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Empirical study of the Bee Colony Optimization (BCO) algorithm

Miloš Nikolić, Dušan Teodorović *

Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305, 11000 Belgrade, Serbia

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ABSTRACT

The Bee Colony Optimization (BCO) meta-heuristic deals with combinatorial optimization problems. It is biologically inspired method that explores collective intelligence applied by the honey bees during nectar collecting process. In this paper we perform empirical study of the BCO algorithm. We apply BCO to optimize numerous numerical test functions. The obtained results are compared with the results in the literature. The numerical experiments performed on well-known benchmark functions show that the BCO is competitive with other methods and it can generate high-quality solutions within negligible CPU times.

1. Introduction

In recent years, majority of the hard combinatorial optimization problems in engineering, management, and control have been successfully solved by various metaheuristics. Great number of metaheuristics is based on natural metaphors (*nature-inspired algorithms*). These algorithms are inspired by various biological and natural processes. Genetic algorithm is inspired by evolution principles (Goldberg, 1989; Holland, 1975). Artificial neural networks are composed of the elements that function similarly to a biological neuron (Wasserman, 1993). Cellular automata are based on basic concepts of life. Artificial immune systems are motivated by immune systems. The simulated annealing technique (Cerny, 1985; Kirkpatrick, Gelatt, & Vecchi, 1983) is based on the analogy with certain problems in the field of statistical mechanics (Metropolis, Rosenbluth, Rosenbluth, Teller, & Teller, 1953).

Natural systems have become significant sources of ideas and models for development of various artificial systems (Beni & Wang, 1989; Beni & Hackwood, 1992; Bonabeau, Dorigo, & Theraulaz, 1997). The popularity of the nature-inspired algorithms is mainly caused by the capability of biological systems to successfully adjust to continually varying environment (Teodorović, 2003). Neural networks, evolutionary computation, ant colony optimization (Colorni, Dorigo, & Maniezzo, 1991; Dorigo, 1992; Dorigo & Di Caro, 1999; Dorigo, Maniezzo, & Colorni, 1996), particle swarm optimization, (Kennedy & Eberhart, 1995; Kennedy & Eberhart, 1999; Kennedy, Eberhart, & Shi, 2001) artificial immune systems, and bacteria foraging algorithm are some of the algorithms and concepts that were inspired by nature.

The Bee Colony Optimization (BCO) meta-heuristic (Lučić & Teodorović, 2001, 2002, 2003a, 2003b; Teodorović, 2009) that we analyze in this paper also belongs to the class of nature-inspired algorithms. The BCO is a stochastic, random-search technique. The BCO technique uses a similarity between the way in which bees in nature look for food, and the way in which optimization algorithms search for an optimum of (given) combinatorial optimization problems. In the 1999–2002, the basic concepts of BCO (Lučić & Teodorović, 2001, 2002, 2003a) were introduced by Dušan Teodorović (adviser) and Panta Lučić (Ph.D. candidate) while doing research at Virginia Tech. The BCO was evolving through the later applications (Teodorović, Lučić, Marković and Dell' Orco, 2006; Teodorović, Lučić, Marković, & Orco, 2006; Teodorović & Dell' Orco, 2008; Teodorović, 2008; Dimitrijević, Teodorović, Simić, & Šelmić, 2011). Up to now it is successfully applied to various real-life optimization problems: the vehicle routing problem (Lučić & Teodorović, 2003b), the routing and wavelength assignment (RWA) in all-optical networks (Marković, Teodorović, & Aćimović-Raspopović, 2007), the ride-matching problem (Teodorović & Dell'Orco, 2005), the traffic sensors locations problem on highways (Šelmić, Edara, & Teodorović, 2008), the static scheduling of independent tasks on homogeneous multiprocessor systems (Davidović, Šelmić, & Teodorović, 2009; Davidović, Jakšić, Ramljak, Šelmić, & Teodorović, in press; Davidović, Šelmić, Teodorović, & Ramljak, 2012), determining the locations of uncapacitated inspection stations in a traffic network, the *p*-center problem (Šelmić, Teodorović, & Vukadinović, 2010), disruption management in public transit (Nikolić & Teodorović, submitted for publication).

In this paper, we perform empirical study of the BCO algorithm. We apply BCO to optimize numerous numerical test functions. The obtained results are compared with the results achieved by the Artificial Bee Colony (ABC) (Karaboga, 2005; Karaboga & Basturk, 2007; Karaboga, Basturk, Akay, & Ozturk, 2007; Karaboga & Basturk, 2008), Genetic Algorithm (GA), Differential Evolution (DE), and Particle Swarm Optimization (PSO). The numerical experiments are performed on well-known benchmark functions. We show that the BCO is competitive with other methods and that it can generate high-quality solutions within negligible CPU times.

The paper is organized as follows. Section 2 describes basic principles of the BCO metaheuristic. Function Optimization by

* Corresponding author. Tel.: +381 11 3091210.
E-mail address: duteodor@gmail.com (D. Teodorović).

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BCO is described in Section 3. Results of experiments are given in Section 4. Section 5 contains conclusion.

2. Bee Colony Optimization (BCO)

The basic idea of designing BCO is to compose the multi-agent system (colony of artificial bees) that will search for good solutions of a variety of combinatorial optimization problems. The artificial bees explore the principles used by honey bees for the period of nectar collection process. In other words, BCO principles are gathered from natural systems. Artificial bees explore through the search space, looking for the feasible solutions. In order to discover better and better solutions, artificial bees collaborate and exchange information. via collective knowledge and sharing information among themselves, artificial bees focus on more promising areas, and gradually discard solutions from the less promising ones. Little by little, artificial bees jointly generate and/or improve their solutions. The BCO search is running in iterations until some predefined stopping criteria is satisfied. Population of agents (artificial bees) consisting of *B* bees collaboratively searches for the optimal solution. Every artificial bee generates one solution to the problem.

There are constructive (Lučić & Teodorović, 2001, 2002, 2003a, 2003b) and improvement version (Davidović, Ramljak, Šelmić, & Teodorović, 2011; Nikolić & Teodorović, submitted for publication) of the BCO algorithm. In constructive BCO each bee adds a (different) new component to the previously generated partial solution,

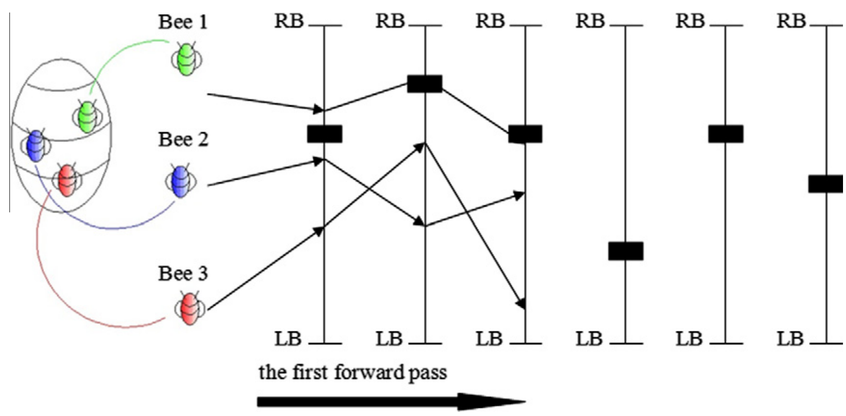

Fig. 1. An example of partial solutions after the first forward pass, $NC = 3$, $B = 3$.

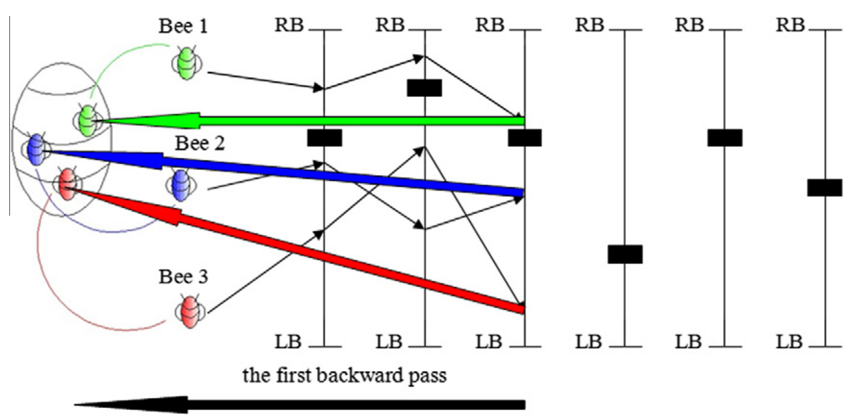

Fig. 2. The first backward pass, $NC = 3$, $B = 3$.

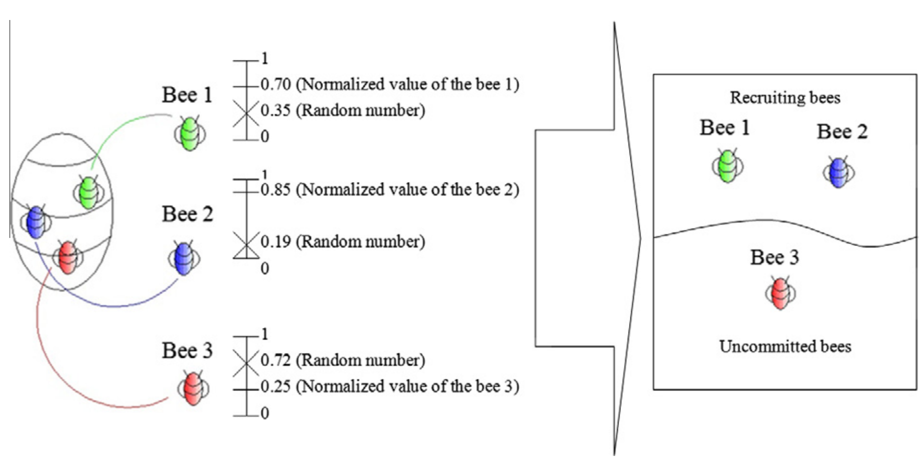

Fig. 3. Dividing bees into two groups ($B = 3$).