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An improved discrete bat algorithm for symmetric and asymmetric Traveling Salesman Problems

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ABSTRACT

Bat algorithm is a population metaheuristic proposed in 2010 which is based on the echolocation or biosonar characteristics of microbats. Since its first implementation, the bat algorithm has been used in a wide range of fields. In this paper, we present a discrete version of the bat algorithm to solve the well-known symmetric and asymmetric Traveling Salesman Problems. In addition, we propose an improvement in the basic structure of the classic bat algorithm. To prove that our proposal is a promising approximation method, we have compared its performance in 37 instances with the results obtained by five different techniques: evolutionary simulated annealing, genetic algorithm, an island based distributed genetic algorithm, a discrete firefly algorithm and an imperialist competitive algorithm. In order to obtain fair and rigorous comparisons, we have conducted three different statistical tests along the paper: the Student's *t*-test, the Holm's test, and the Friedman test. We have also compared the convergence behavior shown by our proposal with the ones shown by the evolutionary simulated annealing, and the discrete firefly algorithm. The experimentation carried out in this study has shown that the presented improved bat algorithm outperforms significantly all the other alternatives in most of the cases.

1. Introduction

Combinatorial optimization is one of the most studied fields in artificial intelligence, optimization, logistics, and other applications. Multiple research works are published annually in this area, both in journals (Kasperski and Zieliński, 2015), and conferences (Bezerra et al., 2014), and also in books (Levin, 2015). Different sort of problems exist within this kind of optimization, including the routing problems as one of the most appealed. It is noteworthy that the most used and well-known routing problems are the Traveling Salesman Problem (TSP) (Lawler et al., 1985), and the Vehicle Routing Problem (VRP) (Christofides, 1976), which are the focus of a huge amount of studies in the literature (Groba et al., 2015; Bortfeldt et al., 2015).

The main reasons for the popularity and importance of the routing problems are two folds: the social interest they generate, and their inherent scientific interest. On the one hand, routing problems are normally designed to deal with real world situations related to the transport or logistics. This is the reason why their efficient resolution entails a profit, either social or business one. On the other hand, most of the problems arising in this field have a great computational complexity. Being NP-Hard, the resolution of these problems is a major challenge for the scientific community.

In line with this, diverse appropriate approaches can be found in the literature to address this kind of problems efficiently. Arguably the most successful techniques are the exact methods (Laporte 1992a,b), heuristics and metaheuristics. In this paper, we focus our attention in the last ones. Some classical examples of metaheuristics can be the simulated annealing (SA) (Kirkpatrick et al., 1983), and the tabu search (Glover, 1989), as local search-based methods, and genetic algorithm (GA) (Goldberg, 1989; De Jong, 1975), particle swarm optimization (Kennedy and Eberhart, 1995; Tang et al., 2015), and ant colony optimization (Dorigo and Blum, 2005) as population-based ones. Despite having been proposed many years ago, these techniques remain successful in scientific community nowadays, being the cornerstone of multiple studies (Rodriguez et al., 2015; Cao et al., 2015; İnkaya et al., 2015).

In spite of the existence of these classic approaches, the design and implementation of novel meta-heuristics for addressing optimization and routing problems is a hot topic for the scientific

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community today. For this reason, many different metaheuristics have been proposed in the last decade, which have been successfully applied to various problems and fields. Some examples of these techniques are the artificial bee colony, proposed in 2005 by Karaboga (Karaboga, 2005; Karaboga and Basturk, 2007; Imanian et al., 2014; Moayedikia et al., 2015), the imperialist competitive algorithm, presented by Gargari and Lucas in 2007 (Atashpaz-Gargari and Lucas, 2007), or the firefly algorithm, proposed by Yang in 2009 (Yang, 2009).

For this reason, this paper is focused on one metaheuristic proposed few years ago, called Bat Algorithm (BA). This population technique was proposed by Yang in 2010 (Yang, 2010), and it is based on the echolocation behavior of microbats, which can find their prey and discriminate different kinds of insects even in complete darkness. As can be read in several surveys (Yang and He, 2013; Parpinelli and Lopes, 2011), since its proposal the BA has been successfully applied to different optimization fields and problems. Additionally, the fact that many research works focused on BA are being currently published confirms that BA still attracts a lot of interest (Fister et al., 2015; Meng et al., 2015). As we have mentioned, the BA has been applied to many different optimization problems, anyway, it has been rarely applied to any routing problem (Saji et al., 2014). This lack of works and the growing interest in the BA by the scientific community has motivated this work.

In this work, we present a discrete BA for solving routing problems. Being one of the first times that BA addresses this sort of problems, two of the most studied routing problems have been used for the experimentation: the TSP and the Asymmetric TSP (ATSP). Besides this, we also present an improved version of the basic BA (IBA), which outperforms the basic versions significantly.

The main objective of this study is to prove that the IBA is a promising approximation method for the TSP and ATSP. To prove that, we compare the results obtained by the IBA with the ones obtained by two basic versions of the BA, and with the ones obtained by five different well-known metaheuristics: GA, evolutionary simulated annealing (ESA) (Yip and Pao, 1995), the Island based Distributed Genetic Algorithm (IDGA) (Alba and Troya, 1999), a Discrete Firefly Algorithm (DFA), and a Discrete Imperialist Competitive Algorithm (DICA). To perform this comparison, 37 different TSP-ATSP instances have been used in the experimentation carried out. Furthermore, with the objective of drawing rigorous and fair conclusions, in addition to the conventional comparison based on the typical descriptive statistics parameters (results average, standard deviation, best result, etc.), we also perform three statistical tests along the paper: the Student's *t*-test, the Holm's test, and the Friedman test.

The remainder of this paper is structured as follows. In Section 2, a brief literature related to the BA is presented. In Section 3 the basic aspects of the BA are detailed. In Section 4 a brief description of the TSP and ATSP is made. Then, our proposed discrete BA and IBA are described in Section 5. Additionally, the experimentation carried out is described in Section 6. Finally, conclusions and future work are explained in Section 7.

2. Related work

As we have mentioned in the previous section, the BA is a population algorithm proposed in 2010 by Yang. The basic BA is based on the echolocation or bio-sonar characteristics of microbats, and its first version was proposed for solving continuous optimization problems. Since this first implementation, the BA has been applied in a wide range of fields. Some of these fields are the continuous optimization, in which some additional works have been published apart from to the original one, (Bora et al., 2012; Yang and Hossein Gandomi, 2012), combinatorial optimization (Marichelvam et al., 2013), image processing (Zhang and Wang, 2012) and clustering problems (Komarasamy and Wahi, 2012).

Besides this, many variations of the basic BA have been proposed in the literature. One example is the Fuzzy Logic BA (FLBA), presented by Khan et al. in 2011 (Khan et al., 2011), which introduces some fuzzy logic mechanisms in the basic structure of the BA. This first FLBA was proposed as method for ergonomic screening of office workplaces. Another example of FLBA can be seen in Pérez et al. (2015). In this work the authors present a FLBA for dynamical parameter adaption. Other example of BA variation is the chaotic BA (CBA). The first CBA, which uses Lévy flights and chaotic maps, was proposed by Lin et al. for parameter estimation in dynamic biological systems (Lin et al., 2012). Furthermore, in 2014 an improved CBA was presented by Abdel-Raouf et al. for solving integer programming problems (Abdel-Raouf et al., 2014). In the same year, Gandomi and Yang proposed a CBA for robust global optimization (Gandomi and Yang, 2014). Two other examples of BA variants are the BA with mutation (Zhang and Wang, 2012) or the multi-objective BA (Yang, 2011).

Additionally, some hybrid techniques have been developed using the BA as one of the hybridized methods. In Pan et al. (2015), for example, a hybrid particle swarm optimization with BA was developed. This approach, presented by Pan et al. in 2015, was implemented to deal with numerical optimization problems. One year earlier, Nguyen et al. proposed a hybrid bat algorithm with artificial bee colony also for solving the same kind of problems (Nguyen et al., 2014). On the other hand, Meng et al. presented in 2015 a hybrid BA with differential evolution strategy for addressing constrained optimization problems (Meng et al., 2015). Furthermore, Ramawan et al. developed in 2014 a BA hybridized with an artificial neural network. This novel approach was implemented to predict the output power of grid-connected photovoltaic system. At last, in Roeva and Fidanova (2013) a method which combines the BA with sequential quadratic programming for facing the parameter identification of an E. coli fed-batch cultivation process model was presented.

In the present work, we develop a discrete version of the BA. Although its first version was designed for continuous problems, the BA has been modified many times in the literature with the intention of addressing discrete optimization problems. In Nakamura et al. (2012), for instance, we can find the first Binary Bat Algorithm (BBA) applied to feature selection problems. Another successful BBA was developed by Mirjalili et al. in 2014 for solving discrete optimization problems (Mirjalili et al., 2014). A recently paper published by Fister et al. presents another discrete version of the BA for the correct planning of the sports training sessions (Fister et al., 2015). Finally, in Luo et al. (2014) a discrete BA was developed by Luo et al. for addressing the optimal permutation flow shop scheduling problem, and in Marichelvam et al. (2013) another discrete version of the BA was proposed for solving hybrid flow shop scheduling problems.

In spite of this great amount of research studies, as we have mentioned in the introduction of this paper, the BA has been rarely applied to any routing problem. This lack of studies has been the main motivation that has driven the realization of this work. Anyway, the main novelty of the presented IBA is not only its application field. The technique developed in this work presents the originality of using the Hamming Distance function to measure the distance between two bats of the swarm. This approach has been used previously in other techniques applied to the TSP, proving its good performance (Zhou et al., 2014), but it has been never used for any BA. In addition, according to the basic philosophy of BA, all the bats of the swarm perform their movements always in the same way. This strategy is not used in the proposed IBA, where the bats are endowed with certain “intelligence”. In