Transportation Research Part C 16 (2008) 651–667

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Overview Paper

Swarm intelligence systems for transportation engineering: Principles and applications

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A R T I C L E   I N F O

Article history:
Received 27 July 2007
Received in revised form 20 March 2008
Accepted 21 March 2008

Keywords:
Swarm intelligence
Transportation modeling
Nature inspired algorithms
Metaheuristics

A B S T R A C T

Agent-based modeling is an approach based on the idea that a system is composed of decentralized individual "agents" and that each agent interacts with other agents according to localized knowledge. Special kinds of artificial agents are the agents created by analogy with social insects. Social insects (bees, wasps, ants, and termites) have lived on Earth for millions of years. Their behavior is primarily characterized by autonomy, distributed functioning, and self-organizing capacities. Social insect colonies teach us that very simple organisms can form systems capable of performing highly complex tasks by dynamically interacting with each other. Swarm intelligence is the branch of artificial intelligence based on study of behavior of individuals in various decentralized systems. The paper presents a classification and analysis of the results achieved using swarm intelligence (SI) to model complex traffic and transportation processes. The primary goal of this paper is to acquaint readers with the basic principles of Swarm Intelligence, as well as to indicate potential swarm intelligence applications in traffic and transportation.

1. Introduction

Many phenomena in nature, society, and various technological systems are found in the complex interactions of various issues (biological, social, financial, economic, political, technical, ecological, organizational, engineering, etc.). Majority of these phenomena cannot be successfully analyzed by analytical models. For example, urban traffic congestion represents complex phenomenon that is difficult to precisely predict and which is sometimes counterintuitive. In the past decade, the concept of agent-based modeling has been developed and applied to problems that exhibit a complex behavioral pattern. Agent-based modeling is an approach based on the idea that a system is composed of decentralized individual "agents" and that each agent interacts with other agents according to localized knowledge. Through the aggregation of the individual interactions, the overall image of the system emerges. This approach is called the bottom up approach.

The interacting agents might be individual travelers, drivers, economic or institutional entities, which have some objectives and decision power. Transportation activities take place at the intersection between supply and demand in a complex physical, economic, social and political setting. Local interactions between individual agents most frequently lead to the emergence of global behavior.

Special kinds of artificial agents are the agents created by analogy with social insects. Social insects (bees, wasps, ants, and termites) have lived on Earth for millions of years. Their behavior in nature is, first and foremost, characterized by autonomy and distributed functioning and self-organizing. In the last couple of years, the researchers started studying the behavior of social insects in an attempt to use the swarm intelligence concept in order to develop various artificial systems.

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0968-090X/$ - see front matter © 2008 Published by Elsevier Ltd.
doi:10.1016/j.trc.2008.03.002

Social insect colonies teach us that very simple organisms can form systems capable of performing highly complex tasks by dynamically interacting with each other. On the other hand, great number of traditional models and algorithms are based control and centralization. It is important to study both advantages and disadvantages of autonomy, distributed functioning and self-organizing capacities in relation to traditional engineering methods relying on control and centralization.

Swarm intelligence (Beni and Wang, 1989) is the branch of Artificial Intelligence based on study of behavior of individuals in various decentralized systems. In this paper, we present a classification and analysis of the results achieved using Swarm intelligence (SI) to model complex traffic and transportation processes.

The paper is organized in the following way. The basic concepts of swarm intelligence are described in Section 2. The ant colony optimization (ACO) is analyzed in Section 3. The ACO applications to traffic and transportation engineering problems are given in Section 4. The particle swarm optimization (PSO) is analyzed in Section 5. Section 6 is devoted to the bee colony optimization (BCO). Stochastic diffusion search (SDS) is analyzed in Section 7. The comparison of the ACO, PSO, BCO, and the SDS is given in Section 8. Section 9 contains conclusions and recommendation for the future research.

2. Basic elements of swarm intelligence

Swarm behavior is one of the main characteristics of many species in the nature. Herds of land animals, fish schools and flocks of birds are created as a result of biological needs to stay together. It has been noticed that, in this way, animals can sometimes confuse potential predator (predator could, for example, perceive fish school as some bigger animal). At the same time individuals in herd, fish school, or flock of birds has a higher chance to survive, since predator usually attack only one individual. Herds of animals, fish schools, and flocks of birds are characterized by an aggregate motion. They react very fast to changes in the direction and speed of their neighbors.

Swarm behavior is also one of the main characteristics of social insects. Social insects (bees, wasps, ants, and termites) have lived on Earth for millions of years. It is well known that they are very successful in building nests and more complex dwellings in a societal context. They are also capable of organizing production. Social insects move around, have a communication and warning system, wage wars, and divide labor. The colonies of social insects are very flexible and can adapt well to the changing environment. This flexibility allows the colony of social insects to be robust and maintain its life in an organized manner in spite of considerable disturbances (Bonabeau et al., 1999). Communication between individual insects in a colony of social insects has been well recognized. The examples of such interactive behavior are bee dancing during the food procurement, ants' pheromone secretion, and performance of specific acts which signal the other insects to start performing the same actions. These communication systems between individual insects contribute to the formation of the "collective intelligence" of the social insect colonies. The term "Swarm intelligence", denoting this "collective intelligence" has come into use (Beni, 1988; Beni and Wang, 1989; Beni and Hackwood, 1992; Bonabeau et al., 1999).

The self-organization of the ants is based on relatively simple rules of individual insect's behavior (Deneubourg et al., 1990). The ants successful at finding food leave behind them a pheromone trail that other ants follow in order to reach the food (Deneubourg et al., 1989). The appearance of the new ants at the pheromone trail reinforces the pheromone signal. This comprises typical autocatalytic behavior, i.e., the process that reinforces itself and thus converges fast.

The "explosion" in such processes is regulated by a certain restraint mechanism. In the ant case, the pheromone trail evaporates with time. In this behavioral pattern, the decision of an ant to follow a certain path to the food depends on the behavior of his nestmates. At the same time, the ant in question will also increase the chance that the nestmates leaving the nest after him follow the same path. In other words, one ant's movement is highly determined by the movement of previous ants.

Self-organization of bees is based on a few relatively simple rules of individual insect's behavior. In spite of the existence of a large number of different social insect species, and variation in their behavioral patterns, it is possible to describe individual insects' behavior as follows (Camazine and Sneyd, 1991). Each bee decides to reach the nectar source by following a nestmate who has already discovered a patch of flowers. Each hive has the so-called dance floor area in which the bees that have discovered nectar sources dance, in that way trying to convince their nestmates to follow them. If a bee decides to leave the hive to get nectar, she follows one of the bee dancers to one of the nectar areas. Upon arrival, the foraging bee takes a load of nectar and returns to the hive relinquishing the nectar to a food storer bee. After she relinquishes the food, the bee can (a) abandon the food source and become again an uncommitted follower, (b) continue to forage at the food source without recruiting nestmates, or (c) dance and thus recruit nestmates before returning to the food source. The bee opts for one of the above alternatives with a certain probability. Within the dance area the bee dancers "advertise" different food areas. The mechanisms by which the bee decides to follow a specific dancer are not well understood, but it is considered that the recruitment among bees is always a function of the quality of the food source.

It is important to state here that the development of artificial systems does not entail the complete imitation of natural systems, but explores them in search of ideas and models. The multiagent systems (MAS) are composed of virtual creatures or robots. Within the ALife scientific arena, researchers are developing artificial system that posses some of the basic characteristics of life. The entities in some artificial systems are virtual creatures that breed, learn, think, fight, collaborate, age, and die. Often, when making different ALife models, researchers try to explain complex system behavior that is derived from relatively simple rules. In essence, multiagent systems are computational systems in which a number of agents interact and work together in order to complete some task or to achieve some objective.