.

2. Novel compartmental models of infectious disease

Scott Greenhalgh[1,*], *Carly Rozins*[2]

[1]Siena College; *sgreenhalgh@siena.edu;[2]University of California Berkeley;

Many methodologies in disease modeling have proven invaluable in the evaluation of health interventions. Of these methodologies, one of most fundamental is compartmental modeling. Compartmental models come in many different forms with one of the most general characterizations occurring from the description of disease dynamics with nonlinear Volterra integral equations. Despite this generality, the vast majority of disease modellers prefer the special case whereby the nonlinear Volterra integral equations are reduce to systems of differential equations through the traditional assumptions that 1) the infectiousness of a disease corresponds to incidence, and 2) the duration of infection follows either an Exponential distribution or an Erlang distribution. However, these assumptions are not the only ones that simplify nonlinear Volterra integral equations in such a way.
In this talk, we demonstrate how a biologically more accurate description of the infectiousness of a disease combines with nonlinear Volterra integral equations to yield a novel class of differential equation compartmental models, and then illustrate the novelty of this approach with several examples.

3. Using a realistic SEIR model to assess the burden of vaccine-preventable diseases in China and design optimal mitigation strategies

John Glasser[1,*], *Zhilan Feng*[2]

[1]Centers for Disease Control and Prevention;
*jglasser@cdc.gov;[2]Purdue University;

Mathematical modelers often make simplifying assumptions, but only rarely ascertain the consequences. We developed an age-stratified population model with births, deaths, aging and – because nonrandom mixing exacerbates the effect of heterogeneity on reproduction numbers (JTB 2015; 386:177-87) – realistic mixing between age groups. Using this model, we assessed the burden of congenital rubella syndrome (CRS) and evaluated the impact of demographic details on optimal vaccination strategies for disease elimination. Our estimate of the burden of CRS is 5 times that of Vynnycky, et al. (PLoS ONE 2016; 11(3): e0149160), and the 2014 serological profile suggests that it will dramatically increase absent timely immunization of susceptible adolescents. As is typical of developed countries, China's mortality schedule is type I. The impact on the optimal strategy of assuming type II mortality is modest, but our approach will be useful when and wherever vaccine availability is limited.

■ Games: theory and applications 1

Room: **Room 85** (10:15 - 11:45) Chair: *M. Cojocaru*

1. A game-theoretic model for emergency preparedness among NGO's

Myles Nahirniak[1,*]

[1]University Of Guelph; *mnahirni@uoguelph.ca;

Natural disasters in the United States last year resulted in a cost of almost $100 billion. In this talk, we consider the issue of disaster relief efforts by Non-Governmental Organizations (NGOs). We develop an asymmetric game to describe the behavior of two NGOs competing to purchase supplies. The players' payoff matrices depend on their level of preparedness for a disaster, and failure to make adequate provisions results in financial penalty. A replicator dynamics is introduced to investigate the time evolution of the players' optimal strategies, as well as stability. Finally, we impose a shared constraint, in order to place an upper limit on the total available supplies, and examine the effect on the players' strategies.

2. Generalized Nash games and replicator dynamics

Monica Cojocaru[1,*]

[1]University of Guelph; *mcojocar@uoguelph.ca;

In this talk I plan to introduce an evolutionary generalized Nash game (eGN). Generalized Nash games were introduced in the 50's, and represent models of noncooperative behaviour among players whose both strategy sets and payoff functions depend on strategy choices of other players.
Among these games, a specific class is represented by evolutionary games, which consist of populations where individuals play many times, against many different opponents, with each contributing a relatively small contribution to the total reward. Given strategies 1, ..., n, an individual of type i is one using strategy i, where xi is the frequency of type i individuals in the population. Thus the vector x = (x1, ..., xn) in the unit simplex is the state of the population. Interaction between players of different types can be described by linear or nonlinear payoffs. One known dynamic evolution of such a game is described by a replicator dynamics. However, assuming constraints imposed on the strategy sets of players (upper limits on resources for instance) the classic replicator dynamics is not appropriate anymore.
In these cases we show that we can reinterpret the game dynamics of an eGN differently. The new dynamics and its relation to evolutionary steady states is investigated.

3. On Decomposition Methods for Generalized Nash Equilibrium Problems

Tangi Migot[1,*], *Monica Cojocaru*[1]

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Generalized Nash equilibrium problems (GNEP) are a potent modeling tool that have developed a lot in recent decades. Much of this development has centered around applying variational methods to the so-called GNSC, a subset of GNEP where each player has the same constraint set. One popular approach to solve the GNSC is to use the apparent separability of each player to build a decomposition method.

This method has the benefit to be easily implementable and can be parallelized. Our aim in this talk is to show an extension of the decomposition methods to the GNEP, that is not necessarily with shared constraints.

■ Energy - II

Room: **Room 271** (10:15 - 11:45) Chair: *L. A. Roald*

1. Distribution Electricity Pricing under Uncertainty

Yury Dvorkin[1,*]

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Distribution locational marginal prices (DLMPs) facilitate the efficient operation of low-voltage electric power distribution systems. We propose an approach to internalize the stochasticity of renewable distributed energy resources (DERs) and risk tolerance of the distribution system operator in DLMP computations. This is achieved by means of applying conic duality to a chance-constrained AC optimal power flow. We show that the resulting DLMPs consist of the terms that allow to itemize the prices for the active and reactive power production, balancing regulation, and voltage support provided. Finally, we prove the proposed DLMP constitute a competitive equilibrium, which can be leveraged for designing a distribution electricity market, and show that imposing chance constraints on voltage limits distort the equilibrium.

2. Distributionally Robust Chance Constrained Optimal Power Flow Assuming Unimodal Distributions with Misspecified Modes

Bowen Li[1,*], *Ruiwei Jiang*[2], *Johanna Mathieu*[2]

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Chance-constrained optimal power flow (CC-OPF) formulations have been proposed to minimize operational costs while controlling the risk arising from uncertainties like renewable generation and load consumption. To solve CC-OPF, we often need access to the (true) joint probability distribution of all uncertainties, which is rarely known in practice. A solution based on a biased estimate of the distribution can result in poor reliability. To overcome this challenge, recent work has explored distributionally robust chance constraints, in which the chance constraints are satisfied over a family of distributions called the ambiguity set. Commonly, ambiguity sets are only based on moment information (e.g., mean and covariance) of the random variables; however, specifying additional characteristics of the random variables reduces conservatism and cost. Here, we consider ambiguity sets that additionally incorporate unimodality information. In practice, it is difficult to estimate the mode location from the data and so we allow it to be potentially misspecified. We formulate the problem and derive a separation-based algorithm to efficiently solve it. Finally, we evaluate the performance of the proposed approach on a modified IEEE-30 bus network with wind uncertainty and compare with other distributionally robust approaches. We find that a misspecified mode significantly affects the reliability of the solution and the proposed model demonstrates a good trade-off between cost and reliability.

3. Risk-Sensitive Economic Dispatch: Theory and Algorithms

Subhonmesh Bose[1,*], *Avinash N. Madavan*[1], *Ye Guo*[2], *Lang Tong*[3]

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In economic dispatch problems with uncertain supply or network conditions, an inherent tradeoff arises between power procurement costs and reliability of power delivery. In this talk, we explore risk-sensitive economic dispatch problem formulations, where risk is modeled via the conditional value at risk (CVaR) measure. Such formulations allow a system operator to explore the cost-reliability tradeoff. We provide customized algorithms to solve these risk-sensitive problems—a critical region exploration algorithm to guard against possible line failures and an online stochastic primal-dual subgradient method to dispatch against uncertain wind.

■ Computational Nonlinear Optimization with Applications

Room: **Room 241** (10:15 - 11:45) Chair: *G. Fasano*

1. An Empirical Quantification of the Impact of Choice Constraints on Generalizations of the 0-1 Knapsack Problem using CPLEX

Yun Lu[1,*] *Francis, Vasko*[1]

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It has been well-known for some time that adding choice constraints to certain types of knapsack formulations improves the solution time for these problems when using integer programming solvers, but by how much? In this paper, by using the integer programming option of CPLEX, we provide comprehensive empirical and analytical evidence of the impact of choice constraints on two important categories of knapsack problems. Specifically, we show using multidimensional knapsack problems (MKP) and multi-demand multidimensional knapsack problems from Beasley's OR-Library that adding choice constraints reduces solution time by more than 99.9%. Additionally, using these same problem instances, we show that even if only some of the variables have choice constraints imposed on them, the CPLEX solution times are drastically reduced. These results provide motivation for operations research practitioners to check if choice constraints are applicable when solving real-world problems involving generalizations of the 0-1 knapsack problem.

2. Optimization Problems in Space Engineering

Giorgio Fasano[1,*]

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Space engineering has since the very beginning represented a field where optimization methodologies were inevitable. In the earliest studies, the primary concern was related to the viability of the mission to accomplish. Therefore optimization generally focused on mission analysis aspects, with specific attention to technical feasibility and mission safety. Space engineering projects typically required the analysis and optimization of trajectories and fuel consumption. As time has passed a number of further issues, related, inter alias, to logistics and systems engineering aspects, have become increasingly important. Among the various optimization challenges relevant to this context, object packing, in the presence of balancing conditions, as well as additional requirements, are of great relevance. This wide class of problems are notorious for being NP-hard. Some packing scenarios arising in space applications are illustrated, pointing out the specificity of the instances to cope with. An overall global optimization heuristic approach is outlined, introducing a tailored modeling philosophy, as opposed to a purely algorithmic one. The orthogonal packing of three-dimensional "tetris-like" items, within a convex polyhedral domain, is briefly discussed. Additional constraints are also investigated, including balancing requirements. The general spacecraft control dispatch problem is proposed as a further optimization challenge in space applications. A dedicated controller has the task of determining the overall control action, to achieve the desired system attitude. A number of thrusters are available to exert the overall forces and torques, as required. Their positions and orientations on the external surface of the spacecraft is usually critical, since different layouts may yield different performance, in terms of energy usage throughout the entire mission. Once on orbit, the requested spacecraft control has to be dispatched, in compliance with given operational constraints, through the thrusters, with the aim of minimizing the overall propellant consumption. The relevant mathematical models and the overall heuristic approach adopted are overviewed.

3. A General Lagrange Multipliers Based Approach for Object Packing Applications

Janos D. Pinter[1,], Frank Kampas[2], Ignacio Castillo[3]*

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We have extended our previous work on packing circles, ellipses and generalized ellipses (ovals) in regular convex polygons. Now we can pack ellipses, ovals and smooth polygons into convex and non-convex regions formed by multiple ellipses and smooth polygons. The smooth polygons are generated by aggregating the linear constraints that define the polygon into a single constraint, using a smoothened maximum function. Our general method also allows packing non-convex sets which are composites of ellipses and smooth polygons. The objective function in such problems defines the size of the "container" region being packed. We cast the non-overlap condition for all pairs of packed objects as a minimization problem and use the method of Lagrange multipliers to generate the non-overlap constraints. We present a concise summary of our approach, followed by a selection of packing challenges solved numerically.

■ Predictive disease modelling 2

Room: **Room 91** (14:00 - 15:30) Chair: *E. Thommes*

1. Fitting seasonal influenza epidemic curves to surveillance: Application to the French Sentinelles network

Edward Thommes[1,], Julien Arino[2], Ali Asgary[3], Safia Athar[3], Ayman Chit[4], Laurent Coudeville[5], Michael Glazer[3], Jane Heffernan[3], Jason Lee[1], Zack McCarthy[2], Thomas Shin[1], Yanyu Xiao[3], Jianhong Wu[3]*

[1]Sanofi Pasteur, University of Guelph, York University;
[*]Edward.thommes@sanofi.com;[2]University of Manitoba;[3]York University;[4]Sanofi Pasteur, University of Toronto;[5]Sanofi Pasteur;

Predicting the course of an influenza season is a long-standing challenge in biomathematical modeling, and the subject of an extensive body of research. Significant success has been achieved in fitting disease transmission models to surveillance data, both retrospectively and prospectively. However, choosing a level of model sophistication appropriate to the availability of data remains a tricky balancing act. Here, we report preliminary results from a particularly simple model. We begin by testing the ability of the model to accurately extract epidemic parameters from synthetic data, using both a simple Monte Carlo sweep and an optimization approach. We demonstrate the ability of the model to simultaneously recover the onset time, effective reproduction number, and under-reporting factor. We then apply our model to retrospective French surveillance data at both the national and regional level, obtained from the Réseau Sentinelles (Sentinel Network) site, http://www.sentiweb.fr/.

Funding statement: ET, AC, LC, JL, TS are employees of Sanofi Pasteur. AA, SA, MG, JH, ZM, YX and JW have received funding from Sanofi Pasteur through a research grant.

2. Impact of influenza vaccine-modified susceptibility and infectivity on the outcomes of immunization

Kyeongah Nah[1,], Mahnaz Alavinejad[1], Ashrafur Rahman[2], Jane M Heffernan[1], Jianhong Wu[1]*

[1]York University; [*]kyeongah.nah@gmail.com ;[2]Lakehead University;

To help informing vaccine manufacturers and individuals at high risks of developing serious flu-related complications, we develop compartmental models to assess the impact of vaccinating the population by different types of vaccines. In this talk, I will present the balance between vaccine-modified susceptibility, infectivity and recovery needed in preventing an influenza outbreak, or in mitigating the health outcomes of the outbreak using the SIRV-type of disease transmission model. We will also observe the impact of influenza vaccination program on the infection risk of vaccinated and non-vaccinated individuals.

3. Novel efficient algorithm for risk-set sampling in cohort studies of large administrative health databases

Salah Mahmud Christiaan Righolt[1,]*

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Large ($N > 10^6$) cohort studies can be efficiently analyzed with minimal loss of statistical power by sampling a smaller risk set from the study population. The risk set consists of all events of interest that occurred over a specified period of time (observation time) and an appropriate set of randomly selected controls individually matched to each event — typically on length of observation time and other important confounding (lurking) variables. It can be shown that the resulting association statistics estimated by fitting conditional logistic regression models to the matched sample are equivalent to the corresponding estimates using the entire cohort with loss of power not exceeding 10% for most scenarios when the sampling ratio is larger than 4.
However, existing algorithms for risk-set sampling are computationally intensive and are often impractical when both the number of events and the cohort size are large which is usually the case in cohort studies of common conditions based on large administrative health databases. They are also not suitable for matching on time-varying variables.
We developed a new algorithm, presently implemented in SAS, to efficiently match on both time-varying and time-independent variables in large databases. Improved efficiency is obtained by combining a new random sampling technique with a flexible matching procedure

based on a user-defined cost function. The new sampling technique also simplifies matching on time-varying variables. We show using simulated datasets that the new algorithm produces valid statistical estimates, and compare its time, memory and CPU performance and resource utilization to those of the most efficient available algorithm (based on SAS's hash tables).

■ Games: theory and applications 2

Room: **Room 85** (14:00 - 15:30) Chair: *M. Cojocaru*

1. Decision making of the population under media effects and spread of Influenza

Safia Athar[1,*], *Jianhong Wu*[2], *M. G. Cojocaru*[3], *J. Heffernan*[2]

[1]York University; [*]sathar18@yorku.ca;[2]York University, Canada;[3]University of Guelph, Canada;

Media plays a vital role in controlling the decision making of the population in an epidemic. Influenza, a disease that affects every age group and causes mortality in many cases, is always a concern for public health. Role of mass-media reports on Influenza is studied in Heffernan et.al. In the mentioned paper, the authors employed a stochastic agent-based model to provide a quantification of mass media reports on the variability in crucial public health measurements. In this research, we are studying the decision making of the population under the effects of media reports. Also, we investigate how their decisions contribute to the control of influenza epidemic. For the purpose, we use the game theory approach to quantify the decision making of the population under the effect of disease and mass media reports. We adapted the model given by Heffernan et al. and modified it by adding sub-compartments to susceptible and vaccinated compartments. We study the movement of population between these sub-compartments under the media effects in the presence of risk of getting an infection.

2. A real-time optimization with warm-start of multiperiod AC optimal power flows

Youngdae Kim[1,*], *Mihai Anitescu*[1]

[1]Argonne National Laboratory; [*]youngdae@mcs.anl.gov;

We present a real-time optimization strategy combined with warm-start for a rolling horizon method applied to multi-period AC optimal power flow problems (MPACOPFs). In each horizon, ACOPFs are temporally inter-linked via ramping constraints, and we assume that each horizon needs to be solved in every few seconds or minutes. An approximate tracking scheme combined with two warm-start methods will be described. Our scheme closely follows the solution path consisting of strongly regular points. Theoretical results bounding the tracking error to the second order of the parameter changes of a single time period will be presented. Experimental results over various sizes of network up to 9k-bus will be given showing fast computation time of our method while maintaining a good solution quality, thus making it best suited to working under a real-time environment.

3. Detecting Organ Failure in Motor Vehicle Trauma Patients: A Machine Learning Approach

Neil Deshmukh[1,*]

[1]Lehigh University; [*]neil.nitin.de@gmail.com;

Motor vehicle accidents are prevalent throughout the U.S.; over five million crashes occur each year. Typically, patients are appropriately diagnosed only after being transported to nearby medical centers, which currently takes about 7-15 minutes on average. This project aims to expedite this diagnostic process by training neural networks on Intensive Care Unit (ICU) data to automate the identification of injuries caused by motor vehicle accidents.
Data was aggregated from the Beth Israel Deaconess Medical Center in Boston, Massachusetts via the Medical Information Mart for Intensive Care III (MIMIC-III) database, for patients' electrocardiogram (ECG) and respiratory rate reports. Natural Language Processing was used to isolate the patients of interest and classify them based on the area of injury, i.e., any of eight combinations of the three vital organs: brain, heart, and lungs. Upon isolation of the waveform data, noise was filtered via normalization, Butterworth and forward-backward filter application, and Fast Fourier transformation. The trained Artificial Neural Network (ANN) contained 23 dense layers with the number of neurons decreasing per two layers with ReLU activation and 10% dropout. Multiclass activation was used for the final layer, in order to allow training for detection of multiple areas of trauma. The trained Convolutional Neural Network (CNN) had 12 convolutions, utilizing batch normalization, six pooling, one flatten, and two dense layers. Both models used AdamOptimizer.
The CNN and ANN produced F1 scores of 0.82 and 0.56 respectively, suggesting the models could potentially perform accurate early detection of injury area and expedite hospital treatment of trauma patients.

■ Energy - III

Room: **Room 271** (14:00 - 15:30) Chair: *Dan Molzahn*

1. Computing and Calibrating Prices for Locational Variability in Power Generation and Load

Bernard Lesieutre[1,*], *Adria Brooks*[1]

[1]University of Wisconsin-Madison; [*]lesieutre@wisc.edu;

Fluctuations in variable power generation (e.g. wind and solar) and load are met in real-time using automatic generation control (AGC). The resources that respond to AGC control are chosen using a competitive market. In typical power systems, the costs for providing this power tracking service is shared among users, but is not weight more for those causing the variations. We cast the problem of procuring AGC resources as a chance-constrained optimization problem and calculate a locational price of variability. In this paper we consider how this locational price of variability might be calibrated to aid in computing charges for variability and for making payments to AGC resources. This approach will allocate higher prices for power fluctuations at locations for which it is difficult to accommodate variations, and lower prices at locations where it is easier to do so.

2. Stability and robustness of feedback based optimization for the distribution grid

Marcello Colombino[1,*], *John W. Simpson Porco*[2], *Andrey Bernstein*[3]

[1]McGill University; [*]Marcello.Colombino@gmail.com;[2]U. Waterloo;[3]NREL;

Feedback-based online optimization algorithms have gained traction in recent years because of their simple implementation, their ability to reject disturbances in real time, and their increased robustness to model mismatch. While the robustness properties have been observed both in simulation and experimental results, the theoretical analysis in the literature is mostly limited to nominal conditions. In this work, we propose a framework to systematically assess the robust stability of feedback-based online optimization algorithms. We leverage tools from monotone operator theory, variational inequalities and classical robust control to obtain tractable numerical tests that guarantee robust convergence properties of online algorithms in feedback with a physical system, even in the presence of disturbances and model uncertainty. The results are illustrated via an academic example and a case study of a power distribution system.

3. Algorithms for Optimal Design and Operation of Networked Microgrids

Harsha Nagarajan[1,], Russell Bent[1], Kaarthik Sundar[2], Hassan Hijazi[1]*

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In recent years, microgrids, i.e., disconnected distribution systems, have received increasing interest from power system utilities to support the economic and resiliency posture of their systems. The economics of long distance transmission lines prevent many remote communities from connecting to bulk transmission systems and these communities rely on off-grid microgrid technology. Furthermore, communities that are connected to the bulk transmission system are investigating microgrid technologies that will support their ability to disconnect and operate independently during extreme events. In each of these cases, it is important to develop methodologies that support the capability to design and operate microgrids in the absence of transmission over long periods of time. Unfortunately, such planning problems tend to be computationally difficult to solve and those that are straightforward to solve often lack the modeling fidelity that inspires confidence in the results. To address these issues, we first develop a high fidelity model for design and operations of a microgrid that include component efficiencies, component operating limits, battery modeling, unit commitment, capacity expansion, and power flow physics; the resulting model is a mixed-integer quadratically-constrained quadratic program (MIQCQP). We then develop an iterative algorithm, referred to as the Model Predictive Control (MPC) algorithm, that allows us to solve the resulting MIQCQP. We show, through extensive computational experiments, that the MPC-based method can scale to problems that have a very long planning horizon and provide high quality solutions that lie within 5% of optimal.

■ Advances in Numerical Optimization 1

Room: **Room 241** (14:00 - 15:30) Chair: *F. Assous*

1. Improving an optimization problem by redatuming via a TRAC approach

Franck Assous[1,], F. Nataf[2]*

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Parameter estimation plays a crucial role in imaging whether in the medical field or in seismic exploration, and remains an active subject of research, with many applications such as tumor detection or stroke prevention in the case of medical imaging. In geophysics, seismic imaging is used as a tool for exploring subsoil for oil, gas or other deposits.

From the mathematical point of view, parameter estimation can be written as a PDE-constrained optimization problem, which tries to minimize the misfit between the recorded data and the reconstruction obtained by an estimated parameter. At each step of the optimization process, this estimation is updated to get closer to the original parameter to recover.

In this context, it is well-known that the closer one is to the location of the parameter, the easier is the mathematical, and so the numerical, problem to solve. For this reason, the literature on this subject is large, since any method moving virtually the recording boundary closer to the parameter area, can be useful. Classical approaches generally solve least square problems based on paraxial approximations.

In this spirit, we propose here a novel method that works directly in the time-dependent domain, and use the full wave equation. Note that it can be extended to other propagation problems, like for instance elastodynamics (elastic wave equation) or electromagnetism (Maxwell's equations). It basically combines an optimization method with the time-reversed absorbing condition (TRAC) method we introduced several years ago, that couples time-reversal techniques and absorbing boundary conditions. Mainly, we aim at reducing the size of the computational domain: in that sense, this can be related to redatuming method, that allows to reduce the size of the optimization problem, by moving virtually the recorded boundary. In our talk, we will describe our approach and illustrate its efficiency on numerical examples.

2. Modeling Hessian-vector products in nonlinear optimization

Lili Song[1,], Luis Nunes Vicente[2]*

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In this paper, we suggest two ways of calculating quadratic models for unconstrained smooth nonlinear optimization when Hessian-vector products are available. The main idea is to interpolate the objective function using a quadratic on a set of points around the current one and concurrently using the curvature information from products of the Hessian times appropriate vectors, possibly defined by the interpolating points. These enriched interpolating conditions form then an affine space of model or inverse model Hessians, from which a particular one can be computed once an equilibrium or least secant principle is defined.

A first approach consists of recovering the Hessian matrix satisfying the enriched interpolated conditions, from which then a Newton approximate step can be computed. In a second approach we pose the recovery problem in the space of inverse model Hessians and calculate an approximate Newton direction without explicitly forming the inverse model Hessian. These techniques can lead to a significant reduction in the overall number of Hessian-vector products when compared to the inexact Newton method, although their expensive linear algebra make them only applicable to problems with a small number of variables.

3. Adaptive randomized rounding in the big parsimony problem

Sangho Shim[1,], Sunil Chopra[2], Eunseok Kim[3]*

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A phylogenetic tree is a binary tree where each node represents a sequence of the states and all the input sequences are represented at the leaf nodes. Given sequences of the states of the same length, the big parsimony problem constructs the most parsimonious phylogenetic tree along with labeling the internal nodes at the maximum parsimony. The big parsimony problem is known to be NP-hard. We describe randomized rounding methods that allow us to obtain good solutions. Our first randomized rounding method starts with a fractional optimal solution to the LP-relaxation of an integer linear programming formulation of the big parsimony problem, and repeats randomized rounding based on this fractional solution, which we refer to as fixed ran-domized rounding without changing the fractional solution. Solutions obtained using the fixed randomized rounding approach are superior to the best solutions obtained using branch-and-bound with GUROBI and can be obtained quicker. We then describe an adaptive randomized rounding approach where the underlying fractional solution changes based on the best integer solution observed so far and produces solutions that are superior to the fixed randomized rounding approach.

■ Health, Data and Optimization

Room: **Room 91** (16:00 - 17:30) Chair: *S. Sozuer*

1. The role of pneumonia/influenza in hospital readmissions: Burden and predictive factors via machine learning

Secil Sozuer[1,*]

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The Hospital Readmissions Reduction Program (HRRP) was established by the 2010 Affordable Care Act. This program requires the Centers for Medicare and Medicaid Services to reduce the reimbursements to hospitals with excessive readmissions. HRRP defines these as an admission for any cause ("all-cause readmission") occurring 30 days or less after an initial ("index") admission falling into one of several specified categories. Due to this program, readmissions are considered as a quality benchmark for health systems. Here, we will discuss our work and methodology on characterizing the contribution of pneumonia and influenza (P&I) to the burden of readmissions among a population of Medicare Advantage patients aged 65 and over. For the index admission, we apply the same inclusion/exclusion criteria for codes and diseases as the Centers for Medicare and Medicaid Services. We calculate probabilities of P&I readmission after an index admission in the following HRRP categories : Acute myocardial infarction (AMI), 2.0%; congestive heart failure (CHF), 3.0%; chronic obstructive pulmonary disease (COPD), 3.8%; type II diabetes, 1.6%. For comparison, the overall probability of readmission (all-cause readmission within 30 days of an all-cause index admission) is 13%, and the probability of P&I readmission following an all-cause index admission is 1.5%. We will also present preliminary work on the construction of machine learning algorithms for identifying individuals at risk for P&I readmission. Predictive performance is measured by the area under the curve of the receiver operating curve (AUC-ROC). Funding statement: EWT and AC are employees of Sanofi Pasteur. SS is paid by Sanofi Pasteur through an internship program.

2. A further study on the trajectory sensitivity analysis of controlled-prescription opioid epidemic dynamical models

Getachew Befekadu[1,*], *Christian Emiyah*[1], *Kofi Nyarko*[2]

[1]Department of Electrical & Computer Engineering, Morgan State University; *Getachew.befekadu@morgan.edu;[2]Department of Electrical and Computer Engineering, Morgan State University;

In the context of a mathematical model describing prescription opioid epidemics, we consider a general formalism of trajectory sensitivity study that complements time-domain simulation in the analysis of nonlinear dynamic behaviors of a controlled-prescription opioid epidemic model. In particular, we perform linearization around a nonlinear, and possibly showing non-smooth, trajectory and study further the influence of parameter variations on the prescription opioid epidemic dynamics from the estimated sensitivities analysis with respect to extra controlling or intervening parameters - where such large (or small) trajectory sensitivities generally indicating that these extra-parameters have significant (or negligible) effects on the opioid epidemic dynamical behavior. Moreover, the insights we get from such trajectory sensitivities studies are useful in analyzing the underlying influences on system behavior dynamics, as well as assessing the significance or consequence to parameter uncertainties. Finally, as an illustrative example, we presented some simulation results that demonstrated the advantages and usefulness of the proposed trajectory sensitivities study using literature-based parameters associated with a typical prescription opioid epidemics. (Joint work with Christian Emiyah and Kofi Nyarko, Department of Electrical & Computer Engineering, Morgan State University).

3. An ABM model of day care center with mobility data

Monica Cojocaru[1,*], *Michael Glazer*[1,*], *Valerie Trew*[1,*],

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We developed an agent-based model (ABM) of the daycare center of the University of Guelph for assessing different outbreak control strategies: vaccination for some pathogens and nonmedical measures (i.e., sanitizing, decreasing outside visitors, etc.). In this first stage implementation of the model children, staff, environment, and their interactions (person-to-person and person-to-environment) are featured during a 6 months interval. Our simulated environment consists of abstract rooms with zones signifying toy boxes, doors, washrooms, etc. We calibrate our agents' movement patterns and person-to-person interactions using data collected in the University of Guelph Child Care and Learning Center (CCLC) over several 2-week periods in March-June 2018. We present our first results here.

■ Advances in Numerical Optimization 3

Room: **Room 85** (16:00 - 17:30) Chair: *M. Takac*

1. Regularized Robust Optimization for Two-Stage Stochastic Programming

Mingsong Ye[1,*], *Somayeh Moazeni*[1]

[1]Stevens Institute of Technology; *mye2@stevens.edu;

Two-stage stochastic optimization problems with parameter uncertainty are ubiquitous in many applications. Coordinating distributed energy resources with intermittent capacities is an example of this class of problems. Robust optimization is a recently popular approach to deal with uncertainty in optimization. In this method, a feasible solution with the best worst-case performance with respect to an uncertainty set is sought. The typical assumption there is that the decision maker can accurately provide the uncertainty set. In this paper, we first analyze the stability and sensitivity of robust two-stage stochastic optimization problems considering general perturbations of the uncertainty set with respect to the Hausdorff distance. We then present a regularized robust optimization using the new concept of regularized uncertainty set and establish the stability of the new approach. Solving the robust counterpart problem with the regularized uncertainty set is discussed.

2. Quasi-Newton Methods for Deep Learning: Forget the Past, Just Sample

Martin Takac[1,*], *Majid Jahani*[1], *Mohammadreza Nazari*[1], *Sergey Rusakov*[1], *Albert Berehas*[1]

[1]Lehigh University; *takac.mt@gmail.com;

We present two sampled quasi-Newton methods for deep learning: sampled LBFGS (S-LBFGS) and sampled LSR1 (S-LSR1). Contrary to the classical variants of these methods that sequentially build Hessian or inverse Hessian approximations as the optimization progresses, our proposed methods sample points randomly around the current iterate at every iteration to produce these approximations. As a result, the approximations constructed making use of more reliable (recent and local) information and do not depend on past iterate information that could be significantly stale. We also show that these methods can be efficiently implemented in a distributed computing environment.

3. Derivative Approximation of some Model-based Derivative Free Methods

Liyuan Cao[1,*], *Albert S. Berahas*[1], *Katya Scheinberg*[1], *Krzysztof Choromanski*[2]

[1]Lehigh University; [*]lic314@lehigh.edu;[2]Google Brain;

To optimize a black-box function, gradient-based methods can be used in conjunction with finite difference methods. Alternatively, optimization can be done with polynomial interpolation models that approximate the black-box function. A class of random gradient-free algorithms based on Gaussian smoothing of the objective function was analyzed by Yurii Nesterov in 2011. Similar random algorithms were implemented and discussed in the machine learning community in more recent years. We compare these methods on their accuracy of gradient approximation and the overall performance.

■ Energy IV

Room: **Room 271** (16:00 - 17:30) Chair: *Kyri Baker*

1. Enabling A Stochastic Wholesale Electricity Market Design

Yury Dvorkin[1,*]

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Efficiently accommodating uncertain renewable and demand-side resources in wholesale electricity markets is among the foremost priorities of market regulators in the US, UK and EU nations. However, existing deterministic market designs fail to internalize the uncertainty and their scenario-based stochastic extensions are limited in their ability to simultaneously maximize social welfare and guarantee non-confiscatory market outcomes in expectation and per each scenario. This paper propose a chance-constrained stochastic market design, which is capable of producing a robust competitive equilibrium and internalizing uncertainty of the renewable and demand-side resources in the price formation process. The equilibrium and resulting prices are obtained for different uncertainty assumptions, which requires using either linear (restrictive assumptions) or second-order conic (more general assumptions) duality in the price formation process. The usefulness of the proposed stochastic market design is demonstrated via the case study carried out on the 8-zone ISO New England testbed.

2. Coupling Artificial Neural Networks with Chance Constrained Optimization for Voltage Regulation in Distribution Grids

Nikolaos Gatsis[1,*]

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Electricity distribution grids are envisioned to host an increasing number of photovoltaic (PV) generators. PV units are equipped with inverters that can inject or absorb reactive power, a capability that can be crucial for enabling adequate voltage regulation. This talk deals with an optimal power flow (OPF) formulation including probabilistic specifications that nodal voltages remain within safe bound. The chance constraints are approximated by the conditional value at risk. The solution of the resulting OPF yields optimal inverter set points for a set of uncertainty realizations. These are subsequently treated as training scenarios for an artificial neural network corresponding to each PV inverter. The objective of each ANN is to produce the reactive power setpoints corresponding to other realizations of the uncertainty in real time and in a decentralized fashion. The overall design is tested on standard test feeders and the voltage regulation capability is numerically analyzed.

3. Learning Methods for Distribution System State Estimation

Ahmed Zamzam[1,*]

[1]University of Minnesota; [*]AhmedZ@umn.edu ;
Distribution system state estimation (DSSE) is a core task for monitoring and control of distribution networks. Widely used Gauss-Newton approaches are not suitable for real-time estimation, often require many iterations to obtain reasonable results, and sometimes fail to converge. Learning-based approaches hold the promise for accurate real-time estimation. This talk presents a data-driven approach to 'learn to initialize' – that is, map the available measurements to a point in the neighborhood of the true latent states (network voltages), which is used to initialize Gauss-Newton. In addition, a novel physics-aware learning model is presented where the electrical network structure is utilized to parametrize a deep neural network. The proposed neural network architecture reduces the number of trainable coefficients needed to realize the mapping from the measurements to the network state by exploiting the separability of the estimation problem. This approach is the first that leverages electrical laws and grid topology to design the neural network for DSSE. We also show that the developed approaches yield superior performance in terms of stability, accuracy, and runtime, compared to conventional optimization-based solvers.

■ Optimization and OR

Room: **Room 241** (16:00 - 17:30) Chair: *T. Terlaky*

1. The Inmate Transportation Problem and its Application in the PA Department of Corrections

Anshul Sharma[1,*]

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The Inmate Transportation Problem (ITP) is a common complex problem in any correctional system. We develop a weighted multi-objective mixed integer linear optimization (MILO) model for the ITP. The MILO model optimizes the transportation of the inmates within a correctional system, while considering all legal restrictions and best business practices. We test the performance of the MILO model with real datasets from the Pennsylvania Department of Corrections (PADoC) and demonstrate that the inmate transportation process at the PADoC can significantly be improved by using operations research methodologies.

2. On the (near) Optimality of Extended Formulations for Multi-way Cut in Social Networks

Sangho Shim[1,*], *Chaithanya Bandi*[2], *Sunil Chopra*[2]

[1]Robert Morris University; [*]shim@rmu.edu;[2]Northwestern University;
In the multiway cut problem we are given an edge-weighted graph and a subset of the nodes called terminals, and asked for a minimum weight set of edges that separates each terminal from all the others. When the number k of terminals is two, this is simply the min cut max flow problem, and can be solved in polynomial time. This problem is known to be NP-hard as soon as k = 3. Among practitioners, an integer programming formulation of the problem introduced by Chopra and Owen (Mathematical Programming 73 (1996) 7-30) is empirically known to be strong on a social network, which is usually tree-like and

almost planar. (We refer to the formulation as EF2 following the authors.) In particular, EF2 is very strong when the edge weights are equally likely and we study the cardinality minimum multiway cut problem (i.e., the edge weights are all 1). We explore the max flow in the cardinality minimum multiway cut problem and show that the cardinality EF2 on a wheel graph has a primal integer solution and a dual integer solution of the same value. We consider a hub-spoke network of wheel graphs constructed by adding to the wheel graphs the edges of a hub graph which consists of the hub nodes of the wheel graphs and edges connecting the hub nodes. We assume that every wheel has a terminal hub or a terminal node with three non-terminal neighbors, and show that if the hub graph is planar, the cardinality EF2 on the hub-spoke network of the wheel graphs has a primal integer solution and a dual integer solution of the same value. An algorithm developed by Chrobak and Eppstein (Theoretical Computer Science 86 (1991) 243-266) is modi
ed and used for the proof.

3. Simulation-Based Optimization of Dynamic Appointment Scheduling Problem with Patient Unpunctuality and Provider Lateness

Secil Sozuer[1,*], *Dr. Miao Bai*[2], *Dr. Robert H. Storer*[1]

[1]Lehigh University; *ses515@lehigh.edu;[2]Mayo Clinic;

Healthcare providers are under growing pressure to improve efficiency due to an aging population and increasing expenditures. This research is designed to address a particular healthcare scheduling problem, dynamic and stochastic appointment scheduling with patient unpunctuality and provider lateness. We consider that the stochasticity is coming from uncertain patient requests, uncertain service duration, patient unpunctuality and provider lateness amount. The aim is to find the optimal schedule start time for the patients in order to minimize the expected cost incurred from patient waiting time, server idle time, and server overtime. By conducting perturbation analysis for the gradient estimation, a Sample Average Approximation (SAA) and a Stochastic Approximation (SA) algorithm are proposed. The structural properties of the sample path cost function and expected cost function are studied. Numerical experiments show the computational advantages of SAA and SA over the mathematical model.

■ Controlling epidemic and environmental diseases

Room: **Room 91** (14:00 - 15:30) Chair: *E. Buyuktahtakin Toy*

1. An Epidemics-Logistics Modeling Framework: Insights into Controlling the Ebola Virus Disease in West Africa

Esra Buyuktahtakin Toy[1,*], *Xuecheng Yin*[2], *Eyyub Kibis*[3]

[1]Associate Professor; *esratoy@njit.edu;[2]NJIT;[3]The College of Saint Rose;

In this study, we address a core limitation of existing epidemiological models by introducing a new epidemics-logistics mixed-integer programming (MIP) formulation to determine the optimal amount, timing and location of resources that are allocated for controlling an epidemic. The present study is the first spatially explicit optimization approach that considers geographically varying rates for disease transmission, migration of infected individuals over different regions, and varying treatment rates due to the limited capacity of treatment centers. We illustrate the performance of the MIP model using the case of the 2014-2015 Ebola outbreak in Guinea, Liberia, and Sierra Leone.

2. A Multi-Stage Stochastic Programming Approach to Controlling the Ebola Virus Disease with Equity Considerations

Xuecheng Yin[1,*], *Buyuktahtakin Toy, Esra*

[1]PhD Student; *xy276@njit.edu;

The optimization of resource allocation for controlling an epidemic outbreak is one big limitation in existing compartmental models. In this study, we formulate the resource allocation problem while forecasting the progression of the disease as a multi-stage stochastic programming epidemic compartmental model. In this model, based on an available budget we formulate spatio-temporally varying treatment rate. This model is applied to study the case of Ebola Virus Disease in West Africa to minimize an overall expected number of infected individuals, considering possible infection scenarios. We also consider equity constraints in order to allocate resources more fairly to three impacted countries in West Africa. Our model is practical and can be adopted to study other infectious diseases in complex situations.

3. Optimizing Search and Control of EAB in Canadian Forests

Sabah Bushaj[1,*], *Esra Buyuktahtakin Toy, Denys Yemshanov, Robert Haight*

[1]PhD Student; *sb2386@njit.edu ;

Emerald Ash Borer (EAB) is a wood-boring invasive insect, which is native to Asia causing extensive damage to ash trees in North America. EAB was discovered in 2002 near Detroit and since its accidental introduction, it has destroyed millions of ash trees in the United States and Canada. Current studies on EAB spread have estimated an enormous economic cost to the Canadian street and backyard trees. Some insecticides have shown to be effective in curing and protecting ash trees from EAB. Possible actions include surveillance, treatment, and removal of ash trees. We study a multistage stochastic mixed-integer programming (M-SMIP) model to optimize the surveillance, treatment and removal decisions over a limited budget. We maximize public benefits by optimally allocating resources to surveillance and control of EAB spread. We calibrate a formerly validated model of ash dynamics with a new dispersal mechanism and apply the optimization model to the city of Winnipeg in the province of Manitoba, Canada. Due to the inability to survey a vast amount of ash trees, we present a more efficient way to predict the dispersal of the invasive species.

■ Nonlinear Optimization Algorithms

Room: **Room 85** (14:00 - 15:30) Chair: *F. Curtis*

1. Derivative Approximation of some Model-based Derivative Free Methods

Liyuan Liyuan[1,*]

[1]Lehigh University; *lic314@lehigh.edu;

To optimize a black-box function, gradient-based methods can be used in conjunction with finite difference methods. Alternatively, optimization can be done with polynomial interpolation models that approximate the black-box function. A class of random gradient-free algorithms based on Gaussian smoothing of the objective function was analyzed by Yurii Nesterov in 2011. Similar random algorithms were implemented and discussed in the machine learning community in more recent years. We compare these methods on their accuracy of gradient approximation and the overall performance.

2. Optimal Decision Trees for Categorical Data via Integer Programming

Minhan Li[1,*], *Oktay Gunluk*[2], *Jayant Kalagnanam*[2], *Matt Menickelly*[3], *Katya Scheinberg*[4]

[1]Lehigh University; *mil417@lehigh.edu;[2]IBM Research;[3]Argonne national laboratory;[4]Cornell University;

Decision trees have been a very popular class of predictive models for decades due to their interpretability and good performance on categorical features. However, they are not always robust and tend to overfit the data. Additionally, if allowed to grow large, they lose interpretability. In this paper, we present a novel mixed integer programming formulation to construct optimal decision trees of a prespecified size. We take the special structure of categorical features into account and allow combinatorial decisions (based on subsets of values of features) at each node. We show that very good accuracy can be achieved with small trees using moderately-sized training sets. The optimization problems we solve are tractable with modern solvers.

3. Limited-Memory BFGS with Displacement Aggregation

Baoyu Zhou[1,*], *Albert S. Berahas*[1], *Frank E. Curtis*[1]

[1]Lehigh University; *baoyu.zhou@lehigh.edu;

We present a displacement aggregation strategy for the curvature pairs stored in a limited-memory BFGS method such that the resulting (inverse) Hessian approximations are equal to those derived from a full-memory BFGS method. Using said strategy, an algorithm employing the limited-memory method can achieve the same convergence properties as when full-memory Hessian approximations are employed. We illustrate the performance of an L-BFGS algorithm that employs the aggregation strategy.

■ Energy

Room: **Room 271** (14:00 - 15:30) Chair: *A. Lamadrid*

1. Convex Restrictions for Optimal Power Flow

Line A. Roald[1,*]

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The optimal power flow is an optimization problem commonly solved in operation of electric power systems, and obtaining tight convex relaxations (i.e., good convex outer approximations) of this problem has recently received significant attention. However, since power systems are critical infrastructure, ensuring safe operations is of paramount importance. In particular, ensuring that there exist a feasible solution to the non-convex equality constraints representing the AC power flow equations is a challenge. In this talk, we describe convex restrictions, which represent safe convex inner approximations of the optimal power flow feasible region. We discuss how this allows us to solve robust AC optimal power flow and guarantee feasible system trajectories.

2. Optimization and control in distribution grids

Dan Molzahn[1,*]

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Optimization and control in distribution grids

3. MIMO Power Electronics and Optimal Power Flow Control at the Grid Edge

Minjie Chen[1,*]

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”Grid edge” is an emerging and important opportunity for power electronics. Power converters usually do not perform active grid support functions at the distribution level. This fact is rapidly changing with the development of renewable energy, transportation electrification, and smart grids, where power electronics serve as the main energy gateway. In future homes and buildings, more and more devices operate in dc, have battery storage, and require bi-directional power flow. Advanced power electronics are needed to perform advanced functions at the grid edge.

This talk will first introduce a novel multi-input-multi-output (MIMO) dc power delivery architecture that can perform many advanced functions, and present the challenges and opportunities in designing an enabling power electronics device – the multiport ac-coupled energy router – which can intelligently route power for this architecture. The operation mechanisms of the energy router will be discussed, followed by a discussion on a few possible power flow control strategies to enable the control of high-performance multi-way power flow. Design methods to optimize the multi-winding transformer and system impedance matrix will be discussed. Finally, we will talk about how to use this architecture to develop a nano-grid test platform to stabilize the electric grid with more than 50% of renewable energy.

■ Computational nonlinear optimization and applications 2

Room: **Room 241** (14:00 - 15:30) Chair: *J. Pinter*

1. Generalized Nonconvex Relaxations to Rank Minimization

April Sagan[1,*], *John Mitchell*[1]

[1]Rensselaer Polytechnic Institute; *sagana@rpi.edu;

Rank minimization is of interest in machine learning applications such as recommender systems and robust principal component analysis. Minimizing the convex relaxation to the rank minimization problem, the nuclear norm, is an effective technique at solving the problem with strong performance guarantees. However, nonconvex relaxations have the capability of solving the rank minimization problem in cases with less measurements than required for exact rank minimization via nuclear norm minimization and in less time.

We develop efficient algorithms utilizing the low rank factorization for semidefinite programs put forth by Burer and Monteiro and show computational results demonstrating the advantages over convex relaxations and alternating minimization methods. Additionally, each iteration of our algorithm is less expensive by O(n) operations for an nxn matrix when compared to similar approaches, allowing us to quickly find solutions to rank minimization for large matrices.

2. Nonlinear regularization for solving non-linear inverse problems

Dimitri Papadimitriou[1,*]

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Neural parameter learning (or parameter/system identification) belong to the class of nonlinear inverse problems. These are ill-posed problems in the Hadamard sense: they require reformulation for numerical processing otherwise existence, uniqueness and stability upon input data variation can’t be guaranteed. This method is known as regularization. Let $F(u) = y^\delta$ denote the nonlinear inverse/ill-posed problem, where F is a nonlinear operator and y^{delta} noisy samples of y such that $\|y\check{\ }y^{delta}\| \leq \delta$, for some noisy level $\delta > 0$. Constructing a (variational) regularization for nonlinear inverse problems of this form consists of finding two functionals: a data fidelity term E (e.g., quadratic fidelity) measuring the distance between $F(u)$ and y^δ, and a regularization functional R favoring appropriate minimizers or penalizing potential solutions with undesired structures. A key question in this respect is the convergence for noisy data, related to the choice of the regularization parameter α in dependence on the noise level δ. With too little regularization, the regularized approximations u^δ_α -that minimizes the total error, a.k.a. generalized Tikhonov functional- are highly oscillatory due to noise amplification whereas with too much regularization, the regularized approximations are too close to the initial guess u^*. Thus, one should select the regularization parameter such that the total error $\|u^\delta_\alpha\check{\ }u^*\|$ is minimized.

Though using the term regularization in much broader sense than its formal definition of regularization (with stability, convergence and efficiency criteria), many experimental papers show that some linear regularization functionals don’t explain or improve the properties of the minimizer of the Tikhonov functional. However, regularization covers also non-quadratic ($L_p, 0 < p \leq 1$) and total variation functionals (TV-Regularization). In this paper, we demonstrate how TV-functionals combined with iterative regularization yields a competitive method for the solving of nonlinear inverse problems yields. The gain compared to Tikhonov regularization is illustrated by numerical examples.

3. Computational Optimization for Nonimaging Solar Concentrators using Generalized Pattern Search

Christine Hoffman[1,*]

[1]UC Merced; [*]choffman7@ucmerced.edu;

We present a computational framework for optimizing nonimaging solar concentrators. Our approach is to represent the concentrator's shape as a polygon, use ray tracing to compute the flux at the receiver, and employ a derivative-free optimization, Generalized Pattern Search (GPS), on the polygon's vertices. Many shape optimization techniques use gradients to seek a direction of steepest ascent or descent. For solar concentrators, these approaches can easily get trapped in local minima. In contrast, GPS is a derivative-free method that seeks a global optimum on suitable meshes, without computing gradients. This helps to avoid getting trapped in local minima. Results for 2D concentrators show that our algorithm can converge to the ideal concentrator's shape as the number of polygon vertices increases. We also show that when the number of vertices is small and fixed, the optimal polygon can differ significantly from the polygon that would be obtained using a uniform collocation of the ideal shape. Uncertainty quantification is used to determine design efficiency robustness. This approach could lead to a simple, accurate, and fast design method, and improve the performance and lower the fabrication costs of nonimaging concentrators for solar and thermal applications.

■ Recent Advances in First-Order Methods for Distributed Optimization

Room: **Room 85** (10:15 - 11:45) Chair: *M. Gurbuzbalaban*

1. Achieving Acceleration in Distributed Optimization via Direct Discretization of the Heavy-Ball ODE

Cesar A. Uribe[1,*], *Jingzhao Zhang*[1], *Aryan Mokhtari*[1], *Ali Jadbabaie*[1]

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We develop a distributed algorithm for convex Empirical Risk Minimization,the problem of minimizing large but finite sum of convex functions over networks. The proposed algorithm is derived from directly discretizing the second-order heavy-ball differential equation and results in an accelerated convergence rate, i.e, faster than distributed gradient descent based methods for strongly convex objectives that may not be smooth. Notably, we achieve acceleration without resorting to the well-known Nesterov's momentum approach. We provide numerical experiments and contrast the proposed method with recently proposed optimal distributed optimization algorithms.

2. An Efficient Method to find approximate Solutions to Linear and Nonlinear Fractional Differential Equations via Fractional Natural Decomposition Method

Mahmoud Alrawashdeh[1,*]

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In this talk, we implement a new method called the Fractional Natural Decomposition Method (FNDM) to solve different types of fractional linear and nonlinear differential equations. Also, we present approximate solutions to two systems of fractional linear ordinary differential equations. Most of the graphs were performed using Mathematica software. The study outlines the significant features of the FNDM. The results have shown that the FNDM is very efficient, convenient and can be applied to a large class of linear and nonlinear fractional differential equations. One can conclude that the method is easy to use and efficient

3. Recent Innovations for the Projective Splitting Algorithm

Patrick Johnstone[1,*], *Jonathan Eckstein*[1]

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Projective splitting is a primal-dual operator splitting algorithm for solving finite-sum convex optimization problems and monotone inclusions. The method is highly flexible and supports asynchronous and distributed computation. In the last two years, we have developed several innovations for the method to do with making use of forward steps rather than only resolvent (i.e. proximal) calculations. Forward steps (i.e. explicit evaluations of an operator) are computationally easier than resolvents and usually more convenient to implement. In this talk, I will provide an overview of these innovations. I will then focus on the most recent progress: developing a projective splitting variant for cocoercive operators that uses a single forward step per iteration.

■ Modeling and Optimization in Energy Sector

Room: **Room 271** (10:15 - 11:45) Chair: *Feng Qiu*

1. Decomposable Formulation of Transmission Constraints for Decentralized Power Systems Optimization

Alinson Santos Xavier[1,*], *Feng Qiu*[1], *Santanu S. Dey*[2]

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When solving large-scale power systems optimization problems, such as the Day-Ahead Security-Constrained Unit Commitment Problem (DA SCUC), one of the most complicating factors is modeling transmission and security constraints. The most common formulation used in the industry, based on Injection Shift Factors (ISF), yields very dense and unstructured constraints, which not only may cause performance issues, but also makes it unsuitable for decentralized studies, such as optimal energy exchange. In this work, we present a novel DC power flow formulation which has a decomposable block-diagonal structure, scales well for large systems, and can efficiently handle N-1 security requirements. Benchmarks on Multi-Zonal Security-Constrained Unit Commitment problems show that the proposed formulation can reliably and efficiently solve instances with up to 6,515 buses, with no convergence or numerical issues.

2. Tight Piecewise Convex Relaxations for Global Optimization of Optimal Power Flow

Harsha Nagarajan[1,*], *Mowen Lu*[2], *Russell Bent*[1]

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Since the alternating current optimal power flow (ACOPF) problem was introduced in 1962, developing efficient solution algorithms for the problem has been an active field of research. In recent years, there has been increasing interest in convex relaxations-based solution approaches that are often tight in practice. Based on these approaches, we develop tight piecewise convex relaxations with convex-hull representations, an adaptive, multivariate partitioning algorithm with bound tightening that progressively improves these relaxations and, given sufficient time, converges to the globally optimal solution. We illustrate the strengths of our formulations and algorithms using extensive benchmark ACOPF test cases from the literature. Computational results show that our novel algorithm reduces the best-known optimality gaps for some hard ACOPF cases.

3. Mixed Integer Programming Formulations for the Unit Commitment Problem

Bernard Knueven[1,*], *James Ostrowski*[2], *Jean-Paul Watson*[1]

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This work is a comprehensive overview of mixed integer programming formulations for the unit commitment (UC) problem. UC formulations have been an especially active area of research over the past twelve years due to their practical importance in power grid operations. Because of this work, researchers now have a much better understanding of the mathematical structure of the UC problem. However, this understanding does not necessarily lead to improved solution times. To better understand the relationship between computational performance and theoretical quality, we implemented and exhaustively tested many of the existing UC formulations in the literature on both academic and real-world data. We provide reference implementations of all formulations examined as part of the EGRET software package, publically available on GitHub.

■ Application of Discrete Optimization in Structural Design Problems

Room: **Room 241** (10:15 - 11:45) Chair: *R. Fakhimi*

1. Warranty of kinematic stability in truss topology design optimization

Mohammad Shahabsafa[1,*], *Ramin Fakhimi*[1], *Weiming Lei*[1], *Luis Zuluaga*[1], *Sicheng He*[2], *Joaquim R. R. A. Martins*[2], *Tamás Terlaky*[1]

[1]Department of Industrial and Systems Engineering, Lehigh University; *mos313@lehigh.edu;[2]Department of Aerospace Engineering, University of Michigan;

In this work, we propose a novel mathematical optimization model for the discrete Truss Topology Design and Sizing Optimization (TTDSO) problem with Euler buckling constraints. Our model is significantly more efficient, from a computational point of view, than previously published models. Random perturbations of external forces are used to obtain kinematically stable structures. We formally prove that by considering the perturbed external forces, the resulting structure is kinematically stable with probability one. Furthermore, we show that necessary conditions for kinematic stability can be used to speed up the solution time of TTDSO problem. Numerical results demonstrate that our model can be solved significantly faster than other discrete TTDSO models introduced before.

2. Solving Large-scale Multi-scenario Truss Sizing Optimization Problem

Ramin Fakhimi[1,*], *Mohammad Shahabsafa*[1], *Weiming Lei*[1], *Sicheng He*[2], *Luis Zuluaga*[1], *Joaquim R. R. A. Martins*[2], *Tamás Terlaky*[1]

[1]Department of Industrial and Systems Engineering, Lehigh University; *raf318@lehigh.edu;[2]Department of Aerospace Engineering, University of Michigan;

Discrete multi-scenario truss sizing problems are very challenging to solve due to their combinatorial, nonlinear, non-convex nature. Consequently, multi-scenario truss sizing problems become unsolvable as the size of the truss grows. We consider various mathematical formulations for the truss design problem with the objective of minimizing weight, while the cross-sectional areas of the bars take only discrete values. Euler buckling constraints, Hooke's law, and bounds for stress and displacements are also considered. We extend the Neighborhood Search Mixed Integer Linear Optimization (NS-MILO) approach to solve large-scale multi-scenario discrete truss design problems and demonstrate that the NS-MILO approach provides high-quality solutions for large-scale real multi-scenario truss sizing problems.

3. A binary expansion method in finding a good lower bound of weight in truss sizing design

Weiming Lei[1,*], *Mohammad Shahabsafa*[1], *Ramin Fakhimi*[1], *Tamás Terlaky*[1], *Luis Zuluaga*[1], *Sicheng He*[2], *Joaquim R. R. A. Martins*[2]

[1]Department of Industrial and Systems Engineering Lehigh University; *wel415@lehigh.edu;[2]MDO Lab, University of Michigan, Ann Arbor;

Continuous truss sizing problem has been widely researched. However, due to the complexity of structure and model, a solution is hard to be proved globally optimal. We introduce the binary expansion method in order to find a good lower bound in minimizing the weight of truss structure with certain topology and continuous cross-section area, so that to evaluate how close a solution is to be optimal. Hooke's law, bounds for stress and displacements, and Euler buckling constraints are considered in our model. In our numerical experiment, the benchmark problem of 10, 25 and 72 bars are considered. The results show that the gap between the lower bound by binary expansion method and the upper bound of the original continuous problem given by IPOPT is less than 1%, which means both methods are close to optimal.

■ ML/AI and optimization

Room: **Room 91** (14:00 - 15:30) Chair: *A. Almomani*

1. Design of neuro-evolutionary model for solving nonlinear singularly perturbed boundary value problems

Muhammed Syam[1,*], *Muhammed Syam*

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In this study, a neuro-evolutionary technique is developed for solving singularly perturbed boundary value problems (SP-BVPs) of linear and nonlinear ordinary differential equations (ODEs) by exploiting the strength of feed-forward artificial neural networks (ANNs), genetic algorithms (GAs) and sequential quadratic programming (SQP) technique. Mathematical modeling of SP-BVPs is constructed by using a universal function approximation capability of ANNs in mean square sense. Training of design parameter of ANNs is carried out by GAs, which is used as a tool for effective global search method integrated with SQP algorithm for rapid local convergence. The performance of the proposed design scheme is tested for six linear and nonlinear BVPs of singularly perturbed systems. Comprehensive numerical simulation studies are conducted to validate the effectiveness of the proposed scheme in terms of accuracy, robustness and convergence.

2. The stochastic multi-gradient algorithm for multi-objective optimization and its application to supervised machine learning

Suyun Liu[1,*], *Luis Nunes Vicente*[1]

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Optimization of conflicting functions is of paramount importance in decision making, and real world applications frequently involve data that is uncertain or unknown, resulting in stochastic multi-objective optimization (MOO). In this paper, we study the stochastic multi-gradient (SMG) method, seen as a natural extension of the classical stochastic gradient method for single-objective optimization.

At each iteration of the SMG method, a stochastic multi-gradient direction is calculated by solving a quadratic subproblem, and it is shown that this direction is biased even when all individual gradient estimators are unbiased. Our convergence analysis establishes rates to compute a point in the Pareto front, of order similar to what is known for stochastic gradient in both convex and strongly convex cases. The analysis handles the bias in the multi-gradient and the unknown a priori weights of the limit Pareto point.
The SMG method is then framed into a Pareto-front type algorithm for the computation of the entire Pareto front. The Pareto-front SMG algorithm is capable of robustly determining Pareto fronts for a number of synthetic test problems. One can apply it to any stochastic MOO problem arising from supervised machine learning, and we report results for logistic binary classification where multiple objectives correspond to distinct-sources data groups.

3. Different approaches between Pattern Search Algorithm and Particle Swarm Optimization

Ahmad Almomani[1,*], *Eric Koessler*[1]

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Different approaches between Pattern Search Algorithm and Particle Swarm Optimization
Eric Koessler and Ahmad Almomani
Mathematics Department, State University of New York at Geneseo, Geneseo, NY, 14454June 30, 2019
Abstract
Pattern Search (PS) are an important class of optimization algorithms which popular with researchers who use Derivative-Free Optimization (DFO). Particle Swarm Optimization (PSO) is one of the most commonly used stochastic optimization algorithms, and population based on the simulation of the social behavior of particles. In this talk, we introduce three approaches of hybridizing PS and PSO to improve the global minima and efficiency. Numerical results and parallel computing using the most known non-differentiable test functions reveal that all three methods improve the global minima and robustness versus PSO.

■ Advances in Numerical Optimization 2

Room: **Room 85** (14:00 - 15:30) Chair: *B. El Khadir*

1. Time-Varying Semidefinite Programs

Bachir El Khadir[1,*]

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We study time-varying semidefinite programs (TV-SDPs), which are semidefinite programs whose data (and solutions) are functions of time. Our focus is on the setting where the data varies polynomially with time. We show that under a strict feasibility assumption, restricting the solutions to also be polynomial functions of time does not change the optimal value of the TV-SDP. Moreover, by using a Positivstellensatz on univariate polynomial matrices, we show that the best polynomial solution of a given degree to a TV-SDP can be found by solving a semidefinite program of tractable size. We also provide a sequence of dual problems which can be cast as SDPs and that give upper bounds on the optimal value of a TV-SDP (in maximization form). We prove that under a boundedness assumption, this sequence of upper bounds converges to the optimal value of the TV-SDP. We demonstrate the efficacy of our algorithms on applications in optimization and control.

2. A decoupled first/second-order steps technique for nonconvex optimization

Clément Royer[1,*], *Serge Gratton*[2], *Luis Nunes Vicente*[3]

[1]University of Wisconsin-Madison; [*]croyer2@wisc.edu;[2]Université de Toulouse;[3]Lehigh University;

Second-order properties are particularly useful in nonconvex optimization, as they can be used to provably avoid convergence towards low-quality solutions such as saddle points. For certain classes of nonconvex problems arising in data science, second-order conditions can even be shown to characterize global optima. Consequently, there has been a surge of interest in developing optimization algorithms with second-order guarantees. However, as enlightened by recent complexity analyses of some of these methods, the overall effort to approach second-order points is significantly larger compared to that of reaching first-order ones. Even more so, several frameworks originally designed with first-order convergence in mind, do not appear to maintain the same first-order performance when modified to incorporate second-order aspects.
In this talk, we propose a technique that separately computes first- and second-order steps, with second-order convergence guarantees. The key idea consists in better connecting the steps to be taken and the stationarity criteria, which potentially leads to larger steps and decreases in the objective. As a result, we obtain an improvement of the complexity bound with respect to the first-order optimality tolerance, and this has a positive impact on the practical behavior. Although its applicability is wider, we present our concept within a trust-region framework based on exact and inexact derivatives. In this latter setting, we also reveal interesting connections between our technique and the criticality steps used in derivative-free optimization.

3. On Local Optimality in Cubic Optimization

Jeffrey Zhang[1,*]

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In this paper we examine local optimality in unconstrained cubic optimization. We give a characterization of when a point is a strict or nonstrict local minimum of a cubic polynomial, and show that it can be checked in polynomial time. We then address the problem of finding local minima of cubic polynomials.

■ Contributed Talks

Room: **Room 271** (14:00 - 15:30) Chair: *S. Shim*

1. Optimizing Energy Storage Operation via Dual Decomposition

Bolun Xu[1,*]

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This talk introduces a novel dual decomposition method for the fast solution of multi-period energy storage control problems. The proposed method solves deterministic single storage control problems to optimal within milliseconds in all application scenarios regardless of the look-ahead horizon or the objective function form, offering significant improvements compared to using commercial optimization solvers. The talk will also introduce our current effort of applying this algorithm in optimizing battery operation under its degradation mechanism and for optimizing multiple storage operations.

2. A strong formulation for the graph partition problem

Sangho Shim[1,*], *Sunil Chopra*[2]

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We develop a polynomial size extended graph formulation of the graph partition problem which dominates the formulation introduced by Chopra and Rao [Mathematical Programming 59 (1993) 87-115], and show that the extended graph formulation is tight on a tree. We introduce exponentially many valid inequalities to the Chopra-Rao formulation, which we call generalized arc inequalities, and develop a linear time algorithm to separate the most violated generalized arc inequality. We show that the polynomial size extended graph formulation is equivalent to the Chopra-Rao formulation augmented by the exponentially many generalized arc inequalities.

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