On Objective Functions for Fixed-Outline Floorplanning

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Abstract--Fixed-outline floorplanning enables multilevel hierarchical design, where aspect ratios and area of floorplans are usually imposed by higher level floorplanning and must be satisfied. Simulated Annealing is widely used in the floorplanning problem. It is well-known that the solution space, solution perturbation, and objective function are very important for Simulated Annealing. In this paper, we focus on the objective functions used in FOFP problem. Up to now, many kinds of objective functions were proposed in the existing researches, but those objective functions had many limitations, and the applicable situation is not clearly. We summarize and analyze the existing objective functions used in Fixed-Outline floorplanning methods, and then suggest some new objective functions respectively used in the fixed-oultine floorplanning with and without wire-length optimization, respectively.

Index Terms – Fixed-Outline Floorplanning, Objective Functions

1. Introduction

As the IC technology advances, integrated density keeps increasing. A single chip can integrate more and more functions and often includes millions of transistors. Multilevel hierarchical design is an essential method to cope with the increasing design complexity. Fixed-outline floorplanning enables multilevel hierarchical design, where aspect ratios and area of floorplans are usually imposed by higher level floorplanning and must be satisfied. Modern hierarchical ASIC design flows based on multi-layer over-the-cell routing naturally imply fixed-die placement and floorplanning, rather than the older variable-die style [1].

A comparison between the classical outline-free floorplanning and fixed-outline floorplanning was shown in [2] [3], which point out that the instances of the fixed-outline floorplan problem are significantly harder than related instances of classical floorplan problems. At the same time, Adya and Markov [3] presented a new objective function to drive Sequence Pair representation based simulated annealing, and also shown a better local search with new type of moves for fixed out-line floorplanning . In the work of [4], Liu and *et al* proposed a new algorithm using Sequence Pair representation addressed to fixed-outline floorplanning based on instance augmentation, which differ from general simulation annealing .Chen and Chang [5] presented an algorithms for the modern floorplanning problems with fixed-outline and bus constraints, based on a new Fast-SA scheme and.

It is easy for the aforementioned fixed-outline floorplanners to get a feasible solution if area is the only objective. However, if wire-length is also taken into account, finding a feasible solution becomes difficult for them. Therefore, Chen and Yoshimura [6] proposed a stable fixed-outline floorplanning method (IARFP),

and suggested a new objective function, which is still effective when combined with other objectives, e.g., wire-length, for the fixed-outline floorplanning.

Simulated annealing is widely used in the floorplanning problem. It is well-known that solution space, solution perturbation method and objective function are very important three aspects for searching-based algorithms, e.g. simulated annealing. For the floorplanning problem, the solution space and solution perturbation are strongly correlated through the floorplan representation, which has been well-studied in last decades. For the traditional floorplanning, the objective function is just a weighted sum of some objectives, typically area and wirelength. In fixed-outline floorplanning, we do not need to minimize the area, whereas we need to place all the blocks into specified region, i.e., fixed-outline constraint. To deal with the fixed-outline constraint, the general method is to add an area-related penalty item to the objective function. How to calculate area costs of floorplans under fixed-outline constraints greatly affects the success rate and the optimization of other objectives.

In this paper, we summarize and analyze the existing objective functions used in Fixed-Outline floorplanning methods, and then we suggest some new methods to calculate the area cost for the fixed-outline floorplans, and compare their effectiveness. Using experiments, we analyzed the advantages and disadvantages of all the objective functions and discussed their applicable situations.

The remainder of the paper is as follows. Section 2 gives the overview of fixed-outline floorplanning problem and the floorplanning flow used in this work. The analysis of the objective functions is done in Section 3. Experimental analysis is shown in Section 4 and Section 5 concludes the work.

2. Fixed-Outline Floorplanning Overview

2.1 Problem Definition

The formulation of the fixed-outline floorplanning (FOFP) problem is as follows.

Let $S = \{a_i \mid 1 \le i \le n\}$ be a set of rectangular blocks among which connections exist, and each blocks a_i has specified width and height. The FOFP is an assignment of tuples (x_i, y_i) to each block such that there is no overlapping between any two blocks, all the blocks are placed inside the specified region (fixed-outline) and some objectives, such as wire-length and etc., are optimal. [2] [3]

For a given collection of blocks with total area A and given maximum white-space fraction γ , we construct a fixed-outline with aspect ratio (W_0/H_0) $\lambda \ge 1$[1]as follows:

$$W_0 = \sqrt{(1+\gamma)A\lambda} \qquad H_0 = \sqrt{(1+\gamma)A/\lambda}$$

2.2 Flow of Fixed-Outline Floorplanning

The fixed-outline constraint is generally dealt with by adding an area-related penalty item to the objective function. By penalizing the floorplans that violated fixed-outline constraint, feasible floorplans may be obtained finally. Consequently, how to calculate the cost item in the objective function is very important.

In this work, the fixed-outline floorplanner IARFP [7] is used for experiments. Figure 1 shows the flow of the fixed-outline floorplan [7].
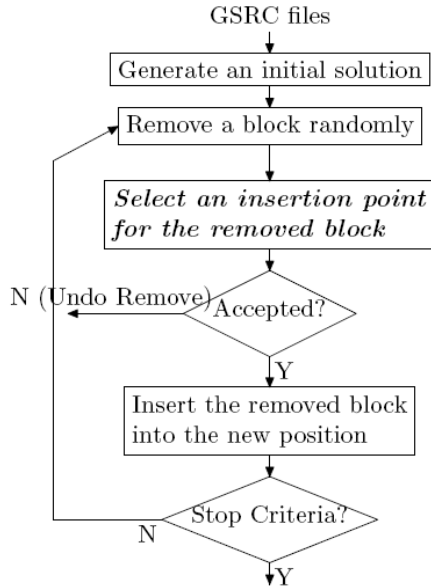

Fig. 1 Flow of fixed-outline floorplanning used in this work

3. Objective Functions for Fixed-Outline Floorplanning

In this section, we summarize and analyze the objective functions in the existing fixed-outline floorplanning methods.

In previous work [1], Adya et al proposed the following objective functions:

$$\max\{W - W_0, 0\} + \max\{H - H_0, 0\} \quad (1)$$

$$\max\{W - W_0, H - H_0\} \quad (2)$$

The authors showed by experiments that a classic annealer-based floorplanner was practically unable to satisfy fixed-outline constraints under these objective functions, thus devised slack-based moves for FOFP. However, when combined with other objectives, for example, wire-length, such functions is likely to be ineffective. Because the function values hardly reach zero if competitions from other objectives exist.

Also, the following functions were proposed in [3] [4]:

$$\alpha(W \cdot H) + (1 - \alpha)(W/H - W_0/H_0)^2 \quad (3)$$

$$W \cdot H + (W/H - W_0/H_0)^2 \quad (4)$$

Without consider the wire-length in floorplanning these objective function seems effective. We think that aspect ratio related penalty makes sure high success rate.

Because in the floorplans that satisfy the fixed-outline constraints we do not care about the aspect ratio. Figure 2 shows an example. Assume that $\gamma = 0.1$, and $\lambda = 1.0$. Then, the

aspect ratios of the floorplans satisfying the fixed-outline constraint range from 0.91 to 1.1. They need not be zero.
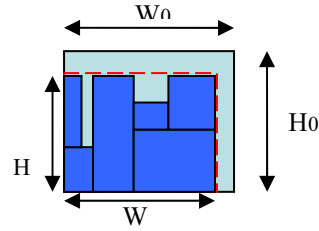

Fig.2 A floorplan meeting fixed-outline constraint

In this paper, we suggest a cost function modified from [7] for fixed-outline floorplanning with the only consideration of fixed-outline constraints.

$$E_w + E_H \cdot \lambda + C_1 \cdot \max(E_w, E_H \cdot \lambda) + C_2 \cdot \max(W, H \cdot \lambda) \\ + C_3 \cdot (W/H - W_0/H_0)^2 \quad (5)$$

The formula combines the aspect ratio item into the function used in [7] as shown in (6).

Because the function (4) makes a trade off between aspect ratio and area as shown in [7], Chen and Yoshimura [2] [3] suggested the following objective function for calculating area costs in fixed-outline floorplanning.

$$E_w + E_H \cdot \lambda + C_1 \cdot \max(E_w, E_H \cdot \lambda) + C_2 \cdot \max(W, H \cdot \lambda) \quad (6)$$

where $E_W = \max\{W - W_0, 0\}, E_H = \max\{H - H_0, 0\}$.

The experiment results showed that this objective function is working well when combined with wire-length. However, it is not better than (5) when the fixed-outline constraint is the only consideration (without wirelength optimization).

Accordingly, we suggest formula (5) for the fixed-outline floorplanning without consideration of wirelength.

On the other hand, the (6) works well when combined with wirelength, But the problem is when the fixed-outline is satisfied,

$$E_w + E_H \cdot \lambda + C_1 \cdot \max(E_w, E_H \cdot \lambda) = 0,$$

whereas $C_2 \cdot \max(W, H \cdot \lambda) > 0$.

That means even the fixed-outline is satisfied the penalty of fixed-outline constraints also exists. Since the best floorplan solution may not have the smallest chip dimensions, it is not good for wirelength optimization.

In this paper, we made experiments the following two modified objective functions from [7] for the fixed-outline floorplanning problem. One is

$$C = \mu\{E_w + E_H \cdot \lambda + C_1 \cdot \max(E_w, E_H \cdot \lambda) + C_2 \cdot \max(W, H \cdot \lambda)\} \quad (7)$$

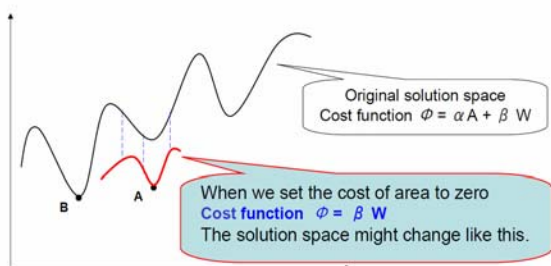Where $\mu = 0$ if ($W < W_0$ and $H < H_0$) and $\mu = 1$ otherwise.

The other is as follows.

$$C = \begin{cases} \max\{W_0, H_0\} & if\ W < W_0\ and\ H < H_0 \\ E_w + E_H \cdot \lambda + C_1 \cdot \max(E_w, E_H \cdot \lambda) + C_2 \cdot \max(W, H \cdot \lambda), & otherwise \end{cases} \quad (8)$$

These two functions mean if the floorplan meets the fixed-outline constraint ($W < W_0$ and $H < H_0$). We can ignore the area costs (setting area costs by zero or a constant) and pay more attention to the wirelength.

In the function (7), if the floorplan meets the fixed-outline constraint ($W < W_0$ and $H < H_0$), we set the value of the function to zero because we want to reduce the weight of area penalty. To give an intuitive explanation, we use a continuous line intuitively represent the discrete solution space of the floorplanning in

Figure 3.

In that case, it is hard to get to the point B (the optimal solution) from point A in the Simulated Annealing.

Fig. 3 The changed solution space by using formula 7

As shown in Figure 3, using formula (7), sometimes the difficulty of climbing hill is increased because of a deep valley.

To deal with this problem, one possible method is setting the cost of area to constant, as shown in the formula 8. The intuitive illustration of the solution space is shown in the figure 4.
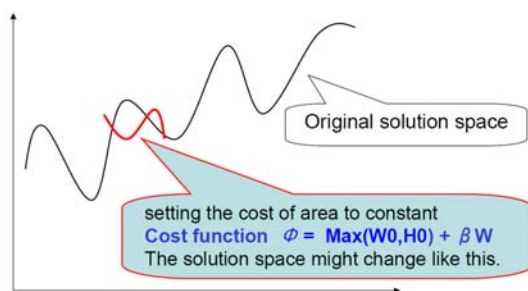

Fig. 4 Raised deep "Valley" in formula (8)

By raising the "valley", the probability of jumping out the valley is increased.

Fig.3 and Fig.4 are only intuitive illustration. The actual solution space of floorplanning is very complex discrete one. And because of the intrinsic characteristics of stochastic optimization algorithms, sometimes it is difficult to find regularity among the experimental results.

4. Experimental Results

The objective functions (5)-(8) have been embedded into the fixed-outline floorplanner IARFP [7] and ran on an IBM workstation (3.2GHz, 3GB RAM) with Linux OS. The GSRC benchmarks (n100, n200, n300) are used for the experiments. The wire-length is estimated using half-perimeter wire-length (HPWL) model:

$$\sum_{nets} (x_{max} - x_{min}) + (y_{max} - y_{min})$$

If the outline of a floorplan is smaller than H_0 and W_0, its aspect ratio can be different from the aspect ratio of the fixed outline. Otherwise, the floorplan fails to meet the outline constraint.

For the fixed-outline floorplanning without consideration of wirelength, we compare the effectiveness of formula 5 and 6. Table I shows the results, in which the white-space percentages are 6%, and each data is an average of 50 runs. "with_ar" is the result of the formula 6 and "wo_ar" is the result of the formula 5. With the aspect-ratio related item, the success rate is increased

17% and 11% respectively on test case n100 and n200.

For the fixed-outline floorplanning with wirelength optimization, we devised the following three groups of experiments by combining the functions (6), (7), (8) with wire-length，and embedded into the IARFP floorplanner to guide a simulated annealing based searching.

1. Linear combination of the formula (6) and wire-length.
Formula (6) combines the excessive width $E_W = \max\{W - W_0, 0\}$ and excessive height $E_H = \max\{H - H_0, 0\}$ with the maximum of width and height.
2. Linear combination of the formula (7) and wire-length.
Formula (7) is modified from (6) by setting area costs to zero when the floorplan meets the fixed-outline constraint (W<W0 and H<H0).
3. Linear combination of the formula (8) and wire-length.
Formula (8) is modified from (6) by setting area costs to constant when the floorplan meets the fixed-outline constraint (W<W0 and H<H0).

We compare the success rate, wire-length, and run time. In the experiments, white space γ was set as 10%~20% with an interval of 5%; the expected aspect ratios of the floorplans are chosen from the range [1, 3] with an interval of 0.5. For each combination of white space percentage and aspect ratio, we run the flooplanner 50 times independently. The I/O pins are scaled on the chip boundaries. The success rate is defined as the ratio of the number of runs that success to meet the fixed-outline constraint to the total run number. In the three groups of experiments, all the parameters are the same.

Figure 5-7 shows the comparison of the minimum wirelength. The results of n100 shown in Fig.5 demonstrate the intuitive analysis of the formula 6 and the formula 7 in Figure 3 and 4.

However, in the results of n200 (Fig.6) with 15% and 20% white-space percentage and the results of n300 (Fig.7), the formula 7 gives the minimum wirelength among all three formulas. When the white space is 20%, the formula 7 gives the best results among three formulas.

We can see that, in most case, the formula 7 can give us good results, especially, when the white space percentage is large.

Figure 8 shows the comparison of the success rate. All the results are average of 750 runs (50 for each combination of aspect ratio and white space). We can see that when using formula 7, the highest success rates are obtained for n100 and n200, two out of three test cases.
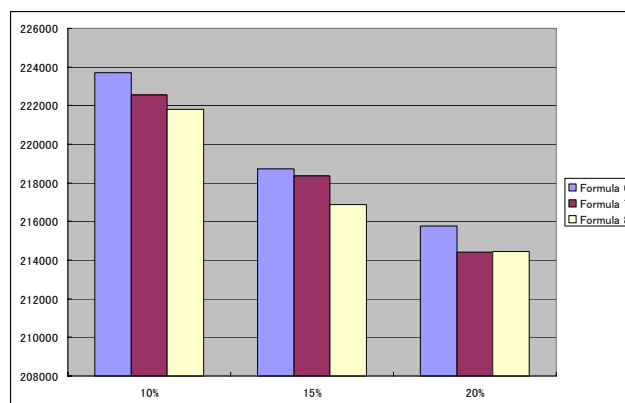

Fig.5 Minimum wirelength of n100

5. Conclusion

In this work, we summarize the existing objective functions used in Fixed-Outline floorplanning methods, analyzed the

limitations the objective functions used in the existing Fixed-outline floorplanning problem. And then we also suggest some new objective functions and compared their effectiveness for fixed-outline constraints with/without wire-length optimization.

Experimental results showed the efficiency and effectiveness of some proposed objective functions for fixed-outline floorplanning. To further verify some regularity discussed in the paper, we will embed the objective functions into more general annealing-based fixed-outline floorplanner.
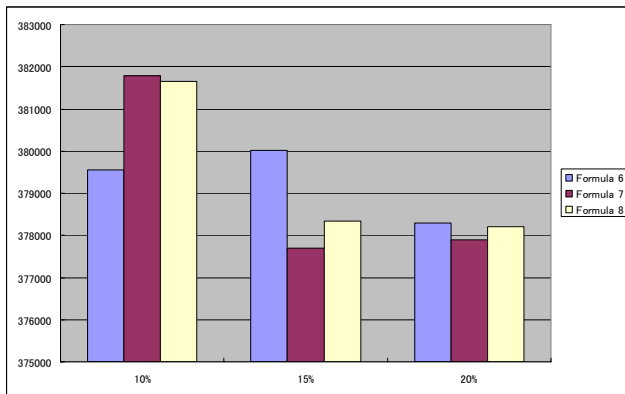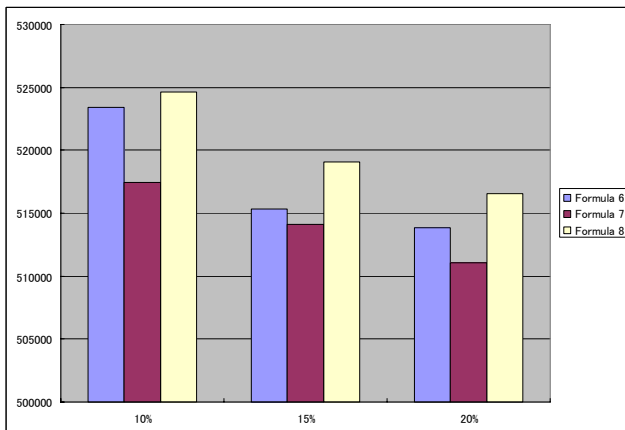

Fig.6 Minimum wirelength of n200
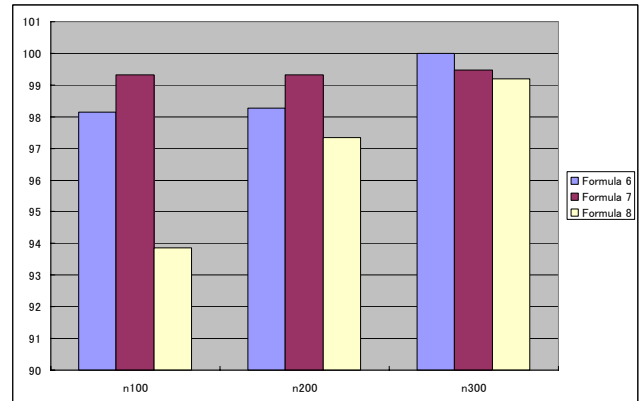

Fig.7 Minimum wirelength of n300

Fig.8 Comparison of success rate

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TABLE I
FIXED-OUTLINE CONSTRSINT ONLY: WITH/WITHOUT ASPECT RATIO

	n100				n200			
	wo_ar		with_ar		wo_ar		with_ar	
	succ	time	succ	time	succ	time	succ	time
1.00	64%	0.75	72%	0.62	92%	2.97	96%	2.55
1.50	62%	0.63	74%	0.56	92%	2.49	100%	2.46
2.00	22%	0.89	54%	0.74	80%	2.37	92%	2.05
2.50	22%	0.80	34%	0.78	60%	3.44	84%	3.14
3.00	36%	0.70	56%	0.82	92%	2.75	96%	2.54
	41%	0.75	58%	0.70	83%	2.80	94%	2.55