Artificial Intelligence: Search Methods for Problem Solving
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Chapter – 09
A First Course in Artificial Intelligence
Lecture – 90
Constraint Processing
Interpreting Line Drawings

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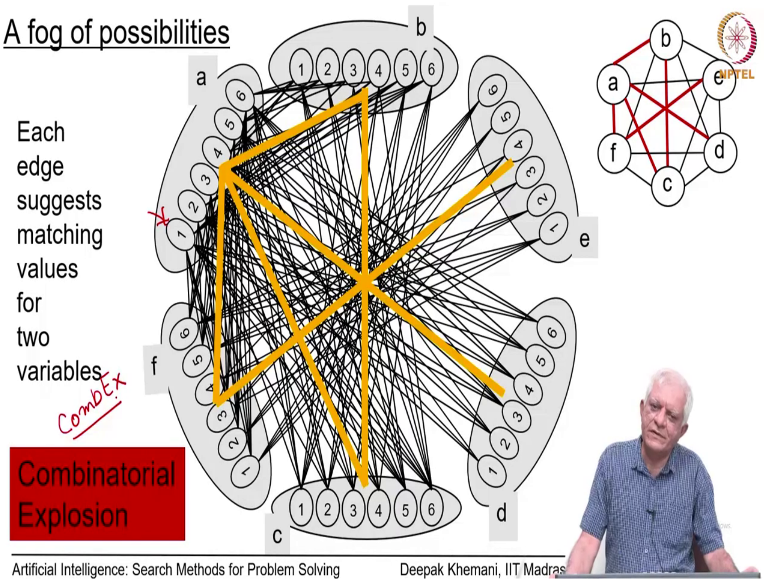

We are trying to get a feel of Constraint satisfaction problems and we were looking at the six queens problem. And we got a feel of the fact that, the number of possibilities are so many and somehow we have to sift through all of them and come up with the solution. And what does the solution look like?

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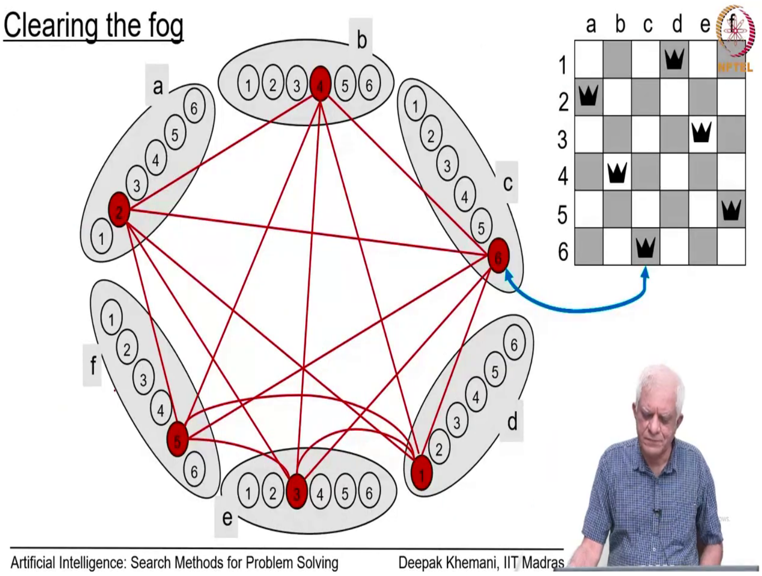

The solution basically has one edge between two variables. So, in this solution, you can see that queen a is placed on row 2 as you can see here; queen b is placed on row 4 as you can see here and so on and so forth, queen c is played on row 6.

And all these choices are a subset, all the edges that we have are a subset of the matching diagram, all these combinations are allowed. Of course, we did all these work in advance by stating the combinations which are out.

It is just that we now want to sift through the fog. So, in when we stated the CSP itself we said that, yes it can be solved provided these are the constraints that you satisfy that, a and b can be in these combinations and so on and so forth. Actually extracting a solution is a task of, in some sense shifting clearing that fog and arriving at the solution.

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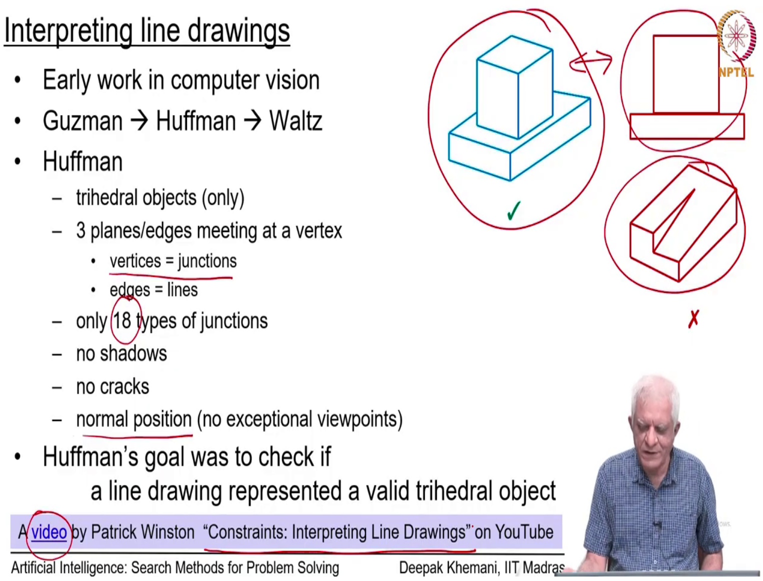

Another interesting problem which has been posed as constraint satisfaction problem is the problem of interpreting line drawings essentially. And it came from the field of early work on computer vision; I think this work was from MIT; there are three people involved in the story that we are looking at. The first was Guzman, who made the first attempt as to saying that if you give me a line drawing.

So, remember that it is assumed that, you have taken a photo of some scene; let us say it is some you know still life scene and it is made up of only objects which are made up of straight lines, then can you separate out one object from the other and things like that?

So, he started with his work on interpreting line drawings and that was part of his PhD work. Then at sub, it was not like making too much progress and then along came Huffman you may be familiar with, if you have studied Huffman quotes, the same Huffman.

He was a mathematician and he was trying to formulate the problem in a well-defined way which is what we will look at now. And eventually came David Waltz, who gave an algorithm an efficient algorithm for solving the line drawing problem, which is also sometimes called as Huffman glow labeling by an efficient constrained satisfaction algorithm essentially.

So, let us look at what Huffman was saying; we will come back to Waltz in a later class. So, Huffman said that, you want to work with trihedral objects only; Guzman was less restrictive over this. When Huffman realized that this problems are not so easy and you restrict the class of objects that you will look at. And he stated that, you should look at trihedral objects only.

What are trihedral objects? Objects in which three faces, 3 plane faces they meet at every vertex or alternatively you can say that 3 edges meet at every vertex. So, exactly three; not less, not more, such objects are called trihedral objects. And you can see that the figure that I have drawn in green satisfies these conditions. And the figure that I have drawn in red does not essentially. Why? First of all it should be plane ok, planes, it cannot be curved edges and secondly, we had this constraint of three.

So, if you imagine the top surface of the object on the right and it is particularly if you focus on the fact that, there is a vertex which has only two edges coming into to meet together; you can see that the top surface is not a plane, it has some kind of a weird curved surface in which an edge cannot be seen. If I had drawn an edge from here to let me see; if there was an additional edge from here to here and this was like this and this was like this, then it would become trihedral.

But as given to us, this thing is not a trihedral object essentially. So, Huffman said restrict yourself to trihedral objects. Then he said that and we will see this shortly that, there are only 18 types of junctions that can be possible.

So, by junctions and vertices we will use the terms interchangeably; edges and lines we will use the term interchangeably. Huffman further said that the figure must be such that there are no shadows and there are no cracks; not only that, they must be all viewed from a normal perspective. What is the normal perspective? A normal perspective is one where if you shift it slightly, the figure should not change drastically.

So, the figure on the top right as you can see is the same as the figure on the left; but the diagram, the line diagram is not normal perspective, because it is seeing it from a frontal view.

And if you were to shift your point of view a little bit to the left or little bit to the right or even little bit above or below, you would see a totally different line drawing. So, he said, Huffman said do not work with such figures; they must be in what he called as normal position essentially, and this figure on the left here in green satisfies this property.

Now, he had said that there are only 18 types of junctions here. So, let us look at that next. And I hope before we do that, we should specify that Huffman's goal was not to write a program to solve the problem; his Huffman goal was to analyze the problem from the mathematician’s point of view. And he wanted to ask the question, whether a line drawing represented the valid trihedral object or not?

So, as you can see with this figure, the answer should be no; whereas on the figure in the green, the answer should be yes. Now, if you want to look at this history of this problem; there is a nice video by Patrick Henry Winston, who was one of the founders of AI and in the 70s and 80s, he had written a book which was very popular; unfortunately he passed away was it last year or the year before last.

And there is a video available from MIT free coursework; I have given you a link here, if you can access the link, it should be accessible through the slide I hope. But I have also given you the name of the video. So, if you go to YouTube and look for this title Constraints Interpreting Line Drawings, you will get this video. And you will get a history of this problem starting with Guzman and going on to Huffman and to Waltz essentially; we will come back to waltz later.

So, let us focus on this problem of how to label these line drawings. And what do we mean by label? We want to characterize the edges in a particular way. So, what Huffman said that, there are only 4 types of edges and there are only 18 types of vertices; if your object is trihedral, there are no cracks, there are no shadows and things like that, then we can work with that.

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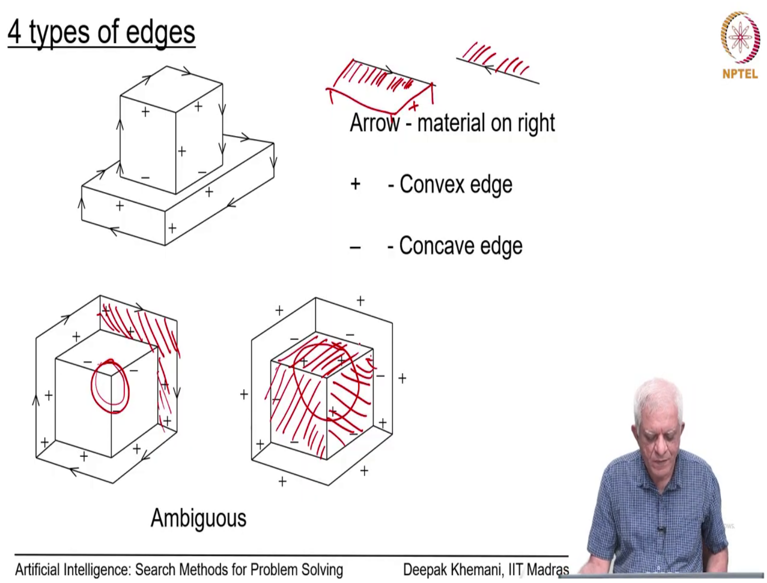

So, there are 4 kinds of edges, let us start with that. These are one, two of them are called arrows; they are similar except that the arrows are pointing in the different direction on the same line.

The interpretation of an arrow is that, it shows an object in which there is material on the right as you go along the direction of the arrow. So, in the left, in the left line you can see that the material would be on this side essentially. And on the right hand side, you can see the material will be on the other side essentially. But, what do we mean by that?

So, for example, this could be an object which looks like this, something like that and you are seeing an edge, which kind of defines the boundary of the object. And it defines it in such a way that, the material is on the right hand side. So, these two kinds of arrows are called, these two kind of edges are called arrows, and basically the direction changes where the material is.

Then we have a convex edge which tells you that, the two planes which are defining that edge, they form a convex body. So, this particular thing could be labeled as a convex edge here and we have correspondingly a concave edge. So, here is an example of the same object that we saw in the last slide and the label that we are seeking essentially.

So, our task is to us to arrive at this labeling; for each edge, give it a value and that value is from this domain of four labels, telling you what kind of an edge it is essentially. A typical algorithm would say that, traverse the, identify the object, isolate it in some way; identify the boundaries, label the boundaries with the arrows and then label the other edges essentially.

Now, if you were to going to do brute force search; then you can see that every edge can be labeled in four ways essentially. And look at the number of edges in the diagram and look at the number of combinations, you know this fog that we were talking about when we were talking about the six queen problems; you can visualize something similar here as well.

So, that is the huge number essentially. What Huffman observed that, you do not have to try all those combinations; that only certain combinations are allowed for vertices essentially. So, that is what he said that, there are 18 kinds of vertices. Before we look at those 18 kind of vertices, let us look at an another example here; to say that we can do valid labeling, but it can still have ambiguity about this.

So, if you look at this diagram and try to visualize it based on the labeling that has been done; then you can see that the inner part is kind of hollow essentially. That the outer surface is that this is the surface which is for example facing you; but those inner vertex is inside a hollow, it is like looking at the corner of a room from inside. So, if you are sitting in a room and you look at a corner; then this is the kind of edge that we, this is the kind of vertex that we will see.

Each of those three edges will be negative in nature; which means they are concave, and it is like sitting inside the room and seeing a cross section of the room essentially. But a perfectly valid labeling would also be like this, in which the inner three edges are labeled with pluses and there is change in the other edges as well. So, now we can see that, the inner part can be seen as a cube.

So, this is one face of a cube, this is another face of a cube and you know this is the top face of a cube. And you can imagine this cube is in the corner of a room. So, it is against a wall and you cannot distinguish whether it is one object or two objects; so you have a negative edge there essentially. So, you could have ambiguity even for labeling these things.

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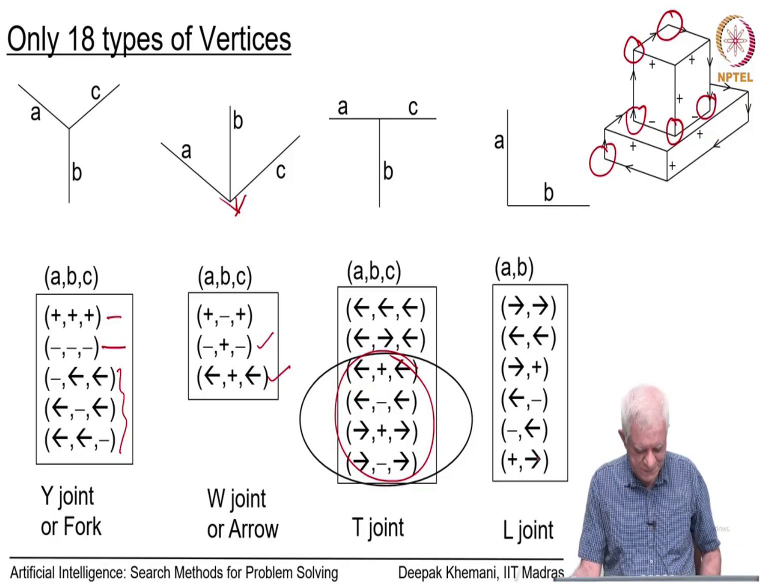

So, coming back to the question of 18 types of variables, 18 types of vertices. What Huffman observed was that, this there are first of all there are four types of vertices; we will look at each of them one by one. One is called the Y joint or the fork; because the three edges they look as you see on the top, they look like a fork and the three edges are labeled a, b and c.

And they can be labeled in only these ways essentially. So, either all three can be plus as seen here or all three can be minus, that is the example that we just saw in the last slide; either a cube or the corner of a room from inside. But also if you are seeing some edges, some boundaries arrows; then you have three combinations, but only these are allowed and no other combinations are allowed.

Remember we are talking about trihedral objects, which are just a subclass of objects essentially. So, instead of 64 possible ways of labeling a, b and c; we have brought them down to 5 essentially. And as we will see later when we look at Waltz algorithm; even this combinations we do not have to try by brute force essentially.

Then there is a W joint or an arrow joint; because it looks like an arrow or it looks like a W as you can see here. And it turns out that it can be labeled only in three ways essentially. I would urge you to draw objects and try and see that, that no other way is possible essentially.

So, you can see a W joint here for example; it has a label of minus, plus, minus, which is this one here. You can see another W joint here, which has a label of arrow, arrow, plus; so arrow, arrow plus essentially. And the third one can be plus, minus, plus which is not there in this figure; but in the other figure that we do, it should be there essentially. Then there are the T joints that from certain angles, some objects will have these kind of edges essentially.

So, these are the in my diagram there are six of these; but in some, in fact in Huffman's own work there were only four of them, because he felt that two of them were kind of same essentially. And then we have the L joints.

So, for example, here is an L joint and here is an L joint and here is an L joint and here is an L joint all these are L joints and you can label them in one of these six possible ways. So, in this diagram there are 80, 20 ways; but in Huffman's own formulation, they were these 4 that I have mentioned were collapsed into 2 essentially.

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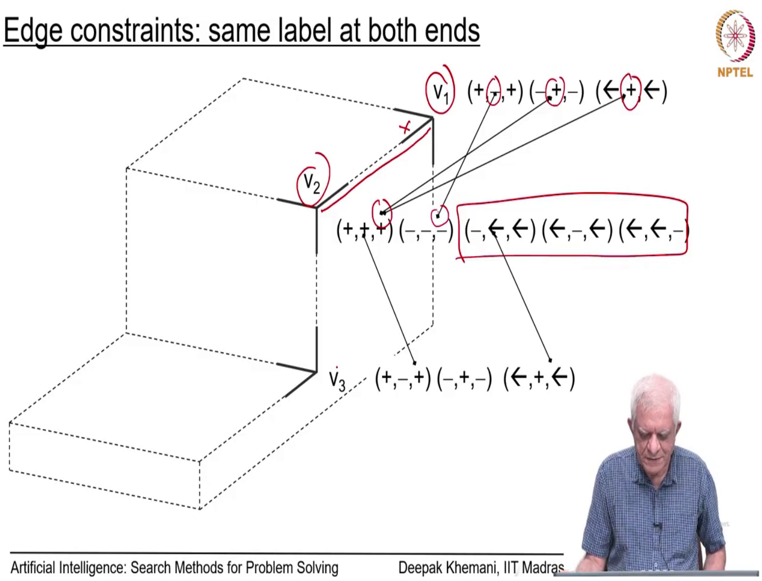

So, how does one go about doing this? So, as I was saying that, the property you want to exploit or the constraints that you want to exploit are that, an edge or a line cannot change its nature from one vertex to another.

So, if you have an edge connecting these two vertices; you can only label it in one way and both the vertices essentially. And this is what this diagram is showing that, this vertex v 1 and this vertex v 2; these are the allowed vertices for v 1, which is a W type of vertex here and these are the allowed vertices for v 2 which is a Y type of a vertice here. But it says that, the middle one in the v 1 which is this one or this one or this one; but correspond to one of them in the this thing.

So, you can see immediately that for this vertex, these cannot be possible combination. So, this is the basic feel of this idea of propagation that we are slowly working through that, only certain combinations are allowed essentially. Likewise between v 2 and v 3 we can see that only certain combinations are allowed.

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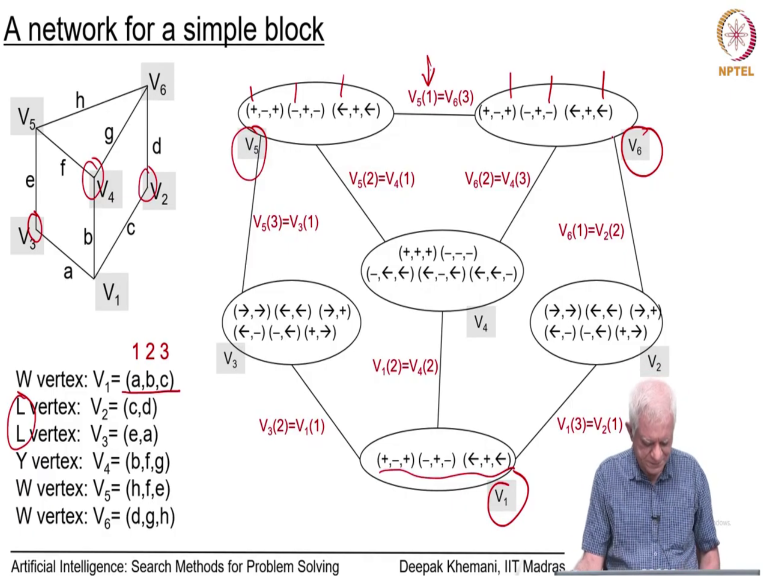

So, here is a even simpler block, it is looks like a slice of cheese as often depicted in diagrams. It has got this six vertices; it is basically a triangular block, it has a six vertices and it is got two of them are L vertices, as you can see this is L and V 2 is L. One of them is a Y vertex, which is the center one and the other three are W vertices. And these are the names of those three edges that we are talking about and of course, we have to find values for them; remember we our task is to find labels for edges.

So, in this case the edges are a, b, c and we have just labeled them 1, 2, 3, so that we understand that when we draw a full diagram for this; so what are we talking about here essentially. So, when we start, when we pose the CSP; this is what we pose as a constraint satisfaction problem, the six vertices. The allowed values as specified by Huffman for those six vertices. So, for example, V 5 has 3, V 1 also has 3. So, this W vertices have only three possibilities, ok. So, these are the three possibilities.

And they are all listed in all the W vertices; there are three of them as you can see V 5, V 1 and V 6. What this notation which I have used says that, if you look at the first element of V 5, which is either this or this it must be equal to the third element of V 6 which is either this or this.

Why? Because they are joined by an edge together and the label must be the same essentially. That is what the constraint is saying, that is what the partial description of the labeling is saying; that this is how you this is the combination of things you allowed for V 5 and V 6 essentially.

So, you have to choose something where both the sides are the same essentially. In this example, the all three values are allowed, so the possibilities still remain; but if you work through this whole thing, you will see that you can, if I may use the phrase, cut through the fog. But we will come back to that when we look at the Waltz algorithm.

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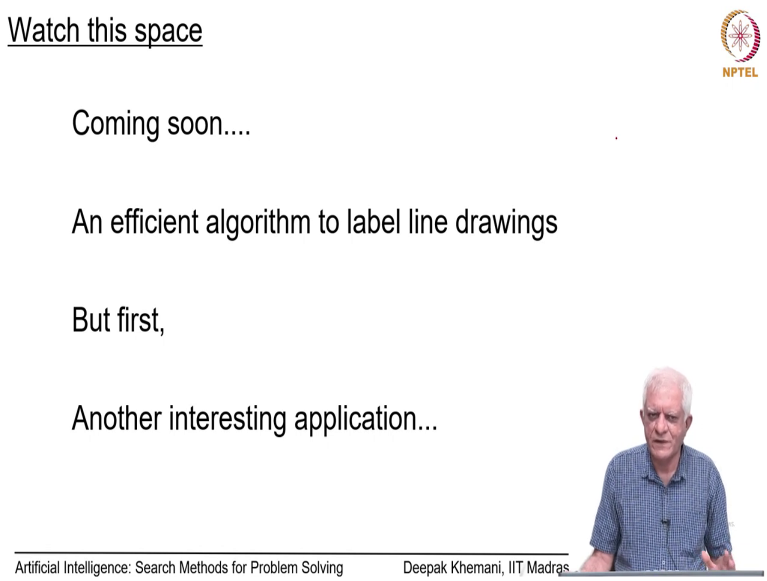

I want to take one more example, which is a very popular example. It is a big application of using constraints and that is the task of model based diagnosis. And we will do that after a short break in the next video. So, see you in a while.