

## Combinatorial Optimization Algorithms And Complexity Kenneth Steiglitz

This book constitutes the thoroughly refereed post-conference proceedings of the Third International Symposium on Combinatorial Optimization, ISCO 2014, held in Lisbon, Portugal, in March 2014. The 37 revised full papers presented together with 64 short papers were carefully reviewed and selected from 97 submissions. They present original research on all aspects of combinatorial optimization, such as algorithms and complexity; mathematical programming; operations research; stochastic optimization; graphs and combinatorics.

Bioinspired computation methods such as evolutionary algorithms and ant colony optimization are being applied successfully to complex engineering problems and to problems from combinatorial optimization, and with this comes the requirement to more fully understand the computational complexity of these search heuristics. This is the first textbook covering the most important results achieved in this area. The authors study the computational complexity of bioinspired computation and show how runtime behavior can be analyzed in a rigorous way using some of the best-known combinatorial optimization problems -- minimum spanning trees, shortest paths, maximum matching, covering and scheduling problems. A feature of the book is the separate treatment of single- and multiobjective problems, the latter a domain where the development of the underlying theory seems to be lagging practical successes. This book will be very valuable for teaching courses on bioinspired computation and combinatorial optimization.

Researchers will also benefit as the presentation of the theory covers the most important developments in the field over the last 10 years. Finally, with a focus on well-studied combinatorial optimization problems rather than toy problems, the book will also be very valuable for practitioners in this field.

Rave reviews for INTEGER AND COMBINATORIAL OPTIMIZATION "This book provides an excellent introduction and survey of traditional fields of combinatorial optimization . . . It is indeed one of the best and most complete texts on combinatorial optimization . . . available. [And] with more than 700 entries, [it] has quite an exhaustive reference list."-Optima "A unifying approach to optimization problems is to formulate them like linear programming problems, while restricting some or all of the variables to the integers. This book is an encyclopedic resource for such formulations, as well as for understanding the structure of and solving the resulting integer programming problems."-Computing Reviews "[This book] can serve as a basis for various graduate courses on discrete optimization as well as a reference book for researchers and practitioners."-Mathematical Reviews "This comprehensive and wide-ranging book will undoubtedly become a standard reference book for all those in the field of combinatorial optimization."-Bulletin of the London Mathematical Society "This text should be required reading for anybody who intends to do research in this area or even just to keep abreast of developments."-Times Higher Education Supplement, London Also of interest . . . INTEGER PROGRAMMING Laurence A. Wolsey Comprehensive and self-contained, this intermediate-level guide to integer programming provides readers with clear, up-to-date explanations on why some problems are difficult to solve, how techniques can be reformulated to give better results, and how mixed integer programming systems can be used more

effectively. 1998 (0-471-28366-5) 260 pp.

Stochastic local search (SLS) algorithms are among the most prominent and successful techniques for solving computationally difficult problems. Offering a systematic treatment of SLS algorithms, this book examines the general concepts and specific instances of SLS algorithms and considers their development, analysis and application.

Clearly written graduate-level text considers the Soviet ellipsoid algorithm for linear programming; efficient algorithms for network flow, matching, spanning trees, and matroids; the theory of NP-complete problems; approximation algorithms, local search heuristics for NP-complete problems, more. "Mathematicians wishing a self-contained introduction need look no further." — American Mathematical Monthly. 1982 edition.

This book constitutes the joint refereed proceedings of the 7th International Workshop on Approximation Algorithms for Combinatorial Optimization Problems, APPROX 2004 and the 8th International Workshop on Randomization and Computation, RANDOM 2004, held in Cambridge, MA, USA in August 2004. The 37 revised full papers presented were carefully reviewed and selected from 87 submissions. Among the issues addressed are design and analysis of approximation algorithms, inapproximability results, approximation classes, online problems, graph algorithms, cuts, geometric computations, network design and routing, packing and covering, scheduling, game theory, design and analysis of randomised algorithms, randomized complexity theory, pseudorandomness, derandomization, probabilistic proof systems, error-correcting codes, and other applications of approximation and randomness.

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.

In recent years, many new techniques have emerged in the mathematical theory of discrete optimization that have proven to be effective in solving a number of hard problems. This book presents these recent advances, particularly those that arise from algebraic geometry, commutative algebra, convex and discrete geometry, generating functions, and other tools normally considered outside of the standard curriculum in optimization. These new techniques, all of which are presented with minimal prerequisites, provide a transition from linear to nonlinear discrete optimization. This book can be used as a textbook for advanced undergraduates or first-year graduate students in mathematics, computer science or operations research. It is also appropriate for

mathematicians, engineers, and scientists engaged in computation who wish to gain a deeper understanding of how and why algorithms work.

This book documents the state of the art in combinatorial optimization, presenting approximate solutions of virtually all relevant classes of NP-hard optimization problems. The wealth of problems, algorithms, results, and techniques make it an indispensable source of reference for professionals. The text smoothly integrates numerous illustrations, examples, and exercises.

Computational complexity, originated from the interactions between computer science and numerical optimization, is one of the major theories that have revolutionized the approach to solving optimization problems and to analyzing their intrinsic difficulty. The main focus of complexity is the study of whether existing algorithms are efficient for the solution of problems, and which problems are likely to be tractable. The quest for developing efficient algorithms leads also to elegant general approaches for solving optimization problems, and reveals surprising connections among problems and their solutions. This book is a collection of articles on recent complexity developments in numerical optimization. The topics covered include complexity of approximation algorithms, new polynomial time algorithms for convex quadratic minimization, interior point algorithms, complexity issues regarding test generation of NP-hard problems, complexity of scheduling problems, min-max, fractional combinatorial optimization, fixed point computations and network flow problems. The collection of articles provide a broad spectrum of the direction in which research is going and help to elucidate the nature of computational complexity in optimization. The book will be a valuable source of information to faculty, students and researchers in numerical optimization and related areas. Contents: Average Performance of a Self-Dual Interior Point Algorithm for Linear Programming (K M Anstreicher et al.) The Complexity of Approximating a Nonlinear Program (M Bellare & P Rogaway) Algorithms for the Least Distance Problem (P Berman et al.) Translational Cuts for Convex Minimization (J V Burke et al.) Maximizing Concave Functions in Fixed Dimension (E Cohen & N Megiddo) The Complexity of Allocating Resources in Parallel: Upper and Lower Bounds (E J Friedman) Complexity Issues in Nonconvex Network Flow Problems (G M Guisewite & P M Pardalos) A Classification of Static Scheduling Problems (J W Herrmann et al.) Complexity of Single Machine Hierarchical Scheduling: A Survey (C-Y Lee & G Vairaktarakis) Performance Driven Graph Enhancement Problems (D Paik & S Sahni) Parametric Flows, Weighted Means of Cuts, and Fractional Combinatorial Optimization (T Radzik) Some Complexity Issues Involved in the Construction of Test Cases for NP-Hard Problems (L A Sanchis) Maximizing Nonlinear Concave Functions in Fixed Dimension (S Toledo) A Note on the Complexity of Fixed-Point Computation for Noncontractive Maps (C W Tsay & K Sikorski) Polynomial Time Weak Approximation Algorithms for Quadratic Programming (S A Vavasis) Complexity Results for a Class of Min-Max Problems with Robust Optimization Applications (G Yu & P Kouvelis) and other papers Readership: Applied mathematicians and computer scientists. keywords:

In vector optimization one investigates optimization problems in an abstract setting which have a not necessarily real-valued objective function. This scientific discipline is closely related to multi-objective optimization and multi-criteria decision making. This book contains refereed contributions to the "International Conference on Vector Optimization" held at the Technical University of Darmstadt from August 4-7, 1986. This meeting was an interdisciplinary forum devoted to new results in the theory, to applications as well as to the solution of vector optimization problems which are relevant in practice. Because of the great variety of topics covered by the contributions, the 25 articles of this volume are organized in different sections: Historical retrospect, mathematical theory, goal setting and decision making, engineering applications, and related topics. The papers of the invited State-of-the-Art Tutorials given by Professors J.M. Borwein, H. Eschenauer, W.

Stadler and P.L. Yu are also included.

A complete, highly accessible introduction to one of today's most exciting areas of applied mathematics. One of the youngest, most vital areas of applied mathematics, combinatorial optimization integrates techniques from combinatorics, linear programming, and the theory of algorithms. Because of its success in solving difficult problems in areas from telecommunications to VLSI, from product distribution to airline crew scheduling, the field has seen a ground swell of activity over the past decade. Combinatorial Optimization is an ideal introduction to this mathematical discipline for advanced undergraduates and graduate students of discrete mathematics, computer science, and operations research. Written by a team of recognized experts, the text offers a thorough, highly accessible treatment of both classical concepts and recent results. The topics include: \* Network flow problems \* Optimal matching \* Integrality of polyhedra \* Matroids \* NP-completeness. Featuring logical and consistent exposition, clear explanations of basic and advanced concepts, many real-world examples, and helpful, skill-building exercises, Combinatorial Optimization is certain to become the standard text in the field for many years to come. This tutorial contains written versions of seven lectures on Computational Combinatorial Optimization given by leading members of the optimization community. The lectures introduce modern combinatorial optimization techniques, with an emphasis on branch and cut algorithms and Lagrangian relaxation approaches. Polyhedral combinatorics as the mathematical backbone of successful algorithms are covered from many perspectives, in particular, polyhedral projection and lifting techniques and the importance of modeling are extensively discussed. Applications to prominent combinatorial optimization problems, e.g., in production and transport planning, are treated in many places; in particular, the book contains a state-of-the-art account of the most successful techniques for solving the traveling salesman problem to optimality.

A concise, comprehensive introduction to the topic of statistical physics of combinatorial optimization, bringing together theoretical concepts and algorithms from computer science with analytical methods from physics. The result bridges the gap between statistical physics and combinatorial optimization, investigating problems taken from theoretical computing, such as the vertex-cover problem, with the concepts and methods of theoretical physics. The authors cover rapid developments and analytical methods that are both extremely complex and spread by word-of-mouth, providing all the necessary basics in required detail. Throughout, the algorithms are shown with examples and calculations, while the proofs are given in a way suitable for graduate students, post-docs, and researchers. Ideal for newcomers to this young, multidisciplinary field.

Graph algorithms are easy to visualize and indeed there already exists a variety of packages to animate the dynamics when solving problems from graph theory. Still it can be difficult to understand the ideas behind the algorithm from the dynamic display alone. CATBox consists of a software system for animating graph algorithms and a course book which we developed simultaneously. The software system presents both the algorithm and the graph and puts the user always in control of the actual code that is executed. In the course book, intended for readers at advanced undergraduate or graduate level, computer exercises and examples replace the usual static pictures of algorithm dynamics. For this volume we have chosen solely algorithms for classical problems from combinatorial optimization, such as minimum spanning trees, shortest paths, maximum flows, minimum cost flows, weighted and unweighted matchings both for bipartite and non-bipartite graphs. Find more information at <http://schliep.org/CATBox/>.

Studies two algorithms in detail: the ellipsoid method and the simultaneous diophantine approximation method.

This volume constitutes the proceedings of the 14th International Conference on Combinatorial Optimization and Applications, COCOA 2020, held in Dallas, TX, USA, in December 2020. The 55 full papers presented in this volume were carefully reviewed and selected from 104 submissions. The papers are grouped into the following topics: Approximation Algorithms; Scheduling; Network Optimization; Complexity and Logic; Search, Facility and Graphs; Geometric Problem; Sensors, Vehicles and Graphs; and Graph Problems. Due to the Corona pandemic this event was held virtually.

This monograph presents the main complexity theorems in convex optimization and their corresponding algorithms. It begins with the fundamental theory of black-box optimization and proceeds to guide the reader through recent advances in structural optimization and stochastic optimization. The presentation of black-box optimization, strongly influenced by the seminal book by Nesterov, includes the analysis of cutting plane methods, as well as (accelerated) gradient descent schemes. Special attention is also given to non-Euclidean settings (relevant algorithms include Frank-Wolfe, mirror descent, and dual averaging), and discussing their relevance in machine learning. The text provides a gentle introduction to structural optimization with FISTA (to optimize a sum of a smooth and a simple non-smooth term), saddle-point mirror prox (Nemirovski's alternative to Nesterov's smoothing), and a concise description of interior point methods. In stochastic optimization it discusses stochastic gradient descent, mini-batches, random coordinate descent, and sublinear algorithms. It also briefly touches upon convex relaxation of combinatorial problems and the use of randomness to round solutions, as well as random walks based methods.

Perceptive text examines shortest paths, network flows, bipartite and nonbipartite matching, matroids and the greedy algorithm, matroid intersections, and the matroid parity problems. Suitable for courses in combinatorial computing and concrete computational complexity.

This well-written textbook on combinatorial optimization puts special emphasis on theoretical results and algorithms with provably good performance, in contrast to heuristics. The book contains complete (but concise) proofs, as well as many deep results, some of which have not appeared in any previous books.

This graduate-level text considers the Soviet ellipsoid algorithm for linear programming; efficient algorithms for network flow, matching, spanning trees, and matroids; the theory of NP-complete problems; local search heuristics for NP-complete problems, more. 1982 edition.

Algorithmic design, especially for hard problems, is more essential for success in solving them than any standard improvement of current computer technologies. Because of this, the design of algorithms for solving hard problems is the core of current algorithmic research from the theoretical point of view as well as from the practical point of view. There

are many general text books on algorithmics, and several specialized books devoted to particular approaches such as local search, randomization, approximation algorithms, or heuristics. But there is no textbook that focuses on the design of algorithms for hard computing tasks, and that systematically explains, combines, and compares the main possibilities for attacking hard algorithmic problems. As this topic is fundamental for computer science, this book tries to close this gap. Another motivation, and probably the main reason for writing this book, is connected to education. The considered area has developed very dynamically in recent years and the research on this topic discovered several profound results, new concepts, and new methods. Some of the achieved contributions are so fundamental that one can speak about paradigms which should be included in the education of every computer science student. Unfortunately, this is very far from reality. This is because these paradigms are not sufficiently known in the computer science community, and so they are insufficiently communicated to students and practitioners.

In the last few years, Algorithms for Convex Optimization have revolutionized algorithm design, both for discrete and continuous optimization problems. For problems like maximum flow, maximum matching, and submodular function minimization, the fastest algorithms involve essential methods such as gradient descent, mirror descent, interior point methods, and ellipsoid methods. The goal of this self-contained book is to enable researchers and professionals in computer science, data science, and machine learning to gain an in-depth understanding of these algorithms. The text emphasizes how to derive key algorithms for convex optimization from first principles and how to establish precise running time bounds. This modern text explains the success of these algorithms in problems of discrete optimization, as well as how these methods have significantly pushed the state of the art of convex optimization itself.

Covering network designs, discrete convex analysis, facility location and clustering problems, matching games, and parameterized complexity, this book discusses theoretical aspects of combinatorial optimization and graph algorithms. Contributions are by renowned researchers who attended NII Shonan meetings on this essential topic. The collection contained here provides readers with the outcome of the authors' research and productive meetings on this dynamic area, ranging from computer science and mathematics to operations research. Networks are ubiquitous in today's world: the Web, online social networks, and search-and-query click logs can lead to a graph that consists of vertices and edges. Such networks are growing so fast that it is essential to design algorithms to work for these large networks. Graph algorithms comprise an area in computer science that works to design efficient algorithms for networks. Here one can work on theoretical or practical problems where implementation of an algorithm for large networks is needed. In two of the chapters, recent results in graph matching games and fixed parameter tractability are surveyed. Combinatorial optimization is an intersection of operations research and mathematics, especially discrete mathematics, which deals

with new questions and new problems, attempting to find an optimum object from a finite set of objects. Most problems in combinatorial optimization are not tractable (i.e., NP-hard). Therefore it is necessary to design an approximation algorithm for them. To tackle these problems requires the development and combination of ideas and techniques from diverse mathematical areas including complexity theory, algorithm theory, and matroids as well as graph theory, combinatorics, convex and nonlinear optimization, and discrete and convex geometry. Overall, the book presents recent progress in facility location, network design, and discrete convex analysis.

Christos H. Papadimitriou and Kenneth Steiglitz have combined the theory of computational complexity developed by computer scientists, and the foundations of mathematical programming developed by the operations research community. This text will be useful to students with a wide range of backgrounds, including computer science, operations research, and electrical engineering. This book constitutes the joint refereed proceedings of the 14th International Workshop on Approximation Algorithms for Combinatorial Optimization Problems, APPROX 2011, and the 15th International Workshop on Randomization and Computation, RANDOM 2011, held in Princeton, New Jersey, USA, in August 2011. The volume presents 29 revised full papers of the APPROX 2011 workshop, selected from 66 submissions, and 29 revised full papers of the RANDOM 2011 workshop, selected from 64 submissions. They were carefully reviewed and selected for inclusion in the book. In addition two abstracts of invited talks are included. APPROX focuses on algorithmic and complexity issues surrounding the development of efficient approximate solutions to computationally difficult problems. RANDOM is concerned with applications of randomness to computational and combinatorial problems.

Online decision making under uncertainty and time constraints represents one of the most challenging problems for robust intelligent agents. In an increasingly dynamic, interconnected, and real-time world, intelligent systems must adapt dynamically to uncertainties, update existing plans to accommodate new requests and events, and produce high-quality decisions under severe time constraints. Such online decision-making applications are becoming increasingly common: ambulance dispatching and emergency city-evacuation routing, for example, are inherently online decision-making problems; other applications include packet scheduling for Internet communications and reservation systems. This book presents a novel framework, online stochastic optimization, to address this challenge. This framework assumes that the distribution of future requests, or an approximation thereof, is available for sampling, as is the case in many applications that make either historical data or predictive models available. It assumes additionally that the distribution of future requests is independent of current decisions, which is also the case in a variety of applications and holds significant computational advantages. The book presents several online stochastic algorithms implementing the framework, provides performance guarantees, and demonstrates a variety of applications. It discusses how to relax some of the assumptions in using historical sampling and machine learning and analyzes different underlying algorithmic problems. And finally, the book discusses the framework's possible limitations and suggests directions for future research.

Combinatorial optimization is a multidisciplinary scientific area, lying in the interface of three major scientific domains: mathematics, theoretical computer science and management. The three volumes of the Combinatorial Optimization series aim to cover a wide range of topics in this area. These topics also deal with fundamental notions and approaches as well as several classical applications of combinatorial optimization. Concepts of Combinatorial Optimization, is divided into three parts: - On the complexity of combinatorial optimization problems, presenting basics about worst-case and randomized complexity; - Classical solution methods, presenting the two most-known methods for solving hard combinatorial optimization problems, that are Branch-and-Bound and Dynamic Programming; - Elements from mathematical programming, presenting fundamentals from mathematical programming based methods that are in the heart of Operations Research since the origins of this field.

This self-contained beginning graduate text covers linear and integer programming, polytopes, matroids and matroid optimization, shortest paths, and network flows.

With the advent of approximation algorithms for NP-hard combinatorial optimization problems, several techniques from exact optimization such as the primal-dual method have proven their staying power and versatility. This book describes a simple and powerful method that is iterative in essence and similarly useful in a variety of settings for exact and approximate optimization. The authors highlight the commonality and uses of this method to prove a variety of classical polyhedral results on matchings, trees, matroids and flows. The presentation style is elementary enough to be accessible to anyone with exposure to basic linear algebra and graph theory, making the book suitable for introductory courses in combinatorial optimization at the upper undergraduate and beginning graduate levels. Discussions of advanced applications illustrate their potential for future application in research in approximation algorithms.

The world of computation according to Turing, an interactive tutoring program, as told to star-crossed lovers: a novel. Our hero is Turing, an interactive tutoring program and namesake (or virtual emanation?) of Alan Turing, World War II code breaker and father of computer science. In this unusual novel, Turing's idiosyncratic version of intellectual history from a computational point of view unfolds in tandem with the story of a love affair involving Ethel, a successful computer executive, Alexandros, a melancholy archaeologist, and Ian, a charismatic hacker. After Ethel (who shares her first name with Alan Turing's mother) abandons Alexandros following a sun-drenched idyll on Corfu, Turing appears on Alexandros's computer screen to unfurl a tutorial on the history of ideas. He begins with the philosopher-mathematicians of ancient Greece—"discourse, dialogue, argument, proof... can only thrive in an egalitarian society"—and the Arab scholar in ninth-century Baghdad who invented algorithms; he moves on to many other topics, including cryptography and artificial intelligence, even economics and developmental biology. (These lessons are later critiqued amusingly and developed further in postings by a fictional newsgroup in the book's afterword.) As Turing's lectures progress, the lives of Alexandros, Ethel, and Ian converge in dramatic fashion, and the story takes us from Corfu to Hong Kong, from Athens to San Francisco—and of course to the Internet, the disruptive technological and social force that emerges as the main locale and protagonist of the novel. Alternately pedagogical and romantic, Turing (A Novel about Computation) should

appeal both to students and professionals who want a clear and entertaining account of the development of computation and to the general reader who enjoys novels of ideas.

Historically, there is a close connection between geometry and optimization. This is illustrated by methods like the gradient method and the simplex method, which are associated with clear geometric pictures. In combinatorial optimization, however, many of the strongest and most frequently used algorithms are based on the discrete structure of the problems: the greedy algorithm, shortest path and alternating path methods, branch-and-bound, etc. In the last several years geometric methods, in particular polyhedral combinatorics, have played a more and more profound role in combinatorial optimization as well. Our book discusses two recent geometric algorithms that have turned out to have particularly interesting consequences in combinatorial optimization, at least from a theoretical point of view. These algorithms are able to utilize the rich body of results in polyhedral combinatorics. The first of these algorithms is the ellipsoid method, developed for nonlinear programming by N. Z. Shor, D. B. Yudin, and A. S. Nemirovskii. It was a great surprise when L. G. Khachiyan showed that this method can be adapted to solve linear programs in polynomial time, thus solving an important open theoretical problem. While the ellipsoid method has not proved to be competitive with the simplex method in practice, it does have some features which make it particularly suited for the purposes of combinatorial optimization.

The second algorithm we discuss finds its roots in the classical "geometry of numbers", developed by Minkowski. This method has had traditionally deep applications in number theory, in particular in diophantine approximation.

The fusion between graph theory and combinatorial optimization has led to theoretically profound and practically useful algorithms, yet there is no book that currently covers both areas together. Handbook of Graph Theory, Combinatorial Optimization, and Algorithms is the first to present a unified, comprehensive treatment of both graph theory and c

This is a supplementary volume to the major three-volume Handbook of Combinatorial Optimization set. It can also be regarded as a stand-alone volume presenting chapters dealing with various aspects of the subject in a self-contained way.

In the past three decades, local search has grown from a simple heuristic idea into a mature field of research in combinatorial optimization that is attracting ever-increasing attention. Local search is still the method of choice for NP-hard problems as it provides a robust approach for obtaining high-quality solutions to problems of a realistic size in reasonable time. Local Search in Combinatorial Optimization covers local search and its variants from both a theoretical and practical point of view, each topic discussed by a leading authority. This book is an important reference and invaluable source of inspiration for students and researchers in discrete mathematics, computer science, operations research, industrial engineering, and management science. In addition to the editors, the contributors are Mihalis Yannakakis, Craig A.

Tovey, Jan H. M. Korst, Peter J. M. van Laarhoven, Alain Hertz, Eric Taillard, Dominique de Werra, Heinz Mühlenbein, Carsten Peterson, Bo Söderberg, David S. Johnson, Lyle A. McGeoch, Michel Gendreau, Gilbert Laporte, Jean-Yves Potvin, Gerard A. P. Kindervater, Martin W. P. Savelsbergh, Edward J. Anderson, Celia A. Glass, Chris N. Potts, C. L. Liu, Peichen Pan, Iiro Honkala, and Patric R. J. Östergård.

This concise, undergraduate-level text focuses on combinatorics, graph theory with applications to some standard network optimization problems, and algorithms. More than 200 exercises, many with complete solutions. 1991 edition.

This volume presents the refereed proceedings of the 10th International Workshop on Approximation Algorithms for Combinatorial

Optimization Problems and the 11th International Workshop on Randomization and Computation. The papers cover design and analysis of approximation algorithms, hardness of approximation, small space and data streaming algorithms, sub-linear time algorithms, embeddings and metric space methods, and much more.

An introduction to the state of the art of the probability theory most applicable to combinatorial optimization. The questions that receive the most attention are those that deal with discrete optimization problems for points in Euclidean space, such as the minimum spanning tree, the traveling-salesman tour, and minimal-length matchings.

Combinatorial optimization is a multidisciplinary scientific area, lying in the interface of three major scientific domains: mathematics, theoretical computer science and management. The three volumes of the Combinatorial Optimization series aim to cover a wide range of topics in this area. These topics also deal with fundamental notions and approaches as with several classical applications of combinatorial optimization. Concepts of Combinatorial Optimization, is divided into three parts: - On the complexity of combinatorial optimization problems, presenting basics about worst-case and randomized complexity; - Classical solution methods, presenting the two most-known methods for solving hard combinatorial optimization problems, that are Branch-and-Bound and Dynamic Programming; - Elements from mathematical programming, presenting fundamentals from mathematical programming based methods that are in the heart of Operations Research since the origins of this field.

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