Preface

Greedy randomized adaptive search procedures, or GRASP, were introduced by T. Feo and M. Resende in 1989 as a probabilistic heuristic for solving computationally difficult set covering problems. Soon after its introduction, it was recognized as a general purpose metaheuristic and was applied to a number of other combinatorial optimization problems, including scheduling problems, the quadratic assignment problem, the satisfiability problem, and graph planarization. At the Spring 1991 ORSA/TIMS meeting in Nashville, T. Feo and M. Resende presented the first tutorial on GRASP as a metaheuristic, which was followed by their tutorial published in *Journal of Global Optimization* in 1995. Since then GRASP has gained a wide acceptance as an effective and easy-to-implement metaheuristic for finding optimal or near-optimal solutions to combinatorial optimization problems.

This book has been many years in planning. Though many books have been written about other metaheuristics, including genetic algorithms, tabu search, simulated annealing, and ant colony optimization, a book on GRASP had yet to be published. Since the subject has had 25 years to mature, we feel that this is the right time for such a book. After Springer agreed to publish this book we began the task of writing it in 2010.

We have been collaborating on the design and implementation of GRASP heuristics since 1994 when we decided, at the TIMS XXXII International Meeting in Anchorage, Alaska, to partner in designing a GRASP for graph planarization. Since then we have worked together on a number of papers on GRASP, including three highly-cited surveys.

This book is aimed at students, engineers, scientists, operations researchers, application developers, and other specialists who are looking for the most appropriate and recent GRASP-based optimization tools to solve particular problems. It focuses on algorithmic and computational aspects of applied optimization with GRASP. Emphasis is given to the end-user, providing sufficient information on the broad spectrum of advances in applied optimization with GRASP.

The book grew from talks and short courses that we gave at many universities, companies, and conferences. “Optimization by GRASP” turned out to be not only a book on GRASP, but also a pedagogical book on heuristics, metaheuristics and

its basics, foundations, extensions, and applications. We motivate the subject with a number of hard combinatorial optimization problems expressed in simple descriptions in the first chapter. This is followed by an overview of complexity theory that makes the case for heuristics and metaheuristics as a very effective strategy for solving hard or large instances of the so called intractable *NP*-hard optimization problems. In our view, most metaheuristics share a number of common building blocks that are combined following different strategies to overcome premature local optimality. Such building blocks are explored, for example, in the chapters or sections on greedy algorithms, randomization, local search, cost updates and candidate lists, solution perturbations and ejection chains, adaptive memory and elite sets, path-relinking, runtime distributions and probabilistic analysis tools, parallelization strategies, and implementation tricks, among other topics. As such, preliminary versions of this text have been used in the last three years as a textbook for the course on Metaheuristics at the graduate program in Computer Science at Universidade Federal Fluminense, Brazil, complemented with specific reading material about other metaheuristics, where it has matured and was exposed to criticisms and suggestions from many students and colleagues.

The book begins in Chapter 1 with an introduction to optimization and a discussion about solution methods for discrete optimization, including exact and approximate methods, including heuristics and metaheuristics.

We then provide in Chapter 2 a short tour of combinatorial optimization and computational complexity, in which we introduce metaheuristics as a very effective tool for approximately solving hard optimization problems.

This is followed in Chapter 3 with solution construction methods, including greedy algorithms and their relation to matroids, adaptive greedy and semi-greedy algorithms, and solution repair procedures.

Chapter 4 focuses on local search. We discuss solution representation, neighborhoods, and the solution space graph. We then focus on local search methods, covering neighborhood search strategies, cost function updates, and candidate list strategies. Ejection chains and perturbations as well as other strategies to escape from local optima are discussed.

Chapter 5 introduces the basic GRASP as a semi-greedy multistart procedure with local search. Techniques for accelerating the basic procedure are pointed out. Probabilistic stopping criteria for GRASP are also discussed. The chapter concludes with a short introduction to the application of GRASP as a heuristic for multiobjective optimization.

Chapter 6 focuses on time-to-target plots (or runtime distributions) for comparing exponentially distributed runtimes, such as those for GRASP heuristics, and runtimes with general distributions, such as those for GRASP with path-relinking. Runtime distribution will be extensively used throughout this book to assess the performance of stochastic search algorithms.

Extended GRASP construction heuristics are covered in Chapter 7. The chapter begins with Reactive GRASP and then covers topics such as probabilistic choice of the construction parameter, random plus greedy and sampled greedy constructions, construction by cost perturbation, the use of bias functions in construction, the use

of memory, learning, and the proximate optimality principle in construction, pattern-based construction, and Lagrangian GRASP.

Path-relinking is introduced in Chapter 8. The chapter provides a template for path-relinking and discusses its mechanics and implementation strategies. Other topics related to path-relinking are also discussed in this chapter. This includes how to deal with infeasibilities in path-relinking, how to randomize path-relinking, and external path-relinking and its relation to diversification.

The hybridization of GRASP with path-relinking is covered in Chapter 9. The chapter begins by providing motivation for hybridizing path-relinking with GRASP to provide GRASP with a memory mechanism. It then goes on to discuss elite sets and how they can be used as a way to connect GRASP and path-relinking. The chapter ends with a discussion of evolutionary path-relinking and restart mechanisms for GRASP with path-relinking heuristics.

Implementation of GRASP on parallel machines is the topic of Chapter 10. The chapter introduces two types of strategies for parallel implementation of GRASP: multiple-walk independent-thread and multiple-walk cooperative-thread strategies. It then goes on to illustrate these implementation strategies with three examples: the three-index assignment problem; the job shop scheduling problem; and the 2-path network design problem.

Continuous GRASP extends GRASP heuristics from discrete optimization to continuous global optimization. This is the topic of Chapter 11. After establishing the similarities and differences between GRASP for discrete optimization and Continuous GRASP (or simply C-GRASP), the chapter describes the construction and local search phases of C-GRASP and concludes with several examples applying C-GRASP to multi-modal box-constrained optimization.

The book concludes with Chapter 12 where three implementations of GRASP and GRASP with path-relinking are described in detail. These implementations are for the graph planarization, the unsplittable network flow, and the maximum cut problems.

Each chapter concludes with bibliographical notes.

Writing this book was certainly a long and arduous task, but most of all it has been an amazing experience. The many trips between Holmdel, Seattle, and Rio de Janeiro and the periods the authors spent visiting each other along the last five years have been gratifying and contributed much to fortify an already strong friendship. We had a lot of fun and we are very happy with the outcome of this project. We will be even happier if the readers appreciate reading and using this book as much as we enjoyed writing it.

Seattle and Rio de Janeiro, *Mauricio G.C. Resende*
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