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Memetic binary particle swarm optimization for discrete optimization problems

Zahra Beheshti, Siti Mariyam Shamsuddin *, Shafaatunnur Hasan

UTM Big Data Centre, Universiti Teknologi Malaysia, Skudai, 81310 Johor, Malaysia

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A B S T R A C T

In recent decades, many researchers have been interested in algorithms inspired by the observation of natural phenomena to solve optimization problems. Among them, meta-heuristic algorithms have been extensively applied in continuous (real) and discrete (binary) search spaces. Such algorithms are appropriate for global searches because of their global exploration and local exploitation abilities. In this study, a memetic binary particle swarm optimization (BPSO) scheme is introduced based on hybrid local and global searches in BPSO. The algorithm, binary hybrid topology particle swarm optimization (BHTPSO), is used to solve the optimization problems in the binary search spaces. In addition, a variant of the proposed algorithm, binary hybrid topology particle swarm optimization quadratic interpolation (BHTPSO-QI), is proposed to enhance the global searching capability. These algorithms are tested on two set of problems in the binary search space. Several nonlinear high-dimension functions and benchmarks for the 0–1 multidimensional knapsack problem (MKP) are employed to evaluate their performances. Their results are compared with some well-known modified binary PSO and binary gravitational search algorithm (BGSA). The experimental results showed that the proposed methods improve the performance of BPSO in terms of convergence speed and solution accuracy.

1. Introduction

Many solutions of optimization problems are expressed as binary representations such as cell formation [15,61], data compression [26,35], feature selection [79,84], unit commitment [14,23], the 0–1 MKP [9,82], and image compression [21,53]. Additionally, problems defined in the real space, may be considered in the binary space. Over the last decades, various population-based meta-heuristic algorithms have been introduced and applied successfully to solve a wide range of the optimization problems in the binary search spaces. Genetic algorithm (GA) [32], simulated annealing (SA) [43], tabu search (TS) [30], artificial immune system (AIS) [25], ant colony optimization (ACO) [24], particle swarm optimization (PSO) [38,39], and gravitational search algorithm (GSA) [69,70] are in the class of such algorithms.

To improve the performance of algorithms in producing better solutions several works in memetic computation (MC) have been carried out. MC is a paradigm that uses the notion of meme(s) as units of information encoded in computational representations for solving problem [20]. It covers a plethora of potentially rich meme-inspired computing methodologies, operational algorithms and frameworks. They have materialized in the form of hybridization between the population-based

* Corresponding author. Tel.: +60 177220717; fax: +60 7 5532215.
E-mail addresses: bzahra2@live.utm.my (Z. Beheshti), mariyam@utm.my (S.M. Shamsuddin), shafaatunnur@gmail.com (S. Hasan).

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search (more explorative) and refinement procedures (more exploitative) [46]. Early studies, the adaptive memetic algorithms have presented the significant findings on the local search problems performance [63]. In advanced, Iacca et al. proposed three stages memes based on Ocham's Razor principle for memetic explorations [34]. Meanwhile, Caraffini et al. proposed parallelism on the memes structures for large scale problems and analysis on separability for memetic computing automatic design [12,13]. The parallel structures can be easily implemented within computational devices characterized by hardware limitations [12] while, the separability approach provide lower experience based human influence and a higher machine automatism [13]. Differ from memetic algorithm; hyper-heuristic uses multi-level structures of hybrid metaheuristics. An upper-level acts as primary key player which control several low-level heuristics on the solution space.

These techniques have shown excellent search capabilities in the small or medium sized problems, but the majority of them still encounter serious challenges in large scale problems. These challenges can be summarized as trapping into local optima, slow convergence rate and taking a long time to achieve the results [5,6]. These problems are due to the facts that the complexity and size of a problem usually increases as the number of decision variables, constraints, or objectives increases.

To deal with the problems, this study introduces an improved BPSO scheme, BHTPSO, in the binary search space. The BPSO faces two problems: firstly, it is easily trapped into local optima when solving complex multimodal problems and secondly, all particles are not converged to the best solution [6,60,71]. These problems have impacted the performance of BPSO. The first problem is because of the poor exploration in PSO and the second is due to the sigmoid function used in BPSO algorithm. Hence, the proposed algorithm performs a global search over the entire search space and increases the ability of jumping from local optima by hybridizing two local and global topologies in PSO. The method applies a suitable function to create new solutions. Additionally, a variant of the proposed algorithm, BHTPSO-QI, is presented to improve the global searching ability.

The remainder of this paper is organized as follows. A brief review of several binary meta-heuristic algorithms is provided in Section 2. Section 3 describes the proposed algorithms in details. In Section 4, BHTPSO and BHTPSO-QI are applied to solve nonlinear high-dimensional benchmark functions, and benchmarks of the 0–1 MKP. In this section, the performance of proposed methods is compared with several modified BPSO algorithms and BGSA algorithms. Finally, conclusions and the future research directions are presented in Section 5.

2. Related works

The binary search space can be considered as a hypercube that a particle or agent may move to nearer and farther corners of the hypercube by flipping various numbers of the bits [69]. Many meta-heuristic algorithms have been proposed for the real and binary search spaces such as GA, PSO and GSA.

PSO and BPSO have simple structure and are easy to implement for solving optimization problems. Hence, they are extensively employed in the problems, however, both algorithms suffer from some disadvantages when solving the complex and high-dimensional multimodal objective functions. PSO may easily get trapped in local optima and show slow convergence rate [6,50]. These drawbacks impact the binary PSO (BPSO) and the algorithm cannot converge well. Hence, a number of variant PSO and BPSO algorithms have been proposed in the literature to overcome the problems. The algorithms have improved the performance of algorithms in different ways using various types of topologies, selecting parameters, combining with other search techniques, and so on.

A local (ring) topological structure PSO (LPSO) [41] and Von Neumann topological structure PSO (VPSO) [40] were proposed by Kennedy and Mendes to enhance the search ability and to avoid trapping into local optima. According to Kennedy [37,41], PSO with a small neighborhood might have a better performance on complex problems, while PSO with a large neighborhood would perform better on simple problems.

Dynamic multi-swarm PSO (DMS-PSO) [49] was suggested by Liang and Suganthan where the population is divided into many small swarms, and these swarms are regrouped frequently to exchange the information among the swarms. Mendes et al. [55] presented the fully informed particle swarm (FIPS) algorithm that uses the information of entire neighborhood to guide the particles for finding the best solution. The fitness-distance-ratio-based PSO (FDR-PSO) was introduced by Peram et al. [65]. In the algorithm, each particle moves towards nearby particle with higher fitness value. Liang et al. [50] developed comprehensive learning particle swarm optimization (CLPSO) that each particle learns its behavior from other particles on different dimensions to avoid trapping in the local optima.

An adaptive fuzzy particle swarm optimization (AFPSO) [36] presented to adjust the parameters in PSO based on fuzzy inferences. Some operations from GA were applied into PSO such as selection [1], crossover [17], and mutation [78] to overcome the disadvantages of PSO. Also, several memetic algorithms (MAs) that hybridized PSO with a local search and other techniques were introduced by researchers [52,66,74,80].

Beheshti et al. proposed the median-oriented PSO (MPSO) [8] based on the information from the median particle. Also, they introduced centripetal accelerated PSO (CAPSO) [7] according to Newton's laws of motion to accelerate the learning procedure and convergence rate of optimization problems. Neri et al. [59] suggested compact particle swarm optimization (cPSO) for some application problems characterized by a limited memory. The algorithm applies the search logic typical of PSO plus a probabilistic representation of the swarm behavior. This feature allows the embedded implementation in small