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Optimal multiple-objective resource allocation using hybrid particle swarm optimization and adaptive resource bounds technique

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Abstract

The multiple-objective resource allocation problem (MORAP) seeks for an allocation of resource to a number of activities such that a set of objectives are optimized simultaneously and the resource constraints are satisfied. MORAP has many applications, such as resource distribution, project budgeting, software testing, health care resource allocation, etc. This paper addresses the nonlinear MORAP with integer decision variable constraint. To guarantee that all the resource constraints are satisfied, we devise an adaptive-resource-bound technique to construct feasible solutions. The proposed method employs the particle swarm optimization (PSO) paradigm and presents a hybrid execution plan which embeds a hill-climbing heuristic into the PSO for expediting the convergence. To cope with the optimization problem with multiple objectives, we evaluate the candidate solutions based on dominance relationship and a score function. Experimental results manifest that the hybrid PSO derives solution sets which are very close to the exact Pareto sets. The proposed method also outperforms several representatives of the state-of-the-art algorithms on a simulation data set of the MORAP.

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Keywords: Multiple-objective resource allocation problem; Adaptive resource bounds; Particle swarm optimization; Genetic algorithm; Mathematical programming

1. Introduction

Decision makers usually need to allocate constrained resource among activities for optimizing the objectives. For instance, project budgeting [23,1] maximizes the profit return by allocating a fixed amount of budget money among a number of projects, software testing [9,2] guarantees the maximum reliability by allotting testing resource to program modules, task allocation [3,32] allocates a given number of tasks to a number of distributed processors for minimizing the incurred cost, health care financing [19,27] allocates health care resource across competing programs promising improved health for patients, just to name a few. These real-world scenarios can be all described by the *resource allocation problem* (RAP).

Several formulations for the RAP have been proposed in accordance with different problem scenarios. Single-objective RAP (SORAP) seeks to optimize a single goal, such as benefit maximization or cost minimization. Multiple-

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objective RAP (MORAP) optimizes a set of goals simultaneously which may involve benefit-type objectives to be maximized and cost-type objectives to be minimized. Linear RAP optimizes linear objectives while nonlinear RAP deals with nonlinear objective functions. Linear RAP can be solved using analytical approach, however, the nonlinear RAP has been shown to be NP-hard [18]. The limited resource to be allocated can be either discrete or continuous, and the amount of resource units to be allocated to an activity may be constrained in a specified range. A comprehensive survey related to RAP can be found in [18].

Over the years, many approaches have been proposed for tackling the RAP. Integer linear programming [4] and mixed integer linear programming [27] have been used to formulate the RAP if the problem objective can be represented by a linear function of discrete and continuous decision variables. When the objective function is nonlinear, the linearization approaches [24,15,13] convert the objective function into a linear form by adding a large number of decision variables, then solve the resulting linear programs. Branch-and-bound approaches [5,6] iteratively solve the RAP subproblems in the branch-and-bound tree and cut-off the branch when the cost of the partial trial solution is worse than the current bound. Basso and Peccati [1] proposed a dynamic programming (DP) algorithm with an efficient pruning heuristic for managing the portfolio optimization in project financing. Morales et al. [26] also presented three parallel DP algorithms using pipeline, dominancy, and resource parallelism to conquer the curse of dimensionality.

Unlike previous works, this paper focuses on solving nonlinear MORAP using metaheuristics. The motivations of our research are three-fold.

- Most existing methods were developed for tackling SORAP, only few of them addressed MORAP issues. Hussein and Abo-Sinna [17] coped with MORAP by a parametric model which transforms MORAP into SORAP by combing multiple objective functions using a weighted sum of them, and solved the resulting problem by a fuzzy DP approach. However, they did not address the issue for determining the relative weights of different objectives. Lai and Li [22] modified Hussein-and-Abo-Sinna's method by introducing marginal evaluation which scales the values of different objectives into the same interval [0,1]. This method measures the performance index of each candidate solution by computing the weighted distance from the solution to a set of given prototypes based on the assumptions that the weights and the prototypes can be determined by the decision makers directly. However, the weighting method for averaging multiple objectives suffers several shortcomings. (1) The relative weights for different objectives are hard to determine, even the decision makers cannot precisely state and quantify the importance degree of each objective. (2) The solution obtained may be not non-dominated (not Pareto-optimal). A solution x dominates another solution y if x is strictly better than y in at least one objective and x is no worse than y in the others. Pareto set consists of solutions that are not dominated by any other solutions. For the decision makers, they prefer to obtain a set of Pareto-optimal solutions. Instead of combing multiple objectives into a single one as used by existing methods, our paper is the first work that identifies the Pareto-optimal solutions of MORAP. As such, the decision makers are comfortable in using our results.
- Most existing methods are based on mathematical programming techniques which may fail to deliver exact solutions within reasonable times for problems of large size. An alternative is to derive approximate solutions within reasonable times by using metaheuristic algorithms. A metaheuristic algorithm is a master strategy that guides a problem-specific heuristic to search for global optima and escape from the barrier of local optimality. Dai et al. [9] proposed a genetic algorithm (GA) for tackling the SORAP in software testing. The chromosome is represented by a list of modular testing times to be allocated and the objective is to maximize the system reliability with the minimum testing cost. Hou and Chang [16] presented a GA for allocating a number of products among plants such that the SORAP in plant allocation is solved. To the best of our knowledge, there is no previous work that applies metaheurisitc algorithms to the MORAP. Encouraged by many successful applications of metaheurisitc algorithms such as simulated annealing (SA) [21], tabu search (TS) [14], and ant colony optimization (ACO) [11], we employ a new metaheuristic developed recently named the particle swarm optimization (PSO) [20] for solving the MORAP.
- The problem constraints of MORAP may incur a computational burden when using the state-of-the-art multiple-objective optimization methods since they are designed for general purpose on optimization. Our methods exhibit better performance on a simulation data set of MORAP. We further propose a problem-specific *adaptive-resource-bound* technique that can significantly reduce the solution space of the MORAP and expedite the search. The adaptive-resource-bound technique is not only useful in our methods but also beneficial when applying representative multiple-objective optimization methods to solve the MORAP.