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Beam-ACO—hybridizing ant colony optimization with beam search: an application to open shop scheduling

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Abstract

Ant colony optimization (ACO) is a metaheuristic approach to tackle hard combinatorial optimization problems. The basic component of ACO is a probabilistic solution construction mechanism. Due to its constructive nature, ACO can be regarded as a tree search method. Based on this observation, we hybridize the solution construction mechanism of ACO with beam search, which is a well-known tree search method. We call this approach *Beam-ACO*. The usefulness of Beam-ACO is demonstrated by its application to open shop scheduling (OSS). We experimentally show that Beam-ACO is a state-of-the-art method for OSS by comparing the obtained results to the best available methods on a wide range of benchmark instances.

Keywords: Ant colony optimization; Beam search; Tree search; Open shop scheduling

1. Introduction

Among the approximate methods for solving combinatorial optimization (CO) problems [1] we can identify two large groups: tree search methods [2] and local search methods [3]. The nature of tree search methods is constructive. The solution construction mechanism maps the search space to a tree structure, where a path from the root node to a leaf corresponds to the process of constructing a solution. Then, the search space is explored by repeated or parallel solution constructions. In contrast, local search methods explore a search space by moving from solution to solution on a landscape that is imposed by a neighborhood structure on the search space. The simplest example is a steepest descent local search that moves at each step from the current solution to the best neighbor of the current solution.

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Most of the classical tree search methods have their origin in the fields of operations research (OR) or artificial intelligence (AI). Examples are greedy heuristics [1], backtracking methods [2], and beam search (BS) [4]. They are often relaxations or derivations of exact methods such as branch and bound [1]. In the past 15–20 years, metaheuristics [5,6] emerged as alternative approximate methods for solving CO problems. Most of the metaheuristic techniques are based on local search. Examples are tabu search (TS) [7], simulated annealing (SA) [8], and iterated local search (ILS) [9]. However, other metaheuristics such as the greedy randomized adaptive search procedure (GRASP) [10] can be regarded as probabilistic tree search methods (see [11]).

1.1. Our contribution

An interesting example of a metaheuristic that can be seen as a probabilistic tree search method is ant colony optimization (ACO) [12,13]. In ACO algorithms, artificial ants construct solutions from scratch by probabilistically making a sequence of local decisions. At each construction step an ant chooses exactly one of possibly several ways of extending the current partial solution. The rules that define the solution construction mechanism in ACO implicitly map the search space of the considered problem (including the partial solutions) onto a search tree. This view of ACO as a tree search procedure allows us to put ACO into relation with classical tree search methods such as beam search (BS) [14]. One of the interesting features of BS is that it works on a set of partial solutions in parallel, extending each partial solution—in contrast to ACO—at each step in several possible ways. However, in BS the extension of partial solutions is usually done by using a deterministic greedy policy with respect to a weighting function that gives weights to the possible extensions. The idea of this paper is to hybridize the solution construction mechanism of ACO with BS, which results in a general approach that we call Beam-ACO. We apply Beam-ACO to open shop scheduling (OSS) [4]. We show that Beam-ACO improves on the results obtained by the best standard ACO approach for OSS that was proposed in [5]. Furthermore, we show that Beam-ACO is a state-of-the-art method for the OSS problem by comparing it to the genetic algorithm by Liaw [16] and to the genetic algorithm by Prins [17].

1.2. Related work

The connection between ACO and tree search techniques was established before in [18–20]. For example in [18], the author describes an ACO algorithm for the quadratic assignment problem (QAP) as an approximate non-deterministic tree search procedure. The results of this approach are compared to both exact algorithms and BS techniques. Recently, an ACO approach to set partitioning (SP) that allowed the extension of partial solutions in several possible ways was presented in [19]. Furthermore, ACO has been described from a dynamic programming (DP) [21] perspective in [20], where ants are described as moving on a tree structure.

The outline of the paper is as follows. In Section 2 we explain the concept of a search tree. In Section 3 we briefly outline ACO and BS, before we outline the general concepts of Beam-ACO in Section 4. In Section 5 we introduce the OSS problem and propose a Beam-ACO algorithm to tackle this problem. Finally, in Section 6 we provide an experimental evaluation of Beam-ACO and we offer a summary and an outlook to the future in Section 7.