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Socio-cognitively inspired ant colony optimization

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ABSTRACT

Recently we proposed an application of ant colony optimization (ACO) to simulate socio-cognitive features of a population, incorporating perspective-taking ability to generate differently acting ant colonies. Although our main goal was simulation, we took advantage of the fact that the quality of the constructed system was evaluated based on selected traveling salesman problem instances, and the resulting computing system became a metaheuristic, which turned out to be a promising method for solving discrete problems. In this paper, we extend the initial sets of populations driven by different perspective-taking inspirations, seeking both optimal configuration for solving a number of TSP benchmarks, at the same time constituting a tool for analyzing socio-cognitive features of the individuals involved. The proposed algorithms are compared against classic ACO, and are found to prevail in most of the benchmark functions tested.

1. Introduction

Recently, there has been an increase of synergistic interaction between biological and cognitive systems on one hand, and computational systems on the other. A number of metaphors inspired from natural systems (ant colonies, bird flocks, bee swarms, and so on) have become bases for constructing interesting metaheuristics and new optimization techniques, thereby affecting the field of computing. As long as the metaheuristics are not merely relabeling terms in existing algorithms [33], they can sometimes lead to novel approaches that outperform classic metaheuristics.

In multi-agent computing systems, it has been found that different micro-level interactions of individuals in a large group often result in unexpected macro phenomena. In our project, we are applying a concept from socio-cognitive research, namely “perspective taking”, which reflects the extent to which an agent is able to incorporate and be influenced by the points of view of other agents, to explore if it results in novel optimization algorithms for classic problems (in this case ant colony optimization, ACO).

An ability to view a situation from another individual's perspective is thought to be a crucial socio-cognitive characteristic for successful social interactions. This allows people to understand and predict other individuals' behaviors, and also helps them to connect emotionally with others. People, however, are not all equally skilled at perspective-taking [1], and contextual factors (e.g. emotional state) also influence how efficiently they use these skills at a given moment [5,37], and the extent to which they use these skills for a pro-social motive [18,22]. Social interactions, thus, usually involve people with diverse levels of efficiency and motivation engaging in perspective taking.

If a model can be constructed showing how perspective taking influences individuals' behaviors in a society, and how macro-level social phenomena emerge from the interaction of people with different levels of perspective taking, it can help us understand why some societies seem harmonious whereas others are ridden with conflict; it would also be useful to devise strategies to reduce conflicts. Moreover, these models, as our preliminary results suggest [32], may also help in developing new optimization strategies for traditional computational problems: for example in increasing the diversity of search for better exploration of the

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search space (similar to introducing islands into evolutionary computing methods). The current study addresses the latter issue.

Optimization heuristics, particularly these biologically-inspired techniques, have been gaining attention, for over three decades. Such approaches are supposed to be universal, though critics point to higher computation time and larger complexity of the algorithms. However, when facing difficult problems, it is usually effective to switch from deterministic approaches to stochastic search and optimization methods [36], which may justify additional costs.

Ant systems are a popular tool for solving many discrete optimization problems, e.g. traveling salesman problem (TSP), vehicle routing problem (VRP), graph coloring problem (GCP), quadratic assignment problem (QAD), and others [15]. In this article, we present the ant system as a way to express socio-cognitive behaviors of a population of ants by introducing various ant species embodying different behaviors from the point of view of their stigmergic interactions. The work presented here substantially extends our earlier research presented in [32].

Although our first goal was simulation of perspective taking during decision making using ACO as a case study, and optimization was only an example of the system application. However, as we progressed, the decision making in this case naturally became dependent on choosing the optimal path by the ants. Based on the simulation results, we discovered that an interesting optimization metaheuristic may be constructed by dividing the ants into different species, and making them interact stigmergically based on the levels of pheromone and attractivity.

This paper presents our exploration of this metaheuristics with a case study. We consider profiling of different socio-cognitively inspired metaheuristic using TSP (from the well-known TSPLIB library). Our study shows the efficiency of different variants of socio-cognitive ACO, and point to future research in this field.

After this introduction, we describe selected variants of ACO systems (Section 2), followed by socio-cognitive aspects relevant for simulations (Section 3). Next, their incorporation into ACO system is described (Section 4). Finally, experimental results are presented and discussed (Section 5), followed by conclusions (Section 6).

2. Ant colony optimization: classic and novel approaches

Ant system, introduced in 1991 by Marco Dorigo, applied to solve graph problems, is a progenitor of all ant colony optimization (ACO) techniques [13]. The classic ACO algorithm is an iterative process during which certain number of agents (ants) create a solution step by step [14,15]. The main goal of the ants is to traverse the graph finding the path with the lowest cost (usually the shortest distance, but can also be least fuel consumption, and so on).

Each step of any particular ant consists in choosing a subsequent component of the solution (that is a graph edge) with certain probability. This decision may be affected by interaction among the ants based on the levels of *pheromones*, which may be deposited into the environment (on the edges of the graph) by some ants and perceived by other ants (representing so-called attractiveness for the observed edges in order to choose the next step). This interaction is guided by stigmergic relations (communication among individuals by the means of environment, instead of direct contact directly) according to the rules proposed in [13]). The computation is finished when a feasible solution is found due to the cooperative efforts of all the ants.

There exist a number of different modifications of the classic ACO. One of them is very relevant for our study, namely multi-type ACO [29,35], which defines many species of ants and makes possible complex stigmergic interactions among them such as attraction and repulsion to/from the pheromone of different ant species. These algorithms have been successfully applied to such problems as edge disjoint path finding [29] and protection of light path [35].

Table 1
Comparison of classic ant colony optimization and socio-cognitively inspired ant colony optimization approaches.

	ACO	Socio-cognitive ACO
Species	One	Many
Pheromone table	Single common pheromone type	One pheromone type per each of species
Path attractiveness	Depending on both: pheromone and path length	Specific for each of species, may depend on pheromone and/or path length
Perception	Ants are perceived equally, pheromone of each ant has the same weight	Ants are perceived differently by other types of ant (depending on its species)

There are many more modifications of the classic ACO, such as hierarchical ACO, where additional means of control are used to manage the output of ant species [31]. Another approach assumes that ants are equipped with different skills (such as sight or speed) in order to realize global path-planning for a mobile robot [27]. Yet another, very effective, ant-based TSP solver is based on using two types of ants, classic and exploratory, and works by creating so-called "shortcuts" for the ants to move according to some predefined conditions like keep close to some selected cities. [20]. In [9], the authors introduce different ant sensitivity to pheromones such that the ants with higher sensitivity follow stronger pheromone trails, while ants with lower sensitivity behave more randomly: together, they strive to maintain a desired balance between exploration and exploitation.

The approach presented in this paper follows the results shown in [32] and the inspirations presented by Nowé et al. [29] as well as by Chira et al. [9]. We introduce different ant species and vary their sensitivity to the pheromones of the other ant species (summarized in Table 1).

3. Incorporating social and cognitive aspects

In cognitive psychology, the character traits of egocentrism (taking one's own perspective) and altercentrism (taking another person's perspective into consideration) have long been recognized to play a key role in interpersonal relationships (see, for instance, [16,28]). Moreover, brain-imaging studies have shown that altercentricity and the strategy of perspective taking develop in parallel with brain maturation and psychosocial development during adolescence [3,10]. Perhaps mirroring this psychological development, in recent years, artificial intelligence researchers have started to incorporate altercentricity into robots and autonomous systems [21]. We also continue with utilizing the notions of ego- and altercentrism, adapting them appropriately to use in our computing system.

Typically, perspective taking is seen as a one-dimensional ability: the degree to which an agent can take another one's perspective. But recent research has explored a two-dimensional approach [4], where one distinguishes between the ability of an agent to handle conflict between its own and the other agent's perspectives, and the relative priority that an agent gives to his own perspective relative to the other's perspective. During social interactions, humans do not always share the same views. Being able to consider the other person's point of view therefore requires putting aside one's own perspective. This is particularly hard if one holds a strong view. Individuals endowed with good cognitive skills to manage conflicting information are therefore usually