VLSI Physical Design with Timing Analysis

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Lecture 32

Placement Algorithms

Welcome to the course on VLSI Physical Design with Timing Analysis. In this lecture, we will discuss about different types of placement algorithms which is used in case of VLSI physical design. So, the content of this lecture includes terminal propagation, then we will discuss about the quadratic placement. So, what is terminal propagation? So, we have discussed about the mean cut algorithm in the last lecture. We discussed about the KL algorithm and the FM algorithm which is used to calculate the location of each logic gates in the layout. However, whenever you are going through the mean cut algorithm, it partition or it places the cells independent of the other partitions.

So, in case of mean cut algorithm, it partitions the design such a way that all the partitions are independent. So, whenever you are considering all the partitions are independent, there might be connection from one partition to the other that needs to be considered. So, in this algorithm, we are basically so what we are doing is that the mean cut algorithm does not consider the location of the connection pin within the partition that has already been visited. So, the terminal propagation algorithm basically takes into account this external pin location during the partition based placement.

So, the terminal propagation algorithm takes into account the external pin location of whenever you are doing the partitioning based on KL or FM algorithm. So, how it is doing that, we will discuss in this slide. So, in case of the mean cut placement algorithm with external connection, we assume that the cells are placed at the center of their respective partitions. The cells are placed at the center of their respective partition. And if the related connections or the dummy nodes are close to the next partition cut line, these nodes are not considered when making the next cut.

So, if basically we have connections which are close to the next partition cut line, those nodes are not considered when making the next cut. So, here take an example here. So, here we have logic gates A, B, C, D is there. So, four logic gates are there. We have four locations are there. It is a 2 by 2 grid. So, this is a 2 by 2 grid. We want to find the location of these logic gates in this 2 by 2 grid. So, what is we are doing? We are doing this placement, mean cut placement without considering the external connection. So, we will do a placement without considering the external connection.

So, how the placement will look like? So, what is this without considering means this pin is not considered in this placement algorithm. Now, we have two partitions now, one two in one partition, four and three in another partition. Now after we do the partition, the first partition, the one is basically it will go to the below left and top left. BL means below left, TL means top left. Now we have four and three.

So, four and three has one connection. So, if you go to this diagram, your one pin which is your one node which is corresponds to logic gate A, two is corresponds to logic gate B and three corresponds to logic gate C and the four is corresponds to logic gate D. So, now we created a graph. So, the one two is in one partition and three four is in another partition. So, if you can see here, we can do this partition using KL or FM does not matter.

We use any kind of mean cut algorithm. Then the only issue is that whenever I am doing the partition of A and B that will go in one partition and that can be done independently and the C and D can be partitioned separately. So, if I do separately, but there is a connection, this connection is there from one to partition two. So, whether we should consider that connection or not, that is the main point of this terminal propagation algorithm. So, if I can see here, so we did the partition without considering the external connection, this connection without considering this connection.

So, this is your external connection between the partitions. So, now if I do not consider that, then there will be a long interconnect from this to this, but this is not a good placement of the cells. So, now what you have to do is that we need to consider this pin whenever we are doing the mean cut placement. So, how we can do that? We can consider a pin P1, so that pin is considered while doing the partition of the next partition the 3 and 4. So, whenever you are doing that, that pin we should consider the interconnect distance from that pin to the gate such that my interconnect distance would be minimum.

After doing this one, the 4 will be occupied in the TR position and the 3 will go to the BR position. TR stands for top right, BR stands for bottom right. So, after doing this placement, we will have a very simpler placement of the cells as shown here where the interconnect distance is minimized. So, we will discuss now about the analytical placement algorithm. This analytical placement algorithm minimizes a given objective function such as we need to minimize the wire length or circuit delay.

So, what we need to do here is that we need to basically express our problem statement in some mathematical formulation such that we can solve that mathematical formulation using some kind of numerical methods and linear programming. So, first target is to how to reduce our VLSI placement problem into a mathematical function, then we can optimize that using some kind of numerical methods or linear programming techniques. So, we discuss about the analytic placement. So, now what we did is that we define a cost function, we define a function, mathematical function which is expressing our placement problem in terms of a quadratic function. So, we need a mathematical function to capture the placement problem in terms of a mathematical function.

So, in this case what we are doing is that we are defining a mathematical function which is quadratic in nature. So, what we define here that function is a squared Euclidean distance. The squared Euclidean distance we taken as the cost function, cost function means the function which needs to be optimized. So, the cost function is a function which is need to be optimized. In this case what we did we have two points corresponding to the center of the block, let us say this is a block and let us say this is a block.

So, this is a block I and this is a block J, the coordinate of block the center of the block is let us say this point corresponds to x i comma y i and this point corresponds to x j comma y j. So, now what I am doing here is that if there is a line between them, if there is a interconnection between the two blocks that can be denoted as x i minus x j whole square plus y i minus y j whole square. So, this is my squared Euclidean distance and this c ij is basically a value if that value becomes 1 if there is a line between i to j. If there is no line or the connection between i j this value of c ij becomes 0. So, now what we are doing this one for all such blocks, so for all such blocks we are defining this function L of P.

$$L(P) = \sum_{i=1, j=1}^{n} c(i, j)(((x_i - x_j)^2 + (y_i - y_j)^2)$$

So, our aim is to optimize this one. So, what is happening here is that we have a quadratic placement. The quadratic placement consists of two stages actually. So, the first stage is called your global placement. So, the first stage is called your global placement. So, the first stage is called your global placement. So, what happens here is the cells are placed so as to minimize that quadratic function what is there. So, we are placing the cells such that the quadratic function is minimized with respect to the centre of the cells or centre of the unit gates or the gates whatever it is there. So, this placement whatever you have done is not a legal placement. It is not a legal placement. Legal means that this is not the actual placement or the ideal means that is not proper placement, but it is a relative placement or what is something which is close to the actual placement.

So, or if I divide the whole chip into multiple grids it can go to one of the grid positions. So, using this global placement, but it cannot find the actual coordinate of the placement of the cells. So, in the second stage what happens is you have a detailed placement. What happens is that that large cluster whatever it is there that is broken up. You have a large cluster of cells are assigned to one particular grid that was broken up and all the cells are placed such that there is no overlap.

So, in case of global placement there might be overlap of cells, but in case of detailed placement there is no overlap of cells. Then what you have to do we have to legalize the cells to cell locations. This means it will assign the particular locations where supply and VDD is properly given to that cells. We are first discussing the global placement algorithm. So, each dimension can be considered independently.

So, whatever we saw in the previous mathematical formulation we are expressing L of P in terms of X and Y, but now this X axis and Y axis are independent. So, we can optimize them independently. There is no relationship between the X coordinate and Y coordinate of a cell. So, we can optimize them independently to find the X and Y coordinate. So, here what is happening we have L of P is equal to summation i equal to 1 and j equal to 1 to n cij xi minus xj whole square. So, this is with respect to X coordinate.

$$L_x(P) = \sum_{i=1,\, j=1}^{n} c(i, j)(x_i - x_j)^2$$

Similarly we can write it further with respect to Y coordinate.

$$L_y(P) = \sum_{i=1,\, j=1}^{n} c(i, j)(y_i - y_j)^2$$

If you can see these two functions both are quadratic. So, what is the requirement of quadratic optimization problem is that the function should be differentiable. So, if whenever I am doing xi minus xj whole square this function should be differentiable.

So, if it is differentiable what will happen is that we can find its minima, global minima. So, now what is happening is that with the cost function the placement becomes a convex quadratic optimization problem. So, with this cost function the placement problem becomes a convex quadratic optimization problem. So, what is this convex quadratic optimization problem let us say my X this is the input variable and this is my cost function, cost function f. So, then the function will look like something like this.

If I keep a ball here then the ball will fall and come to this point. So, what is this point is your global minimum. So, what is happening is that if you differentiate that function your local minimum becomes your global minimum in case of convex function. So, what is saying that since this function is convex, since this function is convex local minimum becomes the global minimum. So, now what we are doing is that now we are differentiating that function since I told this function can be differentiable let us differentiate that del L x p by d x.

So, this is one differentiation and this is with respect to x this is another differentiation with respect to y. Del x p by d x equals to a x minus b x equal to 0. Del L y p by d y equal to a y minus b y equal to 0. So, we have two basically x and y coordinate. So, what is the thing here is that we have a matrix A with these are the variables.

So, a i j equals to minus c i j when i not equals to j and a i j is sum of the incident connections of the weights of cell i. So, these are the two things what we find when we do the final formulation of the problem. So, we have A is a matrix with these are the basically elements of that matrix. Now we have a x. x is a vector of x coordinates of all the non-fixed cell and your b x is a vector also.

What is the elements of b x is the sum of x coordinate of all fixed cell attached to the node i. y is another vector which is vector of all y coordinates of all non-fixed cells. Now we have b y is a vector with b y of i which is ith element is basically the sum of y coordinate of all the fixed cell attached to that block or the node i. So, what we can find here is that we find a system of linear equations which can be solved iteratively using numerical methods. We can solve this problem using numerical methods.

So, what we can use either you can use basically conjugate gradient method or successive over relaxation SOR method to solve the system of linear equations. So, let us take an example. So, the quadratic placement problem with this example what is given to a placement algorithm? So, we have given two pins P 1 and P 2. So, these are the coordinates of the P 1 these are the coordinate of the P 2. Now we have given three blocks basically this A is one block, B is another block, C is another block.

So, then what else is given to us? So, we have given this N 1 to N 4. So, this N 1 says that P pin is connected to A then N 2 says that A is connected to B and N 3 is another nets which is connected between B and C and N 4 is C, P 2. So, this is the placement area is also given this is the placement area. So, what is the task here? The main task is to find the coordinates of all the blocks. So, each block has two parameters or two parameters need to be find for block A x A, y A similarly for block B and block C.

Now how can I find these coordinates? So, let us say I have this LP of x. So, we are dealing with the x coordinates we are dealing with the x coordinate first. So, we can see here this is our formulation. So, how this 100 is coming into picture? If you can go here this is the pin coordinate 100,175 and this is 200,225. So, since I have a pin from P 1 to A so I have a block somewhere located I do not know the location of the block this is the block A.

If I have a line going from this to this what is my square Euclidean distance in the x coordinate? So, x coordinate should be x 100 minus x of A whole square. So, if you can go to their 100 x minus A whole square. So, this is with respect to x coordinate. Similarly if you look into the nets similarly you can find x A minus x B whole square x B minus x C whole square then let us go to the last point. So, let us say this C there is a block C is there which is connected between this is a block C the center of the C and it is connected to P 2.

So, now what is the Euclidean distance in the x direction? So, here basically your x C minus 200 whole square x C minus 200 whole square. So, this is the way you can find L p of x L p of x this value. So, after I find a L p of x now I differentiate with respect to x A and equate to 0. Since I taking the differentiation I find the minimum or maximum. Since I am taking the differentiation equal to 0 I can get the minimum value of that function.

So, now what is happening here is that same thing I can do it for x B and x C. Now I have three equations. So, this is one equation this is another equation and this is another equation. So, three equation so I have three equation I can express this one in terms of a matrix expression A x equal to B.

So, I can express this one in terms of A x equal to B. So, this is the matrix expression for this quadratic placement algorithm. So, if I can go here this is my matrix A and this is my x and this is my B. So, now we have A this is x and this is B. Now if you can express this one we can solve this matrix you can use several method like Gauss elimination method or conjugate gradient method or any other method to solve this system of linear equation. And after solving this one what you got is that x A equals to 125 x B is 150 x C is 1. So, this is 175 for this problem. So, now we can do the same thing for the y coordinates. So, we can do the same thing for the y coordinate. First of all we will find L p of y then we will differentiate with respect to y A then we differentiate this equation with respect to y B and with respect to y C. Then I get three equations. This is one equation, this is one equation and this is one equation.

This equations can again be expressed in terms of a matrix like A y equal to B y. So, A here is this one and y is this one and this is my B y. So, we can solve this using the similar techniques and this is my results. So, after I get this coordinate I can have locations of A is this one and location of block A is 125, 187. 5, B is 150, 200, C is this one. So, this is a method of called quadratic placement of the blocks which is based on the global placement. Here the cell whatever it is found out it is not the exact coordinate of the blocks. During the detail placement which is after the global placement cells are spread out to remove all overlaps. If there is any kind of overlap is there that can be removed after the detail placements. The methods whatever are used here adding a fake nets that pulls the cells away from the dense area towards the anchors.

So, what are the techniques basically used here is that geometrical sorting and scaling or the second method is called repulsion forces. Those techniques are used for the detailed placement. So, if you can see here in the left hand side is a global placement. Here if you can see in case of a global placement these cells are overlapped and some of the cells are located here which is not overlapped. After doing this detailed placement we get such kind of placements.

Now what is the advantage basically of this quadratic placement? So, it basically formulate the placement problem using mathematical functions that is one advantage. So, what is the advantage of this mathematical function is that it can use the efficient numerical techniques and the software to solve the problem in less time. And it can also be used for large circuit. It can also be scalable with and applicable for large circuits. So, and if you have small changes in the input your output will also not change because of the quadratic placement algorithm.

So, what are the disadvantages is that so you have connection to the fixed objects are necessary whenever you are going for a global placement or using the quadratic placement algorithm. So, we need to fix the blocks. We need to fix the blocks such as the IO pads, pins fixed to the macro. So, those pins should be fixed before applying your global placement algorithm because if your pin location will change then again we need to rerun your global placement algorithm. So, in this lecture we discuss about different placement algorithm and we discuss about the terminal propagation algorithm.

We discuss about the quadratic placement algorithm which is very useful for global placement.

Thank you for your attention.