Welcome – Komdu sæl !

We are pleased to welcome you to the

> *5th EUROPT Workshop on Advances in Continuous Optimization*,
> Reykjavik, Iceland, June 30 and July 1, 2006.

The workshop aims to bring together researchers from continuous optimization and from related fields of discrete optimization, operations research, economy and technology. With 6 Invited Lectures, 33 Contributed Lectures and about 80 participants from 23 countries, it intends to be a forum for the exchange of recent scientific developments and for the discussion of new trends. The scope of the conference includes all aspects of smooth, nonsmooth and discrete optimization from fundamental research to numerical methods and applications.

The present workshop continues the line of the EUROPT conferences held 2000 in Budapest, 2001 in Rotterdam, 2003 in Istanbul, and 2004 in Rhodes. The hospitality of our friends and colleagues from the University of Iceland allows us to continue our series of special EUROPT events in a fascinating ambience of Nordic nature and culture. We workshop organizers are very grateful for the close and fruitful collaboration in preparation which we had with the University of Iceland as well as with the organizers of the conference *EURO XXI 2006*. With the EURO conference we are sharing, in particular, a special interest in *Applications in the Energy Sector*.

For making this annual meeting possible at all, we are giving special thanks to our sponsors: *MathFinance AG, Maximal Software, INC, Pinter Consulting Services, TOBB ETÜ, University of Iceland, EURO* and *EUROPT*.

Last, but not least, we would like to express our thanks to our friend *Alexander Rubinov* from the University of Ballarat, Australia. The strong collaboration between EUROPT and the Pacific Optimization Research Activity Group (POP) is closely related with his name. Dear Alex, we wish you all the best for your health!

On behalf of the organizing committee, we thank you for joining the workshop, and we wish you an enjoyable and successful time.

Pall Jensson, Oliver Stein, Georg Still, Aysun Tezel and Gerhard-Wilhelm Weber.

Contents

General Information

Location: The Workshop is held in the building ”Askia” on the Campus of the University of Iceland, Reykjavik.

Registration fees: 90 Euro (to be payed at the registration desk).
All paying participants will get a receipt at the registration desk.

Web-Page of the Workshop: http://wwwhome.math.utwente.nl/∼stillgj/COPT06/

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Invited Speakers

- Adil Bagirov *(University of Ballarat, Australia)*
- Gianni Di Pillo *(Universita di Roma "La Sapienza", Italy)*
- Petra Huhn *(University of Clausthal , Germany)*
- Klaus Schittkowski *(University of Bayreuth, Germany)*
- Marc Teboulle *(Tel-Aviv University, Israel)*
- Henry Wolkowicz *(University of Waterloo, Canada)*

Abstracts of the Presentations

Solving inconsistencys preserving the zero-structure

Paula Amaral, Joaquim Júdice and Hanif Sherali,
University of Coimbra

In this talk we describe an nonlinear optimization model for correcting an inconsistent linear system. By correction we mean a perturbation of both the matrix of coefficients and right-hand-side of the linear system of inequalities. Inconsistency of a linear model arises in many practical applications. Two global optimization approaches for solving this non-convex nonlinear problem are presented. One algorithm uses a linearization approach while the second algorithm exploits Reformulation-Linearization techniques (RLT).

E-mail: *paca@fct.unl.pt* , *Joaquim.Judice@co.it.pt*

A Semidefinite Optimization Approach for Single Row Layout Problems

Miguel F. Anjos, *University of Waterloo*

The row layout problem is concerned with finding optimal linear placements of facilities with varying dimensions. This problem occurs in a number of industrial contexts, such as the layout of goods in a warehouse and the layout of machines on a factory floor. It is closely related to the linear ordering problem, which also has a number of practical applications. Most versions of this problem are known to be NP-hard, and previous globally optimal approaches are ineffective on problems with 20 or more facilities.

We propose a semidefinite programming formulation which provides the first non-trivial global lower bounds for large instances of this problem. The formulation captures the natural symmetry of the problem and does not require symmetry-breaking constraints. Furthermore, applying simple heuristic procedures to the optimal matrix solution yields feasible layouts which are consistently within a few percentage points of the global optimal solution.

This is joint work with Anthony Vannelli (University of Waterloo).

E-mail: *anjos@cheetah.vlsi.uwaterloo.ca*

A New Application of An Uncapacitated Network Flow Problem Using State-Space Approach with Quadratic Penalty Method

Ömer Akin, Necati Ozdemir and Firat Evirgen ,
TOBB Economics and Technology University, Balikesir University

In this work a minimum cost network flow problem with *m* nodes and *n* arcs, which is equivalent to the uncapacitated transportation problem is reformulated as a dynamical system with quadratic penalty method and state space model. By using quadratic penalty method, the minimum cost network flow problem is transformed to quadratic unconstrained problem. Then it can be hold for state space equation. This compose a multiple input multiple output (MIMO) linear state space model with linear state equations

$$\dot{\mathbf{x}}(t) = \mathbf{Ax}(\mathbf{t}) + \mathbf{Bu}(\mathbf{t})$$

and the linear output equations

$$\mathbf{y}(t) = \mathbf{Cx}(\mathbf{t}) + \mathbf{Du}(\mathbf{t})$$

where $x(t) \in IR^n$, $u(t) \in IR^r$, the **A**, **B**, **C** and **D** are appropriately dimension real constant matrix. Using the above equations it can be define transfer function as;

$$\mathbf{G}(\mathbf{s}) = \mathbf{C}(s\mathbf{I} - \mathbf{A})^{-1}\mathbf{B} + \mathbf{D}.$$

The idea of transfer function is desirable to find the optimal solution of the problem. To achieve this, the all eigenvalues of matrix A, which is used in the system, should be left half plane.

The organization of this paper is as follows. We start in Section 2 with problem and preliminaries. We give formulation of our problem and some basic definitions and theorems about minimum cost network flow problem, penalty method and state space modeling. In Section 3, it is presented a solution technique for network flow problem and given an example. Finally, Section 4 describes the conclusion of this paper.

Key Words: Global optimization, State space model, Network flow, Constrained optimization, Quadratic penalty method.

E-mail: *omerakin@etu.edu.tr* , *nozdemir@balikesir.edu.tr* , *fevirgen@balikesir.edu.tr*

Derivative-free algorithms in nonsmooth optimization and their applications

Adil Bagirov, *University of Ballarat*

Problems of nonsmooth optimization appear in many applications and in particular in data mining. Over more than four decades different methods have been developed to solve such problems. Most of these methods are subgradient-based. However, there are many practical problems where the computation of even one subgradient is a difficult task. Therefore in such situations derivative free methods seem to be better choice since they do not use explicit computation of subgradients.

Among derivative free methods, the generalized pattern search methods can be applied to solve nonsmooth optimization problems. However their convergence are proved under quite restrictive differentiability assumptions which are not satisfied in many situations.

In this talk we present new derivative free algorithms for nonsmooth optimization. These algorithms are based on the notion of a discrete gradient. Discrete gradients can be applied to approximate subgradients of a broad class of non-regular functions. We demonstrate that the new algorithms have better convergence properties than other derivative free algorithms.

The modification of the proposed algorithms for solving large scale nonsmooth optimization problems are also discussed. These modifications exploit the special structure of large scale problems such as the piecewise partial separability.

We consider the application of these algorithms in global optimization as well as their application in supervised and unsupervised data classification.

The preliminary results of numerical experiments and the comparison of the proposed algorithms with other nonsmooth and derivative free optimization solvers are presented.

E-mail: *a.bagirov@ballarat.edu.au*

Application of stochastic approximation to nondifferentiable optimization

Vaida Bartkute, *University of Vilnius*

Development of stochastic algorithms to nondifferentiable optimization is of particular theoretical and practical interest. We consider problems related to implementation of stochastic approximation (SA) for optimization of Lipschitz functions, namely, estimation of a stochastic gradient, improvement of convergence, stopping criterion of the algorithm, etc.

Several SA methods (Simultaneous Perturbation Stochastic Approximation (SPSA) with Lipschitz perturbation operator, SPSA with Uniform perturbation operator and Standard Finite Difference Approximation method) are compared and the rate of convergence is established $O(\frac{1}{k^\gamma})$, where $1 \leq \gamma < 2$, if the objective function is computed without error, and $0.5 \leq \gamma < 1$, if the objective function is measured with additive stochastic error. We present the results of computer simulation by Monte-Carlo method that has shown that the empirical estimates of the rate of convergence corroborate the theoretical estimation of the convergence order.

The accuracy of solution and the termination of the algorithm are considered in a statistical way. We build a method for estimating a confidence interval of the objective function extremum and terminating of the algorithm according to order statistics of objective function values provided during optimization. Several illustrative examples of application of the considered approach to real life problems are given, too.

E-mail: *vaidaba@one.lt*

Quadratic Matrix Programming

Amir Beck, *Israel Institute of Technology*

We consider nonconvex quadratic optimization problems of the form

$$\begin{array}{ll} \min & \mathrm{Tr}(X^T A_0 X) + 2\mathrm{Tr}(B_0^T X) + c_0 \\ \text{s.t.} & \mathrm{Tr}(X^T A_i X) + 2\mathrm{Tr}(B_i^T X) + c_i \leq \alpha_i,\ i \in I \\ & \mathrm{Tr}(X^T A_j X) + 2\mathrm{Tr}(B_j^T X) + c_j = \alpha_j,\ j \in \mathcal{E}, \\ & X \in \mathbb{R}^{n \times r}, \end{array} \tag{1}$$

with $A_i = A_i^T \in \mathbb{R}^{n\times n}$, $B_i \in \mathbb{R}^{n\times r}$, $\alpha_i, c_i \in \mathbb{R}$, $i \in \{0\} \cup I \cup \mathcal{E}$. Problems of the above type are called *quadratic matrix programming* (QMP) problems of order r; they naturally arise in several applications such as robust least squares and in problems involving orthogonal constraints such as the orthogonal procrustes problem. QMP problems can be considered as a special class of quadratically constrained quadratic programming (QCQP) problems. However, it is worthwhile to study these problems independently since, as we will show, they enjoy stronger results than those currently known for general nonconvex QCQP problems.

We construct a semidefinite relaxation (SDR) and dual for the QMP problem originating from a homogenization procedure specially devised to QMP problems. Using the SDR formulation combined with results on the existence of low-rank solutions of semidefinite programs we are able to show that strong duality holds for QMP problems of order r with at most r constraints. The latter result is an extension of the well known strong duality result for nonconvex quadratic problems with a single quadratic constraint.

Finally, an alternative construction of SDR and dual is considered. This construction stems from the standard construction of SDR and dual for general QCQP problems. Using a result on the equivalence of two LMI representations of the claim on nonnegativity of a quadratic matrix function, we are able to prove that the two SDR and dual formulations are equivalent. An application of our results in the field of robust optimization will be discussed.

E-mail: *becka@tx.technion.ac.il*

Traversing non-convex regions

<u>Salah Beddiaf</u>, S.J. Kane and M.C. Bartholomew-Biggs,
University of Hertfordshire

This paper is concerned with minimizing a function $F(x)$ by methods based on following the continuous steepest descent path defined by

$$\frac{dx}{dt} = -\nabla F(x) \ \text{ where } \ x = x_k \ \text{ when } \ t = 0. \qquad (1)$$

This approach provides a logical choice of search path away from points in regions where $F(x)$ is non-convex (and it is well-known that there is a strong connection between trust-region methods and the solution to (1) obtained by using the Implicit Euler method).

Such ODE-based methods for optimization have been proposed before – see for instance [1] - [3]; but the present paper considers some variations on the use of search directions involving

$$(I + \delta t G_k) p_k = -\delta t g_k. \qquad (2)$$

where G_k is the Hessian $\nabla 2F(x_k)$ *or some approximation to it.* As δt is varied in (2) the step away from the current point x_k traces out a curvilinear path. Solution of (2) for various trial values of δt can be done very easily if we pay the additional computational cost of doing an eigen-analysis of G_k.

The paper discusses some issues arising in the implementation of a minimization algorithm based on the above ideas. In particular we consider the efficient realization of a curvilinear search. We also present some encouraging numerical results form an algorithm which uses a simple diagonal approximation to G_k to avoid the computational overhead of an eigen-analysis on every iteration.

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E-mail: *S.Beddiaf@herts.ac.uk*

No Gap Second order Optimality Conditions for Optimal Control Problems with a single State Constraint and Control

J. Frédéric Bonnans and Audrey Hermant, *INRIA-Rocquencourt*

Considerable efforts have been done in the past for reducing the gap between second-order necessary or sufficient optimality conditions optimization problems in Banach spaces, with so-called cone constraint (i.e. the constraint mapping must be in a convex cone, or more generally in a convex set). This framework includes many optimal control problems. The theory of second-order necessary optimality conditions involves a term taking into account the curvature of the convex set. By contrast, second-order sufficient optimality conditions typically involve no such term. We say that a no-gap condition holds, when the only change between necessary or sufficient second-order optimality conditions is between a strict and non strict inequality. In that case it is usually possible to obtain a characterization of the second-order growth condition. There are essentially two cases when no-gap were obtained: (i) the polyedric framework, in the case when the Hessian of Lagrangian is a Legendre form, and the extended polyhedricity framework; this framework essentially covers the case of control constraints (and finitely many integral of final state constraints); and (ii) the second-order regularity framework, related to semi definite optimization. We refer to [2] for an overview of these theories.

Generally speaking, problems with nonpositivity constraints in spaces of continuous functions do not fit into these frameworks. However, only sufficient condition without curvature terms are known. Some necessary or sufficient second order optimality conditions for state constrained optimal control problem are known, but there is clearly a gap between them.

Our main result is the following. By a localization argument, we split the curvature terms into a finite number of contributions of boundary arcs and touching points. For the latter we use a reduction argument. The only delicate point is to compute the expansion of the minimum value of a function in $W^{2,\infty}$. Our main result, however, in about boundary arcs. Using the theory of junction conditions in Maurer [3], we are able to prove that, under quite weak assumptions, the contribution of boundary arcs to the curvature term is zero. Since it is not difficult to state sufficient conditions taking into account reductible touching points, we obtain in this way no-gap conditions, that in addition characterize quadratic growth in a convenient two-norms setting.

We will also indicate some consequences of this result for the perturbation analysis and the well-posedness of the shooting algorithm. The results will be published in [1].

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E-mail: *Frederic.Bonnans@inria.fr, audrey.hermant@inria.fr*

Abstract Convexity and Augmented Lagrangians

Regina Sandra Burachik and Alex Rubinov
University of South Australia, University of Ballarat

The ultimate goal of this paper is to demonstrate that abstract convexity provides a natural language and a suitable framework for the examination of zero duality gap properties and exact multipliers of augmented Lagrangians. We study augmented Lagrangians in a very general setting and show that the main definitions and facts describing the augmented Lagrangian theory can be formulated and examined in terms of abstract convexity tools.

Key words: abstract convexity; nonconvex programming; Lagrange-type functions; augmented Lagrangians.

E-mail: *Regina.Burachik@unisa.edu.au*

How Curvy is the Central Path?

Antoine Deza, Tamas Terlaky and Yuriy Zinchenko, *McMaster University*

The central path of linear optimization problems is an intrinsic analytic object and is of key interest from the algorithmic standpoint. To a large extent, its geometric properties determine the efficiency of the so-called path-following interior-point methods in practice. We investigate linear optimization problems with a large central path curvature. In particular, we consider an n-dimensional problem defined by an exponential number m of inequalities. The total curvature of the central path for this construction is at least of order $\sqrt{m}$, and, therefore, provides a counterexample to the conjecture that the order of the worst-case curvature of the central path is n.

E-mail: *deza@mcmaster.ca, terlaky@mcmaster.ca*

A primal-dual algorithm exploiting negative curvature directions

Gianni Di Pillo, Giampolo Liuzzi and Stefano Lucidi,
Università di Roma "La Sapienza"

In this paper we propose a primal-dual algorithm for the solution of inequality constrained optimization problems. The distinguishing feature of the proposed algorithm is that of exploiting as much as possible the local nonconvexity of the problem. In the unconstrained case this task is accomplished by computing a suitable negative curvature direction of the objective function. In the constrained case it is possible to gain analogous information either by exploiting the nonconvexity of a particular exact merit function or by taking into account the nonconvexity of the lagrangian function onto the null space of the gradients of the estimated active constraints.

The algorithm hinges on the idea of comparing, at every iteration, the relative effects of two directions and then selecting the more promising one. The first direction conveys first order information on the problem and can be used to define a sequence of points converging toward a stationary point. Whereas, the second

direction conveys information on the local nonconvexity of the problem and can be used to drive the algorithm away from nonconvexity regions. We propose a proper selection rule for these two directions which, under suitable assumptions, is able to define a sequence of points that is globally convergent to second order stationary points.

Keywords: nonlinear programming, primal-dual algorithm, augmented Lagrangian function, 2nd order stationary points, negative curvature direction.

E-mail: *dipillo@dis.uniroma1.it, liuzzi@dis.uniroma1.it, lucidi@dis.uniroma1.it*

Regularization of non-monotone multivalued variational inequalities

Elisabetta Allevi, Adriana Gnudi and I.V. Konnov,
Brescia University, Bergamo University and Kazan University

Many equilibrium problems arising in Mathematical Physics, Economics, Operations Research and other fields possess a partitionable structure which enable one to essentially weaken the conditions for existence and uniqueness results of solutions and for convergence of solution methods. Usually, such results are based on order monotonicity type assumptions, however, they are restricted with the case where subspaces are one-dimensional.

In this work we consider multi-valued variational inequalities defined on a Cartesian product of finite-dimensional subspaces. We introduce extensions of order monotonicity concepts for set-valued mappings, which are adjusted to the case where the subspaces need not be real lines. These concepts enable us to establish new existence and uniqueness results for the corresponding partitionablemulti-valued variational inequalities. We present a general coercivity condition which ensures both existence of solutions and convergence of the Tikhonov-Browder regularization method without any monotonicity properties. Moreover, the solution set of the problem under consideration may be unbounded. Applying this approach to partitionable variational inequalities we also establish uniqueness of solutions of perturbed problems. An example of applications to a class of imperfectly competitive economic equilibrium models is also given.

E-mail: *allevi@eco.unibs.it, adri@unibg.it*

Stability of the relative position of two sets

Miguel A. Goberna, M. Larriqueta and V.N. Vera de Serio,
University of Alicante

Certain mathematical models arising in functional approximation, data mining, design centering, and other fields, involve two sets, F and G, contained in the same Euclidean space $\mathbb{R}^n$. The first step in the analysis of such models consists of determining which is the relative position of these two sets: containment (either $F \subset G$ or $G \subset F$), empty intersection ($F \cap G = \emptyset$) or neither containment nor empty intersection. Usually F and G are the solution sets of inequality systems with uncertain constraints (e.g., the constraints involve parameters that are empirically estimated and/or functions which are not exactly evaluated during the computation process).

In this talk we present sufficient and necessary conditions for the stability of the relative positions of F and G (the so-called nominal sets), i.e., conditions guaranteeing that the relative position of F and G is preserved by sufficiently small perturbations of the data.

This talk presents recent results from [1] and [2], where F and G are first seen as images of certain parameters, $y_0 \in Y$ and $z_0 \in Z$, through set-valued mappings $\mathcal{F} : Y \rightrightarrows \mathbb{R}^n$ and $\mathcal{G} : Z \rightrightarrows \mathbb{R}^n$, respectively. We assume that (Y, ρ_Y) and (Z, ρ_Z) are given pseudometric spaces formed by all the possible perturbations of y_0 and z_0. We study in some detail the case in which F and G are the solution sets of two given systems, i.e., $y_0 = \left\{ f_t^0(x) \leq 0, t \in T \right\}$ and $z_0 = \left\{ g_s^0(x) \leq 0, s \in S \right\}$, where the index sets T and S are arbitrary (possibly infinite) and $f_t^0, g_s^0 : \mathbb{R}^n \to \mathbb{R}$ for all $t \in T$ and for all $s \in S$. In that case Y and Z are the classes of those systems which have the same space of variables, $\mathbb{R}^n$, and the same index set as y_0 and z_0 (T and S, respectively). Particular attention is paid to the case of convex and linear systems.

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E-mail: *mgoberna@ua.es*

Calculating optimal environmental pollution control strategies by means of continuous programming

Sven-Åke Gustafson, *Stavanger University*

We consider the problem of determining an optimal regulatory policy in the case when several sources of pollution have been identified and we want to maintain acceptable environmental quality in a certain control area. This control area could be a city or a country. In the model it is represented as a set of receptor points, which often is infinite. It is assumed that acceptable quality is defined by the requirement that the pollution concentration at each receptor point is below a certain standard. This means that infinitely many conditions need to be satisfied. For a mathematical treatment we need to know the concentration contribution from each source to each receptor point. Then it is possible to determine a regulatory policy which guarantees an acceptable environmental quality using semi-infinite programming. This problem is discretised and the resulting problem may be solved numerically. However, if several sources of pollution have been found more than one regulatory policy may achieve an acceptable environment as described above and we seek to determine a policy which results in an acceptable environment to minimal combined cost. In the cost function one may include the damage caused by the pollution.

Another issue is how to allocate the costs for cutting back the emissions of pollution in the common situation when the polluting devices are operated by different firms or governments. Several papers discussing these issues appeared about 30 years ago. The construction of algorithms for solving these problems were a stimulus for the development of numerical methods for semi-infinite programs where the index-set has more than one dimension. However, no reliable data for the emisions or cost and damage functions were available at the time. Now the situation has improved in this respect and we will give an overview of recent progress in the field. We will also discuss more accurate discretisations based on higher order interpolation formulas and illustrate with numerical examples.

E-mail: *sven-aake.gustafson@uis.no*

Multiplier rules for ε-efficient solutions in Pareto problems

César Gutiérrez, *Universidad de Valladolid*

In this paper, necessary and sufficient Fritz John and Kuhn-Tucker type conditions for approximate efficient solutions of nondifferentiable convex multiobjective Pareto problems are derived via an ε-efficiency notion introduced by Kutateladze (1979). In obtaining these results, a max type scalarization and ε-subdifferential calculus are used.

E-mail: *cesargv@mat.uva.es*

Average Complexity of Interior Point Methods

Petra Huhn, *Clausthal University of Technology*

We are interested in the average behaviour of interior point methods (IPMs) for Linear Programming problems (LPs) and use the Rotation-Symmetry-Model as the probabilistic model for the average case analysis. This model has been used by Borgwardt in his average case analysis of the Simplex-Method.

While interior point methods are usually applied to self-dual transformations of the original problem to assure feasibility and appropriate starting points we prefer the application of interior point methods to the original formulation of the problem to avoid the inevitable stochastic dependencies of the problem's input data caused by those transformations. This leads to two-phase interior point methods.

Assuming that the origin is feasible this point can be used as starting point for a phase 1 algorithm to find an approximate center, which actually serves as starting point for the subsequent interior point method. From the stochastic settings we can derive some distributional results on the situation at the start of the phase I algorithm and characterize the typical (average) situation at this starting point. Moreover we will give upper bounds on the average number of steps of the phase 1 algorithm for different distributions of the input data, which show that the complexity of the centering in phase 1 does not depend on the boundedness of the underlying distribution.

We will also give results for the average complexity of interior point methdos including phase 2. The bounds on the average number of iterations show, that IPMs solve LPs in strongly polynomial time in the average case, so only the dimension parameters and not the encoding length of the problem determine the average behaviour of IPMs.

E-mail: *petra.huhn@math.tu-clausthal.de*

Sufficient Optimality Criterion for Linearly Constrained, Separable Concave Minimization Problems

T. Illés and A. B. Nagy ,
Eötvös Loránd University of Science and University of Veszprém

A sufficient optimality criterion for linearly constrained, concave minimization problems is given in this paper. Our optimality criterion is based on the sensitivity analysis of the relaxed linear programming problem. The main result is similar to that of Phillips and Rosen (1993), however, our proofs are simpler and constructive.

In Phillips and Rosen's paper (1993), they derived a sufficient optimality criterion for a slightly different, linearly constrained, concave minimization problem using exponentially many linear programming problems. We introduced special test points and using these, for several cases, we are able to show the optimality of the current basic solution.

The sufficient optimality criterion described in this paper can be used as a stopping criterion for branch-and-bound algorithms developed for linearly constrained, concave minimization problems.

Keywords: Separable concave minimization problems, linear relaxation, sensitivity analysis.

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E-mail: *illes@math.elte.hu* , *nagy@dcs.vein.hu*

An augmented primal-dual method for linear conic minimization

Florian Jarre and Franz Rendl ,
University of Düsseldorf and University of Klagenfurt

We present a new iterative method for solving linear minimization problems over convex cones. The problem is reformulated as an unconstrained problem of minimizing a differentiable convex function. The method does not use any homotopy parameter but solves the primal-dual problem in one step using a nonlinear conjugate gradient type approach. In the case of a linear program in standard form with a dense n by m data matrix, each iteration costs order mn arithmetic operations. If the linear program has a unique primal dual optimal solution, the method converges in a finite number of steps. For semidefinite programs with a unique and strictly complementary primal-dual solution, the method is n-step quadratically convergent if $n = k(k+1)/2$ and k is the dimension of the matrix variable.

E-mail: *jarre@opt.uni-duesseldorf.de*

Solution of Complementarity Problems by Enumerative Algorithms

Joaquim Júdice, Isabel Ribeiro and Silvério Rosa,
University of Coimbra, University of Porto, University of Beira Interior

In this talk, the linear and eigenvalue complementarity problems are addressed. It is recalled that these problems can be reduced into Mathematical Programming Problems with Equilibrium Constraints and Nonlinear Programs with a zero optimal value. Enumerative algorithms are discussed, which exploit these formulations. Computational experience is included to highlight the efficacy of these techniques for processing these complementarity problems in practice.

E-mail: *Joaquim.Judice@co.it.pt*

Inexact Restoration in Infinite Dimensions and Optimal Control

C. Yalçin Kaya and José Mario Martinez ,
University of South Australia, IMECC University of Campinas

Inexact Restoration (IR) is a recent technique developed for solving finite dimensional optimization problems. Each iteration of IR consists of two phases: in the first phase, feasibility of the current iterate is improved, and in the second, the value of the cost is reduced in the plane tangent to the constraints. Continuous-time optimal control problems are optimization problems in infinite dimensional spaces. We present a local infinite-dimensional analogue of IR for unconstrained optimal control problems. We illustrate the new technique and its advantages through an example involving the control of the motion of a rigid body.

Key words: Optimal control, inexact restoration, Lagrangian, Lagrange multiplier update, costate update, infinite-dimensional optimization.

E-mail: *yalcin.kaya@unisa.edu.au , martinez@ime.unicamp.b*

About stationarity and regularity in continuous optimization

Alexander Y. Kruger, *University of Ballarat*

Several stationarity and regularity concepts for extended real-valued functions are considered. The properties are characterized in terms of certain local constants. A function is said to be stationary at a point (in some sense) if the corresponding constant is zero (a critical point). Otherwise the function is said to be regular at this point (in the same sense) and the constant provides a quantitative estimate of regularity.

All the variety of constants and corresponding stationary/regularity concepts can be classified in the following way. Firstly, there are "inf" constants and concepts (characterizing a function from below and appropriate for minimization problems) and "sup" ones (characterizing a function from above and appropriate for maximization problems). One can also consider "combined" concepts. Combined stationary means that either an "inf" or a "sup" stationary condition is satisfied, while combined regularity corresponds to the case when both "inf" and "sup" regularity conditions hold true.

Secondly, there are "basic" constants (defined at a point) and "strict" or "fuzzy" ones (accumulating information about the function properties at nearby points). The latter constants lead to weak stationary and strong regularity concepts.

Thirdly, there are "primal" and "dual" constants (defined in terms of primal and dual space elements respectively) and corresponding stationary/regularity concepts. For smooth or convex functions all stationary/regularity concepts reduce to traditional ones.

The definitions of the constants, the relations between them and the corresponding stationary and regularity concepts for real-valued functions are very similar to those for multifunctions and collections of sets (see [1,2,3]). Actually it is another application of the same variational approach.

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E-mail: *a.kruger@ballarat.edu.au*

Global Descent Methods in Global Optimization and its Applications

Musa Mammadov, *University of Ballarat*

We present a new method for global optimization developed at the University of Ballarat. This method uses dynamical systems described by relational elasticities which are suitable for the study of dynamics in finite data sets. For global optimization problems, this method allows one to find directions of global descent that can be used for development of new global optimization algorithms. The first such algorithm (AGOP) developed recently, has already been applied to many difficult practical problems from different areas. In this talk, we present some applications to the optimization problems, where the objective function is: (a) non-smooth (the robust stabilization problem); (b) discontinuous (location problems in Telecommunication and inter-market influences in Finance); (c) smooth, but the number of variables is very large (some data mining problems).

E-mail: *m.mammadov@ballarat.edu.au*

Shape optimization in biofluid flow problems

Mike Nicolai, Marek Behr and Feby Abraham,
RWTH Aachen University , GlaxoSmithKline

Shape optimization of engineering systems involving complex fluid flows has the potential to shorten the design cycle and to give the designer a way of evaluating various, sometimes non-intuitive, configuration changes. In bioengineering the optimization task is often made more difficult by the non-Newtonian, or micro-structured, nature of the flowing medium, such as blood.

As motivation, we present a direct problem involving complex fluid flow in a ventricular assistant device (VAD). The flow is modeled with the incompressible Navier-Stokes equations and solved using a stabilized space-time finite element method. The direct simulation seems relatively insensitive to refinements of the fluid constitutive model, incorporating shear-thinning or viscoelasticity. The simulation gives us important insights into causes of blood damage and suboptimal

performance. Unfortunately this knowledge does not lead directly to better design, because of the complex problem behavior.

For a better design, we must go one step further and not just solve the direct problem but also perform a type of inverse analysis. In our case this would involve identification of shape parameters in a parametrized model of the blood pump which minimize objective function related, e.g., to blood damage.

On the way towards that goal, we will present a model problem including an objective function depending on blood damage as well as a parametrized geometric model of an idealized artificial graft. We will report the results of a sensitivity-based optimization procedure applied to this problem. The fluid may be considered in this problem as a Newtonian as well as a non-Newtonian one. Our results will highlight dependencies between velocity, shear-rate, constitutive model and optimal shape.

E-mail: *nicolai@cats.rwth-aachen.de*

An Optimal Control Policy for Stormwater Management in Two Connected Dams

P.G. Howlett, C.E.M. Pearce and J. Piantadosi,
University of South Australia, University of Adelaide

Stormwater is collected in a capture dam and can be pumped to a supply dam from which it can be drawn for use. Either dams loses water if filled to overflowing. Such a system has been analysed in the literature under simple operating rules using matrix–analytic methodology, but the form of an optimal management policy under reasonably general conditions has only been conjectured. This problem will be discussed and the truth of the conjecture established.

E-mail: *cpearce@maths.adelaide.edu.au*

Global Optimization with Maple: An Introduction with Illustrative Examples

Janos Pinter, *Dalhousie University*

The objective of this talk - based on our electronic book - is to present Maple as an integrated modeling and optimization environment. Within this broad context, the emphasis is placed on solving models, using the Global Optimization Toolbox. We highlight the content and the key features of the e-book, and present 'live' numerical examples.

E-mail: *jdpinter@hfx.eastlink.ca*

Deterministic Chaos Produced by Local Optimization Algorithms

V.E. Podobedov, *Bordeaux Business School*

Many global optimization algorithms combine global exploration of the objective function domain with a number of local optimization searches. In order to minimize a number of the local searches in such multistart algorithms, special clustering techniques are often used for creating the clusters of mutually close points that presumably correspond to relevant regions of attraction. Here, the region of attraction (RA) of a local optimum consists of the points such that the local search, starting from any of these points, converges to this local optimum. Ideally, only one local search must be performed for each RA.

Unfortunately, RAs can have very complex form, especially in deterministic chaos situations, when a negligible change of the algorithm's initial conditions can result in considerable change of the solution.

This work considers deterministic chaos situations produced by local optimization algorithms. A class of test multi-extremal functions is proposed that allows simulating such situations with an arbitrary number of RAs.

Next properties of RAs are discovered:

1. RA generally is neither convex, nor even connected set;
2. Points of different RAs can alternate, forming a chaotic picture;
3. RA's size doesn't reflect the significance of the corresponding local optimum;
4. RAs depend from a local optimization algorithm;
5. RAs depend rather from a distance between local optima, than from the values in these points;
6. Clustering based on a distance between the points isn't an adequate technique for producing of RAs;
7. Notion of RA can be non-productive and ineffective even for simple local optimization algorithms, such as the gradient or Nelder-Mead methods.

It is rather impossible to use clustering approaches for producing any close approximation to RAs in chaotic situations. So, local optimization algorithms must be checked for chaotic nature of RAs generated by them. Regularity of RAs must be a special characteristic of such algorithms, especially for ones used in multistart schemes of global optimization.

E-mail: *podobedov@paytech.ru*

On an Advertising Model with Memory

Pavel Pražák, *University of Hradec Králové*

This paper deals with a modification of the Vidale-Wolfe advertising model. The model is enriched by an assumption that the current intensity of sales depends mainly on the past intensity of advertising. Mathematical formulation results in a system of two ordinary differential equations

$$\dot{x} = \alpha(u - x), \;\; x(0) = x_0, \tag{1}$$

$$\dot{y} = ax(1 - y) - by, \;\; y(0) = y_0, \tag{2}$$

where $u = u(t)$ is the advertising effort at time t measured in a money unit per time unit, $x = x(t)$ is the effect of advertising expenditures u, $\alpha > 0$ is a real constant that represents an inverse value of the length of delay of advertising effect behind the actual advertising expenditures and $y = y(t) \in [0, 1]$ is a fraction of all the sales at the market that the chosen firm can attract. The value x_0 and $y_0 \in [0, 1]$ are initial conditions. Since the firm has limited resources of incomes it is assumed that

$$u \in [0, \; \overline{u}], \tag{3}$$

where $\overline{u} > 0$ is a maximal budget for advertising expenditures.

First we study a special case when the intensity of advertising is constant. Then we concentrate on finding an optimal strategy of advertising with regard to a given cost function. For this purpose we use the Pontryagin maximum principle.

Suppose that the total profit from all the sales at the market is known and it will be denoted P. The chosen firm wishes to maximize its discounted profit stream which can be considered as the difference between its gross profit of $P\,y(t)$ and advertising expenditure $u(t)$, with the constant discount factor $r \in [0, 1]$. The introduced problem can be considered as an optimal control problem with the objective functional

$$\mathcal{J}(u(\cdot)) = \int_0^\infty e^{-rt}(Py(t) - u(t))dt,$$

that is to be maximized subject to the system (1), (2) and the condition (3).

Keywords: ordinary differential equations, stability, optimal control, Pontryagin maximum principle, advertising.

E-mail: *pavel.prazak@uhk.cz*

A Full-Newton Step $O(n)$ Infeasible Interior-Point Algorithm for Linear Optimization

Kees Roos, *Delft University of Technology*

We present a primal-dual infeasible interior-point algorithm. As usual, the algorithm decreases the duality gap and the feasibility residuals at the same rate. Assuming that an optimal solution exists it is shown that at most $O(n)$ iterations suffice to reduce the duality gap and the residuals by the factor $1/e$. This implies an $O(n \log(n/\epsilon))$ iteration bound for getting an ϵ-solution of the problem at hand, which coincides with the best known bound for infeasible interior-point algorithms. The algorithm constructs strictly feasible iterates for a sequence of perturbations of the given problem and its dual problem. A special feature of the algorithm is that it uses only full-Newton steps. Two types of full-Newton steps are used, so-called feasibility steps and usual (centering) steps. Starting at strictly feasible iterates of a perturbed pair, (very) close to its central path, feasibility steps serve to generate strictly feasible iterates for the next perturbed pair. By accomplishing a few centering steps for the new perturbed pair we obtain strictly feasible iterates close enough to the central path of the new perturbed pair. The algorithm finds an optimal solution or detects infeasibility or unboundedness of the given problem. It is conjectured that further investigations may improve the above bound to $O(\sqrt{n})$.

E-mail: *C.Roos@TUDelft.nl*

Stochastic Linear Programming by Monte-Carlo Estimators

Leonidas Sakalauskas and Kestutis Zilinskas, *University of Vilnius*

The stochastic iterative method has been developed to solve the stochastic linear problems by a finite sequence of Monte-Carlo samples. This method is grounded by the stopping procedure, the rule for iterative regulation of the size of Monte-Carlo samples and taking into consideration the stochastic model risk. Our approach distinguishes by treatment of the accuracy of the solution in a statistical manner, testing the hypothesis of optimality according to statistical criteria and

estimating confidence intervals of the objective and constraint functions. To avoid ”jamming” or ”zigzagging” in the solutions of the problem we implement the ? -feasible directions approach. The adjustment of sample size, when it is taken inversely proportional to the square of the norm of the Monte-Carlo estimate of the gradient, guarantees the convergence a. s. at a linear rate. The numerical study and an example in practice corroborate the theoretical conclusions and show that the procedures developed make it possible to solve stochastic problems with a sufficient admissible accuracy by means of the acceptable amount of computations.

E-mail: *sakal@ktl.mii.lt*

SQP Methods with Non-Monotone and Parallel Line Search: Numerical Experiments and an Industrial Application

Klaus Schittkowski, *University of Bayreuth*

First, we outline the standard SQP method which is widely used in academic and industrial applications because of its efficiency and robustness. Practical experience shows, however, that the bottleneck of an SQP algorithm is the line search procedure.
1. Distributed line search: The sequential structure of the standard Armijo-type line search with quadratic interpolation can be replaced by a simpler one proceeding from a certain number of given function values along the search direction, which are supposed to be evaluated in parallel.
2. Non-monotone line search: To satisfy the convergence criterion at an earlier stage and to accept uphill search directions as, e.g., obtained by inaccurate gradients, a non-monotone variant is proposed which requires backup of previous merit function values.

For both versions, we present numerical results based on a collection of more than 300 test problems. Parallel processing is simulated and gradient errors are randomly generated by function noise and forward differences. It turns out that the non-monotone line search is significantly more robust than the monotone one.

Another advantage of SQP methods is their flexibility to solve optimization problems with a completely different structure, e.g., least-squares, L_1, min-max, linearly constrained, mixed-integer, or even global optimization problems. In the first three cases, the given problem can be transferred into a smooth, general nonlinear programming problem of a specific structure. Since this structure is passed to the underlying quadratic programming problem, the solver can be adapted leading to an efficient and robust implementation.

Integer variables are be handled in a special way leading to the successive solution of mixed-integer quadratic programs, as shown in another lecture.

A heuristic procedure to solve global constrained optimization problems is presented in more detail. The idea is to cut off local minima sequentially by introducing additional variables and constraints. The feasibility is shown by a series of test runs based on 37 academic test problems.

Finally, we introduce an industrial application, the optimal design of horn radiators for satellite communication (Astrium AG), where SQP methods are successfully used since many years.

E-mail: *klaus.schittkowski@uni-bayreuth.de*

ABS methods as a bridge from continuous to integer problems

Emilio Spedicato, *Università degli Studi di Bergamo*

ABS methods, introduced in 1982 for solving linear algebraic equations, have been extended to nonlinear algebraic equations and nonlinear continuous programming problems, providing in a class form a unified formulation of all methods of a certain structure and providing the solution of some unsolved problems.

In a series of recent papers ABS methods have been applied to solve linear discrete (Diophantine) systems of equalities and inequalities and some integer LP problems. The algorithmic structure for the continuous case is essentially preserved at the cost of computing certain gcd's. Here we review this approach and present some techniques useful to restrict the growth of the iteration generated integers and to avoid the computation of the gcd.

E-mail: *emilio.spedicato@unibg.it*

A unified continuous optimization approach to center based clustering algorithms

Marc Teboulle, *Tel-Aviv University*

Clustering consists of grouping or classifying data into similar objects. It is a fundamental technique in unsupervised machine learning and arise in a wide spectrum of research fields such as, astrophysics, statistics, biology, computer vision, data compression in image processing, and information retrieval, to name just a few. The interdisciplinary nature of clustering has generated a very large body of literature in cluster analysis, with many clustering problem formulations, and numerous clustering algorithms which are based on various disparate motivations and approaches.

In this talk, we present a unifying framework for center based partitional clustering algorithms from an optimization theory perspective. Starting with the nonconvex and nonsmooth formulation of the clustering problem, which minimizes the sum of a finite collection of “min” functions, we present a systematic way for designing center based clustering methods. Our approach builds on two fundamental mathematical concepts: convex asymptotic functions, and the so-called nonlinear means of Hardy, Littlewood and Polya. This allows us to derive a generic smoothing iterative scheme for clustering, which computationally, is as simple as the popular k-means algorithm. We analyze its properties, and establish its convergence. We then demonstrate that most well known center based clustering algorithms, which were derived either heuristically, or/and which have emerged from intuitive analogies in physics, in statistical techniques, and from information theoretic perspectives, can be simply recovered, analyzed and extended through the proposed framework.

E-mail: *teboulle@math.tau.ac.il*

Convex Parametric Semi-infinite programming problems and properties of their solutions in a neighborhood of irregular points

Tatiana Tchemisova, O.I. Kostyukova and E.A. Kostina, *University of Aveiro*

Given a one-parametric family of convex semi-infinite programming problems depending on a parameter $\tau \in [0, \tau_*]$, we propose the rules for the construction of solutions of these problems in neighborhoods of irregular points and analyze the properties of such the solutions. The differentiability of the solutions with respect to the parameter is examined, and rules for the calculation of one-sided derivatives are presented. An analysis of the sensitivity of solutions at a parameter value $\tau_0 \in [0, \tau_*]$ where the solution is nondifferentiable with respect to the parameter is considered as well. A continuation method based on the results obtained is proposed, which uses an active-set strategy.

E-mail: *tatiana@mat.ua.pt*

On Mehrotra-type Predictor-corrector Algorithms

Maziar Salahi and Tamas Terlaky, *Mcmaster University*

In this talk we study the complexity and convergence behavior of Mehrotra type interior point algorithms. By an example we demonstrate that without safeguard the algorithms might make very short steps, while with appropriate safeguard polynomial complexity and superlinear convergence of the algorithm can be reached.

E-mail: *terlaky@mcmaster.ca*

Linear semi-infinite optimization. Unicity and generic results

Maxim I. Todorov, Universidad de las Americas (UDLA)

We consider parametric linear semi-infinite optimization problems in their very general setting. I.e., we have not any restrictions, neither on the index set nor on the functions, involved in the problems. We have obtained a generalization of the Nurenberger's theorem, characterizing the interior of the set of parameters, having strongly unique solution, known from the continuous and bounded cases. In order to get it we have used the concepts of modified and extended active constraints. We have found an example, showing that the use of such kind of theorems, in order to get generic results, is limited.

E-mail: *maxim.todorov@udlap.mx*

Linear Programming Kernel Methods and Applications

Robin C. Gilbert and Theodore T. Trafalis, *University of Oklahoma*

In the last thirty years, kernel methods have been widely implemented in the domain of Machine Learning. These methods provide a simple framework for manipulating nonlinear relationships and allow old algorithms designed in the sixties and seventies to handle nonlinear cases. These useful methods are very adaptable and require modest computational resources. Among the learning algorithms, Support Vector Machines (SVMs) are using kernel methods in order to solve complex nonlinear classification and regression problems. The aim of this work is to review some statistical foundations of Machine Learning and to use them in order to establish a new family of SVMs. The stability analysis of classification and regression algorithms gave risk bounds that suggest some guiding lines for the construction of adequate SVMs. The resulting formulations are based on simple linear programming problems that have very good computational performances. The evaluation of these SVMs was done on several real life applications in the domains of astronomy, text recognition and manufacturing engineering. The computational requirements of the new machines were empirically

estimated to be smaller than those needed by conventional Vapnik-like SVMs. The new SVMs provide solutions very quickly and can be used efficiently on medium-scale problems.

E-mail: *ttrafalis@ou.edu*

Synergy Analysis of Collaboration in Environmentally Conscious Energy Systems

Metin Turkay and Ahu Soylu, *Koc University*

The energy sector is a high-cost and high-emission sector. With the demanding environmental regulations, the energy producing companies must find new solutions continuously to decrease emissions while satisfying the energy demand. It was shown in previous studies that collaboration by exchanging steam among the energy companies can create synergy both in environmental and economical criteria. In addition to collaboration, transition to new technologies is necessary to satisfy environmental regulations. This paper presents an analysis of the expected gains in a collaborative setting with an environmentally friendly fuel alternative, biodiesel. The problem is modeled as a Mixed-Integer Linear Programming. The results of the solutions are analyzed indicating the benefits of collaboration.

Keywords: Collaborative Planning, Energy Planning, Supply Chain Optimization, Biodiesel, Mixed-Integer Linear Programming.

E-mail: *mturkay@ku.edu.tr*

On Generalized Semi-Infinite Optimization of Genetic Networks

<u>Gerhard-Wilhelm Weber</u> and Aysun Tezel, *Middle East Technical University*

Since some years, the emerging area of computational biology is looking for its mathematical foundations. Based on modern contributions given to this area, our paper approaches modeling and prediction of gene-expression patterns by optimization theory, with a special emphasis on (generalized) semi-infinite optimization. Based on experimental data, nonlinear ordinary differential equations are obtained by the optimization of least-squares errors. The genetic process can be investigated by a time-discretization and a utilization of a combinatorial algorithm to detect the stability regions. We represent the dynamical systems by means of matrices which allow biological-medical interpretation, and by *gene* or new *gene-environment networks*. For evaluating these networks we optimize them under constraints imposed. For controlling the connectedness structure of the network, we introduce GSIP into this modern application field which can lead to important services in medicine and biotechnology, including energy production and material science.

Keywords: Generalized Semi-Infinite Programming, Computational Biology, Mathematical Modeling, Dynamical Systems, Gene-Expression Data, Environment, Prediction, Stability.

E-mail: *gweber@metu.edu.tr*

Regularization and Trust Regions in Optimization

<u>Henry Wolkowicz</u> and Oleg Grodzevic, *University of Waterloo*

The trust region subproblem (the minimization of a quadratic objective subject to one quadratic constraint and denoted TRS) has many applications in diverse areas, e.g. function minimization, sequential quadratic programming, regularization, ridge regression, and discrete optimization. Recent advances in the theory and algorithmic development using Lanczos techniques have allowed TRS to be

used to solve large scale optimization problems. We provide an overview of these new developments along with the relationships to Conjugate Gradient methods and regularization.

E-mail: *hwolkowi@uwaterloo.ca*

List of Speakers (Co-authors) and Lectures

Paula Amaral (Joaquim Júdice and Hanif Sherali)
Solving inconsistencys preserving the zero-structure

Miguel F. Anjos
A Semidefinite Optimization Approach for Single Row Layout Problems

Ömer Akin (Necati Ozdemir and Firat Evirgen)
A New Application of An Uncapacitated Network Flow Problem Using State-Space Approach with Quadratic Penalty Method

Adil Bagirov (Invited talk)
Derivative-free algorithms in nonsmooth optimization and their applications

Vaida Bartkute
Application of stochastic approximation to nondifferentiable optimization

Amir Beck
Quadratic Matrix Programming

Salah Beddiaf (S.J. Kane and M.C. Bartholomew-Biggs)
Traversing non-convex regions

Regina Sandra Burachik (Alex Rubinov)
Abstract Convexity and Augmented Lagrangians

Antoine Deza (Tamas Terlaky and Yuriy Zinchenko)
How Curvy is the Central Path?

Gianni Di Pillo (Giampolo Liuzzi and Stefano Lucidi) (Invited talk)
A primal-dual algorithm exploiting negative curvature directions

Adriana Gnudi (Elisabetta Allevi and I.V. Konno)
Regularization of non-monotone multivalued variational inequalities

Miguel A. Goberna (M. Larriqueta and V.N. Vera de Serio)
Stability of the relative position of two sets

Sven-Åke Gustafson
Calculating optimal environmental pollution control strategies by means of continuous programming

César Gutiérrez
Multiplier rules for ε-efficient solutions in Pareto problem

Audrey Hermant (J. Frédéric Bonnans)
No Gap Second order Optimality Conditions for Optimal Control Problems with a single State Constraint and Control

Petra Huhn (Invited talk)
Average Complexity of Interior Point Methods

Tibor Illés (A.B. Nagy)
Sufficient Optimality Criterion for Linearly Constrained,
Separable Concave Minimization Problems

Florian Jarre (Franz Rendl)
An augmented primal-dual method for linear conic minimization

Joaquim Júdice (Isabel Ribeiro and Silvério Rosa)
Solution of Complementarity Problems by Enumerative Algorithms

C. Yalçin Kaya (José Mario Martinez)
Inexact Restoration in Infinite Dimensions and Optimal Control

Alexander Y. Kruger
About stationarity and regularity in continuous optimization

Musa Mammadov
Global Descent Methods in Global Optimization and its Applications

Mike Nicolai (Marek Behr and Feby Abraham)
Shape optimization in biofluid flow problems

C.E.M. Pearce (P.G. Howlett and J. Piantadosi)
An Optimal Control Policy for Stormwater Management in Two
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A Full-Newton Step $O(n)$ Infeasible Interior-Point Algorithm
for Linear Optimization

Leonidas Sakalauskas (Kestutis Zilinskas)
Stochastic Linear Programming by Monte-Carlo Estimators

Klaus Schittkowski (Invited talk)
SQP Methods with Non-Monotone and Parallel Line Search:
Numerical Experiments and an Industrial Application

Emilio Spedicato
ABS methods as a bridge from continuous to integer problems

Marc Teboulle (Invited talk)
A unified continuous optimization approach to center based clustering algorithms

Tatiana Tchemisova (O.I. Kostyukova and E.A. Kostina)
Convex Parametric Semi-infinite programming problems and properties of their solutions in a neighborhood of irregular points

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On Generalized Semi-Infinite Optimization of Genetic Networks

Henry Wolkowicz (Oleg Grodzevic) (Invited talk)
Regularization and Trust Regions in Optimization

List of Participants

M.A. Abubakar
University of Ibadan, Nigeria

Stephan Alberth E-mail: s.alberth@jbs.cam.ac.uk
University of Cambridge, UK

Elisabetta Allevi E-mail: allevi@eco.unibs.it
University of Brescia, Italy

Paula Amaral E-mail: paca@fct.unl.pt
Campo da Caparica, Portugal

Miguel F. Anjos E-mail: anjos@cheetah.vlsi.uwaterloo.ca
University of Waterloo, Canada

Ömer Akin E-mail: omerakin@etu.edu.tr
TOBB Economics and Technology University, Turkey

Adil Bagirov E-mail: a.bagirov@ballarat.edu.au
University of Ballarat, Australia

Ibrahem Balugun
University of Ibadan, Nigeria

Vaida Bartkude E-mail: vaidaba@one.lt
University of Vilnius, Lithuania

Amir Beck E-mail: becka@techunix.technion.ac.il
University of Haifa, Israel

Salah Beddiaf E-mail: S.Beddiaf@herts.ac.uk
University of Hertfordshire, UK

Immanuel Bomze E-mail: immanuel.bomze@univie.ac.at
University of Vienna, Austria

Frederic Bonnans E-mail: Frederic.Bonnans@inria.fr
INRIA, France

Henri Bonnel E-mail: bonnel@univ-nc.nc
Université de la Nouvelle-Calédonie, France (la Nouvelle-Calédonie)

Regina Burachik E-mail: Regina.Burachik@unisa.edu.au
University of South Australia, Australia

Isaak Chukwudum
University of Ibadan, Nigeria

Zsolt Csizmadia E-mail: csisza@cs.elte.hu
University of Sciences, Hungary

Antoine Deza E-mail: deza@mcmaster.ca
McMaster University, Canada

Gianni Di Pillo E-mail: dipillo@dis.uniroma1.it
University of Rome ”La Sapienza”, Italy

Mirjam Dür E-mail: duer@mathematik.tu-darmstadt.de
Darmstadt University of Technology, Germany

Andrew Eberhard E-mail: andrew.eberhard@ems.rmit.edu.au
RMIT University, Australia

Jenny Edwards E-mail: jenny@it.uts.edu.au
University of Technology, Sydney, Australia

Martin Gavalec E-mail: martin.gavalec@uhk.cz
University of Hradec Kralove, Czech Republic

Esma Gaygisiz E-mail: esma@metu.edu.tr
Middle East Technical University, Ankara, Turkey

Helmut Gfrerer E-mail: gfrerer@numa.uni-linz.ac.at
Johannes Kepler University Linz, Austria

Adriana Gnudi E-mail: adri@unibg.it
Bergamo University, Italy

Miguel A. Goberna E-mail: mgoberna@ua.es
Universidad de Alicante, Spain

Sven-Åke Gustafson E-mail: sven-aake.gustafson@uis.no
Stavanger University, Norway

Cesar Gutierrez Vaquero E-mail: cesargv@mat.uva.es
Universidad de Valadolid, Spain

Oluwasogo Haadi E-mail: sogson68@yahoo.com
University of Ibadan, Nigeria

Oppong Steward Harrisson
Warshaw University, Poland

Audrey Hermant E-mail: audrey.hermant@inria.fr
INRIA, France

Petra Huhn E-mail: petra.huhn@math.tu-clausthal.de
Clausthal University, Germany

Mohammed Hamis Huzair E-mail: harmis2001@yahoo.co.uk
St. Howard Professional Institut, Ghana

Tibor Illes E-mail: illes@math.elte.hu
University of Sciences, Budapest, Hungary

Florian Jarre E-mail: jarre@opt.uni-duesseldorf.de
University of Düsseldorf, Germany

Pall Jensson E-mail: pall@hi.is
University of Iceland, Iceland

Joaquim Judice E-mail: Joaquim.Judice@co.it.pt
University of Coimbra, Portugal

Bülent Karasözen E-mail: bulent@metu.edu.tr
Middle East Technical University, Ankara, Turkey

Yalcin Kaya E-mail: Yalcin.Kaya@unisa.edu.au
University of South Australia, Australia

O.I. Kostyukova E-mail: kostyukova@im.bas-net.by
University of Minsk, Balarus

Kathrin Klamroth E-mail: klamroth@am.uni-erlangen.de
University of Erlangen-Nuremberg, Germany

Etienne De Klerk E-mail: e.deklerk@uvt.nl
Tilburg University, The Netherlands

Bjarni Kristjansson E-mail: bjarni@maximalsoftware.com
Maximal Software, London, UK

Alex Kruger E-mail: a.kruger@ballarat.edu.au
University of Ballarat, Australia

Yihua Li E-mail: li_yihua@yahoo.com
BostonCoach INC, USA

Giampaolo Liuzzi E-mail: liuzzi@dis.uniroma1.it
University of Rome ”La Sapienza”, Italy

Marco A. Lopez Cerda E-mail: Marco.Antonio@ua.es
University of Alicante, Spain

Stefano Lucidi E-mail: lucidi@dis.uniroma1.it
University of Rome ”La Sapienza”, Italy

Musa Mammadov E-mail: m.mammadov@ballarat.edu.au
University of Ballarat, Australia

Abdullah Al Mamun E-mail: advmamun@yahoo.com
Bangladesh

Marianna Nagy E-mail: nmariann@cs.elte.hu
University of Sciences, Budapest, Hungary

Mike Nicolai E-mail: nicolai@cats.rwth-aachen.de
RWTH Aachen University, Germany

Kingsley Odoco
University of Ibadan, Nigeria

Snjolfur Olafsson E-mail: snjolfur@hi.is
University of Iceland, Reykjavik, Iceland

Babatunde Oyeniyi
University of Ibadan, Nigeria

Necati Ozdemir E-mail: nozdemir@balikesir.edu.tr
Balikesir University, Turkey

Juan Parra E-mail: parra@umh.es
Miguel Hernandez University, Spain

Charles Pearce E-mail: Charles.Pearce@Adelaide.Edu.Au
University of Adelaide, Australia

Van Lam Pham E-mail: viet_czech_jsc@yahoo.com
Viet Czech Joint Stock Company, Hanoi, Vietnam

Veronica Piccialli E-mail: Veronica.Piccialli@dis.uniroma1.it
University of Rome ”La Sapienza”, Italy

Janos Pinter E-mail: jdpinter@hfx.eastlink.ca
Pinter Consulting Services, Inc. and Dalhousie University, Canada

Vitaly Podobedov E-mail: podobedov@paytech.ru
Bordeaux Business School, France

Pavel Prazak E-mail: Pavel.Prazak@uhk.cz
University of Hradec Kralove, Czech Republic

Kees Roos E-mail: C.Roos@ewi.tudelft.nl
TU Delft, The Netherlands

Leonidas Sakalauskas E-mail: Sakal@ktl.mii.lt
University of Vilnius, Lithuania

Suresh P. Sethi E-mail: sethi@utdallas.edu
The University of Texas at Dallas, USA

Emilio Spedicato E-mail: emilio.spedicato@unibg.it
University of Bergame, Italy

Klaus Schittkowski E-mail: klaus.schittkowski@uni-bayreuth.de
University of Bayreuth, Germany

Oliver Stein E-mail: stein@mathc.rwth-aachen.de
RWTH Aachen University, Germany

Georg Still E-mail: g.still@math.utwente.nl
University of Twente, The Netherlands

Aysun Tezel E-mail: atezel@metu.edu.tr
Middle East Technical University, Ankara, Turkey

Tatiana Tchemisova E-mail: tatiana@mat.ua.pt
Universidade de Aveiro, Portugal

Marc Teboulle E-mail: teboulle@post.tau.ac.il
Tel Aviv University, Israel

Tamas Terlaky E-mail: terlaky@mcmaster.ca
McMaster University, Canada

Nguyen Thi Thanh Binh E-mail: viet_czech_jsc@yahoo.com
Viet Czech Joint Stock Company, Hanoi, Vietnam

Maxim Todorov E-mail: maxim.todorov@udlap.mx
UDLA, San Andres, Mexico

Theodore Trafalis E-mail: ttrafalis@ou.edu
The University of Oklahoma, USA

Metin Turkay E-mail: mturkay@ku.edu.tr
KOC University, Istanbul, Turkey

Gerhard-Wilhelm Weber E-mail: gweber@metu.edu.tr
Middle East Technical University, Ankara, Turkey

Anton Winterfeld E-mail: winterfeld@itwm.fhg.de
ITWM, Kaiserslautern, Germany

Henry Wolkowicz E-mail: hwolkowicz@uwaterloo.ca
University of Waterloo, Canada