CS 512200 VLSI Design for Manufacturability

Final Project (Due: 2023/6/9)

This design project is completely open in terms of how you solve the problem. (You may propose your own approach or follow previously proposed approaches in the literature.) You may work individually or in a team of two persons, you will receive an additional bonus if you finish this project on your own.

Dummy fill insertion is a mandatory step in modern semiconductor manufacturing process and it is commonly performed after the physical design stage. When a dummy fill is inserted, it increases the metal density and improves planarity but inevitably couples to the signal tracks. If the coupling capacitance to a critical net is significant, the original timing-closure may not be achieved anymore. So, it is important to reduce the capacitance impact when inserting dummy fills.

In this project, **lateral capacitance** is considered. Any two segments of two neighboring conductors on the same layer running parallel to one another without any other conductors in between the segments form the **lateral capacitance** as shown in Figure 1.

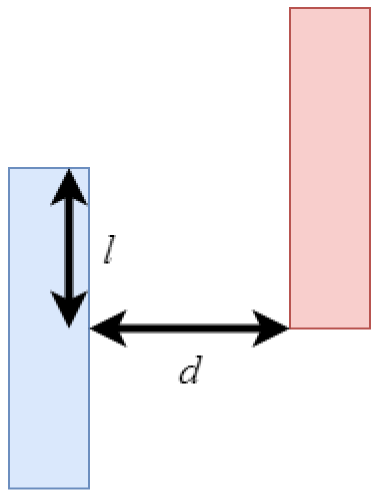

Figure 1: Lateral Capacitance

The **lateral capacitance** is calculated by

$$C = P(d) \times l$$

where l is the length of the parallel edges of the conductors and *P(d)* is the lateral capacitance per unit length, which is a function of distance of the parallel edges d.

$$P(d) = \begin{cases} 0 \; if \; d > 1600 \\ \frac{1}{d} \; if \; d \leq 1600 \end{cases}$$

Note that it is not possible that d equals zero due to the minimum spacing constraint introduced below.

Given a design with several layers, we want to insert dummy fills to each layer while minimizing the weighted sum of critical paths lateral capacitance subject to the following constraints.

1. Minimum fill width constraint: The width and height of the inserted dummy fill need to be larger than or equal to a given length.
2. Maximum fill width constraint: The width and height of the inserted dummy fill need to be smaller than or equal to a given length.
3. Minimum spacing constraint: The spacing between any two conductors should be larger than or equal to a given distance.
4. Minimum metal density constraint: The density of each window after dummy fill insertion needs to be larger than or equal to a given density.
5. Maximum metal density constraint: The density of each window after dummy fill insertion needs to be smaller than or equal to a given density.

Metal Density

The layout with metal fill must meet the density criteria and the density is calculated in a window based manner.

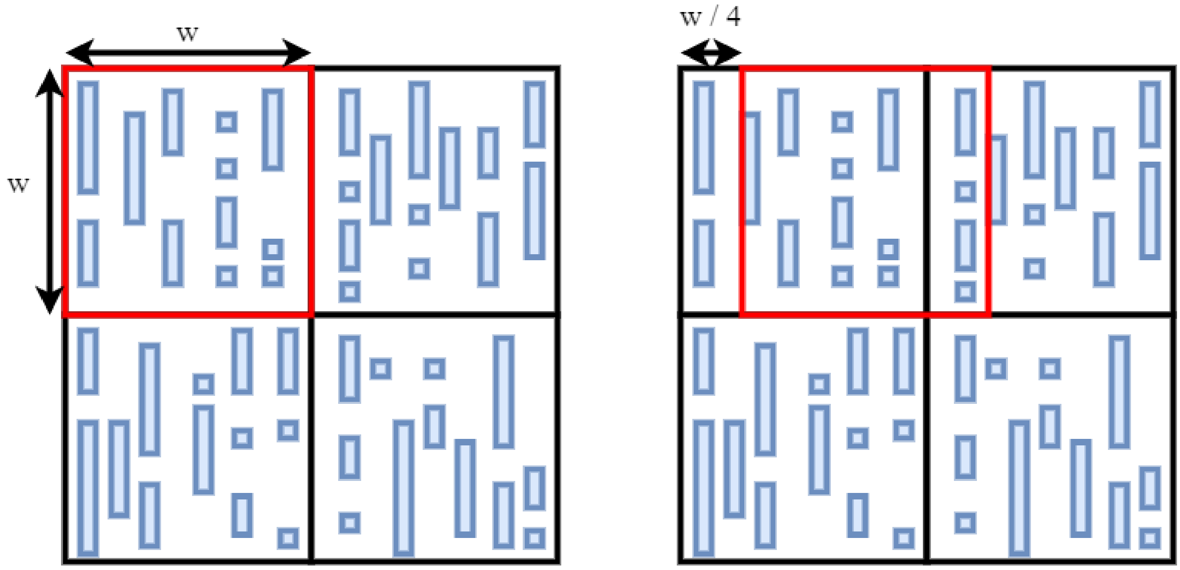

Figure 2: Density Calculation Window

w is the window size for density calculation and the step length is set to *w/4*. The density of a window W_i is calculated as

$$D(W_i) = \sum_{S \in W_i} S / w^2$$

where *S* is the metal area that is enclosed inside W_i. The density in each window must be larger than or equal to the given minimum metal density for that layer and smaller than or equal to the given maximum metal density for that layer.

Input Format

There are mainly four parts in the input file.

1.

The first part consists of two lines. The first line lists the x-coord. of the chip left boundary, y-coord. of the chip bottom boundary, x-coord. of the chip right boundary, y-coord. of the chip top boundary, and window size. The second line lists the total number of critical paths, total number of layers, and total number of conductors.

Format:

<**x-coord. of the chip left boundary**><**y-coord. of the chip bottom boundary**><**x-coord. of the chip right boundary**> <**y-coord. of the chip top boundary**><**Window size**>
<**Total number of critical paths**><**Total number of layers**><**Total number of conductors**>

A sample of the first part is given below.

```
3405000 1800000 3675000 1970000 10000
3 9 5
```

Note that all the numbers in this part are integers.

2.

Each line of the second part lists the id of a critical net. The number of lines in the second part is equal to the total number of critical nets.

Format:

<**Critical path id**>

A sample of the second part is given below.

```
74381
24382
84383
```

Note that all the numbers in this part are integers.

3.

The third part provides the information of the layers. The information of each layer is given by a separate line listing the layer id, minimum fill width, minimum spacing, maximum fill width, minimum metal density, maximum metal density, and layer weight. The number of lines in the third part is equal to the total number of layers.

Format:

<**Layer id**><**Minimum fill width**><**Minimum spacing**><**Maximum fill width**><**Minimum metal density**><**Maximum metal density**><**Layer weight**>

A sample of the third part is given below.

```
1 65 65 1300 0.4 1 1
2 65 65 1300 0.4 1 1.5
3 65 65 1300 0.4 1 2
4 65 65 1300 0.4 1 2.5
5 65 65 1300 0.4 1 3
6 65 65 1300 0.4 1 3.5
7 130 130 1300 0.4 1 4
8 130 130 1300 0.4 1 4.5
```

```
9 360 360 3600 0.4 1 5
```

<**Layer id**><**Minimum fill width**><**Minimum spacing**><**Maximum fill width**> are integers and <**Minimum metal density**><**Maximum metal density**><**Layer weight**> are floating-point numbers.

4.

The final part provides the information of the conductors. The information of each conductor is given by a separate line listing the conductor id, x-coord. of the conductor left boundary, y-coord. of the conductor bottom boundary, x-coord. of the conductor right boundary, y-coord. of the conductor top boundary, net id, and layer id.

Format:

<**Conductor id**><**x-coord. of the conductor left boundary**><**y-coord. of the conductor bottom boundary**><**x-coord. of the conductor right boundary**><**y-coord. of the conductor top boundary**><**net id**><**layer id**>

A sample of the final part is given below.

```
2 3405000 1918660 3407085 1918795 0 1
35 3405000 1952149 3405082 1952212 83630 1
58359 3603393 1815975 3604059 1816038 0 3
59903 3439264 1890409 3439327 1890760 180132 4
64412 3640455 1868383 3642597 1888383 0 8
64818 3646460 1804203 3666460 1804563 14437 9
```

Note that the id of polygons is not guaranteed to be consecutive numbers and all the numbers in this part are integers.

It is possible that the conductors belong to a net overlap with each other. When computing the metal density, beware not to count the overlapping area more than once.

Output Format

The information of inserted dummy fills is given by separate lines. For each line, list the x-coord. of the dummy fill left boundary, y-coord. of the dummy fill bottom boundary, x-coord. of the dummy fill right boundary, y-coord. of the dummy fill top boundary, and layer id.

Format:

<**x-coord. of the dummy fill left boundary**><**y-coord. of the dummy fill bottom boundary**><**x-coord. of the dummy fill right boundary**><**y-coord. of the dummy fill top boundary**><**layer id**>

A sample of the output is given below.

```
3405000 1833988 3410236 1834123 1
3410032 1917877 3410383 1917940 1
```

Note that all the numbers in the output file must be integers.

Project Submission and Makefile Requirement

The source codes should be uploaded to eeclass. Please include a Makefile for compiling your codes. In addition, upload a report describing the details of your approach. If it is a teamwork, each member has to explain what he has done and the percentage of his contribution.

Name the executable file "Fill_Insertion" and make sure your program can be executed by running the command:
$./Fill_Insertion <input file path> <output file path>
like the one below

```
./Fill_Insertion ./input/testcase1.txt ./output/testcase1.txt
```

All codes should be compiled by running the command:
$make
You have to delete the object file and executable file by running the command:
$make clean

Environment and Execution

1. Language: C/C++ (gcc version 9.4.0)
2. Platform: Linux (Ubuntu 18.04.6 LTS)

Evaluation

- For each benchmark, if your result violates any constraints, the quality score on that benchmark will be 0.
- If your program takes more than 10 minutes to generate a result, it fails on that benchmark.
- Any plagiarism will result in a 0 grade for the project.
- If we cannot program your source code or we cannot execute your program by the command mentioned above, then the quality score for all benchmarks will be 0.

Grading

- 30%: The completeness of your program and report.
- 70%: The solution quality (hidden testcases included)
  - The weighted sum of critical nets lateral capacitance, *WS*, is defined as

$$WS = \sum_{n \in N} \sum_{c \in n} \alpha_c W(c_L)$$

    where N is the set of critical nets, c is the conductor in critical net n, α_c is the sum of lateral capacitance related to conductor c, $W(c_L)$ is the weight of the layer where c is placed.
  - The quality score is based on the weighted sum of critical nets lateral capacitance of your solution compared to other students when your solution is valid. Here is the equation for score calculation.

$$100 - 30 \times \frac{Your\ WS - smallest\ WS}{largest\ WS - smallest\ WS}$$

Reference

“Timing-Aware Fill Insertion” in Proc. of 2018 ICCAD CAD Contest.
(http://iccad-contest.org/2018/Problem_C/2018ICCADContest_ProblemC.pdf)