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A Co-evolutionary Decomposition-based Chemical Reaction Algorithm for Bi-level Combinatorial Optimization Problems

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Abstract

Bi-level optimization problems (BOPs) are a class of challenging problems with two levels of optimization tasks. The main goal is to optimize the upper level problem which has another optimization problem as a constraint. In these problems, the optimal solutions to the lower level problem become possible feasible candidates to the upper level one. Such a requirement makes the optimization problem difficult to solve, and has kept the researchers busy towards devising methodologies, which can efficiently handle the problem. Recently, a new research field, called EBO (Evolutionary Bi-Level Optimization) has appeared thanks to the promising results obtained by the use of EAs (Evolutionary Algorithms) to solve such kind of problems. However, most of these promising results are restricted to the continuous case. The number of existing EBO works for the discrete (combinatorial case) bi-level problems is relatively small when compared to the field of evolutionary continuous BOP. Motivated by this observation, we have recently proposed a Co-evolutionary Decomposition-Based Algorithm (CODBA) to solve combinatorial bi-level problems. The recently proposed approach applies a Genetic Algorithm to handle BOPs. Besides, a new recently proposed meta-heuristic called CRO has been successfully applied to several practical NP-hard problems. To this end, we propose in this work a CODBA-CRO (CODBA with Chemical Reaction Optimization) to solve BOP. The experimental comparisons against other works within this research area on a variety of benchmark problems involving various difficulties show the effectiveness and the efficiency of our proposal.

Keywords: Bi-level combinatorial optimization, production-distribution planning problem, chemical reaction optimization.

1. Introduction

Bi-level optimization is a branch of optimization where we find a nested optimization problem within the constraints of the outer one. In such kind of problems, we find a hierarchy between two optimization tasks. The outer optimization task is usually referred as the upper level problem or the leader one and the nested inner optimization

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task is referred as the lower level problem or the follower one. The lower level task appears as a constraint such that only an optimal solution to the lower level problem is a possible feasible candidate to the upper level one[1]. Such a requirement makes the optimization problem difficult to solve, and has kept the researchers busy towards devising methodologies, which can efficiently handle the problem. A number of classical and evolutionary approaches have been proposed to solve such kind of problems. The first family includes the Karush-Kuhn-Tucker approach[2], the extreme point-based method[3], the branch-and-bound method[4], the complementary pivoting method[5], the descent method[6], etc. The main shortcoming of these methods is that they heavily depend on the mathematical characteristics of the BOP, which makes them unsuitable to handle real world problems' difficulties such as dimensionality, non-linearity, etc. For this reason, most of the classical proposed approaches are too restrictive and they are applicable only to a small class of BOPs. The second family includes EAs which are a class of approximate algorithms focusing on finding good-quality solutions for large-size and complex problems in a reasonable amount of time. Some examples of works using EAs to solve BOPs are Sinha et al.[7], Legillon et al.[8], and Koh[9]. The main challenge faced when solving a BOP using an EA is the high computational cost. Indeed, the evaluation of each upper level solution requires executing another EA to find the lower level (near-) optimal solution. For this reason, Sinha et al.[7] proposed a bi-level algorithm based on quadratic approximation which has shown a significant effectiveness in reducing the number of lower level evaluations. This meta-modeling-based approach is shown to be efficient on many benchmark problems. However, it is restricted only to the continuous case. In fact, an interesting observation regarding the EBO literature consists in that most works are restricted to the continuous case. Motivated by these observations, we have recently proposed a Co-evolutionary Decomposition-based Algorithm called CODBA to solve combinatorial BOPs. The purpose of this method is to handle a decomposition based technique as a surrogate of the lower level complexity. Recently, a Chemical Reaction Optimization (CRO) meta-heuristic is established for optimization[10] inspired by the nature of chemical reactions. The CRO algorithm has demonstrated its effectiveness and efficiency in solving different real-world and benchmark problems. In fact, this search algorithm has several nice features rendering it one of the most efficient meta-heuristics for optimization. To this end, we propose in this work a Co-evolutionary Decomposition-based Algorithm projected with the nice CRO features (CODBA-CRO) to solve combinatorial BOPS). Thus, the main contributions of this paper are the following:

1. Propose a novel version of CODBA, called CODBA-CRO that exploits the mechanisms of CODBA and the CRO meta-heuristic.
2. Report a comparative results between CODBA-CRO, CODBA , COBRA , and a naive hierarchical evolutionary approach on the bi-level MDVRP, which is a well-known problem in combinatorial optimization with several possible real world applications.

2. Bi-level Optimization

In this section, we provide some background definitions related to BOPs. As mentioned previously, these problems contain two levels of optimization tasks, such that each one controls its own objectives, constraints and decision variables. In this way, two types of decision variables are handled with this system: (1) The upper level variables $x_u \in X_u$ and (2) the lower level variables $x_l \in X_L$. For the follower problem, the optimization task is performed with respect to the variables x_l and the variables x_u act as parameters. For each x_u corresponds a different follower problem, whose optimal solution needs to be determined. All variables (x_u, x_l) are considered in the leader problem, and the optimization is expected to be performed with respect to both sets of variables. In what follows, we give the formal definition of BOP:

$$\underset{x_u \in X_U, x_l \in X_L}{Min} F(x_u, x_l)$$
$$s.t. \begin{cases} x_l \in ArgMin\{f(x_u, x_l)\}\, g_i(x_u, x_l) \leq 0, \\ G_j(x_u, x_l) \leq 0, \, i = 1, ..., I \, and \, j = 1, ..., J \end{cases} \tag{1}$$

where $G_j : X_U \times X_L \rightarrow \mathbb{R}$ denotes the upper level constraints, and $g_i : X_U \times X_L \rightarrow \mathbb{R}$ represents the lower level constraints respectively. The difficulty in bi-level optimization arises from the fact that only lower level optimal solutions can be considered as feasible members for the upper level task, after satisfying the upper level constraints.