Book Reviews

Ant Colony Optimization—M. Dorigo and T. Stützle (Cambridge, MA: MIT Press, 2004, pp. 3000, $40.00) *Reviewed by Andrea Roli*

One of the most intriguing aspects of being a scientist is the possibility to explore uncharted territories, sometimes following what, to most, seem to be improbable directions. This book reports the results of one such exploration. Beginning with the belief that the behavior of social insects can teach humans how to solve complex problems, the authors guide the reader through a journey from the modeling of real ants foraging behavior to the development of a very successful and widespread methodology for the approximate solution of discrete optimization problems: ant colony optimization (ACO).

ACO has its roots in Dorigo's doctoral thesis [1], in which the idea of simulating the foraging behavior of ants for solving a combinatorial optimization problem—namely, the traveling salesman problem (TSP)—was introduced for the first time with the name of *ant system* (AS). Since then, the number of publications on optimization algorithms inspired by AS has been steadily growing. These extensions of the original AS were eventually formalized in a common framework: the ACO metaheuristic [2], [3].

This book, which will become the main reference on ACO, clearly defines the ACO metaheuristic and its origins, and presents both the state-of-the-art of ACO applications and the most significant theoretical achievements.

The book structure makes it suitable both for research and didactic purposes. Researchers can read it, focusing on the definition of the ACO metaheuristic, its properties and applications (in particular, chapters 2, 4, 5, and 6). But, since the book is also conceived to clearly introduce and explain the basic concepts of ACO with several examples, teachers and students can use the book as a reference to teach and learn the topic (in particular, chapters 1, 2, and 3). Every chapter is complemented with bibliographic remarks, which can be seen as an annotated bibliography specific to the topics presented in the chapter. Exercises, both theory and application oriented, also follow each chapter. Many of these exercises can be useful suggestions for subjects of students' term assignments and degree theses.

In the first book chapter, the reader is guided along the conceptual path that leads from the natural metaphor to the definition of an algorithm for optimization. This path starts with a description of the experiments that were performed by biologists to understand the foraging behavior of some ant species and that led to stochastic models of real ants' behavioral patterns. As a next step, using the problem of finding a shortest path in a graph as an example, the necessary adaptations that lead from the core of the stochastic model to the development of an effective optimization algorithm are illustrated. In fact, this path culminated in the development of the ACO metaheuristic.

The goal of the second chapter is to give a well-structured definition of the ACO metaheuristic. ACO is introduced as a multiagent probabilistic construction procedure that generates potential solutions to the problem at hand. The procedure incorporates a learning mechanism, which modifies the parameters used by the probabilistic construction mechanism, called *artificial pheromones*, with the goal of improving the quality of the solutions produced at each iteration. The chapter starts with a presentation of the basic notions of combinatorial optimization and heuristic techniques for the solution of combinatorial optimization problems (see also [4]). The ACO metaheuristic is then formally introduced and a number of examples of its application to combinatorial optimization problems are given to illustrate how the metaheuristic can be practically applied. This enables the reader to easily understand its basic working principles. The chapter ends with a brief overview of the most important metaheuristics. This is designed to help the reader in situating ACO in the general context of approximate algorithms for combinatorial optimization.

Chapter 3 is devoted to the explanation of the main algorithms belonging to the ACO metaheuristic. This description takes advantage of the traveling salesman problem (TSP) as a running example. The choice of the TSP—one of the most studied $\mathcal{NP}$-hard problems—is particularly fortunate: simple to formulate and to understand, it enables the authors to introduce the most important ACO algorithms focusing only on algorithmic aspects, without distracting the reader with problem specific details. The ACO algorithms described include: AS, the earliest ACO algorithm described in the literature, $\mathcal{MAX}$–$\mathcal{MIN}$ Ant System, AS*rank*, Ant Colony System, and the hyper-cube framework. This first part of the chapter is concluded with a very interesting and detailed analysis of the behavior of exemplary ACO algorithms on the TSP along with a discussion of the role of local search in ACO algorithms. The remaining part of the chapter includes a detailed guide to the implementation of ACO algorithms that complements the code freely available under the GNU license at www.aco-metaheuristic.org.

What is currently known on ACO theory is discussed in chapter 4. The field of ACO is quite young and, so far, most efforts have been directed to empirical research. However, in recent years theoretical results, mostly concerning convergence, have been proved. The convergence proofs presented in the chapter, as it is usual when considering stochastic approximate algorithms, address the question of whether the probability for an algorithm to find an optimal solution tends to one when the number of iterations tends to infinity. This is proved first for special cases of ACO algorithms and then generalized to $\mathcal{MAX}$–$\mathcal{MIN}$ and Ant Colony System, two of the best performing ACO algorithms. The latter part of the chapter discusses the relations between ACO and model-based search, such as estimation of distribution algorithms [5] and stochastic gradient ascent [6].

Chapter 5 presents a comprehensive overview of the main applications of ACO to combinatorial optimization problems that can be found in the literature. For each of these applications a detailed description of the main characteristics of each algorithmic implementation is given. The considered applications are grouped in problem classes—routing, assignment, scheduling, subset, machine learning—so to make the chapter an easy to use reference for the researcher or the practitioner searching for information on a given problem. Finally, the main application principles, that is, rules of thumb to be followed when attacking a new problem, are identified and discussed.

Chapter 6 presents *AntNet*, an ACO algorithm designed for solving the routing problem in packet switched telecommunication networks. The stochastic and distributed nature of this problem makes it particularly suitable for a multiagent approach such as ACO, which is intrinsically distributed and adaptive. The performance of AntNet is, indeed, the state-of-the-art for this problem, at least in simulation.

Chapter 7 concludes the book by summarizing the current knowledge on ACO and outlining ongoing and future research, such as

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the parallelization of ACO algorithms, their application to dynamic, stochastic and multiobjective optimization problems, and the experimental and analytical study of their behavior. The chapter ends with an overview of other models of real ants' behavior that show great promise of serving as inspiring sources for new, exciting developments in the area of ant algorithms [7], [8].

Ant Colony Optimization is accessible and easy to read—a background in computer science or related areas is all that is needed. As a self-contained book, it will make the ideal reading for any researcher, student, or practitioner interested in learning about this exciting and promising new field.

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