Chapter 13
From the Real Ant to the Artificial Ant: Applications in Combinatorial Optimization, Data Clustering, Collective Robotics and Image Processing

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ABSTRACT

Biological studies highlighting the collective behavior of ants in fulfilling various tasks by using their complex indirect communication process have constituted the starting point for many physical systems and various ant colony algorithms. Each ant colony is considered as a superorganism which operates as a unified entity made up of simple agents. These agents (ants) interact locally with one another and with their environment, particularly in finding the shortest path from the nest to food sources without any centralized control dictating the behavior of individual agents. It is this coordination mechanism that has inspired researchers to develop plenty of metaheuristic algorithms in order to find good solutions for NP-hard combinatorial optimization problems. In this chapter, the authors give a biological description of these fascinating insects and their complex indirect communication process. From this rich source of inspiration for researchers, the authors show how, through the real ant, artificial ant is modeled and applied in combinatorial optimization, data clustering, collective robotics, and image processing.

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INTRODUCTION

In the last 20 years, we have seen a growing number of studies in swarm intelligence. A swarm is made up of a population of simple agents which interact locally with one another and with their environment, without any centralized control dictating the behavior of individual agents (De Neubourg, Aron, Goss & Pasteels, 1990; Moyson & Manderick, 1988). This indirect communication in a self-organizing emergent system, where its individual parts communicate with one another by modifying their local environment, is called stigmergy (Abraham, Grosan & Ramos, 2006; Grassé, 1959). The most familiar examples of stigmergy, in natural systems, are observed in ants, bees, wasps, fish school, bird flocks, animal herds, and so on (Brothers, 1999; Gadagkar, 1993). It is this coordination mechanism used by these insects and other social animals that has inspired researchers to develop plenty of metaheuristic computing algorithms. For instance, the observation of the social behavior of some real ant species in finding the shortest paths between the colony and a food source has helped researchers to develop different metaheuristic algorithms used to find good solutions to NP-hard combinatorial optimization problems (Angus, 2006; Ebling, Di Loreto, Presley, Wieland & Jefferson, 1989). This chapter deals with the real ant as well as the artificial one. The biological description of real ants highlighting their life, anatomy and collective behavior in fulfilling various tasks, is given in the following section. This description, absent in most of the known papers related to ant-based algorithms, may be very interesting since the dynamic decision making of real ants constitutes a source of inspiration for the ant-based algorithms. The terms which could be of interest to the engineers are written in bold in the section. Section 3 then shows how, from the study of this fascinating insect, researchers have been induced to develop ant-based algorithms applied in different fields. In section 4, the principles of Ant Colony Optimization (ACO) algorithms, the mathematical foundation and some well-known ACO algorithms are described. In order to illustrate the behavior of some ant-based algorithms and put in evidence its basic components, four examples of applications are given in section 5. The first example of application used, in combinatorial optimization, is the extensively studied Traveling Salesman Problem (TSP). The second example deals with data clustering. The third example is devoted to collective robotics. Following which, in the fourth example, we propose an application of ACO in image segmentation. We conclude this chapter with a discussion of the presented work.

THE REAL ANT

Ant is an insect of the Formicidae family, which belongs to the Hymenoptera order that includes, among others, bees and wasps (Bolton, Alpert, Ward & Naskrecki, 2007). Ants are millions of billion in number, and their total mass is equivalent to the total mass of the human beings. They have been living on Earth for more than 100 million years and they have colonized all the terrestrial spaces compatible with their lives including the deserts, with the exception of the glacial zones and the marine environments (Hölldobler & Wilson, 1990). They can be divided into 16 subfamilies, 300 kinds and roughly 20,000 species that vary in size, color, and way of life. The largest ant can reach over 25 mm in length, while the smallest is about 2.5 mm. Some ants can lift items 50 times their own weight.

Anatomy of the Ant

Physiologically, an ant consists of a head, a trunk and an abdomen. The head is mainly made up of two oral antennae and mandibles. The antennae are special organs that help ants to detect chemicals (Fanjul-Moles, 2006). They are made up of several segments and covered with tactile
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