VLSI Physical Design
Prof. Indrani Sengupta
Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

Lecture - 18
Global Routing (Part 1)

So, we shall now start our discussion on Global Routing. So you recalled in our earlier lectures we have looked at the measure or area routing, where 2 arbitrary points on a 2 dimensional surface could be connected, but one point was there you recall the entire path was laid out on a signal layer that was one of the restriction or requirement whatever you say. But here in global routing and outer subsequently detailed routing that you consist of that kind of restrictions not there. We are allowing to use multiple layers for interconnections.

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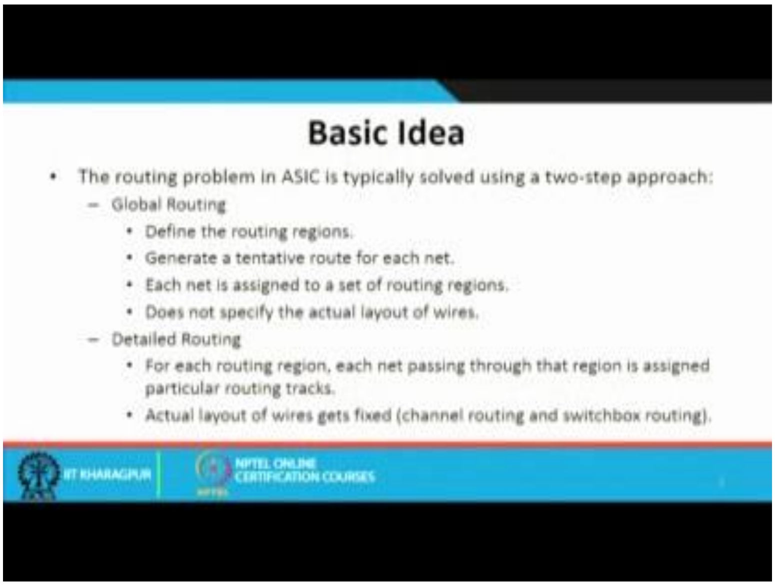

So, global routing and detailed routing, they are not independent they go hand in hand. When contrast the grid routing algorithms which you discussed they are used not directly associated with global or detail routing but whenever we run into some problem we use are routing.

Because area routing is considered to be one, where you can find path between 2 points which are otherwise not so easy to connect. So if there is a path existing it will find a path, but in these method detail or area routing we are basically concentrating on small paths of our design or the layout and you are trying to solve the routing problem in an incremental fashion. So let see the basic objectives of this two.

Global routing is a step very define something called routing regions. So we shall be looking at this. And we generate a tentative route for each net. We do not tell you the exact route to follow. Like for example, if you want to go from a city a to city b, I can give your tentative routes saying that well you first go to town d, then go to town x from there you can go to city b.

But I do not tell you exactly which row the routes to follow to go to your other 2 towns intermediate towns. There can be multiple ways to go there, but I give you a tentative route, this is my global routing. I only specify the tentative route I do not layout the exact wires at this stage. So each interconnection net is assigned to a set of routing regions in this step. As I said it does not specify the actual wire layouts. So where as in detail routing we actually complete the interconnections. So we consider this problem on a region by region basis. Typically, any solve each of the regions by completing all wire layouts vertical and horizontal and this is what is done in detail routing.

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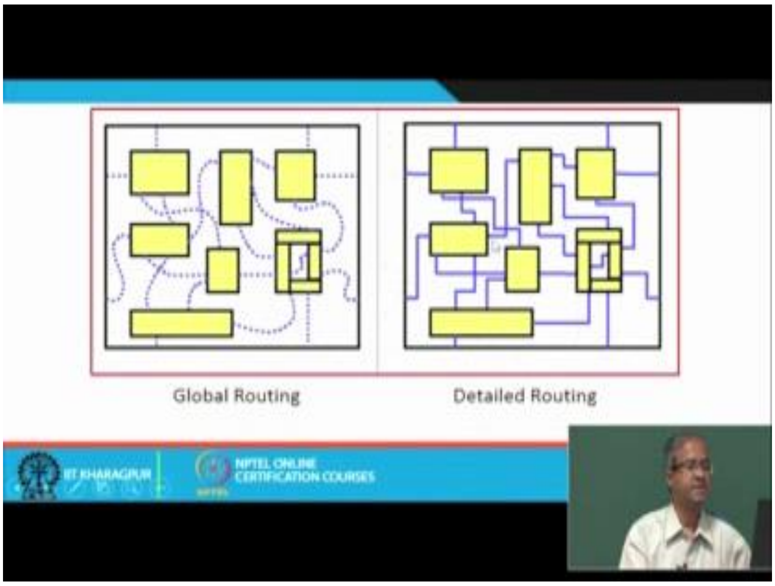

So, here we shall see later there are 2 kinds of detail routing sub problems channel routing and switch box routing. So we shall see this later. Now this is just an example. So here you see some blocks and this dotted lines show you the nets the points which need to be connected. So in global routing here only some rough paths are shown, like for example, when you connect let say point here to point here, it says that you have to follow roughly this path. And alternative could have been you follow this path. Or it could have seen you can follow this path. So global routing does this one, global routing process is done so each of this rough connections and actually map to horizontal and vertical segments.

Now, again I repeat. Here the solution that is shown is 2-layer routing solution, but the horizontal lines are laid out on one layer vertical lines are laid out on another layer. And any crossing here this corresponds to something called the wire connection which means this is connection between the 2 metal layers. Now this detail routing problem can be identified as routing or interconnecting points between 2 parallel surface. This is called a channel. Or you consider a problem like this where you have an enclosed region by pins on all 4 sides. This is called a switch box. This can be a switch box routing.

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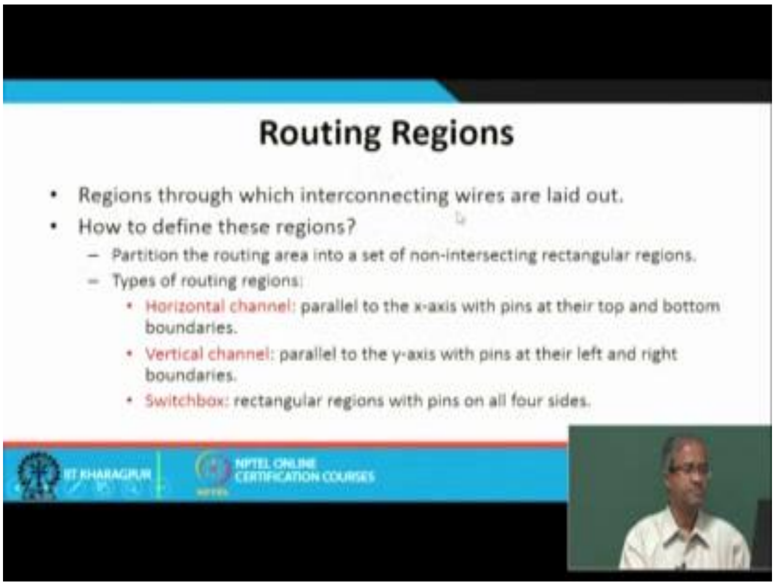

Now, let us come to the concept of routing regions. Routing regions are those so which interconnecting wires are laid out. Now the question is how to define this region like.

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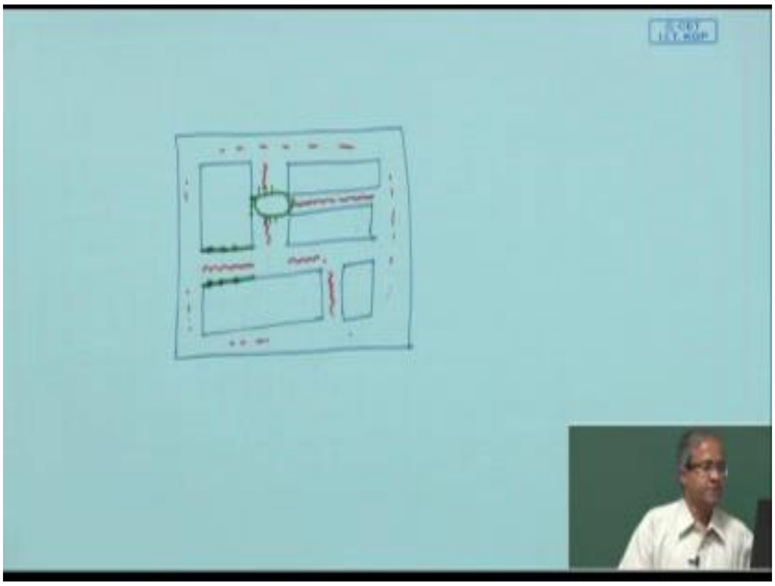

Let me take an example. Let say I have a rectangular layout surface where layer least some blocks like this. One block here, one block here, one block here. Let say one block here and one block here.

Now, now you have once I have placed it. So I can define some regions for routing. So roughly I am showing this is one region. This is one region. This is one region. This is one region. This is one and this is one. When addition you can use this as regions also because you can also make connections through this side. These are all routing regions.

Now, you look at let say places like this. Where your connections coming from 3 different sides. Some wires may come from top some from bottom some from this side and also some from pins here. So this can be a switch box kind of problem where pins are coming from all 4 sides, but problem like this where you have a parallel layer where some pins here and some pins here need to connected. This is channel. This is a horizontal channel this is a vertical channel, vertical channel.

So, the types of routing regions can be either horizontal channel which is parallel to the x axis with the pins corresponding to the nets at that top and bottom boundaries. Vertical channel is a ninety degree rotated version of that. This parallel to the y axis pins on the left and right. And switch box as I said it is a rectangular region with pins coming from all 4 sides. This is the more complex sub problem among the 3. Say horizontal and vertical channel routing problem are the same it is just a 90-degree rotation nothing else.

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So, the point to note is that during the global routing phase the first important step is to identify the routing regions. So, we shall see that how routing regions can be typical identified later on. And routing regions for most of the design styles do not have pre fixed capacities. Like sometimes you can move the blocks around like in a standard cell, you have this cells arranged in rows, but if you find that the space you have kept for the channel is not sufficient, you can always move the 2 blocks away little bit makes space for the channel or if you see that; that means, you do not require that must space you can bring them means you can bring them closer together.

So, the width of the channels can be adjusted as per the situation. And also there is another point which you shall see and little later, the order in which the routing regions are considered is also important. Because the overall routing quality and also the complexity depends on the order in which the routing regions are been considered.

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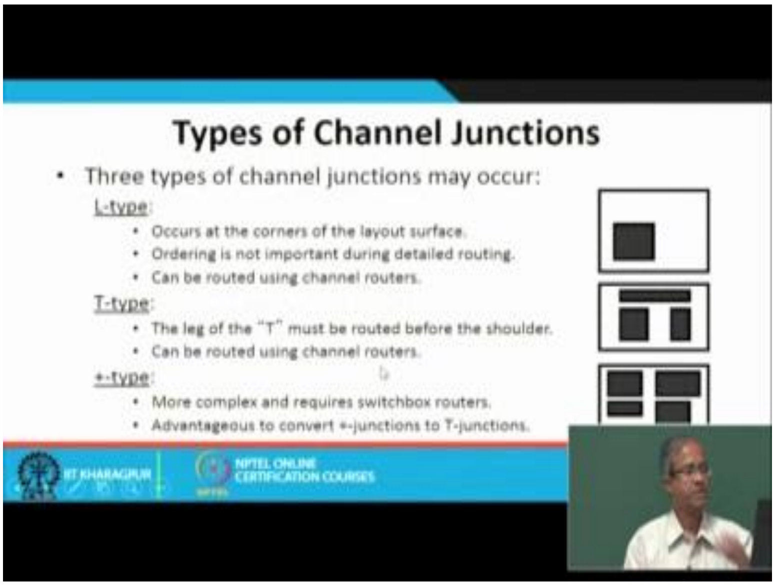

Talking about that the channel junctions, so 3 types of channel junctions occur in layout. First is called L type you see. This is block which is placed. There is a channel here vertical orientation. There is a channel here horizontal orientation the 2 channels are connected as a L, this looks like an L. This is the L type channel. This typically occurs at the corners of the layout circles. So here the ordering is not important you can either route the vertical on first and then horizontal or the reverse.

And simple channel routing algorithms can be used for this. Well you shall see these red is algorithms later, T type means this wide block and 2 smaller width blocks below it. So you see there is a channel here there is a channel here 2 horizontal channels and one vertical channel here, so the 3 channels from T. Now the idea is that you see, here the concept is that the leg of the channel; that means, this vertical channel has to be routed first.

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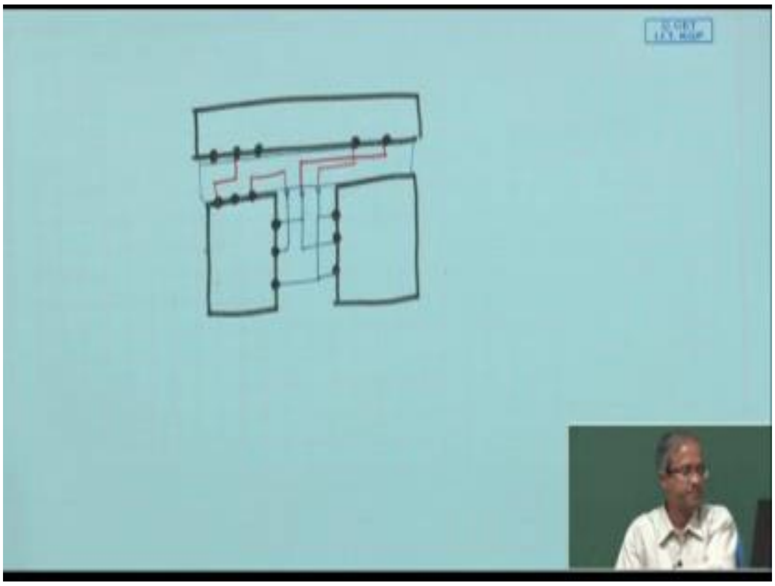

Let us try to understand why. This is an obstacle let say this is an obstacle there is some cells and these are some pins which you want to connect. This is some pins are here, some pins are here and some pins are also here.

So, what we say is that, first we interconnect this leg of the T. Let say we connect these points. So these points can be extended here, because they may also get connected to the other points will be this this is also getting connected here. This is also connected here fine. Now the reason why this channel has to be connected first is that, once you complete this, the position of these 3 signals are fixed. So now, this whole channel looks like a consisting channel routing problem. Fixed in location on the top fixed in location on the bottom, but if you do not consider this first, if you are considering this one initially, so in the middle you really do not know the exact position of these signal it can be here. That is why once you do this, then you can route the other points like this.

You can route this. You can complete the routing. This you can possibly connect to this. So for a T junction the leg of the T has to be routed first and then the shoulder, but for a plus type like here when there are 4 blocks like this, you see the central point here there are pins coming from all 4 sides. This is switch box routing problem. And you just use switch box routers. So you see during placement also it is advisable to place the blocks in this way, so that switchbox problems do not appear. Because channel routing problems are much simpler to solve as compare to the switch box routing problem.

So, if you can change or modify your placement and little bit in such a way that such switchbox kind of regions do not appear, then your routing problem can become simpler.

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There are some design style specific issues also. Like for example, in the full custom design style, the problem formulation is exactly same as what we have discussed just now. So all the types of routing regions like channel and switchboxes and the channel junctions L type, T type and plus type they can occur. And I mentioned the channels can be expanded some blocks will be moved here. And there so some violation in the channel capacity can be allowed, but major violations are not allowed because if you say that I have to move a block too much then other blocks might get disturbed.

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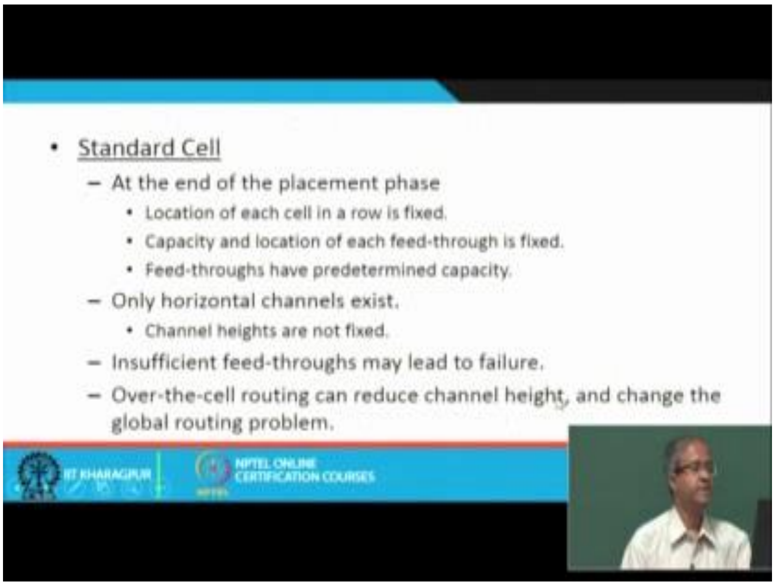

So, some placement may need to be change significantly there is. Standard cell. So in a standard cell if you recall, the cells are placed along rows so after you complete the placement the location of each cell is fixed. The capacitor location of each feed through is fixed. So recall I mention what is the feed through. Feed through are some special standard cells which allow a connection from top to go to the bottom so that across rows you can take a connection and you can connect. Those are the feed through cells. So what it says is that so after placement you have already place the feed through cells. And feed through cells have some predetermined capacity how many such wires can be run across cells.

But if you see that your routing problem is such that you cannot complete the routing using that many feed through; that means, you are in a problem you have to again go back change the feed through and again come back to the routing. And first standard cell there are no vertical channels only horizontal channels. And again you can move the rows so that heights can be adjusted. So as I mentioned if feed thoughts are not sufficient routing might fail and over this cell routing is a method which we shall be discussing later which can be used to further reduce the channel height.

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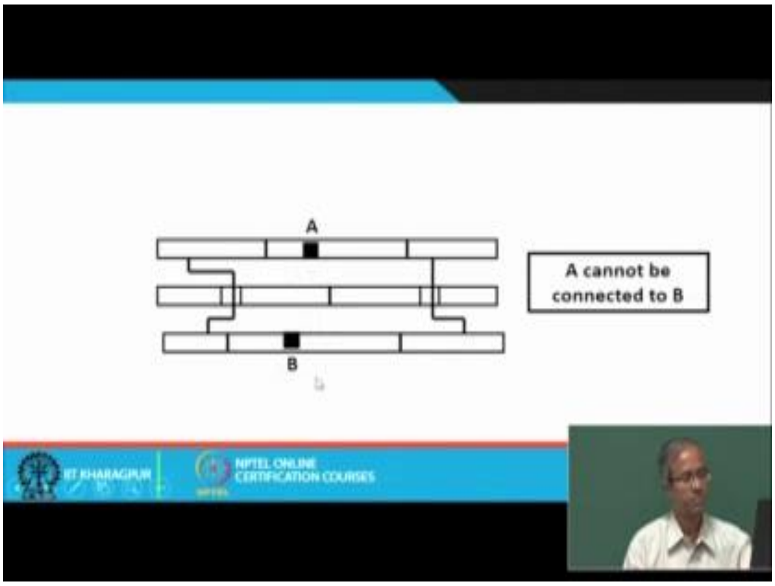

Like an example I have shown here, like say these are three standard cell rows I am showing. And some interconnections have already been done across rows. So there was one feed through cell here, one feed through cell here, only two. But suppose additionally you also have to interconnect A and B. So you do not have another feed through are available. So this routing will fail. So what it means is; that means, either your placement is not good this block should have been placed here or means one more feed through cell should have been included here, so that you can completes routing. Now this is one problem.

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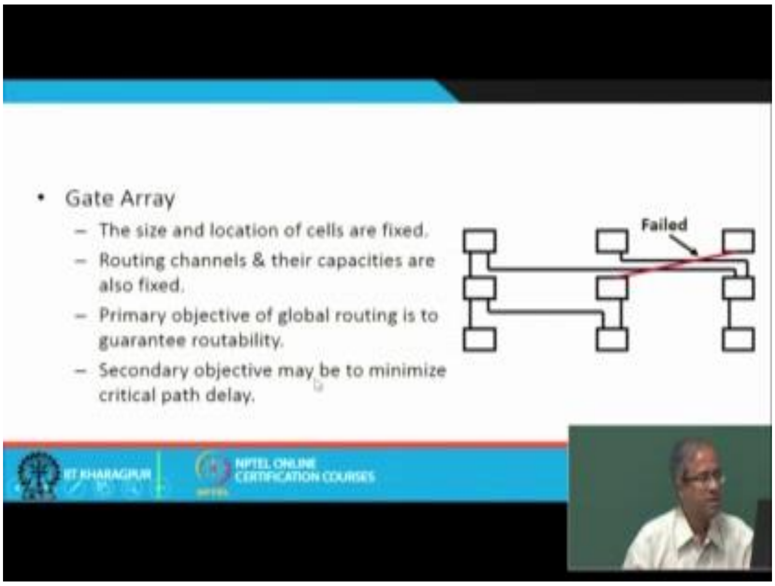

And even for gate arrays where the location of the gates are fixed and also the number of interconnection lines that are allowed between them is fixed. So routing channels and capacities are fixed.

So, routability like for example, I mean if between these cells that is path only to run to parallel interconnection tracks. And so already have some connections like this and like this. So the red connection that is shown this will fail you cannot complete this. Because this will need third track right. So again for gate array your placement should be good enough so that your routing can be completed.

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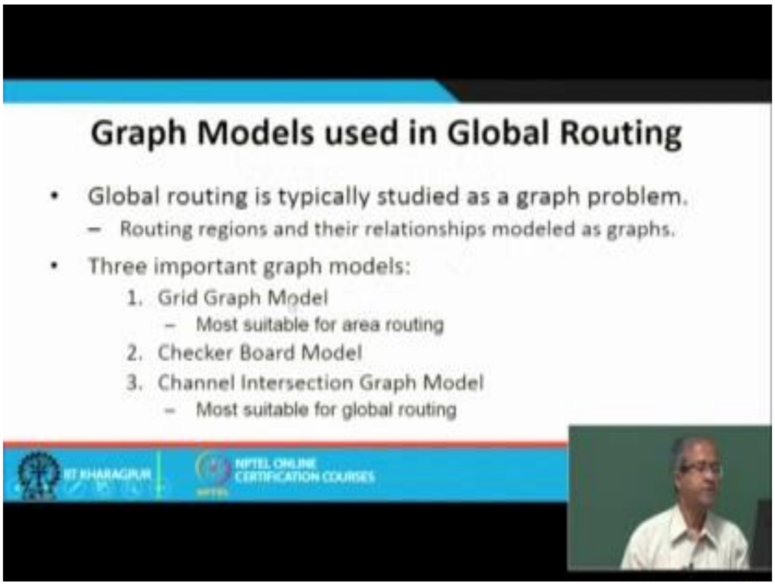

So, in global routing we use some graph theory based models, so which can be used to model the problem and also identified the regions. So some of the important graph models are shown here we shall be looking at them. The grid graph model is more suitable for grid routing, but you shall anyway talk about it here.

This is more suitable for area or grid routing. Checker board model is also similar, but channel intersection graph is something which is the most suitable for global routing and is most wide used. Let see this data structures one by one.

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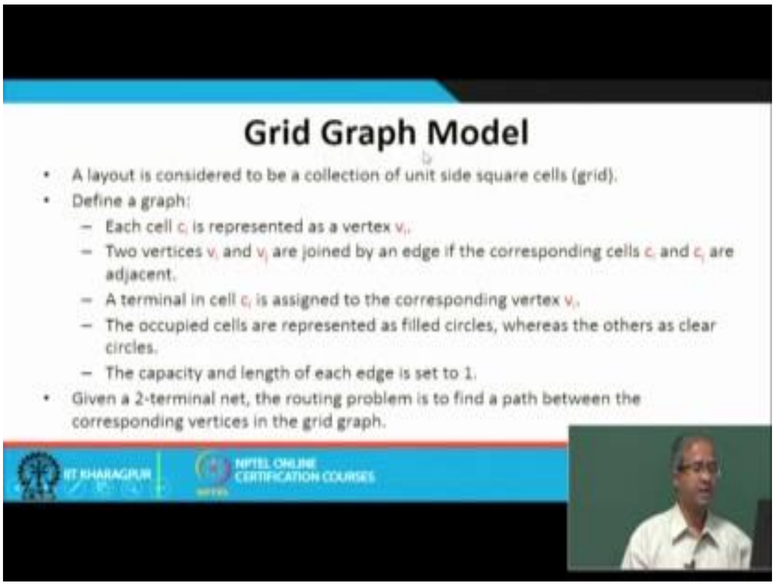

Grid graph model. This actually models the same 2 dimensional grid pattern that we are discussed earlier for Bayes routing algorithm, like for example, Lee's algorithm. So we had a set of cells m by n each cell contains some information and they were represented by obstacle or something.

So, in general in the grid graph model, the layout is considered as a collection of square cells or grid. So we define a graph where each cell c i represents a vertex v i. And 2 vertices are connected by an edge if the corresponding cells are adjacent right. Now a terminal in cell c i suppose, I want to connect point from c i the terminal is assigned to the corresponding vertex v i. There are 2 kinds of vertices some cells are occupied which are represented as filled circles, but the unoccupied cells can be represent as clear circles as you shown example.

So, in this model the capacity and the length of each edge is assumed to be 1. So for every 2 terminal net the task is to find a path between the corresponding vertices.

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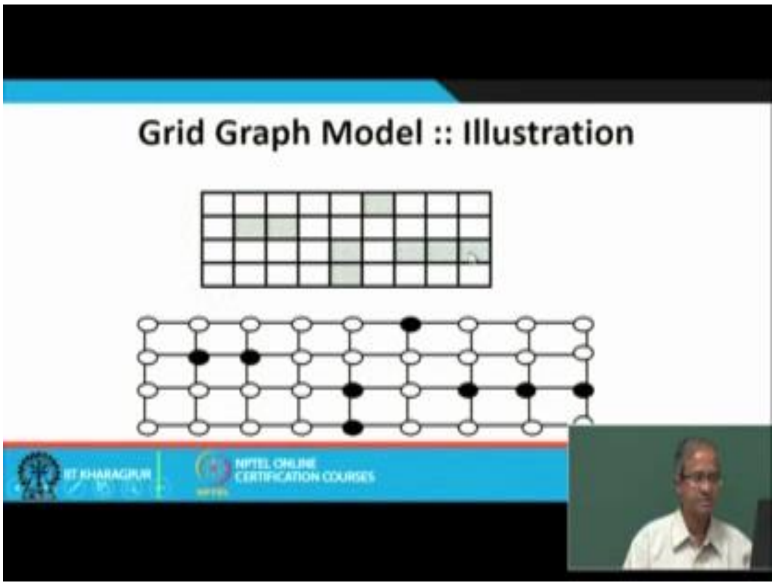

Let us take an example like this. So I have a 2 dimensional grid like this. Where the shaded regions represent the obstacles. So I can map it to a graph, for every region corresponds to a vertex the adjacent regions are connected by an edge, the obstacles are denoted by solid vertices.

If suppose I want to make a connection from this cell to this cell. This cell to this cell, which in this graph represents this vertex and this vertex. So now, the graph theoretic sub problem is find a path through this graph not going through this solid vertices, find a path which can take you from here to here. So once you get a path like this your found out a path. So any area routing algorithm like Lee's algorithm or headlocks algorithm can be used to solve this.

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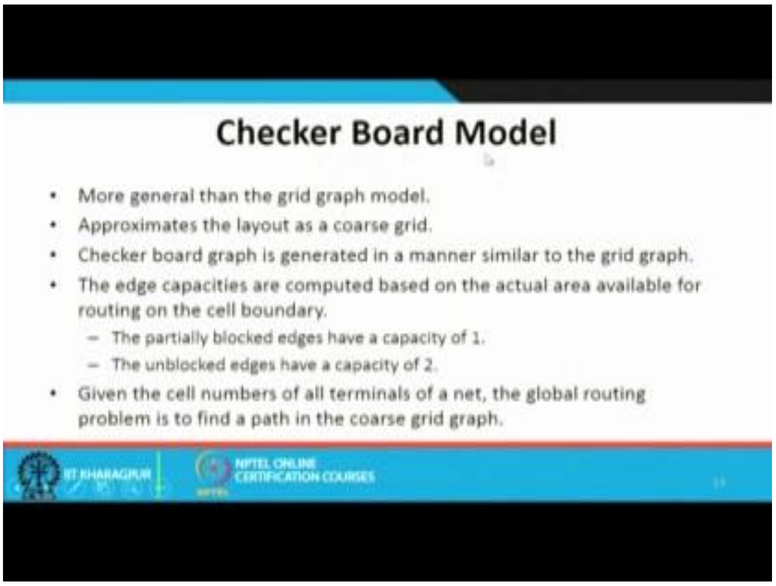

Now, checker board model is more area efficient. It approximates the layout not as I uniform array of fix size cells or grids, but as a course grid, some grid can be bigger some grid can be smaller.

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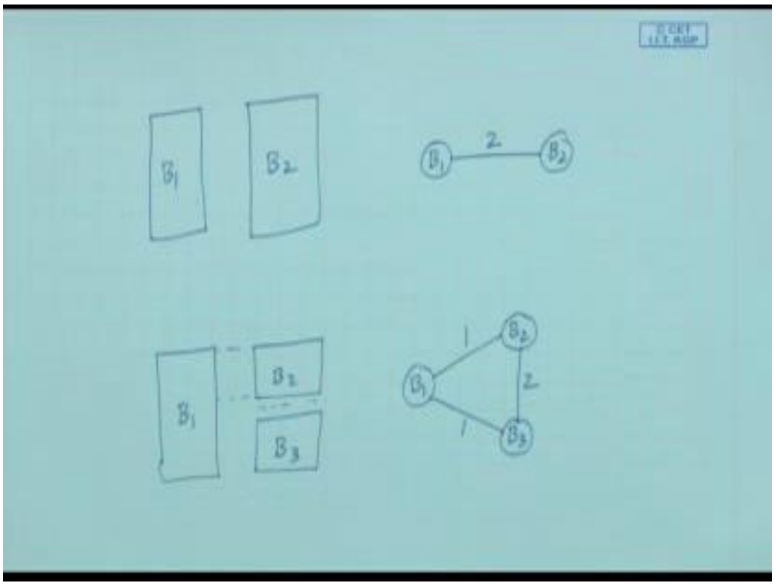

Also the edge capacities between 2 blocks are different. Like for example, there are 2 blocks. There can be one block like this so 2 scenarios I am showing. These are 2 blocks this is one scenario. The other scenario is let say this is the block B 1 and B 2. This is the block B 1, B 2 and B 3. So for this problem let say I have a vertex for B 1 I have a vertex for B 2 they are adjacent. So they are connected together and you see their boundary is totally unblocked, you can use the entire boundary for connection. So I give a weight of two, but in this case B 1, B 2 and B 3. So between B 1 and B 2 you see only a half of it is available, the other half is shared with B 3. So I give a weight of 1, similarly between B 1 and B 3 I give a weight of 1, but between B 2 and B 3 the entire boundary is available. So I give a weight of 2.

So, weights can be assigned accordingly depending on whether the whole boundary between the blocks are available for routing or it is only partially available right. So this is what the checker board model is.

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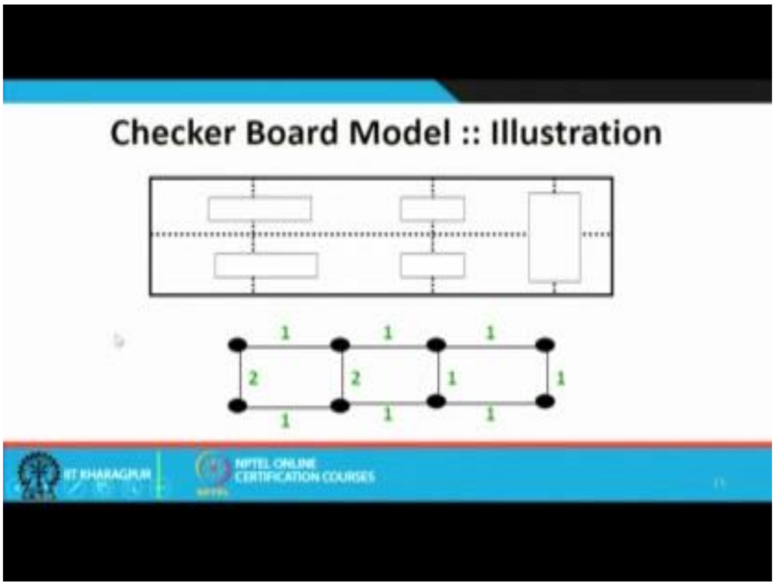

So, here I am showing in example. There are 5 blocks placed in a rectangular region so how many regions are there 1, 2, 3, 4, 5 6, 7 and 8. So there are 8 vertices. So all the vertices are partially block so they are shown as solid. Now this weights, between these 2 regions you see that the whole boundary is available for interconnection. So it is 2. Between these 2 regions, this block is partially blocking the boundary that is why weight is 1.

Similarly, between these 2 weight is 1. These 2 weight is 1 like that. Similarly, between these 2 these 2 region the whole boundaries available that is 2 others are all weight 1. So you can see that the checker board model is more efficient in terms of space the number of vertices in this graph will be much smaller and this is much easier to handle as compare to the grid graph model, fine.

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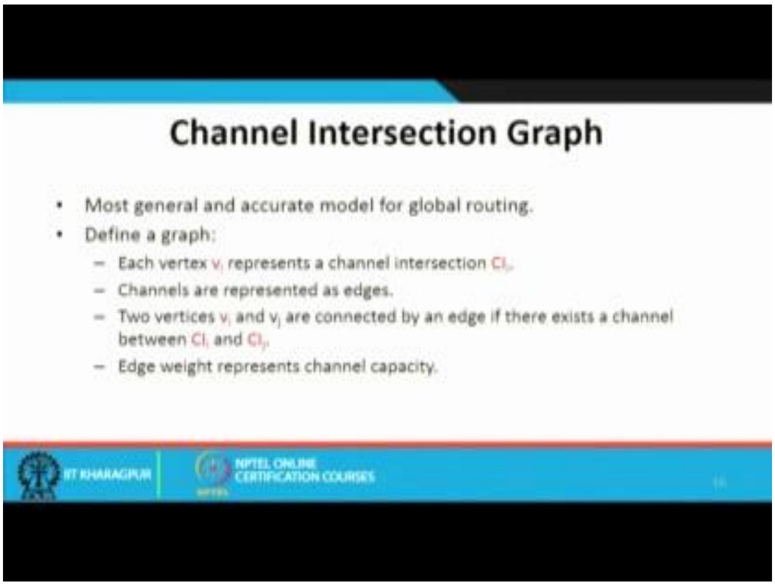

Now, let us come to the representation which is most widely used for you can say global routing particularly in connection with the standard cell routing problem which is most widely used. So just to recall in a standard cell routing problem we have label here.

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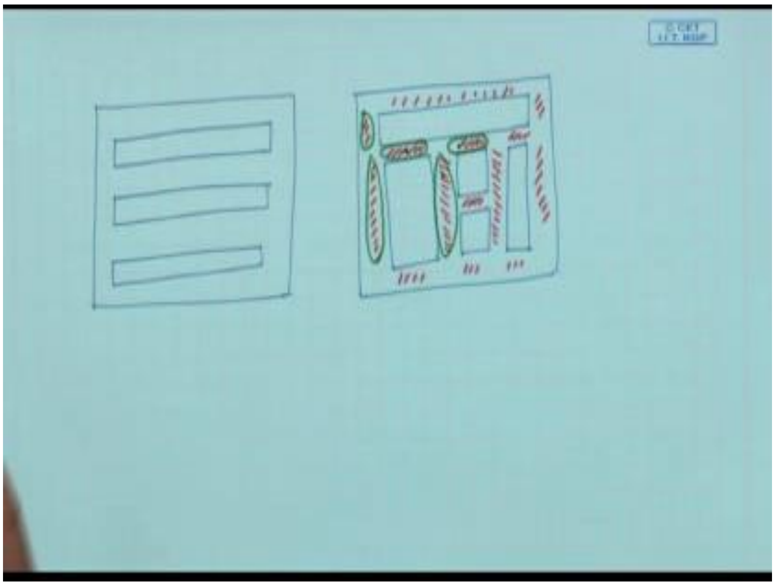

Let me give 2 different scenarios. So one is a standard cell routing problem where you have this cells arranged in rows, and you have identified channels between the rows and also side by side you also consider full custom design style, but also you can use this.

Like here I have the blocks place like this. Let us take some examples like this. So here also there are interconnection channels which I have placed in between the blocks. So you can this identifying the inter the interconnection regions of channels like here. For example, I can have a channel here, I can have a channel here, I can have a channel here, a channel here, a channel here. In fact, this whole thing can be considered as single channel. This whole can be considered as single channel, and so on.

Similarly, this can be regarded as channels. These are all channels, similarly this side. These are all channels. So there are so many channels. So there are channels and some of the channels are intersecting, like for example, this channel and this channel are intersecting here. This channel and this channel are intersecting, this channel and this channel is intersecting, this channel this channel is also intersecting.

So, with this channel there is a intersection with 1, 2, 3, 4 mode channels. The channel intersection graph basically models this kind of intersection between the channels right. So here each vertex represents a channel intersection. Now the edges represent channels right. And 2 vertices are connected by an edge if they are there is a channel intersection between them. Now edge weight represents the capacity of the channel.

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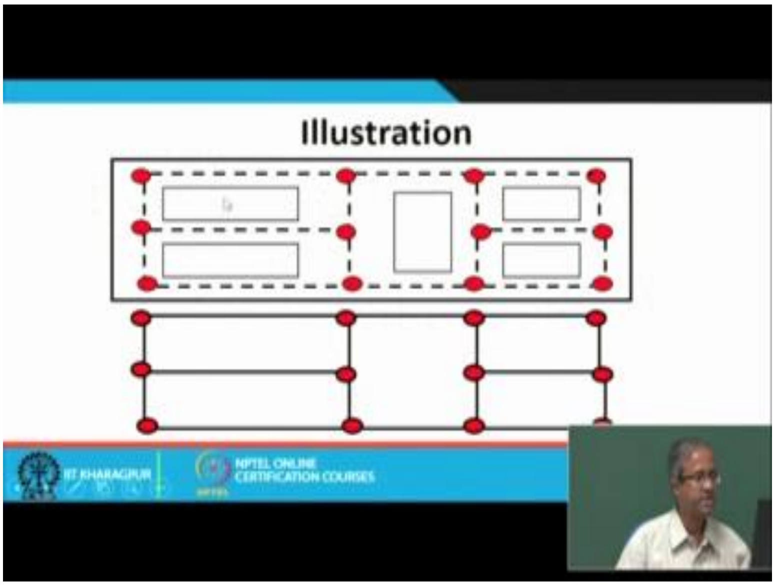

Let us take an example, suppose I have a just example like this you ignore this this embedded graph which is again shown here. There are 5 blocks placed in a rectangular region. So as I showed in that example earlier these are all examples of channels, these are all channels.

And this red dots indicate the intersection between the channels right. In the channel intersection graph I only extract that information. The channel information is extracted as vertices and the 2 channel intersection between which there is a common channel that is connected by an edge. Now depends on the width of the channel how many wires it can handle, you can assign some weights to the different edges right. Now you see the channel intersection graph directly keeps track of the channels and intersections which is important for global routing. We could in global routing what we are trying to do, we are trying to find out an approximate path between 2 points that are require to be connected.

For example, I need to connect point here on this channel to a point here. Then I means I can identify the nearest vertex. So here also I can find out the nearest vertex. So my problem is to find a path between these 2 vertices. This means I can find out which sequence of channels I need to follow to complete this routing right.

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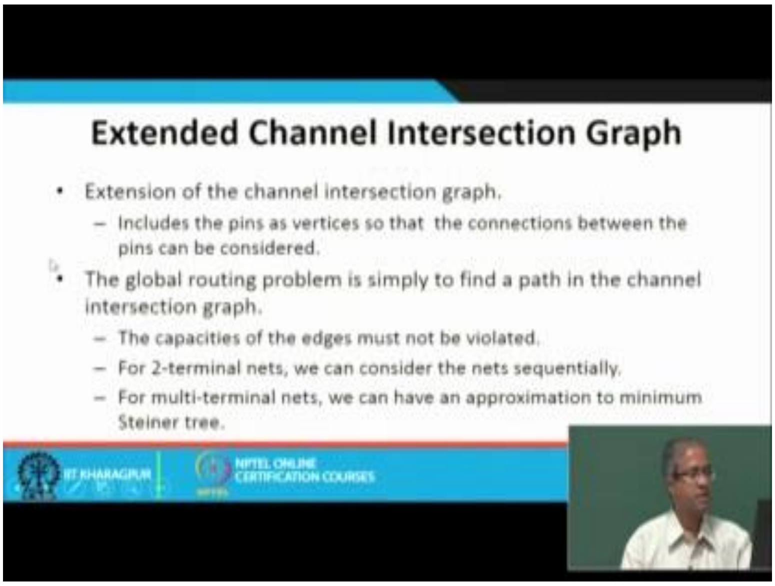

Now, a slight extension makes it more meaningful. Now in this extended channel intersection graph we use not only the channel intersections as vertices, but also the pins as vertices. Now the rest remains same. So let see that how it looks like here.

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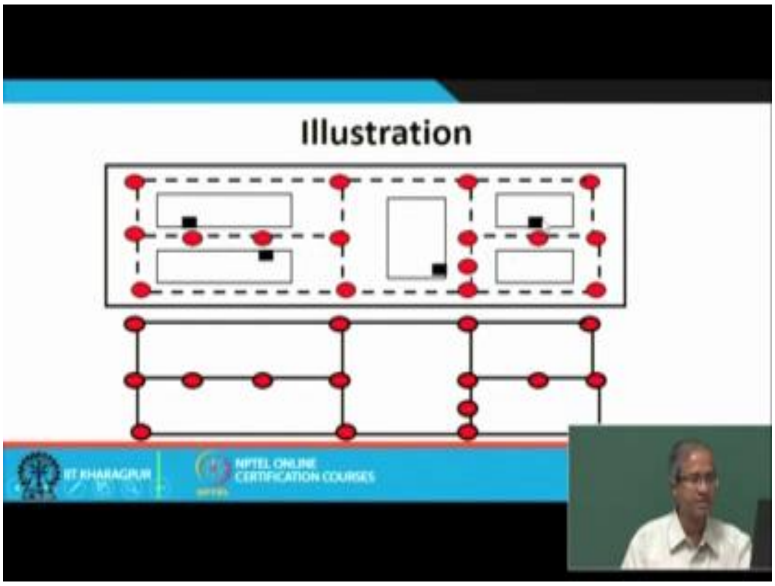

The same example I am showing here. I addition I am showing some pins just for illustration. What I am saying is, that whenever there is a pin there will be vertex added in the corresponding channel edge.

So, now if I want to connect the pin this, to a pin this. I do not have to find out the nearest node, but I have a node or vertex corresponding to this pin directly. So I have to find out path between this and this. So there can be many paths I can for this path. For example, right so going back this is the global routing problem is basically to find a path in the channel intersection graph. The capacities of the edges must not be violated for 2 terminal nets we consider sequentially for multi terminal nets we can have a approximation to minimum Steiner tree.

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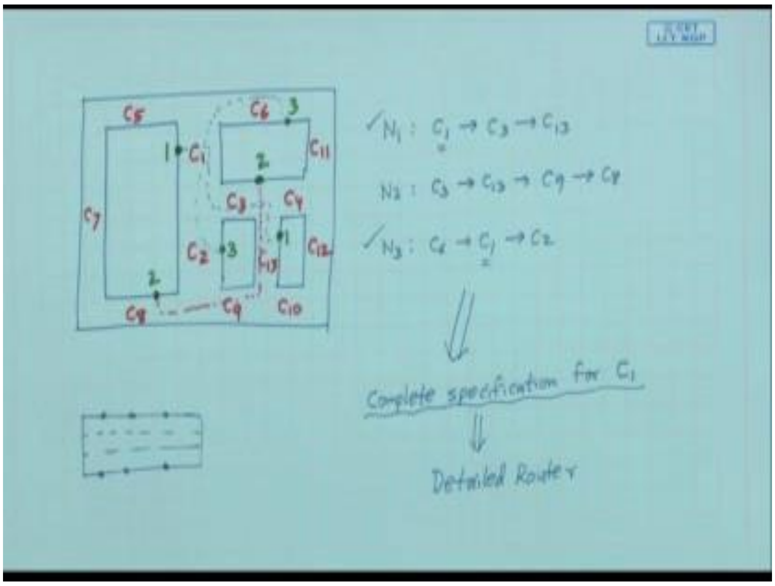

Let me take an example to illustrate how this region are generated very simple example I take fine.

So, let us name the channels let us call this channel as C 1. Let us give them separate C 2. Let us call it C 3. Let us call it C 4. Let us call it C 5, C 6, C 7, C 8, C 9, C 10, C 11 and C 12. Let us now also consider some example nets like for example, pin here let us call it 1. This has to be connected to a pin here let us call it 1. Let us pin here 2 this has to be connected to a pin here this is 2. Let us take another one pin here 3 this has to be connected to a let say pin here 3. So there will be many such nets let say yes these are all 2 terminal net. There is net number 1, net number 2, net number 3, so what does this global routing problem or algorithm generates as output.

So, I have shown the channel intersection graph model. You can get this information from there, represent it as a graph and find some path through that graph. Now let say suppose I want to connect point 1 to point 1. So for net 1, so you identify path, let say the path I follow will be this which means I will be following the channels C 1, C 3. There is m the channel a mist. It let us call it C 13. C 13 for N 2, 2 and 2, let say will be following this path in a different column is show. So N2 will be following first C 3, then C 13 then C 9 then C 8. Then N 3 well, N 3 let say I am following this path.

So, net 3 will start with C 6 then C 1 then C 2. So for each of the nets I generate sequence of the channels are the approximate paths that are to be followed. Now from this what I get, I get a complete specification routing specification I mean, for let say channel C 1. Now in this example 2 of this nets are passing through C 1. So for the first net it is coming from here it is going here. For the second net it is coming from here it is going here. So with respect to a channel, so a channel is a rectangular region so we assume that pins are on the top or the bottom and the tracks will be laid out like this. So from this sequence of net list and the information we have obtained from global routing, we obtain the complete specification for C 1 for this particular channel C 1 and this is with respect to detailed router.

So, now detailed router will be having the exact specification for this channel, how many nets are going through it from where it is coming from when it is going and so on. This is the basic idea. The global router will give information like this from where you can compile information for every channel and the information from every channel will be solved in individually and independently by the detailed router. So it is like a divide and concur problem fine. So for next lecture we should looking at some more global routing algorithms, so how they work and then we will shall be moving towards detailed routing in the next week.

Thank you.