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The effect of elite pool in hybrid population-based meta-heuristics for solving combinatorial optimization problems

Ghaith Jaradat [a,*], Masri Ayob [b], Ibrahim Almarashdeh [c]

[a] Department of Computer Science, Faculty of Information Technology, Jerash University, 26150-311 Jerash, Jordan
[b] Data Mining and Optimization Research Group, Centre of Artificial Intelligence Technology, Faculty of Information Science and Technology, The National University of Malaysia, UKM, 43600 B. B. Bangi, Selangor, Malaysia
[c] Assistant Professor, Department of Management Information Systems, College of Applied Studies and Community Service, University of Dammam, 31433 Dammam, Saudi Arabia

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ABSTRACT

This work investigates the effect of elite pool that has high-quality and diverse solutions in three hybrid population-based meta-heuristics with an elite pool of a hybrid Elitist-Ant System, a hybrid Big Bang-Big Crunch optimization, and a hybrid scatter search. The purpose of incorporating an elite pool in population-based meta-heuristics is to maintain the diversity of the search while exploiting the solution space as in the reference set of the scatter search. This may guarantee the effectiveness and efficiency of the search, which could enhance the performance of the algorithms and generalized well across different datasets. To test the generality of these meta-heuristics via their consistency and efficiency, we use three classes of well-known combinatorial optimization problems as follows: symmetric traveling salesman problem, 0–1 multidimensional knapsack problem, and capacitated vehicle routing problem. Experimental results showed that the performance of our hybrid population-based meta-heuristics, compared to the best known results, is competitive in many instances. This finding indicates the effectiveness of utilizing an elite pool in our hybrid meta-heuristics in diversifying the search and subsequently enhances their performance over different instances and problems.

1. Introduction

The continuing research on building a successful generic problem solver offers the prospect of creating artificial intelligent systems that can generate practical solutions to many combinatorial optimization problems (COPs). Seeking for computational effectiveness and efficiency, research in meta-heuristics has evolved rapidly in an attempt to find good quality solutions to these problems within a desired time frame [1]. A meta-heuristic is a high-level strategy which guides other problem-specific heuristics to search for solutions in a possibly wide set of problem domains [1]. Meta-heuristics are usually effective and flexible; they are increasingly gaining popularity [1]. There are a wide variety of meta-heuristics that have been introduced. They are classified as single solution vs. population-based approaches. Single solution approaches focus on modifying and improving a single candidate solution; e.g. simulated annealing, iterated local search, and variable neighborhood search [2]. On the other hand, population-based approaches maintain and improve multiple candidate solutions (population of solutions), e.g. evolutionary computation, genetic algorithms, and particle swarm optimization [2]. Talbi [3] illustrated another class of meta-heuristics, that is swarm intelligence, which is a collective behavior of decentralized, self-organized agents in a population or swarm; e.g. ant colony optimization, particle swarm optimization, and artificial bee colony.

The population-based method is used because of its capability to explore search space and can be easily combined with local search method in order to enhance solution exploitation mechanism [4]. On the other hand, some common local search methods that have been applied to COPs are tabu search, simulated annealing, and iterated local search. The local search method is utilized because of its capability to exploit solution space [2].

The strength of population-based method is relied on the capability of recombining solutions to obtain new ones [2]. In population-based algorithms such as genetic algorithm, memetic (hybrid genetic) algorithm and scatter search, a structured solution recombination of elite solutions is performed explicitly (which

* Corresponding author. Tel.: +962 796888035.
E-mail addresses: ghaith.jaradat@yahoo.com (G. Jaradat), masri@ukm.edu.my (M. Ayob), ibramars@gmail.com (I. Almarashdeh).

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involve moving or swapping assignments or permutations in a solution, representing the information exchange between generations) using one or more recombination operators, such as crossover and mutation [2]. The term explicit means that a solution is represented directly by the actual assignment/permutation/allocation and fitness values of solutions. Another kind of recombination is the one performed implicitly, where new solutions are generated using a distribution over the search space which is a function of earlier populations representing the search experience [2]. Ant systems and Big Bang-Big Crunch use implicit recombination. The term implicit means that a solution is represented indirectly by the fitness values of the assignments or values of their contribution to search (e.g. constructing a solution). This enables the search process to perform a guided sampling of the search space.

However, in general, the intensification mechanism in a population-based method still needs to be improved in order to obtain high-quality solutions. Hence, in order to enhance the intensification process, a meta-heuristic that has a capability in exploiting the solution space (e.g. hill climbing) is usually hybridized with population-based method. Many studies have recommended this hybridization, such as [2,3] and [5–7]. Local search method is a meta-heuristic that has the capability in exploiting the solution space that can be complemented with population-based approach to overcome the weakness in the population-based method and to further enhance the quality of solution in the pool.

Generally, we can define the term elite pool as an – adaptive – memory structure with a set of diverse and high-quality solutions that stores useful information about the global optima in the form of a diverse and elite set of solutions. This structure gives the search process the ability to recombine samples from the elite set, so as to exploit useful information about the global optima.

In addition, the utilization of an elite pool or reference set (that has high-quality and diverse solutions), to control the diversity of search, and a dynamic manipulation of the population size are also recommended for better performance of hybrid meta-heuristics [4]. A good performance (w.r.t. consistency, efficiency, effectiveness, and may be generality) is presented by maintaining a balance between diversification and intensification of the search [8]. Therefore, we have chosen the scatter search (SS), Elitist-Ant System (Elitist-AS), and Big Bang Big Crunch (BB-BC) for this study that had been hybridized (in our previous studies) with some diversification and intensification mechanisms to enhance their exploration and exploitation of the solution space. This has been achieved (in our previous works) by incorporating an elite pool (containing both diverse and high-quality solutions) and employing a local search heuristic to intensify the search around elite solutions, while a degree of diversity is maintained. These were applied to the course timetabling problems (see [9–11]). The reason of choosing those three meta-heuristics (Elitist-AS, BB-BC, and SS) are [8,12,13]:

- SS provides a deterministic selection of reference set or pool of elite solutions in terms of quality and diversity. This performs a systematic neighborhood search in the Euclidean or Hamming spaces.
- SS and BB-BC have structured solution combinations using diversification strategies that do not merely rely on randomization.
- SS evolves a strategy of updating in a form of exploiting an adaptive memory to preserve good quality and diversity.
- Elitist-AS, SS, and BB-BC provide useful information about the collection of elite or diverse solutions. However, Elitist-AS and BB-BC do not originally possess elite pool of high-quality and diverse solutions.
- SS and BB-BC support direct solution representation in a Hamming or Euclidean space that is easy to manipulate.
- BB-BC has an elitism strategy and a fast convergence toward high-quality or diverse solutions. However, this process needs to be controlled in order to maintain a balance between diversity and quality of the search.
- BB-BC uses the Euclidean distance to measure similarities between solutions which help to point elite solutions (high-quality and diverse solution).
- Elitist-AS has an elitism strategy with a memory (pool) of diverse solutions. It is sufficient for exploring and exploiting the solution space but still insufficient to balance between diversification and intensification in the search.

In addition, we have chosen both Elitist-AS and BB-BC to experiment the effect of employing an elite pool alongside their implicit solution recombination. That is, we also aim to compare both meta-heuristics against the SS as an explicit recombination-based meta-heuristic. Therefore, this study aims to investigate the effect of elite pool to the performance of the population approaches in terms of their generality in solving a variety of COPs. Based on the utilization of an elite pool, the study investigates the performance (consistency, efficiency, effectiveness and generality) of the three hybrid meta-heuristics by testing them on three classes of NP-hard COPs. The three COPs are: (i) packing problems: the 0–1 multidimensional knapsack problem; (ii) permutation optimization problems: symmetric traveling salesman problem; and (iii) routing problems: Capacitated Vehicle Routing problem.

In this study, we have intentionally fixed the size of the memory structures in our hybrid meta-heuristics and maintained the same update strategy. We have also compared them to similar hybrid approaches and standalone methods such as genetic algorithm, particle swarm optimization and ant systems. In addition, it is worth mentioning that some studies that are similar to our study give us confidence about investigating the effect of elite pools. These studies include [14] who applied a learning procedure (based on gene-expression programming hyper-heuristic) to a number of COPs, including vehicle routing problems. Other examples include [15–17]. Those studies were applied to the course timetabling problems but their interesting contributions are related to the effect of permutations in the first place which might somehow affect the performance or even the importance of an elite pool. As mentioned above, we are motivated, thus, to investigate the effect of the elite pool in hybrid population-based meta-heuristics.

Therefore, our research question boils down to the following: "*Does the use of elite pool (a pool of diverse and high-quality solutions) in a population-based meta-heuristic enhance the performance of a meta-heuristic when compared to the one that only uses the diverse pool?*" Therefore, our objectives include the following:

1. Propose a population-based meta-heuristic by incorporating a memory structure (e.g. elite pool) which contains a set of diverse and high-quality solutions to strike a balance between diversification and intensification – exploration and exploitation – within the search space; and
2. Test the performance, i.e. generality and consistency, of the proposed hybrid population-based metaheuristic over three different COP domains, that are of a very different nature. We also compare the results with the state-of-the-art population-based meta-heuristics.

The paper is organized as follows: Section 2 describes the problems chosen for the study. Some related works are presented in Section 3. The proposed hybrid meta-heuristics and their design are presented in Section 4. Section 5 shows and discusses experimental results obtained by the proposed hybrid metaheuristics. Finally, the conclusions are presented in Section 6.