

Linear Programming Lecture Notes

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Numerical Optimization - Jorge Nocedal 2006-12-11

Optimization is an important tool used in decision science and for the analysis of physical systems used in engineering. One can trace its roots to the Calculus of Variations and the work of Euler and Lagrange. This natural and reasonable approach to mathematical programming covers numerical methods for finite-dimensional optimization problems. It begins with very simple ideas progressing through more complicated concepts, concentrating on methods for both unconstrained and constrained optimization.

Stochastic Linear Programming - Peter Kall 2010-11-02

This new edition of Stochastic Linear Programming: Models, Theory and Computation has been brought completely up to date, either dealing with or at least referring to new material on models and methods, including DEA with stochastic outputs modeled via constraints on special risk functions (generalizing chance constraints, ICC's and CVaR constraints), material on Sharpe-ratio, and Asset Liability Management models involving CVaR in a multi-stage setup. To facilitate use as a text, exercises are included throughout the book, and web access is provided to a student version of the authors' SLP-IOR software. Additionally, the authors have updated the Guide to Available Software, and they have included newer algorithms and modeling systems for SLP. The book is thus suitable as a text for advanced courses in stochastic optimization, and as a reference to the field. From Reviews of the First Edition: "The book presents a comprehensive study of stochastic linear optimization problems and their applications. ... The presentation includes geometric interpretation, linear programming duality, and the simplex method in its primal and dual forms. ... The authors have made an effort to collect ... the most useful recent ideas and algorithms in this area. ... A guide to the existing software is included as well." (Darinka Dentcheva, Mathematical Reviews, Issue 2006 c) "This is a graduate text in optimisation whose main emphasis is in stochastic programming. The book is clearly written. ... This is a good book for providing mathematicians, economists and engineers with an almost complete start up information for working in the field. I heartily welcome its publication. ... It is evident that this book will

constitute an obligatory reference source for the specialists of the field." (Carlos Narciso Bouza Herrera, Zentralblatt MATH, Vol. 1104 (6), 2007)

Linear Programming - Robert J Vanderbei 2013-07-16

This Fourth Edition introduces the latest theory and applications in optimization. It emphasizes constrained optimization, beginning with a substantial treatment of linear programming and then proceeding to convex analysis, network flows, integer programming, quadratic programming, and convex optimization. Readers will discover a host of practical business applications as well as non-business applications. Topics are clearly developed with many numerical examples worked out in detail. Specific examples and concrete algorithms precede more abstract topics. With its focus on solving practical problems, the book features free C programs to implement the major algorithms covered, including the two-phase simplex method, primal-dual simplex method, path-following interior-point method, and homogeneous self-dual methods. In addition, the author provides online JAVA applets that illustrate various pivot rules and variants of the simplex method, both for linear programming and for network flows. These C programs and JAVA tools can be found on the book's website. The website also includes new online instructional tools and exercises.

Mathematical Foundations of Computer Science 2008 - Edward Ochmanski 2008-08-12

This book constitutes the refereed proceedings of the 33rd International Symposium on Mathematical Foundations of Computer Science, MFCS 2008, held in Torun, Poland, in August 2008. The 45 revised full papers presented together with 5 invited lectures were carefully reviewed and selected from 119 submissions. All current aspects in theoretical computer science and its mathematical foundations are addressed, ranging from algorithmic game theory, algorithms and data structures, artificial intelligence, automata and formal languages, bioinformatics, complexity, concurrency and petrinets, cryptography and security, logic and formal specifications, models of computations, parallel and distributed computing, semantics and verification.

Integer Optimization by Local Search - Joachim P. Walser 1999-08-04

Integer Optimization addresses a wide spectrum of practically important optimization problems and represents a major challenge for algorithmics. The goal of integer optimization is to solve a system of constraints and optimization criteria over discrete variables. Integer Optimization by Local Search introduces a new approach to domain-independent integer optimization, which, unlike traditional strategies, is based on local search. It develops the central concepts and strategies of integer local search and describes possible combinations with classical methods from linear programming. The surprising effectiveness of the approach is demonstrated in a variety of case studies on large-scale, realistic problems, including production planning, timetabling, radar surveillance, and sports scheduling. The monograph is written for practitioners and researchers from artificial intelligence and operations research.

Theory of Linear and Integer Programming - Alexander Schrijver 1998-06-11

Theory of Linear and Integer Programming Alexander Schrijver Centrum voor Wiskunde en Informatica, Amsterdam, The Netherlands This book describes the theory of linear and integer programming and surveys the algorithms for linear and integer programming problems, focusing on complexity analysis. It aims at complementing the more practically oriented books in this field. A special feature is the author's coverage of important recent developments in linear and integer programming. Applications to combinatorial optimization are given, and the author also includes extensive historical surveys and bibliographies. The book is intended for graduate students and researchers in operations research, mathematics and computer science. It will also be of interest to mathematical historians. Contents 1 Introduction and preliminaries; 2 Problems, algorithms, and complexity; 3 Linear algebra and complexity; 4 Theory of lattices and linear diophantine equations; 5 Algorithms for linear diophantine equations; 6 Diophantine approximation and basis reduction; 7 Fundamental concepts and results on polyhedra, linear inequalities, and linear programming; 8 The structure of polyhedra; 9 Polarity, and blocking and anti-blocking polyhedra; 10 Sizes and the theoretical complexity of linear inequalities and linear programming; 11 The simplex method; 12 Primal-dual, elimination, and relaxation methods; 13 Khachiyan's method for linear programming; 14 The ellipsoid method for polyhedra more generally; 15 Further polynomiality results in linear programming; 16 Introduction to integer linear programming; 17 Estimates in integer linear programming; 18 The complexity of integer linear programming; 19 Totally unimodular matrices: fundamental properties and examples; 20 Recognizing total unimodularity; 21 Further theory related to total unimodularity; 22 Integral polyhedra and total dual integrality; 23 Cutting planes; 24 Further methods in integer linear programming; Historical and further notes on integer linear programming; References; Notation index; Author index; Subject index

Introduction to Linear Programming with MATLAB - Shashi Kant Mishra 2017-09-07

This book is based on the lecture notes of the author delivered to the students at the Institute of Science, Banaras Hindu University, India. It covers simplex, revised simplex, two-phase method, duality, dual simplex, complementary slackness, transportation and assignment problems with good number of examples, clear proofs, MATLAB codes and homework problems. The book will be useful for both students and practitioners.

How the World Computes - Barry S. Cooper 2012-05-28

This book constitutes the refereed proceedings of the Turing Centenary Conference and the 8th Conference on Computability in Europe, CiE 2012, held in Cambridge, UK, in June 2012. The 53 revised papers presented together with 6 invited lectures were carefully reviewed and selected with an acceptance rate of under 29,8%. The CiE 2012 Turing Centenary Conference will be remembered as a historic event in the continuing development of the powerful explanatory role of computability across a wide spectrum of research areas. The papers presented at CiE 2012 represent the best of current research in the area, and forms a fitting tribute to the short but brilliant trajectory of Alan Mathison Turing. Both the conference series and the association promote the development of computability-related science, ranging over mathematics, computer science and applications in various natural and engineering sciences such as physics and biology, and also including the promotion of related non-scientific fields such as philosophy and history of computing.

Bond Portfolio Optimization - Michael Puhle 2008-01-08

The book analyzes how modern portfolio theory and dynamic term structure models can be applied to government bond portfolio optimization problems. The author studies the necessary adjustments, examines the models with regard to the plausibility of their results and compares the outcomes to portfolio selection techniques used by practitioners. Both single-period and continuous-time bond portfolio optimization problems are considered.

STACS 92 - Alain Finkel 1992-02-04

This volume gives the proceedings of the ninth Symposium on Theoretical Aspects of Computer Science (STACS). This annual symposium is held alternately in France and Germany and is organized jointly by the Special Interest Group for Fundamental Computer Science of the Association Francaise des Sciences et Technologies de l'Information et des Syst mes (AFCET) and the Special Interest Group for Theoretical Computer Science of the Gesellschaft für Informatik (GI). The volume includes three invited lectures and sections on parallel algorithms, logic and semantics, computational geometry, automata and languages, structural complexity, computational geometry and learning theory, complexity and communication, distributed systems, complexity, algorithms, cryptography, VLSI, words and rewriting, and systems.

Linear Programming Applications to Economic Development and Policy Analysis - Arthur L. Stoecker 1988*

Optimal Whole Forest Management Planning - Peter Tarp 1997

Linear Programming 1 - George B. Dantzig 1997-01-27

Encompassing all the major topics students will encounter in courses on the subject, the authors teach both the underlying mathematical foundations and how these ideas are implemented in practice. They illustrate all the concepts with both worked examples and plenty of exercises, and, in addition, provide software so that students can try out numerical methods and so hone their skills in interpreting the results. As a result, this will make an ideal textbook for all those coming to the subject for the first time. Authors' note: A problem recently found with the software is due to a bug in Formula One, the third party commercial software package that was used for the development of the interface. It occurs when the date, currency, etc. format is set to a non-United States version. Please try setting your computer date/currency option to the United States option. The new version of Formula One, when ready, will be posted on WWW.

Qualitative topics in integer linear programming - Valery N. Shevchenko 1996-10-15

Integer solutions for systems of linear inequalities, equations, and congruences are considered along with the construction and theoretical analysis of integer programming algorithms. The complexity of algorithms is analyzed dependent upon two parameters: the dimension, and the maximal modulus of the coefficients describing the conditions of the problem. The analysis is based on a thorough treatment of the qualitative and quantitative aspects of integer programming, in particular on bounds obtained by the author for the number of extreme points. This permits progress in many cases in which the traditional approach--which regards complexity as a function only of the length of the input--leads to a negative result.

Lecture Notes Series - 1977

Linear Optimization and Extensions - Manfred Padberg 2013-04-17

From the reviews: "Do you know M.Padberg's Linear Optimization and Extensions? [...] Now here is the continuation of it, discussing the solutions of all its exercises and with detailed analysis of the applications mentioned. Tell your students about it. [...] For those who strive for good exercises and case studies for LP this is an excellent volume." Acta Scientiarum Mathematicarum

Gutachten und Anträge zur Reform der juristischen Studien - 1887

Multicriteria Analysis - Joao Climaco 2012-12-06

J. Climaco and C. H. Antunes After the pleasure which has been to host the community of researchers and

practitioners in the area of multicriteria analysis (MA) in Coimbra in August 1994, this volume of proceedings based on the papers presented at the conference is the last step of that venture. Even though this may not be the appropriate place we cannot resist, however, the temptation to express herein some brief feelings about the conference. Almost everything concerning the conference organisation has been "handcrafted" by a small number of people, with the advantages and disadvantages that this approach generates. Our first word of acknowledgement is of course due to those who have had a permanent and active role in the multiple aspects which make the success of a conference: Maria Joao Alves, Carlos Henggeler Antunes (who is a co author of this introduction since he has closely collaborated with me in the scientific programme), Joao Paulo Costa, Luis Dias (who greatly contributed to the organisation of this volume) and Paulo Melo, as well as Leonor Dias, from the Faculty of Economics, who has shown an outstanding dedication. To those who collaborated with the organisers in the framework of their professional activity, special thanks due to Adelina whose dedication greatly exceeded her duties. As you probably know from your own experience every small detail of the conference organisation required a lot of "sweating", but the atmosphere of joy and friendship then generated has been a generous "pay-off".

Duality in Stochastic Linear and Dynamic Programming - Willem K. Klein Haneveld 2013-04-17

Math 5593 Linear Programming Lecture Notes - Alexander Engau 2014-11-25

Math 5593 Linear Programming Lecture Notes By Alexander Engau

On Round-Off Errors in Linear Programming - H. Müller-Merbach 2012-12-06

Due to the limited number of digits or bits per storage location in electronic computers, round-off errors arise during arithmetic operations. Depending upon the kind of operation, the structure of the data, and the skillfulness of the program, these errors increase and spread out more or less quickly during a continued computation process in which the computed data affected by errors are themselves used for generating new data. The purpose of this investigation was to learn about the increase of round-off errors in linear programming procedures. Less attention was paid to the theory of round-off errors or to the effectiveness of error elimination procedures. In regard to these questions the results of investigations which have been made on round-off errors in a more general context dealing with matrix inversion and eigenvalue problems could be used for the purposes of this paper. The emphasis of this investigation lay rather on studying the behavior of typical linear programming problems from the point of view of error cumulation.

Lectures on Stochastic Programming - Alexander Shapiro 2014-07-09

Optimization problems involving stochastic models occur in almost all areas of science and engineering, such

as telecommunications, medicine, and finance. Their existence compels a need for rigorous ways of formulating, analyzing, and solving such problems. This book focuses on optimization problems involving uncertain parameters and covers the theoretical foundations and recent advances in areas where stochastic models are available. In *Lectures on Stochastic Programming: Modeling and Theory, Second Edition*, the authors introduce new material to reflect recent developments in stochastic programming, including: an analytical description of the tangent and normal cones of chance constrained sets; analysis of optimality conditions applied to nonconvex problems; a discussion of the stochastic dual dynamic programming method; an extended discussion of law invariant coherent risk measures and their Kusuoka representations; and in-depth analysis of dynamic risk measures and concepts of time consistency, including several new results.

Linear Programming - Saul I. Gass 2003-01-01

Comprehensive, well-organized volume, suitable for undergraduates, covers theoretical, computational, and applied areas in linear programming. Expanded, updated edition; useful both as a text and as a reference book. 1995 edition.

Ellipsoidal Algorithm for Linear Programming - Stanislaw Walukiewicz 1980

Infinite Programming - Edward J. Anderson 2012-12-06

Infinite programming may be defined as the study of mathematical programming problems in which the number of variables and the number of constraints are both possibly infinite. Many optimization problems in engineering, operations research, and economics have natural formulations as infinite programs. For example, the problem of Chebyshev approximation can be posed as a linear program with an infinite number of constraints. Formally, given continuous functions f, g_1, g_2, \dots, g_n on the interval $[a, b]$, we can find the linear combination of the functions g_1, g_2, \dots, g_n which is the best uniform approximation to f by choosing real numbers a, x_1, x_2, \dots, x_n to minimize $\max_{t \in [a, b]} |f(t) - \sum_{i=1}^n x_i g_i(t)|$. This is an example of a semi-infinite program; the number of variables is finite and the number of constraints is infinite. An example of an infinite program in which the number of constraints and the number of variables are both infinite, is the well-known continuous linear program which can be formulated as follows. Minimize $\int_0^T c(t)x(t)dt + b(t)$, subject to $Bx(t) + \int_0^t Kx(s)ds \leq 0$, $t \in [0, T]$. If x is regarded as a member of some infinite-dimensional vector space of functions, then this problem is a linear program posed over that space. Observe that if the constraint equations are differentiated, then this problem takes the form of a linear optimal control problem with state IV variable inequality constraints.

Lectures on Modern Convex Optimization - Aharon Ben-Tal 2001-01-01

Here is a book devoted to well-structured and thus efficiently solvable convex optimization problems, with emphasis on conic quadratic and semidefinite programming. The authors present the basic theory underlying these problems as well as their numerous applications in engineering, including synthesis of filters, Lyapunov stability analysis, and structural design. The authors also discuss the complexity issues and provide an overview of the basic theory of state-of-the-art polynomial time interior point methods for linear, conic quadratic, and semidefinite programming. The book's focus on well-structured convex problems in conic form allows for unified theoretical and algorithmical treatment of a wide spectrum of important optimization problems arising in applications.

On round-off errors in linear programming - Heiner Müller-Merbach 1970

Elementary Linear Programming with Applications - Bernard Kolman 1995-07-06

Disk contains: linear programming code SMPX.

Business Mathematics - Kit Tyabandha 2005

Linear Programming and Its Applications - James K. Strayer 2012-12-06

Linear Programming and Its Applications is intended for a first course in linear programming, preferably in the sophomore or junior year of the typical undergraduate curriculum. The emphasis throughout the book is on linear programming skills via the algorithmic solution of small-scale problems, both in the general sense and in the specific applications where these problems naturally occur. The book arose from lecture notes prepared during the years 1985-1987 while I was a graduate assistant in the Department of Mathematics at The Pennsylvania State University. I used a preliminary draft in a Methods of Management Science class in the spring semester of 1988 at Lock Haven University. Having been extensively tried and tested in the classroom at various stages of its development, the book reflects many modifications either suggested directly by students or deemed appropriate from responses by students in the classroom setting. My primary aim in writing the book was to address common errors and difficulties as clearly and effectively as I could.

Linear and Nonlinear Optimization - Richard W. Cottle 2017-06-11

This textbook on Linear and Nonlinear Optimization is intended for graduate and advanced undergraduate students in operations research and related fields. It is both literate and mathematically strong, yet requires no prior course in optimization. As suggested by its title, the book is divided into two parts covering in their individual chapters LP Models and Applications; Linear Equations and Inequalities; The Simplex Algorithm; Simplex Algorithm Continued; Duality and the Dual Simplex Algorithm; Postoptimality Analyses; Computational

Considerations; Nonlinear (NLP) Models and Applications; Unconstrained Optimization; Descent Methods; Optimality Conditions; Problems with Linear Constraints; Problems with Nonlinear Constraints; Interior-Point Methods; and an Appendix covering Mathematical Concepts. Each chapter ends with a set of exercises. The book is based on lecture notes the authors have used in numerous optimization courses the authors have taught at Stanford University. It emphasizes modeling and numerical algorithms for optimization with continuous (not integer) variables. The discussion presents the underlying theory without always focusing on formal mathematical proofs (which can be found in cited references). Another feature of this book is its inclusion of cultural and historical matters, most often appearing among the footnotes. "This book is a real gem. The authors do a masterful job of rigorously presenting all of the relevant theory clearly and concisely while managing to avoid unnecessary tedious mathematical details. This is an ideal book for teaching a one or two semester masters-level course in optimization – it broadly covers linear and nonlinear programming effectively balancing modeling, algorithmic theory, computation, implementation, illuminating historical facts, and numerous interesting examples and exercises. Due to the clarity of the exposition, this book also serves as a valuable reference for self-study." Professor Ilan Adler, IEOR Department, UC Berkeley "A carefully crafted introduction to the main elements and applications of mathematical optimization. This volume presents the essential concepts of linear and nonlinear programming in an accessible format filled with anecdotes, examples, and exercises that bring the topic to life. The authors plumb their decades of experience in optimization to provide an enriching layer of historical context. Suitable for advanced undergraduates and masters students in management science, operations research, and related fields." Michael P. Friedlander, IBM Professor of Computer Science, Professor of Mathematics, University of British Columbia

Linear Programming and Network Flows - Mokhtar S. Bazaraa 1990

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Recent Advances in Optimization - Alberto Seeger 2006-01-26

This volume contains the Proceedings of the Twelfth French-German-Spanish Conference on Optimization held at the University of Avignon in 2004. We refer to this conference by using the acronym FGS-2004. During the period September 20-24, 2004, about 180 scientists from around the world met at Avignon (France) to discuss recent developments in optimization and related fields. The main topics discussed during this meeting were the following: 1. smooth and nonsmooth continuous optimization problems, 2. numerical methods for mathematical programming, 3. optimal control and calculus of variations, 4. differential inclusions and set-valued analysis, 5. stochastic optimization, 6. multicriteria optimization, 7. game theory and equilibrium concepts, 8. optimization models in finance and mathematical economics, 9. optimization

techniques for industrial applications. The Scientific Committee of the conference consisted of F. Bonnans (Rocqucourt, France), J.-B. Hiriart-Urruty (Toulouse, France), F. Jarre (Diisseldorf, Germany), M.A. Lopez (Alicante, Spain), J.E. Martinez-Legaz (Barcelona, Spain), H. Maurer (Miinster, Germany), S. Pickenhain (Cottbus, Germany), A. Seeger (Avignon, France), and M. Thera (Limoges, France). The conference FGS-2004 is the 12th of the series of French-German meetings which started in Oberwolfach in 1980 and was continued in Confolant (1981), Luminy (1984), Irsee (1986), Varetz (1988), Lambrecht (1991), Dijon (1994), Trier (1996), Namur (1998), Montpellier (2000), and Cottbus (2002).

DECOMP: an Implementation of Dantzig-Wolfe Decomposition for Linear Programming - James K. Ho 2013-11-11

For linear optimization models that can be formulated as linear programs with the block-angular structure, i.e. independent subproblems with coupling constraints, the Dantzig-Wolfe decomposition principle provides an elegant framework of solution algorithms as well as economic interpretation. This monograph is the complete documentation of DECOMP: a robust implementation of the Dantzig-Wolfe decomposition method in FORTRAN. The code can serve as a very convenient starting point for further investigation, both computational and economic, of parallelism in large-scale systems. It can also be used as supplemental material in a second course in linear programming, computational mathematical programming, or large-scale systems.

Understanding and Using Linear Programming - Jiri Matousek 2007-07-04

The book is an introductory textbook mainly for students of computer science and mathematics. Our guiding phrase is "what every theoretical computer scientist should know about linear programming". A major focus is on applications of linear programming, both in practice and in theory. The book is concise, but at the same time, the main results are covered with complete proofs and in sufficient detail, ready for presentation in class. The book does not require more prerequisites than basic linear algebra, which is summarized in an appendix. One of its main goals is to help the reader to see linear programming "behind the scenes".

Lecture Notes in Control and Information Sciences - A. V. Balakrishnan 1981

Mathematical Developments Arising from Linear Programming - Ams-Ims-Siam Joint Summer Research Conference on Mathematical developm 1990

In recent years, there has been intense work in linear and nonlinear programming, much of it centered on understanding and extending the ideas underlying N. Karmarkar's interior-point linear programming algorithm, which was presented in 1984. This interdisciplinary research was the subject of an AMS Summer Research

Conference on Mathematical Developments Arising from Linear Programming, held at Bowdoin College in the summer of 1988, which brought together researchers in mathematics, computer science, and operations research. This volume contains the proceedings from the conference. Among the topics covered in this book are: completely integrable dynamical systems arising in optimization problems, Riemannian geometry and interior-point linear programming methods, concepts of approximate solution of linear programs, average case analysis of the simplex method, and recent results in convex polytopes. Some of the papers extend interior-point methods to quadratic programming, the linear complementarity problem, convex programming, multi-criteria optimization, and integer programming. Other papers study the continuous trajectories underlying interior point methods. This book will be an excellent resource for those interested in the latest developments arising from Karmarkar's linear programming algorithm and in path-following methods for solving differential equations.

Lectures on Stochastic Programming - Alexander Shapiro 2009-01-01

Optimization problems involving stochastic models occur in almost all areas of science and engineering, such as telecommunications, medicine, and finance. Their existence compels a need for rigorous ways of formulating, analyzing, and solving such problems. This book focuses on optimization problems involving uncertain parameters and covers the theoretical foundations and recent advances in areas where stochastic models are available. Readers will find coverage of the basic concepts of modeling these problems, including recourse actions and the nonanticipativity principle. The book also includes the theory of two-stage and multistage stochastic programming problems; the current state of the theory on chance (probabilistic) constraints, including the structure of the problems, optimality theory, and duality; and statistical inference in and risk-averse approaches to stochastic programming.

Linear Multiobjective Programming - M. Zeleny 2012-12-06

1.1. The origin of the multiobjective problem and a short historical review The continuing search for a

discovery of theories, tools and concepts applicable to decision-making processes has increased the complexity of problems eligible for analytical treatment. One of the more pertinent criticisms of current decision-making theory and practice is directed against the traditional approximation of multiple goal behavior of men and organizations by single, technically-convenient criterion. Reinstatement of the role of human judgment in more realistic, multiple goal settings has been one of the major recent developments in the literature. Consider the following simplified problem. There is a large number of people to be transported daily between two industrial areas and their adjacent residential areas. Given some budgetary and technological constraints we would like to determine optimal transportation modes as well as the number of units of each to be scheduled for service. What is the optimal solution? Are we interested in the cheapest transportation? Do we want the fastest, the safest, the cleanest, the most profitable, the most durable? There are many criteria which are to be considered: travel times, consumer's cost, construction cost, operating cost, expected fatalities and injuries, probability of delays, etc.

The Design of Approximation Algorithms - David P. Williamson 2011-04-26

Discrete optimization problems are everywhere, from traditional operations research planning (scheduling, facility location and network design); to computer science databases; to advertising issues in viral marketing. Yet most such problems are NP-hard; unless $P = NP$, there are no efficient algorithms to find optimal solutions. This book shows how to design approximation algorithms: efficient algorithms that find provably near-optimal solutions. The book is organized around central algorithmic techniques for designing approximation algorithms, including greedy and local search algorithms, dynamic programming, linear and semidefinite programming, and randomization. Each chapter in the first section is devoted to a single algorithmic technique applied to several different problems, with more sophisticated treatment in the second section. The book also covers methods for proving that optimization problems are hard to approximate. Designed as a textbook for graduate-level algorithm courses, it will also serve as a reference for researchers interested in the heuristic solution of discrete optimization problems.