Fuzzy-clustering-based algorithm for circuit partitioning in standard cell placement

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Indexing terms: Circuit layout, layout, Fuzzy set theory

The technique of circuit partitioning has been applied to standard cell placement for many years. A fuzzy-clustering-based algorithm is proposed to obtain a better two-way area-constrained partitioning for a partitioning-oriented standard cell placement. The proposed algorithm has tested several industrial circuit benchmarks, and the experimental results have shown that the algorithm obtains a better partitioning than the traditional F-M algorithm.

Introduction: In standard cell layout, the placement phase plays an important role in the automation of physical design. However, it is well known that the placement problem has been proved to be NP-hard [1]. Thus, the technique of circuit partitioning has been extensively proposed to develop a partitioning-oriented placement. Thus, the technique of circuit partitioning has been extensively proposed to develop a partitioning-oriented standard cell placement. In particular, the Fiducial-Integral-Menthes (F-M) algorithm [2] is most often applied in the design of a standard cell placement [3, 4]. In Fig. 1, two-way circuit partitioning is applied to a partitioning-oriented standard cell placement.

Fig. 1 Two-way circuit partitioning in a partitioning-oriented standard cell placement

Fuzzy-clustering algorithms [5] have been extensively proposed for image processing and pattern recognition. Traditionally, based on the measure of geometrical distance, fuzzy-clustering algorithms will be applied to classify the image data on an image surface. In this Letter we extend these fuzzy clustering algorithms to a graph structure and further solve circuit partitioning for standard cell placement.

For circuit partitioning in a partitioning-oriented standard cell placement, first, a circuit netlist of standard cells will be transformed into an edge-weighted graph by a tree net model. Furthermore, based on the definition of the clustering distance on a graph structure, fuzzy graph clustering will be applied to obtain two groups of fuzzy memberships. Finally, according to these memberships and the information of cell areas, all the standard cells in a circuit netlist will be partitioned into two subcircuit netlists with a given area constraint.

Problem formulation: In standard cell layout, the height of each cell will be the same and the width of each cell may be different. Therefore, the area of each cell may be different. In general, based on the area consideration of standard cell layout, full-area-balanced partitioning is more suitable for partitioning-oriented standard cell placement. However, owing to the area irregularity of standard cells and the assignment of feedthrough cells, area-constrained partitioning is more practical for partitioning-oriented standard cell placement. In two-way area-constrained partitioning, based on the net and area distributions of standard cells, a lower bound \( \alpha \) and an upper bound \( \beta \) of any partitioning area will be estimated and given, where \( 0 < \alpha \leq 0.5, 0.5 \leq \beta < 1 \) and \( \alpha + \beta = 1 \). Hence, if a circuit netlist \( C \) is partitioned into two subcircuit netlists \( C_1 \) and \( C_2 \), two-way area-constrained partitioning for a standard cell placement will be formulated as a partition \((C_1, C_2)\) of \( C \) such that the cut of the partition \((C_1, C_2)\) is minimised with

\[
\alpha \frac{\text{total_area}(C)}{\text{total_area}(C)} \leq 1 \quad \text{for} \quad 1 \leq i \leq 2
\]

where \( \text{total_area}(C) \) is the sum of areas of all the standard cells in \( C \).

Fuzzy-clustering-based partitioning algorithm: In general, a circuit netlist is mapped as a hypergraph. Thus, circuit partitioning will correspond to hypergraph partitioning. It is well known that hypergraph partitioning is more difficult than graph partitioning. Hence, circuit partitioning is always solved by first transforming a hypergraph into a graph using a clique net model, that is, for any \( p \)-pin hyperedge \( p \geq 1, p=1/2 \) complete connections of \( p \) pins will be generated in the mapped graph. In general, based on the connection of \( p \) pins, only \( (p-1) \) edges in a tree net model are applied to maintain the connection of a \( p \)-pin hyperedge.

For a circuit netlist, we propose a tree net model to transform a multiple-pin net into a tree connection and assume that the cut contribution in a tree representation of a net must be obtained by an expected value of 1. Thus, for two-way partitioning of a \( p \)-pin net, the number of distributions of \( p \) pins is \( (2^p-1) \). Assume that any distribution of \( p \) pins is uniform, hence, the probability of any distribution of \( p \) pins is \( 1/(2^p-1) \). If \( p \) is 1, \( 1/(2^1-1) = 1/0 \) is infinite. Because the expected cut contribution of a \( p \)-pin net in a tree representation is 1, it is clear that

\[
\frac{1}{2^{p-1}} \sum_{i=1}^{2^p-1} \sum_{j=1}^{2^p-1} w_{ij} = 1
\]

where \( w_{ij} \) is the edge weight of \( (p-1) \) connections for a \( p \)-pin net in a tree net model.

Therefore, according to the previous equation, \( w_{ij} \) will be obtained as \( w_{ij} = 2/(p-1) \). By transforming all the hyperedges, a circuit netlist will be mapped by an edge-weighted graph. Hence, two-way circuit partitioning will be approximately obtained by two-way graph partitioning. In this Letter, two further phases are applied to obtain a two-way area-constrained partitioning after the graph transformation.

In phase 1, according to the mapped edge-weighted graph \( G(V, E) \), a related clustering graph \( G'(V', E') \) will be defined by modifying all the edge weights as \( e' = \frac{e}{2(p-1)} \), where \( V' = V, E' = E \) and \( e' \) is the weight of the edge \((i, j)\). Furthermore, the clustering distance will be defined as follows: for any pair of vertices \( i \) and \( j \), the clustering distance \( d'_{ij} \) between vertex \( i \) and \( j \) will be further obtained as

\[
d'_{ij} = \begin{cases} d_{ij} & \text{if } (i, j) \text{ is an edge in } G \\ \text{ShortPath}(i, j) & \text{if } (i, j) \text{ is not an edge in } G 
\end{cases}
\]

where ShortPath \((i, j)\) represents the sum of weights on the shortest path from vertex \( i \) to \( j \). Based on the definition of \( d'_{ij} \), fuzzy \( c \)-means clustering [5] as fuzzy graph clustering converges on all the fuzzy memberships, two groups of fuzzy memberships for all the vertices in \( G' \) will be generated.

In phase 2, first, according to one group of fuzzy memberships, all the vertices \( x_1, x_2, \ldots, x_n \) in \( G' \) will be sorted decreasingly into a vertex list \( x_1', x_2', \ldots, x_n' \). Furthermore, based on the areas of all the standard cells and the values of a lower bound \( \alpha \) and an upper bound \( \beta \), two pairs of feasible area-constrained indices \((i, u)\) and \((i, l)\) for two clusters will be obtained by sequentially searching the vertex list such that

\[
\sum_{i=1}^{x_1'} A(x_i) \leq \alpha \sum_{i=1}^{x_n'} A(x_i)
\]

and

\[
\sum_{i=1}^{x_1'} A(x_i) \leq \beta \sum_{i=1}^{x_n'} A(x_i)
\]

and

\[
\sum_{i=x_1'}^{x_n'} A(x_i) \leq \alpha \sum_{i=x_1'}^{x_n'} A(x_i)
\]

and

\[
\sum_{i=x_1'}^{x_n'} A(x_i) \leq \beta \sum_{i=x_1'}^{x_n'} A(x_i)
\]

where \( A(x) \) is the area of the standard cell representing vertex \( x \). Finally, according to \((i, u)\) and \((i, l)\), a feasible partitioning index \( (i, l) \) will be generated for two-way area-constrained partitioning. Hence, a two-way min-cut par-
tation will be further obtained by searching all the area-constrained partitioning.

As mentioned above, the fuzzy-clustering-based algorithm for circuit partitioning in a partitioning-oriented standard cell placement is as follows:

Step 1: Map a circuit netlist into a hypergraph $H(V, E)$.

Step 2: Transform $H(V, E)$ into an edge-weighted graph $G(V, E)$ by a tree net model.

Step 3:
1. Initial an arbitrary two-way partitioning and establish a fuzzy matrix $U$.
2. Compute all the clustering distance $d_{ij}$ in $G$.

Step 4:
1. Calculate the centres $v_i = \frac{\sum_{j=1}^{n} u_{ij}d_{ij}}{\sum_{j=1}^{n} u_{ij}}$ for $1 \leq i \leq 2$.
2. Compare $d_{ij}$, where $D_{ij} = \frac{d_{ij}^2}{d_{ii}^2 + d_{jj}^2}$.
3. Compare $U$ and $U'$ if $d_{ij} < \varepsilon$, for $1 \leq i \leq 2, 1 \leq k \leq n$.
4. Stop; otherwise, $U = U'$, and go to (1).

Step 5:
1. Sort the vertex set $\{x_1, x_2, ..., x_n\}$ and construct an increasing vertex list $x_1', x_2', ..., x_n'$ according to one group of fuzzy memberships $u_{ij}, 1 \leq i \leq n$.
2. Generate two pairs of feasible area indices, $(l_i, u_i)$ and $(l_i, u_i')$ and the feasible partitioning index $U$.
3. Find a two-way min-cut partitioning by searching all the feasible area-constrained partitioning according to the partitioning index $l_i, u_i$ and computing the partitioning cut.

Experimental results: The proposed fuzzy-clustering-based algorithm has been implemented using standard C language and on a SUN workstation under the Berkeley 4.2 UNIX operating system. In this implementation, the $\varepsilon$ value in this algorithm is assigned as 0.01, and the proposed algorithm is run on each test benchmark 20 times with different initial partitioning.

For two-way circuit partitioning in a partitioning-oriented standard cell placement with an area constraint (a, b), the total cell area (TCA) is the sum of areas of the standard cells in a circuit netlist, and the area constraint (a, b) for any partitioning part $(P_A, P_B)$ is as follows:

$$TCA \leq a \leq PA, \leq TCA + b$$

for $1 \leq i \leq 2, 0 \leq a \leq 0.5, 0.5 \leq b \leq 1$ and $a + b = 1$

<table>
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<th>Example</th>
<th>SA (10 runs)</th>
<th>F&amp;M (100 runs)</th>
<th>PD</th>
<th>HGCUP</th>
<th>TCB (20 runs)</th>
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</tr>
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</table>

For MCNC benchmarks in circuit partitioning, Table 1 shows the experimental results for two-way min-cut partitioning with $a = 0.4$ and $b = 0.6$. In this table, the simulated annealing (SA), Fiduccia-Mattheyses (F-M), primal-dual (PD), HGCEP and fuzzy-clustering-based (FCB) algorithms are evaluated. The results of SA, F-M, PD and HGCEP are from [6] and the results of FCB are from 20 runs.

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17 October 1994

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References


Mixed-mode Schmitt trigger equivalent circuit

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**Mixed-mode Schmitt trigger circuit**

**Fig. 1 Traditional voltage mode Schmitt trigger principle of operation**

**Table 1: Comparison of experimental results with (\(a, b = 0.4, 0.6\)**)