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Mathematical Optimization Theory and Operations Research

20th International Conference, MOTOR 2021
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Proceedings

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Preface

This volume contains the refereed proceedings of the 20th International Conference on Mathematical Optimization Theory and Operations Research (MOTOR 2021)[1] held during July 5–10, 2021, at Lake Baikal, near Irkutsk, Russia.

MOTOR 2021 was the third joint scientific event unifying a number of well-known international and Russian conferences that had been held in Ural, Siberia, and the Far East for a long time:

- The Baikal International Triennial School Seminar on Methods of Optimization and Their Applications (BITSS MOPT) established in 1969 by academician N. N. Moiseev; the 17th event[2] in this series was held in 2017 in Buryatia
- The All-Russian Conference on Mathematical Programming and Applications (MPA) established in 1972 by academician I. I. Eremin; was the 15th conference[3] in this series was held in 2015 near Ekaterinburg
- The International on Discrete Optimization and Operations Research (DOOR) was organized nine times since 1996 and the last event[4] was held in 2016 in Vladivostok
- The International Conference on Optimization Problems and Their Applications (OPTA) was organized regularly in Omsk since 1997 and the 7th event[5] was held in 2018

First two events of this series, MOTOR 2019[6] and MOTOR 2020[7], were held in Ekaterinburg and Novosibirsk, Russia, respectively.

As per tradition, the main conference scope included, but was not limited to, mathematical programming, bi-level and global optimization, integer programming and combinatorial optimization, approximation algorithms with theoretical guarantees and approximation schemes, heuristics and meta-heuristics, game theory, optimal control, optimization in machine learning and data analysis, and their valuable applications in operations research and economics.

In response to the call for papers, MOTOR 2021 received 181 submissions. Out of 102 full papers considered for reviewing (79 abstracts and short communications were excluded for formal reasons) only 30 papers were selected by the Program Committee (PC) for publication in this volume. Each submission was reviewed by at least three PC members or invited reviewers, experts in their fields, in order to supply detailed and helpful comments. In addition, the PC recommended 34 papers for inclusion in the

[1] https://conference.icc.ru/event/3/.

[2] http://isem.irk.ru/conferences/mopt2017/en/index.html.

[3] http://mpa.imm.uran.ru/96/en.

[4] http://www.math.nsc.ru/conference/door/2016/.

[5] http://opta18.oscsbras.ru/en/.

[6] http://motor2019.uran.ru.

[7] http://math.nsc.ru/conference/motor/2020/.

supplementary volume after their presentation and discussion during the conference and subsequent revision with respect to the reviewers' comments.

The conference featured nine invited lectures:

- Dr. Christian Blum (Artificial Intelligence Research Institute, Spain), "On the Design of Matheuristics that make Use of Learning"
- Prof. Emilio Carrizosa (Institute of Mathematics, University of Seville, Spain), "Optimal Classification and Regression Trees"
- Prof. François Clautiaux (Université de Bordeaux, France), "Integer Programming Formulations Based on Exponentially Large Networks: Algorithms and Applications"
- Prof. Andreas Griewank (Institute of Mathematics, Humboldt University, Germany), "Beyond Heuristic Gradient Descent in Machine Learning"
- Prof. Klaus Jansen (Christian-Albrechts-Universität, Germany) "Integer Programming and Convolution, with Applications"
- Prof. Sergey Kabanikhin (Institute of Numerical Mathematics and Mathematical Geophysics, Russia) "Optimization and Inverse Problems"
- Prof. Nenad Mladenovic (Khalifa University, United Arab Emirates), "Minimum Sum of Squares Clustering for Big Data – Heuristic Approach"
- Prof. Claudia Sagastizábal (IMECC - University of Campinas, Brazil), "Exploiting Structure in Nonsmooth Optimization"
- Prof. Mikhail Solodov (Institute for Pure and Applied Mathematics, Brazil), "State-of-the-art on Rates of Convergence and Cost of Iterations of Augmented Lagrangian Methods"

The following three tutorials were given by outstanding scientists:

- Prof. Alexander Gasnikov (Moscow Institute of Physics and Technology, Russia), "Reinforcement Learning from the Stochastic Optimization Point of View"
- Prof. Alexander Krylatov (Saint Petersburg State University, Russia), "Equilibrium Traffic Flow Assignment in a Multi-Subnet Urban Road Network"
- Prof. Alexander Strekalovsky (Matrosov Institute for System Dynamics and Control Theory, Irkutsk, Russia), "A Local Search Scheme for the Inequality-Constrained Optimal Control Problem"

We thank the authors for their submissions, the members of the Program Committee (PC), and the external reviewers for their efforts in providing exhaustive reviews. We thank our sponsors and partners: the Mathematical Center in Akademgorodok, Huawei Technologies Co., Ltd., the Sobolev Institute of Mathematics, the Krasovsky Institute of Mathematics and Mechanics, the Ural Mathematical Center, the Center for Research and Education in Mathematics, the Higher School of Economics (Campus Nizhny Novgorod), and the Matrosov Institute for System Dynamics and Control Theory. We are grateful to the colleagues from the Springer LNCS and CCIS editorial boards for their kind and helpful support.

July 2021

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Abstracts of Invited Talks

On the Design of Matheuristics that make Use of Learning

Christian Blum

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Abstract. Approximation techniques for solving combinatorial optimization problems, such as metaheuristics, often make use of learning. Examples include evolutionary algorithms and ant colony optimization. On the other side, matheuristics — that is, heuristic techniques making use of mathematical programming - rarely include a learning component. Most variants of large neighbourhood search, for instance, do not take profit from learning. In this talk I will present examples of our recent work in which we design matheuristics that make successful use of learning, considering both positive and negative feedback.

Keywords: Combinatorial optimization • Approximation • Learning

Optimal Classification and Regression Trees

Emilio Carrizosa

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Abstract. Classification and Regression Trees are very powerful Machine Learning tools. Their design expressed as an optimization problem enables us to obtain excellent accuracy performance, and, at the same time, to have some control on important issues such as sparsity, explainability or fairness. In this talk, some recent advances in the field and future research lines will be discussed.

Keywords: Classification • Regression trees

Integer Programming Formulations Based on Exponentially Large Networks: Algorithms and Applications

François Clautiaux

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Abstract. The last ten years have seen much progress in the field of so-called extended formulations, which aims at reformulating effectively a problem/polyhedron with the help of (exponentially many) additional variables. In particular, network-flow formulations have received an increasing interest from the community. A considerable difficulty to overcome when dealing with such a formulation is to handle its size. In this talk we recall some key results concerning these formulations, and present several recent successful applications that have been obtained using innovative aggregation/disaggregation techniques.

Keywords: Exponential size MIP models • Integer programming

Beyond Heuristic Gradient Descent in Machine Learning

Andreas Griewank

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Abstract. In neural network training and other large scale applications, deterministic and stochastic variants of Cauchy's steepest descent method are widely used for the minimization of objectives that are only piecewise smooth. From the classical optimization point of view the roaring and almost exclusive success of this most basic approach is somewhat puzzling. The lack of convergence analysis typically goes along with a large number of method parameters that have to be adjusted by trial and error. We explore several ideas to derive more rigorous but still efficient methods for classification problems. One is a Newton adaptation that can exploit the internal structure of the so-called sparse-max potential, the other a generalization of Wolfe's conjugate gradient method to nonsmooth and nonconvex problems. Our observations and results are demonstrated on the well known MNIST and CIFAR problems with one- and multilayer prediction functions.

Keywords: Neural networks • Conjugate gradient method

Integer Programming and Convolution, with Applications

Klaus Jansen

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Abstract. Integer programs (IP) with m constraints are solvable in pseudo-polynomial time. We give a new algorithm based on the Steinitz Lemma and dynamic programming with a better pseudo-polynomial running time than previous results. Moreover, we establish a strong connection to the problem (min,+) - convolution. (min,+) - convolution has a trivial quadratic time algorithm and it has been conjectured that this cannot be improved significantly. Finally we show for the feasibility problem also a tight lower bound, which is based on the Strong Exponential Time Hypothesis (SETH), and give some applications for knapsack and scheduling problems. This is joint work with Lars Rohwedder.

Keywords: Integer program • Strong exponential time hypothesis • Pseudo-polynomial time

Optimization and Inverse Problems

Sergey Kabanikhin

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Abstract. Inverse problems arise in many applications in science and engineering. The term "inverse problem" is generally understood as the problem of finding a specific physical property, or properties, of the medium under investigation, using indirect measurements. In general, an inverse problem aims at recovering the unknown parameters of a physical system which produces the observations and/or measurements. Such problems are usually ill-posed. This is often solved via two approaches: a Bayesian approach which computes a posterior distribution of the models given prior knowledge and the regularized data fitting approach which chooses an optimal model by minimizing an objective taking into account both fitness to data and prior knowledge. Optimization plays an important role in solving many inverse problems. Indeed, the task of inversion often either involves or is fully cast as a solution to an optimization problem. In this talk, we discuss current state-of-the-art optimization methods widely used in inverse problems. We then survey recent related advances in addressing similar challenges in problems faced by the machine learning community and discuss their potential advantages for solving inverse problems.

Keywords: Inverse problem • Optimization • Machine learning

Minimum Sum of Squares Clustering for Big Data – Heuristic Approach

Nenad Mladenovic

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Abstract. We first present a review of local search methods that are usually used to solve the minimum sum-of-square clustering (MSSC) problem. We then present some their combinations within Variable neighbourhood descent (VND) scheme. They combine *k*-means, *h*-means and *j*-means heuristics in a nested and sequential way. To show how these local searches can be implemented within a metaheuristic framework, we apply the VND heuristics in the local improvement step of variable neighbourhood search (VNS) procedure. Computational experiments are carried out which suggest that this new and simple application of VNS is comparable to the state of the art. Then we discuss some decomposition and aggregation strategies for solving MSSC problem with huge data sets. Following the recent Less is more approach, the data set is divided randomly into a few smaller subproblems and after solving, the centroids of each subproblem is chosen to represent its cluster for a new aggregation stage. Encouraging computational results on instances of several million entities are presented.

Keywords: Minimum sum-of-square clustering • Variable neighbourhood search • Decomposition

Exploiting Structure in Nonsmooth Optimization

Claudia Sagastizábal

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Abstract. In many optimization problems nonsmoothness appears in a structured manner. Composite structures are found in LASSO-type problems arising in machine-learning. Separable structures result from applying some decomposition technique to problems that cannot be solved directly. This context is frequent in stochastic programming, bilevel optimization, equilibrium problems. The talk will give a panorama of techniques that have proven successful in exploiting structural properties that are somewhat hidden behind nonsmoothness. Throughout the presentation the emphasis is put on transmitting the main ideas and concepts, illustrating with examples the presented material.

Keywords: Optimization • Structural properties

State-of-the-Art on Rates of Convergence and Cost of Iterations of Augmented Lagrangian Methods

Mikhail Solodov

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Abstract. We discuss state-of-the-art results on local convergence and rate of convergence of the classical augmented Lagrangian algorithm. The local primal-dual linear/superlinear convergence is obtained under the sole assumption that the dual starting point is close to a multiplier satisfying the second-order sufficient optimality condition. In fact, in the equality-constrained case, even the weaker noncriticality assumption is enough. In particular, no constraint qualifications of any kind are needed. Classical literature on the subject required the linear independence constraint qualification (in addition to other things). In addition to the most standard form of the augmented Lagrangian algorithm, the general lines of analysis apply also to its variant with partial penalization of the constraints, to the proximal-point version, and to the modification with smoothing of the max-function. Moreover, we show that to compute suitable approximate solutions of augmented Lagrangian subproblems which ensure the superlinear convergence of the algorithm, it is enough to make just two Newtonian steps (i.e., solve two quadratic programs, or two linear systems in the equality-constrained case). The two quadratic programs are related to stabilized sequential quadratic programming, and to second-order corrections, respectively.

Keywords: Convex programming • Augmented Lagrangian methods • Convergence rates

Abstracts of Tutorials

Reinforcement Learning from the Stochastic Optimization Point of View

Alexander Gasnikov

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Abstract. We consider the problem of learning the optimal policy for infinite-horizon Markov decision processes (MDPs). We discuss lower bounds and optimal algorithms for discount and average-reward MDPs with a generative model. We also pay attention to parallelization aspects. In the core of the described approaches lies the idea to relate the problem of learning the optimal policy for MDP with the stochastic optimization algorithms (Mirror Descent type) for optimization reformulations, based on Bellmans' equations (D. Bertsekas).

Keywords: Markov decision process • Reinforcement learning • Stochastic optimization

Equilibrium Traffic Flow Assignment in a Multi-subnet Urban Road Network

Alexander Krylatov

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Abstract. Today urban road network of a modern city can include several subnets. Indeed, bus lanes form a transit subnet available only for public vehicles. Toll roads form a subnet, available only for drivers who ready to pay fees for passage. The common aim of developing such subnets is to provide better urban travel conditions for public vehicles and toll-paying drivers. The present paper is devoted to the equilibrium traffic flow assignment problem in a multi-subnet urban road network. We formulate this problem as a non-linear optimization program and prove that its solution corresponds to the equilibrium traffic assignment pattern in a multi-subnet road network. Moreover, we prove that obtained equilibrium traffic assignment pattern guarantees less or equal travel time for public vehicles and toll-paying drivers than experienced by all other vehicles. The findings of the paper contribute to the traffic theory and give fresh managerial insights for traffic engineers.

Keywords: Non-linear optimization • Traffic assignment problem • Multi-subnet urban road network

A Local Search Scheme for the Inequality-Constrained Optimal Control Problem

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Abstract. This paper addresses the nonconvex optimal control (OC) problem with the cost functional and inequality constraint given by the functionals of Bolza. All the functions in the statement of the problem are state-DC, i.e. presented by a difference of the state-convex functions. Meanwhile, the control system is state-linear. Further, with the help of the Exact Penalization Theory we propose the state-DC form of the penalized cost functional and, using the linearization with respect to the basic nonconvexity of the penalized problem, we study the linearized OC problem. On this basis, we develop a general scheme of the special Local Search Method with a varying penalty parameter. Finally, we address the convergence of the proposed scheme.

Keywords: Nonconvex optimal control • DC-functions • Local search

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