Two Evolutionary Hybrid Stages for the Rectangular Bin Packing Problem with Constraints

Slimane Abou-Msabah[1], Ahmed Riadh Baba-Ali[2] and Basma Sagr[1]

[1]Department of Computer Science, University of Science and Technology Houari Boumedienne, USTHB, Bab Ezzouar, Algiers, Algeria
[2]Department of Electronics, University of Science and Technology Houari Boumedienne, USTHB, Bab Ezzouar, Algiers, Algeria

Abstract

The Bin Packing problem is met in several domains of application, especially in the industry of: sheet metal, wood, glass, paper etc. In this article we are interested to the orthogonal cutting problem, with the hold in charge of the constraint of end-to-end cutting, and orientation constraint. The bin packing problem belongs to the class of NP-hard problems; therefore, our work has turned towards heuristic methods of resolution, and more particularly evolutionary methods. The application of genetic algorithms that are part of the evolutionary methods has limitations for solving the bin packing problem with large data. To minimize this disadvantage, we propose an original method which consists in subdividing the initial problem into two sub-problems. The first step tries to apply a hybrid genetic algorithm based on the order of appearance of pieces, to be packed on levels in an infinite band by applying the new placement routine (BLF2G). The second step uses the results of the first, namely the levels, and tries to project them on Bins by applying a second hybrid genetic algorithm. Besides that, we propose a new definition of the problem, it's about seeing the strip not as usual, with a fixed width and infinite height, but with a fixed height and infinite width. And we must apply some improvements, found in the literature, to the classic genetic algorithm to improve results, by introducing greedy heuristics to the population. Results are compared with other heuristic methods on data sets found in the literature.

Keywords

Rectangular Bin Packing, Orthogonal Cutting stock, Combinatorial Optimization, Heuristic, Hybrid Genetic Algorithm.

1. Introduction

The problem of placement is an optimization problem whose objective is to find a good arrangement of different objects in other wider ones. The main objective is to maximize the exploitation of the raw material, and therefore to minimize losses. It is important for industries of massive production where the optimization of the raw material plays an important role in reducing manufacturing costs. The development of an algorithm for the resolution of an industrial investment problem must take in consideration the complexity of the problem determined by the shape of objects manipulated, and of the bound constraints (imposed by the system of production). In our case we take into consideration an orthogonal cutting problem of which handles raw rectangular bins to generate rectangular items as well. The material used can be sheet metal and the production machines are typically guillotine shears (end-to-end cutting). In order to generalize our approach, we take into consideration a constraint often found in the

David C. Wyld et al. (Eds): SAIM, SIPM, ACSIT, FCST, ICITE - 2020
pp. 41-49, 2020. CS & IT - CSCP 2020 DOI: 10.5121/csit.2020.100805

literature [1], it is about imposing the orientation of the objects. Therefore, our algorithm will be adapted for a wide range of applications, such as wood, glass, fabric, and in the layout of newspapers, magazines, or web pages, … where there are motifs and decorations for which the orientation is fixed.

2. CONSTRAINTS OF THE PROBLEM

2.1. The orthogonal cutting-up

Cuts are made in length or width. Diagonal cuts are not feasible, see figure 1.

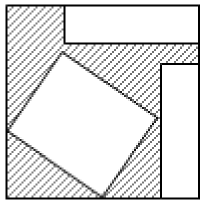
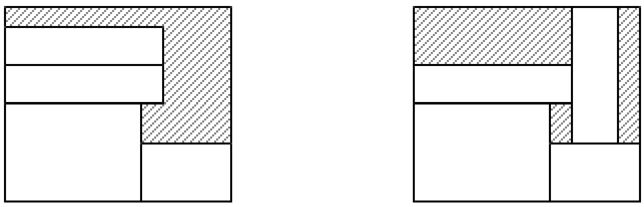


Figure 1. Non feasible shape by the shears

2.2. The end-to-end cutting

This constraint is directly related to the guillotine shears, which are the typical machines for handling sheet metal considered by our approach. This is a constraint that ensures the feasibility of cutting formats in the production facility, see figure 2.



(a) (b)

Figure 2. (a) feasible Shape, (b) impracticable Shape

2.3. The orientation of pieces

The pieces retain their original orientation, this constraint aims to ensure the feasibility of cutting formats made on textured or decorated surfaces.

3. STATE OF THE ART

Few works have used genetic algorithms for the resolution of this problem, recently E. Hopper & B. Turton has been interested, in the application of genetic algorithms for the resolution of this problem. After a state of the art in 1997 that lists the work done in this field [2], they present two hybridized genetic algorithms with placement heuristics in 1999 [3]. This work is crowned by a doctoral thesis in philosophy in 2000 [4], other work has referred to genetic algorithms for solving the problem we can quote [5], [6], [1], [7] and more recently [8] …

Recently a new tendency has tried to guide the genetic algorithm to improve the results by modifying the evolutionary process, [7] [8].

A common disadvantage confirmed by the authors, ([4], [1], [7], [8] …), encountered by genetic algorithms, is the problem of the resolution time which becomes increasingly large for big sized problems. It reduces the effectiveness of the genetic algorithms applied to the placement problem for which they give significantly less good results than simple heuristics. Our resolution approach attempts to minimize this disadvantage through the improvements we have proposed to the classical evolutionary process.

4. THE GENETIC ALGORITHM

Generally, evolutionary algorithms developed for the problem of layout, operate a hybridization of the genetic algorithm with a placement heuristic [3]. The genetic algorithm explores the research space to generate individuals. A second non-genetic step is needed to assess the quality of these individuals. The genetic algorithm offers solutions based on the order of appearance of the pieces for the arrangement process, the exact cut-out format is then given by the placement routine.

The quality of an individual depends essentially on the order in which the pieces are presented to the adopted placement routine. The genetic algorithm is the most effective research strategy [3], using order-based representation. This representation requires a new definition of crossing and mutation operators, which are identical to those of sales traveler problem.

4.1. The operator of crossing:

We propose to apply a hybrid genetic algorithm based on the order of appearance of the pieces, using the Partial Mapped Crossover (PMX) [9], given that the PMX crossover is the most effective for order-based representations [10] [3].

However, the conventional PMX crossover operator may give birth to individuals that are not feasible, for example:

parent 1 : 1234|5678		**son1 : 1234|4321**
and	gives	and
parent 2 : 8765|4321		**son2 : 8765|5678**

These two new individuals do not represent an attainable order. To do this, we need to modify the two individual sons so that they are feasible. For each son the PMX crossing replaces the double genes with genes missing in the individual according to the order of their appearance in the other parent individual.

We will have:

son 1 :1234|8765
and
son 2 :8756|1234

4.2. The operator of mutation:

The mutation operator can simply be presented as a permutation. Just randomly select two sites in the individual and make the swap between these two sites.
Exemple : 81|67432|5 became s: 81|57432|6

5. OUR CONTRIBUTION

Our contribution to solving the problem can be summarized in the following improvements:

5.1. The first stage «pre-processing»

The quality of the individuals produced by the genetic algorithm is measured after the arrangement of the pieces according to a placement routine. The pieces are arranged on an infinite band subdivided into levels [1], as shown in figure 3.

The arrangement is done by applying an adequate heuristic, it is about the Bottom Left Fill (BLF) heuristics, which tries to place the pieces in the lowest possible place on the left [3]. This phase allows us to realize the effective arrangement of the pieces on the strip structured in levels, moreover, it gives us a value that is the height of the strip. This value defines the quality of the solution under consideration.

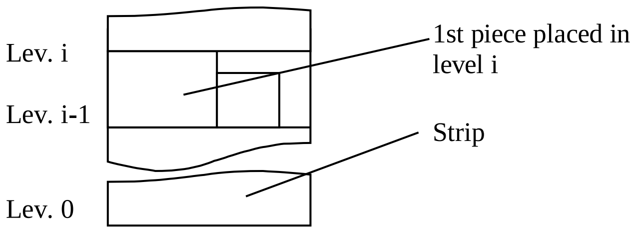


Figure 3. The strip is constituted of several levels.

In order to make better use of the space, the new BLF2G placement routine will be adopted, which carries out vertical and horizontal exploitation of intra-level residues, and which checked the end-to-end cutting constraint [7], see figure 4.

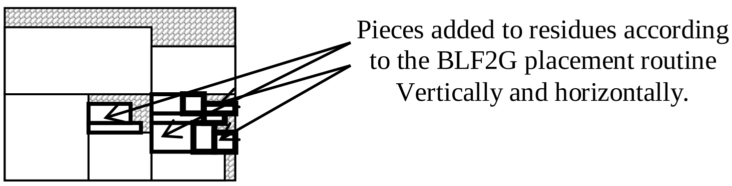


Figure 4. Filling the gaps under BLF2G Policy

5.2. The second phase « Packing »

It is now a question of projecting the levels obtained previously into bins of known dimensions. For each individual in the population, the placement routine is applied to assess his quality (fitness). Recall that the levels have an identical width and varied length, the heuristics BL (Bottom Left), which places the current level in the first plate offering a sufficient residue is the most adequate, so it is applied in this phase.

5.3. Guide the genetic algorithm

Several studies have found that by applying genetic algorithms to medium and large placement problems, heuristic methods, based on sorting, offer better results. [7] proposes to guide the genetic algorithm by adding an individual sorted to the population, thus the method takes over from the heuristics, and gives results equal and even better than the conventional heuristic methods regardless of the size of the problem.

Recently, a new technique has been proposed to guide the genetic algorithm by introducing, with control, individuals into the population, it's about csGA. It's a question of controlling the evolution of the genetic phase, and when there is no improvement, a sorted individual is injected into the population, the author finds that the introduction of several sorted individuals can disrupt the genetic process and thus degrade the results [8].

For our case these improvements will be taken into consideration to take advantage of the benefits.

5.4. Optimization in Width OW

In some cases, the gap between the lengths of the pieces is high and the results are therefore unsatisfactory. Our second improvement will therefore be to arrange the pieces on the strip not in length but also in width, that is by fixing the length of the strip, and by arranging the pieces in width.

Figure 5 illustrates the width arrangement, using the following example:

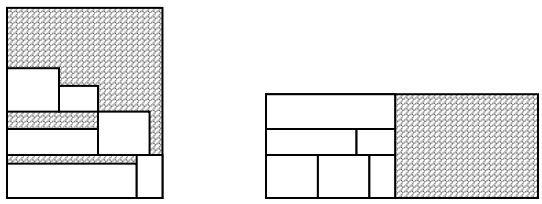


Figure 5. Result of arrangement of a set of pieces in length and width.

We note the contribution of this improvement for this set of pieces. Note that the pieces keep their original orientations, only the band changes direction and the arrangement is made in width.

With this enhancement, the user retains the choice between length and width layout depending on the pieces set used, giving the user more flexibility, as shown in figure 6.

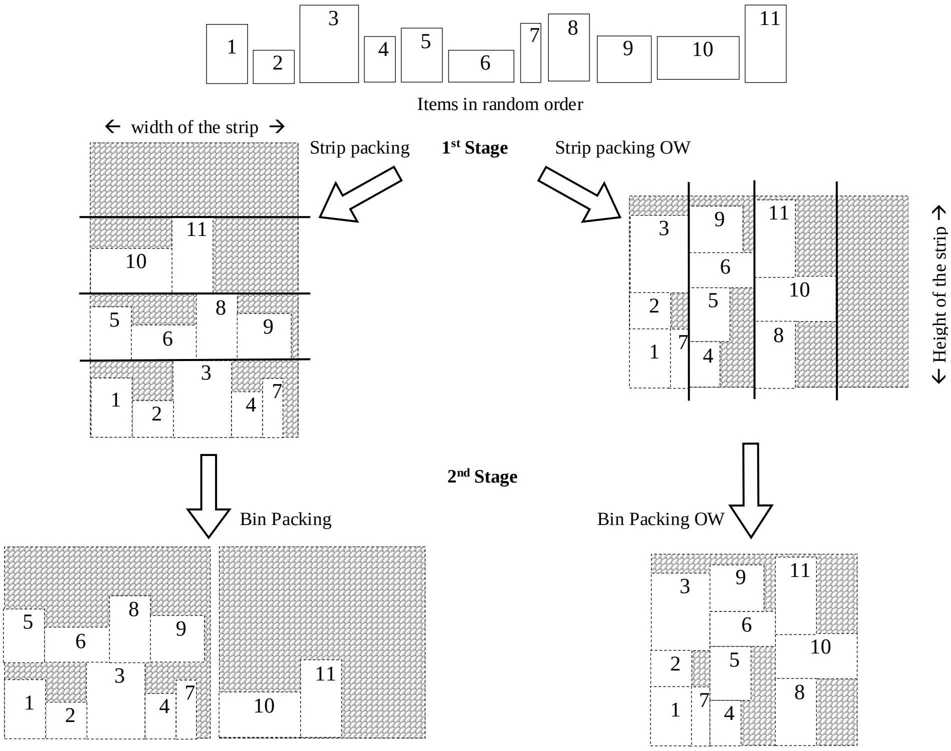


Figure 6. Our Approach 1st and 2nd stages: Classical Strip packing and Bin Packing vs. Optimization width Strip packing and Bin Packing

6. RESULTS

To evaluate our method, we chose a large number of examples found in the literature, for which we know the optimal solution, described in table 1:

Table 1. Data sets.

Reference	Name	Size	Optimal
[11]	Kendall	13	140 x 80
[12]	D2	21	40 x 60
[13]	J1	25	40 x 15
	J2	50	40 x 15
[3]	T1a, T1b, … T1e	17	200 x 200
	T2a, T2b, … T2e	25	200 x 200
	T3a, T3b, … T3e	29	200 x 200
	T4a, T4b, … T4e	49	200 x 200
	T5a, T5b, … T5e	73	200 x 200
	T6a, T6b, … T6e	97	200 x 200
	T7a, T7b, … T7e	197	200 x 200
[7]	Msa17a, b, c	17	200 x 200
	Msa35a, b, c	35	200 x 200
	Msa75a, b, c	75	200 x 200
	Msa150a, b, c	150	200 x 200

The results obtained with these examples using the csGA = csGAOH (Optimization in Hight) and csGAOW (Optimization in Width) are summarized in table2. Note that the test sets were made in length (i.e. the width arrangement does not guarantee the optimal).

Table 2. Resluts csGS vs csGAow.

Name	**Instance N**	**W**	**csGA = csGA$_{OH}$ Fitness/Percentage**		**csGA$_{OW}$ Fitness/Percentage**	
Msa17a	17	200 x 200	**200x200**	**0%**	200x222	11%
Msa17b	17	200 x 200	**200x200**	**0%**	200x222	11%
Msa17c	17	200 x 200	**200x200**	**0%**	200x222	11%
Msa35a	35	200 x 200	**200x200**	**0%**	200x221	10.5%
Msa35b	35	200 x 200	210x200	5%	200x213	6.5%
Msa35c	35	200 x 200	213x200	6.5%	200x211	5.5%
Msa75a	75	200 x 200	205x200	2.5%	200x212	6%
Msa75b	75	200 x 200	205x200	2.5%	200x211	5.5%
Msa75c	75	200 x 200	208x200	4%	200x210	5%
Msa150a	150	200 x 200	205x200	2.5%	200x211	5.5%
Msa150b	150	200 x 200	**200x200**	**0%**	200x210	4%
Msa150c	150	200 x 200	210x200	5%	200x209	4.5%
10xMsa17	170	2000 x 200	2106x200	5.3%	200x2101	5.05%
Kendall	13	140 x 80	162x80	15.7%	140x102	27.5%
D2	21	40 x 60	**40x60**	**0%**	**40x60**	**0%**
J1	25	40 x 15	43x15	7.5%	40x18	20%
J2	50	40 x 15	42x15	5%	40x16	6.67%
T1a	17	200 x 200	237x200	18.5%	200x231	15.5%
T3a	29	200 x 200	229x200	14.5%	200x232	16%
T5a	73	200 x 200	217x200	8.5%	200x215	7.5%
T7a	197	200 x 200	212x200	6%	200x210	5%
Optimum reached:			6		1	
Best results:			15		7	

These results show the power of our new method csGAOW, we manage to give best results 7 times, and we reach the optimal 1 time, despite the data set are confectioned in length. With our method we give a second alternative to the classical csGA method, and we improve the result by 33.33%.

7. CONCLUSION

Our contribution, to the cutting problem, showed its efficiency. Firstly, we use a powerful placement routine (BLF2G) that verify the guillotine constraint. Secondly, we hybridized this routine with an improved genetic algorithm, in a first stage, using existed improvements, that surmounts problems met by the classic genetic algorithms, for problems of large size. After the 1st stage is done, we generate an open-end strip with pieces packed in levels. These levels are used by a 2nd stage hybrid genetic algorithm to be packed on bins.

A new and powerful technic is applied in the 1st stage, by seeing the strip horizontally with a fixed height and infinite width, not vertically as usual, with a fixed width and infinite height. With this improvement we can see the same problem in the same context with different parameters, vertical placement, and horizontal placement. The results show that for some cases the width placement is more efficient than height placement, and we have an improvement of 33.33%, compared with the standard vertical placement.

8. FUTURE WORK

The genetic algorithm is a powerful tool that explore the research space to find the best solution, using genetic operators. We find in the literature that the genetic algorithm knows limits in application to problem of middle and large size. In perspective, and seen the clear improvement brought by the introduction of the sorted individual to the population, the development of a heuristic method that serves to guide the genetic algorithm all along the genetic process since the initial population until the genetic operators, remain to explore.

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AUTHORS

Slimane Abou-Msabah PHD Student last year, Department of computer science, University of Science and Technology Houari Boumedienne, USTHB. His researches revolve around the application of artificial intelligence methods to solve problems with combinatorial explosion, using greedy heuristics, metaheuristics, and hyperheuristics, to find near optimum solutions. Especially the Bin Packing Problem, using Evolutionary Approaches.

Ahmed-Riadh Baba-Ali Professor and director of research within the Faculty of Electronics and computer science in the University of Sciences and Technology of Algiers. His research integrates fast algorithm development applied to several application areas such as CAD, data mining, machine learning cryptography. He is also interested in parallel algorithms development such as evolutionary algorithms.

Basma Sager Computer Engineer, Department of computer science, University of Science and Technology Houari Boumedienne, USTHB. Her research turns around applying Evolutionary Approaches to solve Np-Hard problems.