Swarm Intelligence in Optimization

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Summary. Optimization techniques inspired by swarm intelligence have become increasingly popular during the last decade. They are characterized by a decentralized way of working that mimics the behavior of swarms of social insects, flocks of birds, or schools of fish. The advantage of these approaches over traditional techniques is their robustness and flexibility. These properties make swarm intelligence a successful design paradigm for algorithms that deal with increasingly complex problems. In this chapter we focus on two of the most successful examples of optimization techniques inspired by swarm intelligence: ant colony optimization and particle swarm optimization. Ant colony optimization was introduced as a technique for combinatorial optimization in the early 1990s. The inspiring source of ant colony optimization is the foraging behavior of real ant colonies. In addition, particle swarm optimization was introduced for continuous optimization in the mid-1990s, inspired by bird flocking.

1 Introduction

Swarm intelligence (SI), which is an artificial intelligence (AI) discipline, is concerned with the design of intelligent multi-agent systems by taking inspiration from the collective behavior of social insects such as ants, termites, bees, and wasps, as well as from other animal societies such as flocks of birds or schools of fish. Colonies of social insects have fascinated researchers for many years, and the mechanisms that govern their behavior remained unknown for a long time. Even though the single members of these colonies are non-sophisticated individuals, they are able to achieve complex tasks in cooperation. Coordinated colony behavior emerges from relatively simple actions or interactions between the colonies' individual members. Many aspects of the collective activities of social insects are self-organized and work without a central control. For example, leafcutter ants cut pieces from leaves, bring them back to their nest, and grow fungi used as food for their larvae. Weaver

Fig. 1. Ants cooperate for retrieving a heavy prey. (Photographer: Christian Blum)

ant workers build chains with their bodies in order to cross gaps between two leaves. The edges of the two leaves are then pulled together, and successively connected by silk that is emitted by a mature larva held by a worker. Another example concerns the recruitment of other colony members for prey retrieval (see, for example, Fig. 1).

Other examples include the capabilities of termites and wasps to build sophisticated nests, or the ability of bees and ants to orient themselves in their environment. For more examples and a more detailed description see Chap. 1 of this book, as well as [21, 92]. The term swarm intelligence was first used by Beni in the context of cellular robotic systems where simple agents organize themselves through nearest-neighbor interaction [4]. Meanwhile, the term swarm intelligence is used for a much broader research field [21]. Swarm intelligence methods have been very successful in the area of optimization, which is of great importance for industry and science. This chapter aims at giving an introduction to swarm intelligence methods in optimization.

Optimization problems are of high importance both for the industrial world as well as for the scientific world. Examples of practical optimization problems include train scheduling, timetabling, shape optimization, telecommunication network design, and problems from computational biology. The research community has simplified many of these problems in order to obtain scientific test cases such as the well-known traveling salesman problem (TSP) [99]. The TSP models the situation of a traveling salesman who is required to pass through a number of cities. The goal of the traveling salesman is to traverse these cities (visiting each city exactly once) so that the total traveling distance is minimal. Another example is the problem of protein folding, which is one of the most challenging problems in computational biology, molecular biology, biochemistry, and physics. It consists of finding the functional shape or conformation of a protein in two- or three-dimensional space, for example, under simplified lattice models such as the hydrophobic-polar model [169]. The TSP and the protein folding problem under lattice models