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Continuous Global Optimization Software: *A Brief Review*

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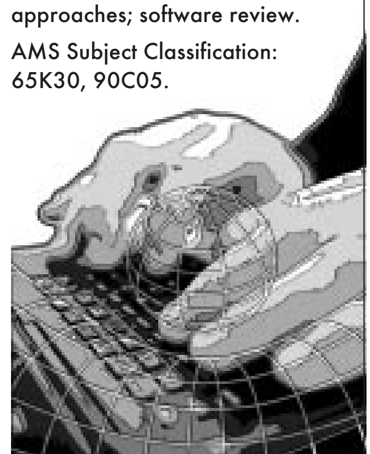
Abstract

Following a concise introduction to multiextremal mathematical programming problems and global optimization (GO) strategies, a commented list of software products for analyzing and solving continuous GO problems is presented.



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1. Global Optimization Models and Solution Approaches

A large variety of quantitative decision issues, arising in the sciences, engineering and economics, can be perceived and modelled as a constrained optimization problem. According to this generic description, the best decision – often expressed by a real vector – is sought which satisfies all stated feasibility constraints and minimizes (or maximizes) the value of an objective function. Applying standard mathematical programming notation, we shall consider problems in the general form

(1) $\min f(x)$ subject to $x \in D \subset R^n$.

The function f symbolizes the objective(s) in the decision problem, and D denotes the (non-empty) set of feasible decisions. D is usually defined by a finite number of functions; for the purposes of the present discussion, we shall assume that

(2) $D = \{x \in D \subset R^n: l \leq x \leq u; \; g_j(x) \leq 0 \; j=1,\ldots,J\}$.

In (2) l and u are explicit (finite) bounds, and g_j are given constraint functions. Postulating now that all functions defined above are continuous, the optimal solution set to problem (1)-(2) is non-empty.

Most typically, it is assumed that the decision problem modelled by (1)-(2) has a unique – locally and, at the same time, also globally – optimal solution. Uniextremality is often implied by the mathematical model structure (for example, by the strict convexity of f, and the convexity of D). This paradigm corresponds to the situation in which one, supposedly, has a sufficiently close initial 'guess' of the feasible region where the optimal solution x* is located. Hence, the global optimality of the solution directly follows, having found the single local optimum of f on D. For example, linear and convex nonlinear programming models – both, in essence, satisfying the mentioned

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uniextremality assumption in most practical cases – have been extensively applied in the past decades to formulate and solve an impressive range of decision problems.

Although very important classes of models naturally belong to the above category, there is also a broad variety of problems in which the property of uniextremality cannot be simply postulated or verified. Consider, for instance, the following general problem types:

• nonlinear approximation, including the solution of systems of nonlinear equations and inequalities
• model fitting to empirical data (calibration, parameterization)
• optimized design and operation of complex 'black box' ('oracle') systems, e.g., in diverse engineering contexts
• configuration / arrangement design (e.g., in various data classification, facility location, resource allocation, or scientific modelling contexts)

Such problems – together with numerous other prospective application areas – are discussed by Pintér (1996) and in the extensive list of related references therein. For further applications consult, e.g., Pardalos and Rosen (1987), Törn and Žilinskas (1989), Floudas and Pardalos (1990, 1992), Grossmann (1996), Bomze, Csendes, Horst and Pardalos (1996), or special application-related issues of the Journal of Global Optimization.

The emerging field of Global Optimization (GO) deals with mathematical programming problems, in the (possible) presence of multiple local optima. Observe that, typically, the number of local (pseudo)solutions is unknown and it can be quite large. Furthermore, the quality of the various local and global solutions may differ significantly. In the presence of such structure – often visualized by 'hilly landscapes' corresponding to projections of the objective function into selected subspaces (given by coordinate-pairs of the decision variable *x*) – GO problems can be extremely difficult. Hence, most classical numerical approaches are, generally speaking, not directly applicable to solve them. For illustration, see Figure 1 which displays a relatively simple composition of trigonometric functions with imbedded polynomial arguments, in just two variables (denoted by *x* and *y*).

Naturally, under such circumstances, it is essential to use a proper global search strategy. Furthermore, instead of 'exact' solutions, most typically one has to accept diverse numerical approximations to the globally optimal solution (set) and optimum value.

Following early sporadic work related to GO (since the late fifties), the present state-of-the-art is characterized by several dozen monographs, a professional journal and at least a few thousand research articles devoted primarily to the subject. A few illustrative references are provided at the end of this brief review.

The most important GO model-classes which have been extensively studied include the following examples. (Please recall the general model form (1)-(2), and note that the problem-classes listed below are not necessarily distinct; in fact, several of them are hierarchically contained by more general problem-types listed.)

• Bilinear and biconvex programming (*f* is bilinear or biconvex, *D* is convex)
• Combinatorial optimization (problems which have discrete decision variables in *f* and / or in g_j can be equivalently reformulated as GO problems in continuous variables)
• Concave minimization (*f* is concave, *D* is convex)
• Continuous global optimization (*f* is continuous, *D* is compact)
• Differential convex (D.C.) optimization (*f* and g_j can all be represented as the difference of two corresponding convex functions)
• Fractional programming (*f* is the ratio of two real functions, and g_j are convex)
• Linear and nonlinear complementarity problems (*f* is the scalar product of two vector functions, *D* is typically convex)
• Lipschitz optimization (*f* and g_j are arbitrary Lipschitz-continuous functions)
• Minimax problems (*f* is some minimax objective, the maximum is considered over a discrete set or a convex set, *D* is convex)
• Multilevel optimization (models non-cooperative games, involving hierarchies of decision-makers, their conflicting criteria are aggregated by *f*; *D* is typically assumed to be convex)
• Multiobjective programming (e.g., when several conflicting linear objectives are to be optimized over a polyhedron)
• Multiplicative programming (*f* is the product of several convex functions, and g_j are convex, or – more generally – multiplicative functions)

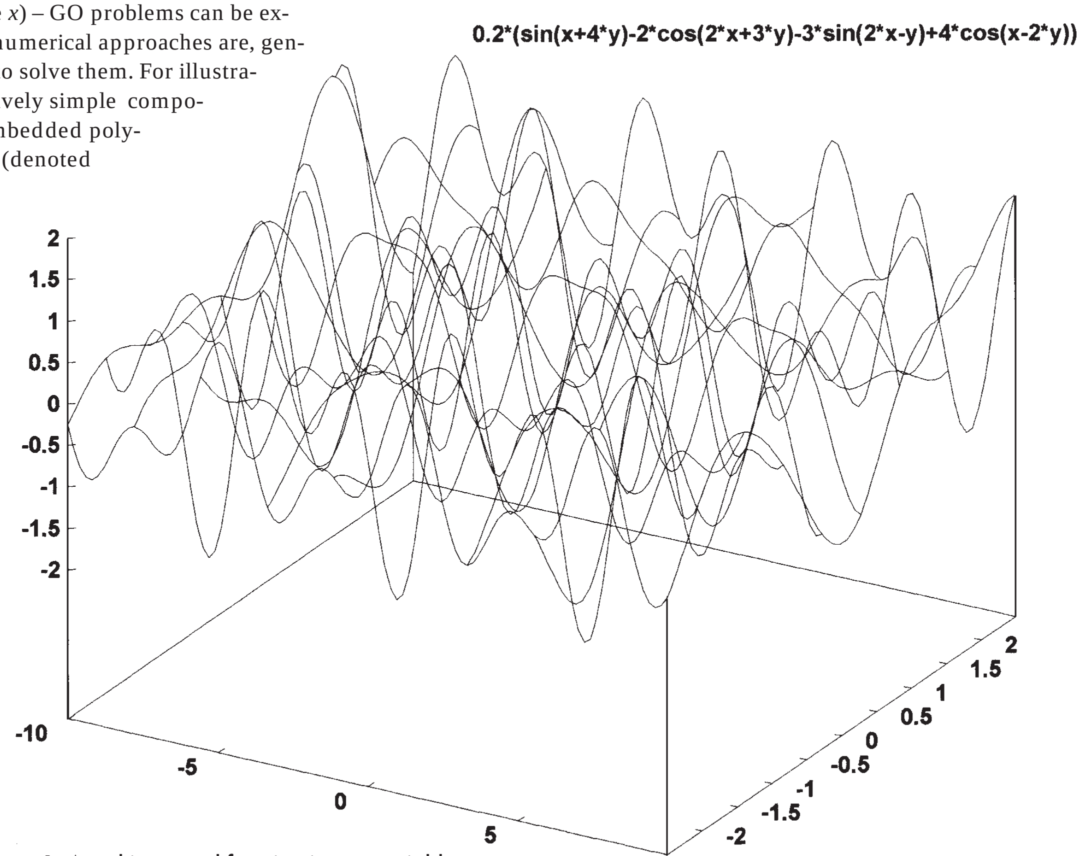

Figure 1. A multiextremal function in two variables

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• Network problems (f can be taken from several function-classes including nonconvex ones, and g_j are typically linear or convex)
• Parametric nonconvex programming (the feasible region D and / or the objective f may also depend on a parameter vector)
• Quadratic optimization (f is an arbitrary – indefinite – quadratic function; g_j are linear or, in the more general case, can be arbitrary quadratic functions)
• Reverse convex programming (at least one of the functions g_j expresses a reverse convex constraint)
• Separable global optimization (f is an arbitrary nonlinear – in general, nonconvex – separable function, D is typically convex)
• Various other nonlinear programming problems, including, e.g., nonconvex stochastic models (in which the defining functions f, g_j depend on random factors, possibly in an implicit, 'black box' manner)

For detailed descriptions of most of these model-types and their connections consult, e.g., Horst and Pardalos (1995), with numerous further references.

There are several main classes of algorithmic GO approaches which possess strong theoretical convergence properties, and – at least in principle – are straightforward to implement and apply. All such rigorous GO approaches have an inherent computational demand which increases non-polynomially, as a function of problem-size, even in the simplest GO instances. It should be emphasized at this point that GO approaches are (should be) typically completed by a 'traditional' local optimization phase – at least when considering also numerical efficiency issues. Global convergence, however, needs to be guaranteed by the global-scope algorithm component which – theoretically – should be used in a complete, 'exhaustive' fashion. These remarks indicate the significant difficulty of developing robust and efficient GO software.

Without aiming at completeness, several of the most important GO strategies are listed below; for details, consult, for instance, the corresponding works from the list of references. (Note that the listing is not complete, and its items are not necessarily mutally exclusive; some software implementations combine ideas from several approaches.)

• Adaptive partition and search strategies (including, e.g., branch-and-bound algorithms, Bayesian approaches and interval arithmetic based methods) (Forgó, 1988; Ratschek and Rokne, 1988; Mockus, 1989; Neumaier, 1990; Zhigljavsky, 1991; Hansen, 1992; Horst and Pardalos, 1995; Horst and Tuy, 1996; Pintér, 1996; Kearfott, 1996)
• Adaptive stochastic search algorithms (including random search, simulated annealing, evolution and genetic algorithms) (van Laarhoven and Aarts, 1987; Zhigljavsky, 1991; Horst and Pardalos, 1995; Michalewicz, 1996; Pintér, 1996)
• Enumerative strategies (for solving combinatorial problems, or certain 'structured' – e.g., concave – optimization problems) (Forgó, 1988; Horst and Pardalos, 1995; Horst and Tuy, 1996)
• 'Globalized' local search methods (applying a grid search or random search type global phase, and a local search algorithm) (Horst and Pardalos, 1995; Pintér, 1996)
• Heuristic strategies (deflation, tunneling, filled function methods, approximate convex global underestimation, tabu search, etc.) (Horst and Pardalos, 1995; Pintér, 1996)
• Homotopy (parameter continuation) methods and related approaches (including fixed point methods, pivoting algorithms, etc.) (Horst and Pardalos, 1995)
• Passive (simultaneous) strategies (uniform grid search, pure random search) (Zhigljavsky, 1991; Horst and Pardalos, 1995; Pintér, 1996)
• Successive approximation (relaxation) methods (cutting plane, more general cuts, minorant construction approaches, certain nested optimization and decomposition strategies) (Forgó, 1988; Horst and Pardalos, 1995; Pintér, 1996)
• Trajectory methods (differential equation model based, path-following search strategies) (Horst and Pardalos, 1995)

In spite of a considerable progress related to the rigorous theoretical foundations of GO, software development and 'standardized' use lag behind. The main reason for this is, of course, the inherent numerical difficulty of GO, even in the case of 'simpler' specific instances (such as, the indefinite quadratic programming problem). In general, the difficulty of a global optimization problem (GOP) can be expected to increase as some exponential function of the problem dimension n. Consequently, dimensions 100, 50 or even 10 can be considered as 'large', depending on the GOP type investigated. In the remainder of this paper, an illustrative list of software products to solve GOPs is reviewed.

2. GO Software: Information Sources and Some General Remarks

For the purposes of collecting information for this survey, GO software authors have been asked (mainly by sending e-mail messages, and by placing 'electronic ads' at several prominent mathematical programming sites on the WWW) to submit documentation related to their work. The information – or lack thereof – summarized below is largely based on the responses received. Additional information has been collected from the Internet, from several GO books, and from the Journal of Global Optimization. Note that though in many research publications reference is made to numerical examples, or even to sophisticated specific applications, only such work is reported below which is understood to be a general purpose and legally distributable program system.

For obvious reasons, the present survey is far from being 'complete' in any possible sense; rather, it is an attempt to provide a realistic picture of the state-of-the-art, supported by instances of existing software. This short review is not intended to be either comparative or 'judgemental': one simple reason being that the information received from GO software developers is used 'as is', mostly without the possibility of actual software testing. By the same token, the accuracy of all information cannot be guaranteed either. Further research in this direction – including the preparation of a more comprehensive and detailed survey – is currently in progress.

The software list provided in the next section is simply alphabetical, without categorization. For a more uniform presentation style, abbreviations are associated with all software products listed, even when such names were not given in the documentation available for this survey (existing names were not changed, of course). The descriptions are almost formula-free and extremely concise – due to space restrictions. For the latter reason, we decided not to include important classes of more specific GO approaches and related methodology. In particular – as reflected by the title – pure or mixed integer programming and more general combinatorial optimization algorithms are not discussed here. Furthermore, although most of the available top-of-the-line continuous nonlinear (convex) optimization software can be applied – with good taste and some luck – to analyze GOPs, even the most prominent such systems are excluded from this review. Again, a more detailed survey is planned, appropriately discussing also the program system types mentioned.

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The hardware and software platform of the systems reviewed is also shown when such information is available. In order to assist in obtaining additional information, contact person(s), their e-mail addresses, ftp and / or WWW sites are listed, whenever known to me. (For brevity, only a few such pointers are provided in each case.)

The reader is assumed to have at least some basic familiarity with the GO approaches mentioned; for related discussions, please consult the references.

3. Short Software Descriptions

αBB ***A GO Algorithm for General Nonconvex Problems***

An implementation of a Branch-and-Bound (B&B) algorithm which is based on the difference of convex functions (D.C.) transformation. Nonconvexities are identified and categorized as of either special or generic structure. Special nonconvex (such as bilinear or univariate concave) terms are convex lower bounded using customized bounding functions. For generic nonconvex terms, convex lower bounding functions are derived by utilizing the parameter α (specified by the user or derived based on theory). αBB solves general unconstrained and constrained problems; it requires MINOS and / or NPSOL for the solution of linear or convex optimization subproblems. (Languages: C and Fortran.) Contact: I.P. Androulakis <androula@titan.princeton.edu>, C.A. Floudas <floudas@titan.princeton.edu>, C.D. Maranas <kmaranas@titan.princeton.edu>, http: / / titan.princeton.edu / .

ANNEAL ***Simulated Annealing***

ANNEAL is based on the core SA approach, including several possibilities for parameter adjustment and a deterministic solution refinement phase. It has been applied to predict complex crystal structures. Workstation implementation. Contact: W. Bollweg <bollweg@math.uni-muenster.de>, H. Maurer <maurer@math.uni-muenster.de>, H. Kroll <kroll@uni-muenster.de>.

ASA ***CalTech Adaptive Simulated Annealing***

ASA was developed to find the global optimum of a continuous non-convex function over a multidimensional interval (box). This algorithm permits an annealing schedule for 'temperature' decreasing exponentially in annealing time. The introduction of re-annealing also permits adaptation to changing sensitivities in the parameter-space. Some other adaptive options in ASA include self-optimize (to find optimal starting conditions) and quenching (to methodically find faster performance that might be useful for large parameter-spaces). (Language: C.) Contact: L. Ingber <ingber@alumni.caltech.edu>, http: / / www.ingber.com / #ASA-CODE.

B&B ***A Family of B&B Algorithms***

This obvious acronym (by the present author) attempts to summarize several B&B type algorithms developed to solve certain structured GOP classes. These include (among others) indefinite quadratic, quasiconvex-concave, and general Lipschitz problems. Workstation implementations. (Language: C.) Contact: R. Horst <horst@orsun3.uni-trier.de>, M. Nast <nast@orsun1.uni-trier.de>, N. Thoai <thoai@orsun2.uni-trier.de>.

BARON ***Branch-And-Reduce Optimization Navigator***

Combines interval analysis and duality with enhanced B&B concepts. The BARON modules can handle structured nonconvex problems up to thousands of constraints and variables. The library of specialized modules includes solvers for numerous specific GOP-classes. (For other, more general problems, underestimation routines need to be provided by the user.) All modules can solve also such problems in which some or all of the variables are restricted to integer values. The specialized modules use OSL or MINOS to solve interim subproblems. Workstations, UNIX type operating systems. (Languages: Fortran and GAMS.) Contact: N.V. Sahinidis, http: / / archimedes.me.uiuc.edu / sigma / baron.html, ftp: / / aristotle.uiuc.edu.

BGO ***Bayesian Global Optimization***

This program system includes four versions of Bayesian search, clustering, uniform deterministic grid, and pure Monte Carlo search. Bound constraints and more general constraints can be handled. Interactive DOS and UNIX versions are available. (Languages: Fortran and C.) Contact: J. Mockus <jonas.mockus@mii.lt>, L. Mockus <mockus@ecn.purdue.edu>.

cGOP ***Global Optimization Program***

Solves structured GOPs which have an objective function of the form $a^T x+b^T y+x^T Ay+f_1(x)+f_2(y)$ with convex f_1, f_2, and linear constraints. Requires the presence of the commercial codes MINOS and / or CPLEX to solve linear, mixed-integer linear and convex subproblems. cGOP has been used to solve problems involving several hundred variables and constraints. Versions are available for workstations. (Language: C.) Contact: V. Visweswaran <vishy@titan.princeton.edu>, C.A. Floudas <floudas@titan.princeton.edu>, http: / / titan.princeton.edu / .

CGU ***Convex Global Underestimator***

This approach is designed to generate efficient approximations to the global minimum of a multiextremal function, by fitting a convex function to the set of all known (calculated) local minima. This heuristically attractive strategy requires only the sequential solution of auxiliary LPs and some rather elementary calculations. CGU has been applied to calculate molecular structure predictions, up to several dozen variables. Implemented on parallel workstations and supercomputers. Contact: K.A. Dill, A.T. Phillips <phillips@haney.scs.usna.navy.mil>, J.B. Rosen <rosen@cs.umn.edu>.

CRS ***Controlled Random Search***

This is a recently developed variant of a popular class of random search based methods which can be applied under very mild analytical conditions imposed on the GOP. Several other related stochastic search methods have also been developed by this group. Workstation implementations. Contact: M.M. Ali, A. Törn <torn@finabo.abo.fi>, S. Viitanen <sami.viitanen@abo.fi>.

CURVI ***Bound-Constrained Global Optimization***

Windward Technologies (WTI) develops advanced numerical and visualization software, for solving constrained and unconstrained nonlinear optimization problems. One of their solvers, CURVI is aimed at solving bound-constrained nonlinear programs which have a complicated – possibly multiextremal – objective function. (Language: Fortran.) Contact: T. Aird <tomaird@aol.com>, http: / / users.aol.com / WTI / .

DE ***Differential Evolution Genetic Algorithm for Bound Constrained GO***

DE won third place at the 1st International Contest on Evolutionary Computation on a real-valued function test set. It was the best genetic algorithm approach (the first two places of the contest were won by non-GA algorithms). (Languages: Matlab and C.) Contact: R. Storn <storn@icsi.berkeley.edu>, http: / / http.icsi.berkeley.edu / ~storn / code.html.

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ESA *Edge Searching Algorithm*

An implementation of an edge search algorithm for finding the global solution of linear reverse convex programs. ESA is based on an efficient search technique and the use of fathoming criteria on the edges of the polytope representing the linear constraints. In addition, the method incorporates several heuristics, including a cutting plane technique which improves the overall performance. Implemented for several UNIX platforms; the TPG Test Problem Generator is also available. (Language: Fortran.) Contact: K. Moshirvaziri <moshir@beach.csulb.edu>, <moshir@ee.ucla.edu>.

GA *Genetic Algorithms*

Genetic algorithms – as a rule – can be applied to GOPs under mild structural requirements. Both general and specific information related to this popular solver class is available from the following sources: – A Commented List of Genetic Algorithm Codes, ftp://ftp.germany.eu.net/pub/research/softcomp/ec/faq/www/q20_1.htm – GA Archive, http://www.aic.nrl.navy.mil/galist/src/. Only a few illustrative examples are listed in the present review.

GAS *Genetic Algorithm*

Unconstrained and bound-constrained versions are available. For DOS and UNIX operating systems. (Language: C++.) Contact: M. Jelasity <jelasity@inf.u-szeged.hu>, J. Dombi <dombi@inf.u-szeged.hu>, ftp://ftp.jate.u-szeged.hu/pub/math/optimization/GAS/.

GAucsd *Genetic Algorithm*

Developed and maintained at the University of California, San Diego. GAucsd was written in C under Unix but should be easy to port to other platforms. The package is accompanied by brief information and a User's Guide. (Language: C.) Contact: nici@ucsd.edu, GAucsd-request@cs.ucsd.edu, ftp://cs.ucsd.edu/pub/GAucsd/.

GENERATOR *Genetic Algorithm Solver*

This method is aimed at solving a variety of (combinatorial and continuous multiextremal) scientific and engineering optimization problems. It is designed to interact with Excel which serves as a user interface. (Platform: Excel.) Contact: New Light Industries <nli@comtch.iea.com>, http://www.iea.com/~nli/.

GC *Global Continuation*

GC is a continuation approach to GO applying global smoothing in order to derive a simpler approximation to the original objective function. GC is applied by the authors to distance geometry problems, in the context of molecular chemistry modelling. IBM SP parallel system implementation. Contact: J.J.Moré <more@mcs.anl.gov>, Z. Wu.

GENOCOP III *Genetic Algorithm for Constrained Problems*

Solves general GOPs, in the presence of additional constraints and bounds (using quadratic penalty terms). System parameters, domains, and linear inequalities are input via a data file. The objective function and any nonlinear constraints are to be given in appropriate C files. (Language: C.) Contact: Z. Michalewicz, http://www.coe.uncc.edu/~zbyszek/gcreadme.html, ftp://ftp.uncc.edu/coe/evol/genocopIII.tar.Z.

GEODES *Minimum-Length Geodesic Computing*

Approximating a minimum-length geodesic on a multidimensional manifold, GEODES is differential geometry software. However, it has potential also in the GO context. GEODES includes example manifolds and metrics; it is implemented in Elements (a matrix and function oriented scientific modelling environment) to compute and visualize geodesics on 2D surfaces plotted in 3-space. Portable to various hardware platforms. (Languages: C, C++.) Contact: W.L. Anderson <elements@ix.netcom.com>, http://www.netcom.com/~elements/, http://www.netlib.org/ode/geodesic/.

GLO *Global and Local Optimizer*

GLO is a modular optimization system developed for 'black box' problems in which objective function calculations may take a long time. Its methodology is based on the coupling of global (genetic) and local (variable metric) nonlinear optimization software with scientific applications software. It has been applied to automated engineering design. Besides the modular optimization control system, GLO also has a graphical user interface and includes a pre-processor. Contact: M.J. Murphy, http://www.llnl.gov/glo/09glo.html, M. Brosius <brosius2@llnl.gov>.

GLOBAL *Multistart with Stochastic Clustering*

GLOBAL can be used for the solution of the general bound-constrained GOP which has a (measurable) real objective function. The algorithm is a derivative-free implementation of the clustering stochastic multistart method of Boender et al., supplemented with a quasi-Newton local search routine and with a robust random local search method. Available for UNIX machines, IBM-compatible mainframes and PCs. (Languages: Fortran and C.) Contact: T. Csendes <csendes@inf.u-szeged.hu>, http://www.inf.u-szeged.hu/~csendes/, ftp://ftp.jate.u-szeged.hu/pub/math/optimization/index.html.

GLOBALIZER *An Educational Program System for Global Optimization*

Serves for solving univariate GOPs. After stating the problem, the user can choose among various (random search, B&B based, or Bayesian partition based) solver techniques. The software has interactive tutoring capabilities, provides textual and graphical information. Works on PCs, under MS-DOS. Contact: R.G. Strongin <strongin@nnucnit.nnov.su>, V.P. Gergel, A.V. Tropichev.

GLOPT *Constrained Global Optimization*

Solves GOPs with a block-separable objective function subject to bound constraints and block-separable constraints; it finds a nearly globally optimal point that is near to a true local minimizer. GLOPT uses a B&B technique to split the problem recursively into subproblems that are either eliminated or reduced in their size. It includes a new reduction technique for boxes and new ways for generating feasible points of constrained nonlinear programs. The current implementation of GLOPT uses neither derivatives nor simultaneous information about several constraints. (Language: Fortran.) Contact: A. Neumaier <neum@cma.univie.ac.at>, S. Dallwig and H. Schichl.

GOPP *Global Optimization of Polynomial Problems using Gröbner Bases*

The (local) optimality conditions to polynomial optimization problems lead to polynomial equations, under inequality constraints. Applying recent Gröbner basis techniques, this approach is aimed at finding all solutions to such systems, hence also finding global optima. (Language: Maple.) Contact: K. Hagglof <kroffa@math.kth.se>, P.O. Lindberg <pol@math.kth.se>, L. Svensson <larss@math.kth.se>, http://www.optsyst.math.kth.se.

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GOT ***Global Optimization Toolbox***

GOT combines random search and local (convex) optimization. DOS and HP UX versions are available. (Language: Fortran.) Contact: A.V. Kuntsevich <kun@d120.icyb.kiev.ua>.

GSA ***Generalized Simulated Annealing***

GSA is based on the generalized entropy by Tsallis. The algorithm obeys detailed balance conditions and, at low 'temperatures', it reduces to steepest descent. (Note that the members of the same research group have been involved in the development of several SA type algorithms.) Contact: J.E. Straub <straub@chem.bu.edu>, P.Amara <amara@chem.bu.edu>, J. Ma <jma@chem.bu.edu>.

IHR ***Improving Hit-and-Run***

IHR is a random search based GO algorithm that can be used to solve both continuous and discrete optimization problems. IHR generates random points in the search domain by choosing a random direction and selecting a point in that direction. Versions have been implemented, using different distributions for the random direction, as well as several ways to randomly select points along the search line. The algorithm can also handle inequality constraints and a hierarchy of objective functions. IHR has been used to solve GOPs in various disciplines such as in engineering design. Contact: Z. Zabinsky <zelda@u.washington.edu>, ftp://ftp.bart.ieng.washington.edu.

IMINBIS ***Interval Arithmetic Based GO***

This method applies interval arithmetic techniques to isolate the stationary points of the objective function. Next, a topological characterization is used to separate minima from maxima and saddle points, followed by local minimization (sub)searches to select the global solution. The method has been applied also to 'noisy' problems. Workstation and PC implementations, extensive related research. (Language: Fortran.) Contact: M.N. Vrahatis <vrahatis@mars.math.upatras.gr>, D.G. Sotiropoulos <dgs,@math.upatras.gr>, E.C. Triantaphyllou.

INTBIS ***Global Solver for Polynomial Systems of Equations***

Finds all solutions of polynomial systems of equations, with rigorously guaranteed results. The software package INTBIS is ACM-TOMS Algorithm 681; it is available through NETLIB. Distributed with the package are four source code files, sample input and output files, and a brief documentation file. The source files consist of the following: interval arithmetic, stack management, core INTBIS routines, and machine constants. (Language: Fortran.) Contact: R.B. Kearfott <rbk@usl.edu>, http://interval.usl.edu/kearfott.html, ftp://interval.usl.edu/pub/interval_math/intbis/.

INTOPT_90 ***Verified (Interval) Global Optimization***

Serves to the verified solution of nonlinear systems of equations and unconstrained and bound-and-equality-constrained global optimization. Based on exhaustive search, driven by a local optimizer, epsilon-inflation, interval Newton methods, and interval exclusion principles; uses automatic differentiation. Test results with hundreds of test examples. The underlying interval arithmetic package (ACM TOMS Algorithm 737) is also distributed. Workstation and PC implementations. (Language: Fortran.) Contact: R.B. Kearfott <rbk@usl.edu>, http://interval.usl.edu/kearfott.html, ftp://interval.usl.edu/pub/interval_math/intbis/.

INTGLO, INTGLOB ***Integral Global Optimization***

These methods solve unconstrained and constrained, as well as discrete GOPs by the integral method. They also include a discontinuous penalty function approach for constrained problems. Problems up to one hundred variables have been solved. A set of test problems is also available, including box or unconstrained, constrained, concave minimization, discrete variable programs and multicriteria programs. For IBM PCs. (Language: Fortran.) Contact: Q. Zheng <qzheng@linden.msvu.ca>, D. Zhuang <deming.zhuang@msvu.ca>.

ISA ***Inductive Search Algorithm***

ISA won first place at the 1st International Contest in Evolutionary Computation on a real-valued function test-suite. (Language: C++.) Contact: G. Bilchev, information available at http://solon.cma.univie.ac.at/~neum/glopt/test_results.html#bilchev.

LGO ***Continuous and Lipschitz Optimization***

Solves bound-constrained and more general GOPs under mild structural requirements; it can be applied also to 'black box' problems. LGO integrates several global (adaptive partition and random search based) and local (derivative-free conjugate directions type) strategies: these can be activated in interactive or automatic execution modes. The PC version has a menu interface to assist the application development process, includes a concise information / tutoring session, and has visualization capabilities. Available also for workstations. LGO has been applied to problems with up to 100 variables (can be configured to encompass larger sizes). Accompanied by a User's Guide and sample problems. (Language: Fortran.) Contact: J.D. Pintér <pinter@tuns.ca>, http://www.tuns.ca/~pinter/.

LOPS ***Lipschitz Optimization Program System***

In all approaches listed below, the objective function is defined over n-intervals. The Lipschitz-continuity of f or f' is also assumed. Problem-classes and corresponding available versions include: one-dimensional GOPs (sequential methods with local tuning, PC version (Language: C++) – one-dimensional GOPs, parallel solver implementations (Language: Alliant FX/80, parallel Fortran) – multi-dimensional GOPs: sequential and parallel algorithms using Peano curves (Language: Alliant FX/80, parallel Fortran) Contact: Y.D. Sergeyev <yaro@si.deis.unical.it>.

MAGESTIC ***Data Fitting by Global Optimization***

Automatic global optimization based on a fast modified Gauss-Newton approach combined with Monte Carlo search. MAGESTIC handles calibration model variants (e.g., parameter and error masks for restricted sub-fitting, implicit equation fitting without solving, etc.). Suitable for use also with Lagrange multipliers for constrained optimization. Uses Excel as an interface (under Windows) and for generating graphics. (Platform: Excel.) Contact: Logix Consulting <magestic@lgx.com>, http://www.lgx.com/magestic.html.

MULTISTART ***Clustering Algorithm***

This widely used approach is based on random search – or some other initial sampling in the feasible set – combined with clustering and local optimization launched from the most 'promising' point(s). Implemented on SUN workstations. Several interesting applications – in combination with simulation models – are related to the analysis of oil resources. (Language: Fortran.) Contact: S. Buitrago <saul.intevep.pdv.com>.

GO CONTINUED

NETSPEAK ***General Network Optimization***

This is an algebraic modelling language used to specify, solve, and analyze general – linear, but also possibly nonconvex – minimum cost network flow problems. A wide variety of network and network-related topologies (pure networks, networks with side-constraints and / or side variables, generalized networks) can be modelled using NETSPEAK. The language is being developed as a Windows application; it features flexible I / O, robust program control, and intuitive commands. Contact: B.W. Lamar <bwlamar@canterbury.ac.nz>.

PA ***Packet Annealing***

In PA, the Gibbs distribution of the objective function is deterministically 'annealed' by tracing the evolution of a multiple Gaussian packet approximation. The approach has been applied to analyze complex molecular conformation models. IBM PC implementation. Contact: D. Shalloway <dis2@cornell.edu>, B.W. Church <bwc1@cornell.edu>, M. Oresic <matej@lancelot.bio.cornell.edu>.

PROFIL ***Interval Branch and Bound Method***

Bound constrained interval global optimization, with rigorously guaranteed results. PROFIL is based on BIAS (Basic Interval Arithmetic Subroutines) which provides an interface for interval operations. For PC and a number of UNIX systems. (Language: C.) Contact: C. Jansson, O. Knueppel <knueppel@tu-harburg.d400.de>, http: / / www.ti3.tu-harburg.de / Software / PROFILEnglisch.html, ftp: / / ti3sun.ti3.tu-harburg.de / pub / profil / unix / profopt.tar.Z, ftp: / / ti3sun.ti3.tu-harburg.de / pub / profil / pc / profopt.tgz.

PVGO ***Parallel Verified Global Optimization***

PVGO is a new parallel method for interval global optimization. Implemented on a Connection Machine CM5. (Language: Pascal-XSC.) Contact: S. Berner <sonja@math.uni.wuppertal.de>.

RSBB ***Reduced Space Branch-and-Bound Method***

RSBB applies variable domain reductions and an underestimating module. Two versions run under Unix; one of these algorithms is described in Chapters 1 and 2 of Grossmann (1996). (Language: both versions in C++, they use external Fortran procedures.) Contact: T. Epperly, t.epperly@ic.ac.uk, http: / / www.ps.ic.ac.uk / ~epperly / index.html.

SA ***Simulated Annealing***

In addition to the algorithm itself, this includes on-line interactive demonstration, and additional information on C++ classes , random number generation, Monte Carlo methods and Forth. A Nelder-Mead simplex method implementation is also available. (Languages: C, C++, Ada and Forth.) Contact: E. Carter, Taygeta Scientific Inc. <skip@taygeta.com>, http: / / www.taygeta.com / annealing / simanneal.html.

SAT ***Global Optimization for Satisfiability Problems***

Boolean satisfiability (SAT) problems can be directly transformed into unconstrained GOPs. These, in turn, can be solved by specifically tailored solvers. Workstation implementations. Contact: J. Gu <gu@enel.ucalgary.ca>.

SIGMA ***Stochastic Integration Global Minimization Algorithm***

The software package SIGMA is Algorithm 667; appeared in ACM-TOMS 14 (1988) 366-380. Includes also the code of several test GOPs. (Language: Fortran.) Contact: F. Aluffi-Pentini, V. Parisi and F. Zirilli <apzrm@itcaspur.caspur.it>, http: / / www.netlib.no / netlib / toms / 667.

SIMANN ***Simulated Annealing***

This program implements the continuous simulated annealing global optimization algorithm described in Corana et al., ACM TOMS 13 (1987) No. 3, 262-280. Algorithm modifications and many details on its use can be found in Goffe et al., J. of Econometrics 60 (1994) No. 1-2, 65-100. (Language: Fortran.) Contact: B. Goffe, <bgoffe@whale.st.usm.edu>, http: / / www.netlib.no / netlib / opt / simann.f.

SOLVEX ***Solver for Nonlinear Optimization Problems***

For solving constrained and unconstrained nonlinear, multiobjective and GOPs. SOLVEX algorithm libraries include the methods listed below: unconstrained minimization: Hooke-Jeeves direct search, conjugate gradient method, Shor R-algorithm, Powell-Brent method; general nonlinear programming problem: penalty functions, Lagrange function method, parameterization method; global optimization: sequential set covering technique, simulated annealing, clustering algorithm; multicriteria optimization: convolution methods, including goal programming, direct Pareto approximation. Interactive use enhanced by a built-in problem editor and graphics capabilities. Contact: M.A. Potapov <potapov@sms.ccas.msk.su>.

TORUS ***Stochastic Algorithm for Global Minimization with Constraints***

It is a Monte Carlo algorithm, combined with annealing search principles. The software package TORUS is Algorithm 774; appeared in ACM-TOMS 21 (1995) 194-213. Includes also the code of several test GOPs. Contact: F. M. Rabinowitz, http: / / www.netlib.no / netlib / toms / 744.

TRUST ***Terminal Repeller Unconstrained Subenergy Tunneling***

This method formulates the GOP as the solution of a deterministic dynamical system incorporating terminal repellers and a subenergy tunneling function. Benchmark tests comparing this method to other global optimization procedures are presented, with favourable results. The TRUST formulation leads to a simple stopping criterion. In addition, the structure of the equations enables an implementation of the algorithm in analog VLSI hardware (in the spirit of artificial neural networks) for further speed enhancements. Contact: B.C. Cetin, J. Barhen and W. Burdick; TRUST is described in JOTA 77 (1993) No. 1.

TVC ***Toolbox for Verified Computing***

Can be applied to the rigorous solution of nonlinear systems of equations and to general unconstrained and bound-constrained GOPs. TVC is based on interval B&B and interval Newton methods; it also has automatic differentiation capabilities. The toolbox can be used on PCs, workstations and parallel computers. (Languages: PASCAL-XSC, C++.) Test problems have been solved up to one hundred variables. A driver program and hundreds of test examples are available from the author. Contact: D. Ratz <toolbox-xsc@math.uni-karlsruhe.de>, http: / / www.uni-karlsruhe.de / ~iam, http: / / ourworld.compuserve.com / homepages / numerik_software.

UFO ***Universal Functional Optimization***

Interactive modular system for solving problems and for algorithm development. Several types of GO methods – random search, continuation, clustering, and random plus local search – can be applied. For PCs. (Language: Fortran.) Contact: L. Luksan <luksan@uivt.cas.cz>, M. Tuma, M. Siska, J. Vlcek and N. Ramesova, ftp: uivt.cas.cz / pub / msdos / ufo.

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O P T I M A

GO CONTINUED

UNICALC *Interval Branch and Bound Algorithm*

UNICALC serves for bound-constrained GO; accepts also inequality and/or equality constraints and decision variables. Contact: A. Semenov, information available at ftp://ftp.iis.nsk.su/pub/ai/unicalc.

VerGO *Verified Global Optimization*

VerGO is designed for rigorous bound (and approximate general constrained) GO of a twice continuously differentiable objective function. VerGO features include interval arithmetic, automatic differentiation, non-convexity test, monotonicity test, and local optimization. Tested on problems up to over 30 variables. DOS, OS/2, Linux and workstation versions. (Language: C++.) Contact: R. van Iwaarden <rvaniwaa@cs.hope.edu>, http://www.cs.hope.edu/~rvaniwaa/VerGO/VerGO.html.

VTT *Interval Arithmetic Research*

The goals of the Interval Arithmetic, Constraint Satisfaction and Probability Project are summarized as follows: development of portable C++ libraries for interval programming tasks; integration of the libraries to Microsoft Excel; application in financial planning software products (Platforms: C++, Excel.) Contact: S. De Pascale <Stefano.Depascale@vtt.fi>, http://www.vtt.fi/tte/.

4. Acknowledgements

The software review presented here is based to a significant extent on information kindly provided by colleagues working on GO and/or closely related areas. I would like to especially thank Arnold Neumaier and Simon Streltsov for the information collected on their WWW Global Optimization Pages (respectively, http://solon.cma.univie.ac.at/~neum/glopt/, and http://cad.bu.edu/go/). I also wish to thank Faiz Al-Khayyal for his valuable comments on the manuscript.

The space (and time) limitations of this review certainly have made it illusory to include 'all' existing software on this rapidly changing area; omissions are entirely possible but absolutely unintentional. It is planned to continue this work and to provide a more comprehensive and informative picture of the state-of-the-art for the mathematical programming community. Comments and suggestions are most welcome; they will contribute to an 'unabridged' GO software review in the near future.

References

To avoid a superfluously long listing, the reference list is reduced to the most topical journal, and to several GO monographs and handbooks published in the past ten years.

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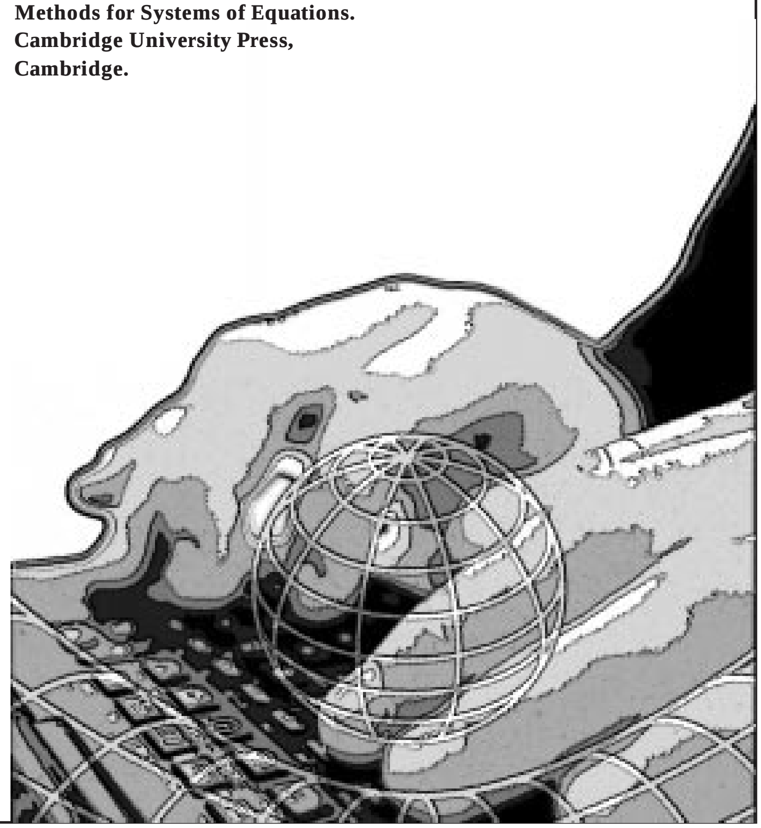
van Laarhoven, P.J.M. and Aarts, E.H.L. (1987) Simulated Annealing: Theory and Applications. Kluwer Academic Publishers, Dordrecht / Boston / London.

Zhigljavsky, A.A. (1991) Theory of Global Random Search. Kluwer Academic Publishers, Dordrecht / Boston / London.



Nominations for the A.W. Tucker Prize

Extended Deadline

The Mathematical Programming Society invites nominations for the A.W. Tucker Prize for an outstanding paper authored by a student. The award will be presented at the International Symposium on Mathematical Programming in Lausanne (August 24-29, 1997). All students, graduate and undergraduate, are eligible. Nominations of students who have not yet received the first university degree are especially welcome. In advance of the Symposium an award committee will screen the nominations and select at most three finalists. The finalists will be invited, but not required, to give oral presentations at a special session of the Symposium. The award committee will select the winner and present the award prior to the conclusion of the Symposium. The members of the committee for the 1997 A.W. Tucker Prize are Kurt Anstreicher, Department of Management Sciences, University of Iowa; Rolf Moehring, Fachbereich Mathematik, Technical University of Berlin; Jorge Nocedal, EECS Department, Northwestern University; Jean-Philippe Vial (Chairman), HEC/Management Studies, University of Geneva; David Williamson, IBM T.J. Watson Research Center, Yorktown Heights.

Eligibility The paper may concern any aspect of mathematical programming; it may be original research, an exposition or survey, a report on computer routines and computing experiments, or a presentation of a new and interesting application. The paper must be solely authored and completed after January 1994. The paper and the work on which it is based should have been undertaken and completed in conjunction with a degree program.

Nominations Nominations must be made in writing to the chairman of the award committee as follows:

Jean-Philippe Vial
HEC/Management Studies
University of Geneva
102, Bd Carl-Vogt
CH-1211 Geneva 4
Switzerland
Fax: 41 22 705 81 04
E-mail: jpvial@uni2a.unige.ch

They must be submitted by a faculty member at the institution where the nominee was studying for a degree when the paper was completed. Letters of nomination must be accompanied by a statement that each member of the committee (including the chairman) was sent the following documents: the student's paper; a separate summary of the paper's contributions, written by the nominee, and no more than two pages in length; and a brief biographical sketch of the nominee.

Deadline Nominations must be sent to the chairman and postmarked no later than February 15, 1997.

Addresses of the other members of the committee:

Prof. Kurt M. Anstreicher
Department of Management Sciences
University of Iowa
Iowa City, IA 52242 USA
E-mail: kanstrei@scout-po.biz.uiowa.edu

Prof. Dr. Rolf H. Moehring
Fachbereich Mathematik, Sekr. 6-1
Technische Universitat Berlin
Strasse des 17. Juni 136
10623 Berlin Germany
Fax: 49 30 314-25191
E-mail: moehring@math.tu-berlin.de

Prof. Jorge Nocedal
Electrical Engineering and Computer Science
Northwestern University
Evanston, IL 60208-3118 USA
Fax: (847) 467-4144
E-mail address: nocedal@eecs.nwu.edu

Dr. David P. Williamson
IBM T.J. Watson Research Labs
P.O. Box 218
Yorktown Heights, NY 10598 USA
Fax: (914) 945-3434
E-mail: dpw@watson.ibm.com

The above information is reproduced on the web at the address:

http://dmawww.epfl.ch/roso.mosaic/ismp97/tucker.html

Beale-Orchard-Hays Prize

Call for Nominations: Nominations are being sought for the Mathematical Programming Society Beale-Orchard-Hays Prize for Excellence in Computational Mathematical Programming.

Purpose: This award is dedicated to the memory of Martin Beale and William Orchard-Hays, pioneers in computational mathematical programming. To be eligible a paper or a book must meet the following requirements:

1) It must be on computational mathematical programming. The topics to be considered include:

a) experimental evaluations of one or more mathematical algorithms,

b) the development of quality mathematical programming software (i.e. well-documented code capable of obtaining solutions to some important class of MP problems) coupled with documentation of the applications of the software to this class of problems (note: the award would be presented for the paper which describes this work and not for the software itself),

c) the development of a new computational method that improves the state-of-the-art in computer implementations of MP algorithms coupled with documentation of the experiment which showed the improvement, or

d) the development of new methods for empirical testing of mathematical programming techniques (e.g., development of a new design for computational experiments, identification of new performance measures, methods for reducing the cost of empirical testing).

2) It must have appeared in the open literature.

3) If the paper or book is written in a language other than English, then an English translation must also be included.

4) Papers eligible for the 1997 award must have been published within the years 1993 through 1996.

These requirements are intended as guidelines to the screening committee but are not to be viewed as binding when work of exceptional merit comes close to satisfying them.

Frequency and Amount of the Award: The prize is awarded every three years. The 1997 prize of $1500 and a plaque will be presented in August 1997, at the Swiss Federal Institute of Technology (EPFL), Lausanne Switzerland, at the Awards Session of the International Symposium on Mathematical Programming sponsored by the Mathematical Programming Society.

Judgement criteria: Nominations will be judged on the following criteria:

1) Magnitude of the contribution to the advancement of computational and experimental mathematical programming.

2) Originality of ideas and methods.

3) Clarity and excellence of exposition.

Nominations: Nominations must be in writing and include the title(s) of the paper(s) or book, the author(s), the place and date of publication and four copies of the material. Supporting justification and any supplementary materials are welcome but not mandatory. The awards committee reserves the right to request further supporting materials from the nominees.

Nominations should be mailed to:

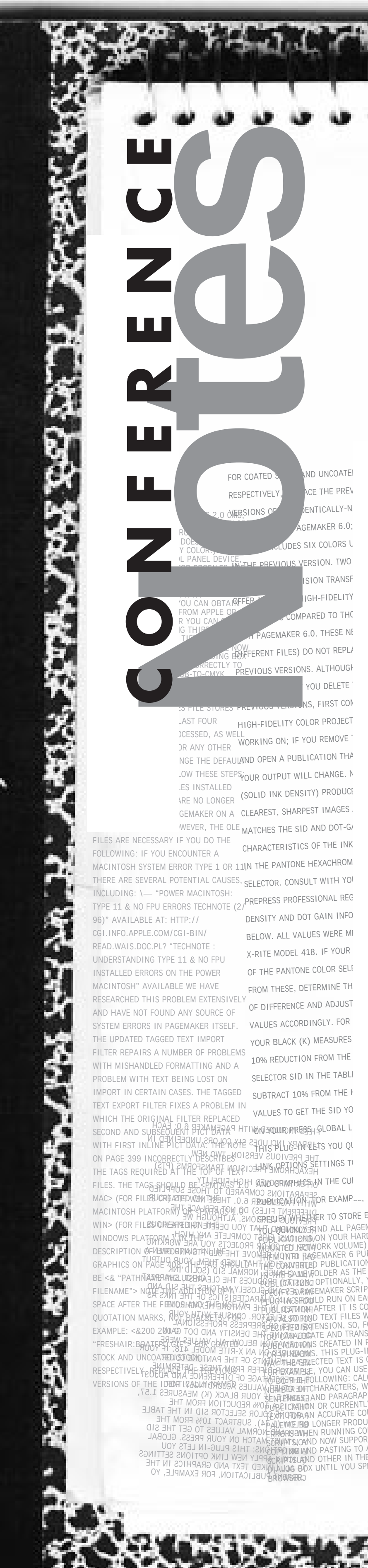
Professor Robert J. Vanderbei
Dept. of Civ. Eng. and Operations Research
ACE-42 Engineering Quad
Princeton University
Princeton, NJ 08544 USA

The deadline for submission of nominations is January 1, 1997.

This call-for-nomination can be viewed online by visiting:

http://www.sor.princeton.edu/~rvdb/BOH97.html

O P T I M A



CONFERENCE Notes

- **Optimal Control: theory, algorithms, and applications**
  Center for Applied Optimization
  University of Florida
  Feb. 27 - March 1, 1997
- **Third Workshop on Models and Algorithms for Planning and Scheduling Problems**
  Cambridge, England
  April 7-11, 1997
- **5th Twente Workshop on Graphs and Combinatorial Optimization**
  University of Twente
  Enschede, The Netherlands
  20 - 22 May 1997
- **MPDP-19 Nineteenth Symposium on Mathematical Programming with Data Perturbations**
  The George Washington University, Washington, DC
  May 22-23, 1997
- **XVI International Symposium on Mathematical Programming, Lausanne Switzerland, Aug. 1997**
- **ICM98**
  Berlin, Germany
  August 18-27, 1998

5th Twente Workshop on Graphs & Combinatorial Optimization

University of Twente, Enschede, The Netherlands
20 - 22 May 1997

The Twente Workshop on Graphs and Combinatorial Optimization is organized biennially at the Faculty of Applied Mathematics at the University of Twente. Topics are theory of graphs and discrete algorithms (both deterministic and random) and their applications in operations research and computer science.

We have attempted to keep a "workshop atmosphere" and thus far have succeeded in scheduling no more than two parallel presentations. Costs have been kept as low as possible in order to make the workshop particularly accessible to young researchers.

Prospective speakers are asked to submit an extended abstract of their presentation which will be refereed by a programming committee. The extended abstract should be at least three but not more than four pages in length and should reach the organizers before 28 February 1997.

The accepted extended abstracts will be collected as a conference volume which will be available at the workshop.

The external program committee members include: J.A. Bondy (Lyon), R.E. Burkard (Graz), W.J. Jackson (London), R.H. Moehring (Berlin), H. Sachs (Ilmenau), R. Schrader (Cologne), A. Schrijver (Amsterdam), C. Thomassen (Copenhagen).

A refereed special issue of Discrete Applied Mathematics will be devoted to the proceedings of the workshop.

If you are interested in participating in the 5th TWENTE WORKSHOP, please pre-register now informally and give your complete postal as well as your e-mail address. Indicate whether you would like to give a presentation of about 30 minutes, naming subject and/or title if you know it. Then you should receive a registration form and more detailed information by December 1996.

U. Faigle C. Hoede
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hoede@math.utwente.nl;
hunting@math.utwente.nl

SYMPOSIUM *n e w s*

The number of preregistrations for the 16th International Symposium on Mathematical Programming, to be held in Lausanne, August 24-29 1997, is growing nicely! So far 773 people from 54 countries have preregistered. Some 145 invited sessions have been organized, and 20 speakers have agreed to give plenary or semi-plenary talks.

All people interested in the symposium are encouraged to consult the homepage at the address http://dmawww.epfl.ch/roso.mosaic/ismp97/. Here you can find information about the symposium site and the planned topics, as well as travel information, suggestions regarding accommodation, and a preregistration form.

People from soft currency countries can apply for financial support at their local SOROS foundation. If there is no such foundation in your home country, you can also apply for funding toward meeting the expenses directly to the organizing committee of the Symposium. In the application you should provide justification for the application and provide a title and an abstract of the presentation you intend to give at the Symposium. The applications should be received by April 30, 1997, and can be sent by mail or e-mail to: Chairman of the Organizing Committee Professor Th.M. Liebling, Department of Mathematics, EPFL CH-1015, Lausanne, Switzerland. e-mail: liebling@dma.epfl.ch

On behalf of the Symposium Organizers, Karen Aardal

O P T I M A

Financial Support for INTERNATIONAL CONGRESS OF MATHEMATICIANS Berlin, 1998

The ICM'98 Organizing Committee has already received quite a number of requests concerning financial support for participation at the International Congress of Mathematicians 1998 in Berlin. The Circular Letter ICM98-CL6 describes how mathematicians from developing countries can apply for financial help. The local Organizing Committee is currently making efforts to obtain donations from German industry, government, foundations and individuals to be able to partially support mathematicians from Eastern Europe and the independent states of the former Soviet Union.

To secure participation of as many persons as possible, the local Organizing Committee will only support local costs in Berlin. Berlin is very close to Eastern Europe, and it is expected that applicants will find other means to cover their travel costs.

To handle the applications and manage the financial support the ICM'98 Organizing Committee has set up a subcommittee, Committee for Support of Mathematicians from Eastern Europe (CSMEE).

CSMEE will distribute application forms for grants, as described above, for mathematicians from Eastern Europe in late summer 1997. These forms will be made available through the ICM'98 server (http://elib.zib.de/ICM98) and by e-mail. Applicants will be asked to provide a brief curriculum vitae (including academic education, degree, professional employment, and a list of publications).

Applicants should submit their application form before January 1, 1998 to CSMEE to one of the following addresses:

Prof. Dr. H. Kurke
Humboldt-Universitaet Institut fuer Mathematik
Unter den Linden 6 D-10099 Berlin
Germany

e-mail: kurke@mathematik.hu-berlin.de

Prof. Dr. W. Roemisch
Humboldt-Universitaet
Institut fuer Mathematik Ziegelstrasse 13A
D-10099 Berlin
Germany

e-mail: romisch@mathematik.hu-berlin.de

All applications will be reviewed.

Further questions concerning financial support for mathematicians from Eastern Europe to attend ICM'98 should be directed to Professors Kurke or Roemisch.

More information about ICM98 can be found in the ICM98 WWW-server (URL: http://elib.zib-berlin.de/ICM98). This WWW-server also offers an electronic preregistration form. If you do not have access to the World Wide Web and would like to subscribe to the ICM98 circular letters, just send an e-mail to

icm98@zib-berlin.de
writing
PRELIMINARY PREREGISTRATION
in the SUBJECT line.

MARTIN GRÖETSCHEL, PRESIDENT OF THE ICM98 ORGANIZING COMMITTEE

Call for Papers

Special Issue of Computers & Operations Research:

Travelling Salesman Problem

Computers & Operations Research will publish a special issue on the "Travelling Salesman Problem." Papers are sought in the broad area of the travelling salesman problem and its variations which discuss computational and/or algorithmic aspects. In particular, we are soliciting papers on computational study of exact and/or heuristic algorithms, analysis of heuristics, domination analysis and exponential neighbourhoods, problems with special structures, new applications, etc.

All papers submitted for consideration will undergo standard review process. Four copies of the paper, following the standard guidelines for Computers & Operations Research, should be sent by March 1997 to:

Dr. Abraham Punnen
Dept. of Mathematics, Statistics & Computer Science
University of Brunswick
Saint John, New Brunswick
CANADA E2L 4L5

MPDP-19 Nineteenth Symposium on Mathematical Programming with Data Perturbations

May 22-23, 1997, The George Washington University, Washington, DC

The NINETEENTH Symposium on Mathematical Programming with Data Perturbations will be held at George Washington University's Marvin Center on 22-23 May 1997. The objective is to bring together practitioners who use mathematical programming optimization models, and deal with questions of sensitivity analysis, with researchers who are developing techniques applicable to these problems.

The symposium webpage is :
http://rutcor.rutgers.edu:80/~bisrael/MPDP-19.html

CONTRIBUTED papers in mathematical programming are solicited in the following areas: 1. Sensitivity and stability analysis and their applications; 2. Solution methods for problems involving implicitly defined functions; 3. Solution approximation techniques and error analysis. "CLINICAL" presentations that describe problems in sensitivity analysis encountered in applications are also invited.

DEADLINES: 15 March 1997 Registration and submission of tentative title and abstract;
1 May 1997 Submission of final abstract for inclusion in the Symposium Program

REGISTRATION FEE: $50 USD payable at the meeting.

To REGISTER and/or SUBMIT ABSTRACT please use the electronic form in the URL:
http://rutcor.rutgers.edu:80/~bisrael/MPDP-19.html#form

Or mail to:
MPDP-19
c/o Adi Ben-Israel
RUTCOR - Rutgers Center for Operations Research
P.O. Box 5062
Rutgers University
New Brunswick, NJ 08903-5062, USA

Or email/fax to one of the organizers listed below:

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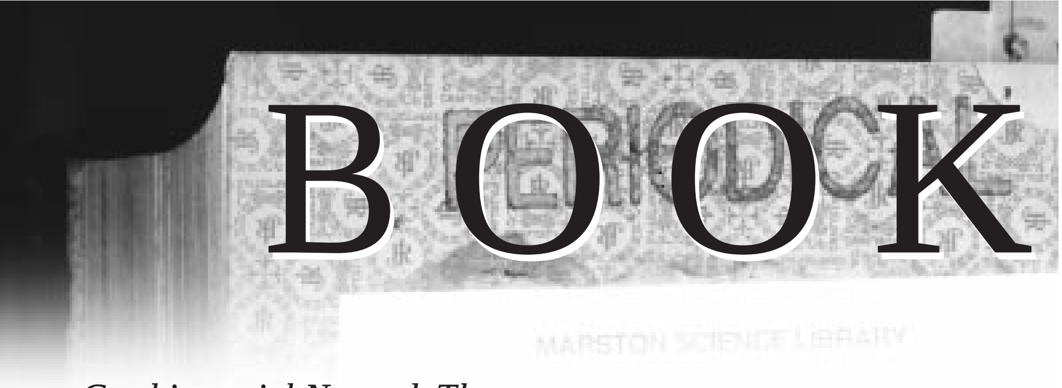
Anthony V. Fiacco, General Chairman

Sponsored by the Dept. of Operations Research & the Institute for Management Science & Engineering, School of Engineering & Applied Science The George Washington University Washington, DC 20052, USA



BOOK reviews

Combinatorial Network Theory

Edited by Ding-Zhu Du and D. Frank Hsu
Series of Applied Optimization
Kluwer Academic Publishers
Dordrecht, 1996
ISBN 0-7923-3777-8

The design of interconnection networks and related theoretical research has received a lot of attention in recent years. A network suitable for parallel computation should satisfy two major requirements. First, a network should have computational efficiency to run parallel algorithms. One of the main overheads incurred during parallel execution is the time spent on communication between processors. Thus, the ability of an interconnection network to disseminate information efficiently is one of the most important properties of a network. Secondly, reliability of a network is another important requirement. An interconnection network should be fault-tolerant so that it can work even if some of its links or nodes fail. This book is devoted to the theoretical study of dissemination of information in interconnection networks and their reliability.

Caley graphs provide suitable candidates for interconnection networks. One of their advantages is their symmetric structure, which makes them easy to build and simplifies routing and communication algorithms. Examples of prominent interconnection networks which are Caley graphs include the Hypercube, the Butterfly and the Cube-Connected-Cycles network. In the first two chapters of the book Caley graphs are considered. Since Caley graphs are defined on groups, group theory provides a powerful tool in the study of Caley graphs.

An extensive study of the connectivity of Caley graphs defined on finite Abelian groups is presented in Chapter 1. Connectivity can be viewed as a measure of the reliability of a network. Along with the presentation of new results, it is shown how some well-known results from the additive group theory were rediscovered and applied to graph-theoretical problems such as that of network connectivity. Unfortunately, this chapter contains many textual mistakes.

The study of edge and vertex connectivity in Caley graphs continues in Chapter 2. In contrast to Chapter 1, most of the proofs in this chapter are obtained by using atoms of graphs.

De Bruijn and Kautz digraphs and their generalizations are other popular candidates for interconnection networks. Their popularity is explained by the fact that these networks have a highly symmetric structure and give optimal or nearly optimal solutions of the problem of minimizing the diameter and maximizing connectivity for a graph with a given number of nodes and degree. Connectivity and diameter are important parameters for both reliability and the ability of a network to disseminate information efficiently. Chapter 3 presents an extensive study of diameter, connectivity, line-connectivity, super-line connectivity and the Hamiltonian property of de Bruijn and Kautz digraphs and their generalizations.

In Chapter 4 various properties (in particular, link connectivity) of extended double loop networks (EDLN) are studied. A large class of EDLN includes such well-known networks as generalized de Bruijn networks, the Imase-Itoh networks and double loop networks. This study shows that certain EDLN networks are suitable candidates for good interconnection networks.

Dissemination of information in interconnection networks is considered in Chapter 5. The three main problems of dissemination of information are broadcasting, accumulation and gossiping. These problems are considered for all well-known interconnection networks under several communication modes. The solutions for these problems are given mainly in terms of lower and upper bounds on communication time. This chapter provides the reader with many basic proof techniques and ideas in this area, gives a good survey of known results and formulates many open problems.

The book is aimed at graduate students and researchers and provides the reader with a deep insight into combinatorial network theory. Some of its chapters (especially Chapter 5) would also be suitable for undergraduate students.

-E.A. STÖHR

State of the Art in Global Optimization

Computational Methods and Applications
Edited by C.A. Floudas and P.M. Pardalos
Nonconvex Optimization and Its Applications 7
Kluwer Academic Publishers
Dordrecht 1996
ISBN 0-7923-3838-3

This is the seventh volume of an excellent and much needed series in "Nonconvex Optimization and Its Applications" put together by leaders in this field. The volume contains 36 invited and thoroughly refereed papers that were presented at the conference on "State of the Art in Global Optimization: Computational Methods and Applications." The conference was organized by C.A. Floudas and P.M. Pardalos and held at Princeton University, April 28-30, 1995. The conference papers spanned the gamut of theory, computational implementations and applications of global optimization.

Among other fine contributions, one finds the following:

• R. Horst and N. van Thoai propose two types of new finite branch and bound algorithms for global minimization of separable concave functions under linear constraints with totally unimodular matrices. The key observation is that the underlying problems can be viewed as integer programs. Finiteness can, therefore, be achieved by integral branching.

• K.G. Ramakrishnan, M.G.C. Resende and P.M. Pardalos report on computational experience with a branch and bound algorithm for Quadratic Assignment Problems. All problems of dimension $n \leq 15$ of QAPLIB are solved.

• R.B. Kearfott reports practical experience with an interval branch and bound algorithm for equality-constrained optimization.

• T. Van Voorhis and F. Al-Khayyal use range reduction techniques to accelerate a branch and bound algorithm for quadratically constrained quadratic programs.

• J.P. Shectman and N.V. Sahinidis prove that exhaustiveness and branching on the incumbent whenever possible in tandem ensure finiteness of rectangular-subdivision-based branch and bound algorithms for global minimization if separable concave programs.

• H. Tuy shows that many important location problems (Weber's problem with attraction and repulsion, constrained multisource and multifacility problems and others) can be formulated as d.c. optimization problems in low-dimensional spaces and describes algorithms for their solution.

Additional articles in the volume are authored by S. Zlobec; E. Novak and K. Ritter; S. Shi, Q. Zheng and D. Zhuang; B. Ramachandran and J.F. Pekny; G. Isac; P. Maponi, M.C. Recchioni and F. Zirilli; G.H. Staus, L.T. Biegler and B.E. Ydstie; V. Visweswaran, C.A. Floudas, M.G. Ierapetritou and E.N. Pistikopoulos; J. Barhen and V. Protopopescu; D. MacLagan, T. Sturge and W. Baritompa; K. Holmqvist and A. Migdalas; D.W. Bulger and G.R. Wood; W. Edmonson, K. Srinivasan, C. Wang and J. Principe; E. Falkenauer; I.P. Androulakeis, V. Visweswaran and C.A. Floudas; T. Qian, Y. Ye and P.M. Pardalos; A. Torn and S. Viitanen; K.I.M. McKinnon, C. Millar and M. Mongeau; E. Haddad; J. Shi and Y. Yoshitsugu; I. Garcia and G.T. Herman; P. Sussner, P.M. Pardalos and G.X. Ritter; J.A. Filar, P.S. Gaertner and M.A. Janssen; W.F. Eddy and A. Mockus; L. Mockus and G.V. Reklaitis; A. Lucia and J. Xu; J.R. Banga and W.D. Seider; M. Turkay and I.E. Grossmann; F. Friedler, J.B. Varga, E. Feher and L.T. Fan; E.S. Fraga.

The above papers cover the theory and algorithms of deterministic global optimization, stochastic global optimization, branch and bound methods, interval arithmetic methods, d.c. programming, duality, concave programming, bilevel programming, integral optimization, decomposition methods, logic-based algorithms, and trust algorithms.

The book is also very rich in applications in resource allocation, computer vision, chemical process design, control and optimization, chemical and phase equilibrium, facility location, climate change dynamic visualization, batch process scheduling, and process synthesis.

One, therefore, cannot help but to fully agree with the editors that "the book will be a valuable source of information to faculty, students and researchers in optimization, engineering, mathematics, computer sciences and related areas."

-NIKOLAOS SAHINIDIS

Postoptimal Analyses, Parametric Programming and Related Topics

Tomas Gal
de Gruyter
Berlin, 1995
ISBN 3-11-014060-8.

This book is the second edition of a monograph first written in the years 1968-1969 in Czech, translated in 1973 to German and in 1979 to English. Each chapter is divided into two parts. The first is based on illustrative examples; the second part is an abridged mathematical presentation. Each chapter ends by a selected bibliography.

This presentation in two parts has the great advantage that the book is easy to read and understand for a wide audience in the first part and is mathematically complete in the second part. It is also a good, quite complete reference on the subject. However, it has two main disadvantages. The first is probably linked to the origin of the book: there remain some typographical errors and inconsistencies in the notations. Furthermore, the references at the end of each chapter often date before 1970. The second disadvantage is an omission: the consideration of the sensitivity analysis results in case of degeneracy. This part is quite poor and recently proposed new results should be introduced.

Chapter one is devoted to fixed basic concepts and notations in linear programming. It recalls all the very well-known concepts in linear programming such as basic variables, reduced cost, dual value, etc. It also recalls the basis of the Simplex method for solving linear problems. The dual problem is also presented with the dual Simplex method and finally the concepts of primal or dual degenerate solutions are presented.

Chapter two is devoted to suboptimal solutions, redundant constraints and degeneracy. For suboptimal solution, the effect on the objective level and on the activities level of producing a nonoptimal activity level is derived from the optimal Simplex tableau. A redundant constraint is defined as a constraint that does not influence the feasible region. A weakly redundant constraint has a point in common with the feasible region. The strongly redundant one does not. This simply means that the associate slack cannot be equalised to zero. This can be easily detected and the corresponding constraint can be deleted. A primal degenerate solution is obtained when some basic variables are equal to zero. This can lead to a degenerate step in the Simplex algorithm: the base changes but the algorithm remains at the same vertex.

Chapter three is devoted to sensitivity analysis with respect to changing right-hand side without basis exchange. The classical sensitivity analysis with a single component of the right-hand side is introduced through a simple example. The same basis remains optimal if the basic variables remain nonnegative. One can deduce a range for the maximal variation of this component. The effect on the optimal basic variables is given by the corresponding column of the inverse of the basic matrix. The effect on the objective function is given by the value of the corresponding dual variable. Then sensitivity analysis with respect to several components of the right-hand side depending on a scalar parameter is examined. Finally, the multiparametric sensitivity analysis case is considered, i.e. changing several components of the right-hand side depending on several parameters.

Chapter four concerns linear parametric programming with respect to change in the right-hand side. This implies in general a basis exchange. The critical values of the parameters are defined as the values for which the optimal basis changes. First, the case of a single change in the right-hand side is considered. Then, a change in several components of the right-hand side is considered. The case where these components change linearly with a single parameter and the case where they change multilinearly with several parameters are both considered.

At the end of this chapter, the problem of sensitivity analysis under primal degeneracy is briefly considered. In fact, the sensitivity analysis with the right-hand side consists of determining the critical interval where the same basis remains optimal. If the optimal solution is degenerate, several optimal bases exist. The critical interval is defined here as the union of all the critical intervals associated with the different optimal bases. Note that the analysis concerning the shadow price that can be different left and right is not very developed here. For a more complete analysis, see, for example, M.P. Williams, Model Building in Mathematical Programming, John Wiley, 1990. Also, the assertion of Gal (see page 175) that commercial LP software offering sensitivity analysis and shadow prices yield false results when primal degeneracy occurs, is not correct. There is one exception that I know: XPRESS-MP of Dash Associated which gives the two (left and right) correct values.

Chapter five concerns sensitivity analysis with respect to changing cost coefficients without basis exchange. Note the very bad choice made for notations: the market price is denoted by c and the unit cost by p (see page 211). The cases of a single change for a nonbasic objective coefficient and for a basic variable objective coefficient are considered. Then the case of changing several cost coefficients depending on a scalar or multiple parameters is considered. In each case the critical region of the parameter (i.e. the region in which the same basis is optimal) is computed.

Chapter six is devoted to linear parametric programming with respect to change in cost coefficients with basis exchange. Since the partial derivative of the optimal value of the objective function with cost coefficient is the value of the primal variables, it is sufficient to compute the successive optimal solutions when the objective coefficients vary. This can be done by changing from basis to adjacent basis, simply by a primal Simplex step. Then the problem of finding the minimal and maximal value of the parameter such that the problem has a bounded optimal solution is considered. It is asserted (see example 6-2, page 239) that the example has no solution for zero value of the parameter. This is false. There is not finite optimal solution. The geometric interpretation (slope change) of cost coefficient change is then given. Then the case of changes depending on several parameters is considered. The chapter ends with the problem of determining the optimal objective cost coefficients where these coefficients can vary homogeneously with a parameter. The consideration of degeneracy is omitted in this chapter.

Chapter seven is dedicated to sensitivity analysis to simultaneous changing of the right-hand side and of the cost coefficients. The objective coefficients and the right-hand side are written here as linear functions of the same parameter. First, the case of changing of the right-hand side and cost coefficient with a scalar parameter is considered. Then the case of the dependence on a vector of parameters is considered.

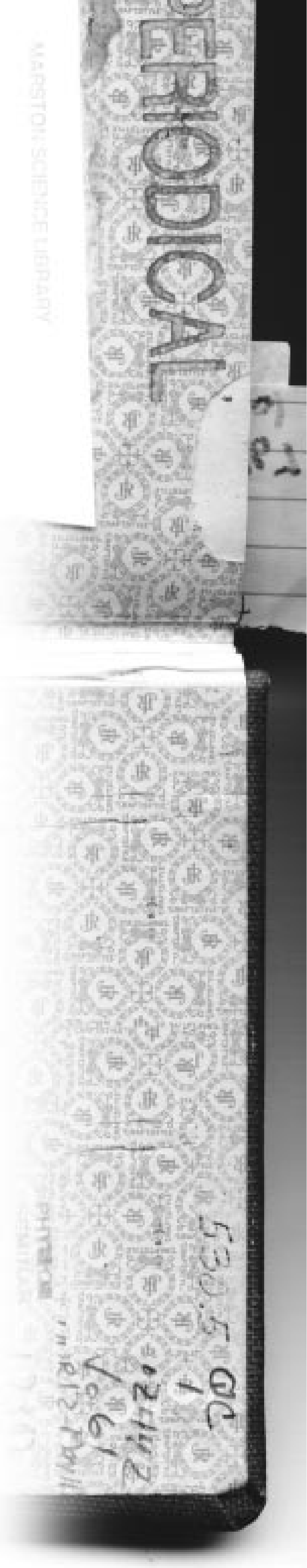
Chapter eight is dedicated to sensitivity analysis with respect to the elements of the technological matrix often noted A in linear problems. The coefficient at the intersection of line i and column j denotes the consumption of the ith production factor per unit of the jth production and can be affected by a change in technology. Two small examples of one column of A depending on a single parameter illustrate the complications which arise from such changes: the optimal value of the objective function varies nonlinearly with this parameter! This chapter is certainly one of the most original as such results are rarely presented in books and most of the time not published. I agree totally with the author when he says that, despite the importance of this sensitivity analysis with respect to matrix coefficients, papers have been rarely published. He cites as examples his CORE discussion papers 7013 and 7018 dating from 1970!

However, I regret that the author directly goes to the case of one column that entirely varies and does not consider the partial derivatives of the optimal value of the objective function with respect to a single coefficient of matrix A. One can derive from the (more complicated) formula of the abridged mathematical presentation of chapter 8 the pretty nice result: this partial derivative is equal to the opposite of the product of the dual optimal value associated with the line of the coefficient by the primal optimal value associated with the column of the coefficient. The degenerate case is also totally omitted. The result however exists: it is forthcoming in Mathematical Programming under the title 'Generalised derivative of the optimal solution of the objective function of a linear problem with respect to matrix coefficient' by D. De Wolf and Y. Smeers.

Chapter nine is dedicated to multicriteria linear programming, i.e. the problem of maximising several conflicting linear goals over a linear feasible region. One can define in this framework an efficient solution as a nondominated solution in Pareto sense: i.e. when trying to improve the value of one goal, the value of at least one of the remaining objective functions becomes worse. A method for determining the set of all efficient solutions is proposed. The reason why multicriteria problems are considered in this book is the following: the so-called Efficiency Theorem states that there is a one-to-one correspondence between efficient solutions and optimal solutions for the homogeneous multiparametric problem that is defined in chapter six. Therefore parametric programming can help to compute efficient solutions for the multicriteria linear problem. Finally, the non-essential objective functions are defined as objective functions that do not affect the set of efficient solutions. By an efficiency test, one can identify these non-essential objectives and thus reduce the number of objective functions to consider.

Chapter ten indicates possible applications of sensitivity analysis and linear parametric programming in decision making. Firstly, if for some reason, one wants to change the value of some basic variables, it is sufficient to change the corresponding right-hand side. Changing the value of some nonbasic value is equivalent to considering a suboptimal solution. Secondly, the problem of the inconsistency of the constraint is considered. For practical applications with thousands of constraints, it often occurs that the solution set is empty (one artificial variable remains positive in phase one). A simple way of removing inconsistency is to change the value of the right-hand side. Thirdly, the problem of redundancy of some linear inequalities is considered. Recall that a redundant constraint is a constraint that does not affect the feasible region. One way for detecting such constraints using sensitivity analysis is to notice that the range of variation of the right-hand side of such constraints varies from minus infinity to plus infinity. In conclusion, sensitivity analysis helps to compute efficient solutions in multicriteria programming (first application), to remove inconsistency (second application) and to detect redundant constraints (third application).

-DANIEL DE WOLF



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Harvey Greenberg has developed a Mathematical Programming Glossary on the Web. URL is http://www-math.cudenver.edu/cudenver.edu/~hgreenbe/glossary/glossary.html and it includes links to several bibliographies. He invites comments and suggestions via a link to his home page. Other useful URLs are the MPS home page http://www.caam.rice.edu/~mathprog/ and the home page for the next Symposium: http://dmawww.epfl.ch/roso.mosaic/ismp97/welcome.html . Deadline for the next OPTIMA is Feb. 15, 1997.

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