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Edited by G. Goos, J. Hartmanis, and J. van Leeuwen

Christian Bliek Christophe Jermann
Arnold Neumaier (Eds.)

Global Optimization and Constraint Satisfaction

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and Constraint Satisfaction, COCOS 2002
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Revised Selected Papers

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Series Editors

Gerhard Goos, Karlsruhe University, Germany
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Jan van Leeuwen, Utrecht University, The Netherlands

Volume Editors

Christian Bliek
ILOG, 1681-HB2 Route des Dolines, 06560 Valbonne, France
E-mail: bliek@ilog.fr

Christophe Jermann
Laboratoire IRIN, Université de Nantes,
2, rue de la Houssinière, BP 44322 Nantes, France
E-mail: christophe.jermann@irin.univ-nantes.fr

Arnold Neumaier
Institute for Mathematics, University Wien, Strudlhofgasse 4, A-1090 Wien, Austria
E-mail: Arnold.Neumaier@univie.ac.at

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Preface

Continuous constraints are the natural way of representing many practical problems and the knowledge they involve. Such constraints may be simple or complex, linear or nonlinear, and may or may not involve transcendental functions. They are widely used to express chemical or mechanical models, process descriptions, building codes or cost restrictions, for example. Many industrial problems involving continuous constraints can be modelled as continuous constraint satisfaction (CSP) or optimization problems (CSOP, often also called mathematical programs).

In practice, such models are often large in size and nonlinear. There may also be constraints involving integer variables, giving rise to mixed integer nonlinear programs (MINLP). The nonlinearities often result in the presence of multiple solutions, or suboptimal local extrema. The challenge is to find all the solutions of a CSP and verify that all have been found, and, in the case of optimization problems, to find the global optimum and verify that it has been found. Complete solution techniques guarantee that all constraints – e.g., safety conditions or tolerance criteria – are satisfied and the global optima identified. Completeness would thus benefit directly the quality and reliability of decisions or analyses based on the provided solutions. This has obvious implications in many industrial and economic areas.

None of the existing approaches for solving nonlinear CSOPs is fully satisfactory in practice. Nonlinear programming techniques are routinely used and can solve large-scale nonlinear problems. However, they are complete only in the convex case and if roundoff errors are controlled. In contrast, constraint programming solvers preserve completeness, but suffer from poor scalability. However, the respective strengths of mathematical programming and constraint programming appear to be highly complementary, and a number of recent developments show that there is a lot to be gained by merging the different inference techniques they provide and by combining their specific advantages.

The goal of the workshop "Global Constrained Optimization and Constraint Satisfaction" (COCOS 2002), which took place during October 2–4, 2002 in Valbonne-Sophia Antipolis (France), was to bring together the communities from global optimization, mathematical programming and constraint programming, giving the participants the opportunity to promote presentation and discussion of ongoing work on solving techniques for continuous CSP and (MI)NLPs. The workshop focused on complete solving techniques for continuous CSOPs which provide all solutions with full rigor. Less rigorous solution techniques were, however, not excluded, since they may be part of complete relevant techniques; for example, local optimization methods are valuable in quickly locating good points and prospective global minimizers.

Three invited lectures and 26 contributed talks were given at the workshop; papers for two of the invited lectures and 15 of the contributed talks are included in the present proceedings.

Invited lectures. The three invited lectures were given by Chris Floudas, Nick Sahinidis, and Baker Kearfott; excluding the author of the constraint satisfaction package Numerica, Pascal Van Hentenryck, who could not attend the workshop, these are the leaders in providing quality software for complete global optimization and constraint propagation. Specifically, Floudas is the author of αBB, and Sahinidis is the author of BARON, both successful global optimization packages based primarily on convex relaxations. Kearfott is the author of GlobSol, an interval-analysis-based global optimization package that provides results with mathematical guarantee, even in the presence of rounding errors.

Unfortunately, Chris Floudas was too busy to provide a written version of his invited lecture *Deterministic Global Optimization: Theoretical, Computational and Implementation Advances*, where he described αBB and its use in industrial applications, mainly in chemical engineering. (Scanned copies of the slides for his talk can be found at [1].) The present volume contains written versions of the remaining two invited lectures.

The paper *Global Optimization and Constraint Satisfaction: The Branch-and-Reduce Approach* by Nick Sahinidis contains a description of the software package BARON for the global solution of mixed integer nonlinear programs, explaining the factorable programming approach, various convex relaxation procedures, and reduction processes based on constraint propagation and Lagrange multiplier techniques. Some typical results for the BARON package (which is complete apart from the possible adverse effects of rounding errors) on real-life applications are presented at the end; the reader is referred to Nick's recent book for more complete descriptions of these applications and results.

The paper *GlobSol: History, Composition, and Advice on Use* by Baker Kearfott describes GlobSol, a rigorous global optimization system incorporating the state of the art in interval analysis, as far as applications to optimization are concerned. Based on automatic differentiation techniques for obtaining interval gradients and Hessians, interval Newton methods for reducing boxes and verifying optimality conditions are discussed. The algorithmic structure is outlined and some advice on how to use the package is given.

Optimization. Eight contributed papers are primarily concerned with optimization. Nowak, Alperin and Vigerske present the object-oriented library LaGO, which solves mixed integer nonlinear programs using convex relaxations. It combines elements from αBB and BARON with convex quadratic underestimation techniques and heuristics for finding feasible points. Henrion and Lasserre show how techniques from semidefinite programming and algebraic geometry can be used to solve many global optimization problems without the need for branching. It is likely that this new approach, which is complementary to the traditional techniques (convexity, intervals, constraint propagation), will play a significant role in the future of global optimization. Jansson shows that the bounds from linear programming (LP) solvers (which are part of the toolkit of all convexity-based global optimization systems) can be made fully rigorous without excessive additional effort, using a simple postprocessing step that is independent of the LP solver used. This raises the possibility of making systems like αBB, BARON and LaGO, which currently suffer from occasional failures due to rounding error issues, fully rigorous. A paper on the COPRIN project (Merlet et al.) shows how to find the exact range for real roots of polynomials with variable coefficients, a global optimization problem with important applications in robotics. Le Thi discuss the reformulation of several classes of optimization problems (including bilevel linear programs) as difference of convex functions (D.C.) programming problems, thus making them amenable to solution with D.C. optimization algorithms. Petrov presents a heuristic for finding good feasible points, relevant for obtaining good upper bounds in global minimization problems, and thus speeding up the branching part of a complete global search. Schmied solves an engine calibration problem by means of a stochastic multistart global optimization algorithm. Mostafa, Vicente and Wright discuss the identification of relevant constraints for degenerate solutions of optimization problems. While the techniques are local they may be of relevance to global problems since these have special difficulties (excessive branching) at degenerate solutions.

Constraint satisfaction. Five contributed papers are primarily concerned with constraint satisfaction problems. Boddy and Johnson show that even large systems of linear and quadratic constraints (with thousands of variables and up to 140,000 constraints) arising in oil refinery problems can be solved successfully using specially adapted constraint propagation and subdivision stategies. Jaulin gives another successful large-scale application, the state estimation of a satellite, using in place of the traditional (local) Kalman filter estimation an interval-based formulation. Walster and Hansen show how to use interval Newton methods to solve overdetermined equations, when the error in the right-hand side is given by worst-case bounds. Cruz and Baharona discuss higher-order consistency methods for constraint-propagation, and argue that maintaining global hull consistency is an efficient alternative. Vu, Sam-Haroud and Silaghi discuss the problem of representing the solution set of constraint satisfaction problems with a continuum of solutions, where a compact description is essential for an intelligible interpretation of the results.

Benchmarking. Finally, two contributed papers discuss questions related to the comparison of different solvers. Shcherbina et al. describe a benchmarking suite containing over 1000 global optimization and constraint satisfaction problems, coded in the AMPL modeling language, and publicly available (with annotations) on the Web. A benchmarking protocol for comparing results on the benchmarking suite is also proposed. Bussieck et al. discuss the assurance of quality in global optimization codes in the GAMS modeling system environment, and associated efforts for standardizing inexpensive, efficient and reproducible tests. They describe the data collection and analysis tools offered by GAMS, which is applicable to the analysis of solver results whether obtained within or outside the GAMS environment.

The present volume of contributions to global optimization and constraint satisfaction shows that the field is growing towards maturity, becoming more reliable and better scalable to larger problems while still posing numerous challenges for the future.

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Christian Bliek
Christophe Jermann
Arnold Neumaier

References

1. C. Floudas, Deterministic Global Optimization: Theoretical, Computational and Implementation Advances. Slides (132 MB) http://liawww.epfl.ch/Cocos02/invited_talks/Slides_Talk_Floudas.pdf

Organization

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