**IP1**

**Sparse Optimization**

Many computational problems of recent interest can be formulated as optimization problems that contain an underlying objective together with regularization terms that promote a particular type of structure in the solution. Since a commonly desired property is that the vector of unknowns should have relatively few nonzeros (a “sparse vector’), the term “sparse optimization’ is used as a broad label for the area. These problems have arisen in machine learning, image processing, compressed sensing, and several other fields. This talk surveys several applications that can be formulated and solved as sparse optimization problems, highlighting the novel ways in which algorithms have been assembled from a wide variety of optimization techniques, old and new.

Stephen Wright
University of Wisconsin
Dept. of Computer Sciences
swright@cs.wisc.edu

**IP2**

**Optimizing Radiation Therapy - Past Accomplishments and Future Challenges**

Optimization has found a successful and broad application in intensity-modulated radiation therapy (IMRT). We will briefly review the standard model of IMRT optimization. There is still a lot of space for improvement in IMRT and elsewhere in radiation therapy: 1. Optimization of the irradiation geometry including multiple fixed beams and dynamic arcs. 2. The adaptation (re-optimization) of the treatment during the course of treatment. 3. The handling of motion and uncertainties, particularly in proton therapy, and 4. The direct optimization of treatment outcome rather than physical (dosimetric) surrogates of it. A general challenge is that physicians often cannot provide clear mathematical objectives and strict constraints. Instead, they pursue an I know it when I see it approach. We try to address this issue through interactive multi-criteria optimization.

Thomas Bortfeld
Massachusetts General Hospital and Harvard Medical School
Department of Radiation Oncology
tbortfeld@partners.org

**IP3**

**On Some Optimal Control Problems of Electromagnetic Fields**

In this survey, a sequence of optimal control problems for systems of partial differential equations of increasing complexity is discussed. The audience is guided step by step from an academic heating problem to fairly complex control problems of induction heating. While the first problem is modeled by the Poission equation, the last one is related to industrial applications. It includes equations for heat conduction, heat radiation, and Maxwell equations modeling induction heating. To introduce into main principles of PDE control, the talk begins with a simplified optimal control problem for a linear elliptic equation with box constraints on the control function. It can be interpreted as a heating problem. Next, nonlinear local and nonlocal radiation boundary conditions are considered and the geometry of the computational domain will be more general. Moreover, box constraints on the state function are also admitted. Later, the model is improved by including Maxwell equations for induction heating and state constraints on the generated temperature. Also the completion of the model by Navier-Stokes equations in a melt is briefly mentioned. For these problems, the well-posedness of the underlying systems of PDEs and the principal form of optimality conditions are sketched. Numerical examples illustrate the theory, justify certain simplifications and and motivate the necessity of more complex models. Finally, ongoing research on applications to industrial processes of crystal growth is briefly addressed.

Fredi Tröltzsch
Technische Universität, Berlin
troeltz@math.tu-berlin.de

**IP4**

**Matrix Optimization: Searching Between the First and Second Order Methods**

During the last two decades, matrix optimization problems (MOPs) have undergone rapid developments due to their wide applications as well as their mathematical elegance. In the early days, second order methods, in particular the interior point methods (IPMs), seemed to be a natural choice for solving MOPs. This choice has been perfectly justified over the years by the success of using IPMs to solve small and medium sized semi-definite programming (SDP) problems. On the other hand, since at each iteration the memory requirement and the computational cost for second order methods grow too fast with the number of constraints and the matrix dimensions in MOPs, second order methods have recently become less popular. The current trend is to apply first order methods to MOPs. This comes no surprise as first order methods normally need less computational cost at each iteration. To say the least while first order methods can often run for some iterations even for large scale problems, the second order methods may fail even at the first iteration. However, for many MOPs the overall cost of first order methods for obtaining a reasonably good solution is often prohibitive, if possible at all. To break this deadlock, we need to construct algorithms that possess two desirable properties: 1) at each iteration the computational cost is affordable; and 2) the convergence speed is fast but may not be as fast as second order methods (no free lunch). In this talk, by using least squares correlation matrix and SDP problems as examples we demonstrate how these two properties can be potentially achieved simultaneously. Variational analysis, in particular semi-smooth analysis, will be emphasized and inexact proximal point algorithms (PPAs) will be recommended for solving large scale symmetric and nonsymmetric MOPs.

Defeng Sun
Dept of Mathematics
National University of Singapore
matsundf@nus.edu.sg

**IP5**

**Replacing Spectral Techniques for Expander Ratio, Normalized Cut and Conductance by Combinatorial Flow Algorithms**

We address challenging problems in clustering, partitioning and imaging including the normalized cut problem, graph expander, Cheeger constant problem and conductance problem. These have traditionally been solved using the "spectral technique". These problems are formulated here as a quadratic ratio (Raleigh) with discrete constraints and a single sum constraint. The spectral method solves a relaxation that omits the discreteness constraints. A new relaxation, that omits the sum constraint, is shown to be solvable in strongly polynomial time. It is shown, via an experimental study, that the results of the combinatorial algorithm often improve dramatically on the quality of the results of the spectral method in image segmentation and image denoising instances.

Dorit Hochbaum
Industrial Engineering and Operations Research
University of California, Berkeley
hochbaum@ieor.berkeley.edu

**IP6**

**Nonsmooth Optimization: Thinking Outside of the Black Box**

In many optimization problems, nonsmoothness appears in a structured manner, because the objective function has some special form. For example, in compressed sensing, regularized least square problems have composite objective functions. Likewise, separable functions arise in large-scale stochastic or mixed-integer programming problems solved by some decomposition technique. The last decade has seen the advent of a new generation of bundle methods, capable of fully exploiting structured objective functions. Such information, transmitted via an oracle or black box, can be handled in a highly versatile manner, depending on how much data is given by the black box. If certain first-order information is missing, it is possible to deal with inexactness very efficiently. But if some second-order information is available, it is possible to mimic a Newton algorithm and converge rapidly. We outline basic ideas and computational questions, highlighting the main features and challenges in the area on application examples.

Claudia Sagastizábal
CEPEL
sagastiz@impa.br

**IP7**

**Nonlinear Integer Optimization: Incomputability, Computability and Computation**

Within the realm of optimization, the Nonlinear Integer Optimization problem is, in some sense, the mother of all deterministic optimization problems. As such, in its most general form, it is hopelessly intractable. Yet, because of its obviously broad scope, it has its allure. By looking at structured yet broad subclasses, interesting and useful results emerge. I will present several results that expand on its intractability. Looking at these results optimistically, we are guided toward directions that can be fruitful for positive results for theory and computation. I will go into a lot of detail on combinatorial structures and types of functions for which we have polynomial-time exact and approximation algorithms. Finally, I will present the status of some efforts to develop rather "general-purpose' computational tools (bearing in mind that the general problem is provably intractable).

Jon Lee
IBM T.J. Watson Research Center
jonlee@us.ibm.com

**IP8**

**Title Not Available at Time of Publication**

Abstract not available at time of publication.

Thomas F. Coleman
The Ophelia Lazaridis Research Chair
University of Waterloo
tfcoleman@uwaterloo.ca

**CP1**

**Chance-Constrained Second-Order Cone Programming: A Definition**

Second-order cone programs (SOCPs) are class of convex optimization problems. Stochastic SOCPs have been defined recently to handle uncertainty in data defining SOCPs. A prominent alternative for stochastic programming for handling uncertain data is chance constrained programming (CCP). In this presentation, we introduce an extension of CCPs termed chance-constrained second-order cone programs (CCSOCPs) for handling uncertainty in data defining SOCPs. Some applications of this new paradigm of CCP will be described.

Baha M. Alzalg, Ari Ariyawansa
Washington State University
baha2math@gmail.com, ari@wsu.edu

**CP1**

**On Semidefinite Programming Relaxations of Maximum K-Section**

We derive a semidefinite programming bound for max k-equipartition problem, which is, for $k = 2$, at least as strong as the well-known bound by Frieze and Jerrum. For $k \geq 3$ this new bound dominates a bound of Karish and Rendl [S.E. Karish, F. Rendl. *Semidefinite Programming and Graph Equipartition.* In: Topics in Semidefinite and Interior-Point Methods, P.M. Pardalos and H. Wolkowicz, Eds., 1998.] The new bound coincides with a recent bound by De Klerk and Sotirov for the more general quadratic assignment problem.

Cristian Dobre
TiUniversity of Groningen
Groningen, The Netherlands
C.Dobre@uvt.nl

Etienne De Klerk
Tilburg University
E.deKlerk@uvt.nl

Dmitrii Pasechnik
NTU Singapore
dima@ntu.edu.sg

Renata Sotirov
Tilburg University
r.sotirov@uvt.nl

**CP1**

**Robust Design of Active Trusses Via Mixed Integer Semidefinite Programming**

This work is an extension of Ben-Tal and Nemirovskis approach on Robust Truss Topology Design to active trusses. Active trusses may use active components to react on uncertain loads. We present the implementation of the optimal positioning of active components within a semidefinite model for robust truss-topology design using binary variables. Different robust approaches (polyhedral and ellipsoidal uncertainty sets), solution methods (e.g. cascading techniques, projection approaches) and numerical results will be presented.

Kai Habermehl
TU Darmstadt, Department of Mathematics
Nonlinear Optimization
habermehl@mathematik.tu-darmstadt.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

Sonja Friedrich
TU Darmstadt, Department of Mathematics
Discrete Optimiation
friedrich@mathematik.tu-darmstadt.de

### CP1

### Distributionally Robust Optimization and Its Tractable Approximations

We focus on a linear optimization problem with uncertainties, having expectations in the objective and in the set of constraints. We present a modular framework to obtain an approximate solution to the problem that is distributionally robust and more flexible than the standard technique of using linear rules. We convert the uncertain linear program into a deterministic convex program by constructing distributionally robust bounds on these expectations.

Melvyn Sim
NUS Business School
dscsimm@nus.edu.sg

Joel Goh
Stanford University
joelgoh@stanford.edu

### CP1

### Attacking Molecular Conformation Problem by SDP

We present an improvement of the DISCO algorithm of Leung and Toh for molecular conformation. In the algorithm, the recursive steps recursively divide large group of atoms into two overlapping subgroups until each subgroups is sufficient small. At that point, the graph realization problems in the basis steps are solved via semidefinite programs. After which, the subgroups are stitched back together using the overlapping atoms, and the stitched configurations are refined by a gradient decent method. We use chemical information such as bond lengths and angles for atoms on the backbone of a protein molecule to improve the robustness of the DISCO algorithm for computing the structure of a protein molecule given only a very sparse subset (20%) of inter-atomic distances that are less than 6Åand are corrupted by high level of noise. Tests on molecules taken from the Protein Data Bank show that our improved algorithm is able to reliably and efficiently reconstruct the conformation of large molecules. For instance, a 6000-atom conformation problem is solved within an hour with an RMSD of less than 1Å.

Xingyuan Fang
Princeton University
ethanfangxy@gmail.com

Kim-Chuan Toh
National University of Singapore
Department of Mathematics and Singapore-MIT Alliance
mattohkc@nus.edu.sg

### CP1

### Optimization over the Doubly Nonnegative Cone

We often see that each element of the semidefinite relaxation matrix is meant to be nonnegative. Such a matrix is called a doubly nonnegative matrix. In this talk, we will show that the doubly nonnegative relaxation gives significantly tight bounds for a class of quadratic assignment problems. We also provide some basic properties of the doubly nonnegative cone aiming to develop new and efficient algorithms for solving the doubly nonnegative optimization problems.

Yasuaki Matsukawa
Graduate School of Systems and Information Engineering
University of Tsukuba
matsuk50@sk.tsukuba.ac.jp

Akiko Yoshise
University of Tsukuba
raduate School of Systems and Information Engineering
yoshise@sk.tsukuba.ac.jp

### CP2

### On Maximally Violated Cuts Obtained from a Basis

Most cuts used in practice can be derived from a basis and are of the form $\alpha^T x \geq 1$, where $x$ is a vector of non-basic variables and $\alpha \geq 0$. Such cuts are called *maximally violated* wrt. a point $\bar{x} \geq 0$ if $\alpha^T \bar{x} = 0$. In an earlier paper we presented computational results for maximally violated cuts derived from an optimal basis of the linear relaxation. In this talk we also consider pivoting and deriving maximally violated cuts from alternative non-optimal bases.

Kent Andersen
University of Aarhus
kent@imf.au.dk

### CP2

### A New Feasibility Pump-Like Heuristic for Mixed Integer Problems

Mixed-Integer optimization represents a powerful tool for modeling many optimization problems arising from real-world applications. The Feasibility pump is a heuristic for finding feasible solutions to mixed integer linear problems. In this work, we propose a new feasibility pump approach using concave non differentiable penalty functions for measuring solution integrality. We present computational results on general MILP problems from the MIPLIB library showing the effectiveness of our approach.

Marianna De Santis, Stefano Lucidi, Francesco Rinaldi
University of Rome
mdesantis@dis.unirma1.it, lucidi@dis.uniroma1.it,

rinaldi@dis.uniroma1.it

**CP2**

**A Traveling Salesman Problem with Quadratic Cost Structure**

We regard a traveling salesman problem with quadratic cost terms (QTSP) depending on any two successive arcs in the tour. This problem is motivated by an application in bioinformatics – the recognition of transcription factor binding sites in gene regulation. It can also be used to solve the angular-metric traveling salesman problem appearing in connection with robotics and traveling salesman problems with reload costs. For the linearized QTSP model we present a polyhedral study and investigate the computational complexity of the corresponding separation problems. Using the new cuts, real world instances from biology can be solved up to 80 cities in less than 13 minutes. Random instances turn out to be difficult, but on these semidefinite relaxations help to reduce the gap in the root node significantly.

Anja Fischer, Christoph Helmberg
Chemnitz University of Technology
anja.fischer@mathematik.tu-chemnitz.de,
christoph.helmberg@mathematik.tu-chemnitz.de

**CP2**

**A Novel Model: Planning, Scheduling and Resource Allocation of Engineering Activities in Manufacturing Systems and Service Industries**

This research deals with planning, scheduling and resource allocation of activities in non-shop floor areas of manufacturing systems and service industries. A mixed integer programming model and a decision support system was developed, including operational features such as flexibility of work force, legal restrictions on workload, and accessible capacities and resources. A real-life test, originating from an industrial partner, shows the flexibility and the robustness of the model by solving planning and scheduling problems.

Yousef Hooshmand
Institute for Product Engineering
University of Duisburg-Essen, Germany
yousef.hooshmand@uni-due.de

Amir Hooshmand
Institute for Advanced Study
Technical University of Munich, Germany
amir.hooshmand@pe.mw.tum.de

Dalibor Dudic
Stuttgart University
Germany
dalibor.dudic@gmail.com

**CP2**

**New Continuous Reformulations for Zero-One Programming Problems**

In this work, we study continuous reformulations of zero-one programming problems. We prove that, under suitable conditions, the optimal solutions of a zero-one programming problem can be obtained by solving a specific continuous problem. Furthermore, we develop a new feasibility-pump like approach for zero-one programming problems based on the proposed reformulations, and we present computational results on binary MILP problems showing the usefulness of the approach.

Francesco Rinaldi, Marianna De Santis
University of Rome
rinaldi@dis.uniroma1.it, mdesantis@dis.uniroma1.it

**CP2**

**Orbital Branching for Quadratic Assignment Problems of High Symmetry**

Quadratic assignment problems are notoriously difficult to solve to optimality, and the difficulties are often compounded in instances exhibiting a high degree of symmetry among decision variables. To address symmetry, we propose an orbital-branching approach geared specially toward quadratic assignment problems.

Stephen E. Wright
Miami University
Dept of Math & Statistics
wrightse@muohio.edu

**CP3**

**Adjoint-Based Global Error Techniques for Integration in Optimal Control Problems**

Using the direct multiple shooting method to solve optimal control problems requires integrating dynamical systems and generating sensitivity information for function and derivative evaluation. To do this efficiently, discretization schemes should be chosen to balance accuracy requirements for a successful optimization against computational effort. To this end we investigate global error techniques based on adjoint information. We present how this adjoint information can efficiently be obtained from quantities computed by backward differentiation of the integration scheme in the case of variable-stepsize, variable-order BDF methods.

Doerte Beigel
Interdisciplinary Center for Scientific Computing (IWR)
Heidelberg University
doerte.beigel@iwr.uni-heidelberg.de

Hans Georg Bock
IWR, University of Heidelberg
bock@iwr.uni-heidelberg.de

Johannes Schloeder
IWR, University of Heidelberg, Germany
schloeder@iwr.uni-heidelberg.de

**CP3**

**Symmetric Error Estimates for Discontinuous Time Stepping Schemes for Optimal Control Problems**

A discontinuous Galerkin finite element method for an optimal control problem having states constrained to linear and semi-linear parabolic PDE's is examined. The schemes under consideration are discontinuous in time but conforming in space. We present some results concerning error estimates for the first order necessary conditions under minimal regularity assumptions. The estimates are of symmetric type and lead to optimal convergence rates under suitable assumptions on the data.

Konstantinos Chrysafinos
Department of Mathematics
National Technical University of Athens, Greece
chrysafinos@math.ntua.gr

### CP3
### Convex Optimization for Model Predictive Control

In this contribution, we describe algorithms and computational performance of quadratic programming algorithms tailored for linear MPC with soft output constraints. We consider a primal active-set algorithm, a dual-active set algorithm, and a primal-dual interior-point algorithm for solution of convex QPs and tailor these algorithms for the special structure of linear MPC with soft output constraints. Linear MPC with soft output constraints is an attractive optimization model for control of uncertain linear systems and systems with asymmetric penalty functions. However, the size of the decision variables grows with the number of soft output constraints and slack variables introduced to shape the penalty function for the MPC problem. The resulting convex QP for the linear MPC with soft constraints easily becomes much larger than the equivalent linear MPC without soft output constraints. Due to the real-time computational requirement off-the-shelf QP algorithms are often too slow and efficient convex QP algorithms tailored for this problem are needed.

John B. Jorgensen
DTU Informatics
Technical University of Denmark
jbj@imm.dtu.dk

### CP3
### A Total Site Optimization Study for Plantwide Control

In order to develop control strategies for entire plants (plantwide control) and to jump over the lack of algorithms that is still present in this field we can apply total site steady-state optimization and then select the best control strategy. This paper is presenting a study of a total site optimization for a vacuum residue processing plant in order to maximize profit. The results will then be used as a priori information in the development of control strategies for the same plant.

Ionut Muntean, Andreea Savu, Gheorghe Lazea, Mihail Abrudean
Technical University of Cluj-Napoca, Faculty of Automation
and Computer Science, Automation Department
ionut.muntean@aut.utcluj.ro,
andreea.savu@aut.utcluj.ro, gheorghe.lazea@aut.utcluj.ro,
mihai.abrudean@aut.utcluj.ro

### CP3
### Trajectory Planning and Task Allocation of Cooperating Vehicles Based on Discrete-Continuous Modeling and Optimization

Optimal task allocation and trajectory planning for cooperating vehicles is characterized by complex multi-phase control problems with tight coupling of discrete structure and continuous dynamics. Using hierarchical hybrid automata and applying appropriate transformations, makes the model accessible for mathematical optimization. In particular, linear approximations are used for reasons of efficiency and global optimality of the resulting mixed-integer linear problem. For benchmark scenarios and for new problems numerical results are demonstrating real-time competitiveness as well as limitations.

Christian Reinl
Technische Universität Darmstadt
reinl@sim.tu-darmstadt.de

Oskar Von Stryk
Department of Computer Science
Technische Universität Darmstadt
stryk@sim.tu-darmstadt.de

### CP3
### Experiments of Automatic Differentiation in Aerospace Applications

EADS Innovation Works, as research center of EADS, is involved in the development of inverse methods for trajectory tools. Two aerospace applications will be presented with a focus on inverse problem, optimal control and first experiments with automatic differentiation (AD): 1. Identification of aerodynamics coefficients of a probe for different flight conditions given trajectories measurements. The industrial objective is to design space vehicles having an accurate stability. 2. Identification of heat flux coefficients from time domain temperature measurements. The industrial objective is the dimensioning of thermal protection system for atmospheric re-entry missions of aerospace vehicles. For these two applications, the inverse problem is also formulated as a minimization problem with optimal control formulation (lagrangian, adjoint and gradients computations and connected to an optimization loop). First encouraging results of automatic differentiation procedure on these industrial applications will be presented, with validations in agreement with measurements

Stéphane alestra, Vassili Srithammavanh
EADS INNOVATION WORKS
stephane.alestra@eads.net,
vassili.srithammavanh@eads.net

### CP4
### Approximating the Solution Set in Multi-Criteria Radiation Therapy Optimization

Optimal planning of a radiation therapy treatment is a multi-criteria decision problem due to the conflict between tumor dose and sparing of healthy tissue. An algorithm for generating a set of treatment plans such that these constitute a representative approximation of the solution set to this problem is considered. We provide a dual formulation of the algorithm that improves its computational complexity, thus extending the range of treatment cases to which the algorithm is amenable.

Rasmus Bokrantz
Royal Institute of Technology, Stockholm
Raysearch Laboratories
bokrantz@kth.se

Anders Forsgren
Royal Institute of Technology (KTH)
Dept. of Mathematics
andersf@kth.se

**CP4**

**Robust Optimization for Proton Therapy Treatment Planning**

Proton therapy is sensitive to errors such as patient misalignments and incorrect treatment volume densities. Failing to account for uncertainties may compromise the treatment plan quality drastically. By utilizing information about the uncertainties and performing minimax optimizations, we achieve robust treatment plans. We show that these plans provide more robustness and better sparing of healthy tissues than those of conventional methods for robustness, such as using margins and enforcing uniform beam doses.

Albin Fredriksson
Royal Institute of Technoloy, Stockholm
RaySearch Laboratories, Stockholm
albin.fredriksson@raysearchlabs.com

Anders Forsgren
Royal Institute of Technology (KTH)
Dept. of Mathematics
andersf@kth.se

Björn Hårdemark
RaySearch Laboratories, Stockholm
bjorn.hardemark@raysearchlabs.com

**CP4**

**A Mathematical Model for Increasing the Effectiveness of the Treatment of Cancer Patients**

A stochastic model is developed to describe the growth of heterogenous tumor for dispersed cell regime. The mathematical model is non-linear stochastic partial differential equation with a multiplicative colored noise term in the three dimensional space. The main feature of the model is that it takes into account random interactions between tumor cells, immune system cells, and ati-cancer drugs. The existence of weak solutions, pathwise uniqueness and the convergence in probability of the approzimated solutions to the exact solution of the stochastic problem are established. Some applications are suggested. The mathematical results of the study make possible the construction of computer programs and simulations for predicting the effect of chemotherapy, immunotherapy or genetherapy for each patient. The main idea of this study is: taking into consideration the biomedical parameters of each patient and the computer simulations for chemotherapy, immunotherapy or genetherapy, it will support and assist the medical staff to identify the most effective treatments for each cancer patient.

Fejzi Kolaneci
University of New York, Tirana
fkolaneci@unyt.edu.al

**CP4**

**Models and Algorithms for Imat and Vmat Arc Therapy Plan Optimization in Radiation Oncology**

In contrast with traditional IMRT, an IMAT or VMAT machine delivers radiation in a non-stop fashion while the gantry moves continuously during treatment. IMAT/VMAT machines allow the possibility of delivering high-quality treatments in shorter time than IMRT. However, their complex settings require new classes of models and algorithms to design treatment plans that take advantage of this technology. We propose some exact and heuristic approaches, and present results on real patient data.

Marina A. Epelman, Fei Peng, Edwin Romeijn
University of Michigan
Industrial and Operations Engineering
mepelman@umich.edu, fei peng ¡feipeng@umich.edu¿, romeijn@umich.edu

**CP4**

**An Inexact Algorithm in Function Space for Optimization with Non-Linear Pdes**

We consider an algorithm for non-linear equality constrained optimization in function space, which is taylored for optimization problems with non-linear PDEs. The algorithm computes inexact steps in function space, where inexactness arises from the discretization of a PDE. Discretization errors are controlled by an a-posteriori error estimation and adaptive grid refinement. As an application we present a problem from medical therapy planning.

Anton Schiela
ZIB, Berlin
schiela@zib.de

Martin Weiser
Zuse Institute (ZIB)
Berlin, Germany
weiser@zib.de

**CP4**

**Optimization of Freezing and Thawing Protocols for Reduction of Injuring Effects of Cryopreservation**

Mathematical models of ice formation inside and outside of living cells during freezing and thawing are derived by applying an appropriate averaging technique to partial differential equations describing the dynamics of water-to-ice phase change. This reduces spatially distributed relations to a few ordinary differential equations with control parameters and uncertainties. Additionally, state constraints are introduced to avoid the excessive heating of cells. The obtained equations together with an appropriate objective functional that expresses some injuring effects of cell freezing or thawing are considered as a conflict-controlled problem where the aim of the control is to minimize the objective functional, and the aim of the disturbance is opposite. A stable finite-difference scheme for computing the value function of this problem is developed. Using the computed value function, optimized cooling and thawing protocols are designed.

Varvara Turova, Nikolai D. Botkin, Karl-Heinz Hoffmann, Natalie Mayer
Technische Universität München, Department of Mathematics
Chair of Mathematical Modelling
turova@ma.tum.de, botkin@ma.tum.de, hoffmann@ma.tum.de, mayern@in.tum.de

**CP5**

**Selection of Districts for Data Entry Sites in East-**

**ern Java Household Census**

Eastern Java has 38 districts and an estimated population size of thirty eight millions. District can be kabupaten or kota such as Kediri, Malang, Pasuruan, if it is a kabupaten then the word kabupaten is not written. Most economical data entry is achieved with six districts as data entry sites serving Eastern Java , they are 22Bojonegoro, 08Kediri, 15Malang, 20Probolinggo, 25kotaSurabaya, 35Jember . Since 25kota Surabaya has a short distance to provincial capital, 25kota Surabaya can serve as an alternative to data entry in provincial capital. Under current plan, provincial capital is preselected as data entry site. This work however is done without such constraint as preselected provincial capital . This work is minimizing cost by p-median linear programming. Cost includes scanner price and questionnaire delivery cost.

Rosa Dahlia
STIS
pope_meyhara@yahoo.com

### CP5
### Risk Aversion in The Newsvendor Problem with Uncertain Supply: CVaR Criterion

In this presentation, we consider a production firm with stochastic yield. We assume the decision maker is risk-averse and wants to optimize and control the risk of shortfall. The model is one-period and the decision variables are selling price and the mean of production quantity. The decision criterion which is used, is the Conditional Value at Risk(CVaR).

Saman Eskandarzadeh, Kourosh Eshghi
Sharif University of Technology
saman.eskandarzadeh@gmail.com, eshghi@sharif.edu

### CP5
### Dynamic Graph Generation and Asynchronous Parallel Bundle Methods for Train Timetabling Problems

The Train Timetabling Problem deals with finding conflict free routes for different trains in a railway network. A traditional approach uses Lagrangian decomposition of coupling constraints in a network flow model. We develop dynamic graph generation techniques and asynchronous parallel bundle methods optimizing over dynamically determined subspaces to handle the very large scale instances from the railway-network of Deutsche Bahn.

Frank Fischer
Chemnitz University of Technology
frank.fischer@mathematik.tu-chemnitz.de

Christoph Helmberg
TU Chemnitz
Germany
helmberg@mathematik.tu-chemnitz.de

### CP5
### Modified Balanced Assignment Problem in Vector Case

We extend the well known balanced assignment problem to the case where costs are expressed by $m$-dimensional vectors. For the balanced assignment problem, a polynomial time algorithm has been proposed. Our problem is as follows : find the one to one correspondence between two sets of vectors that minimizes the maximal difference of the maximum sum and the minumum one. We propose approximate algorithms that use the searching method for the balanced assignment problem.

Yuusaku Kamura, Mario Nakamori
Tokyo A&T University
kamura@cc.tuat.ac.jp, nakamori@cc.tuat.ac.jp

### CP5
### A Distributed Optimization Framework for Maximizing Occupant Comfort in Smart Buildings

We propose a distributed optimization framework for maximizing the thermal comfort of occupants in a smart building, subject to occupant preferences, HVAC equipment, and energy constraints, by modeling the building as a hierarchical, distributed parameter system. We propose different algorithms to decompose the resulting non-convex, constrained optimization problem into subproblems, that are solved by multiple agents. At each timestep, the agents play a cooperative game and converge to an equilibrium to decide the optimal values of the building operational variables. Our experimental evaluation shows that the coupling among the variables and constraints affects the performance of the distributed algorithms and that the optimal comfort achieved by the distributed algorithms is comparable to that of the centralized approach.

Sudha Krishnamurthy, Arvind Raghunathan
United Technologies Research Center
krishnadots@gmail.com, raghunau@utrc.utc.com

### CP5
### Scheduling Algorithm for Sensors on Network

We consider a scheduling algorithm for optical space surveillance sensors on a network. The algorithm is structured in several stages of approximation using linear programming formulation in each stage, such as bin-packing or traveling salesman, to closely approximate an optimal solution. We present results for 1500 satellites over a 24h scheduling period. Using only one optical sensor, the results compare very favorably to an analogous greedy scheduling algorithm. We also present results using 3 optical sensors.

Zoran Spasojevic
Massachusetts Institute of Technology - Lincoln Laboratory
zoran@ll.mit.edu

### CP6
### Allocation of Maximal Capacities in Gas Networks

Given a gas network, we search an optimal allocation of capacities for each supply and demand node. An allocation is feasible if each request (supply equals demand) is guaranteed to be transportable through the network. We propose an algorithm for solving a reduced variant of the capacity allocation problem using an MIP relaxation of the original (nonconvex) MINLP transportation problem as black box. The suitability of our approach is demonstrated on real-life gas network instances.

Christine Hayn
University of Erlangen-Nuremberg
EDOM

christine.hayn@math.uni-erlangen.de

Lars Schewe
Friedrich-Alexander-Universität Erlangen Nürnberg,
Department Mathematik, EDOM
lars.schewe@math.uni-erlangen.de

Alexander Martin
University of Erlangen-Nürnberg
alexander.martin@math.uni-erlangen.de

**CP6**

**Topology Planning for Natural Gas Distribution Networks**

We present a procedure for topology planning of large-scale real-world natural gas distribution networks. For a given budget, it decides which combination of network extensions such as additional pipelines, compressors or valves should be added to increase the network's capacity or enhance its operational flexibility. We formulate this as a nonlinear mixed-integer problem. For its solution we use a combination of linear outer approximation and NLP solution techniques. Computational results obtained by a special tailored version of the MINLP solver SCIP are presented.

Armin Fügenschuh
Zuse Institut Berlin
fuegenschuh@zib.de

Thorsten Koch
Zuse Institute Berlin
koch@zib.de

Jesco Humpola, Robert Schwarz, Thomas Lehmann,
Jonas Schweiger, Benjamin Hiller, Jacint Szabo
Zuse Insitut Berlin
humpola@zib.de, schwarz@zib.de, lehmann@zib.de,
schweiger@zib.de, hiller@zib.de, szabo@zib.de

**CP6**

**Mixed-Integer-Programming Methods for Gas Network Optimization**

We present methods to formulate and solve MINLPs originating in stationary gas network optimization. To this aim we use a hierachy of MIP-relaxations and a graph decomposition approach. Thus, we are able to give tight relaxations of the underlying MINLP. The methods we present can be generalized to other non-linear weakly-coupled network optimization problems with binary decisions. We give computational results for a number of real world instances.

Lars Schewe, Bjoern Geissler
Friedrich-Alexander-Universität Erlangen Nürnberg,
Department Mathematik, EDOM
lars.schewe@math.uni-erlangen.de,
bjoern.geissler@math.uni-erlangen.de

Alexander Martin
University of Erlangen-Nürnberg
alexander.martin@math.uni-erlangen.de

Antonio Morsi
Friedrich-Alexander-Universität Erlangen Nürnberg,
Department Mathematik, EDOM
antonio.morsi@math.uni-erlangen.de

**CP6**

**A MINLP Primal Heuristic for Gas Networks**

We consider the problem of stationary optimization in gas networks. The combination of nonlinear gas dynamics together with combinatorial aspects of switchable network devices leads to very difficult mixed integer nonlinear optimization problems. We present a MINLP primal heuristic that models most of the combinatorial aspects by smooth approximations or relaxations and additionally incorporates ODEs of gas dynamics and highly detailed models of active devices. The practicability of our approach is shown on real-world instances.

Martin Schmidt
Leibniz Universität Hannover
Institute of Applied Mathematics
mschmidt@ifam.uni-hannover.de

Marc Steinbach
Leibniz Universität Hannover
steinbach@ifam.uni-hannover.de

Bernhard Willert
Institute of Applied Mathematics
Leibniz Universität Hannover
willert@ifam.uni-hannover.de

**CP6**

**Technical Capacities of Gas Networks**

Announcing the maximal technical capacities of gas networks is a legal demand against network operators. Examining the gas network with detailed modeling of gas physics leads to highly nonlinear problems with discrete decisions. Occurring non-convexities and holes in the feasible region additionally complicate the computation of the maximal technical capacity. With the help of minimal network examples the catch of the problem is explained and its complexity is shown.

Martin Schmidt
Leibniz Universität Hannover
Institute of Applied Mathematics
mschmidt@ifam.uni-hannover.de

Marc Steinbach
Leibniz Universität Hannover
steinbach@ifam.uni-hannover.de

Bernhard Willert
Institute of Applied Mathematics
Leibniz Universität Hannover
willert@ifam.uni-hannover.de

**CP6**

**Designing Multiple Energy Carrier Networks**

We consider a network design problem where single energy carrier networks are coupled by cogeneration plants. Modeling the physical properties results in a complex mixed-integer nonlinear problem which is approximated by a mixed-integer linear model using piecewise linear functions. This mixed-integer program is solved using a branch-and-cut approach which is enhanced by problem-specific mixed-integer programming methods.

Andrea Zelmer, Debora Mahlke
Friedrich-Alexander-Universität Erlangen-Nürnberg

Lehrstuhl für Wirtschaftsmathematik
andrea.zelmer@math.uni-erlangen.de,
debora.mahlke@math.uni-erlangen.de

Alexander Martin
University of Erlangen-Nürnberg
alexander.martin@math.uni-erlangen.de

### CP7

### Finding Low-Rank Submatrices with Nuclear Norm and $l_1$-Norm

We propose a convex optimization formulation using nuclear norm and $l_1$-norm to find a large low-rank submatrix for a given matrix. We are able to characterize the low-rank and sparsity structure of the resulting solutions. We show that our model can recover low-rank submatrices for matrices with subgaussian random noises. We solve the proposed model using a proximal point algorithm and apply it to an application in image feature extraction.

Xuan Vinh Doan
C&O Department
University of Waterloo
vanxuan@uwaterloo.ca

Stephen A. Vavasis
University of Waterloo
Dept of Combinatorics & Optimization
vavasis@math.uwaterloo.ca

Kim-Chuan Toh
National University of Singapore
Department of Mathematics and Singapore-MIT Alliance
mattohkc@nus.edu.sg

### CP7

### Convergence Properties for a Self-Dual Regularization for Convex and Saddle Functions

The convergence properties for a one-parameter regularization technique for convex optimization problems are studied. Such regularization scheme, introduced by Goebel, has as its main feature its self-duality with respect to the usual convex (and saddle) conjugation. In particular, we show that if a saddle function has at least one saddle point, then the sequence of saddle points of the regularized saddle functions converges to the saddle point of minimal norm of the original one.

Alvaro J. Guevara
Louisiana State University
Department of Mathematics
alvaro.guevara@vsi.cs.uni-frankfurt.de

### CP7

### Integration of Univariate and Bivariate Piecewise Higher Order Convex Functions by Bounding

A new numerical integration method is proposed for univariate piecewise higher order convex functions. The method uses piecewise polynomial lower and upper bounds on the function, created in connection with suitable dual feasible bases in the univariate discrete moment problem and the integral of the function is approximated by tight lower and upper bounds on them. We provide the extention of the method for the bivariate case and numerical illustrations for some probability density functions.

Mariya Naumova
Rutgers University, NJ, USA
mnaumova@eden.rutgers.edu

András Prékopa
Rutgers University
prekopa@rutcor.rutgers.edu

### CP7

### On Rate of Convergence of Discretization Methods for Semi-Infinite Minimax Problems

This presentation deals with semi-infinite minimax problems and their solution by discretization algorithms. These algorithms apply an algorithm map to solve approximate problems obtained by replacing the uncountable number of functions in the original problem by a finite number of functions. We develop rate of convergence results for such algorithms as a computational budget increases and find that the asymptotic rate is the same for different algorithm maps used to solve the approximate problems.

Johannes O. Royset
Asst. Prof.
Naval Postgraduate School
joroyset@nps.edu

Eng Yau Pee
Naval Postgraduate School
epee@nps.edu

### CP7

### On Implementing a Homogeneous Interior-Point Algorithm for Nonsymmetric Conic Optimization

Based on earlier work by Nesterov, an implementation of a homogeneous interior point algorithm for nonsymmetric conic optimization is presented. The method computes (nearly) primal-dual symmetric approximate tangent directions followed by a primal centering procedure. Quasi-Newton updating is employed to compute higher order directions and to reduce work in the centering process. Extensive and promising computational results are presented for facility location problems, entropy problems and geometric programs; all formulated as nonsymmetric conic optimization problems.

Anders Skajaa, John Bagterp Jørgensen
Technical University of Denmark
andsk@imm.dtu.dk, jbj@imm.dtu.dk

Per Christian Hansen
Technical University of Denmark
Informatics and Mathematical Modelling
pch@imm.dtu.dk

### CP8

### Adjoint Subgradient-Propagation by Algorithmic Differentiation

Optimization problems in engineering often have nonconvex objective and constraints and require global optimization algorithms. Deterministic global optimization algorithms based on branch-and-bound methods solve relaxations of the original program. These are constructed by convex/concave under-/over-estimators of the func-

tions involved. One of the alternative methods to construct these estimating functions are McCormick relaxations [McCormick, Computability of global solutions to factorable nonconvex programs: Part I. Convex underestimating problems, Mathematical Programming, 1976]. In General this technique results in nonsmooth estimators. Hence to obtain derivative information, subgradients are needed. These can be calculated using Algorithmic Differentiation (AD) techniques as shown in [Mitsos et al, McCormick-Based Relaxations of Algorithms, SIAM Journal on Optimization, 2009] and [Corbett et al, Compiler-Generated Subgradient Code for McCormick Relaxations, ACM Transactions on Mathematical Software, submitted]. In this talk we present a method for calculating subgradients by an adjoint method which makes the complexity of subgradient computation independent of the number of optimization parameters. Thus one bottleneck on the way to large-scale global optimization is eliminated.

Markus Beckers
German Research School for Simulation Sciences
LuFG Informatik 12: STCE
beckers@stce.rwth-aachen.de

Uwe Naumann
RWTH Aachen University
Software and Tools for Computational Engineering
naumann@stce.rwth-aachen.de

Viktor Mosenkis
LuFG Informatik 12: STCE
RWTH Aachen University
mosenkis@rwth-aachen.de

Alexander Mitsos
Department of Mechanical Engineering
Massachusetts Institute of Technology
mitsos@mit.edu

### CP8

### Particle Swarm Optimization in the Analysis of the Two Process Model of Sleep Regulation

The two process model of sleep regulation is widely used to understand the sleep-wake cycle in humans. Although the model is typically tuned to produce monophasic sleep with a duration in the neighborhood of 8 hours, it also admits solutions with a much richer character. By careful choice of objective function, a global optimization scheme such as particle swarm optimization can lead to a number of different stable sleep-wake scenarios.

Cavendish Q. McKay, David Hickman, Max Kenngott
Marietta College
cavendish.mckay@marietta.edu, dah003@marietta.edu, mmk002@marietta.edu

### CP8

### Increased Solution Quality for the Tsp with Ga Rank-Based Selection Method

This study examines the solution quality of some travelling salesman problem (TSP) instances solved with two genetic algorithm (GA) selection schemes; proportional roulette wheel and rank-based roulette wheel. By using the same crossover and mutation operation, the results show that rank-based selection outperformed proportional selection in reaching minimum travelling distance within acceptable computation time. Results also reveal that proportional selection becomes susceptible to premature convergence as problem size increases.

Noraini Mohd Razali
Ms.
norainimbr@ump.edu.my

### CP8

### Metamodel-Based Global Optimization Using Dynamic Radial Basis Function

To enhance the efficiency of modern engineering optimizations involving computational-intensive models, metamodels become more and more attractive. The main contribution of this work is to explore a new dynamic metamodel approach based on radial basis function, which improves the approximate accuracy of metamodel in the region which designers are interested in, and makes optimization converged to the global optimization with minimum evaluations of expensive models. In several testing problems, the efficiency of SRBF is demonstrated.

Lei Peng
School of Areospace Engineering
Beijing Institute of Technology
penglay312@gmail.com

Li Liu, Teng Long
School of Aerospace Engineering
Beijing Institute of Technology
liuli@bit.edu.cn, bitryu@gmail.com

### CP8

### Midaco on Continuous and Mixed Integer Space Applications

MIDACO is a novel software for global optimization of continuous, combinatorial and mixed integer problems. The software is based on a stochastic Gauss approximation algorithm (also known as *Ant Colony Optimization*) that incorporates the *Oracle Penalty Method* to handle nonlinear equality and inequality constraints. This contribution discusses the application of MIDACO on some challenging optimization problems arising from space applications. This is the well known set of continuous GTOP benchmark problems published by the ESA/ACT and a mixed integer multi stage optimal control application, representing a multi gravity assist interplanetary space mission. Comparing the performance with other approaches on the GTOP benchmark set, MIDACO obtains very good results and even reveals new best known solutions in some cases. In case of the mixed integer interplanetary mission, MIDACO is able to provide a first solution to this kind of complex application.

Martin Schlueter
School of Mathematics
University of Birmingham (UK)
martin@midaco-solver.com

Matthias Gerdts
University of Wuerzburg
Germany
gerdts@mathematik.uni-wuerzburg.de

Jan Rueckmann
University of Birmingham
UK
ruckmanj@for.mat.bham.ac.uk

**CP8**

**Optimal Positioning of Microphones for Engine Noise Measurement**

With an ever increasing air traffic,the reduction of noise pollution due to engines is a major issue for aircraft manufacturers.The prediction of the acoustic sources inside the nacelle is essential to master the acoustic radiation of the engine and design noise reduction solution. Moreover, test facilities have to be optimized in terms of microphones positioning and number. An inverse method allowing to rebuild acoustic sources from microphones measurement is presented. It is based on a 3D parallel Boundary Elements Method solving the acoustic waves equation in the frequency domain and using a transfer matrix formulation. The inverse problem is solved by a least square minimization approach. Finally, a heuristic based on local search on a discretized subspace of possible locations (hill climbing, tabu search) is presented to solve the problem of optimal microphones positioning. The purpose is to find the location and the minimum number of microphones that reconstructs at best an a priori known source.

Vassili Srithammavanh, Régis Lebrun, Stéphane alestra
EADS INNOVATION WORKS
vassili.srithammavanh@eads.net, regis.lebrun@eads.net, stephane.alestra@eads.net

**CP9**

**Milano: A Matlab-Based Toolbox for Minlp**

In this talk, we present details of MILANO (Mixed-Integer Linear and Nonlinear Optimizer), a Matlab-based toolbox for solving mixed-integer optimization problems. For MINLP, it includes implementations of branch-and-bound and outer approximation algorithms and solves the nonlinear subproblems using an interior-point penalty method introduced by Benson and Shanno (2005) for warmstarts. Special consideration is given for problems with cone constraints. Numerical results will be presented.

Hande Y. Benson
Drexel University
Department of Decision Sciences
benson@drexel.edu

**CP9**

**A New (Parallel) Algorithm for Nonlinear Programming**

We propose a new parallel algorithm for solving the general nonlinear constrained optimization problem on a set of shared-memory parallel processors. The algorithm is not a direct parallelization of an existing method. The objective in its design is to achieve an inherently parallel algorithm that performs comparable to the state-of-the-art methods even when sequentially applied. The algorithm only requires the solution of a sequence of unconstrained problems and linear programs that are interrelated but can be solved concurrently to a degree. We provide numerical examples illustrating the potential of the proposed algorithm and study its convergence behavior.

Figen Oztoprak
Sabanci Univeristy
figen@su.sabanciuniv.edu

Ilker S. Birbil
Sabanci University
sibirbil@sabanciuniv.edu

**CP9**

**A Hybrid Optimization Algorithm for Solving Time Dependent Pde-Constrained Optimization Problems**

One approach to solving time dependent PDE problems on parallel machines is to divide the time into intervals and estimate (by solving the problem on a coarse mesh first) the initial conditions. One can then iterate to make the solution across the intervals be smooth. We describe a method that integrates such an approach with the additional requirement to optimize some objective. We illustrate the algorithm by applying it to the optimal control of a flapping wing and using a modified version of the code PITA (Parallel Implicit Time-integration Algorithm).

Walter Murray
Dept of Management Science and
Engineering, Stanford University
walter@stanford.edu

Youngsoo Choi
Stanford University
yc344@stanford.edu

**CP9**

**Recent Advances in Solving Milp Problems with Sas**

We give an overview of SAS software to solve various types of optimization problems with a focus on mixed integer linear programming. The talk discusses current research topics of the SAS/OR development team including search strategies, heuristics and LP integration.

Philipp M. Christophel
SAS Institute Inc.
Philipp.Christophel@sas.com

**CP9**

**Structure-Exploiting Parallel Solver for Tree-Sparse KKT Systems**

By exploiting the rich hierarchical structure in KKT systems of tree-sparse programs recursive algorithms not only reduce the solution computation to linear complexity but are also well suited for massive parallelization. A sophisticated separation of the underlying tree structure reduces communication and idle time and leads to an ideal exploitation of the multicore system with an almost linear speedup. The parallel approach and computational results with shared and distributed memory systems will be presented.

Jens Hübner
Institute of Applied Mathematics
Leibniz Universität Hannover
huebner@ifam.uni-hannover.de

Marc Steinbach
Leibniz Universität Hannover
steinbach@ifam.uni-hannover.de

**CP10**

**Convergence Analysis of a Family of a Family of Damped Quasi-Newton Methods for Nonlinear Op-**

**timization**

In this talk we will extends the technique in the damped BFGS method of Powell (Algorithms for nonlinear constraints that use Lagrange functions, Math. Programming, 14: 224–248, 1978), in augmented Lagrange and SQP methods for constrained ptimization, to a family of quasi-Newton methods with applications to unconstrained optimization problems. An appropriate way for defining this damped-technique will be suggested to enforce safely the positive definiteness property for all quasi-Newton positive and indefinite updates. It will be shown that this technique maintains the global and superlinear convergence property of a restricted class of quasi-Newton methods for convex functions. This property is also enforced on an interval of nonconvergent quasi-Newton methods. Numerical experiences will be described to show that the proposed technique improves the performance of quasi-Newton methods substantially in certain robust cases (eg, the BFGS method) and significantly in inefficient cases (eg, the DFP method).

Mehiddin Al-Baali
Sultan Quaboos University
albaali@squ.edu.om

### CP10

### On the Solution of the Gps Localization and Circle Fitting Problems

We consider the problem of locating a user's position from a set of noisy pseudoranges to a group of satellites. Two different formulations are studied: the nonlinear least squares formulation in which the objective function is nonconvex and nonsmooth, and the nonlinear squared least squares variant in which the objective function is smooth, but still nonconvex. We show that the squared least squares problem can be solved efficiently, despite is nonconvexity. Conditions for attainment of the optimal solutions of both problems are derived. The problem is shown to have tight connections to the well known circle fitting and orthogonal regression problems. Finally, a fixed point method for the nonlinear least squares problems is derived and analyzed.

Amir Beck
Faculty of Industrial Engineering and Management
TECHNION - Israel Institute of technology
becka@ie.technion.ac.il

Dror Pan
Technion - Israel Institute of Technology
drorpan@tx.technion.ac.il

### CP10

### A Globaly Convergent Inexact Restoration Method Using Lagrange Multipliers

In this work we present a new Inexact Restoration method, combining the basic ideas of the Fischer-Friedlander method with the use of Lagrange multipliers, a sharp Lagrangian as a merit function, and the use of a quadratic model in the optimization fase. We show an example in which the original method suffers from the Maratos effect but not ours. Also a watchdog strategy combining this new global method with the Birgin-Martínez local method is proposed.

Luis Felipe Bueno
Unicamp
lfelipe@ime.unicamp.br

José Mario Martínez
Department of Applied Mathematics
State University of Campinas
martinez@ime.unicamp.br

### CP10

### Constrained Optimization Algorithms Using Directions of Negative Curvature

In this work, we show how to include low cost procedures to improve directions of negative curvature within an interior-point algorithm for constrained optimization, extending results for the unconstrained case. The key feature is that the directions are computed within the null subspace of the Jacobian matrix of the constraints. Finally, some numerical experiments are presented, including real problems from the CUTEr collection, and simulated problems with a controlled spectral structure.

Javier Cano, Javier M. Moguerza
Rey Juan Carlos University
javier.cano@urjc.es, javier.moguerza@urjc.es

Francisco J. Prieto
Carlos III University
fjp@est-econ.uc3m.es

### CP10

### A Sparse Augmented Lagrangian Algorithm for Minimizing the Kohn-Sham Energy

With the constantly increasing power of computers, the realm of experimental chemistry is increasingly being brought in contact with the field of computational mathematics. In particular, the ability to compute the charge density, i.e., the probabilistic location of a molecule's electrons, allows numerous properties of matter to be displayed graphically, as opposed to investigated in the chemistry lab. As many current methods scale at a rate proportional to the cube of the number of atoms, such problems are still too large for direct *ab initio* computations. This work describes recent advances in using an augmented Lagrangian approach to minimizing a specific energy function under orthogonality-constraints. Scaling is obtained by relaxing full-orthogonality and exploiting the local properties of the molecular systems in question.

Marc Millstone
Courant Institute of Mathematical Sciences
New York University
millstone@cims.nyu.edu

Chao Yang
Lawrence Berkeley National Lab
CYang@lbl.gov

Michael L. Overton
New York University
Courant Instit. of Math. Sci.
overton@cs.nyu.edu

Juan C. Meza
Lawrence Berkeley National Laboratory
JCMeza@lbl.gov

### CP10

### Can Directional Hessian Refinement Reduces

**Quasi-Newton Iterations by More Than Half?**

Directional Hessian refinement was recently proposed for BFGS quasi-Newton method with BFGS as the refiner, approximately halving iteration numbers but doubling cost in each iteration. Here we report experiments in which DFP is used as the refiner for the DFP quasi-Newton method. Experimental data showed that the DFP refiner consistently reduces iteration numbers substantially for problems for which the DFP method converges slowly, and in one case it reduced iterations from 3975 to 73.

Yu Zhuang
Texas Tech University
zhuang@cs.ttu.edu

**CP11**

**Lll-Based Polynomial Time Algorithm for Integer Knapsacks**

In this talk we will discuss a recent application of lattice basis reduction to the computational integer knapsack problem. We obtain a LLL-based polynomial time algorithm that solves the problem subject to a geometric constraint.

Iskander Aliev
Cardiff University
alievi@cf.ac.uk

**CP11**

**Cutting Planes for Mixed Integer Programs with Quadratic Constraints and Objectives**

We discuss some heuristics to generate cutting planes for mixed-integer programs which have quadratic constraints or a quadratic objective, and present computational results on a a number of instances, including some from Mittelmann's library of instances.

Sanjeeb Dash
IBM T.J. Watson Research Center
sanjeebd@us.ibm.com

Marcos Goycoolea
Universidad Adolfo Ibanez, Chile
mgoycool@uai.cl

**CP11**

**A Polynomial-time Algorithm for Separable Convex Minimization over N-fold 4-block Decomposable IPs**

In this talk, we generalize $N$-fold IPs and two-stage stochastics IPs with $N$ scenarios to $N$-fold 4-block decomposable integer programs. We show that for fixed blocks but variable $N$, these integer programs are polynomial-time solvable for any separable convex function that is to be minimized. This implies, for example, that for given fixed network, stochastic integer multi-commodity flow problems can be solved in polynomial time in the number of scenarios and commodities and in the binary encoding length of the input data.

Raymond Hemmecke
Dept. of Mathematics
Technische Univ. Munchen Germany
hemmecke@ma.tum.de

Matthias Köppe
Dept. of Mathematics
University of California, Davis, USA
mkoeppe@math.ucdavis.edu

Robert Weismantel
ETH Zuerich
robert.weismantel@ifor.math.ethz.ch

**CP11**

**Irreducible Infeasible Sets in Convex Integer Programs**

In this paper we address the problem of the infeasibility of systems defined by convex inequality constraints, where some or all of the variables are integer. In particular, we provide an algorithm that identifies a set of all constraints that may affect a feasibility status of the system after some perturbation of the right-hand sides. Furthermore, we analyse properties of the irreducible infeasible sets and we investigate the problem of the maximal consistent partition, showing that for the considered class of convex functions the system can be partitioned into two subsystems each of which has an integer solution.

Wieslawa T. Obuchowska
Department of Mathematics
Chowan College
obuchowskaw@ecu.edu

**CP11**

**Designing An Efficient Branch-and-Bound Approach for Exact Mixed-Integer Programming**

We present a hybrid symbolic-numeric approach for solving mixed-integer-programming problems exactly over the rational numbers. By performing many operations using fast floating-point arithmetic and then verifying and correcting results using symbolic computation, exact solutions can be found without relying entirely on rational arithmetic. Computational results will be presented based on an exact branch-and-bound algorithm implemented within the constraint integer programming framework SCIP.

Daniel Steffy
GeorgiaTech
desteffy@gmail.com

William Cook
Georgia Institute of Technology
bico@isye.gatech.edu

Thorsten Koch, Kati Wolter
Zuse Institute Berlin
koch@zib.de, wolter@zib.de

**CP12**

**An Optimal Control of Probability Density Functions of Stochastic Processes with the Fokker-Planck Formulation**

An optimal control strategy of stochastic processes is formulated by using the Fokker-Planck model. The control objectives are defined based on the probability density functions and the optimal control is achieved as the minimizer of the objective under the constraint given by the Fokker-Planck equation. The purpose of the control is attaining a final target configuration, or tracking a desired

trajectory, for which a receding-horizon algorithm over a sequence of time windows is implemented.

Mario Annunziato
Università degli Studi di Salerno
Dipartimento di Matematica e Informatica
mannunzi@unisa.it

**CP12**

**Optimal Flow Control Based on POD for the Cancellation of Tollmien-Schlichting Waves by Plasma Actuators**

We present a Model Predictive Control approach for the cancellation of Tollmien-Schlichting waves in the boundary layer. To control the flow a bodyforce is induced by a plasma actuator. Proper Orthogonal Decomposition is used for the low-order description of the flow model. We show methods for improving the reduced model whose quality is verified in comparison to the results of a Finite Volume based Large Eddy simulation. Numerical results of the cancellation will be presented.

Jane Elsemüller
Technische Universität Darmstadt
Graduate School of Computational Engineering
elsemueller@gsc.tu-darmstadt.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

**CP12**

**Crank-Nicolson and Störmer-Verlet Discretization Schemes for Optimal Control Problems with Parabolic Partial Differential Equations**

In this talk we present a family of second order discretization schemes for parabolic optimal control problems based on Crank-Nicolson schemes with different time discretizations for state and adjoint state so that discretization and optimization commute. One of the schemes can be explained as the Störmer-Verlet scheme. So we can interpret the method in the context of geometric numerical integration. The Hamiltonian structure of parabolic optimal control problem is also discussed.

Thomas Flaig
Universität der Bundeswehr München
Institut für Mathematik und Bauinformatik
thomas.flaig@unibw.de

Thomas Apel
Universität der Bundeswehr München
thomas.apel@unibw.de

**CP12**

**Multilevel Optimization for Flow Control with Discrete Adjoints**

We present a technique to efficiently obtain the discrete adjoint via a sparsity-exploiting forward mode of Automatic Differentiation. This approach has been applied to a fast CFD code including turbulence models. Using the adjoint, we can apply multilevel optimization techniques. These are well suited for flow control problems, since we have different discretization levels and models of increasing complexity (POD, RANS, LES). Numerical results including unsteady problems and shape optimization will be given.

Rolf Roth
TU Darmstadt
rroth@mathematik.tu-darmstadt.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

**CP12**

**Optimal Control of a Melt Flow in Laser Cutting**

We consider optimal control for a mathematical model of a melt flow in laser cutting. The optimization goal is to find a laser intensity function that keeps the two free boundaries of the flow region as close as possible to the stationary solution. The dynamical behavior of the free boundaries is described by a system of two nonlinear coupled partial differential equations. We discuss theoretical aspects and propose a numerical solution.

Georg Vossen
Nonlinear Dynamics of Laser Processing (NLD)
RWTH Aachen University
georg.vossen@nld.rwth-aachen.de

**CP13**

**Shortest Path Estimation of Mra Images Using Genetic Algorithm**

MRA, a technique used to detect vascular pathologies during brain surgery, provides 3D data of cerebral vascular structures. Where it is difficult to access the region of interest, the best point of entry is found. Choosing the shortest path with the minimum inconvenience is a routing problem. We discuss the use of Genetic Algorithm to estimate the shortest path between two points in the system of blood vessels in the brain using skeletonized MRA images.

Anthony Y. Aidoo
Eastern Connecticut State University
aidooa@easternct.edu

Joseph Ackora-Prah
Kwame Nkrumah University of Science and Technolygy
Kumasi, Ghana
ackoraprah@yahoo.co.uk

**CP13**

**Influenza Vaccination Strategies When Supply Is Limited**

The aim of this work is to find alternatives that mitigate the transmission of influenza via limited vaccination in a finite (200 days) time period. To understand the dynamics of transmission we will use an extension of the SIR model with data from the 1918-19 Pandemic Influenza. We use optimal control techniques to explore these constraints and provide a more realistic approach that public health Policy makers can work with when facing a Pandemic threat.

Romarie Morales
Arizona State University
romarie.morales@asu.edu

Sunmi Lee
Mathematical, Computational and Modeling Sciences Center,
Arizona State University,
mathever@gmail.com

Carlos Castillo-Chavez
Arizona State University and
Department of Mathematics
ccchavez@asu.edu

**CP13**

**A Multiple Sequence Alignment Algorithm based on Compression**

Multiple alignments play an important role in detecting conserved subregions among biological sequences and inferring evolutionary history. Many alignment methods that exist to date do not use the specific properties of biological sequences and suffer from bad quality or high computational cost. Here, we introduce an approach that is based on compression and combinatorial optimization techniques. It uses common subsequences to produce alignments and therefore runs faster on sets of sequences that share common properties.

Susanne Pape
FAU Uni-Erlangen, Germany
Chair of EDOM
susanne.pape@math.uni-erlangen.de

Sebastian Pokutta
Massachusetts Institute of Technology
sebastianpokutta@me.com

Alexander Martin
University of Erlangen-Nürnberg
alexander.martin@math.uni-erlangen.de

**CP13**

**Parameters Optimization in S-System Models using Population-based Reverse Engineering Methods**

Reverse Engineering can be considered as a process from which is possible inferring structural and dynamics features of a given system from external observations and relevant knowledge. RE techniques play a central role in systems biology, since it is not only important a knowledge of genes and proteins, but also to understand their structures and dynamics. RE works for inferring genetic networks are based on evolutionary algorithms, because they are applicable where mathematical analysis fail.

Mario Pavone
Dept. of Maths and C.S. - University of Catania
mpavone@dmi.unict.it

**CP14**

**A Multistage Stochastic Optimization Model for Livestock Production**

In this work the authors presents a stochastic optimization model for planning piglet production as a decision support tool in the first stage of the pig supply chain. The model includes the uncertainty in the sow biological behaviour as well as in future prices, under a finite set of possible scenarios. The proposed model provides an optimal replacement policy and schedules purchases of gilts during a medium term planning horizon, based on weekly periods. In our opinion, the stochastic programming framework provides a flexible and effective decision support tool for planning production of swine farm.

Victor M. Albornoz
Univ Tech Fed Santa Maria
Departamento de Industrias
victor.albornoz@usm.cl

Lluis M. Plà
Departamento de Matemática.
Universidad de Lleida
lmpla@matematica.udl.cat

SARA V. Rodríguez-Sánchez
Facultad de Ingeniera Mecánica y Eléctrica
Universidad Autónoma de Nuevo León.
sara@yalma.fime.uanl.mx

**CP14**

**Optimization of Environmental Adaptation Policies**

Economic-environmental model with vintage capital is constructed to analyze the optimal balance among different categories of investments into the environmental adaptation that compensate negative consequences of environmental hazards and changes. The model distinguishes three categories of adaptation measures that compensate the decrease of the environmental amenity value, compensate the decrease of total productivity, and develop new hazard-protected capital and technology. The results provide insight into rational environmental adaptation policies.

Natali Hritonenko
Prairie View A&M University
nahritonenko@pvamu.edu

Yuri Yatsenko
Houston Baptist University
yyatsenko@hbu.edu

**CP14**

**Hydrocarbon Reservoir Production Optimization under Uncertainty - A Case Example**

Sequential Bayesian inversion methods are entering the domain of updating the knowledge one has about physical properties of a reservoir from production measurements. One example of these methods is the ensemble Kalman filter. The result of such methods is an ensemble of models representing the posterior uncertainty. The task is to apply production optimization methods to the ensemble. We present an evolutionary algorithm-based approach to that problem and apply it to a fairly large benchmark case.

Oliver Pajonk
Institute of Scientific Computing
Technische Universität Braunschweig
o.pajonk@tu-bs.de

Ralf Schulze-Riegert
SPT Group GmbH
ralf.schulze-riegert@sptgroup.com

Hermann G. Matthies
Institute of Scientific Computing
Technische Universität Braunschweig
wire@tu-bs.de

**CP14**

**Communication Complexity of Scheduling Problems**

Motivated by an application from aviation, the optimal utilization of runways, we study the communication complexity of scheduling problems. In aviation, there exist an arrival and a departure planning tool which have to communicate to obtain an optimal schedule.
Considering feasibility problems, we investigate communication protocols for scheduling problems. Therefore, we analyze monochromatic rectangles in symmetric scheduling matrices. Furthermore, their relation to protocols and proofs of lower bounds are presented.

Andrea Peter
University Erlangen-Nürnberg
andrea.peter@math.uni-erlangen.de

Alexander Martin
University of Erlangen-Nürnberg
alexander.martin@math.uni-erlangen.de

Sebastian Pokutta
Massachusetts Institute of Technology
sebastianpokutta@me.com

**CP14**

**Piecewise Monotonic Regression Algorithm for Problems Comprising Seasonal and Monotonic Trends**

In this research piecewise monotonic models for problems comprising seasonal cycles and monotonic trends are considered. In contrast to the conventional piecewise monotonic regression algorithms, our approach can efficiently exploit a priori information about temporal patterns. It is based on reducing these problems to monotonic regression problems defined on partially ordered data sets. The latter are large-scale convex quadratic programming problems. They are efficiently solved by the GPAV algorithm.

Amirhossein Sadoghi
Department of Computer Science
Linköping University
amisa242@student.liu.se

Oleg Burdakov
Linkoping University
olbur@mai.liu.se

Anders Grimvall
Department of Computer Science
Linköping University,Sweden
anders.grimvall@liu.se

**CP14**

**Smaller Compact Formulation for Lot-Sizing with Constant Batches**

We consider a variant of the classical lot-sizing problem in which the capacity in each period is an integer multiple of some basic batch size. Pochet and Wolsey (Math. Oper. Res. 18, 1993) presented an $O(n^2 \min\{n, C\})$ algorithm to solve this problem and a linear program with $MO(n^3)$ variables and inequalities, where $n$ is the number of periods and $C$ the batch size. We provide a linear program of size $O(n^2 \min\{n, C\})$, that is, for $C < n$, our formulation is smaller.

Ruediger Stephan
Technische Universität Berlin
stephan@math.tu-berlin.de

**CP15**

**Survivable Network Design Using 3 and 4-Partition Facets**

Given a graph G and a set of traffic demand among nodes of G, the problem is to find minimum cost capacity installation on the edges of G, which will permit a feasible routing of all traffic under any single edge failure. We derive several families of facets based on 3- and 4-partitions of G to derive very tight lower bounds, and report optimal solutions on problems of up to 35 nodes and 70 edges.

Yogesh K. Agarwal
Indian Institute of Management, Lucknow, India
yka@iiml.ac.in

**CP15**

**Local Search for Hop-Constrained Directed Steiner Tree Problem with Application to UAV-Based Multi-Target Surveillance**

Given a weighted directed graph with a selected root node and a set of terminal nodes, the directed Steiner tree problem (DSTP) is to find a directed tree of the minimal weight which is rooted in the root node and spanning all terminal nodes. We consider the DSTP with a constraint on the total number of arcs (hops) in the tree. This problem is known to be NP-hard, and therefore, only heuristics can be applied in the case of its large-scale instances. For the hop-constrained DSTP, we propose local search strategies aimed at improving any heuristically produced initial Steiner tree. They are based on solving a sequence of hop-constrained shortest path problems for which we have recently developed efficient label correcting algorithms. The approach presented in this talk is applied to solving the problem of 3D placing unmanned aerial vehicles (UAVs) used for multi-target surveillance. The efficiency of our algorithms is illustrated by results of numerical experiments.

Oleg Burdakov
Linkoping University
olbur@mai.liu.se

Patrick Doherty
Dept. of Computer and Information Science
Linkoping University
patrick.doherty@liu.se

Kaj Holmberg
Department of Mathematics
Linkoping University
kahol@mai.liu.se

Jonas Kvarnström, Per-Magnus Olsson
Dept. of Computer and Information Science
Linkoping University
jonas.kvarnstrom@liu.se, per-magnus.olsson@liu.se

**CP15**

**Graph Products for Faster Separation of Wheel Inequalities**

A stable set in a graph $G$ is a set of pairwise nonadjacent vertices. The problem of finding a maximum weight stable set is one of the most basic NP-hard problems. An important approach to this problem is to formulate it as the problem of optimizing a linear function over the convex hull STAB($G$) of incidence vectors of stable sets. Then one has to solve separation problems over it. Cheng and Cunningham (1997) introduced the wheel inequalities and presented an algorithm for their separation using time $O(n^4)$ for a graph with $n$ vertices and $m$ edges. We present a new separation algorithm running in $O(mn^2 + n^3 \log n)$.

Sven De Vries
Universität Trier
devries@uni-trier.de

**CP15**

**Optimization Methods for Radio Resource Management**

We consider heuristic methods for wireless telecommunications cellular systems in which each base station manages the orthogonal radio resources for its own users. Inter-cell interference is an issue if nearby cells simultaneously use the same resource. We discuss the fairness issue for users in the system. We have previously shown that our optimization problem is NP-hard and even inapproximable, unless P is equal to NP.

Mikael P. Fallgren
Royal Institute of Technology (KTH)
Optimization and Systems Theory
werty@kth.se

**CP15**

**A Continuous Quadratic Programming Formulation of the Vertex Separator Problem**

A vertex separator of a connected graph $G$ is a subset of vertices $A$ whose removal splits $G$ into two disconnected subsets $B$ and $C$. The Vertex Separator Problem is the problem of finding the smallest such subset $A$ when $B$ and $C$ are subject to size constraints. We formulate the VSP as a continuous quadratic program and provide necessary and sufficient conditions for local optimality which depend only on the edges in the graph.

James T. Hungerford
University of Florida
Department of Mathematics
freerad@ufl.edu

William Hager
University of Florida
hager@ufl.edu

**CP15**

**Algorithms for Computing a Hamiltonian Cycle by Minimizing a Smooth Function**

The holy grail of solving hard binary optimization problems is to find a smooth function whose minimizer are all binary. We discuss algorithms based on a result that shows minimizing a determinant of a matrix whose variables are the elements of the adjacency matrix of graph is such a function whose global minimizer is a Hamiltonian cycle. Finding the global minimizer is not without issues most of which are caused by symmetry induced from the existence of multiple Hamiltonian cycles. We show that the use of directions of negative curvature is instrumental is breaking this symmetry.

Walter Murray
Dept of Management Science and
Engineering, Stanford University
walter@stanford.edu

Jerzy Filar
CIAM
University of South Australia
jerzy.filar@unisa.edu.au

Michael Haythorpe
University of South Australia
michael.haythorpe@unisa.edu.au

**CP16**

**First-Order Methods for Convex Optimization with Inexact Oracle**

We introduce a new definition of inexact oracle for convex optimization problems, and study the first-order methods (classical and fast gradients) based on this oracle. We link oracle accuracy and achievable solution accuracy, and show that only fast gradient suffers from error accumulation, casting a doubt over its absolute superiority over the classical gradient. We present applications to saddle-point problems and obtain a universal optimal method for smooth and non-smooth convex problems.

Olivier Devolder
Center for Operations Research and Econometrics
Université catholique de Louvain
Olivier.Devolder@uclouvain.be

François Glineur
Center for Operations Research and Econometrics
Universit
'e catholique de Louvain
francois.glineur@uclouvain.be

Yurii Nesterov
CORE
Universite catholique de Louvain
yurii.nesterov@uclouvain.be

**CP16**

**Bandgap Optimization of Photonic Crystals Via Semidefinite Programming and Subspace Methods**

The mathematical formulation of bandgap optimization problems is made tractable by discretizing and using the finite element method, yielding a series of finite-dimensional eigenvalue optimization problems that are large-scale and non-convex, with low regularity and non-differentiable objective. By restricting to appropriate eigen-subspaces, we reduce the problem to a sequence of small-scale convex semidefinite programs (SDPs) for which modern SDP solvers can be efficiently applied. Among several illustrations we show that it is possible to achieve optimized photonic crystals which exhibit multiple absolute bandgaps, whose structures show complicated patterns which are far different from existing photonic crystals.

Robert M. Freund
MIT
Sloan School of Management
rfreund@mit.edu

H. Men
National University of Singapore
men@nus.edu.sg

JOEL Saa-Seoane
M.I.T.
jsaa@mit.edu

Cuong Nguyen, Pablo A. Parrilo, Jaime Peraire
Massachusetts Institute of Technology
cuongng@mit.edu, parrilo@MIT.EDU, peraire@MIT.EDU

**CP16**

**An Optimal Algorithm for Minimizing Convex Functions on Simple Sets**

We describe an algorithm based on Nesterov's and on Auslender and Teboulle's ideas for minimizing a convex Lipschitz continuously differentiable function on a simple convex set (a set into which it is easy to project a vector). The algorithm does not depend on the knowledge of any Lipschitz constant, and it achieves a precision $\epsilon$ for the objective function in $O(1/\sqrt{\epsilon})$ iterations. We describe the algorithm and the main complexity result.

Clovis C. Gonzaga
Federal Univ of Sta Catarina
clovis@mtm.ufsc.br

Elizabeth W. Karas
Federal Univ. of Paraná, Brazil
Dep. of Mathematics
karas@mat.ufpr.br

Diane Rossetto
University of Sao Paulo, Brazil
dianerossetto@gmail.com

**CP16**

**Subgradient Methods for Convex Problem Based on Gradient Sampling**

We present a new subgradient algorithm, based on gradient sampling, to solve a nondifferentiable constrained convex optimization problem. Our motivation comes from the fact that the gradient is cheap to compute compared with the subgradient in many applications. We prove the convergence of our proposed algorithm for the primal problem. We also apply our algorithm to the Lagrangian dual of a convex constrained optimization problem. Numerical results demonstrate that our algorithms are comparable with some existing subgradient algorithms.

Yaohua Hu
The Hong Kong Polytechnic University
hyh19840428@163.com

Chee Khian Sim
Department of Applied Mathematics
The Hong Kong Polytechnic University
macksim@inet.polyu.edu.hk

Xiaoqi Yang
The Hong Kong Polytechnic University
mayangxq@polyu.edu.hk

**CP16**

**Implementation and Tests of An Optimal Algorithm for Minimizing Convex Functions on Simple Sets**

We summarize an algorithm described by the authors for minimizing continuously differentiable functions on simple sets, and incorporate to it adaptive procedures for using strong convexity constants. Then we show computational results comparing our method to optimal algorithms by Nesterov and by Auslender and Teboulle, and to other efficient methods for optimization on simple sets.

Elizabeth W. Karas
Federal Univ. of Paraná, Brazil
Dep. of Mathematics
karas@mat.ufpr.br

Clovis C. Gonzaga
Federal Univ of Sta Catarina
clovis@mtm.ufsc.br

Diane Rossetto
University of Sao Paulo, Brazil
dianerossetto@gmail.com

**CP16**

**Conjugate Gradient with Subspace Optimization**

In this talk, we present Conjugate Gradient with Subspace Optimization (CGSO), an algorithm for solving unconstrained optimization problems. CGSO is closely related to Nonlinear Conjugate Gradient and Nemirovsky-Yudin's algorithm from early 80's, with advantages from each. We will address issues on implementation of the algorithm as well as its properties and convergence rate. In addition to its efficiency in practice, CGSO has a convergence rate of $O(\log \frac{1}{\epsilon})$ for the class of strictly convex problems.

Sahar Karimi
University of Waterloo
s2karimi@math.uwaterloo.ca

Stephen A. Vavasis
University of Waterloo
Dept of Combinatorics & Optimization
vavasis@math.uwaterloo.ca

**CP17**

**GloptLab - A Configurable Framework for Global Optimization and Introducing the Test Environment**

GloptLab is an easy-to-use testing and development platform for solving quadratic optimization problems by using branch and prune and filtering. In order to avoid a loss of feasible points, rigorous error estimation using interval arithmetic and directed rounding are used. Various new and state-of-the-art algorithms implemented in GloptLab are used to reduce the search space: constraint propagation, linear relaxations, strictly convex enclosures, conic methods, probing and branch and bound. Other tech-

niques, such as finding and verifying feasible points, enable to find the global minimum of the objective function. The Test Environment is a free interface to efficiently test different optimization solvers. It is designed as a tool for both developers of solver software and practitioners who just look for the best solver for their specific problem class. It enables users to choose and compare diverse solver routines, organize and solve large test problem sets, select interactively subsets of test problem sets, perform a statistical analysis of the results and automatically produce a LaTeX and PDF output.

Ferenc Domes
Faculty of Mathematics, University of Vienna,
ferenc.domes@univie.ac.at

Arnold Neumaier
University of Vienna
Department of Mathematics
Arnold.Neumaier@univie.ac.at

Martin Fuchs
CERFACS
Parallel Algorithms Team
martin.fuchs81@gmail.com

Hermann Schichl
University of Vienna
Faculty of Mathematics
Hermann.Schichl@esi.ac.at

### CP17

### A Multi-Step Interior Point Warm-Start Approach for Stochastic Programming

We present an Interior Point based multi-step solution approach for stochastic programming problems, given by a sequence of scenario trees of increasing sizes. These trees can be seen as successively more accurate discretization of an underlying continuous probability distribution. Each problems in the sequence is warmstarted from the previous one. We analyse the resulting algorithm, argue that it yields improved complexity over either the coldstart or a naive two-step scheme, and give numerical results.

Andreas Grothey
School of Mathematics
University of Edinburgh
A.Grothey@ed.ac.uk

Marco Colombo
University of Edinburgh
m.colombo@ed,ac,uk

### CP17

### A Bound Constrained Interval Global Optimization Solver in the COCONUT Environment

In this presentation we introduce coco_gop_ex, a general purpose interval branch–and–bound solver for bound constrained global optimization. It is written as a solver component of the COCONUT Environment, a modular opensource software environment for global optimization. After running coco_gop_ex on over 150 standard bound constrained test problems, we concluded that is is competitive with current state–of–the–art GO solvers such as BARON and outperforms them in many cases.

Mihály Csaba Markót
Faculty of Mathematics
University of Vienna
mihaly.markot@univie.ac.at

Hermann Schichl
University of Vienna
Faculty of Mathematics
Hermann.Schichl@esi.ac.at

### CP17

### Surrogate Model Choice and Averaging Based on Dempster-Shafer Theory for Global Optimization Problems

The literature on solving global optimization problems using surrogate models shows that the surrogate model choice may greatly influence the solution quality. However, model uncertainty has thus far rarely been taken into account when deciding for a specific model. This talk therefore focuses on Dempster-Shafer theory for combining and selecting surrogate models during the optimization process. Advantages and disadvantages of this approach will be demonstrated on numerical experiments. This is a collaborative work between Tampere University of Technology and Cornell University.

Juliane Mueller
Tampere University of Technology
Visiting Researcher at Cornell University
juliane.mueller@tut.fi

Christine A. Shoemaker
Cornell University
cas12@cornell.edu

Robert Piché
Tampere University of Technology
robert.piche@tut.fi

### CP17

### Exclusion Regions for Global Optimization Problems

Interval methods for GO often have the difficulty that subboxes containing no solution cannot be easily eliminated if there is a nearby optimizer outside the box. Thus, near each solution, many small boxes are created by repeated splitting. We discuss how to reduce this so-called cluster effect by defining exclusion regions around each optimizer found, that are guaranteed to contain no other solution. The proposed methods are implemented in the COCONUT Environment for global optimization.

Hermann Schichl
University of Vienna
Faculty of Mathematics
Hermann.Schichl@esi.ac.at

Mihaly Csaba Markot
Faculty of Mathematics
University of Vienna
mihaly.markot@univie.ac.at

### CP17

### An Optimal Design of Ball Bearings Using Evolutionary Algorithms

In the optimum design of ball bearings the long life is one

of the most important criterions. For solving constrained non-linear optimization formulations, an optimal design methodology has been proposed by two evolutionary algorithms, namely the artificial bee colony and genetic algorithms. A sensitivity analysis of various design parameters, using the Monte Carlo simulation method, has been performed to see changes in the dynamic capacity. There is an excellent improvement found in optimized bearing designs.

Rajiv Tiwari
Professor, Department of Mechanical Engineering
IIT Guwahati
rtiwari@iitg.ernet.in

U. Venkatesu
Graduate Student, IIT Guwahati
venkatesu@iitg.ac.in

**CP18**

**Solving Highly Symmetric Integer Linear Programs**

We present a new algorithm which solves integer linear programs of dimension $n$ with symmetry groups isomorphic to the alternating or the symmetric group of order $n$. The main idea of the algorithm is to reduce the problem to a feasibility check of a linear number of certain points lying close to the fixed space of the symmetry group. This is joint work with Richard Bödi and Michael Joswig.

Katrin Herr
TU Darmstadt
herr@mathematik.tu-darmstadt.de

**CP18**

**A Bound for the Number of Different Basic Solutions Generated by the Simplex Method**

In this presentation, we give an upper bound for the number of different basic feasible solutions generated by the simplex method for linear programming problems having optimal solutions. The bound is polynomial of the number of constraints, the number of variables, and the ratio between the minimum and the maximum values of all the positive elements of primal basic feasible solutions. When the primal problem is nondegenerate, it becomes a bound for the number of iterations. We show some basic results when it is applied to special linear programming problems. The results include strongly polynomiality of the simplex method for Markov Decision Problem by Ye and utilize its analysis.

Tomonari Kitahara, Shinji Mizuno
Tokyo Institute of Technology
kitahara.t.ab@m.titech.ac.jp, mizuno.s.ab@m.titech.ac.jp

**CP18**

**Infeasible Constraint-Reduced Interior-Point for Linear Optimization**

Constraint reduction in the context of interior-point methods can yield substantial computational savings per iteration for linear programs with many more inequality constraints than variables in standard dual form. Previously proposed constraint-reduced algorithms require initial dual feasibility. Here an exact-penalty-based framework for *infeasible* constraint-reduced primal-dual interior-point algorithms, including a scheme for iterative adjustment of the penalty parameter, is proposed and analyzed. Promising numerical results with an MPC variant (which fits within the framework) are reported.

Andre L. Tits
University of Maryland, College Park
Dept of ECE and Institute for Systems Research
andre@umd.edu

Meiyun Y. He
University of Maryland, College Park
myhe@umd.edu

**CP18**

**The Accuracy of Interior-Point Methods Based on Kernel Functions**

Interior-point methods that use barrier functions induced by some real univariate kernel functions have been studied for the last decade. In these IPM's the algorithm stops when finds a solution such that is close enough (in the barrier function sense) to a point in the central path such that satisfies some accuracy conditions. But this does not directly imply that we got a solution that has the desired accuracy. In this talk, we analyze the accuracy of the solution produced by the mentioned algorithm.

Manuel Vieira
Delft University of Technology
mvcv@fct.unl.pt

**CP18**

**Strange Behaviors of Interior-Point Methods for Solving Semidefinite Programming Problems in Polynomial Optimization**

We observe that in a simple one-dimensional polynomial optimization problem (POP), the 'optimal' values of semidefinite programming (SDP) relaxation problems reported by the standard SDP solvers converge to the optimal value of the POP, while the true optimal values of SDP relaxation problems are strictly and significantly less than that value. Some pieces of circumstantial evidences for the strange behaviours of the SDP solvers are given. This result gives a warning to users of the SDP relaxation method for POPs to be careful in believing the results of the SDP solvers. We also demonstrate how SDPA-GMP, a multiple precision SDP solver developed by one of the authors, can deal with this situation correctly.

Hayato Waki
The University of Electro-Communications
waki@cs.uec.ac.jp

Maho Nakata
RIKEN
maho@riken.jp

Masakazu Muramatsu
University of Electro-Communications
muramatu@cs.uec.ac.jp

**CP18**

**Symmetry in the Basis Partition of the Space of Linear Programs**

A linear program (LP) is associated with an optimal basis.

The space of linear programs (SLP) can be partitioned into a finite number of sets, each consisting of all LPs with a common basis. If the partition of SLP can be characterized, we can solve infinitely many LPs in closed form. A tool for characterizing the partition of SLP is a dynamical system on the Grassmann manifold M'=h(M), where M is a projection matrix. An LP defines a projection matrix, starting from which the solution of M'=h(M) converges to a limit projection matrix which can determine the basis of the LP. Some properties on structures of the partition, in particular, symmetric structures, will be presented.

Gongyun Zhao
Department of Mathematics
National University of Singapore
matzgy@nus.edu.sg

**CP19**

**Flash Crash, Market Impact, and Stability of Optimal Execution Strategy**

The U.S. market Flash Crash on May 6, 2010 illustrated effect of trading impact and challenges in optimal execution. In this talk, I will describe market price and impact models which have been proposed for developing optimal execution algorithms. In addition, I will present properties of the resulting execution algorithms, describe sensitivity of execution strategies to market impact functions, and how to achieve better stability using robust optimization and regularized robust optimization. *This is joint work with T. F. Coleman and S. Moazeni

Yuying Li
School of Computer Science
University of Waterloo
yuying@uwaterloo.ca

**CP19**

**Optimization with Time-Periodic PDE Constraints: Numerical Methods and Applications**

Optimization problems with time-periodic parabolic PDE constraints can arise in important chemical engineering applications, e.g., in periodic adsorption processes. We present a novel direct numerical method for this problem class. The main numerical challenges are the high nonlinearity and high dimensionality of the discretized problem. The method is based on Direct Multiple Shooting and inexact Sequential Quadratic Programming with globalization of convergence based on natural level functions. We highlight the use of a generalized Richardson iteration with a novel two-grid Newton-Picard preconditioner for the solution of the quadratic subproblems. At the end of the talk we explain the principle of Simulated Moving Bed processes and conclude with numerical results for optimization of such a process.

Andreas Potschka
Interdisciplinary Center for Scientific Computing
University of Heidelberg
potschka@iwr.uni-heidelberg.de

Hans Georg Bock
IWR, University of Heidelberg
bock@iwr.uni-heidelberg.de

Johannes Schlőder
Interdisciplinary Center for Scientific Computing
University of Heidelberg
johannes.schloeder@iwr.uni-heidelberg.de

**CP19**

**A Class of Preconditioners for Newton-Krylov Methods in Large Scale Optimization**

In this work, we propose a class of preconditioners for Newton-Krylov methods in nonconvex large scale unconstrained optimization. We focus on the solution of the large scale (possibly indefinite) linear system which arises at each iteration of any truncated Newton method. In particular, we use the set of directions generated by Krylov subspace methods, as by product, to provide the preconditioners.

Massimo Roma
Dipartimento di Informatica e Sistemistica
SAPIENZA - Universita' di Roma
roma@dis.uniroma1.it

Giovanni Fasano
Dip. Matematica Applicata
Universita' Ca' Foscari di Venezia
fasano@unive.it

**CP19**

**On Saddle Points in Nonconvex Semi-Infinite Programming**

We apply two convexification procedures to the Lagrangian of a nonconvex semi-infinite programming problem. Under the reduction approach it is shown that, locally around a local minimizer, this problem can be transformed equivalently in such a way that the transformed Lagrangian fulfills saddle point optimality conditions. These results allow that local duality theory and corresponding numerical methods (e.g. dual search) can be applied to a broader class of nonconvex problems.

Jan-J Ruckmann
University of Birmingham
J.Ruckmann@bham.ac.uk

Francisco Guerra Vazquez
University of the Americas
francisco.guerra@udlap.mx

Ralf Werner
Hochschule Munich
ralf.werner@hm.edu

**CP19**

**Necessary Optimality Conditions for the O-D Matrix Adjustment Problem**

Most of the work on this topic has been based on assuming that the traffic assignment problem admits a unique optimal flow in a certain neighborhood, which is very strong. Hence, designing necessary optimality conditions for the problem appears to be crucial, since it is typically nonsmooth. Only Fritz-John's type necessary optimality conditions have been derived so far. In this talk, we present some approaches to obtain Karush-Kuhn-Tucker type optimality conditions using mathematical tools from variational analysis.

Alain B. Zemkoho, Stephan Dempe
Instiut of Numerical Mathematics and Optimization

TU Bergakademie Freiberg
zemkoho@student.tu-freiberg.de, dempe@tu-freiberg.de

**CP20**

**Simulation of Interface Evolution for Several Phases Using a Primal-Dual Active Set Method**

Interface evolution with applications including material science (e.g. grain growth), image processing and geology can be modelled using a phase field approach. In particular, we consider an Allen-Cahn variational inequality and include nonlocal constraints to guarantee mass conservation. Moreover, due to the consideration of several phases, we study a system of inequalities. Simulation in time leads to a sequence of optimization problems, where the unknowns are vector valued functions in space, which have to ly in the Gibbs-Simplex and additionally have to fulfill an integral condition. We propose and analyze a primal-dual active set method for the solution. Convergence of the algorithm is shown and numerical simulations in two and three dimensions as well as for two and more phases are presented demonstrating its efficiency.

Luise Blank
NWF I - Mathematik
Universität Regensburg
luise.blank@mathematik.uni-regensburg.de

**CP20**

**Wind Climatologies from a Mass-Consistent Wind Model for Small Terrain**

Wind measurements in Sri Lanka are sparse particularly in the hill country of Sri Lanka and interpolation of these observations provides unrealistic wind patterns in mountainous areas. Here we use a mass-consistent wind model that takes account of topography to compute monthly wind climatologies for Sri Lanka at a resolution of 6 km. The model predicts realistic wind fields and brings out the high wind speed at various gaps in the mountain ridges in Sri Lanka. Quantitative comparison with measurements at stations across Sri Lanka shows that the predictions are reasonably realistic. Thus this technique provides detailed and useful wind climatologies that can be used for research, development and applications purposes.

Ajith Gunaratne
Florida A & M University
Department of Mathematics
ajith.gunaratne@famu.edu

**CP20**

**Multi-Objective PDE Constrained Optimization for a 250 MeV Injector**

We present a PDE constrained multi-objective optimization model for the 250 MeV electron injector to be commissioned at Paul Scherrer Institut. Realizing good beam quality (compact in phase space) and attaining the design energy are crucial to achieve the desired performance. In this context, state of the art massively parallel multi-objective optimization algorithms will be instrumental for the optimal design of the injector. We discuss suitable multi-objective optimization algorithms and plans for their implementation.

Yves Ineichen
ETHZ
PSI
yves.ineichen@psi.ch

Andreas Adelmann
Paul Scherrer Institut
andreas.adelmann@psi.ch

Peter Arbenz
ETH Zurich
Chair of Computational Science
arbenz@inf.ethz.ch

Costas Bekas
IBM Research
Zurich Research Laboratory
BEK@zurich.ibm.com

Alessandro Curioni
IBM Research-Zurich
cur@zurich.ibm.com

**CP20**

**Sensitivity-Based Optimization of Navier-Stokes Problems with Heat Transfer**

This work presents the methodology of a sensitivity analysis utilizing the continuous sensitivity equation approach regarding laminar, incompressible fluid flows with heat transfer. The arising set of equations is solved with an efficient finite-volume solver on a block structured grid. Furthermore, the resulting sensitivities of the flow concerning changes in boundary conditions such as velocities and temperature as well as geometric variations using NURBS are presented via a generic testcase.

Johannes Siegmann, Julian Michaelis, Michael Schaefer
Fachgebiet Numerische Berechnungsverfahren
TU Darmstadt
siegmann@fnb.tu-darmstadt.de, michaelis@fnb.tu-darmstadt.de, schaefer@fnb.tu-darmstadt.de

**CP20**

**An Interior-Point Algorithm for Shakedown Analysis of Large-Scale Engineering Structures**

An interior-point algorithm for the computation of shakedown loads of large-scale engineering structures subjected to varying thermo-mechanical loading is presented. The according optimization problem is characterized by a large number of variables and constraints. Thus, the calculation can be computationally expensive and time-consuming. A selective algorithm is introduced to overcome this problem by dynamic reduction of the entire system to critical substructures. The method is illustrated by numerical examples in mechanical engineering.

Jaan W. Simon, Dieter Weichert
Institute of General Mechanics
RWTH Aachen University
simon@iam.rwth-aachen.de, weichert@iam.rwth-aachen.de

**CP20**

**An Iterative Regularization Algorithm for Optimization in Parameters Identification Problems.**

In this work we present an iterative regularization algorithm for solving a parameter identification problem relative to a system of diffusion, convection and reaction equa-

tions (state equations). The parameters to be identified are the diffusivity and reaction terms. The problem is solved by means of a succession of nonlinear constrained optimization problems. The problems are ill-posed and need regularization. For each problem, the proposed algorithm computes the sequence of regularization parameters by using the lagrangian dual formulation of the constrained optimization problem. The state parameters are computed by truncated iterative solution of the inner system. The effectiveness of the method is evaluated on 1D and 2D test problems with different levels of noise in the measurements.

Fabiana Zama
Department of Mathematics, University of Bologna
zama@dm.unibo.it

Elena Loli Piccolomini
Department of Mathematics,
University of Bologna
piccolom@dm.unibo.it

**CP21**

**Scenario Decomposition of Risk-Averse Multistage Stochastic Programming Problems**

For a risk-averse multistage stochastic optimization problem with a finite scenario tree, we introduce a new scenario decomposition method and we prove its convergence. The main idea of the method is to construct a family of risk-neutral approximations of the problem. The method is applied to a risk-averse inventory and assembly problem.

Ricardo A. Collado
IOMS-Operations Management Group
Stern School of Business, NYU
rc134@nyu.edu

Andrzej Ruszczynski
Rutgers University
MSIS Department
rusz@business.rutgers.edu

David Papp
Rutgers Center for Operations Research
dpapp@rutcor.rutgers.edu

**CP21**

**Uncertainty Modeling for Robust Optimization**

Polyhedral clouds have recently demonstrated strength in dealing with higher dimensional uncertainties in robust optimization, even in case of partial ignorance of statistical information. However, in real-life applications the computational effort to account for robustness, i.e., to find worst-case scenarios, should not exceed certain limitations. We propose a simulation-based approach for optimization over a polyhedron, inspired by the Cauchy deviates method. Thus we achieve a tractable method to compute worst-case scenarios with polyhedral clouds.

Martin Fuchs
CERFACS
Parallel Algorithms Team
martin.fuchs81@gmail.com

**CP21**

**A Sparsity Preserving Stochastic Gradient Descent Algorithm**

In this paper, we propose new stochastic gradient descent algorithms for solving convex composite optimization problems. Our algorithms utilize a stochastic approximation of the gradient of the smooth component of objective functions in each iteration. We prove that the expectation and the variance of the solution errors converge to zeros. The convergence rates are proved using the arguments of stochastic estimate sequences. When applied to regularized regression problems, our algorithms distinguish from other stochastic gradient methods by preserving sparsity structures in the solutions in all iterations.

Qihang Lin
Carnegie Mellon University
Tepper School of Business
qihangl@andrew.cmu.edu

Xi Chen
Carnegie Mellon University
School of Computer Science
xichen@cs.cmu.edu

Javier Peña
Carnegie Mellon University
Tepper School of Business
jfp@andrew.cmu.edu

**CP21**

**Efficient Bayesian Updating of Parameters for Heat and Moisture Transport in Heterogenous Materials**

The Bayes formula can be used to provide a reliable estimation of the probability distributions of heat and moisture transport in structures. It combines a priori information about material properties and measurment data. We present a new method to numericaly compute a Bayes update in a direct, fast and reliable manner. As an example we focus on the description of heterogeneous material which includes the uncertainty in material parameters together with its spatial fluctuations.

Bojana V. Rosic
Institute of Scientific Computing
TU Braunschweig
bojana.rosic@tu-bs.de

Hermann G. Matthies, Oliver Pajonk
Institute of Scientific Computing
Technische Universität Braunschweig
wire@tu-bs.de, o.pajonk@tu-bs.de

ANNA Kucerova, JAN Sykora
Faculty of Civil Engineering, Prague, Czech TU
anicka@cml.fsv.cvut.cz, jan.sykora.1@fsv.cvut.cz

**CP21**

**Bundle Methods for Hydro Reservoir Management with Joint Chance Constraints**

In the electrical industry, offer-demand equilibrium problems for hydrothermal systems are often solved by using price decomposition techniques. In this setting, the particular sub-problems optimizing one hydraulic valley are typically large-scale combinatorial network flow problems. The combinatorial nature of such problems is due to complex dynamic constraints on the watershed controls. For these reasons, such problems are often considered in a deterministic setting, even though reservoir streamflow is uncertain in practice. We propose to tackle uncertainty (in a continuous setting, without complex watershed constraints) by formulating the flow constraints using joint chance constraints. We consider inflows following any causal time series model with Gaussian innovations. The sub-problem is convex, with probabilistic constraints defined in a highly dimensional cube that can be efficiently evaluated by the so-called Genz code. Since the cutting planes technique takes too many iterations to converge to an accurate solution rapidly, we consider how to use a constrained variant of the bundle method, capable of handling inaccurate subgradient calculations. The approach is assessed on a real-size hydro-sub-problem typical of the French power mix.

Wim Van Ackooij
EDF R&D
Department OSIRIS
wim.van-ackooij@edf.fr

Rene Henrion
Weierstrass Institute
Berlin, Germany
henrion@wias-berlin.de

Claudia A. Sagastizabal
IMPA
sagastiz@impa.br

Riadh Zorgati
EDF R&D
Department OSIRIS
riadh.zorgati@edf.fr

**CP21**

**Approximate Dynamic Programming with Bezier Curve Approximations for Top Percentage Traffic Routing**

This study investigates the optimal routing strategy under multi-homing where cost are computed with top-percentile pricing. This problem is stochastic and large. Solution approaches based on Stochastic Dynamic Programming require discretization in state space, which suffers from the curse of dimensionality. To overcome this we use Approximate Dynamic Programming to construct approximations of value function, and develop Bezier Curves/Surfaces aggregation in time. This accelerates the efficiency of parameter training, which makes the real-sized TpTRP tractable.

Xinan Yang
University of Edinburgh
x.yang-12@sms.ed.ac.uk

Andreas Grothey
School of Mathematics
University of Edinburgh
A.Grothey@ed.ac.uk

**CP22**

**Planning the Expansion of Railway Networks A Network Design Problem**

We present a mixed integer model to support the decision process at Deutsche Bahn, the largest European Railway Company, on how to optimally invest their annual budget in expanding the railway infrastructure to cope with future demands. Our model views the problem as a network design problem with an underlying routing problem. It considers a long-term planning horizon, where expensive measures can be stretched over several years. We also give computational results on real-world instances.

Andreas Bärmann
Friedrich-Alexander-Universität Erlangen-Nürnberg
baermann@mathematik.tu-darmstadt.de

Alexander Martin
University of Erlangen-Nürnberg
alexander.martin@math.uni-erlangen.de

Sebastian Pokutta
Massachusetts Institute of Technology
sebastianpokutta@me.com

**CP22**

**Optimization of Gas and Water Supply Networks**

The optimal control of gas and water supply networks is a challenging task. The dynamics in both types of networks are governed by hyperbolic systems of PDEs. Additionally, components like compressor/pumping stations and valves introduce binary decisions in the optimal control problem. A key ingredient is to efficiently solve the underlying simulation task with reliable error bounds. Therefor, we apply adjoint-based error estimators. This approach also provides gradient information for the optimization.

Pia Domschke, Oliver Kolb
TU Darmstadt
domschke@mathematik.tu-darmstadt.de,
kolb@mathematik.tu-darmstadt.de

Jens Lang
Department of Mathematics
Darmstadt University of Technology
lang@mathematik.tu-darmstadt.de

**CP22**

**Bounded Diameter Minimum Spanning Trees: A New Approach Combining Branch-and-Bound and Enumeration Algorithms**

We address the problem of computing diameter-constrained minimum spanning trees. So far this problem has mainly been investigated for the case of unit length. We aim at exploring the more general case where the length of the edges can be any number. To approach this problem, we develop a new algorithm combining branch-and-bound procedures with enumeration algorithms for spanning trees. The latter can be used for producing upper and lower bounds. Computational experiments are reported.

Ute Guenther
TU Darmstadt
FB Mathematics
uguenther@mathematik.tu-darmstadt.de

Alexander Martin
University of Erlangen-Nürnberg
alexander.martin@math.uni-erlangen.de

**CP22**

**A Polyhedral Approach for Solving Two-Facility**

**Network Design Problem**

The paper studies the problem of designing telecommunication networks using transmission facilities of *two* different capacities. We fully characterize and enumerate all the extreme points of the 3-node subproblem polyhedron. A new approach for computing facets is introduced and a new family of facets is identified. The 3-partition based facets strengthen the linear programming formulation to a great extent. Computational results show these facets significantly reduce integrality gap and size of the branch-and-bound tree.

Faiz Hamid, Yogesh K. Agarwal
Indian Institute of Management, Lucknow, India
faiz@iiml.ac.in, yka@iiml.ac.in

**CP22**

**On Clearing Coupled Day-Ahead Electricity Markets**

The European power grid is divided into several market areas connected by power lines with restricted transmission capacity. Hence supply and demand of adjacent areas can not always be balanced. The goal of a day-ahead auction is to determine prices and cross border flow maximizing the economic surplus of all participants. Also the transmission and distribution losses must be considered. A MIQP is used to model this challenge.

Johannes C. Müller, Alexander Martin
University of Erlangen-Nürnberg
Johannes.Mueller@math.uni-erlangen.de,
alexander.martin@math.uni-erlangen.de

Sebastian Pokutta
Massachusetts Institute of Technology
sebastianpokutta@me.com

**CP23**

**Model Hierarchy Based Multilevel SQP-Methods for PDAE-Constrained Optimal Control Problems with Application to Radiative Heat Transfer**

We present a multilevel-SQP-method, applied to a radiative heat transfer problem in glass manufacturing. To handle the direction- and frequency-dependent radiation, we make use of series expansion and discretize the continuous frequency spectrum into different bands. The focus is on the multilevel strategy, which is based on a hierarchy of mathematical models and a sequence of adaptive space-time discretizations with increasing accuracy. Mathematical models are obtained by varying the expansion order and the number of frequency bands.

Debora Clever
Graduate School CE,
Technische Universität Darmstadt
clever@mathematik.tu-darmstadt.de

**CP23**

**Solving the Einstein Constraint Equations Using Barrier Methods**

The Einstein field equations for general relativity describe how gravity interacts with matter and energy. The equations are a system of ten coupled equations, comprised of six evolution equations and four constraint equations. The constraint equations must be enforced at each time step when solving the evolution equations. Implicit in the Einstein constraint equations is an additional simple inequality. We look at solving these equations using barrier methods together with a traditional finite element approach.

Jennifer Erway
Wake Forest University
erwayjb@wfu.edu

**CP23**

**Nonlinear Optimum Experimental Design for Industrial Processes**

Dynamical processes from industry can be modeled by systems of differential equations. These models have to be validated by estimation of unknown parameters from experimental data. Designing experiments which minimize the uncertainty of the parameters leads to intricate non-standard optimal control problems. This talk presents recent advances in the formulation and solution methods of these problems including adjoint differentiation, multiple shooting and an online approach. Examples from the practice of our industrial partners are given.

Stefan Körkel
Interdisciplinary Center for Scientific Computing
Heidelberg University
stefan.koerkel@iwr.uni-heidelberg.de

**CP23**

**Optimization under Uncertainty of a Wind Turbine**

In this work a model of wind turbine is presented, considering a variable pitch and rotational speed control, fluid-structural interaction and acoustics. Hence a typical turbine design is analyzed under uncertainty (e.g. wind speed) by the use of a Simplex Elements Stochastic Collocation (SESC) method, based on adaptive grid refinement of a simplex elements discretization in probability space. The approach is equally robust as Monte Carlo (MC) simulation in terms of the Extremum Diminishing (ED) robustness concept. In conclusion a process of shape optimization under uncertainty via genetic algorithms will be considered.

Giovanni Petrone, Carlo De Nicola
Università degli Studi di Napoli Federico II
gpetrone@stanford.edu, denicola@unina.it

Domenico Quagliarella
Centro Italiano Ricerche Aerospaziali
d.quagliarella@cira.it

Gianluca Iaccarino
Stanford University
jops@stanford.edu

Jeroen Witteveen
Stanford University
Center for Turbulence Research
jasw@stanford.edu

**CP23**

**Optimum Experimental Design for Advection-Diffusion-Reaction Problems**

Optimum Experimental Design is the task of finding an experiment that behaves best in the sense of reducing uncertainties in the parameters that are to be estimated from it. With PDE constraints new challenges arise for this optimization problem. We want to present an adjoint mode for the costly gradient calculation following Automatic Differentiation principles and discuss questions for the placing of measurement points in time and space.

Andreas Schmidt
Interdisciplinary Center For Scientific Computing, Heidelberg
Andreas.Schmidt@iwr.uni-heidelberg.de

### CP24

### Multilevel Shape Optimization for the Instationary Navier-Stokes Equations

We consider shape optimization problems governed by the instationary incompressible Navier-Stokes equations. We use an approach based on transformations of a reference domain which is very flexible and allows arbitrary types of parametrizations. Shape derivatives are derived in a continuous adjoint approach. Our focus is on the efficient numerical solution of discretized shape optimization problems. This is achieved by using multilevel optimization with adaptivity based on goal oriented error estimators. Numerical results are presented.

Christian Brandenburg
TU Darmstadt
Germany
brandenburg@mathematik.tu-darmstadt.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

### CP24

### New Discrete Approach for Topology-Optimization in Mechanical Engineering

The new discrete approach combines simple but very powerful ideas for topology optimizations. No gradient information is necessary to reduce and add material. Here a controller-mechanism is used. Only the changes of target function, e.g. displacements or reaction forces, are necessary to solve the optimization problem. All non-linear effects in FEM-simulations can be considered. The simple and basic approach solves the optimization problems (academic examples as well as industrial problems) in an amazing way.

Sierk Fiebig
Volkswagen
sierk.fiebig@volkswagen.de

### CP24

### Actuator Positioning in Truss Topology Design

The aim is to find the optimal topology of a truss and the optimal positioning of the actuators within this truss by solving just one optimization problem. The actuators are modelled as binary variables so we get a MINLP. We are going to compare different models, such as a semidefinite MIP, a MIP and a quadratic MIP. For solving the MISDP we put a branch-and-bound-framework together with a SDP-solver. First computational results are presented.

Sonja Friedrich
TU Darmstadt, Department of Mathematics
Discrete Optimiation
friedrich@mathematik.tu-darmstadt.de

Lars Schewe
Friedrich-Alexander-Universität Erlangen Nürnberg, Department Mathematik, EDOM
lars.schewe@math.uni-erlangen.de

Jakob Schelbert
Friedrich-Alexander-Universität Erlangen-Nürnberg
Department Mathematik, EDOM
jakob.schelbert@math.uni-erlangen.de

Kai Habermehl
TU Darmstadt, Department of Mathematics
Nonlinear Optimization
habermehl@mathematik.tu-darmstadt.de

### CP24

### Nonlinear Elastic Shape Optimization and Uncertain Loading

Shape optimization of mechanical devices is investigated in the context of large, geometrically strongly nonlinear deformations and nonlinear hyperelastic constitutive laws. A weighted sum of the structure compliance, its weight, and its surface area are minimized. The resulting nonlinear elastic optimization problem differs significantly from classical shape optimization in linearized elasticity. Indeed, there exist different definitions for the compliance: the change in potential energy of the surface load, the stored elastic deformation energy, and the dissipation associated with the deformation. Furthermore, elastically optimal deformations are no longer unique so that one has to choose the minimizing elastic deformation for which the cost functional should be minimized, and this complicates the mathematical analysis. Additionally, along with the non-uniqueness, buckling instabilities can appear, and the compliance functional may jump as the global equilibrium deformation switches between different bluckling modes. This is associated with a possible non-existence of optimal shapes in a worst-case scenario.
In this paper the sharp-interface description of shapes is relaxed via an Allen–Cahn or Modica–Mortola type phase-field model, and soft material instead of void is considered outside the actual elastic object. An existence result for optimal shapes in the phase field as well as in the sharp-interface model is established, and the model behavior for decreasing phase-field interface width is investigated in terms of Γ-convergence. Computational results are based on a nested optimization with a trust-region method as the inner minimization for the equilibrium deformation and a quasi-Newton method as the outer minimization of the actual objective functional.

Martin Rumpf
Rheinische Friedrich-Wilhelms-Universität Bonn
Institut für Numerische Simulation
martin.rumpf@ins.uni-bonn.de

Benedikt Wirth
Rheinische Friedrich-Wilhelms-Universität Bonn
benedikt.wirth@ins.uni-bonn.de

Patrick Penzler
Universität Bonn
penzler@iam.uni-bonn.de

**CP24**

**An Approximation Technique for Robust Shape Optimization**

We present a second-order approximation for the robust counterpart of general nonlinear programs with state equation given by a PDE. We show how the approximated robust counterpart can be formulated as trust-region problem which can be solved efficiently using adjoint techniques. This method is applied to shape optimization in structural mechanics in order to obtain optimal solutions that are robust with respect to uncertainties in acting forces and other quantities. Numerical results are presented.

Adrian Sichau
TU Darmstadt, Department of Mathematics
Research Group Nonlinear Optimization
sichau@mathematik.tu-darmstadt.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

**CP25**

**A Family of Dantzig-Wolfe Type Decomposition Algorithms for Variational Inequality Problems.**

We present a family of algorithms for variational inequalities based on ideas of Dantzig-Wolfe decomposition for linear programming. Constraints of the problem are separated into "hard" and "easy". At each iteration, two subproblems are solved. One deals with easy constraints, dualizing hard using Lagrange multipliers provided by the second subproblem. Second subproblem involves hard constraints, reducing variables restricting to convex hull of previously generated points. Various approximations of the constraints and VI mapping are allowed.

Juan Pablo Cajahuanca Luna
Instituto de Matemática Pura e Aplicada IMPA
jluna@impa.br

Mikhail V. Solodov
Inst de Math Pura e Applicada
solodov@impa.br

Claudia Sagastizábal
CEPEL
sagastiz@impa.br

**CP25**

**The Split Variational Inequality Problem**

We propose a new variational problem which we call the Split Variational Inequality Problem (SVIP). It entails finding a solution of one Variational Inequality Problem (VIP), the image of which under a given bounded linear transformation is a solution of another VIP. This problem is interesting not only from the theoretical point of view but also because of its potential applications. We construct iterative algorithms that solve such problems, under reasonable conditions, in Hilbert space and then discuss special cases, some of which are new even in Euclidean space.

Aviv Gibali
The Technion - Israel Institute of Technology
aviv_gibali@yahoo.com

Yair Censor
University of Haifa
Department of Mathematics
yair@math.haifa.ac.il

Simeon Reich
Department of Mathematics,
The Technion - Israel Institute of Technology
sreich@tx.technion.ac.il

**CP25**

**Second-Order Cone Based Reformulation for Robust Wardrop Equilibrium Problems**

In this paper, we define the notion of robust Wardrop equilibrium for traffic model with uncertain data. Particularly, we show that the problem of finding such an equilibrium can be cast as a second-order cone complementarity problem, when the uncertain data are expressed by means of Euclidean norms. We also report some numerical results to observe the behavior of obtained equilibria with various choices of uncertainty structures.

Yoshihiko Ito, Hitoshi Takahashi
Kyoto University
y-ito@amp.i.kyoto-u.ac.jp, t-hitoshi@amp.i.kyoto-u.ac.jp

Shunsuke Hayashi
Dept of Applied Mathematics and Physics
Graduate School of Informatics, Kyoto University
shunhaya@amp.i.kyoto-u.ac.jp

**CP25**

**Interior-Point Method for Nonlinear Programming with Complementarity Constraints**

We propose an algorithm for solving nonlinear programming problems with complementarity constraints, which is based on the interior-point approach. Main theoretical results concern direction determination and step-length selection. We use an exact penalty function to remove complementarity constraints. Thus a new indefinite linear system is defined with a tridiagonal low-right submatrix. Furthermore, new merit function is defined, which includes barrier, exact penalty, and augmented Lagrangian terms.

Ladislav Luksan, Ctirad Matonoha, Jan Vlcek
Institute of Computer Science
Academy of Sciences of the Czech Republic
luksan@cs.cas.cz, matonoha@cs.cas.cz, vlcek@cs.cas.cz

**CP25**

**Two Strong Convergence Theorems for Bregman Strongly Nonexpansive**

We study the convergence of two iterative algorithms for finding common fixed points of finitely many Bregman strongly nonexpansive operators in reflexive Banach spaces. Both algorithms take into account possible computational errors. We establish two strong convergence theorems and then apply them to the solution of convex feasibility, variational inequality and equilibrium problems.

Shoham Sabach
Technion - Israel institute of Technology
ssabach@tx.technion.ac.il

**CP25**

**Control of Variational Inequalities**

We consider the problem of "critical excitation" (i.e., the lowest energy input connecting prescribed states within a given time span) for the variational inequality describing a single degree of freedom elasto-plastic oscillator. This is an optimal control problem for a non smooth state evolution. We obtain Pontryagin's necessary condition of optimality. An essential difficulty lies with the non continuity of adjoint variables. We define an algorithm which leads to the optimal control.

Janos Turi
University of Texas at Dallas
turi@utdallas.edu

Alain Bensoussan
University of Texas at Dallas
and the Hong Kong Polytechnic University, Hong Kong
alain.bensoussan@utdallas.edu

**CP26**

**A Bound for Super-Resolution Power of Compressive Sensing Imaging Systems**

Compressive Sensing (CS) has proven a robust and high-resolution method for Synthetic Aperture Radar Tomography (TomoSAR) from space. For the typical satellite orbit configurations, resolution is a crucial aspect. This paper quantifies the super-resolution power of CS, i.e. the minimum separable distance between two point scatterers, as a function of SNR, number of measurements N, and amplitude ratio of the scatterers for the typical low SNR and low N cases of TomoSAR.

Richard Bamler
German Aerospace Center (DLR)
Remote Sensing Technology Institute (IMF)
richard.bamler@dlr.de

Xiao Xiang Zhu
Technische Universität München (TUM)
Lehrstuhl für Methodik der Fernerkundung
xiao.zhu@dlr.de

**CP26**

**Sparsity-Regularized Methods for Practical Optical Imaging**

Traditionally, optical sensors have been designed to collect the most directly interpretable measurements possible. However, recent advances in image reconstruction and compressed sensing indicate that substantial performance gains may be possible in many contexts via computational methods. In this talk, we explore the potential of physically realizable systems for acquiring "incoherent" measurements. Specifically, we describe how given a fixed size photodetector, compressive measurements with sophisticated optimization algorithms can significantly increase image quality and resolution.

Roummel F. Marcia
School of Natural Sciences
University of California, Merced
rmarcia@ucmerced.edu

**CP26**

**Efficient Methods for Least-Norm Regularization**

We consider the problem: min $\|x\|_2$ $s.t.$ $\|Ax - b\|_2 \leq \epsilon$, where $A$ is an $m \times n$ matrix, $b$ is an $m \times 1$ data vector containing errors (noise), and $\epsilon$ is an upper bound on the norm of the noise. This problem arises, for example, in the regularization of discrete forms of ill-posed problems. We present two classes of methods: a Newton iteration for small, dense problems, and two matrix-free algorithms for the large-scale case. We present numerical results that demonstrate that the new methods are accurate, efficient, and robust

Marielba Rojas
Delft University of Technology
marielba.rojas@tudelft.nl

Danny C. Sorensen
Rice University
sorensen@rice.edu

**CP26**

**The Sl1mmer Algorithm for Spectral Estimation With Application to Tomographic Sar Inversion**

We introduce SL1MMER, a spectral estimation algorithm based on L1-norm minimisation, model order selection and final parameter estimation. It combines the advantages of compressive sensing with the amplitude and phase accuracy of linear estimators. Our target application is differential Synthetic Aperture Radar (SAR) tomography. We will also show that by means of our proposed time warp method the tomographic imaging equation with an M-component motion model can be rewritten as an M+1-dimensional spectral estimation problem.

Xiao Xiang Zhu
Technische Universität München (TUM)
Lehrstuhl für Methodik der Fernerkundung
xiao.zhu@dlr.de

Richard Bamler
German Aerospace Center (DLR)
Remote Sensing Technology Institute (IMF)
richard.bamler@dlr.de

**CP27**

**Decomposition Methods for Two-Stage Problems with Stochastic Dominance Constraints**

We consider two-stage stochastic optimization problems with risk control by a stochastic dominance constraint on the recourse function. We propose two decomposition methods to solve the problems and prove their convergence. Our methods exploit the decomposition structure of the expected value two-stage problems and approximate the stochastic dominance constraints. The dominance relation is represented by the Lorenz functions or by the expected excess functions of the random variables involved. Numerical results confirm the efficiency of the methods.

Darinka Dentcheva
Department of Mathematical Sciences
Stevens Institute of Technology
darinka.dentcheva@stevens.edu

Gabriela Martinez
Stevens Institute of Technology

maria.martinez@stevens.edu

**CP27**

**A Sampled Fictitious Play Based Learning Algorithm for Infinite Horizon Markov Decision Processes**

Using Sampled Fictitious Play (SFP) concepts, we develop a learning algorithm for solving discounted homogeneous Markov Decision Problems where the transition probabilities are unknown and need to be learned via simulation or direct observation of the system in real time. Thus, SFP estimates and simultaneously updates the unknown transition probabilities, optimal value and optimal action in observed state. We prove convergence of the algorithm and compare its performance with other adaptive learning methods.

Marina A. Epelman
University of Michigan
Industrial and Operations Engineering
mepelman@umich.edu

Esra Sisikoglu
University of Missouri
Industrial & Manufacturing Systems Engineering
sisikoglue@missouri.edu

Robert L. Smith
Industrial and Operations Engineering
University of Michigan
rlsmith@umich.edu

**CP27**

**Optimizing Stochastic Mixed-Integer Problems with Application in Energy Production**

We consider a stochastic mixed-integer model, where uncertainty is described by a scenario tree. To solve this block-structured problem, we apply a decomposition approach which exploits the problem specific structure. On this basis a branch-and-bound algorithm is used to ensure feasibility and solve the problem to global optimality. As an application, we present a power generation problem with fluctuating, regenerative power supply.

Debora Mahlke, Andrea Zelmer
Friedrich-Alexander-Universität Erlangen-Nürnberg
Lehrstuhl für Wirtschaftsmathematik
debora.mahlke@math.uni-erlangen.de,
andrea.zelmer@math.uni-erlangen.de

Alexander Martin
University of Erlangen-Nürnberg
alexander.martin@math.uni-erlangen.de

**CP27**

**Stochastic Network Design with Random Demands and Arc Capacities.**

Networks are considered where the demands at the nodes and some of the arc capacities are random variables that have joint normal distribution. A network design problem is formulated where a probabilistic constraint assures the existence of a feasible flow by a large probability. The numerical solution is obtained using several methods:the method of Prekopa that combines a cutting plane method with supporting hyperplane method; dynamic quadratic approximation method, so called "supporting hyperbolae".

Olga Myndyuk
Rutgers University, RUTCOR
olgamyn@eden.rutgers.edu

Andras Prekopa
Rutgers University
Rutgers Center for Operations Research
prekopa@rutcor.rutgers.edu

**CP27**

**Partly Inexact Bundle Methods for Two-Stage Stochastic Linear Programming**

For two-stage stochastic linear programs, we consider partly inexact bundle methods, corresponding to a regularized Benders decomposition that can handle inexactness in the second-stage subproblems solution. Subproblems are solved exactly only at some specific points, when inaccuracy is deemed too large. The remaining subproblems solution is approximated by means of previously generated vertices. We analyze two alternatives, derived the proximal and level bundle methods, and assess their performance on a battery of two-stage problems from the stochastic programming literature.

Welington Oliveira
Federal University of Rio de Janeiro
wlo@cos.ufrj.br

Claudia A. Sagastizabal
IMPA
sagastiz@impa.br

Susana Scheimberg
Federal University of Rio de Janeiro
Brazil
susana@cos.ufrj.br

**CP27**

**Risk-Averse Dynamic Programming for Stochastic Shortest Path Problems**

We introduce the concept of a Markov risk measure and we use it to formulate a risk-averse version of the undiscounted stochastic shortest path problem in an absorbing Markov chain. We derive risk-averse dynamic programming equations and we show that a randomized policy may be strictly better than deterministic policies, when risk measures are employed.

Andrzej Ruszczynski, Ozlem Cavus
Rutgers University
rusz@business.rutgers.edu, ozlem_cavus@yahoo.com

**CP28**

**Bounds for the Nonnegative Rank Using a Geometric Interpretation**

The minimum number of nonnegative rank-one factors summing to a given matrix is its nonnegative rank. Determining this rank and the corresponding factors is computationally difficult but has many applications, e.g., in graph theory, or to characterize the minimal size of any LP extended reformulation of a combinatorial optimization program. In this talk, we shed new light on this problem using a geometric interpretation involving polyhedral combinatorics, leading to improved upper and lower bounds.

Nicolas Gillis
Université catholique de Louvain
Center for Operation Research and Econometrics
nicolas.gillis@uclouvain.be

François Glineur
Université catholique de Louvain
Center for Operations Research and Econometrics
francois.glineur@uclouvain.be

**CP28**

**Manifold Learning by Semidefinite Facial Reduction**

We propose a new semidefinite programming formulation for nonlinear dimensionality reduction by manifold learning. By observing that the structure of a large chunk of the data can be preserved as a whole, we are able to use a recent result on semidefinite facial reduction [Krislock and Wolkowicz, 2010] to significantly reduce the size and the number of constraints of the semidefinite programming problem, allowing us to solve much larger problems than previously possible.

Nathan Krislock
INRIA Grenoble Rhône-Alpes
nathan.krislock@inrialpes.fr

Babak Alipanahi
David R. Cheriton School of Computer Science
University of Waterloo
balipana@uwaterloo.ca

Ali Ghodsi
University of Waterloo
aghodsib@uwaterloo.ca

**CP28**

**Robust Covariance Estimation Using Mathematical Programming**

The outlier detection problem and the robust covariance estimation problem are often interchangeable. Without outliers, the classical method of Maximum Likelihood Estimation (MLE) can be used to estimate parameters of a known distribution from observational data. When outliers are present, they dominate the log likelihood function causing the MLE estimators to be pulled toward them. Many robust statistical methods have been developed to detect outliers and to produce estimators that are robust against deviation from model assumptions. However, the existing methods suffer either from computational complexity when problem size increases or from giving up desirable properties, such as affine equivariance. An alternative approach is to design a special mathematical programming model to find the optimal weights for all the observations, such that at the optimal solution, outliers are given with smaller weight and can be detected. This method produces a covariance estimator that has the following properties: First, it is affine equivariant. Second, it is computationally efficient even for large problem sizes. Third, it easy to incorporate prior beliefs into the estimator by using semi-definite programming. The accuracy of this method is tested for different contamination models, including the most recently proposed ones.

Tri-Dung Nguyen
University of Southampton
School of Mathematics
T.D.Nguyen@soton.ac.uk

**CP28**

**Learning over Manifolds via Iterative Projection**

The problem of recovering an unknown signal belonging to a manifold from linear measurements has multiple applications, one important one being imaging. In this work we introduce an algorithm known as Manifold Iterative Projection to solve the problem of recovering an unknown signal from a manifold using linear measurements. We show that when the linear measurement operator operates benignly on the manifold, the algorithm recovers the unknown signal. We also extend the analysis to the case where the signal varies slowly with time on the manifold, and show that using the algorithm one can track the time-varying signal. For well-behaved manifolds, random (Gaussian) matrices are suitable measurement operators, and the sample-complexity and time-complexity can be characterized in terms of the geometric properties of the manifold. We illustrate the algorithm on several examples.

Parikshit Shah
MIT
pari@mit.edu

Venkat Chandrasekaran
Massachusetts Institute of Technology
venkatc@mit.edu

**CP29**

**Extension of the Semidefinite Characterization of Sum of Squares Functional Systems to Algebraic Structures**

Nesterov has shown that the cone of functions that can be expressed as sums of squares of functions in a finite dimensional linear functional space can be represented by positive semidefinite matrices. We extend this result to any abstract algebraic system. Our extension is particularly useful for formally real algebras. As a result we unify some results under this framework. A noted example is the characterization of polynomials (ordinary, exponential and trigonometric) which take only positive semidefinite values in Jordan algebras. Using Youla's theorem we show that such sets of polynomials are SDP-representable. We also extend our results by defining the notion of $A$-sdp matrices, which are matrices whose entries are from an algebra $(A, \diamond)$. Finally, we explore some concrete applications of these characterizations in statistical function estimation and some problems in shape optimization.

Farid Alizadeh
RUTCOR and School of Business,
Rutgers University
alizadeh@rutcor.rutgers.edu

David Papp
Rutgers Center for Operations Research
dpapp@rutcor.rutgers.edu

**CP29**

**A Geometric Theory of Barriers in Conic Opti-**

**mization**

We interpret barriers in conic optimization as Lagrangian submanifolds of some universal para-Kähler space form and establish close links to centro-affine hypersurface geometry. As an application, we construct a universal self-concordant barrier which, in contrast to the classical universal barrier, is invariant with respect to duality and the operation of taking products of cones. This barrier corresponds to the minimal Lagrangian submanifolds, or to hyperbolic affine hyperspheres in centro-affine geometry.

Roland Hildebrand
Laboratoire Jean Kuntzmann
University Grenoble 1 / CNRS
roland.hildebrand@imag.fr

### CP29

### A Globally Convergent Algorithm for Semi-Infinite Programs with an Infinite Number of Conic Constraints

The semi-infinite program (SIP) is normally represented with infinitely many inequality constraints, and has been much studied so far. However, there have been only a few studies on the SIP involving conic constraints such as second-order cone constraints, even though it has important applications such as Chebychev-like approximation and filter design. In this paper, we focus on the SIP with infinitely many conic constraints, called the SICP for short. We show that, under an appropriate constraint qualification, an optimum of the SICP satisfies the Karush-Kuhn-Tucker conditions that can be represented with only a *finite* subset of the conic constraints. Next we provide an algorithm for solving the SICP and show that it generates iterates converging to a solution of the SICP under some mild assumptions. Moreover, we report some numerical experiments.

Takayuki Okuno
Department of Applied Mathematics and Physics
Graduate School of Informatics Kyoto University
t_okuno@amp.i.kyoto-u.ac.jp

Shunsuke Hayashi
Dept of Applied Mathematics and Physics
Graduate School of Informatics, Kyoto University
shunhaya@amp.i.kyoto-u.ac.jp

Masao Fukushima
Department of Applied Mathematics and Physics
Graduate School of Informatics Kyoto University
fuku@i.kyoto-u.ac.jp

### CP29

### Optimizing Extremal Eigenvalues of the Weighted Laplacian of a Graph

In order to better understand spectral properties of the Laplace matrix of a graph, we optimize the edge weights so as to minimize the difference of the maximal and the second smallest eigenvalue of the weighted Laplacian. Using a semidefinite programming formulation, the dual program allows to interpret the dual solutions living in the optimized eigenspaces as a graph realization. We study connections between structural properties of the graph and geometrical properties of graph realizations.

Susanna Rei
Chemnitz University of Technology
susanna.reiss@mathematik.tu-chemnitz.de

Christoph Helmberg
TU Chemnitz
Germany
helmberg@mathematik.tu-chemnitz.de

### CP29

### Riemannian Optimization for Rank-Constrained Matrix Problems

We present a Riemannian framework for solving optimization problems involving a rank constraint. The proposed methods exploit that the set of $n \times n$ matrices of fixed rank $k$, denoted $\mathcal{M}_\backslash^\|$, form a smooth embedded submanifold of $R^{n\times n}$. This enables the use of so-called Riemannian optimization, the generalization of classic optimization to Riemannian manifolds. Since the manifold $\mathcal{M}_\backslash^\|$ is of dimension $O(nk)$, these algorithms are inherently defined on a lower dimensional search space compared to the full-rank case when $k \ll n$. Furthermore, the framework is flexible enough to allow for second-order algorithms, preconditioning and multilevel optimization. We illustrate this with two applications: Lyapunov equations involving PDEs and low-rank matrix completion.

Bart Vandereycken
Katholieke Universiteit Leuven
bart.vandereycken@sam.math.ethz.ch

### CP30

### Finite Element Error Estimates on the Boundary and Its Application To Optimal Control

Finite element error estimates in the $L^2$-norm on the boundary are proved for elliptic boundary value problems in polygonal domains. Local mesh grading is used in the vicinity of corners with interior angle greater than $2\pi/3$. The result is used to estimate the discretization error of elliptic linear-quadratic Neumann boundary control problems with pointwise inequality constraints on the control.

Thomas Apel
Universität der Bundeswehr München
thomas.apel@unibw.de

Johannes Pfefferer
UniBw München
johannes.pfefferer@unibw.de

Arnd Rösch
University of Duisburg-Essen
arnd.roesch@uni-due.de

### CP30

### A Finite Element Method Based Numerical Algorithm for Calculus of Variations Problems Derived from Gâteaux First Variation

A standard calculus of variations problem consists in minimising a given objective functional, subject to Dirichlet boundary conditions. Stationary points of this problem are obtained by imposing the Gâteaux first variation necessary condition. A corresponding numerical scheme is attained by approximating the problem's true solution, expressing the interpolant as a linear combination of cubic spline ba-

sis functions. Different numerical integration rules for the integrals intervening in Gâteaux first variation expression are applied.

Ana Garcia-Bouso
Universidad Rey Juan Carlos
Statistics and Operations Research Department
ana.bouso@urjc.es

Alberto Olivares, Ernesto Staffetti
Universidad Rey Juan Carlos (Madrid)
Statistics and Operations Research Department
alberto.olivares@urjc.es, ernesto.staffetti@urjc.es

### CP30

### Multivariate Shape-Constrained Estimation Using Polynomial Splines

We present a solution to multivariate function estimation problems with shape constraints on the estimator. We apply tools from polynomial programming and decomposition methods. The estimator is a multivariate spline, for which most natural shape constraints are intractable, hence we consider tractable restrictions involving weighted-sum-of-squares cones. The size of these problems often makes the direct solution of the models impossible, hence the need to combine the conic programming technique with decomposition methods.

David Papp
Rutgers Center for Operations Research
dpapp@rutcor.rutgers.edu

Farid Alizadeh
RUTCOR and School of Business,
Rutgers University
alizadeh@rutcor.rutgers.edu

### CP30

### Numerical Explorations of Benford Distributed Random Variables

A random variable is Benford distributed if the occurrence frequency of its most significant digit is $p(d) = \log_{10}(1 + 1/d)$. Using numeric data from 2-d relativistic gas simulations, we observed that the generalized relativistic equipartition terms are Benford distributed. They are also base and scale invariant. Because the equipartition terms are nonlinear functions of non-uniform distributed random variables, we expect that the exponentiation theorem of Adhikari and Sarkar be extended to non-uniform probability distribution functions as well.

Constantin N. Rasinariu, Azar Khosravani
Department of Science and Mathematics
Columbia College Chicago
crasinariu@colum.edu, akhosravani@colum.edu

### CP30

### Optimal Input Design with $B$-Splines: Linear Versus Semidefinite Programming

Input design is considered for linear controllable systems by means of a $B$-spline parametrization of the flat output. Actuator and state constraints are satisfied continuously in time by either conservative linear or exact semidefinite constraints on the spline coefficients resulting in a linear or semidefinite program in which both the spline coefficients and the knot locations are optimized simultaneously. To illustrate and compare both approaches, time optimal inputs are calculated for an overhead crane.

Wannes Van Loock
Katholieke Universiteit Leuven
Department of Mechanical Engineering, division PMA
wannes.vanloock@mech.kuleuven.be

Goele Pipeleers, Jan Swevers
Katholieke Universiteit Leuven
goele.pipeleers@mech.kuleuven.be,
jan.swevers@mech.kuleuven.be

### CP31

### Solving DFO Non Convex Subproblems with a Global Optimizer

The SQA (Sequential Quadratic Approximation) is a constrained derivative-free algorithm developed at IFPEN. In the minimization stage, quadratic subproblems, not necessarily convex, subjected to bound and quadratic constraints are solved using a standard SQP algorithm. Due to the non-convexity issue, subproblem solutions computed through the local SQP algorithm may only be local solutions. This motivates our choice to use GloptiPoly, a global optimizer for polynomial optimization for solving quadratic subproblems. In order to integrate GloptiPoly as the subproblem solver, it was tested for some quadratic problems of the Hock Shitkowski benchmark. Then, it was plugged in SQA as the quadratic subproblem solver for the Moré & Wild benchmark. Finally, GloptiPoly was used for solving a real engine calibration problem. Comparisons of GloptiPoly with standards SQP methods and multistart ones will be given for the Moré & Wild benchmark and the calibration problem, respectively.

Frédéric Delbos
IFP Energies Nouvelles
frederic.delbos@ifpenergiesnouvelles.fr

Laurent Dumas
Université de Versailles
laurent.dumas@uvsq.fr

Eugenio Echague
IFP energies nouvelles
eugenio.echague@ifpenergiesnouvelles.fr

### CP31

### Estimating Parameters in Optimal Control Models

We consider numerical methods for identifying models that describe dynamical processes that can be assumed to be optimal, such as gaits of cerebral palsy patients. This leads to challenging parameter estimation problems whose constraints are constrained optimal control problems. We present a multiple shooting approach to discretize this hierarchical optimization problem and discuss methods to treat the resulting problem: a Gauß-Newton approach, a bundle method, and a derivative-free technique. Numerical results are provided.

Kathrin Hatz
Interdisciplinary Center for Scientific Computing (IWR)
University of Heidelberg, Germany
kathrin.hatz@iwr.uni-heidelberg.de

Johannes Schloeder

Interdisciplinary Center for Scientific Computing (IWR)
University of Heidelberg
johannes.schloeder@iwr.uni-heidelberg.de

Hans Georg Bock
IWR, University of Heidelberg
bock@iwr.uni-heidelberg.de

Sven Leyffer
Argonne National Laboratory
leyffer@mcs.anl.gov

**CP31**

**Optimal Control of Hydroforming Processes**

We consider optimal control problems for quasi-static elastoplasticity with linear hardening. As a first step derivative free optimization algorithms were used to control the blank holder force and the fluid pressure, which are typical control variables. The commercial FEM-software ABAQUS is invoked for the simulations. Because of the huge computational effort of the simulation, optimization algorithms based on reduced models are under investigation. Numerical results for the hydroforming process of sheet stringers will be presented.

Daniela Koller
TU Darmstadt
koller@mathematik.tu-darmstadt.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

**CP31**

**Derivative-free Methods for Large Nonlinear Data Assimilation Problems**

To estimate the state of the ocean and of the atmosphere, very large nonlinear least-squares problems have to be solved. These problems involve a model operator which integrates a set of partial differential equations describing the evolution of the system. Evaluating the derivatives is challenging, as one needs to compute the Jacobian of the model operator and its transpose, which implies the derivation of a tangent linear and adjoint codes. In this talk, we present a derivative-free alternative based on the solution of subproblems in well-choosen small subspaces.

Patrick Laloyaux
University of Namur
patrick.laloyaux@fundp.ac.be

**MS1**

**A Variational Inequality Approach for the Evolution of Heterogeneous Materials**

We aim to predict the evolution of microstructure in heterogeneous materials, as appears, for example, in materials that are submitted to radiation for long periods of time. Such phenomena can be modeled by phase field approaches with double obstacle potentials. Such formulations result in differential variational inequalities. We discuss approaches for solving the large-scale variational inequalities that result from spatial discretization combined with time-stepping approaches.

Mihai Anitescu, Jungho Lee, Lois Curfman McInnes, Todd Munson
Argonne National Laboratory
Mathematics and Computer Science Division
anitescu@mcs.anl.gov, julee@mcs.anl.gov, mcinnes@mcs.anl.gov, tmunson@mcs.anl.gov

Barry F. Smith
Argonne National Lab
MCS Division
bsmith@mcs.anl.gov

Lei Wang
University of Michigan
olivewl@umich.edu

**MS1**

**Extended Mathematical Programming: Multi-agent Modeling Simplified**

We present the GAMS Extended Mathematical Programming framework (EMP). This new tool enables multi-agent models to be formulated in terms of individual agents, e.g., optimization/complementarity models, and the structure and relationships that connect them, e.g. via a Nash game or a leader-follower structure. The JAMS solver automatically reformulates the problem to create an equivalent but tractable model, solves it, and brings back the solution to the EMP framework. Several examples are furnished for illustration.

Steven Dirkse
GAMS Development Corp.
Washington DC
sdirkse@gams.com

Michael C. Ferris
University of Wisconsin
Department of Computer Science
ferris@cs.wisc.edu

Jan-H. Jagla, Alex Meeraus
GAMS Development Corp.
Washington DC
jhjagla@gams.com, ameeraus@gams.com

**MS1**

**On C-stationarity for Parabolic MPECs**

A constraint-relaxation technique for a class of optimal control problems for parabolic variational inequalities is considered. The relaxed problem can be treated by well-known results from optimization in Banach space and yields, upon passing to the limit in the relaxation parameter, a weak form of C-stationarity for the original problem. The theoretical results are illustrated by numerical tests.

Michael Hintermueller
Humboldt-University of Berlin
hint@math.hu-berlin.de

**MS1**

**Semismooth Newton Methods for Quasi-Variational Inequalities of**

**Elliptic Type and Applications**

A problem arising from a nonlinear elliptic quasi-variational inequality (QVI) with gradient constraints is considered. We address the existence of solutions based on a penalization approach and a fixed point iteration without resorting to Mosco convergence. The numerical approximation of the solution is done by developing a semismooth Newton strategy in combination with the fixed point iteration in function space. Numerical examples related to the p-Laplacian and a superconductivity model will be treated.

Carlos N. Rautenberg
Department of Mathematics and Scientific Computing
Karl-Franzens University of Graz
carlos.rautenberg@uni-graz.at

## MS2

### Polynomial Descriptions of Special Classes of Semi-algebraic Sets

Bosse, Groetschel and Henk asked whether an arbitrary $d$-dimensional polytope can be described by d polynomial inequalities, i.e., in the form $p_1 \geq 0, \ldots, p_d \geq 0$, where $p_1, \ldots, p_d$ are $d$-variate polynomials. This question is answered in positive (in a joint work with Ludwig Bröcker) and the corresponding theorem is also extended to the case of unbounded polyhedra. In this talk I will sketch the proof and present some related problems.

Gennadiy Averkov
University of Magdeburg
gennadiy.averkov@googlemail.com

## MS2

### Spectrahedra and Determinantal Representations of Polynomials

Spectrahedra are the feasible sets of semidefinite optimization problems. It is an important problem to characterize sets that are spectrahedra. The algebraic problem behind this geometric question is to represent polynomials as determinants of linear matrix polynomials. I will discuss positive and negative results concerning this problem.

Tim Netzer
University of Leipzig
tim.netzer@math.uni-leipzig.de

## MS2

### Algebraic Certificates for Global Optimization and Generalized Critical Values

We consider the problem of computing algebraic certificates certifying lower bounds for the global infimum a multivariate polynomial subject to equality constraints satisfying transversality assumptions. Following a previous work of Demmel, Nie and Sturmfels involving sums-of-squares decompositions modulo gradient ideals, Nie has recently established the existence of SOS certificates modulo generalized gradient ideals and convergence results in the case where the infimum is a minimum. Following an idea introduced by Schweighofer which consists in considering larger varieties than the ones defined by gradient ideals, we provide existence results for algebraic certificates certifying lower bounds of the considered global infimum even when it is not a minimum. This is joint work with Aurelien Greuet, Feng Guo and Lihong Zhi.

Mohab Safey El Din
UPMC, Univ Paris 6
Mohab.Safey@lip6.fr

## MS3

### Implementation of Nonsymmetric Interior-point Methods for Linear Optimization Over Sparse Matrix Cones

We describe implementations of nonsymmetric interior-point methods for linear optimization over two types of sparse matrix cones: the cone of positive semidefinite matrices with a given sparsity pattern, and the cone of completable matrices. The implementations take advantage of fast sparse matrix algorithms for evaluating the associated logarithmic barriers and their derivatives. We present numerical results of an implementation of an interior-point algorithm based on these techniques with applications to robust quadratic optimization problems.

Martin S. Andersen
University of California, Los Angeles
Electrical Engineering Department
martin.andersen@ucla.edu

Joachim Dahl
MOSEK Aps
joachim@mosek.com

Lieven Vandenberghe
University of California
Los Angeles
vandenbe@ee.ucla.edu

## MS3

### Semidefinite Programming Algorithm for Distributed Stability Analysis

We investigate stability of uncertain large-scale interconnected systems using $\mu$-analysis. The interconnections are few. This means that the system matrix relating input to output signals is sparse. The $\mu$-analysis problem can be formulated as a semidefinite programming (SDP) problem involving the system matrix. We will present results on how this SDP problem can be solved efficiently in a distributed fashion.

Sina Khoshfetrat Pakazad
Division of Automatic Control
Linköping University
sina.kh.pa@isy.liu.se

Anders Hansson
Division of Automatic Control
Linköping University
hansson@isu.liu.se

Anders Rantzer
Lund University
anders.rantzer@control.lth.se

Martin S. Andersen
University of California, Los Angeles
Electrical Engineering Department
martin.andersen@ucla.edu

**MS3**

**Parallel Multilevel Computing in SDPARA for Large-scale Semidefinite Programming**

We discuss a hybrid MPI and multi-threading parallel computation on multi-core CPUs. It is employed in the latest version 7.3.1 of SDPARA (a parallel version of SDPA). SDPARA 7.3.1 adopts a new storage scheme to reduce of memory consumption and to derive an ideal load balance among processors. Numerical results show that this parallel scheme provides an astonishing speed up on SDPs.

Kazuhiro Kobayashi
National Maritime Research Institute
kobayashi@nmri.go.jp

Makoto Yamashita
Tokyo Institute of Technology
Dept. of Mathematical and Computing Sciences
makoto.yamashita@is.titech.ac.jp

Katsuki Fujisawa
Department of Industrial and Systems Engineering
Chuo University
fujisawa@indsys.chuo-u.ac.jp

**MS4**

**Enhanced Hospital Resource Management using Anticipatory Policies in Online Dynamic Multi-objective Optimization**

Evolutionary algorithms are well-suited to solve both multi-objective and dynamic optimization problems. Studying problems that are multi-objective *and* dynamic is only rather recent. An important problem difficulty (in practice) is that decisions taken now have future consequences. We tackle this issue by optimizing policies that are well-designed for the problem at hand with a multi-objective evolutionary algorithm and apply this approach to a complex, real-world optimization problem, namely the management of resources in a hospital.

Peter Bosman
Centrum Wiskunde & Informatica (CWI)
(Centre for Mathematics and Computer Science)
peter.bosman@cwi.nl

**MS4**

**Calculation of Uncertainty Information During Calibration**

The problem of calibration of a computer simulator involves determining the optimal values of several tuning input variables that, when combined with input variables matching known conditions, produce output values that match real observed data. At its heart is the comparison of experimental data and simulation results. Complicating this comparison is the fact that both data sets contain uncertainties which must be quantified in order to make reasonable comparisons. Therefore, UQ techniques must be applied to identify, characterize, reduce, and, if possible, eliminate uncertainties. In this talk, we will discuss an approach to calibration which combines Bayesian statistical models and derivative-free optimization in order to monitor sensitivity information throughout the calibration process.

Genetha Gray
Sandia National Laboratories
gagray@sandia.gov

Herbie Lee
University of California, Santa Cruz
Dept. of Applied Math and Statistics
herbie@ams.ucsc.edu

Katie Fowler
Clarkson University
kfowler@clarkson.edu

**MS4**

**Application of Optimization-Under-Uncertainty in the Design of Pump-and-Treat Systems**

Pump-and-treat systems can prevent groundwater contaminant migration and candidate systems are typically evaluated via groundwater models. Such models should be calibrated so that parameter uncertainties can be incorporated into subsequent simulation-based optimization. Numerous calibration procedures have been proposed, yielding varying expressions of parameter uncertainty. A series of numerical experiments were performed utilizing optimization-under-uncertainty to design a remedial system for groundwater contamination. Results indicate that alternative approaches for parameter estimation can significantly influence optimal system design.

L. Shawn Matott, Philip Sheffield
University of Waterloo
lsmatott@uwaterloo.ca, psheffie@engmail.uwaterloo.ca

**MS4**

**Post-inference Optimization in a Multi-scale Bayesian Setting**

Simulations in difficult optimization problems often depend on the solution of an inference problem. An example is the permeability field in a well placement design problem which is often derived from pressure or saturation measurements. Furthermore, uncertainty in the inverse solution can have a significant impact on the optimization. Incorporating this during optimization is difficult and we present a method to take advantage of structure in a Bayesian inference problem during the optimization.

Matthew Parno, Youssef M. Marzouk
Massachusetts Institute of Technology
mparno@mit.edu, ymarz@mit.edu

**MS5**

**Feasibility Pump Heuristics for Nonconvex MINLP**

Finding feasible solutions of Mixed Integer Nonlinear Programming (MINLP) problems is crucial to the performance of any branch-and-bound MINLP solver. We describe a variant of the Feasibility Pump heuristic, which was introduced for Mixed Integer Linear Programming (MILP) problems and extended to MINLP. Our implementation takes advantage of an LP relaxation of the MINLP problem that can be dynamically refined. We provide computational results based on Couenne, an Open Source solver for non-convex MINLP problems.

Pietro Belotti
Clemson University
pbelott@clemson.edu

Timo Berthold
Zuse Institute Berlin
Takustr. 7 14195 Berlin
berthold@zib.de

**MS5**
**MINOTAUR: A Solver for MINLPs**

In this talk we describe MINOTAUR, a solver that we are developing for general MINLPs. MINOTAUR provides a flexible framework for implementing a variety of techniques for relaxing, branching, cutting, searching and other methods that are necessary for solving MINLPs. We describe some new techniques that we have developed and compare their performance to existing ones. MINOTAUR is also capable of identifying certain basic problem structures that can be exploited effectively. We describe these methods also.

Sven Leyffer
Argonne National Laboratory
leyffer@mcs.anl.gov

Ashutosh Mahajan
Argonne National Laboratory
mahajan@mcs.anl.gov

Todd Munson
Argonne National Laboratory
Mathematics and Computer Science Division
tmunson@mcs.anl.gov

**MS5**
**Linear and Nonlinear Inequalities for a Nonseparable Quadratic Set**

We describe some integer-programming based approaches for finding strong inequalities for the convex hull of a quadratic mixed integer nonlinear set containing two integer variables that are linked by linear constraints. This study is motivated by the fact that such sets appear can be defined by a convex quadratic program, and therefore strong inequalities for this set may help to strengthen the formulation of the original problem. Some of the inequalities we define for this set are linear, while others are nonlinear (specifically conic). The techniques used to define strong inequalities include not only ideas related to recent perspective reformulations of MINLPs, but also disjunctive and lifting arguments. Initial computational tests will be presented.

Hyemin Jeon, Jeffrey Linderoth
University of Wisconsin-Madison
jeon5@wisc.edu, linderoth@wisc.edu

Andrew Miller
Institut de Mathématiques de Bordeaux
France
andrew.miller@math.u-bordeaux1.fr

**MS5**
**A Computational Study on Branching and Bound Tightening Techniques for MINLPs**

Within the context of developing a parallel Branch-and-Bound solver for nonconvex MINLPs, we perform a computational investigation of branching and bound tightening techniques. We propose new methods that try to exploit the large amount of CPU power available in order to reduce the size of the enumeration tree, studying their effect and discussing their applicability in the single-processor case. Our focus will be on bound tightening techniques. If time permits, we will also discuss branching.

Giacomo Nannicini
Carnegie Mellon University
Tepper School of Business
nannicin@andrew.cmu.edu

Pietro Belotti
Clemson University
pbelott@clemson.edu

Jon Lee
IBM T.J. Watson Research Center
jonlee@us.ibm.com

Jeff Linderoth
University of Wisconsin-Madison
Dept. of Industrial and Sys. Eng
linderoth@wisc.edu

Francois Margot
Carnegie Mellon University
Tepper School of Business
fmargot@andrew.cmu.edu

Andreas Waechter
Thomas J. Watson Research Center
andreasw@us.ibm.com

**MS6**
**Nested Multigrid for Optimal Control of Time-periodic Parabolic PDEs**

We present a nested multigrid (mg) method to solve optimal control problems with time-periodic parabolic PDEs. The method relies on the reduction of the first order optimality conditions to a Fredholm integral equation of the second kind which is solved by the outer mg method. In every outer iteration a space-time mg approach of the first kind is applied as inner mg method for the evaluation of the integral kernel to solve for the state and adjoint state.

Dirk Abbeloos
Department of Computer Science
K. U. Leuven
dirk.abbeloos@cs.kuleuven.be

Moritz Diehl
K.U.Leuven
moritz.diehl@esat.kuleuven.be

Michael Hinze
Universität Hamburg
Department Mathematik
michael.hinze@uni-hamburg.de

Stefan Vandewalle
Department of Computer Science
Katholieke Universiteit Leuven
stefan.vandewalle@cs.kuleuven.be

## MS6

### Multi-level Optimization Algorithms for PDE-constrained Problems Arising in Materials Design

Motivated by gas storage in nanoporous materials, we consider a novel class of optimization problems. Applications require a specified rate of charge and discharge which is facilitated by creating channels of various widths. The objective is to minimize the total volume of the channels. The physics changes as scale is reduced and must be correct on all scales to solve the problem. We describe extensions to the multi-grid optimization method to solve such multi-scale problems.

Paul Boggs
Sandia National Lab
ptboggs@sandia.gov

David M. Gay
AMPL Optimization LLC
University of New Mexico
dmg@acm.org

Robert M. Lewis
College of William and Mary
rmlewi@wm.edu

Stephen G. Nash
George Mason University
Systems Engineering & Operations Research Dept.
snash@gmu.edu

## MS6

### Nonlinear Domain Decomposition Methods for the Solution of Constrained Nonlinear Programming Problems

The parallel numerical solution of realistic problems, such as large-deformation contact between an elastic body and a rigid obstacle, gives rise to nonlinear programming problems (NLPs) which will reliably be solved employing globalization strategies. In this talk, we will consider an extension to the concept of globalization strategies, nonlinearly preconditioned globalization strategies, and focus on the application of such strategies to the multiscale solution of large-scale NLPs arising from the discretization of constrained PDEs.

Christian Gross
Universita' della Svizzera Italiana
Institute of Computational Science
christian.gross@usi.ch

Rolf Krause
Universita' della Svizzera Italiana
rolf.krause@usi.ch

## MS6

### Approximation and Correction Techniques for Design of a Nanoporous Material

We discuss approaches to the hierarchical design of a nanoporous material for energy storage. The structure and physical nature of the material varies on different length-scales. The system can be approximated using a small number of decision variables, which makes it possible to consider algebraic approximations of the objective and constraints in the resulting optimization problem. We discuss such approximations, as well as techniques for aggregating information from different length-scales for the purposes of optimization.

Robert M. Lewis
College of William and Mary
rmlewi@wm.edu

## MS7

### Infeasibility Detection in Nonlinear Programming

We address the deficiencies of current nonlinear optimization software with respect to infeasibility detection. In particular, it is suggested in this talk that algorithms be reworked and reanalyzed so that, if given an infeasible problem, useful information is returned to the user efficiently. We also propose our own approaches for sequential quadratic optimization and interior-point methods that provide the same convergence guarantees as contemporary methods, but also provide fast local convergence guarantees for infeasible problems.

Frank E. Curtis, Hao Wang
Industrial and Systems Engineering
Lehigh University
frank.e.curtis@gmail.com, haw309@lehigh.edu

## MS7

### Active Set Strategies for the Gradient Projection Algorithm

When solving a nonlinear programming problem using the gradient projection method, we often need to project a vector into the linearized constraints. Active set strategies for solving the projection problem are examined, including the dual active set algorithm.

William Hager
University of Florida
hager@ufl.edu

## MS7

### A Robust Algorithm for Semidefinite Programming

Current successful methods for solving semidefinite programs, SDP, use symmetrization and block elimination steps that create ill-conditioning in the Newton equations. We derive and test a backwards stable primal-dual interior-point method for SDP that avoids the ill-conditioning. Our algorithm is based on a Gauss-Newton approach that allows for a preconditioned (matrix-free) iterative method for finding the search direction at each iteration.

Henry Wolkowicz
University of Waterloo
Department of Combinatorics and Optimization
hwolkowicz@uwaterloo.ca

Xuan Vinh Doan
C&O Department
University of Waterloo
vanxuan@uwaterloo.ca

Serge Kruk
Department of Mathematics and Statistics
Oakland University, Rochester, MI
kruk@oakland.edu

**MS7**

**A Trust Region Algorithm for Inequality Constrained Optimization with a New Scaling Technique**

In this paper, we propose a trust region algorithm for inequality constrained optimization with a new scaling technique. The scaling is derived by considering the special case of bound constraints, where the scaling matrix depends on the gradients of the objective function and the distances to the bounds. Global convergence results of the algorithm are presented.

Xiao Wang
Inst of Comp Math & Sci/Eng. AMSS
Chinese Academy of Sciences
wangxiao@lsec.cc.ac.cn

Ya-Xiang Yuan
Chinese Academy of Sciences
Inst of Comp Math & Sci/Eng, AMSS
yyx@lsec.cc.ac.cn

**MS8**

**Efficient Aerodynamic Design**

We present our methods for aircraft aerodynamic shape optimization based on Computational Fluid Dynamics. The examples of applications are total drag minimization at cruise flight conditions, which involves resolving the propagation of disturbances in the boundary layer, and lift maximization at landing and take-off, which requires solutions of the Reynolds Averaged Navier-Stokes equations. We also present our investigations in static aeroelastic optimization based on CFD.

Olivier G. Amoignon
FOI-Swedish Defence Research Agency
olivier.amoignon@foi.se

Ardeshir Hanifi, Jan Pralits, Daniel Skoogh, Fredrik Berefelt, Lars Tysell, Adam Jirasek, Mattias Chevalier
FOI
ardeshir.hanifi@foi.se, jan.pralits@foi.se, daniel.skoogh@foi.se, fredrik.berefelt@foi.se, lars.tysell@foi.se, adam.jirasek@foi.se, mattias.chevalier@foi.se

**MS8**

**An Adaptive One-Shot Approach for Aerodynamic Shape Optimization**

We focus on so-called one-shot methods and their applications to aerodynamic shape optimization, where the governing equations are the Navier-Stokes or Reynolds-averaged Navier-Stokes (RANS) equations. We constrain the one-shot strategy to problems, where steady-state solutions are achieved by pseudo-time stepping schemes. The one-shot optimization strategy pursues optimality simultaneously with the goals of primal and adjoint feasibility. To exploit the domain specific experience and expertise invested in the simulation tools, we propose to extend them in an automated fashion by the use of automatic differentiation (AD). First they are augmented with an adjoint solver to obtain (reduced) derivatives and then this sensitivity information is immediately used to determine optimization corrections. Finally, we discuss how to use the adjoint solutions also for goal-oriented error estimation and how to make use of the resulting error sensor for mesh adaptation and its integration into the presented one-shot procedure.

Nicolas R. Gauger
Department of Mathematics and CCES
RWTH Aachen University
gauger@mathcces.rwth-aachen.de

**MS8**

**Avoiding Mesh Deformations in Boundary Shape Optimization**

We propose an approach to boundary shape optimization in which the geometry is represented through varying coefficients in the governing equation. Our method constructs raster representations of the geometries, which circumvents the need for re-meshing and enables flexible choices of admissible designs. The method has been assessed on an acoustic optimization problem, using a shape parameterization that is difficult to employ with traditional methods, for which it generated visually smooth devices with favorable acoustic properties.

Fotios Kasolis
Department of Computing Science
Umea University, Sweden
fotios.kasolis@cs.umu.se

Eddie Wadbro
Department of Computing Science
Umeå University
eddiew@cs.umu.se

Martin Berggren
Department of Computing Science, Umea University
martin.berggren@cs.umu.se

**MS8**

**Aerodynamic Design based on Shape Calculus**

Shape optimization based on the Hadamard form of the shape derivative is considered. The Hadamard form provides an analytically exact surface formulation of the gradient, allowing shape optimization without the need to compute so called mesh sensitivities. Thus, shape optimization based on a first optimize then discretize fashion is enabled, where e.g. all mesh surface nodes can be used as design unknowns with next to no additional costs. Furthermore, approximations to shape Hessians are considered, thereby creating a shape one-shot optimization method. The talk conculdes with the optimization of a blended wing-body aircraft using 113,956 surface nodes as the shape unknowns.

Stephan Schmidt
University of Trier
Stephan.Schmidt@uni-trier.de

**MS9**

**4D Imaging using Optimal Transport and Sparsity Concepts**

We present models and efficient algorithms for 4D reconstruction in biomedical imaging using optimal transport and sparsity concepts. Standard reconstruction methods do not incorporate time dependent information or kinetics. This can lead to deficient accuracy particularly at object boundaries, e.g. at cardiac walls. We discuss constraint optimization models combining reconstruction techniques known from inverse problems, spatio-temporal regularization and mass conservation. The numerical realization is based on multigrid preconditioned Newton-SQP with filtered line-search and efficient operator splitting techniques with parallelization. Dynamic large-scale biomedical data illustrate the performance of our methods.

Christoph Brune
Institute for Computational and Applied Mathematics
University of Muenster, Germany
christoph.brune@wwu.de

Martin Burger
Institute for Numerical and Applied Mathematics
University of Muenster
martin.burger@uni-muenster.de

Eldad Haber
Department of Mathematics
The University of British Columbia
haber@math.ubc.ca

**MS9**

**Numerical Optimization for Constrained Image Registration with Application to Medical Imaging**

Image registration is a technique aimed at establishing meaningful correspondences between image voxels from different perspectives. It is an essential tool for various applications in medicine, geosciences, and other disciplines. However, obtaining plausible deformations is a complex task as often transformations are required to be locally invertible or even more challenging, are required to bound volume changes within a reasonable range. In this work, solutions to the registration problem were obtained by directly imposition of a volume constraint upon each voxel in a discretized domain. This study focuses on the development of an efficient and robust numerical algorithm and in particular, the application of an augmented Lagrangian method with a multigrid as preconditioner. We demonstrate that this combination yields an almost optimal solver for the problem.

Raya Horesh
Institute of Mathematics and its Applications
University of Minnesota
rhoresh@ima.umn.edu

Eldad Haber
Department of Mathematics
The University of British Columbia
haber@math.ubc.ca

Jan Modersitzki
University of Lübeck
Institute of Mathematics and Image Computing
jan.modersitzki@mic.uni-luebeck.de

**MS9**

**Optimal Control of the Bidomain Equations**

Well-posedness of the bidomain equations is investigated for several well-established ionic current models. Optimal control problems are formulated to influence the extra and intracellular potentials by means of extracellular applied current. Optimality conditions are derives rigorously. Numerical examples illustrate, for the two dimensional case, the feasibility of dampening excitation waves and controlling reentry phenomena.

Karl Kunisch
Karl-Franzens University Graz
Institute of Mathematics and Scientific Computing
karl.kunisch@uni-graz.at

Nagaiah Chamakuri, Marcus Wagner
Karl-Franzens University Graz
nagaiah.chamakuri@uni-graz.at,
marcus.wagner@uni-graz.at

**MS9**

**Large Scale Optimization Problems in Medical Imaging**

This talk presents a brief introduction to image registration and introduces the FAIR (Flexible Algorithms for Image Registration) package for a numerical solution using MATLAB. Moreover, a new component which enables mass preserving registration is discussed. The mass preserving registration is based on a new and thorough discretization of the determinant of the Jacabian and the co-factor matrix. Numerical results related to fast magnetic resonance imaging sequences are presented.

Jan Modersitzki
University of Lübeck
Institute of Mathematics and Image Computing
jan.modersitzki@mic.uni-luebeck.de

Lars Ruthotto
Institute of Mathematics and Image Computing
ruthotto@mic.uni-luebeck.de

**MS10**

**Conservation Laws Coupled with Ordinary Differential Equations**

This presentation describes some recent results concerning the basic well posedness theory of systems consisting of conservation laws coupled with ordinary differential equations. Several examples will be considered in more detail and numerical result will be presented.

Rinaldo M. Colombo
University of Brescia
Department of Mathematics
rinaldo@ing.unibs.it

**MS10**

**Feedback Stabilization for the Gas Flow in Networks**

The control of the gas flow in pipe networks plays an important role for the supply with natural gas. The gas flow through pipelines can be modeled by the isothermal Euler equations with friction, which are a hyperbolic 2x2-PDE-system of balance laws. We present recent results on the boundary feedback stabilization of the isothermal Euler equations locally around a given stationary state. The stabilization methods are based upon transformation to Riemann invariants and upon Lyapunov functions. The feedback laws guarantee an exponential decay of the Lyapunov functions with time.

Markus Dick
Universität Erlangen-Nürnberg

Dept. of Mathematics
dick@am.uni-erlangen.de

**MS10**

**On Control and Controllability of Systems of Nonlinear Conservation Laws**

We give an overview on optimal control and controllability for one–dimensional hyperbolic systems. We present a short summary of theoretical as well as numerical results. Applications towards network flows and controllability results on those are given.

Michael Herty
RWTH Aachen Universtiy
Department of Mathematics
herty@mathc.rwth-aachen.de

**MS10**

**Numerical Approximation of Optimal Control Problems for Discontinuous Solutions of Hyperbolic Conservation Laws**

We analyse the convergence of discrete approximations to optimal control problems for discontinuous solutions of hyperbolic conservation laws. Building on a sensitivity and adjoint calculus for the optimal control problem we show that an appropriate discretization by finite difference schemes with sufficient numerical viscosity at shock discontinuities leads to convergent approximations of the linearized and the adjoint equation and thus to convergent gradient approximations of the cost functional. Hence, efficient optimization methods are applicable. We present numerical results.

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

**MS11**

**Set-Valued Optimization Revisited: From Minimal Points to Lattice Solutions**

Motivated by duality issues, set-valued optimization problems have been studied since the 1980ies. Later, Tanaka et al. initiated solution concepts based on set relations. Recently, it has been shown that set-valued optimization (only) admits a complete (duality) theory if lattice extensions both of image and pre-image space are used. This theory matches the needs of applications in finance: optimization problems for set-valued risk measures in markets with transaction costs. The talk will be a guided tour through these subjects.

Andreas H. Hamel
Yeshiva University
Department of Mathematical Sciences
hamel@yu.edu

**MS11**

**About Set-valued Optimization via the Set Scheme**

The goal of this talk is to explore solution concepts in set-valued optimization and to clarify some links between them. Exactly, we study some criteria of solution associated to a set-valued optimization problem and we give optimality conditions by revising several existing results in the literature.

Elvira Hernandez
Departamento de Matemática Aplicada
UNED Madrid
ehernandez@ind.uned.es

Miguel Sama
Universidad Nacional de Educación a Distancia
msama@ind.uned.es

Luis Rodriguez-Marin
UNED
lromarin@ind.uned.es

**MS11**

**Fenchel-Rockafellar Duality for Set-valued Problems via Scalarization**

New Fenchel-Rockafellar type duality results for set-valued optimization problems are proven. The image space is a complete lattice of subsets of a preordered locally convex space. The proof consists of characterizing set-valued functions by families of extended real-valued ones and applying the scalar result. As corollaries, calculus rules for set-valued conjugates are shown. Applications to vector optimization problems are given by introducing a set-valued dual.

Carola Schrage
Institute for Mathematics
Martin-Luther-University Halle-Wittenberg
carola.schrage@mathematik.uni-halle.de

Andreas H. Hamel
Yeshiva University
Department of Mathematical Sciences
hamel@yu.edu

**MS11**

**Lagrange Necessary Conditions for Pareto Minimizers in Asplund Spaces and Applications**

In this talk, new necessary conditions for Pareto minimal points of sets and Pareto minimizers of constrained multiobjective optimization problems are established without the sequentially normal compactness property and the asymptotical compactness condition imposed on closed and convex ordering cones. Our approach is based on a version of a separation theorem for nonconvex sets and the subdifferentials of vector-valued and set-valued mappings. Furthermore, applications in mathematical finance and approximation theory are discussed.

Christiane Tammer
Faculty of Sciences III, Institute of Mathematics
University of Halle-Wittenberg
christiane.tammer@mathematik.uni-halle.de

Bao Q. Truong
Mathematics and Computer Science. Department
Northern Michigan University
btruong@nmu.edu

**MS11**

**Extended Pareto Optimality in Multiobjective**

**Problems**

This talk presents new developments on necessary conditions for minimal points of sets and their applications to deriving refined necessary optimality conditions in general models of set-valued optimization with geometric, functional, and operator constraints in finite and infinite dimensions. The results obtained address the new notions of extended Pareto optimality with preference relations generated by ordering sets satisfying the local asymptotic closedness property instead of that generated by convex and closed cones. In this way we unify and extend most of the known notions of efficiency/optimality in multiobjective models and establish optimality conditions that are new even in standard settings. Our approach is based on advanced tools of variational analysis and generalized differentiation.

Bao Q. Truong
Mathematics and Computer Science. Department
Northern Michigan University
btruong@nmu.edu

Boris Mordukhovich
Wayne State University
Department of Mathematics
boris@math.wayne.edu

### MS12
### On Calmness Conditions in Convex Bilevel Programming

We compare two well-introduced calmness conditions in the context of convex bilevel programming, namely partial calmness related to the value function approach and calmness of the solution set to the lower level problem under linear perturbations of the lower level objective. Both concepts allow to derive first order necessary optimality conditions. They differ, however, in their assumptions and in the resulting optimality conditions. We illustrate by theoretical results as well as by the example of a dicretized obstacle control problem that partial calmness is too restrictive in general.

Rene Henrion
Weierstrass Institute
Berlin, Germany
henrion@wias-berlin.de

Thomas M. Surowiec
Department of Mathematics
Humboldt University of Berlin
surowiec@math.hu-berlin.de

### MS12
### Handling Set Constraints in Variational Problems like Usual Inequalities

In many optimization and variational problems, abstract set-constraints of the type $h(x) \in C$, $C$ polyhedral, appear. Such set constraints are often handled separately in its algebraic form when deriving stability (and solvability) conditions, since standard constraint qualifications may fail to hold. We show how such problems can be rewritten in traditional inequality and equation form in such a way that results on stability of solutions and feasible points for the related classical models can be directly applied.

Diethard Klatte
University of Zurich
diethard.klatte@business.uzh.ch

Bernd Kummer
Humboldt-University of Berlin
kummer@math.hu-berlin.de

### MS12
### Introduction to Mathematical Programs with Cone Complementarity Constraints

Optimization problems involving symmetric positive semidefinite matrix variables,i.e., Semidefinite programs (SDPs), are well studied in engineering control and structural mechanics. Mathematical programs with semidefinite complementarity constraints are nonconvex optimization problems arising, e.g., as inverse problems when the forward model is an SDP. After penalizing the complementarity/orthogonality constraint,a nonconvex problem with both matrix and vector variables and constraints remains. Stationarity conditions are analyzed and the penalty formulation is solved for an application from structural optimization.

Daniel Ralph
University of Cambridge
Dept. of Engineering & Judge Institute of Management
danny.ralph@jims.cam.ac.uk

Michal Kocvara
School of Mathematics
University of Birmingham
kocvara@maths.bham.ac.uk

### MS12
### On the Derivation of Optimality Conditions for Elliptic MPECs via Variational Analysis

An elliptic MPEC is any mathematical program whose feasible set is governed by an elliptic variational inequality. After demonstrating new results concerning the contingent derivative of the solution mapping associated with the variational inequality, we derive an upper approximation of the Fréchet normal cone of the feasible set. This leads to optimality conditions resembling S-stationarity conditions. The strength of the results are then demonstrated by considering a model from the theory of elastoplasticity.

Thomas M. Surowiec
Department of Mathematics
Humboldt University of Berlin
surowiec@math.hu-berlin.de

### MS13
### Semidefinite Programming and Occupation Measures for Impulsive Control of Dynamical Systems

The problem of dynamical systems control can be approached constructively via occupation measures characterised by their moments satisfying semidefinite programming constraints. This allows for a genuine primal approach focusing on systems trajectories, in contrast with more classical dual approaches based on Lyapunov or similar energy functionals satisfying Hamilton-Jacobi-Bellman partial differential equations. We survey recent achievements in the area, with a focus on the design of impulsive control laws with application in satellite orbital transfer problems. Joint work with Denis Arzelier, Mathieu Claeys and Jean-Bernard Lasserre.

Didier Henrion
LAAS-CNRS, University of Toulouse, & Faculty of Electrical Engineering, Czech Technical University
henrion@laas.fr

**MS13**

**Algebraic Certificates for Linear Matrix Inequalities and Semidefinite Programming**

Given linear matrix inequalities (LMIs) $L_1$ and $L_2$ it is natural to ask:

1. when does one dominate the other, that is, does $L_1(X) \succeq 0$ imply $L_2(X) \succeq 0$?
2. when are they mutually dominant, that is, when do they have the same solution set?

In this talk we describe a natural relaxation of an LMI, based on substituting matrices for the variables $x_j$. With this relaxation, the domination questions (1) and (2) have elegant answers. Assume there is an $X$ such that $L_1(X)$ and $L_2(X)$ are both positive definite, and suppose the positivity domain of $L_1$ For our "matrix variable' relaxation a positive answer to (1) is equivalent to the existence of matrices $V_j$ such that

$$L_2(x) = V_1^* L_1(x) V_1 + \cdots + V_\mu^* L_1(x) V_\mu. \qquad (1)$$

As for (2), $L_1$ and $L_2$ are mutually dominant if and only if, up to certain redundancies, $L_1$ and $L_2$ are unitarily equivalent. Particular emphasis will be given to the case of *empty* LMI sets

$$\{X \mid L(X) \succeq 0\}.$$

We shall explain how to derive a polynomial sos version of the Farkas lemma for linear programming thus giving rise to a polynomial size infeasibilty certificate for semidefinite programs (SDP). The talk is based on joint works with *M. Schweighofer*, and *J.W. Helton* and *S. McCullough*; see e.g. http://arxiv.org/abs/1003.0908

Igor Klep
University of California, San Diego
iklep@math.ucsd.edu

**MS13**

**Error Bounds for Sums of Squares Relaxations of Some Polynomial Optimization Problems**

We consider semidefinite programming relaxations for polynomial optimization problems based on sums of squares of polynomials and the dual relaxations based on moment matrices. In particular, we give new error bounds for optimization over the hypercube for the hierarchy of relaxations corresponding to Schmüdgen's Positivstellensatz. These bounds are explicit and sharpen an earlier result of Schweighofer (2004). This is based on joint work with E. de Klerk. We also discuss recent bounds of Karlin, Mathieu and Nguyen (2011) for the case of a linear objective and a unique linear constraint (corresponding to the knapsack problem) and show that they extend to a block-diagonal version of Lasserre's hierarchy.

Monique Laurent
Tilburg University
CWI, Amsterdam
monique@cwi.nl

Etienne Klerk, de
Faculty of Economic Sciences
Tilburg University
e.deklerk@uvt.nl

**MS13**

**Pólya's Theorem and Optimization**

Let $\mathbf{R}[X] := \mathbf{R}[X_1, \ldots, X_n]$. Pólya's Theorem says that if a form (homogeneous polynomial) $p \in R[X]$ is positive on the standard $n$-simplex $\Delta_n$, then for sufficiently large $N$ all the coefficients of $(X_1 + \cdots + X_n)^N p$ are positive. In 2001, Powers and Reznick gave a bound on the $N$ needed, in terms of the degree of $p$, the coefficients, and minimum of $p$ on . This quantitative Pólya's Theorem has many applications, in both pure and applied mathematics. For example, it is an ingredient in the degree bound for Putinar's Positivstellensatz given by J. Nie and M. Schweighofer in 2007. This degree bound gives information about the convergence rate of Lasserre's procedure for optimizaiton of a polynomial subject to polynomial constraints. In joint work with M. Castle and B. Reznick, we extend the quantitative Pólya's Theorem to forms which are allowed to have zeros on $\Delta_n$. We give a complete characterization of forms for which the conclusion of Pólya's Theorem holds (with "positive on $\Delta_n$" relaxed to "nonnegative on $\Delta_n$"), and a bound on the $N$. We discuss these results and connections with optimization using Lasserre's method.

Victoria Powers
Emory University
vicki@mathcs.emory.edu

**MS14**

**An Introduction to a Class of Matrix Cone Programming**

In this talk, we introduce a class of matrix cone programming (MCP), which consists of linear conic programming problems whose conic constraints involve the epigraphs of $l_1$, $l_\infty$, spectral or nuclear matrix norms. We study several important properties, including its closed form solution, calm Bouligand-differentiability and strong semismoothness, of the metric projection operator over these matrix cones. These properties make it possible to design some efficient algorithms such as augmented Lagrangian methods, to solve MCP problems.

Chao Ding
National University of Singapore
g0700498@nus.edu.sg

Defeng Sun
Dept of Mathematics
National University of Singapore
matsundf@nus.edu.sg

Kim-Chuan Toh
National University of Singapore
Department of Mathematics and Singapore-MIT Alliance
mattohkc@nus.edu.sg

**MS14**

**Iteration-Complexity of Block-Decomposition Algorithms and the Alternating Minimization Augmented Lagrangian Method**

In this talk, we discuss the complexity of block-decomposition methods for solving monotone inclusion problems consisting of the sum of a continuous monotone map and a point-to-set maximal monotone operator with a separable two-block structure. As a consequence, we derive complexity results for alternating minimization augmented Lagragian methods for for solving block-structured convex optimization problems. Moreover, we also apply our results to derive new methods and corresponding complexity results for the monotone inclusion problem consisting of the sum of two maximal monotone operators.

Renato C. Monteiro
Georgia Institute of Technology
School of ISyE
monteiro@isye.gatech.edu

Benar Svaiter
IMPA
Rio de Janeiro, Brazil
benar@impa.br

**MS14**

**An Inexact Interior Point Method for L1-regularized Sparse Covariance Selection**

Sparse covariance selection (CSC) problems can be formulated as log-determinant optimization problems with large number of linear constraints. We propose a customized inexact interior-point algorithm for solving such large scale problems. At each iteration, we solve the large and ill-conditioned linear system of equations by an iterative solver using highly effective preconditioners constructed based on the special problem structures. Numerical experiments on synthetic and real CSC problems show that our algorithm can outperform other existing algorithms.

Kim-Chuan Toh
National University of Singapore
Department of Mathematics and Singapore-MIT Alliance
mattohkc@nus.edu.sg

Lu Li
ANZ Bank
lu.li@anz.com

**MS14**

**A Proximal Point Algorithm for Log-Determinant Optimization with Group Lasso Regularization**

We propose a practical proximal point algorithm for solving large scale log-determinant optimization problem with group Lasso regularization and linear equality constraints. At each iteration, as it is difficult to update the primal variables directly, we solve the dual problem by a Newton-CG method, and update the primal variables by an explicit formula based on the computed dual variables. We present numerical results to demonstrate that the proposed algorithm is efficient, especially when high accuracy is required.

Junfeng Yang
Nanjing University
jfyang2992@gmail.com

Defeng Sun
Dept of Mathematics
National University of Singapore
matsundf@nus.edu.sg

Kim-Chuan Toh
National University of Singapore
Department of Mathematics and Singapore-MIT Alliance
mattohkc@nus.edu.sg

**MS15**

**Optimizing over the Complement of Ellipsoids**

We describe continuing work related to the optimization of convex functions over the complement of a union of ellipsoids. This arises in several practical nonconvex optimization problems, and is related to several fundamental problem areas in optimization. Joint work with Alex Michalka and Mustafa Tural.

Daniel Bienstock
Columbia University IEOR and APAM Departments
IEOR Department
dano@columbia.edu

**MS15**

**Pooling Problems with Binary Variables**

The pooling problem consists of finding the optimal quantity of final products to obtain by blending different compositions of raw materials in pools. We study a generalization of the problem where binary variables are used to model fixed costs associated with using a raw material in a pool. We derive four classes of strong valid inequalities, that can be separated in polynomial time, and dominate classic flow cover inequalities. Successful computational results are reported.

Claudia D'Ambrosio
University of Bologna
DEIS
c.dambrosio@unibo.it

Jeff Linderoth
University of Wisconsin-Madison
Dept. of Industrial and Sys. Eng
linderoth@wisc.edu

James Luedtke
University of Wisconsin-Madison
Department of Industrial and Systems Engineering
jrluedt1@wisc.edu

**MS15**

**Computationally Effective Disjunctive Cuts for Convex Mixed Integer Nonlinear Programs**

We discuss computationally effective methods for generating disjunctive inequalities for convex mixed-integer nonlinear programs (MINLPs). Computational results indicate that disjunctive inequalities have the potential to close a significant portion of the integrality gap for convex MINLPs and to be as effective for solving convex MINLPs as they have been for solving mixed-integer linear programs.

Mustafa Kilinc
University of Wisconsin-Madison
Dept. of Industrial and Sys. Eng
kilinc@wisc.edu

Jeff Linderoth
University of Wisconsin-Madison
Dept. of Industrial and Sys. Eng

linderoth@wisc.edu

Jim Luedtke
University of Wisconsin-Madison
Dept. of Industrial and Sys. Eng
jrluedt1@wisc.edu

**MS15**

**Lifted Inequalities for Mixed Integer Nonlinear Sets with Special Structure**

Lifting is the process of converting a seed inequality valid for a restriction of the set to the unrestricted set. We apply lifting to specially-structured nonlinear sets. For mixed-binary bilinear knapsacks, we derive inequalities that are not easily obtained using IP techniques. For mixed-binary bilinear covers, we obtain facet-defining inequalities that generalize well-known inequalities for certain flow models. Finally, we derive valid nonlinear inequalities for disjunctive sets by projecting families of parameterized linear lifted inequalities.

Mohit Tawarmalani
Purdue University
mtawarma@purdue.edu

Jean-Philippe Richard
Department of Industrial and Systems Engineering
University of Florida
richard@ise.ufl.edu

Kwanghun Chung
Center for Operations Research and Econometrics
kwanghun.chung@uclouvain.be

**MS16**

**The Lifted Newton Method for Nonlinear Optimization**

The lifted Newton method is designed for the solution of nonlinear optimization problems that have objective and constraint functions with intermediate variables. Introducing these as additional degrees of freedom into the original problem offers more freedom for initialization and often, faster contraction rates are observed. An algorithmic trick allows us to perform each lifted Newton iteration at almost no additional computational cost compared to a non-lifted Newton iteration. We discuss under which conditions faster local quadratic convergence for lifted iterations can be expected, and demonstrate the speedup due to the lifted Newton method at a large PDE parameter estimation example. Part of the material was published in [Albersmeyer and Diehl, The Lifted Newton Method and Its Application in Optimization. SIAM Journal on Optimization (2010) 20:3,1655-1684].

Moritz Diehl
K.U.Leuven
moritz.diehl@esat.kuleuven.be

Jan Albersmeyer
previously at IWR, Uni Heidelberg
jan@albersmeyer.de

**MS16**

**Domain Decomposition Methods for Structural Optimization**

We investigate two approaches to the solution of topology optimization problems using decomposition of the computational domain. The first approach is based on a two stage algorithm; a block Gauss-Seidel algorithm is combined with a first order method guaranteeing convergence. The second approach uses the semidefinite programming formulation of the problem. We replace the original large matrix constraint by several smaller constraints. This leads to a significant improvement in efficiency.

Michal Kocvara
School of Mathematics
University of Birmingham
kocvara@maths.bham.ac.uk

Masakazu Kojima
Tokyo Institute of Technology
kojima@is.titech.ac.jp

James Turner
School of Mathematics
University of Birmingham, UK
turnerj@for.mat.bham.ac.uk

**MS16**

**Inexact Solution of NLP Subproblems in MINLP**

We investigated how the outer approximation method and the generalized Benders decomposition method are affected when the NLP subproblems are solved inexactly. We show that the cuts in the master problems can be changed to incorporate the inexact residuals, still rendering equivalence and finiteness in the limit case. Some numerical results will be presented to illustrate the behavior of the methods under NLP subproblem inexactness.

Luis N. Vicente, Min Li
University of Coimbra
lnv@mat.uc.pt, limin@mat.uc.pt

**MS16**

**Fast NLP Solvers for MINLP**

Branch-and-bound is the underlying framework for all efficient mixed-integer optimization solvers. In the linear case (MILP), significant speed improvements have been made using strong-branching and diving techniques, because LP solvers can handle problem changes consisting of changing just one bound very effectively. In this talk, we explore whether similar improvements can be made in the nonlinear (MINLP) context.

Andreas Waechter
Thomas J. Watson Research Center
andreasw@us.ibm.com

**MS17**

**A Linearized Model for Dynamic Positron Emission Tomography**

Dynamic Positron Emission Tomography allows monitoring physiological processes within the body that can be described by kinetic parameters. However, recovery of these parameters often requires the solution of complex and nonlinear operator equations. A variational framework is introduced that allows to promote sparsity of minimizers with respect to a temporal exponential basis.

Martin Benning
Institute for Computational and Applied Mathematics
University of Muenster
martin.benning@wwu.de

**MS17**

**Exact Relaxation to Bounded Variation Problems**

In this talk, we consider a class of problems given by the constrained minimization problems of the form

$$\min_{(u,v)\in BV(\Omega;\{0,1\})\times\mathcal{V}} F(v) + \int_\Omega G(v)u\ dx + TV(u), \quad (2)$$

where $F : \mathcal{V} \to \mathbf{R}$ is a (sequentially)weakly lower semicontinuous functional bounded below and $G : \mathcal{V} \to \mathcal{L}^{\checkmark}(\otimes)$ is a strongle continuous nonlinear operator for some $p > 1$. The model covers a lot of applications, such as the total variation (ROF) model for binary image restoration, Mumford-Shah model for image segmentation, minimal compliance in topology optimization, etc. In order to solve these binary constrained problems, we introduce the exact relaxation of (1) and give an efficient algorithm based on the Fenchel dual technique. Moreover, we show that the minimizers of (1) are able to be obtained by taking level sets of minimizers of the relaxation.

Yiqiu Dong
Institute of Biomathematics and Biometry
Helmholtz Zentrum München
yiqiu.dong@gmail.com

Michael Hintermueller
Humboldt-University of Berlin
hint@math.hu-berlin.de

Martin Burger
Institute for Numerical and Applied Mathematics
University of Muenster
martin.burger@uni-muenster.de

**MS17**

**Dynamic PET Reconstruction using Parallel ProXimal Algorithm**

We propose to extend a recent convex optimization approach based on the Parallel ProXimal Algorithm to improve the estimation at the voxel level in dynamic Positron Emission Tomography (PET) imaging. The criterion to be minimized is composed with a Kullback-Leibler divergence as a data fidelity term, an hybrid regularization (defined as a sum of a total variation and a sparsity measure), and a positivity constraint. The total variation is applied to each temporal frame and a wavelet regularization is considered for the space+time data. This allows us to smooth the wavelet artifacts introduced when the wavelet regularization is used alone. The proposed algorithm is evaluated on simulated and real dynamic fluorodeoxyglucose (FDG) brain data.

Caroline Chaux
Université Paris-Est
caroline.chaux@univ-mlv.fr

Claude Comtat
SHFJ, CEA
claude.comtat@cea.fr

Jean-Christophe Pesquet, Nelly Pustelnik
LIGM
Université Paris-Est
jean-christophe.pesquet@univ-paris-est.fr,
nelly.pustelnik@ims-bordeaux.fr

**MS17**

**Image Restoration in the Presence of Non-additive Noise**

We are concerned with the restoration of (blurred) images corrupted by multiplicative or Poisson noise. On the one hand, we propose alternating direction methods of multipliers for minimizing an I-divergence/TV functional which is related to both multiplicative and Poisson noise. On the other hand, we suggest novel nonlocal filters for removing multiplicative noise. To this end, a suitable similarity measure has to be found for defining the weights occurring in these filters in dependence on the noise statistics.

Gabriele Steidl
Institute of Mathematics und Computer Science
Universitaet Mannheim, Germany
steidl@kiwi.math.uni-mannheim.de

Tanja Teuber
University of Mannheim, Germany
Dept. of Mathematics and Computer Science
tteuber@mathematik.uni-kl.de

**MS18**

**Optimal Treatment Strategies Determined by Kinetic Equations**

Using a Boltzmann transport model, we consider the question of optimal treatment strategies in radiation therapy. We derive optimality conditions for an optimal control problem with space-dependent constraints on the size of the dose and present numerical results.

Richard C. Barnard
RWTH Aachen University
Center of Computational Engineering Sciences
barnard@mathcces.rwth-aachen.de

**MS18**

**Title Not Available at Time of Publication**

TBA.

Günter Leugering
University Erlangen-Nuremberg
Institute of Applied Math.
leugering@am.uni-erlangen.de

**MS18**

**Relaxation Schemes and Optimal Control**

Relaxation schemes are well-known and easy to implement discretization schemes for systems of conservation or balance laws. Hereby, the original (nonlinear) system of balance laws is replaced by a linear system of double size, called the relaxation system. Using asymptotic analysis it can be shown that the relaxation system is well-posed if the new system matrix satisfies the so-called subcharacteristic condition. Under this assumption a solution to the relaxation system is known to converge to a solution of the original system. Furthermore, using IMEX-schemes for the time integration of the numerical scheme, it can be shown that the discretized relaxation system converges to a discretization of the limit equations. To provide consistent schemes for optimal control, we derive conditions such that the discrete adjoint of the relaxation system is a valid discretization of the continuous adjoint relaxation system in the context of smooth solutions. Furthermore, we prove that the discretization of the adjoint relaxation system converges to a discretization of the adjoint limit equation. This discretization then turns out to be the adjoint of the discretized limit equation.

Veronika Schleper
University of Stuttgart
Institute of applied Analysis and Numerical Simulation
veronika.schleper@mathematik.uni-stuttgart.de

**MS18**

**H1-controllability of Nonlinear Conservation Laws**

We present a relaxation scheme to the optimal control of nonlinear hyperbolic systems, in particular the control of Euler flows in gas dynamics. The relaxation approximation under consideration has a linear transport part combined with a stiff source term. We discuss how the relaxation scheme can be applied to controllability problems involving nonlinear hyperbolic equations. We present some numerical results.

Sonja Steffensen
RWTH Aachen University
Dept. of Mathematics
veelken@mathc.rwth-aachen.de

**MS19**

**Derivative Free Optimization Method with Non Linear Constraints: Some Industrial Applications**

Derivative free optimization takes place in various application fields and often requires dedicated techniques to limit the number of evaluations of the usually time consuming simulator. We propose the Sequential Quadratic Approximation method (SQA) based on a trust region method with quadratic interpolation models. Its efficiency is illustrated on two industrial applications: an inverse problem for reservoir characterization which requires an adapted implementation for least-square problems and an engine calibration problem with derivative free constraints.

Delphine Sinoquet
IFP Energies nouvelles
delphine.sinoquet@ifp.fr

Delbos Frédéric, Langouët Hoël
IFPEN
frdric.delbos@ifpen.fr, hoel.langouet@ifpen.fr

**MS19**

**Challenges in Derivative-free Optimization**

Derivative-free optimization made substantial progress since the times of the Nelder-Mead simplex method. But several important challenges remain. In particular, there is a need for improvements in at least three areas where current methods frequently perform poorly: – the large-scale case (50 or more variables), – the noisy case (uncertainties of 10% or more), – the constrained case (tight black box constraints). This talk reviews some of the better techniques, including new approaches.

Arnold Neumaier
University of Vienna
Department of Mathematics
Arnold.Neumaier@univie.ac.at

**MS19**

**An Active Set Trust-region Method for Derivative-free Nonlinear Bound-constrained Optimization**

We consider an implementation of a recursive model-based active-set trust-region method for solving bound-constrained nonlinear non-convex optimization problems without derivatives using the technique of self-correcting geometry proposed in [Scheinberg and Toint, 2009]. Considering an active-set method in model-based optimization creates the opportunity of saving a substantial amount of function evaluations. It allows to maintain much smaller interpolation sets while proceeding optimization in lower dimensional subspaces. The resulting algorithm is shown to be numerically competitive.

Anke Troeltzsch
CERFACS
Toulouse, France
anke.troeltzsch@cerfacs.fr

Philippe L. Toint
University of Namur
philippe.toint@fundp.ac.be

Serge Gratton
ENSEEIHT, Toulouse, France
serge.gratton@enseeiht.fr

**MS20**

**Computational Experience with Copositive Programming-Based Approximations of the Stability Number**

We present recent advances in the approximate computation of the stability number of a graph using the doubly nonnegative relaxation introduced by Lovasz, McEliece, Rodemich, Rumsey, and Schrijver. Two possible improvements to handle its quadratic number of constraints are discussed. First, we consider reducing the size of the original relaxation by a partial aggregation of its equality constraints. Second, we relax the doubly nonnegative relaxation to a semidefinite relaxation and discuss a new cutting-plane method to handle the nonnegativity constraints more efficiently. The approach is based on a new interior-point algorithm that selects relevant sets of inequalities dynamically while exploiting the capability to warm start problems after updates without the need to restart or to modify previous iterates. We present computational results that quantify the computational benefit from each of these two techniques.

Miguel F. Anjos
Mathematics and Industrial Engineering & GERAD
École Polytechnique de Montréal
anjos@stanfordalumni.org

Alexander Engau
University of Colorado, Denver, USA.
alexander.engau@ucdenver.edu

Immanuel Bomze
University of Vienna
immanuel.bomze@univie.ac.at

**MS20**

**Second Order Motivated Scaling Approaches for the Spectral Bundle Method**

The spectral bundle method is a nonsmooth first order solver for semidefinite optimization over large sparse matrices. Oustry outlined how to combine first order approaches with the second order approach of Overton and Womersly. We report on work in progress towards using second order models in a large scale setting for practical scaling variants within the spectral bundle package "ConicBundle" and present first numerical results.

Christoph Helmberg
TU Chemnitz
Germany
helmberg@mathematik.tu-chemnitz.de

Michael L. Overton
New York University
Courant Instit. of Math. Sci.
overton@cs.nyu.edu

Franz Rendl
Alpen-Adria Universitaet Klagenfurt
Austria
rendl@uni-klu.ac.at

**MS20**

**Semidefinite Relaxations of Ordering Problems**

Ordering problems assign weights to each ordering and ask to find an ordering of maximum weight. The linear ordering problem is wells tudied, with exact solution methods based on polyhedral relaxations. The quadratic ordering problem does not seem to have attracted similar attention. We present a systematic investigation of semidefinite optimization based relaxations for the quadratic ordering problem, extending and improving existing approaches. We show the efficiency of our relaxations by providing computational experience on a variety of problem classes.

Philipp Hungerlaender, Franz Rendl
Alpen-Adria Universitaet Klagenfurt
Austria
philipp.hungerlaender@uni-klu.ac.at, rendl@uni-klu.ac.at

**MS20**

**A Semidefinite Relaxation for Sparse Max-Cut Problems**

We investigate semidefinite relaxations of the Max-Cut problem, which are formulated in terms of the edges of the graph, thereby exploiting the (potential) sparsity of the problem. We show how this is related to higher order liftings of Anjos and Wolkowicz and Lasserre. Contrary to the basic semidefinite relaxation, which is based on the nodes of the graph, the present formulation leads to a model which is significantly more difficult to solve. To solve the resulting SDP we developed an algorithm where we factorize the matrix in the dual SDP and apply an augmented Lagrangian algorithm to the resulting minimization problem. We present computational results that indicate that this model is manageable for sparse graphs on a few hundred nodes and yields very tight bounds.

Veronica Piccialli
Università degli Studi di Roma Tor Vergata
piccialli@disp.uniroma2.it

Franz Rendl
Universitat Klagenfurt
Institut fur Mathematik
franz.rendl@uni-klu.ac.at

Angelika Wiegele
Alpen-Adria-Universit{
"a}t Klagenfurt
Institut f. Mathematik
angelika.wiegele@uni-klu.ac.at

**MS21**

**Minty Variational Principle for Set-valued Variational Inequalities**

It is well known that a solution of a Minty scalar variational inequality of differential type is a solution of the related optimization problem, under lower semicontinuity assumption. This relation is known as "Minty variational principle". In this presentation we study this principle in the vector case for an arbitrary ordering cone and a non differentiable objective function. Further, we extend the Minty variational principle to set-valued variational inequalities.

Giovanni Crespi
Université de la Vallée d'Aoste
g.crespi@univda.it

Ivan Ginchev, Matteo Rocca
University of Insubria
Department of Economics
iginchev@eco.uninsubria.it, matteo.rocca@uninsubria.it

**MS21**

**On the Notion of Approximate Strict Solution in Set-valued Optimization via the Set Solution Criterion**

This talk is concerned with set-valued optimization problems. A new concept of approximate strict solution based on coradiant sets and the set optimality criterion is introduced. Then, the behavior of these approximate solutions when the error tends to zero is studied. Finally, some existence results are obtained through scalarization processes.

César Gutiérrez
Departamento de Matemática Aplicada
Universidad de Valladolid
cesargv@mat.uva.es

Bienvenido Jimenez
Universidad Nacional de Educacion a Distancia
bjimenez@ind.uned.es

Vicente Novo
Universidad Nacional de Educación a Distancia
vnovo@ind.uned.es

Lionel Thibault
D
'epartement des Sciences Math

'ematiques
Universit
'e de Montpellier II
thibault@math.univ-montp2.fr

**MS21**
**Bishop-Phelps Cones**

For Bishop-Phelps (BP) cones various properties are presented in normed spaces. Representations of the interior and the interior of the dual cone of a BP cone are given. A characterization of the reflexivity of a Banach space is formulated using these cones. For an arbitrary cone with a closed bounded base it is shown how an equivalent norm can be constructed so that this cone is representable as a BP cone.

Johannes Jahn
Department of Mathematics
University of Erlangen-Nuremberg
jahn@am.uni-erlangen.de

Truong Xuan Duc Ha
Institute of Mathematics of Hanoi
txdha@math.ac.vn

**MS21**
**Conic Regularization for Some Optimization Problems**

In recent years new optimality conditions, by means of multiplier rules, were obtained for abstract optimization problems in function spaces where the associated ordering cone of has a nonempty interior. However, it turns out that the multipliers for these problems belong to non-regular spaces of measures. One of the essential requirement of these studies is the validity of a Slater's type constraint qualification. It is known that Slater's type constraint qualification is a stringent condition and it does not hold for many important cases of interest. In this talk, we will discuss a new conical regularization technique that gives optimality conditions without requiring any Slater's type constraint qualification. The Henig dilating cones is the basic technical tool for this study. Finite element discretization of the dilating cone will be discussed and numerical examples will be presented.

Akhtar A. Khan
Rochester Institute of Technology
aaksma@rit.edu

Miguel Sama
Universidad Nacional de Educación a Distancia
msama@ind.uned.es

**MS22**
**Optimal Control of the Cahn-Hilliard Variational Inequality**

An optimal control problem governed by Allen-Cahn variational inequality is studied. These problems are phase field versions of optimal control problems for interfaces and free boundaries. First order optimality conditions are derived by using a penalization/relaxation technique. We also use ideas of Hintermüller/Kopacka concerning stationarity concepts for MPECs in function spaces.

Hassan Farshbaf-Shaker
Department of Mathematics
University of Regensburg
hassan.farshbaf-shaker@mathematik.uni-regensbur

**MS22**
**Optimal Shape Design Subject to Variational Inequalities**

The shape of the free boundary arising from the solution of a variational inequality is controlled by the shape of the domain where the variational inequality is defined. Shape and topological sensitivity analysis is performed for the obstacle problem and for a regularized version of its primal-dual formulation. The shape derivative for the regularized problem is defined and converges to the solution of a linear problem. These results are applied to the electrochemical machining problem.

Antoine Laurain
Karl-Franzens University of Graz, Austria
antoine.laurain@uni-graz.at

**MS22**
**A Parabolic MPEC Approach to the Calibration of American Options Pricing**

An inverse problem in the pricing of American options is considered. The problem is formulated as an MPEC problem in function space. First-order optimality conditions of C-stationarity-type are derived. The discrete optimality system is solved numerically by using an active-set-Newton solver with feasibility restoration.

Hicham Tber
Department of Mathematics
School of Science and Technology Beni-Mellal
hicham.tber@gmail.com

Michael Hintermueller
Humboldt-University of Berlin
hint@math.hu-berlin.de

**MS22**
**Optimal Control of Mixed Variational Inequalities**

In this talk some theoretical and numerical aspects on the optimal control of variational inequalities of the second kind will be presented. A special kind of regularizing functions with an active-inactive set structure will be introduced and its importance for the obtention of sharp necessary conditions will be highlighted. In addition, the design of second order numerical methods, both globally and locally convergent, for the solution of the control problems will be discussed.

Juan Carlos de los Reyes
Escuela Politécnica Nacional Quito
Quito, Ecuador
delosreyes@math.tu-berlin.de

**MS23**
**Approximating Convex Hulls of Planar Quartics**

Planar quartics are among the simplest examples of algebraic sets for which computing the convex hull is non-trivial, and for which applying sums of squares techniques and other criteria for semidefinite programming-representability is reasonable. However, even in this simple case, the behavior of these methods is not entirely understood. In this talk we will use these objects as an illustration of the techniques, giving a brief survey of what is known and showing, for this particular case, a nice geometric characterization of the first sums of squares relaxations.

Joao Gouveia
University of Washington
jgouveia@math.washington.edu

### MS23
### A New Look at Nonnegativity and Polynomial Optimization

We provide a new characterization of nonnegativity of a continuous function $f$ on a closed and non necessarily compact set $K$ of $R^n$. When $f$ is a polynomial this characterization specializes and provides a hierarchy of nested outer approximations $(C_k)$ of the convex cone $C(K;d)$ of polynomials of degree at most $d$, nonnegative on $K$. Each convex cone $C_k$ is a spectrahedron in the coefficients of $f$ with no lifting. In addition, for a fixed known $f$, checking membership in $C_k$ reduces to solving a generalized eigenvalue problem for which specialized softwares are available.

Jean B. Lasserre
LAAS CNRS and Institute of Mathematics
lasserre@laas.fr

### MS23
### The Central Path in Linear Programming

The central curve of a linear program consists of the central paths for optimizing over any region in the arrangement of constraint hyperplanes. We determine the degree, genus and defining ideal of this curve, thereby answering a 1989 question of Bayer and Lagarias. Refining work of Dedieu, Malajovich and Shub, we bound the total curvature of central paths, and we construct instances with many inflection points. Joint work with Jesus DeLoera and Cynthia Vinzant.

Bernd Sturmfels
University of California , Berkeley
bernd@Math.Berkeley.EDU

### MS23
### Convergence Theory of Successive Convex Relaxation Methods for Optimization over Semi-Algebraic Sets

I will discuss various techniques (new and old) used in convergence proofs for successive convex relaxation methods applied to optimization problems expressed as maximization of a linear function over a finite set of polynomial inequality constraints. I will focus on convergence rates and specially structured nonconvex optimization problems.

Levent Tuncel
University of Waterloo
Dept. of Combinatorics and Optimization
ltuncel@math.uwaterloo.ca

### MS24
### Piecewise Quadratic Approximations in Convex Numerical Optimization

We present a proximal bundle method for convex nondifferentiable minimization where the model is a piecewise quadratic convex approximation of the objective function. Unlike standard bundle approaches, the model only needs to support the objective function from below at a properly chosen subset of points, as opposed to everywhere. We provide the convergence analysis for the algorithm, with a general form of master problem which combines features of trust-region stabilization and proximal stabilization, taking care of all the important practical aspects such as proper handling of the proximity parameter and of the bundle of information. Numerical results are also reported.

Annabella Astorino
Istituto di Calcolo e Reti ad Alte Prestazioni - CNR
astorino@icar.cnr.it

Antonio Frangioni
Dipartimento di Informatica
University of Pisa
frangio@di.unipi.it

Manlio Gaudioso
Dipartimento di Elettronica Informatica e Sistemistica
Università della Calabria, Italia
gaudioso@deis.unical.it

Enrico Gorgone
Dipartimento di Elettronica Informatica e Sistemistica
Università della Calabria
egorgone@deis.unical.it

### MS24
### New Discrete Gradient Limited Memory Bundle Method for Derivative Free Nonsmooth Optimization

A new derivative free method is developed for solving unconstrained nonsmooth optimization problems. The method is based on the discrete gradient method by Bagirov et.al. and the limited memory bundle method by the author. The new method uses a bundle of discrete gradients to approximate the subdifferential of a nonsmooth function. The size of the bundle is kept low by the procedure similar to the limited memory bundle method. Moreover, the limited memory approach is used to limit the needed number of operations and the storage space. The comparison to some existing methods is given.

Napsu Karmitsa
Department of Mathematics
University of Turku
napsu@karmitsa.fi

Adil Bagirov
CIAO, School of ITMS,
The University of Ballarat
a.bagirov@ballarat.edu.au

### MS24
### Science Fiction in Nonsmooth Optimization

In the 1970's Lemaréchal found that a quasi-Newton method for smooth optimization performed well on some nonsmooth test functions. This was confirmed by Lewis and Overton in 2008. In the 1980's Lemaréchal said that

"Superlinear convergence in nonsmooth optimization is science fiction". We discuss the current state of affairs for rapid convergence, based on the $\mathcal{U}$-Hessian of Lemaréchal, Oustry and Sagastizábal, and give a BFGS $\mathcal{VU}$-algorithm that appears to show the achievement of science fiction.

Robert Mifflin
Washington State University
mifflin@math.wsu.edu

Claudia Sagastizábal
CEPEL (Electric Energy Research Center)
Brazil
sagastiz@impa.br

**MS24**

**The Proximal Chebychev Center Cutting Plane Algorithm for Convex Additive Functions**

The recent algorithm based on Chebychev centers proposed recently [Math. Prog., 119, pp. 239-271, 2009] for convex nonsmooth optimization, is extended to the case of additive functions. We highlight aspects where this extension differs from the aggregate case. We consider two different nonlinear multicommodity flows applications in telecommunications to assess the method. The numerical experiments also include some comparison with a proximal bundle algorithm.

Adam Ouorou
France Telecom R&D-Orange Labs
adam.ouorou@orange-ftgroup.com

**MS25**

**Separation and Relaxation for Completely Positive Matrices**

The cone $\mathcal{C}$ of completely positive (CP) matrices is important for globally solving many NP-hard quadratic programs. We construct a conceptual separation algorithm for $\mathcal{C}$ based on optimizing over smaller CP matrices, which in particular yields a concrete separation algorithm for $5 \times 5$ CP matrices. The separation algorithm also motivates a new class of tractable relaxations for $\mathcal{C}$, each of which improves a standard polyhedral-semidefinite relaxation. The relaxation technique can further be applied recursively to obtain a new hierarchy of relaxations, and for constant recursive depth, the hierarchy is tractable.

Samuel Burer
University of Iowa
Dept of Management Sciences
samuel-burer@uiowa.edu

Hongbo Dong
Department of Mathematics
University of Iowa
hondong@math.uiowa.edu

**MS25**

**Symmetric Tensor Approximation Hierarchies for the Completely Positive Cone**

In this work we construct two tensor-structured approximation hierarchies for the completely positive cone. We show they correspond to dual cones of two known approximation hierarchies for the copositive cone, one being polyhedral and the other being semidefinite. As an application, we construct primal optimal solutions with tensor liftings of a class of linear programming bounds for the stability number of a graph.

Hongbo Dong
Department of Mathematics
University of Iowa
hondong@math.uiowa.edu

**MS25**

**Projections onto the Copositive Cone, and Applications**

In this talk we present an algorithm for the projection of a matrix $A$ onto the copositive cone $\mathcal{C}$. By projecting $A$ onto a sequence of polyhedral inner and outer approximations of $\mathcal{C}$, we can approximate the projection of $A$ onto $\mathcal{C}$ with arbitrary precision. Furthermore we consider projections onto the completely positive cone, which is the dual cone of $\mathcal{C}$, and we discuss two applications.

Julia Sponsel
University of Groningen
j.k.sponsel@rug.nl

Mirjam Duer
TU Darmstadt
M.E.Dur@rug.nl

**MS25**

**Computational Experience with Polyhedral Approximations of Copositive Programs**

Relying on the previous results in the literature, the author recently proposed hierarchies of inner and outer polyhedral approximations of the copositive cone. Using these approximations, two sequences of increasingly sharper lower and upper bounds can be computed for the optimal value of a copositive program. Under mild assumptions, both sequences converge to the optimal value in the limit. We present computational results in an attempt to shed light on the performance of these approximations in practice.

E. Alper Yildirim
Koc University
alperyildirim@ku.edu.tr

**MS26**

**New Inequalities for Piecewise Linear Optimization and Mixed-integer Nonlinear Programming**

We give new valid inequalities for the piecewise linear optimization (PLO) knapsack polytope. Then, we present the results of our extensive computational study on their use on branch-and-cut to solve PLO, as well as nonconvex nonliear and mixed-integer nonlinear programming

Ismael De Farias, Rajat Gupta, Ernee Kozyreff
Texas Tech
ismael.de-farias@ttu.edu, rajat.gupta@ttu.edu,
ernee.kozyreff@ttu.edu

Ming Zhao
SAS
ming.zhao@sas.com

**MS26**

**Strong Polyhedral Relaxations for Multilinear Programs**

We study methods for obtaining polyhedral relaxations of problems containing multiple multilinear terms. The goal is to obtain a formulation that is more compact than the convex hull formulation, but yields tighter relaxations than the term-by-term or McCormick relaxation. We present promising computational results for an approach based on grouping the variables into subsets that cover all multilinear terms in the problem.

James Luedtke
University of Wisconsin-Madison
Department of Industrial and Systems Engineering
jrluedt1@wisc.edu

Jeff Linderoth
University of Wisconsin-Madison
Dept. of Industrial and Sys. Eng
linderoth@wisc.edu

Mahdi Namazifar
University of Wisconsin-Madison
namazifar@wisc.edu

**MS26**

**On the Chvatal-Gomory Closure of a Compact Convex Set**

In this talk, we show that the Chvatal-Gomory closure of any compact convex set is a rational polytope. This resolves an open question of Schrijver 1980 for irrational polytopes, and generalizes the same result for the case of rational polytopes (Schrijver 1980), rational ellipsoids (Dey and Vielma 2010) and strictly convex bodies (Dadush, Dey and Vielma 2010).

Juan Pablo Vielma
University of Pittsburgh
jvielma@pitt.edu

Daniel Dadush, Santanu S. Dey
Georgia Institute of Technology
dndadush@gatech.edu, santanu.dey@isye.gatech.edu

**MS27**

**Towards Optimal Newton-Type Algorithms for Nonconvex Smooth Optimization**

We consider a general class of second-order methods for unconstrained minimization that includes Newton's, inexact linesearch, cubic regularization and some trust-region variants. For each algorithm in this class, we exhibit an example of a bounded-below objective with Lipschitz continuous gradient and Hessian such that the method takes at least $\mathcal{O}(\epsilon^{-\ni/\in})$ function-evaluations to drive the gradient below $\epsilon$. Thus cubic regularization has (order) optimal worst-case complexity amongst the methods in this class.

Coralia Cartis
University of Edinburgh
School of Mathematics
Coralia.Cartis@ed.ac.uk

Nick Gould
Numerical Analysis Group
Rutherford Appleton Laboratory
nick.gould@stfc.ac.uk

Philippe L. Toint
The University of Namur
Department of Mathematics
philippe.toint@fundp.ac.be

**MS27**

**On Sequential Optimality Conditions for Constrained Optimization**

This talk is based in joint papers with R. Andreani, G. Haeser and B. F. Svaiter. We are concerned with first-order necessary conditions for smooth constrained optimization. A feasible point satisfies a sequential condition if there exists a sequence that converges to it and fulfills some computable property. These conditions are useful to analyze algorithms and to provide stopping criteria. Usually, sequential conditions exhibit an Approximate-KKT form and are satisfied by local minimizers independently of constraint qualifications.

Jose Mario Martinez
IMECC-UNICAMP
martinez@ime.unicamp.br

**MS27**

**Cubic Regularization Algorithm and Complexity Issues for Nonconvex Optimization**

We consider regularization methods for the nonconvex unconstrained and convexely constrained optimization problems. We review known convergence results their remarkable complexity properties, that is the number of function evaluations that are needed for the algorithm to produce an epsilon-critical point. We also discuss the complexity of the steepest-descent and Newton's methods in the unconstrained case and report surprising conclusions regarding their relative complexity. We also indicate why the cubic relaxation method (ARC) is remarkable and how results obtained for this method may be extended to first-order and DFO algorithms.

Philippe L. Toint
The University of Namur
Department of Mathematics
philippe.toint@fundp.ac.be

Coralia Cartis
University of Edinburgh
School of Mathematics
Coralia.Cartis@ed.ac.uk

Nick Gould
Numerical Analysis Group
Rutherford Appleton Laboratory
nick.gould@stfc.ac.uk

**MS27**

**Back to the Future: Revisiting the Central Path**

Since the mid-1980s—the beginning of modern interior-point methods—the central path has played a major conceptual and computational role in nonlinear optimization. But the same objects (curves of local minimizers of penalty and barrier functions) were studied during the 1960s and 1970s under different names. Reverting temporarily to the earlier interpretations, this talk will examine interesting and useful properties of the central path that have tended to be overlooked in recent years, including the implications of a non-tangential approach to the solution and implicit identification of the active set.

Margaret H. Wright
New York University
Courant Institute of Mathematical Sciences
mhw@cs.nyu.edu

**MS28**

**Control of Glucose Balance in ICU Patients**

Consistent tight blood sugar control in critically ill patients has proven elusive. Properly accounting for the saturation of insulin action and reducing the need for frequent measurements are important aspects in intensive insulin therapy. In this talk we present the composite metabolic model Glucosafe by Pielmeier et al. (Computer Methods and Programs in Biomedicine, 97:211-222, 2010) that integrates models and parameters from normal physiology and accounts for the reduced rate of glucose gut absorption and saturation of insulin action in patients with reduced insulin sensitivity. It is a system of non-linear ordinary differential equations with randomly perturbed parameters whose optimal control is of main focus.

Nicole Marheineke
FAU Erlangen-Nuernberg
marheineke@am.uni-erlangen.de

Thomas Cibis
TU Kaiserslautern / Fraunhofer ITWM
cibis@itwm.fhg.de

Ulrike Pielmeier
Aalborg University
upiel@hst.aau.dk

**MS28**

**Model Reduction, Simulation and Optimization of a Load Change for a Molten Carbonate Fuel Cell**

The ability of fast and save load changes is very important for stationary power plants powered by molten carbonate fuel cells. A hierachy of realistic and validated models exist. They consist of upto 28 PDEs of parabolic and hyperbolic type, some equations are degenerated. Part of the boundary conditions are given by a DAE. Numerical simulation and optimization results are presented. We compare especially some recently via model reduction developed model variants with existing models.

Armin Rund
University of Bayreuth,
Department of Mathematics
armin.rund@uni-bayreuth.de

Kurt Chudej
University of Bayreuth, Lehrstuhl f. Ingenieurmathematik
kurt.chudej@uni-bayreuth.de

Johanna Kerler
University of Bayreuth
kerlerj@gmx.de

**MS28**

**The Use of a Generalized Fisher Equation and Global Optimization in Chemical Kinetics**

A generalized Fisher equation (GFE) relates the time derivative of the average of the intrinsic rate of growth to its variance. The GFE is an exact mathematical result that has been widely used in population dynamics and genetics, where it originated. Here we demonstrate that the GFE can also be useful in other fields, specifically in chemistry, with models of chemical reaction systems for which the mechanisms and rate coefficients correspond reasonably well to experiments. The discrepancy of experimental data with the GFE can be used as an optimization criterion for the determination of rate coefficients in a given reaction mechanism. We illustrate this approach with two examples, the chloriteiodide and the Oregonator systems.

John Ross
Stanford University
Palo Alto, CA
john.ross@stanford.edu

Alejandro F. Villaverde, Julio R. Banga
IIM-CSIC
Vigo, Spain
afvillaverde@iim.csic.es, julio@iim.csic.es

Federico Moran, Sara Vazquez
Universidad Complutense de Madrid
Madrid, Spain
fmoran@bio.ucm.es, sarav@solea.quim.ucm.es

**MS29**

**Direct MultiSearch: A New DFO Approach for Multiple Objective Functions**

DMS is a novel derivative-free algorithm for multiobjective optimization, which does not aggregate any of the objective functions. Inspired by the search/poll paradigm of direct-search, DMS uses the concept of Pareto dominance to maintain a list of nondominated points, from which the new poll centers are chosen. The aim is to generate as many Pareto points as possible from the polling procedure itself, while keeping the whole framework general to accommodate other disseminating strategies.

A. L. Custodio
New University of Lisbon
Department of Mathematics
alcustodio@fct.unl.pt

J. F. A. Madeira
Technical University of Lisbon
jaguilar@dem.ist.utl.pt

A. I. F. Vaz
University of Minho
aivaz@dps.uminho.pt

L. N. Vicente
University of Coimbra
lnv@mat.uc.pt

**MS29**

**A Principled Stochastic Viewpoint on Derivative-**

**Free Optimization**

We consider numerical black-box optimization with little assumptions on the underlying objective function. Further, we consider sampling from a distribution to obtain new candidate solutions. Under mild assumptions, solving the original unknown optimization problem coincides with optimizing a parametrized family of distributions of our choice. Following seminal works of Wierstra and Glasmachers, we can now derive a gradient descend on the distribution manifold in a derivative-free problem context. For multivariate normal distributions this leads to a simplified instantiation of CMA-ES.

Nikolaus Hansen
INRIA-Saclay, Université Paris-Sud, France
nikolaus.hansen@lri.fr

**MS29**

**Derivative-Free methods for Mixed-Integer Optimization Problems**

We consider the problem of minimizing a continuously differentiable function of several variables where some of the variables are restricted to take integer values. We assume that the first order derivatives of the objective function can be neither calculated nor approximated explicitly. We propose an algorithm convergent to points satisfying suitable stationarity conditions. Integer variables are tackled by a local search-type approach. Numerical results on a difficult real application are presented and sustain the proposed method.

Stefano Lucidi
University of Rome
lucidi@dis.uniroma1.it

Giampaolo Liuzzi
CNR - IASI
liuzzi@iasi.cnr.it

Francesco Rinaldi
University of Rome
rinaldi@dis.uniroma1.it

**MS29**

**Optimization With Some Derivatives**

What is the value of knowing some partial derivatives in simulation-based optimization? We attempt an answer through our experience extracting additional structure on problems consisting of both blackbox and algebraic components. These problems include knowing derivatives: of some residuals in nonlinear least squares problems, of some nonlinear constraints, and with respect to a subset of the variables. In each case we use quadratic surrogates to model both the blackbox and algebraic components.

Stefan Wild
Argonne National Laboratory
wild@mcs.anl.gov

Jorge J. Moré
Argonne National Laboratory
Div of Math & Computer Science
more@mcs.anl.gov

**MS30**

**Randomized Dimensionality Reduction for Full-waveform Inversion**

One of the major problems with full-waveform inversion is the requirement of solving large systems of discretized PDE's for each source (right-hand side). For 3-D problems, this requirement is computationally prohibitive. To address this fundamental issue, we propose a randomized dimensionality-reduction strategy motivated by recent developments in stochastic optimization and compressive sensing. In this formulation, conventional Gauss-Newton iterations are replaced by dimensionality-reduced sparse recovery problems with randomized source encodings.

Felix J. Herrmann
Seismic Laboratory for Imaging and Modeling
The University of British Columbia
fherrmann@eos.ubc.ca

Tristan van Leeuwen, Aleksandr Aravkin, Xiang Li
the University of British Columbia
tleeuwen@eos.ubc.ca, saravkin@eos.ubc.ca, lxiang@eos.ubc.ca

**MS30**

**Stochastic Optimization Framework for Design of Proper Orthogonal Decomposition Bases**

Numerical solution of large-scale Partial Differential Equations (PDEs) is challenging from various aspects. The Proper Orthogonal Decomposition (POD) method has been commonly employed for projection of the solution into a lower dimensional subspace. Despite the popularity of the approach, its utility was hitherto limited due to the specificity of the POD basis to the model parameters and the corresponding right-hand-side it has been obtained from. In this study we propose a framework for the design of POD bases. The design problem is formulated as a nonlinear optimization problem with PDEs and reduced order PDE constraints. In order to account for model space variability with respect to the model and the right-hand-side, we resort to a Stochastic Sampling Average (SSA) formulation. Since the design process can be computationally intensive, we accelerate the procedure by the incorporation of stochastic trace estimators. Numerical studies, addressing the solution of large-scale problems, indicate the superiority of the designed bases upon their conventional counterparts.

Lior Horesh
Business Analytics and Mathematical Sciences
IBM TJ Watson Research Center
lhoresh@us.ibm.com

Eldad Haber
Department of Mathematics
The University of British Columbia
haber@math.ubc.ca

Marta D'Elia
MathCS, Emory University
mdelia2@mathcs.emory.edu

**MS30**

**Integration of Data Reduction Techniques and Optimization Algorithms**

We present a comparison of optimization algorithms that enable the use of (nonlinear) data reduction techniques in parameter estimation for partial differential equations. The comparison includes both full-space and reduced-space formulations and algorithms based on these approaches. In order to evaluate their performance, we provide a series of numerical experiments related to a data reduction technique based on compressed sensing.

Denis Ridzal, Joseph Young
Sandia National Laboratories
dridzal@sandia.gov, josyoun@sandia.gov

**MS30**

**Compressed Sensing in a Finite Product of Hilbert Spaces**

We present an extension of the theory of compressed sensing to finite products of Hilbert spaces. This enables the use of compressed sensing in domains such as Sobolov spaces which are the natural setting for partial differential equations (PDEs). Using this extension, we reduce the cost of solving systems of PDEs where each equation uses identical differential operators. Our result allows a reduction in the computational cost of an important class of parameter estimation problems.

Joseph Young, Denis Ridzal
Sandia National Laboratories
josyoun@sandia.gov, dridzal@sandia.gov

**MS31**

**Optimization over a Pareto Set in Multi-Objective Control Problems**

My talk deals with the problem of optimizing a nonsmooth real valued function over the efficient (Pareto) control processes set associated to a multi-objective control problem (grand coalition of a multi-player cooperative differential game). This problem may be considered as an attempt to help a decision maker in his choice of an efficient control process, because the efficient set is often very large (infinite) and not explicitly described.

Henri Bonnel
ERIM, University of New Caledonia
bonnel@univ-nc.nc

**MS31**

**Optimality Conditions for Vector Optimization Problems with Variable Ordering Structures**

Motivated by some recent applications e.g. in medical image registration we discuss vector optimization problems with a variable ordering structure. This structure is assumed to be given by a cone-valued map which associates to each element of the space a cone of preferred or dominated directions. For the case when the values of the cone-valued map are Bishop-Phelps cones we obtain for the first time scalarizations and based on that Fermat and Lagrange multiplier rule.

Gabriele Eichfelder
Department of Mathematics
University of Erlangen-Nuremberg
Gabriele.Eichfelder@am.uni-erlangen.de

Truong Xuan Duc Ha
Institute of Mathematics of Hanoi
txdha@math.ac.vn

**MS31**

**Geometric Duality for Convex Vector Optimization Problems**

Recently, a geometric duality theory for linear vector optimization problems was developed. That theory provides an inclusion-reversing one-to-one correspondence between 'optimal' faces of the image sets of the primal and the dual problem. We will extend this theory to the more general case of convex vector optimization problems.

Frank Heyde
Institute of Mathematics
University of Halle-Wittenberg
frank.heyde@mathematik.uni-halle.de

**MS31**

**Algorithms for Linear Vector Optimization Problems**

In 1998, Benson proposed a very efficient method to solve linear vector optimization problems, called outer approximation method. The idea is to construct the minimal points in the outcome space. Geometric duality for multiobjective linear programming can be used to derive a dual variant of Benson's outer approximation algorithm. Moreover, this duality theory can be used to obtain inner approximations. We propose an extension of Benson's algorithm as well as its dual variant which applies also to problems with an unbounded feasible set. This means that arbitrary linear vector optimization problems with the ordinary ordering cone and having at least one minimal vertex can be solved.

Andreas Loehne
Institute of Mathematics
University of Halle-Wittenberg
andreas.loehne@mathematik.uni-halle.de

**MS32**

**On Hilbert's Theorem about Nonnegative Polynomials in Two Variables**

In 1893 Hilbert showed that for every nonnegative bivariate polynomial $p$ of degree $2d$ there exists a nonnegative bivariate polynomial $q$ of degree $2d-4$ such that $pq$ is a sum of squares. Hilbert's proof is not well understood, and there are no modern expositions of it. As a consequence, the result itself is largely forgotten. I will explain a new proof of this result.

Greg Blekherman
University of California, San Diego
grrigg@gmail.com

**MS32**

**Moment Matrices and the Tensor Decomposition Problem**

In this talk, we will describe some connections between tensor decomposition, algebraic duality and moment matrices. We will show how exploiting the structure of these matrices can help solving the decomposition problem for general or symmetric tensors. This approach will be illustrated by some applications in geometric modelling.

Bernard Mourrain
INRIA Sophia Antipolis
mourrain@sophia.inria.fr

**MS32**

**Inverse Moment Problem for n-dimensional Polytopes**

The inverse moment problem asks to find the measure given (some of) its moments. It is well-studied in the case of the measures supported on a plane polygon, and can be solved exactly for convex polygons. In bigger dimensions, however, it was not known how to solve it exactly even in the case of uniform measures supported on simple convex polytopes, and all the known approximate methods relied on slicing the unknown body into a large number of 2-dimensional cylinders. We present a novel approach that produces exact answers, as well as is it capable of approximate solving. Along the way we show that O(N) moments, for N being the number of vertices of the convex polytope, suffice to reconstruct it. Joint work with N. Gravin, J. Lasserre, and S. Robins

Dmitrii Pasechnik
Nanyang Technological University
D.V.Pasechnik@uvt.nl

**MS32**

**Using Sums of Squares and Semidefinite Programming to Approximate Amoebas**

Amoebas are the logarithmic images of algebraic varieties. We present new techniques for tackling computational problems on amoebas (such as the membership problem) based on sums of sums of squares techniques and semidefinite programming. Our method yields polynomial identities as certificates of non-containedness of a point in an amoeba. As main theoretical result, we establish some degree bounds on the polynomial certificates. Moreover, we provide some actual computations of amoebas based on the sums of squares approach. (Joint work with Timo de Wolff.)

Thorsten Theobald
J.W. Goethe-Universität
Frankfurt am Main, Germany
theobald@math.uni-frankfurt.de

**MS33**

**Immunizing Conic Quadratic Optimization Problems Against Implemention Errors**

We show that the robust counterpart of a convex quadratic constraint with ellipsoidal implementation error is equivalent to a system of conic quadratic constraints. To prove this result we first derive a sharper result for the S-lemma in case the two matrices involved are simultaneously diagonizable. This extension of the S-lemma may also be useful for other purposes. We also extend the results to the case of conic quadratic constraints with implementation error. Several applications are discussed, e.g., design centering, robust linear programming with both parameter uncertainty and implementation error, and quadratic decision rules for the adjustable robust optimization problem.

Dick Den Hertog
Tilburg University
Faculty of Economics and Business Administration
D.denHertog@uvt.nl

Aharon Ben-Tal
Technion - Israel Institue of Technology
Israel
abental@ie.technion.ac.il

**MS33**

**Robust Optimization Made Easy with ROME**

We introduce ROME, a MATLAB-based algebraic modeling toolbox for modeling a class of robust optimization problems. ROME serves as an intermediate layer between the modeler and optimization solver engines, allowing modelers to express robust optimization problems in a mathematically meaningful way. Using modeling examples, we discuss how ROME can be used to model and analyze robust optimization problems. ROME is freely distributed for academic use from www.robustopt.com.

Joel Goh
Stanford University
joelgoh@stanford.edu

Melvyn Sim
NUS Business School
dscsimm@nus.edu.sg

**MS33**

**Robust Optimization of Nonlinear Constrained Dynamic Systems**

We present a technique to solve robust optimal control problems for nonlinear dynamic systems in a conservative approximation. Here, the nonlinear dynamic system is affected by an uncertainty whose L-infinity norm is known to be bounded. In a second part of the talk, we address the discretized problem, a min-max nonlinear program, by a novel variant of SQP type methods, sequential bi-level quadratic programming. Both techniques are illustrated by applying them to numerical examples.

Boris Houska
KU Leuven
boris.houska1@gmx.de

Moritz Diehl
K.U.Leuven
moritz.diehl@esat.kuleuven.be

**MS33**

**Distributionally Robust Joint Chance Constraints with Second-Order Moment Information**

We develop tractable SDP-based approximations for distributionally robust chance constraints, assuming that only the first- and second-order moments and the support of the uncertain parameters are given. We prove that robust individual chance constraints are equivalent to Worst-Case Conditional Value-at-Risk constraints. We also develop a conservative approximation for joint chance constraints, whose tightness depends on a set of scaling parameters. We show that this approximation becomes exact when the scaling parameters are chosen optimally.

Steve Zymler, Daniel Kuhn, Berc Rustem
Imperial College London
sz02@doc.ic.ac.uk, dkuhn@imperial.ac.uk, br@imperial.ac.uk

**MS34**
**Building a Completely Positive Factorization**

Using a bordering approach, and building upon an already known factorization of a principal block, we establish sufficient conditions under which we can extend this factorization to the full matrix. Simulations show that the approach is promising also in higher dimensions, provided there is no gap in the cp-rank. Also, a construction of instances with guaranteed high cp-rank is presented.

Immanuel Bomze
University of Vienna
immanuel.bomze@univie.ac.at

**MS34**
**Checking if a Sparse Matrix is Completely Positive**

The completely positive cone is useful in optimization as it can be used to create convex formulations of $\mathcal{NP}$-complete problems. In this talk we discuss the problem of checking if a sparse matrix is completely positive and finding its cp-rank when it is. We present a linear time algorithm for preprocessing a matrix to reduce the problem. For special types of matrices, for example acyclic matrices, this algorithm in fact solves the problem.

Peter Dickinson
University of Groningen
p.j.c.dickinson@rug.nl

**MS34**
**A Copositive Approach for Perfect Graphs**

If equality between the chromatic number and the click number of a graph holds, and if the same is true for any of its induced subgraphs, the graph is called perfect. Recently, in their celebrated paper "The strong perfect graph theorem", Chudnovsky, Robertson, Seymour and Thomas proved that a graph is perfect if and only if it does not contain an odd hole or odd antihole (with at least 5 nodes) as an induced subgraph. Shortly after, Chudnovsky, Cornejouls, Liu, Seymour and Vuskovic proved that recognition of perfect graphs can also be done in polynomial time. If a graph is perfect, its chromatic number can be determined by a polynomial time algorithm. It was proven by Grtschel, Lovsz and Schrijver in late 80's, and their algorithm is based on semidefinite programming. Nevertheless, one of the most intriguing open questions related to perfect graphs is the design of pure combinatorial polynomial time algorithm for determining their chromatic numbers. We present some copositive formulations for the clique number and the chromatic number of a graph, and study their connections for the class of perfect graphs. We show how such an approach can link the result of Grtschel, Lovsz and Schrijver with pure combinatorial approaches. Still, one of the most intriguing questions of combinatorial optimization is the existence of pure combinatorial algorithm. We will revisit some known mathematical programming formulations for the stable set number

Nebojsa Gvozdenovic
University of Novi Sad
nebojsa.gvozdenovic@gmail.com

**MS34**
**On the Set-Semidefinite Representation of Nonconvex Quadratic Programs with Cone Constraints**

We present a generalization of the well-known result stating that any non-convex quadratic problem over the nonnegative orthant with some additional linear and binary constraints can be rewritten as linear problem over the cone of completely positive matrices. The generalization is done by replacing the nonnegative orthant with an arbitrary closed convex cone. This set-semidefinite representation result implies new semidefinite lower bounds for quadratic problems over several Bishop-Phelps cones, presented in the talk

Janez Povh
Faculty of Information Studies in Novo Mesto
janez.povh@fis.unm.si

Gabriele Eichfelder
Department of Mathematics
University of Erlangen-Nuremberg
Gabriele.Eichfelder@am.uni-erlangen.de

**MS35**
**Robust Independence Systems**

This talk discusses the robustness for independence systems, which is a natural generalization of the greedy property of matroids. An independent set $X$ is called $\alpha$-robust if for any $k$, it includes an $\alpha$-approximation of the maximum $k$-independent set (i.e., an independent set with size at most $k$). We show every independence system $\mathcal{F}$ has a $1/\sqrt{\mu(\mathcal{F})}$-robust independent set, where $\mu(\mathcal{F})$ denotes the exchangeability of $\mathcal{F}$. Our result provides better bounds for various independence systems.

Naonori Kakimura, Kazuhisa Makino
University of Tokyo
kakimura@mist.i.u-tokyo.ac.jp,
makino@mist.i.u-tokyo.ac.jp

**MS35**
**A Primal-Dual Algorithm for Lattice Polyhedra**

Hoffman and Schwartz developed 1978 the Lattice Polyhedron model and proved that it is totally dual integral (TDI), and so has integral optimal solutions. The model generalizes many important combinatorial optimization problems, but has lacked a combinatorial algorithm. We developed the first combinatorial algorithm for this problem, based on the Primal-Dual Algorithm framework. The heart of our algorithm is an efficient routine that uses an oracle to solve a restricted abstract cut packing/shortest path subproblem. This plus a standard scaling technique yields a polynomial combinatorial algorithm. The talk will cover an introduction to the Lattice Polyhedron model, as well as a description of this primal-dual algorithm.

Britta Peis
T. U. Berlin
peis@math.tu-berlin.de

S. Thomas McCormick
Sauder School of Business, Vancouver, Canada
tom.mccormick@sauder.ubc.ca

**MS35**
**Principal Partition and the Matroid Secretary**

**Problem**

The goal in the *Random Assignment Model* of *Matroid Secretary Problem* is to select a maximum weight independent set of elements that arrive online in a random order. The weights are chosen by an adversary but are assigned randomly to the elements from the matroid ground set. By exploiting the *principal partition of a matroid* and its decomposition into *uniformly dense minors* we give the first constant factor competitive algorithm for this problem.

Jose A. Soto
MIT
jsoto@math.mit.edu

### MS35

### Generic Rigidity Matroids with Dilworth Truncations

We prove that the linear matroid that defines generic rigidity of $d$-dimensional body-rod-bar frameworks (i.e., structures consisting of disjoint bodies and rods linked by bars) can be obtained from the union of $\binom{d+1}{2}$ graphic matroids by applying variants of the Dilworth truncation $n_r$ times, where $n_r$ denotes the number of rods. This leads to an alternative proof of Tay's combinatorial characterizations of generic rigidity of rod-bar frameworks and that of identified body-hinge frameworks.

Shin-ichi Tanigawa
Kyoto University
tanigawa@kurims.kyoto-u.ac.jp

### MS36

### An Outer-Inner Approximation for Separable MINLP

We study Mixed Integer Nonlinear programs, where all nonlinear functions are convex and separable. One of the most efficient approaches to solve Mixed Integer Nonlinear programs is Outer Approximation. We show that even when all nonlinear function are separable Outer Approximation based algorithms can require the generation of an exponential number of iterations to converge. We propose a cure that exploits the separability of the functions. We also combine the modified outer approximation with an inner approximation scheme in order to obtain good feasible solution. We test the practical effectiveness of our approach on an application in the telecommunications industry.

Pierre Bonami
Laboratoire d'Informatique Fondamentale de Marseille
pierre.bonami@lif.univ-mrs.fr

Hassan Hijazi
LIX, Ecole Polytechnique, Palaiseau, France
hassan.hijazi@yahoo.com

Adam Ouorou
France Telecom R&D-Orange Labs
adam.ouorou@orange-ftgroup.com

### MS36

### Maximizing Expected Utility in the Presence of Discrete Decisions

We consider the problem of maximizing expected logarithmic utility in conjunction with a linear objective function over a mixed integer polyhedral set. We solve the resulting problems using an outer approximation approach, where we apply an SQP-based algorithm to solve the nonlinear subproblems. Computational results for large-scale portfolio optimization problems are presented both for the continuous as well as for the mixed integer setting.

Sarah Drewes
Technische Universität Darmstadt, Department of Mathematics
University of California - Berkeley
drewes@mathematik.tu-darmstadt.de

Sebastian Pokutta
Massachusetts Institute of Technology
sebastianpokutta@me.com

### MS36

### Optimistic MILP Approximations of Non-Linear Optimization Problems

We present a new piecewise-affine approximation of nonlinear optimization problems that can be seen as a generalization of the classical Union Jack triangulation. Roughly speaking, it is a generalization because it leaves more degrees of freedom to define any point as a convex combination of the samples. As an example, for the classical case of approximating a function of two variables, a convex combination of four points instead of only three is used. Because a plane is defined by only three independent points, the approximation obtained by triangulation is uniquely determined, while different approximations are possible in our case. If embedded in a Mixed-Integer Linear Programming (MILP) model the choice among those alternatives is (optimistically) guided by the objective function. An advantage of the new approximation within an MILP is that it requires a significant smaller number of additional binary variables and the logarithmic representation of these variables recently proposed by Vielma and Nemhauser can be applied. We show theoretical and computational evidence of the quality of the approximation and its impact within MILP models.

Andrea Lodi, Claudia D'Ambrosio
University of Bologna
DEIS
andrea.lodi@unibo.it, c.dambrosio@unibo.it

Silvano Martello
DEIS, University of Bologna
silvano.martello@unibo.it

Riccardo Rovatti
DEIS and ARCES, University of Bologna
rrovatti@arces.unibo.it

### MS36

### Global Optimization of Equilibirum Constrained Networks

Network flows are generally governed by an equilibrium principle such as Kirchoffs Laws in electrical networks, Wardrop Principle in transportation networks and Laws of Static Equilibrium in structural networks. All of above problem classes can be reduced to networks with nonlinear resistances. Earlier formulations cast the problem as a non-convex and non-smooth MINLP with no guarantee of global optimality. We present a novel convex MINLP formulation and describe an algorithm based on linearizations for the efficient solution. We also describe a new projected nonlinear cut that can be generalized to the class of Convex Disjunctive Programs. Effectiveness of the perspective cut for this class of problems will also be explored. Results demonstrating the effectiveness of the approach on applications from literature will be presented.

Arvind Raghunathan
United Technologies Research Center
arvind.uppili@gmail.com

**MS37**

**Practical Algorithmic Strategies in Augmented Lagrangians**

Practical strategies for improving the effectiveness of Augmented Lagrangian methods will be discussed in the present work. The outer-trust region strategy for dealing with the so called greediness phenomenon will be described. A nonmonotone scheme for increasing the penalty parameter will also be discussed. Theoretical results will be presented and numerical evidences of the usefulness of the suggested strategies will be analysed.

Ernesto G. Birgin
Department of Computer Science - IME
University of So Paulo
egbirgin@ime.usp.br

**MS37**

**Augmented Lagrangian Filter Methods**

We introduce a two-phase method for large-scale nonlinear optimization. In the first phase, projected-gradient iterations approximately minimize the augmented Lagrangian to estimate the optimal active set. In the second phase, we solve an equality-constrained QP. An augmented Lagrangian filter determines the accuracy of the augmented Lagrangian minimization and promotes global convergence. Our algorithm is designed for large-scale optimization, and we present promising numerical results.

Sven Leyffer
Argonne National Laboratory
leyffer@mcs.anl.gov

**MS37**

**Local Convergence of Exact and Inexact Augmented Lagrangian Methods under the Second-order Sufficiency Condition**

We establish local convergence and rate of convergence of the classical augmented Lagrangian algorithm (also known as the method of multipliers) under the sole assumption that the dual starting point is close to a multiplier satisfying the second-order sufficient optimality condition. In particular, no constraint qualifications of any kind are needed. Previous literature on the subject required the linear independence constraint qualification and, in addition, either the strict complementarity assumption or the stronger version of second-order sufficiency. For sufficiently large values of the penalty parameters we prove primal-dual $Q$-linear convergence rate, which becomes superlinear if the parameters are allowed to go to infinity. Both exact and inexact solutions of subproblems are considered. In the exact case, we further show that the primal convergence rate is of the same $Q$-order as the primal-dual rate. Previous assertions for the primal sequence all had to do with the the weaker $R$-rate of convergence (and required the stronger assumptions cited above).

Mikhail V. Solodov
Inst de Math Pura e Applicada
solodov@impa.br

Damian Fernandez
FaMAF, Univ. de Cordoba
Argentina
dfernan@impa.br

**MS37**

**Matrix-free Nonlinear Programming for Dynamic Optimization**

We investigate dynamic optimization problems that appear in nonlinear model predictive control. Such problems can be represented as parametric variational inequality problems. Aiming for real-time performance in a resource-limited environment, we propose a method that solves inexactly a quadratic program per step and prove that it stably tracks the optimal manifold. We demonstrate how the approach can be implemented in an iterative matrix-free framework by using an augmented Lagrangian approach.

Victor Zavala
Argonne National Laboratory
vzavala@mcs.anl.gov

Mihai Anitescu
Argonne National Laboratory
Mathematics and Computer Science Division
anitescu@mcs.anl.gov

**MS38**

**Numerical Methods for Model Discrimination in Chemistry and Biosciences**

If two or more model candidates are proposed to describe the same process and information available does not allow to discriminate between the candidates, new experiments must be designed to reject models by lack-of-fit test. Mathematically this leads to highly structured, complex, multiple experiments, multiple models optimal control problems. Special emphasis is placed on robustification of optimal designs against uncertainties in model parameters. New numerical methods and applications from chemistry and biosciences will be discussed.

Thorsten Ante, Ekaterina Kostina, Gregor Kriwet
Fachbereich Mathematik und Informatik
Philipps-Universitaet Marburg
ante@mathematik.uni-marburg.de,
kostina@mathematik.uni-marburg.de, g.kriwet@gmx.de

**MS38**

**Challenges of Parameter Identification for Nonlinear Biological and Chemical Systems**

Mathematical models ensuring a highly predictive power are of inestimable value in systems biology. Their application ranges from investigations of basic processes in living organisms up to model based drug design in the field of pharmacology. For this purpose simulation results have to be in consistency with the real process, i.e., suitable model parameters have to be identified minimizing the difference between the model outcome and measurement data. In this work, graph based methods are used to figure out

if conditions of parameter identifiability are fulfilled. In combination with network centralities, the structural representation of the underlying mathematical model provides a first guess of informative output configurations. As at least the most influential parameters should be identifiable and to reduce the complexity of the parameter identification process further a parameter ranking is done by Sobol' indices. The calculation of these indices goes along with a highly computational effort, hence monomial cubature rules are used as an efficient approach of numerical integration. In addition, a joint application of the previously introduced methods enables an online model selection process, i.e., operation conditions can be derived that make previously undistinguishable model candidates distinguishable. The feature of an online framework is quite attractive as it avoids the need for additional time consuming experiments. All methods are demonstrated for a well known motif in signaling pathways, the MAP kinase cascade.

Michael Mangold
Max-Planck-Institut für Dynamik komplexer technischer System
Magdeburg, Germany
mangold@mpi-magdeburg.mpg.de

Rene Schenkendorf
Max-Planck-Institut fuer Dynamik komplexer technischer Systeme, Magdeburg, Germany
rschenke@mpi-magdeburg.mpg.de

### MS38

### Robust Optimal Experimental Design for Model discrimination of Dynamic Biochemical Systems

Finding suitable models of dynamic biochemical systems is an important task in the biosciences. On the one hand a correct model can explain the underlying mechanisms on the other hand one can use the model to predict the behavior of a biological system under various circumstances. We present a computational framework to compute robust optimal experimental designs for the purpose of model discrimination.

Dominik Skanda
Department of Applied Mathematics
University of Freiburg, Germany
dominik.skanda@biologie.uni-freiburg.de

Dirk Lebiedz
University of Freiburg
Center for Systems Biology
dirk.lebiedz@biologie.uni-freiburg.de

### MS39

### Preconditioned Conjugate Gradient Method for Optimal Control Problems with Control and State Constraints

We consider saddle-point problems arising as linearized optimality conditions in optimal control problems. The efficient solution of such systems is a core ingredient in second-order optimization algorithms. In the spirit of Bramble and Pasciak, the preconditioned systems can be turned into symmetric and positive definite ones with respect to a suitable scalar product. We focus on the solution of problems with control and state constraints and provide numerical examples in 2D and 3D to illustrate the viability of our approach.

Roland Herzog
Chemnitz University of Technology
roland.herzog@mathematik.tu-chemnitz.de

Ekkehard W. Sachs
University of Trier
Virginia Tech
sachs@uni-trier.de

### MS39

### All-at-once Solution of Time-dependent PDE-constrained Optimization Problems

Time-dependent partial differential equations (PDEs) play an important role in applied mathematics and many other areas of science. One-shot methods try to compute the solution to these problems in a single iteration that solves for all time-steps at the same time. In this talk, we look at one-shot approaches for the optimal control of time-dependent PDEs and focus on the fast solution of these problems. The use of Krylov subspace solvers together with an efficient preconditioner allows for minimal storage requirements. We solve only approximate time-evolutions for both forward and adjoint problem and compute accurate solutions of a given control problem only at convergence of the overall Krylov subspace iteration. We show that our approach can give competitive results for a variety of problem formulations.

Martin Stoll
Computational Methods in Systems and Control Theory
Max Planck Institute for Dynamics of Complex Technical Syste
martin.stoll80@gmail.com

Andrew J. Wathen
Oxford University
Numerical Analysis Group
wathen@maths.ox.ac.uk

### MS39

### Preconditioning for An Option Pricing Problem

The pricing of European option using Merton's model leads to a partial integro-differential equation (PIDE). The numerical solution involves the solution of linear systems with dense coefficient matrices. We use a preconditioned conjugate gradient method combined with fast Fourier transform. The choice of the preconditioners is studied thoroughly, including estimates for the spectrum and mesh independence of the number of iterates required. The results are extended to relevant optimization problem and further discussed in such a context.

Xuancan Ye
FB IV - Department of Mathematics
University of Trier
yexuancan@uni-trier.de

Ekkehard W. Sachs
University of Trier
Virginia Tech
sachs@uni-trier.de

### MS39

### Robust Preconditioners for Distributed Optimal

**Control of the Stokes Equations**

In this talk an optimal control problem for steady state Stokes flow with distributed control is considered. The optimal control problem involves a regularization parameter, say $\alpha$, in the cost functional. For solving the discretized optimality system, we will present preconditioned Krylov subspace methods whose convergence rate is uniformly bounded in $\alpha$.

Walter Zulehner
University of Linz, Austria
zulehner@numa.uni-linz.ac.at

**MS40**

**Convergence Properties of Evolution Strategies**

Evolution strategies (ESs) are stochastic optimization algorithms for numerical optimization. In each iteration of an ES, internal parameters are updated using the ranking of candidate solutions and not their intrinsic objective function value. In this talk, we review linear convergence results for evolution strategies and discuss the consequences of the rank-based update in terms of lower bounds for convergence rates and invariance classes for the set of functions where linear convergence holds.

Anne Auger
INRIA Saclay
anne.auger@inria.fr

**MS40**

**Stochastic Second-Order Method for Function-Value Free Numerical Optimization**

We review the counterpart of Quasi-Newton methods in evolutionary computation: the covariance matrix adaptation evolution strategy, CMA-ES. The CMA-ES adapts a second-order model of the underlying objective function. On convex-quadratic functions, the resulting covariance matrix resembles the inverse Hessian matrix. Surprisingly, this can be accomplished derivative- and function-value free. The CMA-ES reveals the same invariance properties as the Nelder-Mead method, works reliably not only in low dimension and is surprisingly efficient also on convex and non-convex, highly ill-conditioned problems.

Nikolaus Hansen
INRIA-Saclay, Université Paris-Sud, France
nikolaus.hansen@lri.fr

**MS40**

**Theory of Randomized Search Heuristics in Combinatorial Optimization**

We analyze the runtime and approximation quality of randomized search heuristics when solving combinatorial optimization problems. Our studies treat simple local-search algorithms and simulated annealing as well as more complex population-based evolutionary algorithms. The combinatorial optimization problems discussed include the maximum matching problem, the partition problem and the minimum spanning tree problem as an example where Simulated Annealing beats the Metropolis algorithm in combinatorial optimization. Important concepts of the analyses will be sketched as well.

Carsten Witt
Technical University of Denmark
Denmark
cawi@imm.dtu.dk

Pietro Simone Oliveto
University of Birmingham
p.s.oliveto@cs.bham.ac.uk

**MS40**

**Some Applications of Evolutionary Computation**

This talk introduces some applications of evolutionary algorithms, including data-driven modelling in astrophysics and materials engineering, route optimisation for salting trucks in winter, multi-objective design of digital filters, software testing resource allocation, redundancy allocation in maximising system reliability, etc. The primary aim of this talk is to illustrate innovative applications of various randomised search heuristics, rather than trying to be comprehensive.

Xin Yao
University of Birmingham
x.yao@cs.bham.ac.uk

**MS42**

**The Infinite Push: A New Support Vector Ranking Algorithm that Directly Optimizes Accuracy at the Absolute Top of the List**

I will describe a new ranking algorithm called the 'Infinite Push' that directly optimizes ranking accuracy at the absolute top of the list. The algorithm is a support vector style algorithm, but due to the different objective, it no longer leads to a quadratic programming problem. Instead, the dual optimization problem involves $l_{1,\infty}$ constraints; we solve this using an efficient gradient projection method. Experiments on real-world data sets confirm the algorithm's focus on accuracy at the absolute top of the list.

Shivani Agarwal
Indian Institute of Science
shivani@csa.iisc.ernet.in

**MS42**

**A Graph Theoretical Approach to Preference Based Ranking: Survey of Recent Results**

I will survey recent results for preference based ranking from a graph theoretical perspective, where the problem is known as "Minimum Feedback Arc-Set". The following results will be highlighted: A simple 3-approximation using QuickSort, a PTAS by Kenyon and Schudy and a more recent sub-linear version of the PTAS. Special attention will be paid to the important Rank Aggregation case, in which the input is a convex combination of permutations.

Nir Ailon
Technion Israel Institute of Technology
nailon@cs.technion.ac.il

**MS42**

**Bayesian Ranking**

I will present several large-scale applications of Bayesian ranking algorithms to various domains including (1) gamer ranking on Xbox Live ("TrueSkill"), (2) professional chess gamer ranking across their lifetime ("TrueSkill-through-

Time"), (3) research school ranking in the 2008 British Research Assessment Exercise, and (4) ranking of advertisements (adPredictor) on Microsoft's search engine, bing. The key challenge in all these domains is data sparsity per entity - usually there are only O(log(n)) comparisons available for O(n) entities. I will also present an information theoretic viewpoint of ranking for evaluating the efficiency of Bayesian ranking algorithms.

Ralf Herbrich
Microsoft Research Cambridge
rherb@microsoft.com

**MS42**

**New Models and Methodologies for Group Decision Making, Rank Aggregation, Clustering and Data Mining**

The aggregate ranking problem is to obtain a ranking that is fair and representative of the individual decision makers' rankings. We argue here that using cardinal pairwise comparisons provides several advantages over score-wise or ordinal models. The aggregate group ranking problem is formalized as the separation model and separation-deviation model and linked to the inverse equal paths problem. This new approach is shown to have advantages over PageRank and the principal eigenvector methods.

Dorit Hochbaum
Industrial Engineering and Operations Research
University of California, Berkeley
hochbaum@ieor.berkeley.edu

**MS43**

**An Efficient Algorithm for Variable Sparsity Kernel Learning**

We present algorithms and applications for a particular class of mixed-norm regularization based Multiple Kernel Learning (MKL) formulations. The formulations assume that the given kernels are grouped and employ L1 norm regularization for promoting sparsity within each group, and Lp norm for promoting non-sparse combinations across groups. Various sparsity levels in combining the kernels can be achieved by varying the grouping of kernels—hence we name the formulations as Variable Sparsity Kernel Learning (VSKL) formulations. While previous attempts have a non-convex formulation, here we present a convex formulation which admits efficient Mirror-Descent (MD) based algorithm, combined with block coordinate descent method. Experimental results show that the VSKL formulations are well-suited for multi-modal learning tasks like object categorization. Results also show that the MD based algorithm outperforms state-of-the-art MKL solvers in terms of computational efficiency.

Aharon Ben-Tal
Technion - Israel Institue of Technology
Israel
abental@ie.technion.ac.il

**MS43**

**Robust PCA and Collaborative Filtering: Rejecting Outliers, Identifying Manipulators**

Principal Component Analysis is one of the most widely used techniques for dimensionality reduction. Nevertheless, it is plagued by sensitivity to outliers; finding robust analogs, particularly for high-dimensional data, is critical. We present an efficient convex optimization-based algorithm we call Outlier Pursuit that recovers the exact optimal low-dimensional subspace, and identifies the corrupted points. We extend this to the partially observed setting, significantly extending matrix completion results to the setting of corrupted rows or columns.

Constantine Caramanis
The University of Texas at Austin
caramanis@mail.utexas.edu

**MS43**

**Robustness Models in Learning**

Robust optimization is a methodology traditionally applied to handle measurement errors or uncertainty about future data in a decision problem. As such, it has a natural place in machine learning applications. In fact, classical learning models such as SVMs or penalized regression can be interpreted in terms of robustness models. This interpretation leads to new insights into important aspects such as consistency and sparsity of solutions. Building on these connections, we show that robust optimization ideas can lead to new, more performant learning models that take into account data structure, such as those arising in text classification, where the data is often boolean or integer-valued. Robustness models can also be used in the context of a large-scale learning problem with dense data, based on the idea of thresholding and taking into account the resulting error when solving the learning problem.

Laurent El Ghaoui
EECS, U.C. Berkeley
elghaoui@eecs.berkeley.edu

**MS43**

**Robust High-Dimensional Principal Component Analysis**

We revisit one of the perhaps most widely used statistical techniques for dimensionality reduction: Principal Component Analysis (PCA). In the standard setting, PCA is computationally efficient, and statistically consistent, i.e., as the number of samples goes to infinity, we are guaranteed to recover the optimal low-dimensional subspace. On the other hand, PCA is well-known to be exceptionally brittle – even a single corrupted point can lead to arbitrarily bad PCA output. We consider PCA in the high-dimensional regime, where a constant fraction of the observations in the data set are arbitrarily corrupted. We show that standard techniques fail in this setting, and discuss some of the unique challenges (and also opportunities) that the high-dimensional regime poses. For example, one of the (many) confounding features of the high-dimensional regime, is that the noise magnitude dwarfs the signal magnitude, i.e., SNR goes to zero. While in the classical regime, dimensionality recovery would fail under these conditions, sharp concentration-of-measure phenomena in high dimensions provide a way forward. Then, for the main part of the talk, we propose a High-dimensional Robust Principal Component Analysis (HR-PCA) algorithm that is computationally tractable, robust to contaminated points, and easily kernelizable. The resulting subspace has a bounded deviation from the desired one, for up to 50% corrupted points. No algorithm can possibly do better than that, and there is currently no known polynomial-time algorithm that can handle anything above 0%. Finally, unlike ordinary PCA algorithms, HR-PCA has perfect recovery in the limiting case where the proportion of corrupted points goes to zero.

Shie Mannor
Electrical Engineering
Technion
shie@ee.technion.ac.il

**MS44**

**Copositivity and Constrained Fractional Quadratic Problems**

Completely Positive (CpPP) and Copositive Programming (CoP) formulations for the Constrained Fractional Quadratic Problem (CFQP) and Standard Fractional Quadratic Problem (StFQP) are introduced. Dual and Primal attainability are discussed. Semidefinite Programming (SDP) formulations are proposed for finding good lower bounds to these fractional programs. A global optimization branch-and-bound approach is proposed for the StFQP. Applications of the CFQP and StFQP, related with the correction of nfeasible linear systems and eigenvalue complementarity problems are also discussed.

Paula Amaral
Universidade Nova de Lisboa
Portugal
paca@fct.unl.pt

Immanuel Bomze
University of Vienna
immanuel.bomze@univie.ac.at

Joaquim Judice
Universidade de Coimbra
Portugal
joaquim.judice@co.it.pt

**MS44**

**Some New Results in Copositive Programming**

We will present some new results concerning the cones of copositive and completely positive matrices which play an important role in quadratic and binary optimization.

Mirjam Duer
TU Darmstadt
M.E.Dur@rug.nl

**MS44**

**Testing Copositivity with the Help of Difference-of-Convex Optimization**

In this joint work with Mirjam Duer, we consider the problem of minimizing an indefinite quadratic function over the nonnegative orthant, or equivalently, the problem of deciding whether a symmetric matrix is copositive. We formulate the problem as a difference-of-convex functions (d.c.) problem. Using an appropriate conjugate duality, we show that there is a one-to-one correspondence between their respective stationary points and minima. We then apply a subgradient algorithm to approximate those stationary points and obtain an efficient heuristic to verify non-copositivity of a matrix. Keywords: Copositive matrices; difference-of-convex functions(d.c.); Legendre-Fenchel transforms; nonconvex duality; subgradient algorithms for d.c.functions.

Jean-Baptiste Hiriart-Urruty
University of Toulouse
France
jbhu@cict.fr

**MS44**

**Accelerated Projection Methods for Semidefinite Programs**

Accelerated projection methods are particularly suitable for optimization problems over the intersection of the semidefinite cone and the nonnegative cone or other polyhedral cones of sparse structure such as triangle inequalities. We present a simple algorithm and numerical results for the Lovasz-Schrijver $\theta$-number of graphs with up to 1000 vertices.

Florian Jarre
Mathematisches Institut
Universitaet Duesseldorf, Germany
jarre@opt.uni-duesseldorf.de

Thomas Davi
Universitaet Duesseldorf, Germany
Mathematisches Institut
davi@opt.uni-duesseldorf.de

**MS45**

**Dynamic Markets as Differential Variational Inequalities**

We investigate the effects of the physical layer of the energy infrastructure on the behavior of energy markets. We use differential variational inequalities as a flexible framework in which to describe both the market and physical layers. We investigate the effects of the various market design strategies and on the overall stability of the closed-loop system. We discuss the computational cost of the strategies of decision-makers and approximations that make them suitable for real-time environments.

Mihai Anitescu
Argonne National Laboratory
Mathematics and Computer Science Division
anitescu@mcs.anl.gov

Victor Zavala
Argonne National Laboratory
vzavala@mcs.anl.gov

**MS45**

**Differential Variational Inequalities in Control**

It is well-known that checking certain controllability properties of very simple piecewise linear systems are undecidable problems. This paper deals with the controllability problem of a class of piecewise linear systems, known as linear complementarity systems. By exploiting the underlying structure and employing the results on the controllability of the so-called conewise linear systems, we present a set of inequality type conditions as necessary and sufficient conditions for controllability of linear complementarity systems. The presented conditions are of PopovBelevitch-Hautus type in nature.

Kanat Camlibel
University of Groningen
Institute of Mathematics and Computer Science
m.k.camlibel@rug.nl

**MS45**

### A Unified Numerical Scheme for Linear-Quadratic Optimal Control Problems with Joint Control and State Constraints

We present a numerical scheme for the convex linear-quadratic optimal control problem with mixed polyhedral state-control constraints. Unifying the technique of model predictive control and a time-stepping method based on the differential variational inequality reformulation, the scheme solves a sequence of finite-dimensional problems whose optimal solutions are employed to construct a discrete-time trajectory. Such a numerical trajectory is shown to converge to an optimal trajectory of the continuous-time problem.

Jong-Shi Pang
University of Illinois at Urbana-Champaign
jspang@illinois.edu

**MS45**

### Runge-Kutta Methods for Solving Differential Variational Inequalities (DVIs)

Runge-Kutta methods can be used for DVIs as they can be used for differential inclusions (see Taubert (1976, 1981), Kastner-Maresch (1990), Dontchev & Lempio (1992)). However, some issues arise in the DVI setting that complicate the proofs and results. Under conditions known to imply uniqueness of solutions for the DVI, provided the exact solution is smooth on a given time interval, it can be shown that the numerical solutions from certain Runge-Kutta methods have the appropriate orders of convergence. Included in these methods is the Radau IIA family of methods which can give arbitrarily high order of convergence.

David E. Stewart
University of Iowa
Department of Mathematics
dstewart@math.uiowa.edu

**MS46**

### Fast Mixed-integer Model-predictive Control

We present work on nonlinear model predictive control problems. In this problem class, some control functions such as gear choices may only take values from a discrete set. Based on an Outer Convexification, on Bock's direct multiple shooting method, and on real-time iterations by Diehl, Bock, and Schlöder we present a new mixed-integer real time iteration scheme and discuss theoretical and algorithmic aspects.

Christian Kirches
Interdisciplinary Center for Scientific Computing
University of Heidelberg, Germany
christian.kirches@iwr.uni-heidelberg.de

Sebastian Sager
Interdisciplinary Center for Scientific Computing
sebastian.sager@iwr.uni-heidelberg.de

**MS46**

### Computational Complexity Certificates for MPC Based on the Fast Gradient Method

MPC requires the solution of a constrained finite horizon optimal control problem in a receding horizon fashion. Consequently, the solution to this optimization problem has to be obtained within one sampling period of the control loop. But guaranteeing deterministic termination of iterative solution methods is a challenging problem in general. This talk focuses on certifying Nesterov's fast gradient method for constrained linear quadratic MPC and points out links between problem data and convergence speed.

Stefan Richter
Institut für Automatik
ETH Zürich
richters@control.ee.ethz.ch

Colin Jones, Manfred Morari
Institut für Automatik
ETH Zürich, Switzerland
cjones@ee.ethz.ch, morari@ethz.ch

**MS46**

### Fast Explicit Nonlinear MPC via Multiresolution Interpolet Approximation

An algorithm for nonlinear explicit model predictive control is introduced based on multiresolution function approximation that returns a low complexity approximate receding horizon control law built on a hierarchy of second order interpolets. Feasibility and stability guarantees for the approximate control law are given using reachability analysis. A constructive algorithm is provided that results in a control law that is built on a grid hierarchy that is fast to evaluate in real-time systems.

Sean Summers, Davide Raimondo, Colin Jones, John Lygeros, Manfred Morari
Institut für Automatik
ETH Zürich, Switzerland
summers@control.ee.ethz.ch,
davide.raimondo@control.ee.ethz.ch, cjones@ee.ethz.ch,
lygeros@control.ee.ethz.ch, morari@ethz.ch

**MS46**

### Multilevel Iteration Schemes for Nonlinear Model Predictive Control

Although nonlinear model predictive control has seen many theoretical and computational advances, the application to systems requiring fast feedback is still a major computational challenge. In this contribution, we investigate new multi-level iteration schemes, which distribute the computations occurring in SQP iterations among up to four independent levels, ranging from fast feedback on the lowest level, where small QPs are solved very quickly, to complete derivative information generation on the topmost level. We give details on the implementation and we apply the multi-level iteration schemes to some test problems.

Leonard Wirsching
Interdisciplinary Center for Scientific Computing (IWR)
Heidelberg University
leonard.wirsching@iwr.uni-heidelberg.de

Hans Georg Bock
IWR, University of Heidelberg
bock@iwr.uni-heidelberg.de

Johannes Schloeder
IWR, University of Heidelberg, Germany
schloeder@iwr.uni-heidelberg.de

**MS47**
**On Convergence in Mixed Integer Programming**

We define the integral lattice-free closure $L(P)$ of a rational polyhedron $P$ as the set obtained from $P$ by adding all inequalities obtained from disjunctions associated with integral lattice-free sets. We show that $L(P)$ is again a polyhedron, and that repeatedly taking the integral lattice-free closure of $P$ gives its mixed integer hull after a finite number of iterations.

Alberto Del Pia
ETH
alberto.del.pia@ifor.math.ethz.ch

**MS47**
**Crooked Cross Cuts for Mixed Integer Programs**

We describe a family of asymmetric disjunctive cuts called crooked cross cuts. These cuts subsume two dimensional lattice-free cuts and they give the convex hull of mixed-integer programs with two integer variables (and many constraints). We also present separation heuristics and encouraging computational results on standard test sets. Joint work with Sanjeeb Dash, Santanu Dey and Juan-Pablo Vielma.

Oktay Gunluk
IBM, Watson, New York
gunluk@us.ibm.com

**MS47**
**Intersection Cuts with Infinite Split Rank**

We consider a mixed integer linear programs where $m$ free integer variables are expressed in terms of nonnegative continuous variables. When $m = 2$, Dey and Louveaux characterized the intersection cuts that have infinite split rank. We show that, for any $m \geq 2$, the split rank of an intersection cut generated from a bounded convex set $P$ is finite if and only if the integer points on the boundary of $P$ satisfy a certain "2-hyperplane property'.

Amitabh Basu
Dept. of Mathematics
Universiity of California, Davis
abasu@math.ucdavis.edu

Gerard Cornuejols
Tepper School of Business
Carnegie Mellon University
gc0v@andrew.cmu.edu

Francois Margot
Carnegie Mellon University
Tepper School of Business
fmargot@andrew.cmu.edu

**MS48**
**Detecting Structures in Matrices**

Permuting matrices into particular structures, like double-bordered block-diagonal or staircase forms is an area of interest in e.g., numerical linear algebra for preparing a matrix for parallel processing. The topic is also interesting when it comes to applying decomposition algorithms in linear and integer programming. As there is a canonical relationship between matrices and (hyper-)graphs, we study some of the structure detection problems on the graph theoretic side, formulate optimization problems for finding "best" structures, and discuss their usefulness for the mentioned decomposition algorithms.

Marco Lübbecke, Martin Bergner
RWTH, Aachen University
marco.luebbecke@rwth-aachen.de, martin.bergner@rwth-aachen.de

**MS48**
**Network Design with a Set of Traffic Matrices**

A crucial assumption in many network design problems is that we are given a single matrix of traffic demands (and that is known in advance). Unfortunately, in several applications, communication patterns among terminals change over time, and therefore we are given a set D of non-simultaneous traffic matrices. Still, we would like to design a min-cost network that is able to support any traffic matrix that is from D. In this paper, we discuss strategies for approaching this problem when D is a finite set. We settle a few complexity questions, present some approximation based results, and in some cases give exact polynomial-time algorithms.

Gianpaolo Oriolo
Università di Tor Vergata
oriolo@disp.uniroma2.it

Laura Sanita'
Ecole Polytechnique Federale de Lausanne
laura.sanita@epfl.ch

Rico Zenklusen
EPFL Lausanne
rico.zenklusen@gmail.com

**MS48**
**Steiner Tree Approximation Via Iterative Randomized Rounding**

The Steiner tree problem is one of the most fundamental NP-hard problems: given a weighted undirected graph G=(V,E) and a subset of terminal nodes, find a minimum weight tree spanning the terminals. In this talk, we introduce a directed LP relaxation and describe an approximation algorithm based on iterative randomized rounding of a fractional solution. We prove an approximation guarantee of 1.39 for the algorithm (improving over the previously best known factor of 1.55) and show that the mentioned LP has an integrality gap of at most 1.55 (improving over the previously best known factor of 2). This is joint work with Jaroslaw Byrka, Fabrizio Grandoni and Laura Sanita.

Thomas Rothvoss
EPF Lausanne
jocelyne.blanc@epfl.ch

**MS48**
**Scheduling and Power Assignments in the Physical Model for Wireless Networks**

In the interference scheduling problem, one is given a set of $n$ communication requests each of which corresponds to a sender and a receiver in a multipoint radio network. Each request must be assigned a power level and a color such that signals in each color class can be transmitted simultaneously. The feasibility of simultaneous communication within a color class is defined in terms of the signal to interference plus noise ratio (SINR) that compares the strength of a signal at a receiver to the sum of the strengths of other signals. This is commonly referred to as the physical model and is the established way of modeling interference in the engineering community. The objective is to minimize the schedule length corresponding to the number of colors needed to schedule all requests. We study oblivious power assignments in which the power value of a request only depends on the path loss between the sender and the receiver, e.g., in a linear fashion. At first, we present a measure of interference giving lower bounds for the schedule length with respect to linear and other power assignments. Based on this measure, we devise distributed scheduling algorithms for the linear power assignment achieving the minimal schedule length up to small factors. In addition, we study a power assignment in which the signal strength is set to the square root of the path loss. We show that this power assignment leads to improved approximation guarantees in two kinds of problem instances defined by directed and bidirectional communication request. Finally, we study the limitations of oblivious power assignments by proving lower bounds for this class of algorithms.

Berthold Vocking
RWTH Aachen University
voecking@cs.rwth-aachen.de

**MS49**

**On a Problem of Optimal Control of Magnetic Fields**

A problem of optimal magnetization is considered. It is related to the time-optimal switching between magnetic fields and leads to the minimization of a tracking type functional subject to a system of parabolic equations of differential algebraic type. We discuss the sensitivity analysis and present 3D numerical results for a slightly simplified geometry.

Kristof Altmann
Technische Universitaet Berlin
Institut fuer Mathematik
altmann@math.tu-berlin.de

Fredi Troeltzsch
Techn. University of Berlin
Department of Mathematics
troeltzsch@math.tu-berlin.de

**MS49**

**Error Estimates for an Optimal Control Problem with a Non Differentiable Cost Functional**

In this talk, semilinear elliptic optimal control problems involving the $L^1$ norm of the control in the objective are considered. Necessary and sufficient second-order optimality conditions are derived. A priori finite element error estimates for piecewise constant discretizations for the control and piecewise linear discretizations of the state are shown. Error estimates for the variational discretization of the problem, as introduced by Hinze (2005), are also obtained. Finally, numerical experiments confirm the convergence rates.

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

Roland Herzog
Chemnitz University of Technology
roland.herzog@mathematik.tu-chemnitz.de

Gerd Wachsmuth
TU Chemnitz
Fakultät für Mathematik
gerd.wachsmuth@mathematik.tu-chemnitz.de

**MS49**

**Bang Bang Control of Elliptic PDEs**

In this talk we describe the use of variational approach in order to discretize elliptic optimal control problems with bang-bang controls. We prove error estimates for the resulting scheme and present a numerical example which supports our analytical findings.

Nikolaus von Daniels
Universität Hamburg
Fachbereich Mathematik
nikolaus.von.daniels@uni-hamburg.de

Klaus Deckelnick
Otto-von-Guericke-University Magdeburg
klaus.deckelnick@mathematik.uni-magdeburg.de

Michael Hinze
Universität Hamburg
Department Mathematik
michael.hinze@uni-hamburg.de

**MS49**

**A Priori Error Analysis of the Petrov Galerkin Crank Nicolson Scheme for Parabolic Optimal Control Problems**

In this talk, a finite element discretization of an optimal control problem governed by the heat equation is considered. The temporal discretization is based on a Petrov Galerkin variant of the Crank Nicolson scheme, whereas the spatial discretization employs usual conforming finite elements. With a suitable post-processing step, a discrete solution is obtained for which error estimates of optimal order are proven. A numerical result is presented for illustrating the theoretical findings.

Boris Vexler, Dominik Meidner
Technische Universitaet Muenchen
Centre for Mathematical Sciences, M1
vexler@ma.tum.de, meidner@ma.tum.de

**MS50**

**SQP Methods for Large-scale NLP**

Recent advances in MINLP and the solution of NLPs with differential equation constraints have revived interest in methods that may be warm started from a good estimate of a solution. In this context, we review some recent developments in methods for large-scale convex and nonconvex quadratic programming and consider the use of these methods in a sequential quadratic programming (SQP) method that exploits both first and second derivatives of the objective and constraint functions.

Philip E. Gill, Elizabeth Wong
University of California, San Diego
Department of Mathematics
pgill@ucsd.edu, elwong@ucsd.edu

**MS50**

**Preconditioners for Matrix-free Interior Point Method**

A new variant of Interior Point Method (IPM) will be addressed which allows for a matrix-free implementation. Preconditioner(s) suitable in this context will be presented and their spectral properties will be analysed. The performance of the method will be illustrated by computational results obtained for very large scale optimization problems. This work is an extension of the paper available from: http://www.maths.ed.ac.uk/~gondzio/reports/mtxFree.html.

Jacek Gondzio
The University of Edinburgh, United Kingdom
J.Gondzio@ed.ac.uk

**MS50**

**CQP: a Fortran 90 Module for Large-Scale Convex Quadratic Programming**

We describe the design of a new software package CQP for large-scale convex quadratic programming. The method is based on high-order Taylor and Puiseux approximation to a variety of infeasible arcs connecting the current iterate to a better target point. Possible arcs include those by Zhang and by Zhou and Sun based on work by Stoer, Mizuno, Potra and others. The resulting algorithm is provably both globally and polynomially convergent at an ultimately high-order (depending on the series used) in both non-degenerate and degenerate cases. We will illustrate a number of algorithmic options on the CUTEr QP test set. CQP is available as part of the fortran 90 library GALAHAD.

Nick Gould
Numerical Analysis Group
Rutherford Appleton Laboratory
nick.gould@stfc.ac.uk

Dominique Orban
Ecole Polytechnique de Montreal
dominique.orban@polymtl.ca

Daniel Robinson
Oxford University
daniel.p.robinson@gmail.com

**MS50**

**A Regularized Primal-Dual SQP Method**

We present a regularized SQP method based on a primal-dual augmented Lagrangian function. Trial steps are computed from carefully chosen subproblems that utilize relationships between traditional SQP, stabilized SQP, and the augmented Lagrangian. Each subproblem is well defined regardless of the rank of the Jacobian, and (to some extent) we challenge the belief that large penalty parameters should be avoided. Numerical results on equality constrained problems from the CUTEr test set are provided.

Daniel Robinson
Oxford University
daniel.p.robinson@gmail.com

Philip E. Gill
University of California, San Diego
Department of Mathematics
pgill@ucsd.edu

**MS52**

**Integer Optimization Methods for Ranking Problems in Machine Learning**

In supervised ranking, the goal is to optimize a "rank statistic," which measures the quality of a ranked list. We present novel mixed integer programming (MIP) formulations for a wide variety of supervised ranking tasks. Other ranking methods use convex functions to approximate rank statistics in order to accommodate extremely large problems. In contrast, our MIP approach provides exact modeling. We report computational results that demonstrate significant advantages for MIP methods over current state-of-the-art.

Dimitris Bertsimas, Allison Chang
Massachusetts Insitute of Technology
dbertsim@mit.edu, aachang@mit.edu

Cynthia Rudin
Massachusetts Institute of Technology
rudin@mit.edu

**MS52**

**Learning to Rank with a Preference Function**

We discuss novel algorithmic solutions to the problem of learning to rank in the preference-based setting. This formulation of the ranking problem is important since it closely models that of search engines. Its crucial advantage is that it does not require the learning algorithm to return a linear ordering of all the points, which may be impossible to achieve faultlessly with a preference function in general non-transitive.

Mehryar Mohri
Courant Institute of Mathematical Sciences & Google Research
mohri@cs.nyu.edu

**MS52**

**Label Ranking through Soft Projections onto Polyhedra**

In the talk we focus on the problem of learning to rank labels from a real valued feedback associated with each label. We cast the feedback as a preferences graph where the nodes of the graph are the labels and edges express preferences over labels. We tackle the learning problem by defining a loss function for comparing a predicted graph with a feedback graph. This loss is materialized by decomposing the feedback graph into bipartite sub-graphs. We then adopt the maximum-margin framework which leads to a quadratic optimization problem with linear constraints. While the size of the problem grows quadratically with the number of the nodes in the feedback graph, we derive a problem of a significantly smaller size and prove that it attains the same minimum. We then describe an efficient algorithm, called SOPOPO, for solving the reduced problem by employing a soft projection onto the polyhedron defined by a reduced set of constraints. We also describe and analyze a wrapper procedure for batch learning when multiple graphs are provided for training. We conclude with the description of experiments and applications that demonstrate the merits of SOPOPO. Based on joint work with Shai Shalev-Shwartz and Samy Bengio. For more details and code see http://www.magicbroom.info/Research.html

Yoram Singer
Google Research
singer@google.com

**MS52**

**Ranking by Pairwise Comparison: Choice of Method can Produce Arbitrarily Different Rank Order**

For the three methods Principal Eigenvector, HodgeRank and Tropical Eigenvector for obtaining cardinal ranking from a paired comparison matrix, we proved the following: for all $n > 3$, for any rank order pair $(\sigma_1, \sigma_2)$, there exists a comparison matrix in which one method gives the ranking $\sigma_1$, and another method gives the ranking $\sigma_2$. We discuss the implications of this result in practice, study the geometry of the methods, and state some open problems.

Ngoc Mai Tran
University of California, Berkeley
tran@stat.berkeley.edu

**MS53**

**Hyperspectral Data Unmixing using Compressive Sensing—Method and Real-Data Simulations**

Hyperspectral data unmixing typically demands enormous computational resources in terms of storage, computation and I/O throughputs, especially for real-time processing. In light of the emerging field compressive sensing, we investigate a low complexity scheme for hyperspectral data acquisition and reconstruction. Specifically, compressed hyperspectral data are acquired directly by a device similar to the single-pixel camera. Instead of firstly collecting the pixels/voxels, it acquires the random projections of a scene based on the principle of compressive sensing. To decode the compressed data, we propose a numerical procedure to straightly compute the unmixed abundance fractions of given endmembers, completely bypassing high-complexity tasks involving the hyperspectral data cube itself. Grounded on the former work of splitting idea and TVAL3 algorithm, an augmented Lagrangian type algorithm is developed to solve the unmixing model. In practice, either the observed data or the priori info may contain disturbance or noise, which causes the trouble of unmixing. Experimental and computational results show that the proposed scheme has a high potential in real-world applications, even if the noise exists.

Chengbo C. Li
Rice University
Dept of Comp and Applied Math
cl9@rice.edu

**MS53**

**A Simple and Efficient SVD Algorithm for Principal Component Analysis**

Many data-related applications utilize principal component analysis and/or data dimension reduction techniques that require efficiently computing leading parts of singular value decompositions (SVD) of very large matrices. In this talk, we introduce a subspace iteration scheme that uses limited memory Krylov subspace optimization to do acceleration. We present extensive numerical results comparing a Matlab implementation of the algorithm with state-of-the-art SVD solvers. Our tests indicate that the proposed method can provide better performance under the Matlab environment over a wide range of problems.

Xin Liu
CAAM
RICE UNIVERSITY
liuxin@lsec.cc.ac.cn

**MS53**

**Feasible Methods for Optimization with Orthogonality Constraints: Part II**

We extended the gradient approaches for minimization with orthogonality constraints from two perspectives. First, a limited-memory BFGS method is proposed without using the expensive parallel translation or vector transport. Second, in order to handle general constraints, we embed the orthogonality constraint preserving approaches in the augmented Lagrangian framework. Numerical experiments on a variety of problems are presented.

Zaiwen Wen
Shanghai Jiao Tong University
Department of Mathematics
zw2109@sjtu.edu.cn

**MS53**

**Feasible Methods For Optimization with Orthogonality Constraints: Part I**

Minimization with orthogonality constraints (e.g., $X^\top X = I$) and/or spherical constraints (e.g., $\|x\|_2 = 1$) has wide applications in polynomial optimization, combinatorial optimization, eigenvalue problems, matrix rank minimization, etc. To deal with these difficulties, we propose to use a Crank-Nicolson-like update scheme to preserve the constraints and, based on it, develop a curvilinear search algorithm. Preliminary numerical experiments on a wide collection of problems show that the proposed algorithm is very promising.

Wotao Yin
Rice University
wotao.yin@rice.edu

**MS54**

**Implementation of a Predictive Controller on an FPGA**

Predictive control is an advanced control technique that relies on the solution of a convex QP at every sample instant. In order to apply predictive control at faster sampling rates, there is a need for faster methods for solving the optimization problems. We present an FPGA implementation of an interior-point solver, which provides substantial acceleration over a sequential CPU implementation. In addition, the proposed architecture possesses special features that increase the potential performance benefit by an extra order of magnitude.

Juan L. Jerez, George Constantinides, Eric C. Kerrigan
Imperial College London
juan.jerez-fullana05@imperial.ac.uk,
g.constantinides@imperial.ac.uk,
e.kerrigan@imperial.ac.uk

### MS54

### A Well-conditioned Interior Point Method with an Application to Optimal Control

We propose an approximate method for computing the search direction at each iteration of an interior point method. If the ratio of the slack variable and dual variable associated with a constraint is above a given threshold, the KKT system is modified in an appropriately-defined way. We show that the condition number of the KKT matrix is improved and that the method performs favorably, compared to existing methods, when solving constrained optimal control problems.

Amir Shahzad, Eric C. Kerrigan, George Constantinides
Imperial College London
a.shahzad07@imperial.ac.uk, e.kerrigan@imperial.ac.uk,
g.constantinides@imperial.ac.uk

### MS54

### Multiple Shooting for Large-Scale Systems

We propose a variant of the standard multiple shooting method which takes into account the structure of certain large-scale systems in order to obtain a better controller design flexibility and high parallelizability. We solve large-scale optimal control problems by making use of adjoint-based sequential quadratic programming. A numerical experiment shows that this can lead to considerable savings in computational time for the sensitivity generation.

Carlo Savorgnan, Attila Kozma
Department of Electrical Engineering
KU Leuven, Belgium
carlo.savorgnan@esat.kuleuven.be,
attila.kozma@esat.kuleuven.be

Joel Andersson
Electrical Engineering Department
K.U.Leuven
joel.andersson@esat.kuleuven.be

Moritz Diehl
K.U.Leuven
moritz.diehl@esat.kuleuven.be

### MS54

### Distributed Optimization Methods for Large - Scale Control Problems

In this paper we analyze the optimization-theoretic concepts of parallel and distributed methods for solving large-scale coupled optimization problems and demonstrate how several estimation and control problems related to complex network systems can be formulated in these settings. The paper presents a systematic framework to exploit the potential of the decomposition structures as a way to obtain different parallel algorithms, each with a different tradeoff among convergence speed, message passing amount, and distributed computation architecture.

Ion Necoara, Ioan Dumitrache, Valentin Nedelcu
University Politehnica Bucharest
i.necoara@yahoo.com, idumitrache@ics.pub.ro,
valinedelcu@yahoo.com

### MS55

### Warmstarting Interior-Point Methods for SDP in the Cutting-Plane Method

We present our recent progress with warmstarting successive SDP relaxations in cutting-plane schemes for combinatorial optimization problems. Following previous advances of interior-point warmstarts for LP, we show how to generalize such strategies for SDP and explore their computational promise and effectiveness. We also plan to address the problem of warmstarting SDP after data perturbations and propose a set of test problems to be used as warmstarting benchmarks.

Alexander Engau
University of Colorado, Denver, USA.
alexander.engau@ucdenver.edu

### MS55

### Warmstaring Interior Point Strategies for Combinatorial Optimization Applications

When solving a sequence of closely-related problems, warmstaring strategies are essential. In recent years several of these techniques have been proposed for interior point methods. In this talk, we present some of these techniques and propose new warmstarting strategies applicable in a column generation framework. We compare them with other strategies in the literature when solving combinatorial optimization problems. Our preliminary results suggest that an efficient warmstarting strategy offers savings in both, time and iterations.

Pablo Gonzalez-Brevis
School of Mathematics
P.Gonzalez-Brevis@sms.ed.ac.uk

Jacek Gondzio
The University of Edinburgh, United Kingdom
J.Gondzio@ed.ac.uk

### MS55

### Approximate Solutions of SDP Relaxations

Interior point methods for semidefinite programs are limited in the size of instances they can solve, so many alternative approaches have been developed. These may lead to solutions that satisfy the positive semidefiniteness requirement only in the limit. Randomization techniques are often applied to the SDP solution to provide a solution to an underlying problem. We quantify the effect of solving the SDP approximately on the quality of the randomized solution for some problem classes.

Tim Lee
Dept of Mathematical Sciences
Rensselaer Polytechnic Institute
leet@rpi.edu

John E. Mitchell
Rensselaer Polytechnic Institute

110, 8th Street, Troy, NY, 12180
mitchj@rpi.edu

**MS55**

**Solving Combinatorial Optimization Problems with Interior Point Methods**

A wealth of solution methods is available for solving combinatorial optimization problems. Focusing on general-purpose exact methods based on integer programming models, the standard approaches rely on solving a sequence of closely related linear programming problems. In this talk, we address the challenging issues of using a primal-dual interior point method within a branch-and-price-and-cut strategy, and present preliminary computational results for classical combinatorial optimization problems from the literature.

Pedro Munari
University of Sao Paulo, Brazil
munari@icmc.usp.br

Jacek Gondzio
The University of Edinburgh, United Kingdom
J.Gondzio@ed.ac.uk

**MS56**

**A Parallel Framework for Identifying Vulnerabilities in the Electric Power Grid**

Identifying multiple contingencies of an electric power grid requires the solution of a large bilevel optimization problem, which is computationally expensive. We explore a parallel branch-and-bound framework that exploits the discreteness of the outer-level variables instead of relaxing them to continuous ones. The framework is nicely decoupled in the sense that it allows various optimal power flow (OPF) algorithms to be used for the inner-level load shedding problem. We evaluate our framework on a real-sized problem.

Juan C. Meza
Lawrence Berkeley National Laboratory
JCMeza@lbl.gov

Aydin Buluc
Lawrence Berkeley Lab
abuluc@lbl.gov

**MS56**

**MOPEC Models for Energy Problems**

We consider MOPEC models: collections of optimization problems linked by equilibrium (or complementarity) constraints. We show the relevance of this modeling framework to a number of different problems associated with energy planning, and detail several algorithms for their solution. The model will incorporate stochastic effects, contracts, and the possibility of retention of goods.

Michael C. Ferris
University of Wisconsin
Department of Computer Science
ferris@cs.wisc.edu

Roger Wets
University of California, Davis
rjbwets@ucdavis.edu

**MS56**

**Optimal Design of System Architectures**

Design of large complex systems (e.g. buildings, distributed power systems, transportation networks, etc.) has been challenging due to the huge design space, non-linear discontinuous dynamic behavior, and uncertainties operational scenarios unknown during the design phase. These problems fall in the class of non-convex mixed integer nonlinear programs which is an active area of research. In this talk, we will present a two phase optimization approach - Comprehensive Screening (CS) and High Fidelity Evaluation (HFE) for the optimal design of large systems with specific application to microgrid architectures. In the CS phase, a mixed integer linear program (MILP) representation is used to mathematically capture the space of design alternatives. Key to this is the assumption of linear models for the components in the system. The HF phase uses the optimal architecture and nonlinear model for the components to determine the optimal sizing and dispatching decisions. In this talk, we will overview the methodology when applied to the design of energy supply systems that would minimize lifecycle costs while meeting a given electrical and thermal demand pattern. We will also investigate approaches for including uncertainty in input variables.

Arvind Raghunathan, Niranjan Desai, Ritesh Khire, Stella Oggianu, Xin Wu, Shui Yuan, Larry Zeidner
United Technologies Research Center
arvind.uppili@gmail.com, desaina@utrc.utc.com, khirer@utrc.utc.com, oggiansm@utrc.utc.com, wuxi@utrc.utc.com, yuans@utrc.utc.com, zeidnele@utrc.utc.com

**MS56**

**Title: Multi-stage Stochastic Decomposition with Applications in Energy Systems Planning**

Many energy systems planning require that they be integrated with simulators that are capable of providing sample paths over hours, and sometimes days. However, most stochastic programming algorithms are designed to use a collection of scenarios rather than working with sample paths, one at a time. We will discuss a multi-stage version of Stochastic Decomposition which allows us to integrate outputs from a simulator directly into the planning model. Applications in power system planning and operations will be discussed.

Suvrajeet Sen
Integrated Systems Eng
Ohio State Univ
sen.22@osu.edu

**MS57**

**Identification of an Unknown Parameter in the Main Part of an Elliptic PDE**

Identification of an Unknown Parameter in the Main Part of an Elliptic PDE We are interested in identifying an unknown material parameter $a(x)$ in the main part of an elliptic partial differential equation

$$-\text{div }(a(x) \text{ grad } y(x)) = g(x) \text{ in } \Omega$$

with corresponding boundary conditions. We discuss a Tichonov regularization

$$\min_a J(y,a) = \|y - y_d\|^2_{L^2(\Omega)} + \alpha \|a\|^2_{H^s(\Omega)}$$

with $s > 0$. Moreover, we require the following constraints for the unknown parameter

$$0 < a_{min} \leq a(x) \leq a_{max}.$$

The talk starts with results on existence of solutions and necessary optimality conditions. The main part of the talk will be devoted to sufficient optimality conditions.

Arnd Rösch, Ute Aßmann
University of Duisburg-Essen
arnd.roesch@uni-due.de, ute.assmann@uni-due.de

**MS57**

**Optimal Control of PDEs with Directional Sparsity**

We study optimal control problems in which controls with certain sparsity patterns are preferred. For time-dependent problems the approach can be used to find locations for control devices that allow controlling the system in an optimal way over the entire time interval. The approach uses on a non-differentiable cost functional to implement the sparsity requirements; additionally, bound constraints for the optimal controls can be included. We study the resulting problem in appropriate function spaces and present two solution methods of Newton type, based on different formulations of the optimality system. Using elliptic and parabolic test problems we research the sparsity properties of the optimal controls and analyze the behavior of the proposed solution algorithms.

Gerd Wachsmuth
TU Chemnitz
Fakultät für Mathematik
gerd.wachsmuth@mathematik.tu-chemnitz.de

**MS57**

**Adaptive Discretization Strategies for Parameter Identification Problems in PDEs in the Context of Tikhonov Type and Newton Type Regularization**

Parameter identification problems for PDEs often lead to large scale inverse problems. To reduce the computational effort for the repeated solution of the forward and even of the inverse problem as it is required for determining the regulrization parameter according to the discrepancy principle in Tikhonov regularization we use an adaptive discretization based on goal oriented error estimators. This concept originating from optimal control provides an estimate of the error in a so-called quantity of interest a functional of the control $q$ (which in our context is the searched for parameter) and the PDE solution $u$ based on which the discretizations of $q$, $u$ (and possibly also the adjoint PDE solution) are locally refined. The crucial question for parameter identification problems is now the choice of an appropriate quantity of interest. A convergence analysis of the Tikhonov regularization with the discrepancy principle on discretized spaces for $q$ and $u$ shows, that in order to determine the correct regularization parameter, one has to guarantee sufficiently high accuracy in the squared residual norm which is therefore our quantity $i$ of interest whereas $q$ and $u$ themselves need not be computed precisely everywhere. This fact allows for relatively low dimensional adaptive meshes and hence for a considerable reduction of the computational effort. Alternatively to Tikhonov regularization we consider Newton type regularization methods and their adaptive discretization, again based on a goal oriented approach. Numerical tests will illustrate the efficiency oft he proposed methods.

Barbara kaltenbacher
University of Graz
Institute for Mathematics and Scientific Computing
barbara.kaltenbacher@uni-graz.at

**MS58**

**Deciding Polynomial Convexity Is NP-hard**

We show that unless P=NP, there exists no polynomial time (or even pseudo-polynomial time) algorithm that can decide whether a multivariate polynomial of degree four (or higher even degree) is globally convex. This solves a problem that has been open since 1992 when N. Z. Shor asked for the complexity of deciding convexity for quartic polynomials. We also prove that deciding strict convexity, strong convexity, quasiconvexity, and pseudoconvexity of polynomials of even degree four or higher is strongly NP-hard. By contrast, we show that quasiconvexity and pseudoconvexity of odd degree polynomials can be decided in polynomial time.

Amir Ali Ahmadi, Alex Olshevsky, Pablo A. Parrilo
MIT
a_a_a@mit.edu, alex_o@mit.edu, parrilo@mit.edu

John N. Tsitsiklis
Massachusetts Institute of Technology
jnt@mit.edu

**MS58**

**Positive Polynomials on Equality-Constrained Domains**

We establish a simple connection between the set of polynomials that are non-negative on a given domain and the set of polynomials that are non-negative on the intersection of the same domain and the zero of a given polynomial. This connection has interesting algorithmic implications. For instance, it readily yields a succinct derivation of a copositive programming formulation for quadratically constrained quadratic programs.

Javier Pena
Carnegie Mellon University
jfp@andrew.cmu.edu

**MS58**

**Dynamic Generation of Valid Polynomial Inequalities for Polynomial Programs**

Recently semidefinite programs have been used to build hierarchies of convex relaxations to polynomial programs. This approach is computationally expensive and is only tractable for small problems. We propose an algorithm to dynamically generate valid polynomial inequalities to general polynomial programs. When use iteratively this algorithm solves a cheap "master relaxation" - "inequality generating subproblem" pair to improve the relaxation of the original problem, obtaining better bounds for the optimal value. We present results on non-convex binary quadratic problems to illustrate the effectiveness of this approach.

Juan C. Vera
Tilburg University
Department of Econometrics and Operations Research
j.c.veralizcano@uvt.nl

Bissan Ghaddar
University of Waterloo
bghaddar@uwaterloo.ca

Miguel F. Anjos
Mathematics and Industrial Engineering & GERAD
École Polytechnique de Montréal
anjos@stanfordalumni.org

### MS58

### Computing General Static-arbitrage Bounds for European Basket Options via Dantzig-Wolfe Decomposition

We study the problem of computing general static-arbitrage bounds for European basket options; that is, computing bounds on the price of a basket option, given the only assumption of absence of arbitrage, and information about prices of other European basket options on the same underlying assets and with the same maturity. In particular, we provide a simple *efficient* way to compute this type of bounds by solving a *large* finite non-linear programming formulation of the problem. This is done via a suitable Dantzig-Wolfe decomposition that takes advantage of an integer programming formulation of the corresponding subproblems.
Our computation method equally applies to both upper and lower arbitrage bounds, and provides a solution method for general instances of the problem. This constitutes a substantial contribution to the related literature, in which upper and lower bound problems need to be treated differently, and which provides efficient ways to solve particular static-arbitrage bounds for European basket options; namely, when the option prices information used to compute the bounds is limited to vanilla and/or forward options, or when the number of underlying assets is limited to two assets.
Also, our computation method allows the inclusion of real-world characteristics of option prices into the arbitrage bounds problem, such as the presence of bid-ask spreads. We illustrate our results by computing upper and lower arbitrage bounds on gasoline/heating oil crack spread options.

Luis F. Zuluaga
University of New Brunswick
lzuluaga@unb.ca

Javier Pena
Carnegie Mellon University
jfp@andrew.cmu.edu

Xavier Saynac
Faculty of Business Administration
University of New Brunswick
q79j1@unb.ca

Juan C. Vera
Tilburg University
Department of Econometrics and Operations Research
j.c.veralizcano@uvt.nl

### MS59

### Quantifying and Managing Complexity in Transport Systems

Growing autonomy and distribution will characterize future air transportation systems. Managing the ensuing complexity requires new approaches to quantifying and controlling complexity. We investigate techniques aimed at modeling complexity computationally based on nonlinear programming formulations, as well as algorithms for handling complexity from a variety of spatial and temporal perspectives.

Natalia Alexandrov
NASA Langley Research Center
n.alexandrov@nasa.gov

### MS59

### Excursions into Multi-disciplinary Design under Uncertainty in Aerospace Engineering

This presentation will discuss the application of design under uncertainty techniques within the context of multi-disciplinary aerospace systems. We pay particular attention to both the design of supersonic low-boom aircraft and of hypersonic propulsion systems where multiple disciplines (aerodynamics, acoustics, turbulence, combustion) need to be considered and where both aleatory and epistemic uncertainties are present. The results of our designs focus on both robust and reliable outcomes.

Juan J. Alonso
Department of Aeronautics and Astronautics
Stanford University
jjalonso@stanford.edu

### MS59

### Evaluation of Mixed Continuous-discrete Surrogate Approaches

Evaluating the performance of surrogate modeling approaches is essential for determining their viability in optimization or uncertainty analysis. To this end, we evaluated categorical regression, ACOSSO splines, and treed GPs on a set of test functions. We describe the principles and metrics we used for this evaluation, the characteristics of the test functions we considered, and our software testbed. Additionally, we present our numerical results and discuss our observations regarding the merits of each approach.

Patricia D. Hough
Sandia National Laboratories
pdhough@sandia.gov

Laura Swiler
Sandia National Laboratories
Albuquerque, New Mexico 87185
lpswile@sandia.gov

Herbie Lee
University of California, Santa Cruz
Dept. of Applied Math and Statistics
herbie@ams.ucsc.edu

### MS59

### Direct Search Methods for Engineering Optimization Problems with General Constraints

We investigate the behavior of derivative-free direct search methods for nonlinear optimization problems with general constraints where either the objective or (some of) the constraints are defined by complex simulations. Of particular interest is why derivative-free methods that rely on building direct models of the objective encounter difficulties –

particularly as the number of variables grows – when the constraints are more than just simple bounds on the variables.

Robert Michael Lewis
College of William & Mary
Dept. of Mathematics
rmlewi@wm.edu

Virginia J. Torczon
College of William & Mary
Department of Computer Science
va@cs.wm.edu

### MS60

### Dynamic Sample Size Selection in Algorithms for Machine Learning

When solving large-scale machine learning and stochastic optimization problems, sample size selection is an important component to consider, given its influence over both efficiency and accuracy. Incorporating dynamic sample sizes may also allow an algorithm's performance to behave more capably in implementation, in comparison to a static sample size. The work that will be presented will suggest appropriate methods for dynamically improving the sample size selection. Both numerical and theoretical complexity results shall be presented.

Gillian Chin
Northwestern University
gillian.chin@u.northwestern.edu

### MS60

### Spectral Gradient Methods for Nonlinear Programming

The development of new software for NLP is described. There are two main design aims (i) to avoid the use of second derivatives, and (ii) to avoid storing an approximate reduced Hessian matrix by using a new limited memory spectral gradient approach based on Ritz values. The basic approach to NLP is that of Robinson's method, globalised by using a filter and trust region, rather than a square penalty term such as in MINOS. A new code for the linear constraint subproblem (LCP) has been developed using the Ritz values approach. Numerical experience will be described.

Roger Fletcher
University of Dundee
Department of Mathematics &
fletcher@mcs.dundee.ac.uk

### MS60

### New Methods for Regularized Machine Learning and Stochastic Programming

We consider machine learning problems, such as those arising in speech recognition, where the number of training points can reach into the billions. We describe new online and distributed gradient methods capable of solving problems of this type. Our methods use regularized logistic models that promote sparse parameters. We demonstrate the efficiency of the proposed methods using a production system at Google. We also present complexity results comparing sequential online methods and mini-batch distributed gradient methods.

Jorge Nocedal
Department of Electrical and Computer Engineering
Northwestern University
nocedal@eecs.northwestern.edu

Yuchen Wu
Google
rainson.wood@gmail.com

### MS60

### Semismooth Newton Methods with Multi-dimensional Filter Globalization for $l_1$ Optimization

The sparsity-promoting properties of $l_1$-regularizations have many important applications. We present a class of methods for $l_1$-regularized optimization problems that combine semismooth Newton algorithms with globally convergent descent methods in a flexible way. The acceptance of semismooth Newton steps is controlled by a multidimensional filter, which efficiently relaxes sufficient decrease requirements for these steps. Global convergence as well as transition to fast local convergence are investigated. We conclude with numerical illustrations.

Michael Ulbrich
Technical University of Munich
Chair of Mathematical Optimization
mulbrich@ma.tum.de

Andre Milzarek
Technische Universitaet Muenchen
Department of Mathematics, TopMath
andre.milzarek@gmx.de

### MS62

### CasADi - A Tool for Dynamic Optimization and Automatic Differentiation for Object-oriented Modelling Languages

We introduce CasADi, an implementation of automatic differentiation in forward and adjoint mode using a hybrid operator-overloading, source-code-transformation approach. For maximum efficiency, CasADi works with a combination of two different graph representations : One supporting only scalar-valued, built-in unary and binary operations without branching and secondly, a representation supporting matrix-valued operations, branchings such as if-statements as well as function calls to arbitrary functions (e.g. ODE/DAE integrators).

Joel Andersson
Electrical Engineering Department
K.U.Leuven
joel.andersson@esat.kuleuven.be

Moritz Diehl
K.U.Leuven
moritz.diehl@esat.kuleuven.be

### MS62

### On an Iterative Range Space Method

We present several modifications for the total quasi-Newton method to solve general nonlinear problems. By the use of low-rank approximation and automatic differ-

entiation, no exact evaluation of the constraint Jacobian and the Hessian of the Lagrangian is required in this approach. To make the method more suitable for large scale optimization we employ a range space factorization using well-known limited memory techniques with compact storage such as L-BFGS and L-SR1.

Torsten F. Bosse
Humboldt-Universität zu Berlin,
Institut für Mathematik
bosse@math.hu-berlin.de

Andreas Griewank
HU Berlin, MATHEON Research Center, Germany
griewank@math.hu-berlin.de

**MS62**

**Solving Time-Harmonic Inverse Medium Optimization Problems with Inexact Interior-Point Step Computation**

We formulate an inverse medium problem as a PDE-constrained optimization problem, where the underlying wave field solves the time-harmonic Helmholtz equation. Ill-posedness is tackled through regularization while the inclusion of inequality constraints is used to encode prior knowledge. The resulting nonconvex optimization problem is solved by a primal-dual interior-point algorithm with inexact step computation. Numerical results both in two and three space dimensions illustrate the usefulness of the approach.

Olaf Schenk
Department of Mathematics and Computer Science
University of Basel, Switzerland
olaf.schenk@unibas.ch

Marcus Grote
Universität Basel
marcus.grote@unibas.ch

Johannes Huber
University of Basel
johannes.huber@uniabs.ch

Andreas Wächter
IBM T. J. Watson Research Center
andreasw@watson.ibm.com

Frank E. Curtis
Industrial and Systems Engineering
Lehigh University
frank.e.curtis@gmail.com

**MS62**

**On an Inexact Trust-region Approach for Inequality Constrained Optimization**

This talk presents a trust-region SQP algorithm for the solution of minimization problems with nonlinear inequality constraints. The approach works only with an approximation of the constraint Jacobian. Hence, it is well suited for optimization problems of moderate size but with dense constraint Jacobian. The accuracy requirements for the presented first-order global convergence result can be verified easily during the optimization process. Numerical results for some test problems are shown

Andrea Walther
Universität Paderborn
andrea.walther@uni-paderborn.de

Lorenz T. Biegler
Carnegie Mellon University
USA
biegler@cmu.edu

**MS63**

**Small Chvatal Rank**

We propose a variant of the Chvatal-Gomory procedure that will produce a sufficient set of facet normals for the integer hulls of all polyhedra $\{x : Ax \leq b\}$ as $b$ varies. The number of steps needed is called the small Chvatal rank (SCR) of $A$. We characterize matrices for which SCR is zero via the notion of supernormality which generalizes unimodularity. SCR is studied in the context of the stable set problem in a graph, and we show that many of the well-known facet normals of the stable set polytope appear in at most two rounds of our procedure. Our results reveal a uniform hypercyclic structure behind the normals of many complicated facet inequalities in the literature for the stable set polytope. Lower bounds for SCR are derived both in general and for polytopes in the unit cube.

Tristram Bogart
San Francisco State University
tcbogart@gmail.com

Annie Raymond
Berlin Mathematical School
annieraymond@gmail.com

Rekha Thomas
University of Washington
rrthomas@u.washington.edu

**MS63**

**Gröbner Bases and Hilbert's Nullstellensatz: Combinatorial Interpretations and Algorithmic Techniques**

Systems of polynomial equations with coefficients over an algebraically closed field K can be used to concisely model combinatorial problems. In this way, a combinatorial problem is feasible (e.g., a graph is 3-colorable, hamiltonian, etc.) if and only if a related system of polynomial equations has a solution. We present a collection of results based on these non-linear models. In the case of the independent set problem, we present a combinatorial interpretation of the Hilbert's Nullstellensatz certificate of infeasibility. In the case of the dominating set problem, we present a combinatorial interpretation of the universal Gröbner basis. In the case of graph 3-coloring, we demonstrate an algorithm that is surprisingly practical in practice.

Susan Margulies
Computational and Applied Mathematics
Rice University
susan.margulies@rice.edu

**MS63**
**The Border Basis Closure**

The Sherali-Adams lift-and-project hierarchy is a fundamental construct in integer programming, which provides successively tighter linear programming relaxations of the integer hull of a polytope. We initiate a new approach to understanding the Sherali-Adams procedure by relating it to methods from computational algebraic geometry. We present a modified version of the border basis algorithm to generate a hierarchy of linear programming relaxations that are stronger than those of Sherali and Adams, and over which one can still optimize in polynomial time (for a fixed number of rounds in the hierarchy). In contrast to the well-known Grbner bases approach to integer programming, our procedure does not create primal solutions, but constitutes a novel approach of using computer-algebraic methods to produce dual bounds.

Sebastian Pokutta, Andreas S. Schulz
Massachusetts Institute of Technology
sebastianpokutta@me.com, schulz@mit.edu

**MS63**
**Graver Bases Methods in Integer Programming**

N-fold integer programming is a fundamental problem with a variety of natural applications in operations research and statistics. Moreover, it is universal and provides a new, variable-dimension, parametrization of all of integer programming.We use Graver bases methods to establish an iterative algorithm that solves this problem in polynomial time. Using it, we also propose a simple Graver approximation hierarchy, parameterized by degree, for nonlinear integer programming in general and optimization over multiway tables in particular, which makes use of quickly constructible approximations of the true Graver basis. We demonstrate this scheme for approximating the (universal) integer three-way table feasibility problem. The talk is based on joint work with S. Onn, R. Hemmecke and on my thesis in preparation (under the supervision of S. Onn).

Lyubov Romanchuk
Technion - Israel Institute of Technology, Haifa
lyuba@techunix.technion.ac.il

**MS64**
**On Maximally Violated Cuts Obtained from a Basis**

Most cuts used in practice can be derived from a basis and are of the form $\alpha^T x \geq 1$, where $x$ is a vector of non-basic variables and $\alpha \geq 0$. Such cuts are called *maximally violated* wrt a point $\bar{x} \geq 0$ if $\alpha^T \bar{x} = 0$. In an earlier paper we presented computational results for maximally violated cuts derived from an optimal basis of the linear relaxation. In this talk we also consider pivoting and deriving maximally violated cuts from alternative non-optimal bases.

Kent Andersen
University of Aarhus
kent@imf.au.dk

Adam N. Letchford
Lancaster University Management School
a.n.letchford@lancaster.ac.uk

Robert Weismantel
ETH Zuerich
robert.weismantel@ifor.math.ethz.ch

**MS64**
**A Verification Based Method to Generate Strong Cutting Planes for IPs**

A cutting-plane procedure for integer programming (IP) problems usually involves invoking a black-box procedure to compute a cutting plane. In this paper, we describe an alternative paradigm of using the same cutting-plane black-box. This involves two steps. In the first step, we design an inequality $cx \leq d$, independent of the cutting plane black-box. In the second step, we verify that the designed inequality is a valid inequality by verifying that the set $P \cap \{x \in R^n : cx \geq d+1\} \cap Z^n$ is empty using cutting planes from the black-box. (Here $P$ is the feasible region of the linear-programming relaxation of the IP.) We refer to the closure of all cutting planes that can be verified to be valid using a specific cutting plane black-box as the verification closure of the considered black box. This verification paradigm naturally leads to the question of how much extra strength one might hope to gain by having an oracle in place that provides us with potential cutting-planes and we are left with the task of verifying that its output is valid. We show that cutting-plane obtained via the verification scheme can be very strong, significantly exceeding the capabilities of the regular cutting-plane procedure. On the other hand, we present lower bounds on the rank of verification cutting planes for known difficult infeasible 0/1 instances, showing that while verification procedure is strong, it is not unrealistically so.

Santanu S. Dey
Georgia Institute of Technology
School of Industrial and System Engineering
sdey30@isye.gatech.edu

Sebastian Pukutta
Sloan School of Management, MIT
pokutta@mit.edu

**MS64**
**Generating Two-Row Cuts from Lattice-Free Bodies**

Andersen et al (2007) and Cornuejols and Margot (2009) show that facet-defining inequalities of a system with two constraints and two integer variables are related to maximal lattice-free convex sets. We give an algorithm to construct those sets, thereby enumerating all facet-defining inequalities for such systems. Computational results are presented.

Kenneth Chen
GeorgiaTech
kchen@math.gatech.edu

William Cook
Georgia Institute of Technology
bico@isye.gatech.edu

Ricardo Fukasawa
University of Waterloo
rfukasaw@math.uwaterloo.ca

Daniel Steffy
GeorgiaTech
desteffy@gmail.com

**MS64**

**Approximating the Split Closure**

The first split closure has been proven in practice to be a very tight approximation of the ideal convex hull formulation of a generic Mixed Integer Program (MIP). However, exact separation procedures for optimizing over it have unacceptable computing times. We present heuristic procedures for approximating the split closure of a MIP, as well as algorithmic techniques for speeding up such separation. Preliminary computational results show the effectiveness of the proposed procedures compared to the state of the art.

Matteo Fischetti, Domenico Salvagnin
University of Padova
fisch@dei.unipd.it, salvagni@math.unipd.it

**MS65**

**Flexible First-order Methods for Rank Minimization**

We describe a flexible framework for solving constrained non-smooth convex programs, such as nuclear norm minimization and LASSO. The technique is based on smoothing and solving the dual formulation. An advantage of the technique is that it allows for many variations, such as a robust-PCA formulation. We also discuss the special case where the solution is known to be PSD, which occurs in covariance estimation and quantum tomography.

Stephen Becker
California Institute of Technology
srbecker@caltech.edu

Ewout van den Berg
Stanford University
ewout@stanford.edu

**MS65**

**Fast First-Order and Alternating Direction Methods for Stable Princial Component Pursuit**

Given a matrix M that is the sum of a low rank matrix X and a sparse matrix Y, it is known that under certain conditions, X and Y can be recovered with very high probability by solving a so-called robust principal component pursuit problem. When M has noise added to it, the recovery problem is called stable principal component pursuit. In this problem one minimizes the sum of the nuclear norm of X plus a scalar times the sum of the absolute values of the elements of Y, subject to the Frobenius norm of X+Y-M being less than some known noise level. We show how to apply Nesterov's optimal gradient and composite methods and a fast alternating linearization method to obtain epsilon-optimal solutions in O(1/epsilon) iterations, while keeping the cost of each iteration low. We also propose an alternating direction augmented Lagrangian method that is extremely efficient, for which we prove convergence.

Don Goldfarb, Necdet Aybat
Columbia University
gold@ieor.columbia.edu, nsa2106@columbia.edu

**MS65**

**A Proximal Point Algorithm for Nuclear Norm Regularized Matrix Least Squares Problems**

We introduce a proximal point algorithm for solving nuclear norm regularized matrix least squares problems with equality and inequality constraints. The inner subproblems are solved by an inexact smoothing Newton method, which is proved to be quadratically convergent under a constraint non-degenerate condition, together with the strong semi-smoothness property of the singular value thresholding operator. Numerical experiments on problems arising from low-rank approximations of transition matrices show that our algorithm is efficient and robust.

Kaifeng Jiang
Department of Mathematics
National University of Singapore, Singapore
kaifengjiang@nus.edu.sg

Defeng Sun
Dept of Mathematics
National University of Singapore
matsundf@nus.edu.sg

Kim-Chuan Toh
National University of Singapore
Department of Mathematics and Singapore-MIT Alliance
mattohkc@nus.edu.sg

**MS66**

**A Bilevel Optimization Approach to Obtaining Optimal Cost Functions for Human Arm Movements**

It is known that human motions are (approximately) optimal for suitable, unknown cost functions subject to the dynamics. We use bilevel optimization to investigate the following inverse problem: Which cost function out of a parameterized family composed from functions suggested in the literature reproduces recorded human arm movements best? The lower level problem is an optimal control problem governed by a nonlinear model of the human arm dynamics. Promising applications are also discussed.

Sebastian Albrecht, Marion Leibold
Technische Universitaet Muenchen
albrecht@ma.tum.de, marion.sobotka@tum.de

Michael Ulbrich
Technical University of Munich
Chair of Mathematical Optimization
mulbrich@ma.tum.de

**MS66**

**Optimality Conditions for Bilevel Programming**

Bilevel programming problems are hierarchical optimization problems where the feasible region is (in part) restricted to the graph of the solution set mapping of a second parametric optimization problem. To solve them and to derive optimality conditions for these problems this parametric optimization problem needs to be replaced with its (necessary) optimality conditions. This results in a (one-level) optimization problem. In the talk different approaches to transform the bilevel programming will be suggested and the relations between the original bilevel problem and the one replacing it will be investigated. The resulting (necessary) optimality conditions will be formulated.

Stephan Dempe
Technical University of Freiberg

09596 Freiberg, Germany
dempe@math.tu-freiberg.de

Alain B. Zemkoho
Instiut of Numerical Mathematics and Optimization
TU Bergakademie Freiberg
zemkoho@student.tu-freiberg.de

## MS66

### Mathematical Programs with Vanishing Constraints

A new class of constrained optimization problems called *mathematical programs with vanishing constraints (MPVC) is considered. This type of problem is known to act as a unified framework for several problems from topology optimization and is hence very interesting from an engineering point of view. Moreover, due nonconvexity and violation of most of the standard constraint qualifications, an MPVC is very challenging from a theoretical and numerical viewpoint. In the face of that, problem-tailored constraint qualifications and the related stationarity concepts are investigated. Moreover, a numerical approach for the solution of an MPVC is surveyed.*

Tim Hoheisel
University of Würzburg
97074 Würzburg, Germany
hoheisel@mathematik.uni-wuerzburg.de

## MS66

### On the Concept of T-stationarity in MPCC and MPVC

We call a stationarity concept for a given class of optimization problems *topologically relevant*, if it allows to establish a Morse theory. Recent results about mathematical programs with vanishing constraints (MPVCs) illustrated that the topologically relevant stationarity concept is not necessarily one which is already known, in contrast to finite smooth constrained optimization and MPCCs, where KKT stationarity and C-stationarity are topologically relevant, respectively. This motivated the introduction of T-stationarity for MPVCs. We point out connections to numerical methods for MPCCs and MPVCs, where KKT points of smooth approximations tend to T-stationary points of the original problems.

Oliver Stein
Karlsruhe Institute of Technology
76131 Karlsruhe, Germany
stein@kit.edu

## MS67

### Optimization Applied to Electricity Generation Management at EdF

We consider the one-day-ahead scheduling of a power mix with about 150 thermal plants and 50 hydro-valleys, as to ensure offer and demand equilibrium at minimal cost, while satisfying the technical constraints of all plants. From the optimization point-of-view, the problem is quite difficult because it must be solved in less than 15 minutes; but it is large-scale, with $10^6$ mixed-integer variables and $10^6$ nonconvex and discontinous constraints. We focus on the latest developments about the optimisation methods that are used to solve this problem.

Sandrine Charousset
EDF Research
sandrine.charousset@edf.fr

## MS67

### The Value of Rolling Horizon Policies for Risk-averse Hydro-thermal Planning

We consider the optimal management of a hydro-thermal power system in the mid-term. This is a large-scale multistage stochastic linear program, often solved by combining sampling with decomposition algorithms, like stochastic dual dynamic programming. However, such methodologies may entail prohibitive computational time, especially when applied to a risk-averse formulation of the problem. For a model that takes into account losses and uncertainty in both the inflows and the demand, we propose a risk-averse rolling horizon approach based on subproblems having deterministic constraints for the current time step and future uncertain constraints dealt with as chance and CVaR constraints. When uncertainty in the problem is represented by a periodic autoregressive stochastic process, each subproblem is a medium-size linear program, easy to solve. Being both nonanticipative and feasible, the resulting risk-averse policy keeps reservoirs above certain critical levels almost surely. In order to evaluate the benefits of the rolling horizon approach, we introduce a non-rolling horizon policy, both robust and feasible, based on solutions obtained at the first time step with the rolling horizon methodology. When applied to a real-life power system, the superiority of the rolling approach becomes evident, compared both to the non-rolling horizon policy aforementioned and to a stochastic dual dynamic programming strategy, frequently employed for this type of problems.

Vincent Guigues
PUC-Rio
Brazil
vguigues@puc-rio.br

Claudia Sagastizábal
CEPEL
sagastiz@impa.br

## MS67

### The N-k Problem using AC Power Flows

Given a power grid, we search for a set of k or fewer lines whose simultaneous outage will impact stability. We study this problem under AC power flows; our concepts of "stability" primarily focus on voltage stability. In our approach we bypass combinatorial complexity by positing an intelligent adversary who can increase the resistance or reactance of power lines, within budgets, so as to maximize the resulting instability. This problem is continuous (though nonconcave) and thus, amenable to continuous optimization techniques. We report on experiments using large, real-world grids.

Sean Harnett
Columbia University
srh2144@columbia.edu

Daniel Bienstock
Columbia University IEOR and APAM Departments
IEOR Department

dano@columbia.edu

**MS67**

**Security Constrained Optimization for Electric Power Systems**

The need for improving security standards for electric power systems is well recognized. Such efforts however, are hindered by lack of decision support tools that can incorporate security into the decision making process. The current practice is to protect the system against known or anticipated failures either by using a post-processing phase or by explicit enumeration of the know cases. These approaches not only lack scalability to larger systems or higher security standards, but also are limited to predicted failures, which is a significant shortcoming with the uncertainty of the renewable generation. In our earlier work, we have developed efficient techniques for vulnerability analysis of electric power systems. We are now in the process of adding our vulnerability analysis techniques into the decision making process. Specifically, we are investigating an alternative formulation of security-constrained unit commitment problem. The key to our approach is our ability to compactly represent security constraints. In this talk, we will present our security formulations, and our results for solving the security-constrained unit-commitment problem.

Ali Pinar
Sandia National Labs
apinar@sandia.gov

Jean-Paul Watson
Sandia National Laboratories
Discrete Math and Complex Systems
jwatson@sandia.gov

**MS68**

**L1 Fitting for Nonlinear Parameter Identification Problems for PDEs**

For parameter identification problems where the measured data is corrupted by impulsive noise, $L^1$-data fitting is more robust than conventional $L^2$-fitting. However, this leads to a non-smooth optimization problem. In this talk, an approach for the numerical solution of parameter identification for PDEs with $L^1$-data fitting is presented and analyzed. This approach is based on a semi-smooth Newton method and shows locally superlinear convergence. The effectiveness is illustrated through numerical examples.

Christian Clason
University of Graz
Institute for Mathematics and Scientific Computing
christian.clason@uni-graz.at

**MS68**

**Simultaneous Identification of Multiple Coefficients in an Elliptic PDE**

We consider the inverse problem of determining multiple, piecewise analytic coefficients in an elliptic PDE from boundary measurements. Based on the theory of localized potentials, we are able to give an exact theoretical characterization of the reconstructible information. We also discuss the consequences of this injectivity result to practical reconstruction schemes.

Bastian Harrach
Department of Mathematics - M1
Technische Universität München
harrach@ma.tum.de

**MS68**

**Nonsmooth Regularization and Sparsity Optimization**

The sparsity optimization for the linear least square problem is considered. The problem is formulated as nonsmooth regularization problem. The necessary optimality condition is derived and a numerical algorithm to determine a solution is developed and analyzed. The property of solutions and the optimal value function as a function of the regularization parameter is analyzed. Various selection principle and algorithms for determining the regularization parameter are developed and analyzed for the sparisity regularization based on the analysis of the optimal value function.

Kazufumi Ito
North Carolina State University
Department of Mathematics
kito@math.ncsu.edu

**MS68**

**Error Estimates for joint Tikhonov and Lavrentiev Regularization of Parameter Identification Problems**

Problems of optimal control often involve constraints both on the control and on the state of the system, but the solution may not be stable to calculate. Hence, one often employs Tikhonov regularization. Then the resulting optimization problem may still be difficult to solve due to low regularity of Lagrange multipliers. This difficulty can be overcome by Lavrentiev-type regularization. In this talk. error estimates for this kind of doubly regularized problems are derived.

Dirk Lorenz
Technical University of Braunschweig
d.lorenz@tu-braunschweig.de

Arnd Rösch
University of Duisburg-Essen
arnd.roesch@uni-due.de

**MS69**

**On Some Strategies for Jacobian-free Preconditioning of Sequences of Nonsymmetric Linear Systems**

An appealing property of Newton-Krylov methods for the solution of nonlinear algebraic systems is that they lend themselves well for matrix-free implementations where multiplication with the Jacobian is replaced by a difference approximation. However, this makes the computation of robust LU-type preconditioners for the Jacobians significantly more challenging. In this talk we address various matrix-free preconditioning techniques for the special case where we wish to *update* preconditioners from previous linear systems.

Jurjen Duintjer Tebbens
Institute of Computer Sciences
Academy of Sciences of the Czech Republic, Prague

tebbens@cs.cas.cz

Miroslav Tuma
Academy of Sciences of the Czech Republic
Institute of Computer Science
tuma@cs.cas.cz

**MS69**

**Limited-memory Preconditioners for Large Sparse Least-squares Problems**

We present a technique for constructing incomplete $LDL^T$ preconditioners for the normal equation matrix of large and sparse linear least-squares problems. The preconditioners obtained can be interpreted as approximate sparse inverse preconditioners. The construction of the preconditioners is breakdown-free and does not need to form the normal matrix. Only matrix-vector products are required and transpose-free implementations are possible. The density and sparsity pattern is fixed in advanced and limited intermediate storage is needed. Numerical experiments are shown.

Benedetta Morini
Universita' di Firenze
benedetta.morini@unifi.it

Stefania Bellavia
Universita di Firenze
stefania.bellavia@unifi.it

Jacek Gondzio
The University of Edinburgh, United Kingdom
J.Gondzio@ed.ac.uk

**MS69**

**Multipreconditioned GMRES with Applications in PDE-constrained Optimization**

The bottleneck in many algorithms for solving large scale optimization problems is the solution of a saddle point system. A common way to do this is by using a Krylov subspace method, which needs to be coupled with a suitable preconditioner to be effective. For a saddle point problems there are a number of possible choices of preconditioner – e.g. constraint or block diagonal preconditioners – and in certain cases one or another may be a better choice. In this talk we present multipreconditioned GMRES (MPGMRES), which is an algorithm that extends GMRES by automatically combining the properties of more than one preconditioner in an optimal way. We will demonstrate the effectiveness of the algorithm by applying it to systems from problems in PDE-constrained optimization.

Tyrone Rees
Department of Computer Science,
University of British Columbia, Canada
rees@math.ubc.ca

Chen Greif
Department of Computer Science
The University of British Columbia
greif@cs.ubc.ca

**MS69**

**Parallel Algebraic Multilevel Preconditioners for PDE-Constrained Optimization**

We investigate the application of parallel multilevel domain-decomposition preconditioners to linear systems arising from the discretization of optimality systems for elliptic optimal control problems. We focus on algebraic multilevel Schwarz preconditioners with smoothed aggregation coarsening, that are modified to take into account the block structure that results from a suitable ordering of the unknowns. We report results of numerical experiments performed on linux clusters with the MLD2P4 package, extended to include the above modifications.

Alfio Borzi'
University of Sannio
Department of Engineering
alfio.borzi@unisannio.it

Valentina De Simone, Daniela di Serafino
Second University of Naples
Department of Mathematics
valentina.desimone@unina2.it,
daniela.diserafino@unina2.it

**MS70**

**Ambiguous Probabilistic Set Covering**

We consider probabilistic set covering constraints, where the covering coefficients are Bernoulli random variables with partial distribution information. Using union bounds, we formulate the corresponding ambiguous probabilistic set covering problem into a deterministic mixed-integer linear program. Some strong valid inequalities for the problem are also developed.

Shabbir Ahmed
H. Milton Stewart School of Industrial & Systems Engineering
Georgia Institute of Technology
sahmed@isye.gatech.edu

Dimitri Papageorgiou
ISyE
Georgia Tech
djpapag@gatech.edu

**MS70**

**On the Complexity of Non-Overlapping Multivariate Marginal Bounds for Probabilistic Combinatorial Optimization Problems**

Given a probabilistic combinatorial optimization problem, we evaluate the tightest bound on the expected optimal value over joint distributions with given multivariate marginals. This bound was first proposed in the PERT context by Meilijson and Nadas (Journal of Applied Probability, 1979). New instances of polynomial time computable bounds are identified. An important feature of the bound we propose is that it is exactly achievable by a joint distribution, unlike many of the existing bounds.

Karthik Natarajan
Department of Management Sciences
City University of Hong Kong
knataraj@cityu.edu.hk

Xuan Vinh Doan
Department of Combinatorics and Optimization
University of Waterloo

vanxuan@uwaterloo.ca

**MS70**

**Multiple Objectives Satisficing under Uncertainty**

We propose a class of functions, called multiple objective satisficing (MOS) criteria, for evaluating the level of compliance of the objectives in meeting their targets collectively under uncertainty. The MOS criteria include the joint targets' achievement probability (success probability criterion) as a special case and also extend to situations when the probability distribution is not fully characterized or ambiguity. We focus on a class of MOS criteria that favors diversification, which has the potential to mitigate severe shortfalls in scenarios when an objective fails to achieve its target. Naturally, this class excludes success probability and we propose the shortfall-aware MOS criterion (S-MOS), which is diversification favoring and is a lower bound to success probability. We show how to build tractable approximations of S-MOS that preserves the salient properties of MOS. We report encouraging computational results on a refinery blending problem in meeting specification targets even in the absence of full distributional information.

Melvyn Sim
NUS Business School
dscsimm@nus.edu.sg

**MS70**

**On Safe Tractable Approximations of Chance Constrained Linear Matrix Inequalities with Partly Dependent Perturbations**

In this talk, we will demonstrate how tools from probability theory can be used to develop safe tractable approximations of chance constrained linear matrix inequalities with partly dependent data perturbations. An advantage of our approach is that the resulting safe tractable approximations can be formulated as SDPs or even SOCPs, thus allowing them to be solved easily by off-the-shelf solvers. We will also discuss some applications of our results.

Anthony So
The Chinese University of Hong Kong
manchoso@se.cuhk.edu.hk

**MS71**

**Derivitive Approximation in Optimization for Statistical Learning**

Optimization problems that occur in machine learning are difficult mainly because of the expense of computing gradient and function values for large data sets. We discuss use of algorithms based on standard concepts such as truncated Newton, that use small-sample approximations to gradients and Hessians. We compare them to some of the special purpose machine learning algorithms that have been developed. We present computational experiments on some examples and also give some complexity results.

Richard H. Byrd
University of Colorado
richard@cs.colorado.edu

**MS71**

**Preconditioning and Globalizing Conjugate Gradients in Dual Space for Quadratically Penalized Nonlinear-Least Squares Problems**

We consider the Gauss-Newton algorithm for solving nonlinear least-squares problems, regularized with a quadratic term, that occur in data assimilation with application to Meteorology or Oceanography. Each quadratic problem of the method is solved with a dual space conjugate-gradient-like method. The use of an effective preconditioning technique is proposed and refined convergence bounds derived, which results in a practical solution method. Finally, stopping rules adequate for a trust-region solver are proposed in the dual space.

Serge Gratton
CERFACS
Toulouse, France
serge.gratton@cerfacs.fr

**MS71**

**Infeasibility Detection in Nonlinear Programming**

We describe an interior point algorithm with infeasibility detection capabilities. By employing a feasibility restoration phase, the new algorithm can give promote fast convergence to infeasible stationary points, or when the problem is feasible, fast convergence to a KKT point. We also describe analysis that shows how two-step active set methods that base the step computation on an appropriate model of the penalty function, can give fast infeasibility detection.

Figen Oztoprak
Sabanci Univeristy
figen@su.sabanciuniv.edu

**MS71**

**Updating Rules for the Regularization Parameter in the Adaptive Cubic Overestimation Method**

The Adaptive Cubic Overestimation method has been recently proposed for solving unconstrained minimization problems. At each iteration, the objective function is replaced by a cubic approximation which comprises an adaptive regularization parameter that estimates the Lipschitz constant of the objective. We present new updating strategies for this parameter based on interpolation techniques which improve the overall numerical performance of the algorithm. Numerical experiments on large nonlinear least-squares problems are shown.

Nick Gould
Numerical Analysis Group
Rutherford Appleton Laboratory
nick.gould@stfc.ac.uk

Margherita Porcelli
Department of Mathematics and naXys
FUNDP - University of Namur
margherita.porcelli@fundp.ac.be

Philippe L. Toint
The University of Namur
Department of Mathematics
philippe.toint@fundp.ac.be

**MS72**

**Semidefinite Relaxations for Non-Convex**

**Quadratic Mixed-Integer Programming**

We present semidefinite relaxations for unconstrained non-convex quadratic mixed-integer optimization problems. These relaxations yield tight bounds and are computationally easy to solve for medium-sized instances, even if some of the variables are integer and unbounded. In this case, the problem contains an infinite number of linear constraints; these constraints are separated dynamically. We use this approach as the bounding routine in an SDP-based branch-and-bound framework. In case of a convex objective function, the new SDP bound improves the bound given by the continuous relaxation of the problem. Numerical experiments show that our algorithm performs well on various types of non-convex instances.

Christoph Buchheim
TU Dortmund
christoph.buchheim@tu-dortmund.de

Angelika Wiegele
Alpen-Adria-Universit{
"a}t Klagenfurt
Institut f. Mathematik
angelika.wiegele@uni-klu.ac.at

## MS72
**Safe Coloring of Large Graphs**

One of the best methods for determining the chromatic number of a graph is the linear-programming branch and price technique. We present an implementation of the method that provides numerically safe results, independent of the floating-point accuracy of the LP solver. We propose an improved branch-and-bound algorithm for finding maximum-weight stable sets that enables us closing previously open DIMACS benchmarks. Finally, computational results on standard benchmarks as well as an application from VLSI-design are presented.

Stephan Held
University of Bonn
held@or.uni-bonn.de

Edward Sewell
Southern Illinois University Edwardsville
esewell@siue.edu

William Cook
Georgia Institute of Technology
bico@isye.gatech.edu

## MS72
**Dantzig-Wolfe Reformulations of General Mixed Integer Programs**

We discuss how Dantzig-Wolfe reformulations can be applied to general Mixed Integer Programs (MIP), which do not necessarily have an explicit or implicit block-diagonal structure, so as to obtain stronger formulations. We show that by looking for almost block-diagonal structures, application of Dantzig-Wolfe reformulation leads to improved results with respect to the direct application of a general MIP solver to the original formulation. We briefly discuss features which characterize an effective reformulation.

Martin Bergner
RWTH, Aachen University
martin.bergner@rwth-aachen.de

Alberto Caprara, Fabio Furini
DEIS - University of Bologna
alberto.caprara@unibo.it, fabio.furini@unibo.it

Marco Luebbecke
RWTH, Aachen University
marco.luebbecke@rwth-aachen.de

Enrico Malaguti
DEIS - University of Bologna
enrico.malaguti@unibo.it

Emiliano Traversi
University of Bologna
emiliano.traversi2@unibo.it

## MS72
**Computational Evaluation of Verification Cuts**

An inequality $c^T x \leq d$ with integral coefficients for an integer program yields a verification cut if $c^T x \geq d+1$ contains no solution to the integer program. Verification cuts can be shown to yield strong cuts in many cases. We investigate the computational use of these cuts. Different methods to produce a base inequality $c^T x \leq d$ and different ways to prove infeasibility of the complementary cut via truncated branch-and-cut are considered.

Marc E. Pfetsch
TU Braunschweig
m.pfetsch@tu-bs.de

Santanu Dey
Georgia Tech
santanu.dey@isye.gatech.edu

Sebastian Pokutta
Massachusetts Institute of Technology
sebastianpokutta@me.com

## MS73
**Regularization and Shifted Barriers for Linear Programming**

We consider the classical problem of solving a linear program. Our concern is regularization of the problem by shifted barriers and quadratic penalties. We discuss the use of regularizations based on different norms. In addition, we discuss how to solve the problem by a primal-dual approach based on simplex-like steps or an interior method.

Anders Forsgren
Royal Institute of Technology (KTH)
Dept. of Mathematics
andersf@kth.se

## MS73
**Incremental Newton-type Methods for Data Fitting**

In many structured data-fitting applications, frequent data access is the main computational cost. Incremental-gradient algorithms (both deterministic and randomized) offer inexpensive iterations by sampling only subsets of the data. These methods can make great progress initially, but often stall as they approach a solution. In contrast,

Newton-type methods achieve steady convergence at the expense of frequent data access. We explore hybrid methods that exhibit the benefits of both approaches. Numerical experiments illustrate the potential for the approach.

Michael P. Friedlander
Dept of Computer Science
University of British Columbia
mpf@cs.ubc.ca

### MS73
### A Gauss-Newton-Type Method for Constrained Optimization Using Differentiable Exact Penalties

We propose a Gauss-Newton-type method for nonlinear constrained minimization problems, using an extension of the exact penalty for variational inequalities, introduced recently by Andre and Silva. The exact penalty is constructed based on the incorporation of a multiplier estimate in an augmented Lagrangian. Using a weaker assumption, we prove exactness and convergence results. A globalization idea is also established, as well as some numerical experiments with the CUTE collection.

Ellen H. Fukuda
University of So Paulo
ellen@ime.usp.br

Paulo J. S. Silva
University of Sao Paulo
pjssilva@ime.usp.br

Roberto Andreani
DMA-IMECC-UNICAMP
andreani@ime.unicamp.br

### MS73
### Iterative Methods for SQD Linear Systems

Symmetric quasi-definite (SQD) systems arise naturally in interior-point methods for convex optimization and in some regularized PDE problems. In this talk we review the connection between SQD linear systems and other related problems and investigate their iterative solution. We report on preliminary numerical experience with an implementation of a regularization method for convex quadratic programming.

Dominique Orban
GERAD and Dept. Mathematics and Industrial Engineering
Ecole Polytechnique de Montreal
dominique.orban@gerad.ca

Mario Arioli
Rutherford Appleton Laboratory
Chilton, UK
m.arioli@rl.ac.uk

### MS74
### System-theoretic Methods for Model Reduction of Linear and Nonlinear Parabolic Systems

We discuss model reduction methods based on ideas from system theory. These methods rely on considering (generalized) transfer functions of the describing state and observation equations. For parabolic systems, these could be formulated in the infinite-dimensional setting or after spatial discretization of the state variables. We will focus on the latter approach, and review methods based on balanced truncation as well as Krylov subspace methods for linear and nonlinear problems.

Peter Benner
Max-Planck-Institute for
Dynamics of Complex Technical Systems
benner@mpi-magdeburg.mpg.de

Tobias Breiten
Max-Planck-Institute for Dynamics of Complex Technical Systems, Magdeburg
breiten@mpi-magdeburg.mpg.de

### MS74
### Model Reduction Methods in the Calibration of Financial Market Models

The calibration of models for derivative pricing is an important application of optimization in finance. The use of reduced order models improves the efficiency of the numerical scheme substantially. We review various venues for the use of reduced order models and discuss in particular proper orthogonal decomposition with a trust region variant. We illustrate the claims with numerical results for the calibration of a PIDE.

Ekkehard W. Sachs
University of Trier
Virginia Tech
sachs@uni-trier.de

### MS74
### Applications of DEIM in Nonlinear Model Reduction

A dimension reduction method called Discrete Empirical Interpolation (DEIM) is described and shown to dramatically reduce the computational complexity of the popular Proper Orthogonal Decomposition (POD) method for constructing reduced-order models for parametrized nonlinear partial differential equations (PDEs). DEIM is a technique for reducing the complexity of evaluating the reduced order nonlinear terms obtained with the standard POD-Galerkin. POD reduces dimension in the sense that far fewer variables are present, but the complexity of evaluating the nonlinear term remains that of the original problem. DEIM is a modification of POD that reduces complexity of the nonlinear term of the reduced model to a cost proportional to the number of reduced variables obtained by POD. The method applies to arbitrary systems of nonlinear ODEs, not just those arising from discretization of PDEs. In this talk, the DEIM method will be developed along with a discussion of its approximation properties. Applications in Shape Optimization and PDE constrained optimization shall be emphasized. Additional applications from Chemically Reacting Flow and Neural Modeling will be presented to illustrate the effectiveness and wide applicability of the DEIM approach.

Danny C. Sorensen, Saifon Chaturantabut
Rice University
sorensen@rice.edu, saifon.chaturantabut@riced.edu

### MS74
### Error Control in POD and RB Discretizations of

**Nonlinear Optimal Control Problems**

In the talk a-posteriori error estimation is utilized to control Galerkin-based reduced-order models for optimal control problems governed by nonlinear partial differential equations. More precisely, the nonlinear problems are treated by an inexact second-order methods, where the inexactness is handled using a-posteriori error analysis. The presented numerical strategies are illustrated for the POD and the Reduced-Basis method.

Stefan Volkwein
Universität Konstanz
stefan.volkwein@uni-konstanz.de

**MS75**

**Computational Methods for Equilibrium: Making the Most of Optimization**

Many phenomena are modeled as equilibrium problems consisting of simultaneous optimization by multiple agents (MOPEC). In the case of Walrasian equilibrium, we consider solution methods that solve a sequence of optimization subproblems for only one agent at a time. We show how to guide this sequence so that the algorithm converges.

Jesse Holzer
University of Wisconsin - Madison
Madison, USA
holzer@math.wisc.edu

**MS75**

**Regularization Methods for Mathematical Programs with Complementarity Constraints**

Mathematical programs with complementarity constraints form a difficult class of optimization problems. Standard constraint qualifications are typically violated. Therefore, more specialized algorithms are applied. A popular method is the regularization scheme by Scholtes. In the meantime, however, there exist a number of different regularization approaches for the solution of MPCCs. Here we first give a survey of the existing methods, introduce a new one, and improve the existing convergence assumptions of most methods.

Christian Kanzow
University of Wuerzburg
kanzow@mathematik.uni-wuerzburg.de

Tim Hoheisel
University of Würzburg
97074 Würzburg, Germany
hoheisel@mathematik.uni-wuerzburg.de

Alexandra Schwartz
University of Würzburg
Institute of Mathematics
schwartz@mathematik.uni-wuerzburg.de

**MS75**

**Effort Maximization in Asymmetric Contest Games with Heterogeneous Contestants – A Bilevel Problem in Economy**

We model the lobbying process between a politician and lobbyists as a contest game where the politician can encourage or discourage specific lobbyists from participating. This extension of the seminal lobbying set-up has important implications: The politician will optimally level the playing field by encouraging weak lobbyists to participate and at least three lobbyists will be active in the leveled lobbying process. Results are established using the implicit programming approach for bilevel problems.

Alexandra Schwartz
University of Würzburg
Institute of Mathematics
schwartz@mathematik.uni-wuerzburg.de

Jörg Franke
University of Dortmund (TU)
Department of Economics
joerg.franke@tu-dortmund.de

Christian Kanzow
University of Wuerzburg
kanzow@mathematik.uni-wuerzburg.de

Wolfgang Leininger
University of Dortmund (TU)
Department of Economics
wolfgang.leininger@tu-dortmund.de

**MS75**

**Convergence Analysis for Path-Following Methods Applied to Optimal Control Problems Subject to An Elliptic Variational Inequality**

In the talk, we consider the approximate solution of an optimal control problem subject to an elliptic variational inequality. The resulting optimization problem is an infinite-dimensional MPCC. The problem is regularized in the following way: The variational inequality is replaced by a semilinear elliptic equation. Existence of solutions of the regularized problem is shown. Moreover, these solutions depend continuously and Frechet differentiably on the regularization parameter. Convergence of the regularized solutions to a solution of the original MPCC is proven together with convergence rates with respect to the regularization parameter.

Daniel Wachsmuth
Johann Radon Institute for Computational and Applied Mathematics, Linz, Austria
daniel.wachsmuth@ricam.oeaw.ac.at

Karl Kunisch
Karl-Franzens University Graz
Institute of Mathematics and Scientific Computing
karl.kunisch@uni-graz.at

Anton Schiela
ZIB, Berlin
schiela@zib.de

**MS76**

**Extended Formulations in Mixed-Integer Programming**

Several problems in the optimal planning of production schedules can be formulated as mixed-integer programs. Extended formulations strengthen the original formulation by adding further variables. We review several techniques to construct extended formulations. We characterize cases where the extended formulation provides the characterization of the convex hull of the feasible set in a higher dimensional space. We discuss cases where the projection of the extended formulation can explicitly computed.

Michele Conforti
Università degli Studi di Padova
conforti@math.unipd.it

**MS76**

**Combinatorial Bounds on Nonnegative Rank and Extended Formulations**

In a breakthrough paper, Yannakakis (1991) proved that all symmetric extended formulations of the perfect matching polytope have exponential size. Very little is known about general lower bounds the sizes of extended formulations. We investigate a natural general lower bound, namely, the minimum number of combinatorial rectangles needed to cover the support of the slack matrix of the polytope.

Samuel Fiorini
Université Libre de Bruxelles
sfiorini@ulb.ac.be

Volker Kaibel, Kanstantsin Pashkovich, Dirk Theis
Otto-von-Guericke Universität Magdeburg
kaibel@ovgu.de, pashkovi@mail.math.uni-magdeburg.de, theis@ovgu.de

**MS76**

**Symmetry of Extended Formulations for Matching-Polytopes**

Yannakakis proved in 1991 that there are no symmetric polynomial size extended formulations for the perfect matching polytopes of complete graphs. He furthermore conjectured that asymmetry cannot help to obtain polynomial size extensions for these polytopes. We prove that, however, the convex hulls of the characteristic vectors of matchings of logarithmic size in a complete graph do admit polynomial size non-symmetric extensions, while all symmetric extensions of these polytopes have super-polynomial sizes.

Volker Kaibel, Kanstantsin Pashkovich, Dirk Theis
Otto-von-Guericke Universität Magdeburg
kaibel@ovgu.de, pashkovi@mail.math.uni-magdeburg.de, dirk.theis@ovgu.de

**MS76**

**Tight Lower Bound on the Sizes of Symmetric Extensions of Permutahedra**

It is well known that the Birkhoff polytope provides a symmetric extended formulation of the permutahedron $\Pi_n$ of size $\Theta(n^2)$. Recently, Goemans described asymptotically minimal extended formulation of $\Pi_n$ of size $\Theta(n \log n)$. In this paper, we prove that $\Omega(n^2)$ is a lower bound for the size of symmetric extended formulations of $\Pi_n$. Thus, it is possible to determine tight lower bounds $\Omega(n^2)$ and $\Omega(n \log(n))$ on the sizes of symmetric and non-symmetric extended formulations of $\Pi_n$ .

Kanstantsin Pashkovich
Otto-von-Guericke Universität Magdeburg
pashkovi@mail.math.uni-magdeburg.de

**MS77**

**Nonlinear Mpc in the Microsecond Range Using An Auto-Generated Real-Time Iteration Algorithm**

We present a strategy for automatic C-code generation of real-time nonlinear model predictive control (MPC) algorithms, which are designed for applications with kilohertz sample rates. The corresponding software module for exporting the code has been implemented within the software package ACADO Toolkit. Its symbolic representation of optimal control problems allows to auto-generate optimized plain C-code. The exported code comprises a fixed step-size integrator that also generates the required sensitivity information as well as a real-time Gauss-Newton method that is tailored for final production. Numerical results show that the exported code has a promising computational performance allowing to apply nonlinear MPC to nontrivial processes at sampling times in the milli- and microsecond range.

Joachim Ferreau
K.U. Leuven
joachim.ferreau@esat.kuleuven.be

Boris Houska
KU Leuven
boris.houska1@gmx.de

Moritz Diehl
K.U.Leuven
moritz.diehl@esat.kuleuven.be

**MS77**

**Solving Linear Complementarity Problems with Fast Numerical Methods**

In this talk we will show how to improve the speed of first order methods for solving linear complementarity problems (LCPs). Specifically, we will concentrate on the numerical solution of LCPs that arise in CPU intensive applications such as rigid body dynamics and the pricing of American options. The methodology consists in interlacing first order iterations with subspace iterations on the free variables detected by the first order phase. The subspace phase contributes to the resulting method in two aspects: a) the accurate identification of the active set; b) the speed of convergence. Thus, the new method is able to compute very accurate solutions in less time than the original first order method.

Jose Luis Morales
Departamento de Matematicas.
ITAM. MEXICO.
jmorales@itam.mx

**MS77**

**A Distributed Newton Method for Network Utility Maximization**

Most existing work uses dual decomposition and subgradient methods to solve Network Utility Maximization (NUM) problems in a distributed manner, which suffer from slow rate of convergence properties. This work develops an alternative distributed Newton-type fast converging algorithm for solving network utility maximization problems with self-concordant utility functions. By using novel matrix splitting techniques, both primal and dual updates for the Newton step can be computed using iterative schemes in a decentralized manner with limited information exchange. We show that even when the Newton direction and the stepsize in our method are computed within some error (due to finite truncation of the iterative schemes), the resulting objective function value still converges superlinearly to an explicitly characterized error neighborhood. Simulation results demonstrate significant convergence rate improvement of our algorithm relative to the existing subgradient methods based on dual decomposition.

Asu Ozdaglar, Ermin Wei
MIT
asuman@mit.edu, erminwei@mit.edu

Ali Jadbabaie
Department of Electrical and Systems Engineering
University of Pennsylvania
jadbabai@seas.upenn.edu

### MS77

### Mixed-Integer Nonlinear Real-Time Optimization

We present work on nonlinear optimal control problems in real time, where some control functions may only take values from a discrete set. Examples are gear choices in transport, or on/off valves in engineering. Our approach is based on an Outer Convexification with respect to the integer control functions, the direct multiple shooting method, and real-time iterations as first proposed by Diehl, Bock, and Schlöder. We discuss theoretical and numerical aspects.

Sebastian Sager
Interdisciplinary Center for Scientific Computing
sebastian.sager@iwr.uni-heidelberg.de

Christian Kirches
Interdisciplinary Center for Scientific Computing
University of Heidelberg, Germany
christian.kirches@iwr.uni-heidelberg.de

### MS78

### On the Lasserre Hierarchy of Semidefinite Programming Relaxations of Convex Polynomial Optimization Problems

The Lasserre hierarchy of semidefinite programming approximations to convex polynomial optimization problems is known to converge finitely under some assumptions. [J.B. Lasserre. Convexity in semialgebraic geometry and polynomial optimization. *SIAM J. Optim.* **19**, 1995–2014, 2009.] We give a new proof of the finite convergence property, that does not require the assumption that the Hessian of the objective be positive definite on the entire feasible set, but only at the optimal solution.

Etienne De Klerk
Tilburg University
E.deKlerk@uvt.nl

Monique Laurent
CWI, Amsterdam
and Tilburg University
M.Laurent@cwi.nl

### MS78

### SDP Approximation for the Electronic Structures of Atoms and Molecules

Determining the ground-state energy (lowest energy) of an electronic system (of an atom or a molecule) is the core problem in quantum chemistry. Solving the SDP approximation of this problem is challenging since it requires parallel computation and high accuracy due to its excellent approximation values. We will present the computational results for the largest dense (Schur complement matrix) SDP solved so far, and further directions tackle this difficult problem.

Mituhiro Fukuda
Tokyo Institute of Technology
Department of Mathematical and Computing Sciences
mituhiro@is.titech.ac.jp

Maho Nakata
RIKEN
maho@riken.jp

Katsuki Fujisawa
Department of Industrial and Systems Engineering
Chuo University
fujisawa@indsys.chuo-u.ac.jp

### MS78

### Moment and SDP Relaxation Methods for Smooth Approximations of Nonlinear Differential Equations

Combining moment and semidefinite programming (SDP) relaxation techniques, we propose an approach to find smooth approximations for solutions of nonlinear differential equations. Given a system of differential equations, we apply a technique based on finite differences and sparse SDP relaxations to obtain a discrete approximation of its solution. In a second step we apply maximum entropy estimation (using moments of a Borel measure associated with the discrete approximation) to obtain a smooth closed-form approximation.

Martin Mevissen
LAAS-CNRS
mevissen.martin@gmail.com

Jean Bernard Lasserre
LAAS-CNRS
France
lasserre@laas.fr

Didier Henrion
LAAS-CNRS, University of Toulouse, & Faculty of
Electrical Engineering, Czech Technical University
henrion@laas.fr

### MS78

### Ellipsoid-type Confidential Bounds on Semi-algebraic Sets via SDP Relaxation

In many applications, we want to know a confidential bound on semi-algebraic sets. For example, a sensor network localization problem is to find a feasible point of semi-algebraic sets. However, if its base network is not rigid, its sensor locations can not be fixed. Our method computes an ellipsoid-type confidential bound on semi-algebraic sets via SDP relaxation. This method can specify the possible region of each sensor even when the network is not rigid. We also apply our method to polynomial optimization problems which have multiple optimal solutions and obtain a bound to cover all the optimal solutions.

Makoto Yamashita
Tokyo Institute of Technology
Dept. of Mathematical and Computing Sciences
makoto.yamashita@is.titech.ac.jp

Masakazu Kojima
Tokyo Institute of Technology
kojima@is.titech.ac.jp

**MS80**

**SDPA Project: Solving Large-scale Semidefinite Programs**

Solving extremely large-scale SDPs has a significant importance for the current and future applications of SDPs. In 1995, we have started the SDPA Project aimed for solving large-scale SDPs with numerical stability and accuracy. SDPA and SDPARA are pioneers' code to solve general SDPs. In particular, it has been successfully applied on quantum chemistry, the SDPARA on a supercomputer has succeeded to solve the largest SDP and made a new world record.

Katsuki Fujisawa
Department of Industrial and Systems Engineering
Chuo University
fujisawa@indsys.chuo-u.ac.jp

Makoto Yamashita
Tokyo Institute of Technology
Dept. of Mathematical and Computing Sciences
makoto.yamashita@is.titech.ac.jp

Maho Nakata
RIKEN
maho@riken.jp

Mituhiro Fukuda
Tokyo Institute of Technology
Department of Mathematical and Computing Sciences
mituhiro@is.titech.ac.jp

**MS80**

**Which Mixed Integer Programs could a Million CPUs Solve?**

There is a trend in supercomputing to employ evermore computing cores. Today, the current top 10 machines have on average 150000 cores and likely a million cores will be available soon. The question arises how to harness these vast computing capabilities to solve new classes of mixed integer programs. Based on our experiences with distributed parallel solvers we will systematically investigate under which conditions such a machine might efficiently solve MIPs.

Thorsten Koch
Zuse Institute Berlin
koch@zib.de

Yuji Shinano
Zuse Institute Berlin
Takustr. 7 14195 Berlin
shinano@zib.de

**MS80**

**DIP with CHiPPS: Parallelizing Algorithms for Solving Integer Programs**

Most practical algorithms for solving integer programs follow the basic paradigm of tree search. Such algorithms are easy to parallelize in principle, but there are many challenges to achieving scalability in practice. We discuss approaches to overcoming these challenges both using the course-grained parallelism afforded by parallelizing the tree search itself and the fine-grained parallelism afforded by parallelizing the computations that take place in processing a single search tree node.

Ted Ralphs
Department of Industrial and Systems Engineering
Lehigh University
ted@lehigh.edu

Matthew Galati, Yan Xu
SAS Institute
matthew.galati@sas.com, yan.xu@sas.com

**MS80**

**Solving Hard MIP Instances using Massively Parallelized MIP Solvers**

We present parallel implementations of state-of-the-art MIP solvers, CPLEX and SCIP, on a distributed memory computing environment. The implementations are constructed using a single software framework that enables us to execute sequential branch-and-bound codes in parallel. We show computational results conducted with the parallel MIP solvers using up to 7,168 cores of HLRN II. These results include the solutions to two open instances from MIPLIB2003 that had not been solved yet.

Yuji Shinano
Zuse Institute Berlin
Takustr. 7 14195 Berlin
shinano@zib.de

Tobias Achterberg
IBM Deutschland Research & Development GmbH
achterberg@de.ibm.com

Timo Berthold, Stefan Heinz
Zuse Institute Berlin
Takustr. 7 14195 Berlin
berthold@zib.de, heinz@zib.de

Thorsten Koch
Zuse Institute Berlin
koch@zib.de

**MS81**

**A POD Approach to Robust Controls in PDE Optimization**

A strategy for the fast computation of robust controls of PDE models with random-field coefficients is presented. A robust control is defined as the control function that minimizes the expectation value of the objective over all coefficient configurations. A straightforward application of the adjoint method on this problem results in a very large optimality system. In contrast, a fast method is presented where the expectation value of the objective is minimized with respect to a reduced POD basis of the space of controls. Comparison of the POD scheme with the full optimization procedure in the case of elliptic control problems with random reaction terms and with random diffusivity demonstrates the superior computational performance of the POD-based method.

Alfio Borzi
Institute for Mathematics
University of Würzburg
alfio.borzi@uni-wuerzburg.de

Gregory von Winckel
University of Graz
Institute of Mathematics
gregory.von-winckel@uni-graz.at

**MS81**

**Stochastic Collocation for Optimization Problems Governed by Stochastic Partial Differential Equations**

Many optimization optimization problems in engineering and science are governed by partial differential equations (PDEs) with uncertainties in the input data. Since the solution of such PDEs is a random field and enters the objective function, the objective function usually involves statistical moments. Optimization problems governed by PDEs with uncertainties in the input data are posed as a particular class of optimization problems in Bochner spaces. This allows us to use the frameworks for derivative based optimization methods in Banach spaces. However numerical solution of these problems is more challenging than deterministic PDE constrained optimization problems, because it requires discretization of the PDE in space/time as well as in the random variables. We discuss stochastic collocation methods for the numerical solution of such optimization problems, explore the decoupling nature of this method for gradient and Hessian computations as well as preconditioning, and we present estimates for the discretization error.

Matthias Heinkenschloss
Rice University
Dept of Comp and Applied Math
heinken@rice.edu

Drew Kouri
Department of Computational and Applied Mathematics
Rice University
drew.kouri@rice.edu

**MS81**

**Numerical Treatment of Uncertainties in Aerodynamic Shape Optimization**

In this talk, a novel approach towards stochastic distributed aleatory uncertainties for the specific application of optimal aerodynamic design under uncertainties will be presented. Proper robust formulations of the deterministic problem as well as efficient adaptive discretization techniques combined with algorithmic approaches based on one-shot methods attacking the additional computational complexity will be discussed. Further, numerical results of robust aerodynamic shape optimization under uncertain flight conditions as well as geometrical uncertainties will be presented.

Claudia Schillings
University of Trier, Germany
Claudia.Schillings@uni-trier.de

Volker Schulz
University of Trier
Department of Mathematics
Volker.Schulz@uni-trier.de

**MS81**

**Shape Optimization under Uncertainty from Stochastic Programming Point of View**

Shape optimization with linearized elasticity under stochastic loading bears conceptual similarity with finite-dimensional two-stage linear stochastic programming. Shapes correspond to nonanticipative first-stage decisions in the stochastic program. The weak formulation of the elasticity pde forms an analogue to the second-stage optimization problem. Based on these observations, we present risk-neutral and risk-averse stochastic shape optimization problems, discuss algorithms for their solution, and report computational results.

Ruediger Schultz
University of Duisburg-Essen
schultz@math.uni-duisburg.de

**MS82**

**Optimization with Risk Via Stochastic Dominance Constraints**

The theory of stochastic dominance provides tools to compare the distributions of two random variables. Notions of stochastic dominance have been used in a wide range of areas, from epidemiology to economics, as they allow for comparison of risks. Such concepts are also useful in an optimization setting, where they can be used as constraints to control for risk – an area that has gained attention in the literature since its introduction by Dentcheva and Ruszczynski in a 2003 paper. The use of stochastic dominance in a multivariate setting can then allow for multi-criterion risk comparisons, which is useful not only for optimization but also from a pure decision-making perspective. The multivariate setting, however, poses significant challenges, as even testing for such conditions may be difficult. In this talk we introduce some alternative concepts based on the notion of multivariate linear dominance, where linear combinations of the underlying random vectors are compared using coefficients from a certain user-specified set that may represent the opinions of multiple decision makers. When the random vectors being compared have discrete distributions, these new stochastic dominance relationships can be represented by a finite number of inequalities. Moreover, some of these concepts can be parameterized in order to allow for a relaxation of the dominance condition. These results yield concrete conditions can be checked, either as stand-alone comparisons or as constraints in the optimization setting. We discuss these formulations in detail and present some practical examples to illustrate the ideas.

Tito Homem-de-Mello
Northwestern University
thmello@uic.edu

Sanjay Mehrotra
IEMS
Northwestern University
mehrotra@iems.northwestern.edu

Jian Hu
Northwestern University
jianhu2010@u.northwestern.edu

**MS82**

**Scenario Generation in Stochastic Optimization**

Some approaches for generating scenarios in stochastic optimization are shortly reviewed. The Quasi-Monte Carlo (QMC) approach is discussed in more detail. In particular, we provide conditions implying that QMC may be successfully applied to two-stage dynamic stochastic programs and is superior to Monte Carlo. Some numerical experience is also presented.

Werner Roemisch
Humboldt-University Berlin
Instititute of Mathematics
romisch@math.hu-berlin.de

**MS82**

**Distributed Schemes for Computing Equilibria of Monotone Nash Games**

In this talk, we consider the distributed computation of equilibria arising in monotone Nash games over continuous strategy sets. Direct application of projection-based schemes are characterized by a key shortcoming: they can accommodate strongly monotone mappings only. We develop single-timescale regularized variants (via Tikhonov and proximal-point methods) that can accommodate a more general class of problems and provide convergence theory. Several extensions of this framework are studied, including inexact projection schemes, partially coordinated generalizations (where players choose steplength sequences independently) and generalizations to the stochastic regime.

Uday Shanbhag
Department of Industrial and Enterprise Systems Engineering
University of Illinois at Urbana-Champaign
udaybag@uiuc.edu

**MS82**

**Stochastic Mathematical Programs with Equilibrium Constraints**

In this talk, we discuss numerical approximation schemes for a two stage stochastic programming problem where the second stage problem has a general nonlinear complementarity constraint: first, the complementarity constraint is approximated by a parameterized system of inequalities with a well-known NLP regularization approach in deterministic mathematical programs with equilibrium constraints; the distribution of the random variables of the regularized two stage stochastic program is then approximated by a sequence of probability measures. By treating the approximation problems as a perturbation of the original (true) problem, we carry out a detailed stability analysis of the approximated problems including continuity and local Lipschitz continuity of optimal value functions, and outer semicontinuity and continuity of the set of optimal solutions and stationary points. A particular focus is given to the case when the probability distribution is approximated by the empirical probability measure which is also known as sample average approximation.

Huifu Xu
Southampton University
h.xu@soton.ac.uk

**MS83**

**Convex Relaxation for the Clique and Clustering Problems**

Given data with known pairwise similarities, partitioning the data into disjoint clusters is equivalent to partitioning a particular graph into disjoint cliques. We consider the related problem of identifying the maximum subgraph comprised of k disjoint cliques of a given graph. We show that this NP-hard problem can be solved exactly by relaxing to a convex optimization problem by replacing rank with the nuclear norm for certain input graphs.

Brendan Ames
University of Waterloo
bpames@math.uwaterloo.ca

Stephen A. Vavasis
University of Waterloo
Dept of Combinatorics & Optimization
vavasis@math.uwaterloo.ca

**MS83**

**Convex Graph Invariants**

The structural properties of graphs are characterized in terms of invariants, which are functions of graphs that do not depend on node labeling. We discuss convex graph invariants, which are graph invariants that are convex functions of the adjacency matrix of a graph. Some examples include the maximum degree, the MAXCUT value (and its semidefinite relaxation), and spectral invariants such as the sum of the k largest eigenvalues. Such functions can be used to construct convex sets that impose various structural constraints on graphs, and thus provide a unified framework for solving several interesting graph problems via convex optimization.

Venkat Chandrasekaran, Pablo A. Parrilo, Alan Willsky
Massachusetts Institute of Technology
venkatc@mit.edu, parrilo@MIT.EDU, willsky@mit.edu

**MS83**

**Nuclear Norm of Multilinear Forms and Tensor Rank**

We will define Schatten and Ky Fan norms for tensors of arbitrary order and discuss their basic properties. In particular, we show that the Schatten 1 norm is the convex envelope of tensor rank on the spectral norm unit ball – a generalization of a well-known result in matrix completion. We will then discuss how one may compute Schatten norms of a tensor via semidefinite relaxation of a generalized moment problem.

Lek-Heng Lim
University of Chicago
lekheng@galton.uchicago.edu

**MS83**

**The Convex Geometry of Linear Inverse Problems**

Building on the success of generalizing compressed sensing to matrix completion, we extend the catalog of structures that can be recovered from partial information. We describe algorithms to decompose signals into sums of atomic signals from a simple, not necessarily discrete, set. These algorithms are derived in a convex optimization framework that generalizes previous methods based on l1-norm and nuclear norm minimization. We discuss general recovery guarantees for our approach and several example applications.

Benjamin Recht
University of Wisconsin – Madison
brecht@cs.wisc.edu

Venkat Chandrasekaran, Pablo A. Parrilo, Alan Willsky
Massachusetts Institute of Technology
venkatc@mit.edu, parrilo@MIT.EDU, willsky@mit.edu

### MS85
### Sparse Interpolatory Surrogate Models for Potential Energy Surfaces

In this presentation we describe recent results on managing interpolatory surrogate models for potential energy surfaces. The objectives are to avoid the use of an expensive simulator with an interpolatory approximation, keep the number of interpolatory nodes at a moderate level for problems of dimension up to ten, and perform well on cluster architectures. We will discuss the motivating application, the algorithmic issues, and our solutions. We will also report computational results

Carl T. Kelley
North Carolina State Univ
Department of Mathematics
tim_kelley@ncsu.edu

David Mokrauer
Dept of Mathematics
NC State University
dsmokrau@ncsu.edu

### MS85
### A Linearly-Constrained Augmented Lagrangian Method for PDE-Constrained Optimization

In this talk, I describe a linearly-constrained augmented Lagrangian method for solving PDE-constrained optimization problems. This method computes two directions, a Newton direction to reduce the constraint violation and a reduced-space direction to improve the augmented Lagrangian merit function. The reduced-space direction is computed from a limited-memory quasi-Newton approximation to the reduced Hessian. This method requires a minimal amount of information from the user, yet obtains good performance on our test problems.

Todd Munson
Argonne National Laboratory
Mathematics and Computer Science Division
tmunson@mcs.anl.gov

### MS85
### Multigrid Methods for PDE-constrained Optimization

MG/Opt is a multigrid optimization approach for the solution of constrained optimization problems. The approach assumes that one has a hierarchy of models, ordered from fine to coarse, of an underlying optimization problem, and that one is interested in finding solutions at the finest level of detail. MG/Opt uses calculations on coarser levels to accelerate the progress of the optimization on the finest level. I discuss convergence results for MG/Opt, along with issues affecting performance.

Stephen G. Nash
George Mason University
Systems Engineering & Operations Research Dept.
snash@gmu.edu

### MS85
### Multilevel Optimization with Reduced Order Models for PDE-Constrained Problems

We present an adaptive multilevel generalized SQP-method for optimal control problems governed by nonlinear PDEs with control constraints. During the optimization iteration the algorithm generates a hierarchy of adaptively refined discretizations. The discretized problems are then each approximated by an adaptively generated sequence of reduced order models. The adaptive refinement strategies are based on error estimators for the original and the discretized PDE, adjoint PDE and a criticality measure. Numerical results are presented.

J. Carsten Ziems
Technische Universitaet Darmstadt
ziems@mathematik.tu-darmstadt.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

### MS86
### Global Optimization Methods for the Identification of Biochemical Networks

Model building is a key task in systems biology. In this context, model identification often becomes a bottleneck due to limited amount and low quality of experimental data. The discrimination among different model candidates faces similar challenges. This work revisits the problems of parameter estimation and the optimal experimental design as challenging non-linear (dynamic) optimization problems and shows, through some examples, how to handle this complexity by means of suitable global optimization techniques.

Eva Balsa-Canto
IIM-CSIC
ebalsa@iim.csic.es

Julio R. Banga
IIM-CSIC
Vigo, Spain
julio@iim.csic.es

### MS86
### Reverse Engineering of Gene Expression via Optimal Control

Many cellular networks have evolved to maximize fitness. Experimental and numerical observations suggest that gene onset in bacterial amino acid metabolism follows a “just-in-time’ pattern that can be understood as the solution of a dynamic optimization problem. Here we use rigorous tools such as the Minimum principle and Linear-Quadratic optimization to reverse engineer genetic timing. Our analysis suggests new hypotheses about the general validity of this design principle.

Diego A. Oyarzun
Department of Bioengineering
Imperial College London
d.oyarzun@imperial.ac.uk

### MS86
### Optimal Design of Transcription Networks

The ongoing advance in synthetic biology allows for the implementation of artificial biochemical networks with increasing complexity and accuracy. This calls for the use of computational methods to cope with the design process and avoid inefficient try and error approaches. Every system is subject to random perturbations and uncertainties and trying to optimize the worst case performance leads to nonlinear semi-infinite min-max optimization problems which we solve by replacing them with a sequence of finite dimensional non linear programs. The method is illustrated by optimizing and stabilizing the period of the circadian oscillator of Drosophila.

Marcel Rehberg
Freiburg University, Germany
marcel.rehberg@biologie.uni-freiburg.de

Dominik Skanda
Department of Applied Mathematics
University of Freiburg, Germany
dominik.skanda@biologie.uni-freiburg.de

Dirk Lebiedz
University of Freiburg
Center for Systems Biology
dirk.lebiedz@biologie.uni-freiburg.de

### MS86
### Robustness Analysis of Biomolecular Networks via Polynomial Programming

Dynamical models of biomolecular networks commonly contain significant parametric uncertainty, which affects the model behaviour and the network's related biological function. The talk presents methods of polynomial programming which allow to quantify the effects of uncertainties on the model behaviour, and to compute a level of parametric uncertainty up to which no significant changes in the qualitative model behaviour occur. In this way, the robustness analysis problem can be handled via a convex optimization approach.

Steffen Waldherr
Institute for Systems Theory and Automatic Control
Universität Stuttgart
waldherr@ist.uni-stuttgart.de

Frank Allgöwer
Institute for Systems Theory in Engineering
University of Stuttgart
allgower@ist.uni-stuttgart.de

### MS87
### Convex Hulls for Non-convex Mixed Integer Quadratic Programs

We study six families of unbounded convex sets that are associated with non-convex mixed-integer quadratic programs. The six cases arise by permitting the variables to be either continuous, integer-constrained, or mixed, and by specifying them to be either non-negative or free. It turns out that none of these convex sets are polyhedra. Nevertheless, we show that most of them have infinitely many facets.

Samuel Burer
University of Iowa
Dept of Management Sciences
samuel-burer@uiowa.edu

Adam N. Letchford
Lancaster University Management School
a.n.letchford@lancaster.ac.uk

### MS87
### Lower Bounds for the Chvtal-Gomory Closure in the 0/1 Cube

Although well studied, important questions on the rank of the Chvtal-Gomory operator when restricting to polytopes in the n-dimensional 0/1 cube have not been answered yet. In this paper we develop a simpler method to establish lower bounds. We show the power and applicability of this method on classical examples as well as provide new families of polytopes with high rank. Furthermore, we provide a deterministic family of polytopes achieving a Chvtal-Gomory rank of at least (1+1/e)n - 1 and we show how to obtain a lower bound on the rank from solely examining the integrality gap.

Sebastian Pokutta
Massachusetts Institute of Technology
sebastianpokutta@me.com

Gautier Stauffer
University of Bordeaux 1
gautier.stauffer@math.u-bordeaux1.fr

### MS87
### The Stable Set Polytope of Claw-free Graphs : Extended Formulations, Optimization and Separation

In this talk, we show how recent algorithmic ideas for optimizing over the stable polytope of claw-free graphs can be straightforwardly converted into an extended formulation for this problem. We then explain how to exploit similar ideas to build another extended formulation from the very basic definition of the convex hull. Finally, building upon those results, we discuss how to derive a polytime separation routine and retrieve the linear description in the original space.

Yuri Faenza
Università degli Studi di Padova
yuri faenza ¡yuri.faenza@gmail.com¿

Gianpaolo Oriolo
Università di Tor Vergata
gianpaolo oriolo ¡oriolo@disp.uniroma2.it¿

Gautier Stauffer
University of Bordeaux 1
gautier.stauffer@math.u-bordeaux1.fr

**MS87**

**2-clique-bond of Stable Set Polyhedra**

A 2-clique-bond is a generalization 2-clique-join where the subsets of nodes that are connected on each shore of the partition are two (not necessarily disjoint) cliques. We study the polyhedral properties of the stable set polytope of a graph G obtained as the 2-clique-bond of two graphs G1 and G2. In particular, we prove that a linear description of the stable set polytope of G is obtained by properly composing the linear inequalities describing the stable set polytopes of smaller graphs that are related to G1 and G2.

Paolo Ventura
Istituto di Analisi dei Sistemi ed Informatica
paolo.ventura@iasi.cnr.it

**MS88**

**Semidefinite Code Bounds Based on Quadruple Distances**

Error correcting codes are stable sets in highly symmetric, but exponential sized graphs. Exploiting this symmetry allows to transform SDP bounds for the stability number into effective coding bounds. A striking example is the Lovász theta bound, which yields a linear sized LP: Delsarte's bound. We present a stronger bound based on quadruples of code words. The feasible region of our SDP consists of matrices indexed by pairs of words, that are invariant under the symmetries of the Hamming cube. Using representation theory of the symmetric group, the invariant algebra can be block diagonalized, allowing the bound to be computed in polynomial time. Computationally, we obtain several improved bounds. In particular we find that the quadruply shortened Golay code is optimal.

Dion Gijswijt
CWI, Amsterdam
Leiden University
dion.gijswijt@gmail.com

**MS88**

**New SDP Relaxations of Stable Set Problems in Hamming Graphs**

We provide a new upper bound on the maximal size of the stable set in Hamming graphs via a new semidefinite programming (SDP) relaxation. Our approach based on an SDP relaxation of the more general quadratic assignment problem. We show how to exploit group symmetry in the problem data and get a much smaller SDP problem in this special case.

Marianna Nagy
Tilburg University, The Netherlands
m.nagy@uvt.nl

Etienne De Klerk, Renata Sotirov
Tilburg University
E.deKlerk@uvt.nl, r.sotirov@uvt.nl

**MS88**

**SDP Versus Eigenvalue Approaches to Bandwidth and Partition Problems**

Bandwidth and partition problems are in general NP complete. As combinatorial optimization problems they have natural formulations in binary variables involving quadratic constraints. We consider eigenvalue based relaxations, which are suitable for large scale problems. The weight redistribution idea allows to tighten these eigenvalue bounds. We present some preliminary computational results which compare favourably with previous eigenvalue based relaxations.

Franz Rendl
Universitat Klagenfurt
Institut fur Mathematik
franz.rendl@uni-klu.ac.at

Abdel Lisser
Paris Orsay
abdel.lisser@lri.fr

Mauro Piacentini
La Sapienza, Roma
piacentini@dis.uniroma1.it

**MS88**

**Comparison of Bounds for Some Combinatorial Optimization Problems**

In this talk we relate several semidefinite programming relaxations for the graph partition problem and the bandwidth problem in graphs, such as those of Donath-Hoffman, Karisch-Rendl, Wolkowicz-Zhao, Zhao-Karisch-Rendl-Wolkowicz. We also present new bounds for the mentioned problems that are competitive with previously known ones.

Renata Sotirov
Tilburg University
r.sotirov@uvt.nl

**MS89**

**A Two-Scale Approach for Optimization of Fine Scale Geometry in Elastic Macroscopic Shapes**

We investigate macroscopic geometries with geometric details located on a regular lattice. These details are supposed to be parametrized via a finite number of parameters over which we optimize. Achieved results reveal phenomena on different length scales and reflect the multiscale nature of the optimization problem. Hence, we employ a two-scale approach based on boundary elements for the elastic problem on the microscale and finite elements on the macroscale. Effective material properties will be studied and relations to laminate based optimization will be investigated.

Benedict Geihe
Rheinische Friedrich-Wilhelms-Universität Bonn
Institut für Numerische Simulation
benedict.geihe@ins.uni-bonn.de

**MS89**

**Shape Optimization with Stochastic Dominance Constraints**

Bringing together stochastic and shape optimization, we investigate elastic structures under random volume and surface forces. Drawing on concepts from linear two-stage stochastic programming we formulate shape optimization models with stochastic dominance constraints. The latter single out shapes, whose compliances compare favourably with preselected benchmark random variables. In our algorithms, shape variations arise from parametric shape descritions, leading to nonlinear programs in finite dimension. Illustrative computational results complete the talk.

Martin Pach
University of Duisburg-Essen
Department of Mathematics
martin.pach@uni-due.de

**MS89**

**On Certain and Uncertain Aerodynamic Shape Optimization**

Almost any technical process is prone to uncertainties withine the model describing this process. Aerodynamic shape optimization is one challenging example as part of this general problem class. We will highlight the challenges caused by uncertainties present in aerodynamics and shape optimization and also give ideas for the numerical treatment of these challenges. Numerical results achieved within collaborative efforts together with aircraft industry and the German Aerospace center will be presented.

Volker Schulz
University of Trier
Department of Mathematics
Volker.Schulz@uni-trier.de

Stephan Schmidt
University of Trier
Stephan.Schmidt@uni-trier.de

Claudia Schillings
University of Trier, Germany
Claudia.Schillings@uni-trier.de

**MS90**

**A Space Mapping Approach for the p-Laplace Equation**

Motivated by car safety applications the goal is to determine a thickness coefficient in the nonlinear p-Laplace equation. The associated structural optimization problem is hard to solve. Therefore, the computationally expensive, nonlinear equation is replaced by a simpler, linear model. A space mapping technique is utilized to link the linear and nonlinear equations and drives the optimization iteration of the nonlinear equation using the fast linear equation. Numerical examples illustrate the presented approach.

Oliver Lass
Universitaet Konstanz
oliver.lass@uni-konstanz.de

Stefan Volkwein
Universität Konstanz
stefan.volkwein@uni-konstanz.de

**MS90**

**Variable-fidelity Design Optimization of Airfoils using Surrogate Modeling and Shape-preserving Response Prediction**

A computationally efficient methodology for airfoil design optimization is presented. Our approach exploits a corrected physics-based low-fidelity surrogate that replaces, in the optimization process, an accurate but computationally expensive high-fidelity airfoil model. Correction of the low-fidelity model is achieved by aligning the airfoil surface pressure distribution with that of the high-fidelity model using a shape-preserving response prediction technique. We present several numerical applications to airfoil design for both transonic and high-lift conditions.

Slawomir Koziel, Leifur Leifsson
Reykjavik University
School of Science and Engineering
koziel@hr.is, leifurth@ru.is

**MS90**

**Optimal Control of Particles in Fluids**

We present techniques for optimizing particle dispersions flows and show the application spectrum, power and efficiency of space mapping approaches that are based on a hierarchy of models ranging from a complex to a simple one. Space mapping allows for the easy and efficient treatment of stochastic design problems. To control the random particle dynamics in a turbulent flow we suggest a Monte-Carlo aggressive space mapping algorithm that yields very convincing numerical results.

Rene Pinnau
Technische Universität Kaiserslautern
Fachbereich Mathematik
pinnau@mathematik.uni-kl.de

**MS90**

**Surrogate-Based Optimization for Marine Ecosystem Models**

Understanding the oceanic $CO_2$ uptake is of central importance for projections of climate change and oceanic ecosystems. The underlying models are governed by coupled systems of nonlinear parabolic partial differential equations for ocean circulation and transport of biogeochemical tracers. The aim is to minimize the misfit between parameter dependent model output and given data. Here we show that using cheaper surrogate models significantly reduces the optimization cost.

Malte Prie
Christian-Albrechts-Universitaet Kiel
mpr@informatik.uni-kiel.de

Thomas Slawig
Christian-Albrechts-Uni Kiel
Department of Computer Science
ts@informatik.uni-kiel.de

Slawomir Koziel
Reykjavik University
School of Science and Engineering
koziel@hr.is

**PP1**

**Optimality Conditions and Duality in Nondifferentiable Multiobjective Programming**

A nondifferentiable multiobjective problem is considered. Fritz John and Kuhn-Tucker type necessary and sufficient conditions are derived for a weak efficient solution. Kuhn-Tucker type necessary conditions are also obtained for a properly efficient solution. Weak and strong duality theorems are established for a Mond-Weir type dual. Moreover, for a converse duality theorem we discuss a special case of nondifferentiable multiobjective problem, where subgradients can be computed explicitly.

Izhar Ahmad
King Fahd University of Petroleum and Minerals
drizhar@kfupm.edu.sa

### PP1

### Adjoint-Based Full-Waveform Inversion for Parameter Identification in Seismic Tomography

We present a Newton-type method for full-waveform seismic inversion and propose a misfit criterion based on the convolution and the $L_2$-distance of observed and simulated seismograms. The implementation features the adjoint-based computation of the gradient and Hessian-vector products of the reduced problem, a Krylov subspace method to solve the Newton system in matrix-free fashion, spatial discretization of the elastic wave equation by high-order finite elements and parallelization with MPI.

Christian Boehm
Technische Universitaet Muenchen
boehm@ma.tum.de

Michael Ulbrich
Technical University of Munich
Chair of Mathematical Optimization
mulbrich@ma.tum.de

### PP1

### An Impulse Control Approach For Dike Height Optimization

This paper determines the optimal timing as well as the optimal level of dike updates to protect against floods. The trade off is that a dike update (i.e. a dike height increase) is costly, but at the same time such an update reduces the probability of a flood. In this paper we present the Impulse Control approach as an alternative method to the Dynamic Programming approach used in Eijgenraam et al. (2010).

Mohammed Chahim
Dept. of Econometrics & Operations Research, CentER
Tilburg University
m.chahim@tilburguniversity.edu

Ruud Brekelmans, Dick den Hertog
Dept. of Econometrics & Operations Research, CentER,
Tilburg University
r.c.m.brekelmans@tilburguniversity.edu,
d.denhertog@tilburguniversity.edu

Peter Kort
Dept. of Econometrics & Operations Research, CentER,
Tilburg
University and Dept. of Economics, University of
Antwerp
kort@tilburguniversity.edu

### PP1

### A New Test-Scenario for Optimization-Based Analysis and Training of Human Decision Making

For computer-based test-scenarios in the domain of complex problem solving, the computation of optimal solutions yields an objective indicator function of participants' performance. However, when these scenarios have been designed, one did not even think of applying mathematical optimization one day, which results in various problems. We present a new model with desirable properties for optimization, which is also capable of extensions to optimization-based feedback and the inclusion of parameter estimation, and optimal solutions therefor.

Michael Engelhart
Heidelberg University
Interdisciplinary Center for Scientific Computing (IWR)
michael.engelhart@iwr.uni-heidelberg.de

Sebastian Sager
Interdisciplinary Center for Scientific Computing
sebastian.sager@iwr.uni-heidelberg.de

Joachim Funke
Heidelberg University
Department of Psychology
joachim.funke@psychologie.uni-heidelberg.de

### PP1

### Solving Classification Problems by Approximate Minimal Enclosing Ball Algorithms

Constructing classification models is, under certain hypotheses, equivalent to the solution of a Minimal Enclosing Ball (MEB) problem. Both tasks require the solution of quadratic programming problems, which in many applications are large and not sparse. We analyze classical Support Vector Machine (SVM) methods and new algorithms that, exploiting the concept of *$\epsilon$-coreset* to compute approximate MEBs, can be fruitfully applied in the classification framework. Experimental results on several benchmark datasets are reported.

Emanuele Frandi
Università degli Studi dell'Insubria
Italy
emanuele.frandi@gmail.com

Maria Grazia Gasparo
Università degli Studi di Firenze
Italy
mariagrazia.gasparo@unifi.it

Ricardo Ñanculef
Federico Santa Maria Technical University
Chile
jnancu@inf.utfsm.cl

Alessandra Papini
Università degli Studi di Firenze
Italy
alessandra.papini@unifi.it

### PP1

### Efficient Simulation and Parameter Estimation for a Biologically Inspired Bipedal Robot

A multi-body systems dynamics model for a bipedal robot whose legs are actuated by eight series-elastic structures approximating the main human leg muscle groups is developed allowing automated differentiation with respect to model parameters. Based on the dynamics model a tailored direct multiple shooting approach is applied for estimation of unknown parameters based on measurements from well defined independent experiments of the real robot.

Christian Reinl, Martin Friedmann, Dorian Scholz
Technische Universität Darmstadt
reinl@sim.tu-darmstadt.de,
friedmann@sim.tu-darmstadt.de,
scholz@sim.tu-darmstadt.de

Oskar Von Stryk
Department of Computer Science
Technische Universität Darmstadt
stryk@sim.tu-darmstadt.de

### PP1

### Robust Optimization Problems with Sums of Maxima of Linear Functions

The sum of maxima of linear functions plays an important role in LP models for inventory management, supply chain management, regression models, tumour treatment, and many other practical problems. In the literature, often the wrong robust counterpart is used. We present new methods for dealing with the correct robust counterpart:

$$\sum_{i \in I} \max_{j \in J} \{\ell_{i,j}(\zeta, x)\} \leq d \qquad \forall \zeta \in \mathcal{Z},$$

where $\ell_{i,j}$ is a bi-affine function. We apply our methods to toy and practical problems, and indeed find that oftenly used methods lead to inferior solutions.

Bram Gorissen, Dick Hertog
Tilburg University
Tilburg, The Netherlands
b.l.gorissen@uvt.nl, d.denhertog@uvt.nl

### PP1

### Geometry Optimization of Branched Sheet Metal Products

We consider the geometry optimization of hydroformed branched sheet metal products which are produced using the technology of linear flow splitting explored in the Collaborative Research Center 666. We present the associated problem for optimizing the stiffness of the structure with 3D linear elasticity equations as constraints. Then an algorithm for solving this problem using exact constraints and a globalization strategy based on adaptive cubic regularization is presented. Numerical results for an example are given.

Thea Göllner, Wolfgang Hess, Stefan Ulbrich
TU Darmstadt
goellner@opt.tu-darmstadt.de,
whess@opt.tu-darmstadt.de, ulbrich@opt.tu-darmstadt.de

### PP1

### On Some Strange Properties in Rank Minimization Problems

Consider a rank minimization problem:

$$(\mathcal{P}) \left\{ \begin{array}{l} \text{Minimize } f(A) := \text{ rank of } A \\ \text{subject to } A \in \mathcal{C}, \end{array} \right.$$

where $\mathcal{C}$ is a subset of $\mathcal{M}_{\Updownarrow,\setminus}(\mathbf{R})$.
We state some strange results for problem $(\mathcal{P})$.

- Every admissible point in $(\mathcal{P})$ is a local minimizer.
- The Moreau-Yosida regularized form and the proximal mapping associated with the rank function can be explicitly calculated.
- *For* $k \in \{0, 1, \dots, p\}$ *and* $r \geq 0$, *let*

  $$S_k^r := \{M \in \mathcal{M}_{\Updownarrow,\setminus}(\mathbf{R}) | \quad \textit{rank } \mathcal{M} \leq \nabla \textit{ and } \|\mathcal{M}\|_{\int_{\surd}} \leq \nabla\}.$$

  *Then*

  $$\textit{co } S_k^r = \{M \in \mathcal{M}_{\Updownarrow,\setminus}(\mathbf{R}) | \quad \|\mathcal{M}\|_{\int_{\surd}} \leq \nabla \textit{ and } \|\mathcal{M}\|_* \leq \nabla\|\}.$$

- The generalized subdifferentials of the rank function all coincide and the common value is a vector space of $\mathcal{M}_{\Updownarrow,\setminus}(\mathbf{R})$

Le Hai Yen
Ph.D Student
yenlhp@gmail.com

Jean-Baptiste Hiriart-Urruty
University of Toulouse
France
jbhu@cict.fr

### PP1

### Selection of Securitization Baskets with Consideration of Conditional Value-at-Risk and Expected Returns

Financial institutes use structured products for transferring risk (Conditional Value-at-Risk) arising from loan baskets. Arranging the basket for such transactions is a complex task often done with naive heuristics being far from optimal. The presented approach is based on MINLPs with various risk-return objectives. We compare different formulations which we transform into MILPs according to Rockafellar and Uryasev. We give numerical examples using a Merton's type portfolio model and Monte-Carlo simulation with Glasserman's Importance Sampling.

Matthias Heidrich
Technische Universit
Fachbereich Mathematik
heidrich@mathematik.tu-darmstadt.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

### PP1

### Sensitivity Analysis and Parameter Estimation Methods for Models of Complex Biological Processes

Mathematical models of complex biological processes require numerical methods for quantitative analysis, where sensitivity analysis and parameter estimation play a crucial role. Especially interesting is reverse sensitivity analysis which allow to determine which model data have what influence on a selected model output and thus to identify model structures.
We present sensitivity analysis and parameter estimation methods for models of reaction-diffusion equations. The methods are successfully applied in modelling of Min-system oscillations in Escherichia coli.

Alexandra G. Herzog

Dep. of Mathematics and Computer Science, Univ. of Marburg
Alexandra.Herzog@synmikro.uni-marburg.de

Jens Herwig, Tanja Binder, Max Nattermann
Dep. of Mathematics and Computer Science,
University of Marburg
herwigj@students.uni-marburg.de,
binder@mathematik.uni-marburg.de,
natterma@mathematik.uni-marburg.de

Ekaterina Kostina
Fachbereich Mathematik und Informatik
Philipps-Universitaet Marburg
kostina@mathematik.uni-marburg.de

**PP1**

### Alternating-Direction Optimization with Massively Parallel Trust-Regions for Partially Separable Non-Linear Objectives

Large inverse problems consisting of a separable fidelity term and non-separable regularization term(s) can be addressed through the ADMM method. Recent methods (like Chambolles) can address the regularization term. The fidelity minimization then becomes a large number (sometimes millions) of low-dimensional independent sub-problems. For vector-valued data, these sub-problems may themselves be multi-dimensional. When highly nonlinear, these can be solved in lock-step parallel using damped trust regions, which are particularly well suited for GPU implementation.

Kevin M. Holt
Varian Medical Systems
kevin.holt@varian.com

**PP1**

### Numerical Solution of a Conspicuous Consumption Model with Constant Control Delay

We derive optimal pricing strategies for conspicuous consumption products in recession periods. We investigate a two-stage economic optimal control problem, including uncertainty of the recession length and delay effects of the pricing strategy. We propose a structure-exploiting direct method for optimal control, targeting uncertainties by scenario trees and control delays by slack control functions. Numerical results illustrate the validity of our approach and show the impact of uncertainties and delay effects on optimal economic strategies.

Tony Huschto
Interdisciplinary Center for Scientific Computing,
Heidelberg University
tony.huschto@iwr.uni-heidelberg.de

Gustav Feichtinger
Institute for Mathematical Methods in Economics
Vienna University of Technology
gustav@eos.tuwien.ac.at

Richard Hartl
Department of Business Administration
University of Vienna
richard.hartl@univie.ac.at

Peter Kort
Department of Econometrics & Operations Research and CentER
Tilburg University
kort@uvt.nl

Sebastian Sager
Interdisciplinary Center for Scientific Computing
sebastian.sager@iwr.uni-heidelberg.de

Andrea Seidl
Institute for Mathematical Methods in Economics
Vienna University of Technology
aseidl@eos.tuwien.ac.at

**PP1**

### Coupling Edges in Graph Cuts

We study a new graph cut problem, cooperative cut, where the cost is a submodular function on sets of edges. The resulting coupling of edges allows novel applications, e.g., improving image segmentation by favoring congruous boundaries. It also generalizes some recent models in computer vision. Such expressive power comes at the price of a lower bound on the approximation factor. However, we also show how to find good solutions with bounded approximation factors.

Stefanie Jegelka
Max Planck for Biological Cybernetics
stefanie.jegelka@tuebingen.mpg.de

Jeff Bilmes
University of Washington
bilmes@u.washington.edu

**PP1**

### The Integral Approximation Problem for Mixed-Integer Nonlinear Optimal Control

We propose a decomposition approach for Mixed Integer Nonlinear Optimal Control Problems (MIOCPs). The MIOCP is decomposed into a relaxed continuous one and a MILP to find values for integer control functions. We discuss the connection of optimal solutions to sum up rounding solutions, tailored Branch-and-Bound algorithms and Lagrangian relaxations. We provide an upper bound on the distance between the optimal MIOCP objective and the one found by our computationally efficient decomposition approach.

Michael Jung
IWR Heidelberg
michael.jung@iwr.uni-heidelberg.de

Sebastian Sager
Interdisciplinary Center for Scientific Computing
sebastian.sager@iwr.uni-heidelberg.de

Gerhard Reinelt
IWR, University of Heidelberg
gerhard.reinelt@iwr.uni-heidelberg.de

**PP1**

### Decentralized Model-Predictive Control for Autonomous Vehicles in Cooperative Missions

For a scenario from environmental monitoring, a decentral-

ized approach for optimal cooperative control of heterogeneous multi-vehicle systems is investigated. It is demonstrated that using approximated motion dynamics and a model-predictive control method based on MILP, optimal control inputs can be computed in real-time. By employing an adaptive sampling strategy, the hybrid control problem is linked to an identification problem for the estimation and prediction of a dispersal process of airborne contaminants.

Juliane Kuhn
Simulation, Systems Optimization, and Robotics Group
Department of Computer Science, TU Darmstadt
kuhn@sim.tu-darmstadt.de

Oskar Von Stryk
Department of Computer Science
Technische Universität Darmstadt
stryk@sim.tu-darmstadt.de

### PP1

### Optimal Deceleration of Rotation of a Symmetric Body with Internal Degrees of Freedom in a Resistive Medium

The problem of time-optimal deceleration of rotation of dynamically symmetric body is studied. It is assumed that the body contains a cavity filled with viscous liquid and a mass connected to the body by coupling with square-low dissipation. Deceleration moment of viscous friction forces acts on the body. The optimal control law for deceleration of rotation in the form of synthesis, the operation time and the phase trajectories are determined.

Dmytro D. Leshchenko
Odessa State Academy of Civil Engineering and Architecture
leshchenko_d@ukr.net

Leonid D. Akulenko
Institute for Problems in Mechanics RAS
kumak@ipmnet.ru

Yanina S. Zinkevich, Alla L. Rachinskaya
Odessa State Academy of Civil Engineering and Architecture
yaninaz@mail.ru, rachinskaya@onu.edu.ua

### PP1

### Low Multilinear Rank Tensor Decomposition Via Singular Value Thresholding

We present a new numerical method for tensor dimensionality reduction. The method is based on the tensor trace class norm which allows an optimization formulation for each tensor mode for finding the best low multilinear rank tensor approximation. By using singular value thresholding (SVT) technique, the method is implemented iteratively to obtain low rank factor in each mode. Some numerical examples illustrate the efficiency and accuracy of our method.

Na Li
Clarkson University
Dept. of Mathematics
nali@clarkson.edu

Carmeliza Navasca
Clarkson University
cnavasca@clarkson.edu

### PP1

### Graph Partitioning and Applications

Applications of graph partitioning problems abound in different areas,among them in theoretical physics and in VLSI layout. In this poster, we introduce exact approaches for solving graph partitioning problems together with results for the applications.

Frauke Liers
Institut für Informatik
Universität zu Köln
liers@informatik.uni-koeln.de

### PP1

### A Fréchet Differentiability Result for Shape Optimization with Instationary Navier-Stokes Flow

We consider shape optimization problems where an object is exposed to instationary Navier-Stokes flow. Assuming the data are sufficiently smooth we show Fréchet differentiability of the velocity with respect to $W^{2,\infty}$ domain variations in 2D/3D. Here, the handling of the incompressibility condition and the low time regularity of the pressure play a crucial role in the analysis. Furthermore, we present numerical results using an adjoint-based approach for calculating the shape derivatives.

Florian Lindemann
Technische Universitaet Muenchen
Germany
lindemann@ma.tum.de

Michael Ulbrich
Technical University of Munich
Chair of Mathematical Optimization
mulbrich@ma.tum.de

Stefan Ulbrich
Technische Universitaet Darmstadt
Fachbereich Mathematik
ulbrich@mathematik.tu-darmstadt.de

Christian Brandenburg
TU Darmstadt
Germany
brandenburg@mathematik.tu-darmstadt.de

### PP1

### Recursive Formulation of Limited Memory Variable Metric Methods

We propose a new recursive matrix formulation of limited memory variable metric methods. This approach enables to approximate both the Hessian matrix and its inverse and can be used for an arbitrary update from the Broyden class. The new recursive formulation requires approximately $4mn$ multiplications and additions for the direction determination.

Ladislav Luksan, Jan Vlcek
Institute of Computer Science
Academy of Sciences of the Czech Republic
luksan@cs.cas.cz, vlcek@cs.cas.cz

### PP1

### Recursive Formulation of Limited Memory Vari-

**able Metric Methods**

In this contribution, we propose a new recursive matrix formulation of limited memory variable metric methods. This approach can be used for an arbitrary update from the Broyden class (and some other updates) and also for the approximation of both the Hessian matrix and its inverse. The new recursive formulation requires approximately $4mn$ multiplications and additions per iteration, so it is comparable with other efficient limited memory variable metric methods. Numerical experiments concerning Algorithm 1, proposed in this report, confirm its practical efficiency.

Ladislav Luksan, Jan Vlcek
Institute of Computer Science
Academy of Sciences of the Czech Republic
luksan@cs.cas.cz, vlcek@cs.cas.cz

## PP1

### The Use of Influenza Vaccination Strategies When Supply Is Limited

The 2009 A (H1N1) influenza pandemic was rather atypical. The world's limited capacity to produce an adequate vaccine supply over just a few months resulted in the development of public health policies that "had" to optimize the utilization of limited vaccine supplies. We use optimal control theory to explore the impact of some of the constraints faced by most nations in implementing a public health policy that tried to meet the challenges that come from having access only to a limited vaccine supply that is never 100% effective.

Romarie Morales
Arizona State University
romarie.morales@asu.edu

Sunmi Lee
Mathematical, Computational and Modeling Sciences Center,
Arizona State University,
mathever@gmail.com

Carlos Castillo Chavez
Arizona State University
ccchavez@asu.edu

## PP1

### Dynamic Modeling and Optimal Control for Industrial Robots in Milling Applications

The application of industrial robots for milling tasks results in high process forces at the end effector which lead to path deviations caused by joint elasticities. A coupled simulation model of robot dynamics and its interaction with the milling process is based on an extended rigid multi-body description incorporating joint elasticities and tilting effects. The implementation of automatic differentiation enables computation of compensation trajectories by direct optimal control methods.

Christian Reinl, Martin Friedmann, Elmar Brendel
Technische Universität Darmstadt
reinl@sim.tu-darmstadt.de,
friedmann@sim.tu-darmstadt.de,
elmar.brendel@googlemail.com

Oskar Von Stryk
Department of Computer Science
Technische Universität Darmstadt
stryk@sim.tu-darmstadt.de

## PP1

### A Randomized Coordinate Descent Method for Large-Scale Truss Topology Design

We develop a randomized coordinate descent method for minimizing the sum of a smooth and a simple nonsmooth separable convex function and prove that the method obtains an $\epsilon$-accurate solution with probability at least $1 - \rho$ in at most $O((n/\epsilon)\log(n/\epsilon\rho))$ iterations, where $n$ is the dimension of the problem. This simplifies, improves and extends recent results of Nesterov [2/2010]. It appears that the method is suitable for solving large-scale truss topology design problems.

Peter Richtarik, Martin Takac
University of Edinburgh
peter.richtarik@ed.ac.uk, m.takac@sms.ed.ac.uk

## PP1

### Piecewise Monotonic Regression Algorithm for Problems Comprising Seasonal and Monotonic Trends

In this research piecewise monotonic models for problems comprising seasonal cycles and monotonic trends are considered. In contrast to the conventional piecewise monotonic regression algorithms, our approach can efficiently exploit a priori information about temporal patterns. It is based on reducing these problems to monotonic regression problems defined on partially ordered data sets. The latter are large-scale convex quadratic programming problems. They are efficiently solved by the GPAV algorithm.

Amirhossein Sadoghi
Department of Computer Science
Linköping University
amisa242@student.liu.se

Oleg Burdakov
Linkoping University
olbur@mai.liu.se

Anders Grimvall
Department of Computer Science
Linköping University,Sweden
anders.grimvall@liu.se

## PP1

### An Infeasible-Point Subgradient Method Using Approximate Projections

We introduce a subgradient algorithm which applies inexact projections and thus is not required to maintain feasibility of the iterates throughout the algorithmic progress. We prove its convergence under reasonable conditions, investigating two classical step size schemes. We also present computational results from an application to $\ell_1$-minimization (Basis Pursuit) as commonly considered in compressed sensing. Here, projection inaccuracies are caused by a truncated CG method which is applied to solve the projection subproblems.

Andreas M. Tillmann
Technische Universität Braunschweig

a.tillmann@tu-bs.de

Dirk Lorenz, Marc Pfetsch
TU Braunschweig
d.lorenz@tu-bs.de, m.pfetsch@tu-bs.de

**PP1**
**Robust Markov Decision Processes**

Markov decision processes (MDPs) are powerful tools for decision making in uncertain dynamic environments. However, the solutions of MDPs are of limited practical use due to their sensitivity to distributional model parameters, which are typically unknown and have to be estimated by the decision maker. To counter the detrimental effects of estimation errors, we consider robust MDPs that offer probabilistic guarantees in view of the unknown parameters. To this end, we assume that an observation history of the MDP is available. Based on this history, we derive a confidence region that contains the unknown parameters with a pre-specified probability $1-\beta$. Afterwards, we determine a policy that attains the highest worst-case performance over this confidence region. By construction, this policy achieves or exceeds its worst-case performance with a confidence of at least $1-\beta$. Our method involves the solution of tractable conic programs of moderate size.

Wolfram Wiesemann
Department of Computing
Imperial College London
wwiesema@imperial.ac.uk

Daniel Kuhn, Berc Rustem
Imperial College London
dkuhn@imperial.ac.uk, br@imperial.ac.uk

**PP1**
**Robust Optimization Using Historical Data**

We provide a robust solution approach for linear optimization problems with uncertain parameters. Only historical data on the uncertain parameters is used in order to construct the uncertainty set. The aim is to find the tightest uncertainty set such that the constraints of the problem are satisfied with at least a given probability. This approach yields tighter uncertainty regions than the standard approach, and moreover does not require independency of the uncertain parameters.

Ihsan Yanikoglu
Department of Econometrics and OR,
Tilburg University
i.yanikoglu@uvt.nl

Dick den Hertog
University of Tilburg
The Netherlands
d.denhertog@uvt.nl

Goos Kant
Tilburg University
goos.kant@ortec.com