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Meta-harmony search algorithm for the vehicle routing problem with time windows

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A B S T R A C T

It has been proven that the hybridization of the harmony search algorithm with a local search algorithm (LS) is essential to compensate for the inadequacy of its exploitation. However, the success of this hybridization relies on the achievement of a proper balance between HSA exploration and LS exploitation. The question is can we obtain this balance by adaptively selecting (i) HSA parameter values, (ii) LS and its parameters and (iii) the LS neighborhood structures? To address these issues, this work proposes a meta-harmony search algorithm (meta-HSA) that uses two HSA algorithms, an HSA-optimizer and HSA-solver. The HSA-optimizer will adaptively adjust the components and the configurations of the HSA-solver based on the search status. The HSA-solver, which is a hybridization of HSA and LS, takes the configuration generated by the HSA-optimizer as input and then solves the given problem instance. That is, the HSA-optimizer operates on the components and the configurations of the HSA-solver, while the HSA-solver operates directly on the given problem instance (the solution search space). The proposed meta-HSA was applied to Solomon's vehicle routing problem with time windows benchmark to verify its effectiveness compared with standard HSA and the state-of-the art methods. The results of the comparison confirmed that the meta-HSA produces competitive results with respect to the other methods. Therefore, we can conclude that the meta-optimization technique does assist the hybrid HSA in obtaining the appropriate selection of its components and configurations during the search process. This demonstrates that the meta-HSA can provide a proper balance between exploration and exploitation by adaptively selecting (i) HSA parameter values, (ii) LS and its parameters and (iii) the LS neighborhood structures. Moreover, the meta-HSA optimizer decreases the effort exerted by the user in tuning these components and configurations.

1. Introduction

Geem et al. [1] introduced the harmony search algorithm (HSA) in 2001. HSA imitates the natural procedures of how musicians play musical instruments to produce more appealing musical tones. HSA has been used by many researchers to solve various complex problems such as university course timetabling [2], web page clustering [3], the scheduling of multiple dam system [4], Sudoku puzzles [5], nurse rostering [6], dynamic optimization [7–9] and several other optimization problems [10–15].

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However, HSA still suffers some deficiencies, such as slow convergence. This leads to less competitive solutions begin obtained by HSA with regard to constrained *NP*-hard problems [2]. The slow convergence issue is common to many other population-based meta-heuristics. This problem is often a twofold one that takes place because of the utilization of a population of solutions and the inadequacy of the exploitation practice [16]. Conventionally, to develop the exploitation process of population-based methods, a local search algorithm (LS) is integrated into them [16,17]. The LS possesses an efficient exploitation process that has the ability to compensate for the insufficiency of the population-based methods. As a result of this integration process, the hybrid HSA emerged. The hybrid HSA consists of three main components: the HSA configuration, the local search algorithm and the local search algorithm configuration (parameter values and neighborhood structures). The design issues that need to be addressed are the following:

1. *What are the suitable values for the HSA parameters*?
2. *Which local search algorithm is the most suitable to be hybridized with population-based approaches*?
3. *What are the suitable values for the parameters of the selected local search algorithm*?
4. *Which neighborhood structure is the most suitable to be adopted inside the selected local search algorithm*?

The appropriate selection of these components has a great effect on the behavior of the hybrid HSA and its efficacy [18]. Manually adjusting these components is a very difficult and time-consuming task because the appropriate choices for these components depend on the problem type and the landscape of the search [19–22]. Furthermore, the degree of difficulty and complexity increases with the increase in the number of components to be adjusted. One way to address this problem is to use a meta-optimization mechanism. A meta-optimization mechanism is suggested by Mercer and Sampson in 1978 to obtain the optimal setting of genetic algorithm parameters [23]. This mechanism adjusts the parameters of any optimization algorithm via another one. Meta-optimization has succeeded in tuning the parameters of many algorithms such as [24–28].

Motivated by the success of the meta-optimization mechanism in tuning the parameters of several meta-heuristic algorithms, we propose a meta-harmony search algorithm (meta-HSA) that has two different HSA algorithms: the HSA-optimizer and the HSA-solver. The question is can we enhance the exploitation mechanism in the hybrid HSA by adaptively selecting HSA and LS parameter values and LS neighborhood structures?

The main role of the meta-HSA optimizer is to adjust HSA parameter values, the local search algorithm type and the local search configurations (parameter values and the neighborhood structures) during the search without any external influence. The main difference between the proposed meta-HSA and the existing ones [24–28] is that the proposed meta-HSA is used to adjust the parameter values, local search types and local search configurations (parameter values and neighborhood operators) while the existing meta-optimizers only adjust the parameter values. Furthermore, the proposed meta-HSA adjusts these components and configurations in an online manner, while existing ones use training and testing instances, which might make them well suited to the training instances only. As far as we are aware, utilizing a meta-optimization mechanism to adjust all aforementioned hybrid HSA components and configurations has not previously been attempted. Moreover, such a mechanism has not been previously utilized to address the vehicle routing problem with time windows (VRPTW). This work aims to

1. Propose a hybrid HSA that uses several local search algorithms to enhance the HSA exploitation process.
2. Propose a meta-HSA that aims to retain a balance between the exploitation and exploration of the hybrid HSA by providing the appropriate selection of the HSA components as well as the local search configurations.
3. Assess the efficiency of the proposed meta-HSA over VRPTW, which is a renowned hard optimization problem. The results of the application of the aforementioned algorithm will be compared with those obtained via the state-of-the-art methods.

Solomon's VRPTW benchmark [29] is employed to assess the performance of the meta-HSA. A comparison among the results of the meta-HSA, the standard HSA, and the best-known results in the literature is conducted in this study.

2. Vehicle routing problem with time windows

The vehicle routing problem (VRP) [30] is one of the most widely investigated problems in transportation and distribution systems. VRP searches for a number of vehicle routes that can serve a number of customers with the least cost (minimum traveling distance) [31]. Many expansions have been made to the basic VRP such as capacitated VRP (CVRP) [31], VRP with time windows (VRPTW) [32], VRP with pickup and delivery (VRPPD) [33], split delivery VRP (SDVRP) [34] and stochastic VRP (SVRP) [35]. VRPTW is the most prevalent and widely examined among these expansions because the involved time windows constraint of VRPTW mimics real-life states [36]. Thus, the present work concentrates on VRPTW [32] in which a number of customers are geographically circulated. Each one of these customers entails a specific quantity of merchandise to be loaded/unloaded (demand). Customers should be served via a group of capacitated vehicles during the time requested by the customer. The intention here is to create a group of vehicle routes that can serve all customers at the least cost (minimum traveling distance) while taking into account the following conditions:

i. A customer must be visited precisely one time during his/her time window.
ii. A vehicle must start and end at the depot.
iii. The total loads of all customers in each route should not surpass the vehicle capacity.

Researchers from various fields have been attracted by VRPTW. They consider it an *NP*-hard problem, and they have proposed many approaches that endeavor to fined workable solutions for it [37,38]. These solutions may be perceived as one of two types: