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An efficient heuristic algorithm for arbitrary shaped rectilinear block packing problem

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ABSTRACT

Arbitrary shaped rectilinear block packing problem is a problem of packing a series of rectilinear blocks into a larger rectangular container, where arbitrary shaped rectilinear block is a polygonal block whose interior angle is either 90° or 270°. This problem involves many industrial applications, such as VLSI design, timber cutting, textile industry and layout of newspaper. Many algorithms based on different strategies have been presented to solve it. In this paper, we proposed an efficient heuristic algorithm which is based on principles of corner-occupying action and caving degree describing the quality of packing action. The proposed algorithm is tested on six instances from literatures and the results are rather satisfying. The computational results demonstrate that the proposed algorithm is rather efficient for solving the arbitrary shaped rectilinear block packing problem.

1. Introduction

Arbitrary shaped rectilinear block packing problem is a problem of packing a series of rectilinear blocks into a larger rectangular container, where the rectilinear block is a polygonal block whose interior angle is either 90° or 270°. This problem involves many industrial applications, such as VLSI design, timber/glass cutting, textile industry and layout of newspaper. It belongs to a subset of classical packing problems and has been shown to be NP hard. For more extensive and detailed descriptions of packing problems, interested readers are referred to [1,2]. A degenerate form of rectilinear block packing problem is rectangle packing problem. Up to now, many efficient algorithms have been proposed to solve the rectangle packing problem, such as genetic algorithm [3], simulated annealing [4], hybrid algorithm [5], quasi-human heuristic algorithm [6–10] and other deterministic algorithms including branch-and-bound algorithms [11–13] and recursive algorithms [14,15]. As compared with rectangle packing problem, the rectilinear block packing problem is more complicated. The block may be an arbitrary polygon with 90° or 270° interior angle. It is very difficult to design efficient data structures to represent the relationships among the rectilinear blocks. For solving the rectilinear block packing problem, researchers introduce various non-deterministic algorithms based on different data structures to represent the geometric relationships among the blocks, e.g., BSG (bounded sliceline grid) [16,17], SP (sequence-pair) [18–22], O-tree [23], B*-tree [24], TCG (transitive closure graph) [25], CBL (corner block list) [26], etc. Some deterministic algorithms based on different packing principles have also been presented [12,15,27]. In recent years, hybrid algorithms combining genetic algorithm or simulated annealing with deterministic method are introduced to solve the two-dimensional orthogonal packing problem [5,28].

Inspired by above approaches, an efficient heuristic algorithm for solving the arbitrary shaped rectilinear block packing problem is proposed in this paper. The objective is to minimize the dead space of the container under packing all blocks into the container. The main idea of our algorithm is to pack a rectilinear block into the container by occupying a corner, and the caving degree should be as large as possible where the caving degree reflects the closeness between the rectilinear block to be packed and its closest rectilinear block. The details of caving degree will be described in Section 3.2.5. In this way, the blocks are close to each other wisely, and the dead space is decreased.

Our method is developed from [9,27]. The basic idea of the algorithm is the same as that of the algorithm presented in Ref. [9]. In Ref. [9], the basic principle is to select a corner-occupying action with maximal caving degree, and we use this basic principle to select a rectilinear block and pack it at the corresponding location. However, instead of just considering rectangular blocks, our method treats not only rectangular blocks but also rectilinear blocks. The method proposed in this paper can solve a wider range of problems than that proposed in [9]. In [27], less flexibility first principle indicates that the rectilinear block

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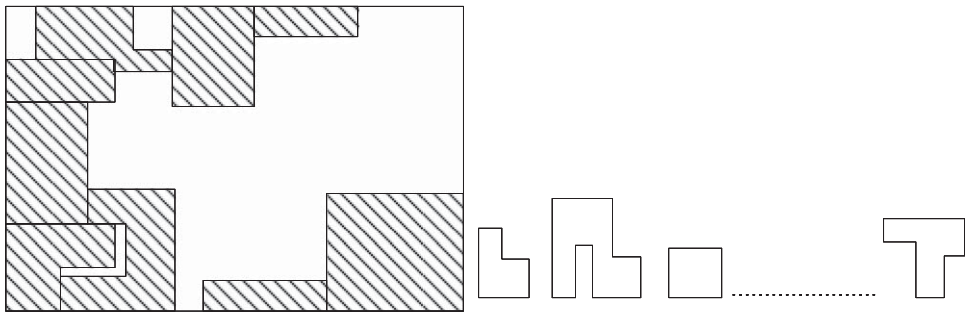

Fig. 1. Configuration.

with less flexibility should be packed first at a less flexibility place. A corner formed by two blocks has the smallest flexibility, a side of a block has larger flexibility and a hollow space has the largest flexibility. So, the corner is the best place to be packed according to the less flexibility first principle. The authors in [27] partition rectilinear block into a set of sub-blocks, where each sub-block is a rectangle. The left-lower sub-block is a main-block, and the others are vice-blocks. The flexibility of a rectilinear block is defined as $M_i^f = R_{im}^f + \omega(R_{io}^f - R_{im}^f)$, where M_i^f is the flexibility of the rectilinear block, R_{im}^f the flexibility of the main-block, R_{io}^f the flexibility of bounding rectangle of the rectilinear block and ω a parameter whose value varies from 0 to 1. In the packing process, the rectilinear block with the smallest flexibility is packed with priority. For more details of less flexibility first principle, please refer to Refs. [6,27]. It should be noted that the scope of the corner used in our method is wider than that of the corner used in [27]. That is to say, a corner can be occupied by a rectilinear block in our method but might not in the method mentioned in [27]. Furthermore, maximal caving degree first principle is much more advanced than less flexibility first principle since the former is developed from the latter.

Our method is tested on six instances. As compared with those obtained by others in literatures, the results from our method are much competitive. Computational results show that the proposed algorithm in this paper is rather efficient for solving the arbitrary shaped rectilinear block packing problem.

2. Problem description

Given a rectangular container B_0 of width w_0 and height h_0, n arbitrary rectilinear blocks $B_1, B_2, \ldots, B_n$ with deterministic shape and size are to be packed into the container B_0. In the plane rectangular coordinates o–xy, bottom left of the container is located at (0, 0) with its four sides parallel to X- or Y-axis. The rectilinear block can be reflected or rotated 90°, 180° or 270°. The objective is to minimize the dead space of the container while packing all blocks into the container. The constraint is that any two rectilinear blocks cannot overlap with each other.

Without loss of generality, it is usual to assume that w_0, h_0 and the lengths of all blocks' sides are integers.

3. Framework of our method

3.1. Main idea

If some rectilinear blocks have been packed into the container without overlapping, the question is which one is the best candidate for the remainder, and which position is the best one to be filled. We should pack a rectilinear block at a corner, even a cave, so as to decrease the dead space as much as possible. So, we

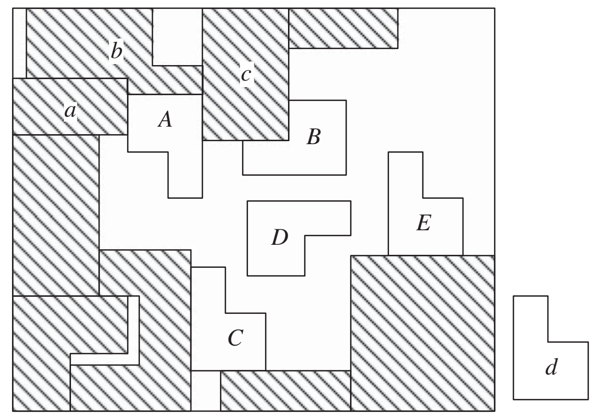

Fig. 2. Corner-occupying action.

always pack a rectilinear block according to the following principle: the rectilinear block to be packed into the container always occupies a corner, and the caving degree should be as large as possible.

3.2. Fundamental conceptions

3.2.1. Configuration

Fig. 1 shows a configuration. Some rectilinear blocks have already been packed into the container without overlapping and some remain outside. A configuration is called an initial one if there is no rectilinear block in the container. A configuration is called an end one if all rectilinear blocks have already been packed into the container without overlapping or, none of remaining rectilinear blocks can be packed into the container.

3.2.2. Corner-occupying action

A packing action is called a corner-occupying action (COA),[1] if the rectilinear block to be packed overlaps with at least two different directional edges of other previously packed blocks including the container, and the overlapping lengths are longer than zero. The rectilinear block to be packed occupies a corner, correspondingly. For example, as shown in Fig. 2, the shadowy rectilinear blocks have been packed, and the rectilinear block d is outside the container. The packing action is a COA, if block d is situated at place A, B or C while it is not a COA if situated at place D or E.

[1] COA is a developed form of corner-occupying packing move (COPM) [6,27]. The scope of COA is wider than that of COPM, that is, a COPM must be a COA, but a COA may not be a COPM since the two blocks formed corner must touch each other in COPM, but may not in COA. For example, as shown in Fig. 2, if rectilinear block d is packed at place C, the packing action is a COA, but not a COPM; if packed at place A, it is a COPM as well as a COA.