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№ 26

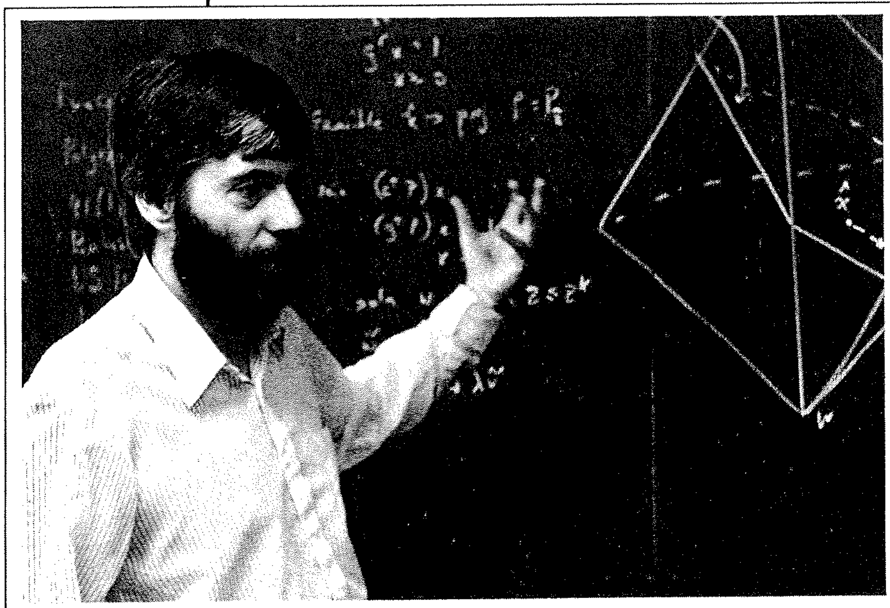
MATHEMATICAL PROGRAMMING SOCIETY NEWSLETTER

APRIL 1989

1988 DANTZIG WINNER

Highlights of Mike Todd's Research

SIAM and MPS have announced the award of the 1988 George B. Dantzig Prize to **Michael J. Todd**, Leon C. Welch Professor in the School of OR and IE at Cornell University. This award, as specified in its charter, is "... for original work, which by its breadth and scope, constitutes an outstanding contribution to the field of mathematical programming." The 1988 Dantzig Prize Committee consisted of O. Mangasarian (Chair), K. Murty, G. Nemhauser and M. Wright. This article highlights certain of Todd's major research contributions.



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TODD received the B.A. degree in mathematics from Cambridge University in 1968 and the Ph.D. degree from Yale University (Department of Administrative Sciences) in 1972. His early research interest was in complementarity and fixed points, initially from an abstract viewpoint. Todd's Ph.D. dissertation [1] introduces an abstract combinatorial setting for complementary pivoting algorithms. These combinatorial structures are also the subject of [2], where a generalized pivoting algorithm is presented and shown to subsume contemporary procedures for complementary pivoting. A convergence proof for the generalized algorithm is also given, along with performance bounds based on the "diameter" of an abstract pivoting system, a notion similar to the pivoting diameter of polytope. This line of research culminates in [3], where dual pairs of abstract pivoting systems are demonstrated to be the circuits of a dual pair of binary matroids, thus linking the subject of complementarity to the rich area of matroid theory. Todd's interest in the combinatorial structure of polytopes is evident once again in [4] with the presentation of a counterexample to the monotonic bounded Hirsch conjecture.

Practical issues related to the actual computation of fixed points quickly began to dominate Todd's work. His research monograph [6] on this subject, *The Computation of Fixed Points and Applications*, is widely known. The presentation of this monograph stresses the basic triangulation as a fundamental component in algorithms for computing fixed points. In order to describe Todd's contributions in this area, the following description of the problem setting, taken from [9], is useful. "Suppose that we seek a zero of a continuous function f from R^n to itself... We then choose a one-to-one affine function f^0: $R^n \rightarrow R^n$ defined by $f^0(x) = Gx - g$ and construct the homotopy h: $R^n \times [0,1] \rightarrow R^n$ by $h(x,ø) = øf(x) + (1 - ø)f^0(x)$. Next we make a piecewise-linear approximation ℓ to h; generally this is done by choosing a triangulation T of $R^n \times [0,1]$, letting ℓ agree with h on the vertices of T and then extending linearly on the simplices... Then a [piecewise-linear] path of zeroes of ℓ is traced from the known zero $(x^0,0)$ where $x^0 = G^{-1}g$. This path either diverges to infinity or produces a zero $(x^1,1)$ of ℓ... x^1 is then an approximate zero of f. The step from x^0 to x^1 is one major iteration." Continuing from [10]: "In order to obtain a sequence converging to a zero of f, a suitable sequence $f^1, f^2, ...,$ of functions is chosen, e.g., [piecewise-linear] approximations with respect to finer and finer meshes."

Todd's initial contributions to fixed point calculation address the dependence of computational efficiency on the particular triangulation used. In [5] Todd begins to quantify this relationship with the introduction of theoretical measures of the efficiency of a triangulation. These measures are based on counting the number of simplices of a triangulation met by certain straight line segments. Such measures are shown to be useful not only in comparing well-known triangulations, but also in suggesting guidelines for the construction of new triangulations.

A natural question raised by the efficiency measures introduced in [5] is whether "optimal" triangulations can be constructed. Though the sense of "optimality" changes, Todd returns to this theme in [7], pointing out that the simple notion of interval bisection provides a minimax procedure for locating a fixed point of continuous function f: $[0,1] \rightarrow [0,1]$. Thus this procedure is "optimal" in the sense that "... the algorithm is guaranteed to find, after any given number of function evaluations, an interval that contains a fixed point and that has length at most ϵ; for any other algorithm, there is a function f for which the interval found has length greater than ϵ." In [7] the bisection procedure is generalized to obtain an "optimal" dissection of an n-simplex into subsimplices through the insertion of one new point; the procedure then iterates on a subsimplex guaranteed to contain a solution.

Improvement to the efficiency of fixed point algorithms remains the subject of interest in [8], though the emphasis now is on implementation. As described in [9]: "... it is important to note that the pieces of linearity of ℓ are usually much larger than simplices, even if f has no special structure; this conglomeration of pieces can be enhanced if f has special structure by an appropriate choice of triangulation T." In [8] Todd shows how this observation can be exploited globally, obtaining improved algorithms that traverse several simplices in a single step. Much of the improved efficiency here is generally applicable, due to large regions of linearity induced by the affine function f^0. But Todd also shows that additional computational advantage accrues when f has special structure relating to separability of variables. Effecting the improvements described in [8] requires operations similar to, though more complicated than, linear programming pivots. Thus in [9] techniques from numerical linear algebra for maintaining numerical stability and exploiting sparsity are adapted to the present setting.

Note that the thrust of Todd's research on fixed point methods has now clearly shifted from the triangulation T to the function f. He emphasizes this in the survey [10] on piecewise-linear homotopy algorithms: "It now seems more natural to state the problem in terms of f, and because of the mode of operation of recent algorithms we shall call them piecewise-linear homotopy methods.... The newer algorithms retain the properties of global convergence under very weak boundary conditions that hold naturally in several applications.... In addition, techniques have been devised to take advantage of smoothness...." Smoothness of f leads to quadratically convergent algorithms via the realization that the kth major iteration of the basic piecewise-linear homotopy algorithm yields both an approximate zero x^k for f **and** an approximation of the derivative of f at x^k (see § 9 of [10]). A further advantage of piecewise-linear homotopy methods is that they are also applicable when f is a point-to-set mapping. In [11] such an application is addressed for a convex union of smooth functions, a setting arising in nonlinear programming and economic equilibrium problems. Superlinear convergence to a zero of f in this general setting is established.

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In the early 1980s linear programming emerges as a second major theme in Todd's research. The extraordinary success of linear programming, ranging from broad practical applicability of the linear model to its supporting combinatorial and computational methodology, serves as a cornerstone for the field of mathematical programming. Today, some four decades after Dantzig's introduction of the simplex method, linear programming remains a very active and fertile research area, as evidenced by recent work on polynomial-time ellipsoidal and interior-point algorithms for linear programming, on average-case analysis of the simplex algorithm in order to explain its observed computational efficiency and an oriented matroid as an abstract combinatorial model for linear programming and the simplex method. Todd's more recent work contributes to each of these topics of current interest in linear programming.

Oriented matroids arise as a natural abstraction of the combinatorial properties of signed linear dependence among the columns of a matrix. These structures thus provide a setting for combinatorial consideration of the theory and algorithms of linear programming. In [12] the goal is "... to show that the natural setting of [the linear complementarity problem] is that of oriented matroids." This is achieved by extending the concepts of "P-matrices" and "completely Q-matrices," objects central to study of the linear complementarity problem, to oriented matroids. Indeed, [12] extends well-known characterizations of these concepts to the setting of oriented matroids and the algorithmic tools developed by Todd for achieving this extension generalize well-known algorithms of linear complementarity. As an added benefit, the combinatorial setting provides a natural duality, distinct from linear (or quadratic) programming duality, yet applicable to the linear complementarity problem. The combinatorial setting is also shown to be an appropriate framework for studying relations among algorithms for linear complementarity. This vein of research is continued in [13], where it is shown that ideas of [12] lead to constructive proofs of linear and quadratic programming duality results for oriented matroids, and in [14], where combinatorial abstractions (i.e., oriented matroid analogues) of well-known matrix properties such as symmetry and definiteness are investigated.

Much of the recent development in the field of analysis of algorithms has been in terms of worst-case analysis and, indeed, it has been well-known for over 15 years that in the worst case many variants of the simplex algorithm require an exponential number of computational steps. Yet, equally well-known is the excellent performance of simplex algorithms in practice, an observation now supported by over three decades of computational experience. Thus, in the words of [15], "It has been a challenge for mathematicians to theoretically confirm the extremely good performance of simplex algorithms for linear programming." The manuscript [15] is thus of particular significance, as it provides an average-case, polynomial-time bound for a simplex algorithm applicable for every linear programming problem. This paper indicates, under nonrestrictive assumptions on the probabilistic model, that the "lexicographic self-dual simplex method" solves a linear programming problem of order m x n with an average number of iterations proportional to $(\min(m,n))^2$. Todd's (independent) work [16] leading to this result provides a probabilistic analysis of a certain pivoting algorithm for the linear complementarity problem. Of particular significance is the specialization in [16] to linear programming problems, yielding the results cited in [15]. Todd's work also addresses implementations of the simplex method for structured, large-scale programming. In [17] linear programming problems with variable upper bound constraints, i.e., of the form $x_j \le x_k$, are considered and a revised simplex implementation is presented that handles these constraints implicitly. In contrast to earlier implementations for such problems, Todd's method is based on a numerically stable, triangular factorization of the basis matrix. In [18] this work is continued through the adaptation of Forrest-Tomlin and Saunders updating schemes to this setting. Todd's basic work on variable upper bounds also led to the treatment in [19] "... for linear programming problems in which many of the constraints are handled implicitly by requiring that the vector of decision variables lie in a polyhedron ..." In this paper the insight gained from the variable upper bounded algorithm of [17] is used to obtain a unified geometric understanding of several methods of large-scale programming.

Khachiyan's indication, scarcely less than a decade ago, that an ellipsoid method could be implemented in polynomial-time to solve linear programming problems settled a theoretical question of long standing and stimulated renewed algorithmic research in linear programming. The feature article [20] provides an important early survey on the ellipsoid method and its theoretical and practical significance, as well as its setting within the context of earlier research. This paper, aside from its technical and historical contribution, is widely known for the important role it played in helping to disspell the early confusion that ensued as word of the ellipsoid method spread more rapidly than technical understanding of its consequences and limitations. Work on the ellipsoid method continues in [21], where the method is implemented in such a way that (linear programming) dual variables are generated.

Much of the stimulus for current research on polynomial-time algorithms for linear programming is provided by Karmarkar's interior-point algorithm, introduced only five years ago. It appears that, for the first time, a potential competitor of the simplex algorithm has emerged. Todd is contributing to this development as well. In [22], for instance, the question of generation of dual variables is again addressed, and an implementation of the basic interior-point algorithm is given that generates dual solutions. This approach also proves useful in extending the basic algorithm's applicability. Of particular significance to this line of research is the manuscript [23], where a unification of ellipsoidal and interior-point (projective) methods is achieved by establishing "... that in fact the heart of each iteration of either algorithm is the solution of a weighted least-squares subproblem, and that these subproblems are very closely related. This viewpoint allows further

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insights into the two methods, in particular suggesting reasons for the very slow convergence of the ellipsoid method compared to the apparently very fast convergence of the projective algorithm . . . Both the ellipsoid and the projective algorithms appear at first sight not to provide solutions to the dual linear programming problem, but a closer examination shows that dual solutions are indeed generated during the course of the methods, essentially from the least-squares problems." Also signficant is [24], where it is shown that specially structured constraints (including, e.g., the variable upper bound constraints studied in [17, 18, 19] can be exploited to computational advantage in implementations of the projective algorithm.

The citation for the award of the Dantzig Prize to Todd notes that, "The entire field of mathematical programming has been enriched by his valuable contributions in algorithmic methodology and analysis for topics ranging from linear programming to fixed points." Indeed, Todd's research publications over the past 15 years, now numbering in excess of 60, constitute an impressive eclectic array of individual advancements. And this work in its entirety makes a significant contribution as well, for it reveals fundamental principles shared by disparate areas of mathematical programming. Abstract combinatorics [1, 2] is used to link complementarity with matroid theory [3], while insight gained from the study of abstract pivoting systems later finds application in invalidating the monotonic bounded Hirsch conjecture [4]. A further connection between complementarity and matroid theory [12] results in algorithms [13] that ultimately provide key motivation for average-case analysis of simplex algorithms for linear programming [15, 16]. Work on improving efficiency of fixed point algorithms by exploitation of linearity [8, 9] motivates later material on large-scale implementation [17, 18, 19] that, in turn, leads to advances in the most recent linear programming methology [24]. And so on. Thus the award of the 1988 Dantzig Prize to Michael J. Todd provides appropriate recognition to a body of work contributing to the very identity and unity of the field of mathematical programming.

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- L. E. Trotter

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DEAR President,

Ladies and Gentlemen:

While thinking of the Orchard-Hays Prize, I am remembering those years Laurence and I tried, successfully to some extent, tackling difficult optimization problems, gearing our efforts toward MPSARX.

The awarded publication culminates a series of seven papers covering our joint research where I was influenced in three ways:

First, I am grateful to Geoffrion, Graves and Erlenkotter who taught me decomposition theory and helped my research in this field. From this research, particularly from the properties exhibited by Cross decomposition, I think I learned to understand why and when problems get hard to solve, the key difficulty being the duality gap to close in an effective way.

Second, from my experience in practise, again with the help of Geoffrion and Graves, I learned that not special but general purpose software must be developed in order to be useful in solving real-life problems effectively.

Finally, the success of Manfred Padberg with Crowder and with Crowder and Johnson in solving pure zero one programming problems by using facet defining cutting planes has been the third stimulating factor. I am very grateful to Manfred for helping us in the earlier stages of our research while he was at Core.

I am very honoured to receive the Orchard-Hays Prize and to share it with Laurence whom I would like to thank for those nice years of professional work at Core. I deeply regret, however, that I cannot be present at your meeting in Tokyo.

Tony Van Roy
Bank Brussels Lambert
Brussels, Belgium
August 1988

(The above letter was received too late for reading at the Tokyo Symposium - Ed.)

New problem-solving system could save customers millions

A superfast problem-solving system derived from an AT&T Bell Laboratories research breakthrough is now available to customers. The AT&T KORBX System combines software and hardware to solve business and government resource allocation problems involving several hundred thousand variables. The system is priced in the millions but can potentially save customers tens of millions of dollars. It is based on a mathematical programming method, the Karmarkar algorithm, named for Bell Labs researcher Narendra Karmarkar.

(Reprinted from the AT&T Quarterly Report dated October 30, 1988 - Ed.)

Conference

Mathematical Programming: A Tool for Engineers

Faculté Polytechnique de Mons
Mons, Belgium
May 17-19, 1989

This meeting is the second in a cycle of conferences devoted to Mathematics for engineers and organized by the Faculté Polytechnique of Mons in Belgium. The theme of the conference will be mathematical programming and its applications in all the fields of engineering. Indeed, this operations research tool is used in chemical, electrical, mechanical engineering, management, etc., for the analysis of models as well as for the optimization of systems.

All subjects related to mathematical programming and numerical optimization will be welcome. Emphasis will be put on real applications in the field of engineering and on advances in mathematical programming.

The aims of the conference are: (1) to show the potential of the various methods of mathematical programming in the field of engineering, thus the use of these techniques in real applications will be emphasized and (2) to describe the advances in applied mathematical programming, linear and nonlinear programming, unconstrained optimization, integer programming, combinatorial optimization, multi-objective optimization, software developments, etc.

To meet these two objectives a large part of the programme will be devoted to tutorial sessions given by some distinguished guest speakers. Further information on these speakers is given in the invitation programme sent in March.

Furthermore, some parallel sessions of contributed papers will give the participants the opportunity to present and discuss more recent and specialized research in the various fields of engineering. A software fair in computing environment and a book exhibition will also be organized.

Papers and software presentations are welcome. For additional information, please contact:

J. Teghem / M. P. for Eng.
Faculté Polytechnique de Mons
9, rue de Houdain
7000 Mons - BELGIUM
Telephone: (065)37-40.48 - 37.40.05
Telefax: (065)37.42.00
Telex: 57764 uemons b

Fifth International Conference on Stochastic Programming

August 13-18, 1989
Ann Arbor, Michigan, U.S.A.

This conference is being organized by the Committee on Stochastic Programming of the Mathematical Programming Society and is co-sponsored by ORSA, TIMS, Technical Committee 7 of IFIP, and the Department of Industrial and Operations Engineering and the College of Engineering, The University of Michigan. The focus will be on stochastic programming theory and applications with particular emphasis on computation. Specific topics will include numerical integration, Monte Carlo approaches, stability and sensitivity analysis, approximation and model simplification, uses of parallel processors, and applications in production, manufacturing, transportation, finance, natural resources, power systems, and long-range planning. A tutorial session will introduce new investigators and users to the field.

Anyone interested in attending the conference or submitting a paper should contact:

Professor J. R. Birge
Department of Industrial and Operations Engineering
1205 Beal
The University of Michigan
Ann Arbor, Michigan, USA, 48109-2117
Telephone: (313) 764-9422
E-mail: John_R._Birge@um.cc.umich.edu

CORE Announces Lecture Series

A new series of lectures and reports entitled the CORE Lecture Series is announced. The first speaker will be Professor Martin Grötschel of the University of Augsburg. He will lecture at the Center for Operations Research and Econometrics (CORE), Université Catholique de Louvain in October 1989 on the subject of Modelling, Algorithms and Practical Problem Solving in Optimization. The series is entitled "Postmen, Ground States of Spin Glasses, Via Optimization and Cycles in Binary Matroids."

Anyone wishing to attend the Series is invited to write to the above address for further details. Some limited financing is available to help students attend the lectures (applications should include a reference letter from one professor).

–Laurence Wolsey
CORSEC @ BUCLLN11

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Notes

Integer Programming and Combinatorial Optimization

University of Waterloo
Waterloo, Ontario
CANADA
May 28-30, 1990

This meeting will highlight recent developments in the theory of integer programming and combinatorial optimization. Topics will include polyhedral combinatorics, integer programming, geometry of numbers, computational complexity, graph theoretic algorithms, network flows, matroids and submodular functions, approximation algorithms, scheduling theory and algorithms, and algorithms for solving counting problems. In all these areas we welcome structural and algorithmic results. The latter may be sequential or parallel, deterministic or probabilistic.

The meeting will be patterned after the highly successful Foundations of Computing Science (FOCS) meetings and Symposia on the Theory of Computing (STOCS) organized by the ACM and IEEE. During the three days, approximately thirty papers will be presented in a series of sequential (nonparallel) sessions. The program committee will accept the papers to be presented on the basis of extended abstracts to be submitted as indicated below. The proceedings of the conference will contain full texts of all presented papers and will be published by the UW Press. Copies will be provided to all participants at registration time. Papers appearing in the proceedings will not be refereed, and it is expected that revised versions of most papers would be submitted for publication in appropriate journals.

This meeting is being organized under the auspices of the Mathematical Programming Society.

The Program Committee members are V. Chvatal, Rutgers University; W. Cunningham, Carleton University; R. Kannan, Carnegie-Mellon University; R. Karp, University of California, Berkeley; G. Nemhauser, George Institute of Technology; W. Pulleyblank, University of Waterloo; and P. Seymour, Bell Communications Research.

Accommodations for participants will be available in the student residences of the University of Waterloo or in local hotels, if preferred.

For more information, please contact the organizers as follows:

R. Kannan
Department of Computer Science
Carnegie Mellon University
or
W. R. Pulleyblank
Department of Combinatorics and Optimization
University of Waterloo

Deadline for submission of extended abstracts of papers is October 31, 1989.

Ninth International Conference on Analysis and Optimization of Systems

June 12-15, 1990
Antibes, France

The purpose of this Conference is to present the advanced research in the field of Systems Analysis and Control where the most promising applications may be expected.

This meeting organized every other year by INRIA will take place near the INRIA Sophia Antipolis Center on the French Riviera.

The organizers strongly encourage the authors to forward proposals of communications describing: the most recent results of research in the field, new applications. Software demonstrations and industrial products will also be presented in an exhibition.

The deadline for submission of papers is October 1, 1989. The deadline for descriptive papers for the exhibition is May 1, 1990.

For information concerning the conference please contact the conference secretariat:

T. Bricheteau / S. Gosset
Public Relations Department
INRIA
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Technical Reports & Working Papers

Cornell University
School of Operations Research and Industrial Engineering
Upson Hall
Ithaca, NY 14853

W. Morris, A. Morton, and M.J. Todd, *"An Implementation of Todd's Algorithm for Variable Upper Bounds,"* TR 799.

R.O. Roundy, *"Efficient, Effective Lot-Sizing for Multi-Product, Multi-Stage Production/ Distribution Systems with Correlated Demands,"* TR 802.

R.O. Roundy and J.A. Muckstadt, *"Analysis of Multistage Production Systems,"* TR 806.

J. Renegar and M. Shub, *"Simplified Complexity Analysis for Newton LP Methods,"* TR 807.

E.M. Arkin and R.O. Roundy, *"A Pseudo-Polynomial Time Algorithm for Weighted-Tardiness Scheduling with Proportional Weights,"* TR 812.

M. Hartmann, *"Cutting Planes and the Complexity of the Integer Hull,"* TR 819.

E. Arkin, *"Complexity of the Multiple Product Single Facility Stockout Avoidance Problem,"* TR 822.

Operations Research Group
The Johns Hopkins University
Baltimore, MD

M. Schneider and S. Zenios, *"A Comparative Study of Algorithms for Matrix Balancing,"* 88-02.

A.T. Benjamin, *"Graphs, Maneuvers and Turnpikes,"* 88-03.

C. ReVelle and K. Hogan, *"The Maximum Reliability Location Problem and ε–Reliable P-Center Problem: Derivatives of the Probabilistic Location Set Covering Problem,"* 88-04.

Z.-P. Zhu, C. ReVelle and K. Rosing, *"Adaption of the Plant Location Model for Regional Environmental Facilities and Cost Allocation Strategy,"* 88-05.

M. Heller, J.L. Cohon and C. ReVelle, *"The Use of Simulation in Validating a Multiobjective EMS Location Model,"* 88-06.

C. ReVelle, *"Review, Extension and Prediction in Emergency Service Siting Models,"* 88-07.

C. ReVelle and K. Hogan, *"The Maximum Availability Location Problem,"* 89-01.

JOURNALS

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J.V. Burke and S-P. Han, *"A Robust Sequential Quadratic Programming Method."*
N.R. Patel, R.L. Smith and Z.B. Zabinsky, *"Pure Adaptive Search in Monte Carlo Optimization."*
M. Sniedovich, *"Analysis of a Class of Fractional Programming Problems."*
J.C. Bernard and J.A. Ferland, *"Convergence of Interval-Type Algorithms for Generalized Fractional Programming."*
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R.D.C. Monteiro and I. Adler, *"Interior Path Following Primal-Dual Algorithms. Part II: Convex Quadratic Programming."*
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Z. Win, *"On the Windy Postman Problem on Eulerian Graphs."*
R.B. Bapat, *"A Constructive Proof of a Permutation-Based Generalization of Sperner's Lemma."*

Annals of Operations Research

Editor-in-Chief: Peter L. Hammer, Rutcor, Hill Center for the Mathematical Sciences, Rutgers University, Busch Campus, New Brunswick, NJ 08903.

New in 1988:

APPROACHES TO INTELLIGENT DECISION SUPPORT
Editor: H.G. Jeroslow, Ass. Editors: E. Barrett, H. Greenberg, F. Leimkuhler, W. Marek, Th. Morton, F. Tonge and A. Whinston
1988. 366 pages. ISSN 0254 5330

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B. Jaumard, P.S. Ow and B. Simeone, A Selected Artificial Intelligence Bibliography for Operations Researchers
H. Wolfson, E. Schonberg, A. Kalvin and Y. Lamdan, Solving Jigsaw Puzzles by Computer
K. Sycara, Utility Theory in Conflict Resolution
P.S. Ow and S.F. Smith, Viewing Scheduling as an Opportunistic Problem-Solving Process
S. De, A Knowledge-Based Approach to Scheduling in an F.M.S.
C.E. Bell, A least Commitment Approach to Avoiding Protection Violations in Nonlinear Planning
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R.R. Yager, A Note on the Representation of Quantified Statements in Terms of the Implication Operation
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S.D. Burd, S.K. Kassicieh, A Prolog-Based Decision Support System for Computer Capacity Planning

PARALLEL OPTIMIZATION ON NOVEL COMPUTER ARCHITECTURES
Editors: R.R. Meyer and S.A. Zenios
1988. 340 pages. ISSN 0254 5330

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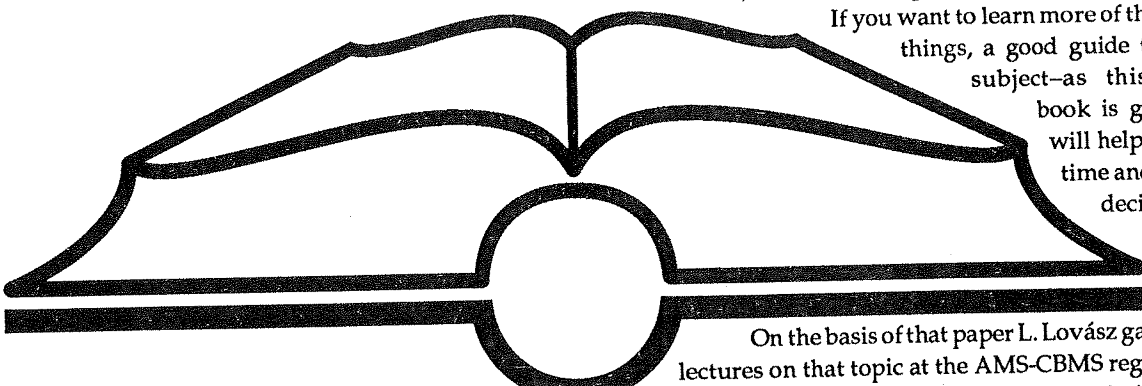
BOOK REVIEWS

An Algorithmic Theory of Numbers, Graphs and Convexity

by László Lovász
SIAM, Philadelphia, 1986
ISBN 0-89871-203-3

In combinatorial optimization one of the most outstanding results in the last decade is that under some appropriate assumptions separation problems and the associated optimization problems are equivalent from the complexity theoretical point of view. This theorem was first published in "The ellipsoid method and its consequences in combinatorial optimization," Combinatorica 1, 1981, 169-197, by M. Grötschel, L. Lovász and A. Schrijver, for which they received the Fulkerson Prize in 1982 from the Mathematical Programming Society. The technical details of this paper are rather sophisticated, and it contains quite a lot of tricky but crucial steps. If you want to learn more of these exciting things, a good guide through the subject–as this beautiful book is going to be–will help you to save time and reveals the decisive points you have to pay attention to.



On the basis of that paper L. Lovász gave a series of lectures on that topic at the AMS-CBMS regional conference in Eugene, Oregon, August 1984, pointing out more underlying material as well as the consequences and implications of the results to combinatorial optimization. So the reader of these lecture notes is at first introduced to the main ingredients, as there are diophantine approximation, bases reduction in lattices and the Ellipsoid Method. The use of square roots and so forth compel the application of sophisticated rounding procedures that are also discussed in detail. Here you will also learn how to deal with real numbers and that in reality they are nothing more than a black box with two slots. With these tools the notes show the complexity theoretical equivalence of quite different descriptions of convex bodies. Then it sketches also proofs of results like: linear programming is ("partly strongly") polynomial, or for every fixed dimension integer programming can be solved in polynomial time, and it evaluates bounds of various measures of convex bodies like volume, widths, diameter, etc. The above mentioned main theorem is proved, of course, as well.

The last chapter surveys applications of these results to combinatorial optimization with particular emphasis on cut problems, optimization in perfect graphs and minimization of submodular functions. Here we find problems whose polynomial time solvability is known only via the equivalence of separation and optimization.

Summarizing the style of representation of the book I completely agree with the author when he says, "Throughout these notes, I have put emphasis on ideas and illustrating examples rather than on technical details or comprehensive surveys. A forthcoming book of M. Grötschel, L. Lovász and A. Schrijver (1985) will contain an in-depth study of the Ellipsoid Method and the simultaneous diophantine approximation problem, their versions and modifications, as well as a comprehensive tour d'horizon over the applications in combinatorial optimization." But these notes won't be obsolete when the announced book is issued. They are definitely an excellent guide for an advanced course in combinatorial optimization, while the joint book of Grötschel, Lovász and Schrijver will rather serve as a reference book containing elaborate proofs and further readings.

- A. Wanka

Theory of Linear Integer Programming

by Alexander Schrijver
John Wiley and Sons, 1986
ISBN 0-471-90854-1

An impressive, indeed astounding, achievement of completeness, conciseness, clarity, and depth, this book is a must-buy for any researcher interested in linear and integer programming. The main emphasis of the book is on theory, and the real strength derives from this restriction since it permits an in-depth presentation of *all* relevant theoretical results, both old and new.

The book consists of three parts. In the first one, relevant background material from linear algebra and the theory of lattices and linear diophantine equations are introduced. The treatment includes the important basis reduction method for lattices due to Lovász. The second part deals with polyhedra, linear inequalities, and linear programming. Here too, all recent results are covered besides the well-known ones, for example, Khachiyan's ellipsoid method, Karmarkar's method for linear programming, Borgwardt's analysis of the average speed of the simplex method, and Tardos' and Megiddo's algorithms for linear programming. Finally, the third part covers integer linear programming. Of the recent results included here, one should mention Lenstra's algorithm for integer linear programming, Seymour's decomposition theorem for totally unimodular matrices, and the theory of total duality.

The number of references provided in the book is simply astonishing. Every relevant reference is simply there, no matter which portion of the book is examined. Clearly the author has made an enormous effort to achieve such completeness.

In the preface, the author promises a companion volume on polyhedral combinatorics. Given such a wonderful book on linear and integer programming, this reviewer looks forward with much anticipation to the publication of that second volume.

- K. Truemper

Linear Programming in Infinite-Dimensional Spaces

by Edward I. Anderson and Peter Nash
Wiley, Chichester, 1987
ISBN 0-471-91250-6

This monograph gives a systematic account of certain types of infinite-dimensional linear programs and certain approaches to their duality theory and their algorithmic solutions.

Chapter 1 is introductory and begins with a display of some specific linear programs in which infinite-dimensional cones occur most naturally, either the variable being taken from an infinite-dimensional space or the number of constraints being infinite, or both: Bellman's bottleneck problem (1957), continuous-time network flows, cutting and filling (Monge 1786 ("deblais et remblais"), Kantorovich 1942), the dual game. The classical theory of finite-dimensional linear programs involving only a finite number of constraints is sketched: duality, simplex method. Three possibilities of carrying over the duality theory to infinite-dimensional cases are envisaged: purely algebraic passage to an adjoint problem, finding a Lagrangian which is suitable for infinite-dimensional generalization, or approximation by finite linear programs whose duals are to approximate some kind of infinite-dimensional dual of the original problem. Moreover, two essential features of the simplex method are pointed out: restriction to basic solutions (i.e. extremal points of the solution set, degeneracy and non-degeneracy of basic solutions, and passage from one basic solution to a better one (pivoting). To a large extent, the

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book is devoted to generalizations of just these two features to infinite-dimensional cases.

Chapter 2 investigates the possibilities of a purely algebraic approach to infinite-dimensional linear programs in general. Passage to the dual program and some kind of weak duality are obvious here. Basic solutions are defined in such a fashion that equivalence to extremality and minimal support property are easily established. Under some finite-dimensionality hypothesis, the existence of basic solutions is proven. Non-degeneracy of basic solutions is defined by a certain splitting property with respect to the underlying linear space. Under the hypothesis that non-degenerate basic solutions exist, strong duality is established.

With Chapter 3, topology comes in: dual pairs of topological vector spaces, etc. The linear maps occurring in linear programs are supposed to be continuous. Some weak duality results are easily obtained. The possibility of a duality gap is displayed by an example of Gale. In view of this possibility, a number of properties of linear programs in the topological vector space setting are defined: consistency (CONS), inconsistency (INC), boundedness (BD), unboundedness (UBD), sub(in)consistency (SUBC/SUBINC), sub(un)boundedness (SUBD/SUBUBD). A table of 6x6 entries according to combinations of such properties of the primal and dual program is set up and partly filled by examples. Upon introducing an associated "modified homogeneous program," the classification scheme is refined still further. The rest of the chapter is devoted to conditions implying the absence of a duality gap or the existence of optimal solutions. In addition to the continuity of the defining linear map, closedness, existence of interior points, boundedness and compactness conditions play a crucial role here.

Chapter 4 treats semi-infinite linear programs: either the number of variables or the number of constraints remains finite. Special emphasis is given to such programs where the "infinite part" is either countable or a continuum $\subseteq R^n$. An example of Karney (1981) displays the possibility of a duality gap. Variants of the simplex algorithm are discussed at length. One of the important applications is to uniform approximation.

The authors deal with the mass transfer problem in Chapter 5. Its finite-dimensional version is a well-known linear program. For the infinite-dimensional version a measure-theoretical setup is chosen here, with a compact basic space F and a continuous transport cost function on FxF. The dual problem is set up with pairs of continuous functions on UxV, where U, V $\subseteq$ F are the "deblai" or "remblai" regions. This is natural in one way but leads to compactness problems which are tackled by introducing L^∞ and exploiting the continuity of the cost function. This leads to satisfactory duality results. The variant of the simplex algorithm discussed here at length goes back to Andy Philpott's Cambridge Thesis (1982), the key notion being "piecewise continuous assignment;" convergence to an optimal solution is proven. The notes to this chapter trace the history from Monge, Dupin, Appell and others to Kantorovich (1942), Levin-Milyutin (1978) and others.

In Chapter 6 the continuous-time dynamic version of the network-flow problem is treated: the network remains finite, but constraints and flow strength vary in time. Ford-Fulkerson's reduction of the discrete-time variant of this problem to a ("time-augmented") static problem is displayed and taken as a motive for the definition of "dynamic cuts" in the original problem. A key lemma shows that a (dynamic) flow may be augmented if the sink is reachable at some time, and a dynamic max-flow theorem involving piecewise continuous flows is proven.

Chapter 7 deals with continuous linear programs of the type of the bottleneck problem: maximize some weighted integrals under a (time) continuum of constraints, i.e. solve a linear optimal control problem. Solvability by piecewise linear functions is proved for so-called separated continuous linear programs with linear or constant weight and constraint functions. The notes to this chapter trace a vast and not very homogeneous literature, including Russian papers not utilizing simplex methods.

A variety of further infinite linear programs is treated in Chapter 8: the "capacity problem" of maximizing total electric charge subject to an upper bound for the potential, given a conducting body; a continuous-time minimum-cost problem in finite networks; a continuous-space max-flow problem in a planar region with piecewise smooth boundary. Much of the material covered in this chapter is from Philpott's thesis (1982). The notes also mention related investigations, e.g. by Hu, Gomory, Jacobs, Seiffert, Strang, Iri.

One of the basic features of this most valuable, stimulating and, within the deliberate choice of its topics, comprehensive monograph is on duality and on continuous simulation of the simplex algorithm. The presentation is of excellent clarity, the notations are very well chosen. Who among the workers in this field would deny himself the pleasure of getting so much well-presented exciting information in such a slim volume? The non-specialist might enjoy it likewise.

- K. Jacobs

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Combinatorial Theory and Statistical Design

by G. M. Constantine
Wiley, New York (1987)
ISBN 0-471-84097-1

As the author states in his preface, his book "is addressed to those who are interested in understanding the fundamental techniques of discrete mathematics as applied to statistical design," with four major topics predominating: enumeration, graphs and networks, statistical and combinatorial designs, and Möbius inversion. The chapter on statistical designs nicely shows how much of the material treated in the other eight chapters ties in with statistical design. The remainder of the book (by far the largest portion) can be read as an advanced exposition of some of the central parts of combinatorial theory. In my opinion, the present book is eminently suitable for courses at the graduate level; I feel that it might be a bit too demanding at the undergraduate level. A unifying theme is the strong emphasis on algebraic methods, in my opinion one of the big advantages of this text. Surely any more penetrating study of combinatorics soon becomes algebraic in flavour and methods.

Regarding the presentation, the author usually starts out with simple motivational examples but rapidly builds towards non-trivial results and interesting theorems which go much beyond what is usually offered in a general textbook on combinatorics. Being a specialist in design theory myself, I was, for instance, quite impressed with the selection of topics in the chapter on combinatorial designs. The style employed is engaging, to a large part avoiding the strictly static and formal presentation usual in mathematics. This is one of the few books I know which reads more like an oral presentation than a formal text. The author does not hide behind his topic, and we get an impression of his personality. I am quite convinced that he must be a stimulating and popular teacher. In short, this text is not only mathematically interesting but also fun to read.

Let me indicate the topics covered in some detail now. We have nine chapters: (1) Ways to choose (covering the essentials of counting and introducing, e.g. binomial numbers, Stirling numbers, Bell numbers, Lah numbers); (2) Generating functions (introducing formal power series, generating functions for some of the topics of Chapter 1, recurrence relations as well as for labelled spanning trees and partitions); (3) Classical inversion (considering various inverse relations, Taylor expansion, formal Laurent series, Lagrange inversion, generating functions in more detail, Gaussian polynomials); (4) Graphs (including theorems of Euler, Ramsye and Turan and emphasizing graph spectra, e.g. treating strongly regular graphs, the adjacency and Kirchhoff matrices and graphs with extreme spectra); (5) Flows in networks (giving the theorems of Birkhoff-von Neumann, König, P. Hall, Dilworth, Ford and Fulkerson, including some algorithms and an introduction to matroid theory); (6) Counting in the presence of a group (giving the counting theory of Polya and de Bruijn, with many interesting examples like enumerating the number of isomorphism classes of graphs); (7) Block designs (including t-designs, Fisher's inequality for t-designs, classes of 2-designs, Cameron's theorem on extending symmetric designs, the Bruck-Ryser-Chowla theorem, automorphism groups of designs, association schemes and Bose-Mesner algebras); (8) Statistical designs (studying random variables, factorial experiments, blocking, 2-designs as optimal designs, E-optimality and line graphs, mixed factorial designs and orthogonal arrays); (9) Möbius inversion (presenting the general inversion theory on locally finite partially ordered sets, with interesting applications, e.g. to determining the number of automorphisms of an abelian group).

I have two more comments: It would have been advisable to give a few comments about issues of complexity in Chapter 5; indeed, I find the statement on p. 137 that the Hamiltonian circuit problem is "much of the same spirit" as the one for Eulerian circuits rather misleading. Regarding Chapter 7, non-trivial (simple) t-designs are now known to exist for all values of t by a result of L. Teirlinck ("Nontrivial t-designs without repeated blocks exist for all t," Discr. Math. 65 (1987), 301-311). Finally, there are some typographical errors, however, which do not really affect the readability of the text.

Summing up, then, this is one of the best texts on combinatorics for graduate students now available, and I am happy to highly recommend it to everybody interested in this area.

- D. Jungnickel

CONTINUES

BOOK REVIEWS

Nonconvex Programming

by Forenc Forgó
Akadémiai Kiadó, Budapest, 1988
ISBN 963-05-4459-9

The book deals with those types of nonlinear programs which find less attention in standard nonlinear programming texts, namely problems where a local maximum may not be a global maximum. Emphasis is placed on solution methods. Theoretical results on the models involved are only discussed to the extent they are needed to describe the algorithms. Small numerical results illustrate the techniques. Computational experience with and relative efficiency of algorithms find little attention. Two topics are excluded from the discussion: integer programming and global optimization (unconstrained programming).

The first two chapters provide the theoretical basis for the remaining eight chapters on algorithms. Optimality conditions and duality as well as convex and concave envelopes of functions are discussed. In Chapter 3 three major solution strategies in nonconvex programming are introduced: complete and implicit enumeration, branch and bound, and cuts. Chapters 4 and 5 deal with two classical problems: maximization of a (quasi)convex function over a convex polytope and maximization of a linear function subject to convex greater-or-equal constraints. Various cutting methods are discussed. In chapter 6 general nonconvex programs are addressed where convexity of the objective function and/or the constraints is replaced by continuity or differentiability. In addition to cutting-plane methods, branch and bound methods are presented. Chapter 7 then focuses on nonconvex quadratic programs. Here cutting-plane generating methods are discussed which exploit the quadratic nature of the objective function. Also special cases such as bilinear programs and generalized linear programs are considered. Chapter 8 deals with algorithms for fixed charge problems. In Chapter 9 SUMT-like procedures are described, and Chapter 10 discusses decomposition procedures for nonconvex programs.

The material is well organized. The reader is assumed to have a knowledge of elementary calculus and linear algebra and familiarity with basic linear and nonlinear programming. The book seems to be particularly useful as an introduction to the field. The experienced researcher in nonlinear programming may miss more up-to-date results published in the 80s.

- S. Schaible

Graphen, Netzwerke und Algorithmen

by Dieter Jungnickel
Bibliographisches Institut, Mannheim 1987
ISBN 3-411-03126-3,68,-DM

Combinatorial optimization, along with graph algorithms and complexity theory, is booming. This results in a great number of textbooks devoted to the subject. However, there is a conspicuous lack of a good German monograph on the topic. Dieter Jungnickel tries to fill this gap for that part of combinatorial optimization that can be treated within the language of graph theory.

The book treats the most prominent problems which are polynomially solvable. The Traveling Salesman Problem is discussed as a paradigm of an NP-complete problem.

Chapters 1 and 2 are of an introductory nature. The basic notions of graph theory and some algorithmic topics are discussed. Hierholzer's algorithm for Euler circuits serves for introducing data structures and polynomiality. Pidgin Pascal is used as the "language" for presenting the algorithms. NP-completeness is mentioned; a somewhat deeper discussion is postponed until the last chapter. Chapter 3 deals with shortest paths. The traditional algorithms are discussed. Two more advanced topics are mentioned: the use of more complicated data structures in the design of fast algorithms and path algebras. Trees and matroids are treated in the subsequent chapter. Besides primal and dual greedy algorithms, more theoretical aspects like the matrix tree theorem are considered. Chapters 5 to 9 are concerned with various aspects and applications of network flows. The most efficient max flow algorithms (without taking advanced data structures into account) are presented in a very clear way. The chapter on combinatorial applications of network flows contains, in addition to more standard topics, the proof of Baranyai's theorem. This result is - even though quite pure in nature - a true gem for somebody in search of applications of graph algorithms in other areas of mathematics. Circulations, network synthesis and algorithmic connectivity is treated in detail. Chapters 10 and 11 are devoted to matchings. After a nice exposition of unweighted matchings in chapter 10, the author meets the limits he has imposed upon himself in chapter 11. It is the declared aim of the book to explain everything without using linear programming techniques. Here the author has to concede that a treatment of Jack Edmonds' matching algorithm makes little sense without LP duality. However, the development of the Hungarian algorithm seems quite natural (and historically justified). The last chapter is definitely a highlight of the book. Using the traveling salesman problem, it introduces the reader to many aspects of and algorithmic approaches to NP-complete problems. It can serve as a sound basis for a deeper study of hard decision problems.

The text is well written; most exercises (at the end of each chapter) are quite enlightening and the hints are clear. Algorithms are described very thoroughly. The list of references is impressive and gives good guidance for further reading. At several points the reader finds himself right at the frontier of current research (e.g. the section on exact matchings). The book serves as a sound foundation for more advanced topics, e.g. polyhedral combinatorics. It presents the matter as a coherent and unified whole. I like the book a lot. It seems to fill the gap I was talking about in the introduction. It might even be desirable to compile an English translation of it.

The book can be recommended to beginners as an introductory text as well as for researchers in academics and industry as a reference.

- M. Leclerc

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George L. Nemhauser, MPS Chairman-Elect, received the Kimball Medal for distinguished service to ORSA and to the Operations Research profession at the Denver meeting of ORSA....**Richard H. F. Jackson** has been appointed the Deputy Director of the Center for Manufacturing Engineering at the National Institute of Standards and Technology (formerly National Bureau of Standards)....**Ralph E. Gomory**, pioneer in mathematical programming and more recently a senior vice president at IBM, will become president of the Sloan Foundation in June. **Dr. Gomory** received the National Medal of Science in July 1988....**Tom Magnanti** (MIT) will spend the Fall, 1989 semester at CORE....**Anna B. Nagurney** (University of Massachusetts) is spending 1988-89 at MIT.

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