Handbook of Approximation Algorithms and Metaheuristics

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Handbook of Approximation Algorithms and Metaheuristics

Edited by
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DEDICATED

To my wife
Dorothy,

and my children
Jeanmarie, Alexis, Julia, Teofilo, and Paolo.

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Preface

Forty years ago (1966), Ronald L. Graham formally introduced approximation algorithms. The idea was to generate near-optimal solutions to optimization problems that could not be solved efficiently by the computational techniques available at that time. With the advent of the theory of NP-completeness in the early 1970s, the area became more prominent as the need to generate near optimal solutions for NP-hard optimization problems became the most important avenue for dealing with computational intractability. As it was established in the 1970s, for some problems one can generate near optimal solutions quickly, while for other problems generating provably good suboptimal solutions is as difficult as generating optimal ones. Other approaches based on probabilistic analysis and randomized algorithms became popular in the 1980s. The introduction of new techniques to solve linear programming problems started a new wave for developing approximation algorithms that matured and saw tremendous growth in the 1990s. To deal, in a practical sense, with the inapproximable problems there were a few techniques introduced in the 1980s and 1990s. These methodologies have been referred to as metaheuristics. There has been a tremendous amount of research in metaheuristics during the past two decades. During the last 15 or so years approximation algorithms have attracted considerably more attention. This was a result of a stronger inapproximability methodology that could be applied to a wider range of problems and the development of new approximation algorithms for problems in traditional and emerging application areas.

As we have witnessed, there has been tremendous growth in field of approximation algorithms and metaheuristics. The basic methodologies are presented in Parts I–III. Specifically, Part I covers the basic methodologies to design and analyze efficient approximation algorithms for a large class of problems, and to establish inapproximability results for another class of problems. Part II discusses local search, neural networks and metaheuristics. In Part III multiobjective problems, sensitivity analysis and stability are discussed.

Parts IV–VI discuss the application of the methodologies to classical problems in combinatorial optimization, computational geometry and graphs problems, as well as for large-scale and emerging applications. The approximation algorithms discussed in the handbook have primary applications in computer science, operations research, computer engineering, applied mathematics, bioinformatics, as well as in engineering, geography, economics, and other research areas with a quantitative analysis component.

Chapters 1 and 2 present an overview of the field and the handbook. These chapters also cover basic definitions and notation, as well as an introduction to the basic methodologies and inapproximability. Chapters 1–8 discuss methodologies to develop approximation algorithms for a large class of problems. These methodologies include restriction (of the solution space), greedy methods, relaxation (LP and SDP) and rounding (deterministic and randomized), and primal-dual methods. For a minimization problem P these methodologies provide for every problem instance I a solution with objective function value that is at most $(1+\epsilon) \cdot f^*(I)$, where ϵ is a positive constant (or a function that depends on the instance size) and $f^*(I)$ is the optimal solution value for instance I. These algorithms take polynomial time with respect to the size of the instance I being solved. These techniques also apply to maximization

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problems, but the guarantees are different. Given as input a value for ϵ and any instance I for a given problem P, an approximation scheme finds a solution with objective function value at most $(1+\epsilon)\cdot f^*(I)$. Chapter 9 discusses techniques that have been used to design approximation schemes. These approximation schemes take polynomial time with respect to the size of the instance I (PTAS). Chapter 10 discusses different methodologies for designing fully polynomial approximation schemes (FPTAS). These schemes take polynomial time with respect to the size of the instance I and $1/\epsilon$. Chapters 11–13 discuss asymptotic and randomized approximation schemes, as well as distributed and randomized approximation algorithms. Empirical analysis is covered in Chapter 14 as well as in chapters in Parts IV–VI. Chapters 15–17 discuss performance measures, reductions that preserve approximability, and inapproximability results.

Part II discusses deterministic and stochastic local search as well as very large neighborhood search. Chapters 21 and 22 present reactive search and neural networks. Tabu search, evolutionary computation, simulated annealing, ant colony optimization and memetic algorithms are covered in Chapters 23–27. In Part III, I discuss multiobjective optimization problems, sensitivity analysis and stability of approximations.

Part IV covers traditional applications. These applications include bin packing and extensions, packing problems, facility location and dispersion, traveling salesperson and generalizations, Steiner trees, scheduling, planning, generalized assignment, and satisfiability.

Computational geometry and graph applications are discussed in Part V. The problems discussed in this part include triangulations, connectivity problems in geometric graphs and networks, dilation and detours, pair decompositions, partitioning (points, grids, graphs and hypergraphs), maximum planar subgraphs, edge disjoint paths and unsplittable flow, connectivity problems, communication spanning trees, most vital edges, and metaheuristics for coloring and maximum disjoint paths.

Large-scale and emerging applications (Part VI) include chapters on wireless ad hoc networks, sensor networks, topology inference, multicast congestion, QoS multimedia routing, peer-to-peer networks, data broadcasting, bioinformatics, CAD and VLSI applications, game theoretic approximation, approximating data streams, digital reputation and color quantization.

Readers who are not familiar with approximation algorithms and metaheuristics should begin with Chapters 1–6, 9–10, 18–21, and 23–27. Experienced researchers will also find useful material in these basic chapters. We have collected in this volume a large amount of this material with the goal of making it as complete as possible. I apologize in advance for omissions and would like to invite all of you to suggest to me chapters (for future editions of this handbook) to keep up with future developments in the area. I am confident that research in the field of approximations algorithms and metaheuristics will continue to flourish for a few more decades.

Teofilo F. Gonzalez

Santa Barbara, California

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About the Cover

The four objects in the bottom part of the cover represent scheduling, bin packing, traveling salesperson, and Steiner tree problems. A large number of approximation algorithms and metaheuristics have been designed for these four fundamental problems and their generalizations.

The seven objects in the middle portion of the cover represent the basic methodologies. Of these seven, the object in the top center represents a problem by its solution space. The object to its left represents its solution via restriction and the one to its right represents relaxation techniques. The objects in the row below represent local search and metaheuristics, problem transformation, rounding, and primal-dual methods.

The points in the top portion of the cover represent solutions to a problem and their height represents their objective function value. For a minimization problem, the possible solutions generated by an approximation scheme are the ones inside the bottommost rectangle. The ones inside the next rectangle represent the one generated by a constant ratio approximation algorithm. The top rectangle represents the possible solution generated by a polynomial time algorithm for inapproximable problems (under some complexity theoretic hypothesis).

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About the Editor

Dr. Teofilo F. Gonzalez received the B. S. degree in computer science from the Instituto Tecnológico de Monterrey (1972). He was one of the first handful of students to receive a computer science degree in Mexico. He received his Ph.D. degree from the University of Minnesota, Minneapolis (1975). He has been member of the faculty at Oklahoma University, Penn State, and University of Texas at Dallas, and has spent sabbatical leaves at Utrecht University (Netherlands) and the Instituto Tecnológico de Monterrey (ITESM, Mexico). Currently he is professor of computer science at the University of California, Santa Barbara. Professor Gonzalez's main area of research activity is the design and analysis of efficient exact and approximation algorithms for fundamental problems arising in several disciplines. His main research contributions fall in the areas of resource allocation and job scheduling, message dissemination in parallel and distributed computing, computational geometry, graph theory, and VLSI placement and wire routing.

His professional activities include chairing conference program committees and membership in journal editorial boards. He has served as an accreditation evaluator and has been a reviewer for numerous journals and conferences, as well as CS programs and funding agencies.

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