IIT Madras

ONLINE DEGREE

Computational Thinking
Professor. Madhav Mukund
Department of Mathematical Institute
Chennai Mathematical Institute
Professor. G. Venkatesh
Indian Institute of Technology, Madras
Represent direct trains using a graph and find a route using multiple hops

Professor. Madhavan Mukund: So, let us come back to our train problem. So we did first, this direct connection. We said that if I want to go from say, Chennai to Bhubaneswar I would look at the list of trains passing through Chennai for each of them I will check whether Bhubaneswar appears in the list of stations that that train goes to.

Professor. G. Venkatesh: Right.

Professor. Madhavan Mukund: So, that is the direct connection. Then, we said, then we said, we could look for one change. So, I would look at, for example, all trains going from Mangalore and then find out what all stations I could go to. And, suppose I want to go to Pune, I would do the same thing from Pune to find out what all stations…

Professor. G. Venkatesh: To find all the stations we can reach from Mangalore, on one side, find all the stations we can reach from Pune, on other side.

Professor. Madhavan Mukund: And then see if there is an…

Professor. G. Venkatesh: Intersection. It means that intersection is a point is a place via which…

Professor. Madhavan Mukund: I can go.

Professor. G. Venkatesh: I can go from Mangalore to Pune or vise-versa; from Pune to Mangalore.

Professor. Madhavan Mukund: And, then we can further, from that list, we can, we saw some redundant things and we could…

Professor. G. Venkatesh: Because it was going like this,

Professor. Madhavan Mukund: And, then coming back.

Professor. G. Venkatesh: That does not make sense. You picked the earliest point.

Professor. Madhavan Mukund: Yes, so you can pick the earliest point. So Mumbai was the better point.

Professor. G. Venkatesh: So, Mumbai was the better point.

Professor. Madhavan Mukund: But, now if I want to it for 3 stations, for instance, then how would I do it? I mean, I would have to take…

Professor. G. Venkatesh: Means, if I want to go from A to…

Professor. Madhavan Mukund: Suppose, I have to change twice…

Professor. G. Venkatesh: I have to change twice.

Professor. Madhavan Mukund: Then I will have to do this whole thing two times.

Professor. G. Venkatesh: It is too painful?

Professor. Madhavan Mukund: And, then it could be 3 times, and then 4 times. And how do we, how, we do not know actually, what if does not. Means, supposing it is possible to go from somewhere to somewhere but you have to change many times and we do not know how many times we have to change. Then, doing this each time, doing this iteration of this list is going to be very…

Professor. G. Venkatesh: It seems, we should just maintain this connection no? See, if I want to go from A to a station, from one station to another station if I want to go. If we can maintain that..

Professor. Madhavan Mukund: Okay.

Professor. G. Venkatesh: Somehow, in a relationship, that relationship somehow we can maintain it.

Professor. Madhavan Mukund: Yeah.

Professor. G. Venkatesh: Graphically that…

Professor. Madhavan Mukund: So, maybe we want to go back to our graph idea and connect stations, if there is, so we want to…

Professor. G. Venkatesh: We want to connect this.

Professor. Madhavan Mukund: Because in the, also we are doing this again and again and we have probably computing the same thing several times.

Professor. G. Venkatesh: Again and again.

Professor. Madhavan Mukund: So, maybe we should just once and for all try to calculate…

Professor. G. Venkatesh: Calculate. Figure out whether we can go from one station to another.

Professor. Madhavan Mukund: Yeah,…

Professor. G. Venkatesh: And, write down that relationship, put it down in some form.

Professor. Madhavan Mukund: In a graph.

Professor. G. Venkatesh: In a graph.

Professor. Madhavan Mukund: So, we will just connect two stations by a line, and edge and if it is possible to go and, by one direct train from here to there.

Professor. G. Venkatesh: Then we would get an edge.

Professor. Madhavan Mukund: An edge and we can label that edge, maybe we can put a name of the train.

Professor. G. Venkatesh: Put the train name.

Professor. Madhavan Mukund: Train number.

Professor. G. Venkatesh: Okay.

Professor. Madhavan Mukund: So, we can have, so we can have like, for instance, I do not have a…

Professor. G. Venkatesh: Just select, take some stations, maybe we can.

Professor. Madhavan Mukund: Let us take a train for example, just to illustrate. So, suppose we have this. So, we could say that Kharagpur and Kolkata are connected by direct edge. And we would write here.

(Refer Slide Time: 03:07)

Professor. G. Venkatesh: A direct edge is what? Arrow?

Professor. Madhavan Mukund: Yes arrow.

Professor. G. Venkatesh: Because direction of the train is there.

Professor. Madhavan Mukund: Yes, direction of the train is there, so we should only draw an arrow. Kolkata to Bhubaneswar, Kolkata to Kharagpur.

Professor. G. Venkatesh: Then, the other train.

Professor. Madhavan Mukund: The other train will be the matching train. It would be zero two two zero. So, we can direct it with edges and put the train number.

Professor. G. Venkatesh: Train number at the edge.

Professor. Madhavan Mukund: As a label and this will give us a picture of what all are the possible ways of going across the stations.

Professor. G. Venkatesh: So, of course, we will do this for all these stations here. This is going to be…

Professor. Madhavan Mukund: Big graph.

Professor. G. Venkatesh: Big graph.

Professor. Madhavan Mukund: So, what we can do is we can pick out a few stations which are interesting and see how they are connected.

Professor. G. Venkatesh: Big big stations are basically somewhere in the middle of India.

Professor. Madhavan Mukund: So let us…

Professor. G. Venkatesh: Many lanes going through

Professor. Madhavan Mukund: Yeah.

Professor. G. Venkatesh: So they are interesting train stations.

Professor. Madhavan Mukund: So, few from kind of center-south, center-west. So, across the…

Professor. G. Venkatesh: Country.

Professor. Madhavan Mukund: Country but not in very extreme places. So, we will not go deep South to say, Trivandrum or…

Professor. G. Venkatesh: Kanyakumari.

Professor. Madhavan Mukund: Kanyakumari.

Professor. G. Venkatesh: [Laughs] okay.

(Refer Slide Time: 04:14)

Professor. Madhavan Mukund: So, for instance, in the South, we could look at Bangalore. And then somewhere in the Middle-North, we can have Kanpur. Then somewhere in between them is Nagpur. And Pune, is little bit west of this. Secunderabad is here. Vijayawada is here, for instance.

Professor. G. Venkatesh: In the east.

Professor. Madhavan Mukund: In the east. And then, because we know that a lot of trains go through Delhi and Kolkata, maybe useful to have them…

Professor. G. Venkatesh: We need the trains. We do not need stations any more.

Professor. Madhavan Mukund: So, let us move stations out of the picture for now.

Professor. G. Venkatesh: We want the trains.

Professor. Madhavan Mukund: So, we will keep the, this, so, essentially we have this six stations. We are interested in knowing how they are connected. And, we keep these because we

would expect, we will not actually think of Kolkata and Delhi as part of our graph. But we will kind of connect through them. So, this is our graph that we want to construct now. Right? So, let us try and..

Professor. G. Venkatesh: What are we trying to find out? We are trying to find out whether there is a way to go directly from Pune to Nagpur, Nagpur to Kanpur.

Professor. Madhavan Mukund: Yes.

Professor. G. Venkatesh: Kanpur to Bangalore, Bangalore to Secunderabad, like that no?

Professor. Madhavan Mukund: For each of this place.

(Refer Slide Time: 05:23)

Professor. G. Venkatesh: So, we might, we might find that there is a way to go to Bangalore to Secunderabad via something Pune something. I do not know what it is. Right? We will find out.

Professor. Madhavan Mukund: So we will say, Bangalore. Let us say, Secunderabad. So actually, you know this railways, they actually have some codes for this. So we do not have to write out. So, these stations on the railways actually has 3 or 4 letter code. Then, you do not have to write the full name.

Professor. G. Venkatesh: But looking at it, we will not make out what it is.

Professor. Madhavan Mukund: [Laughs] somebody needs to know the name. So, since we are not specialist in that, …

Professor. G. Venkatesh: Okay.

Professor. Madhavan Mukund: So, we will just write out. So, we have,…

Professor. G. Venkatesh: Frequent travelers will know all that. If you are travelling frequently, you would know all that, you know.

Professor. Madhavan Mukund: Pune, and then somewhere here is Kanpur, say. So, these are our 6 stations. I have roughly drawn them geographically…

Professor. G. Venkatesh: Geographically, where they would appear. Bangalore is here and Secunderabad is here.

Professor. Madhavan Mukund: [Laughts] It does not matter. So, now, we want to check whether there are edges between them. So, for instance, this is we can do by our old trick. We can just look at...

Professor. G. Venkatesh: Bangalore to Vijaywada, let us say.

Professor. Madhavan Mukund: Bangalore we will see. So, Bangalore…

Professor. G. Venkatesh: Since there is a train which takes you from Bangalore to Vijayawada.

Professor. Madhavan Mukund: So, we do not, I do not think we even need to go to the trains. No? Because we know the trains are there.

Professor. G. Venkatesh: Train numbers are there. I just have to check whether their common…

Professor. Madhavan Mukund: We have the train numbers here. So, we can just see whether…

Professor. G. Venkatesh: Okay, that is nice.

Professor. Madhavan Mukund: Of course, we do not know the directions. Maybe for the directions, it is better to look. But we can see in terms of arrival-departure. So, 12214 our is not

there. Vijayawada. 2246 is there, and 2246 departs from Bangalore. So, it is from Bangalore. And it goes to Vijayawada. So, there is an edge. In this direction which is…

Professor. G. Venkatesh: I just want to confirm.

Professor. Madhavan Mukund: [Laughs]

Professor. G. Venkatesh: 2246.

Professor. Madhavan Mukund: 02246.

Professor. G. Venkatesh: 2246, you are saying, goes from Bangalore to Vijayawada? It must be going somewhere I guess.

Professor. Madhavan Mukund: Must be going further also. But,

Professor. G. Venkatesh: It will at least…

Professor. Madhavan Mukund: It will at least going to Vijayawada.

Professor. G. Venkatesh: Bangalore to Vijayawada to Kolkata.

Professor. Madhavan Mukund: So, Bangalore-Vijayawada-Kolkata. So, this is at least there. And the reverse train is, according to this, it would be 2245 which arrives. So, we can do this. So, we have this information.

Professor. G. Venkatesh: Nice.

Professor. Madhavan Mukund: So, this is one step. Then, we can ask for everything else. So, Bangalore to Secunderabad, for instance, we can check if it has anything. So, we know the two trains. 12214. So, 12214 appears here.

Professor. G. Venkatesh: Arriving in Bangalore?

Professor. Madhavan Mukund: Yes, arriving in Bangalore, so it is coming into Bangalore. And the 12213 must be going the other way. It is departing from Bangalore and it is arriving. And you can check here also. It arrives and leaves. So, so, there is an edge here which is 12213. And,

matching edge is 12214. Bangalore is connected to at least two of these things. What about, looking at this geography, for possibly, Pune and Nagpur we can check. So, 12214 does not appear and there is no train with 0 here. So Bangalore is not actually connected with Pune.

Professor. G. Venkatesh: It is amazing.

Professor. Madhavan Mukund: Nagpur, Nagpur?

Professor. G. Venkatesh: Means by these trains, whatever you have taken, right?

Professor. Madhavan Mukund: So, we will see Nagpur. Nagpur also, I do not see, 12214. I do not see any train. So Bangalore, so, Bangalore is not connected to Nagpur. So, it is a bit unusual. So, this is what Bangalore is connected to. So, now we can do the same thing with each of these stations. So for Secunderabad we can see, now Secunderabad, we know, is connected to Bangalore.

Professor. Madhavan Mukund: It has many trains. So, is it connected to Vijaywada? It is logical. 22203 three appears at the beginning. And, it is arriving in Secunderabad. So it is coming from Vijayawada to Secunderabad. Right? So, that is…

Professor. G. Venkatesh: 22203.

Professor. Madhavan Mukund: And there must be a pair, 22204, which is going the other way.

Professor. G. Venkatesh: This one.

Professor. Madhavan Mukund: So, we know the Secunderabad and Vijayawada. So what about Secunderabad and…

Professor. G. Venkatesh: Nagpur.

Professor. Madhavan Mukund: Nagpur, for instance.

Professor. G. Venkatesh: Very likely.

Professor. Madhavan Mukund: Quite likely, I would say. So, we will check 2203 goes the other way. It is not there. 12213 is not there. 12219, not there. 02285?

Professor. G. Venkatesh: It is this.

Professor. Madhavan Mukund: It is 685.

Professor. G. Venkatesh: it is there. Okay

Professor. Madhavan Mukund: Okay, so, 02 is there departing.

Professor. G. Venkatesh: So, departing Secunderabad, 85, arriving Nagpur

Professor. Madhavan Mukund: 02285 and presumably the reverse..

Professor. G. Venkatesh: 86.

Professor. Madhavan Mukund: Goes back. 02286. So, this is our thing for Secunderabad. I am very much doubtful whether it is connected to Kanpur by a direct train.

Professor. G. Venkatesh: Secundrabad?

Professor. Madhavan Mukund: These are all 122. So, 122, 19, 13, 14. No. These are all higher numbers. So, it is not connected. Pune? We should check.

Professor. G. Venkatesh: Secunderabad to Pune will be surely connected.

Professor. Madhavan Mukund: 12219.

Professor. G. Venkatesh: 12219. So, again here this is arriving. 12219.

Professor. Madhavan Mukund: So, Pune to?

Professor. G. Venkatesh: Secunderabad.

Professor. Madhavan Mukund: So, Pune to Secunderabad is 12219. 12219.

Professor. G. Venkatesh: 12200 is the other direction.

Professor. Madhavan Mukund:. Very good.

Professor. G. Venkatesh: Then, Secunderabad to Kanpur.

Professor. Madhavan Mukund: So, Secunderabad is now covered.

Professor. G. Venkatesh: Banglore, Vijaywada, Secunderabad we are done.

Professor. Madhavan Mukund: So, Vijaywada. Vijaywada should we check anymore?

Professor. G. Venkatesh: Kolkata, it will have, but we are not interested in Kolkata.

Professor. Madhavan Mukund: Kanpur? We did? Kanpur, let us see. One

Professor. G. Venkatesh: Pune?

Professor. Madhavan Mukund: 12269. No. Pune? Let us see. These are all 122. So, 19, 64, 97, 20, 63, 22, 21, 98. No. So, then it also, unlikely to be Kanpur.

Professor. G. Venkatesh: Unlikely to be.

Professor. Madhavan Mukund: Sixty nine, seventy,

Professor. G. Venkatesh: Here we do not have sixty nine, seventy.

Professor. Madhavan Mukund: Okay.

Professor. G. Venkatesh: So, Vijayawada is finished.

Professor. Madhavan Mukund: So, This part is finished. Now, we can look at Pune and Nagpur. So, Pune, we have already compared with this thing. So, we only have to look for Nagpur.

Professor. G. Venkatesh: One two two two zero.

Professor. Madhavan Mukund: One zero two one is there. So, two zero is leaving from Pune and at 7:55. And what time you get it there?

Professor. G. Venkatesh: 12220. Or 122. No, no. It is Two 1 and 22 it is.

Professor. Madhavan Mukund: Two one and two two. Two one, yeah, departs from Pune. So it must be starting from Pune. And going to…

Professor. G. Venkatesh: So Pune to…

Professor. Madhavan Mukund: Nagpur. Because it. So, 1221.

Professor. G. Venkatesh: 12221?

Professor. Madhavan Mukund: One triple two one and one triple two two in the other direction. And Pune to Kanpur, I doubt there is a direct train. And I do not see number which is in common to the two lists. So, Pune is done. And, then finally we have Nagpur, which is not been connected to, I mean, we have already checked. So, Nagpur, Kanpur is what we have already checked.

Professor. G. Venkatesh: It is just likely, huh? Just likely. 60.

Professor. Madhavan Mukund: 60. No. Do you have 60? This is 61.

Professor. G. Venkatesh: Six one?

Professor. Madhavan Mukund: No. six zero will go. And five nine, I think.

Professor. G. Venkatesh: Six one, six two no?

Professor. Madhavan Mukund: No,

Professor. G. Venkatesh: Okay, two two two one?

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: No, zero is not there at all. One two two seven zero?

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: Eight nine?

Professor. Madhavan Mukund: None of them are in the list.

Professor. G. Venkatesh: 85?

Professor. Madhavan Mukund: No. So, I think, for getting to Kanpur, I think, one has to now, go out to Delhi. So, I think Delhi…

Professor. G. Venkatesh: So, these are all kinds of trains these days?

Professor. Madhavan Mukund: Yes, so, this is an interesting graph. Because, not it says, for instance, you can go from Bangalore to Pune via Secunderabad. You can also go from Vijaywada to Pune via Secunderabad. You can go to Banglore to Nagpur.

Professor. G. Venkatesh: Multiple ways of going from Bangalore.

Professor. Madhavan Mukund: So, Secunderabad is actually the best connected here because it is connected to all four of them.

Professor. G. Venkatesh: In this lot.

Professor. Madhavan Mukund: So, if I want to Bangalore to Nagpur, I could go Bangalore–Secunderabad-Nagpur.

Professor. G. Venkatesh: Yes.

Professor. Madhavan Mukund: I could also go Bangalore-Secunderabad-Pune-Nagpur.

Professor. G. Venkatesh: Yes.

Professor. Madhavan Mukund: Multiple ways.

Professor. G. Venkatesh: Yes.

Professor. Madhavan Mukund: I can go Bangalore-Vijaywada-Secunderabad-Nagpur.

Professor. G. Venkatesh: Yes.

Professor. Madhavan Mukund: So, of course, one would obviously, normally one would try to go the shortest way.

Professor. G. Venkatesh: Shortest way.

Professor. Madhavan Mukund: But the traveler…

Professor. G. Venkatesh: May not have the train.

Professor. Madhavan Mukund: Yeah, see, some of these trains run only on some days. So, you may not be able to make a connection. For example, if you take this, you can check for instance, so, this twelve two one three, it leaves only on Saturdays going to Secunderabad.

Professor. G. Venkatesh: So, it looks to be this Kanpur, Right? This Kanpur guy, is only connected to Delhi between …between Delhi and Kolkata I think.

Professor. Madhavan Mukund: Possible, Possible. Because Kanpur should be connected.

Professor. G. Venkatesh: That is way you need to go Delhi or Kolkata to get to Kanpur. So, let us write, I think for the other places we will write via Delhi, Via Kolkata. We will write some labels.

Professor. Madhavan Mukund: Okay.

Professor. G. Venkatesh: But two trains you have to put.

Professor. Madhavan Mukund: So, where will we write them?

Professor. G. Venkatesh: Between Kanpur and Pune, you have to go via Delhi.

Professor. Madhavan Mukund: Okay, so we just say, Via Delhi.

Professor. G. Venkatesh: I hope it is there. We do not know.

Professor. Madhavan Mukund: But I believe that there should be. We can check. We certainly know that Kanpur is connected to Delhi. Because, for instance, if you look at the trains..

Professor. G. Venkatesh: Seventy three?

Professor. Madhavan Mukund: 73 is there. So, Kanpur is connected to Delhi and Kanpur is also connected to Kolkata, I think. Because, It is 2260?

Professor. G. Venkatesh: It is there.

Professor. Madhavan Mukund: So, Kanpur is definitely connected to both.

Professor. G. Venkatesh: Both, Delhi and Kolkata.

Professor. Madhavan Mukund: So, this is how to check whether these are connected there or not. So, Pune, for instance, I think…

Professor. G. Venkatesh: 63 is there

Professor. Madhavan Mukund: 63.

Professor. G. Venkatesh: 12263.

Professor. Madhavan Mukund: One two two six three. So, this is okay. Pune to Delhi, via, Pune-Delhi to Kolkata. Kanpur is there. And Pune to Kolkata to Kanpur also maybe there.

Professor. G. Venkatesh: But, we do not care.

Professor. Madhavan Mukund: Similarly, Nagpur should be connected to Delhi by many trains.

Professor. G. Venkatesh: Nagpur should have many trains. Because it is bound to Chennai.

Professor. Madhavan Mukund: Yeah.

Professor. G. Venkatesh: 69.

Professor. Madhavan Mukund: Sixty nine. So, Nagpur is also connected…

Professor. G. Venkatesh: Via Delhi…

Professor. Madhavan Mukund: Via Delhi. And in the same way,

Professor. G. Venkatesh: Secunderabad?

Professor. Madhavan Mukund: Secunderabad is also possibly connected via Delhi.

Professor. G. Venkatesh: Secunderabad is connected to Delhi?

Professor. Madhavan Mukund: Should be connected, I would expect. There are two sets of trains for Delhi. So we should always check. Twelve two one four, for instance.

Professor. G. Venkatesh: Twelve two one four, okay. So this is also via Delhi.

Professor. Madhavan Mukund: Secunderabad should definitely be connected via Delhi.

Professor. G. Venkatesh: Maybe via Kolkata also?

Professor. Madhavan Mukund: Yeah, we know that Vijayawada goes to Kolkata.

Professor. G. Venkatesh: Vijayawada goes to Kolkata.

Professor. Madhavan Mukund: So,…

Professor. G. Venkatesh: So, we can say Vijayawada via Kolkata.

Professor. Madhavan Mukund: So, we can draw this line here on this outside. So, we have this kind of indirect thing which we are counting as a connection because anyway we are going to connect, eventually we are seeing whether there is a sequence of trains. So, it does not really have to be. So the direct edges are, if we drew the entire graph we would actually draw..

Professor. G. Venkatesh: So, if I want to go Bangalore to Kanpur, let us say, there is no way. Directly I cannot go. With single train via I cannot do.

Professor. Madhavan Mukund: Two trains also you cannot do.

Professor. G. Venkatesh: I can. No, Two trains also I cannot go.

Professor. Madhavan Mukund: Because you have to go somewhere and then go via Delhi. So, in fact…

Professor. G. Venkatesh: The way is Bangalore to Vijayawada- Kolkata- Kanpur.

Professor. Madhavan Mukund: So, minimum, you need to…

Professor. G. Venkatesh: Other way is, Secunderabad.

Professor. Madhavan Mukund: Delhi.

Professor. G. Venkatesh: Nagpur-Delhi- Kanpur.

Professor. Madhavan Mukund: Or even Secunderabad-Delhi- Kanpur you can do.

Professor. G. Venkatesh: Secunderabad-Delhi- Kanpur I can do.

Professor. Madhavan Mukund: We have to do minimum of three trains.

Professor. G. Venkatesh: Okay.

Professor. Madhavan Mukund: And, this is what we were saying that Secunderabad, if you want to go from Bangalore, you can only go on Saturdays.

Professor. G. Venkatesh: Yeah.

Professor. Madhavan Mukund: So, on most days you might prefer to go to Vijayawada. Because, Vijayawada has trains five days a week.

Professor. G. Venkatesh: Okay.

Professor. Madhavan Mukund: So, even though it is one more hop, it might be say, Vijayawada-Secunderabad is also not too bad because Vijayawada to Secunderabad is this triple two, so, this is three days a week. So, there are more ways to go from Bangalore to Secunderabad via Vijayawada. Then to go, if you look at this extra information which, this graph is not capturing that day of the week. So, in principle, you have different graph for every day of the week.
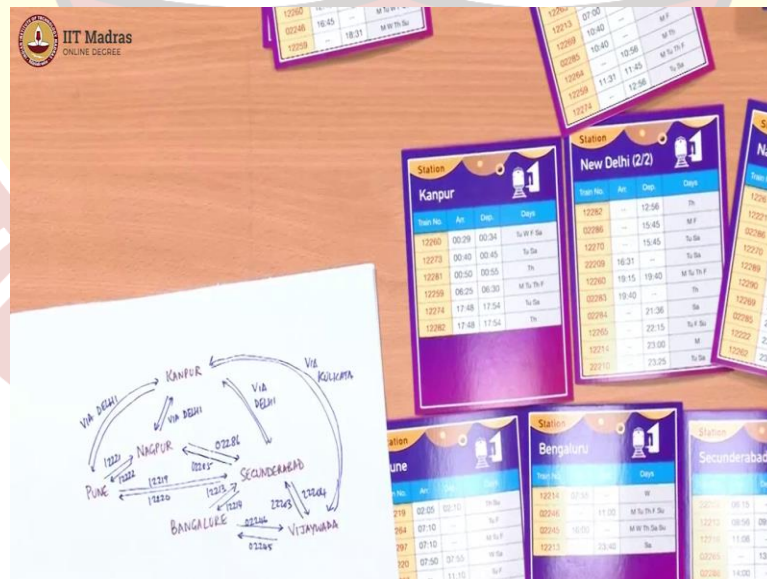
Professor. G. Venkatesh: Correct, correct.

Professor. Madhavan Mukund: The day of the week is also a bit strange because if you say it is Wednesday here.

Professor. G. Venkatesh: When you start and then what time…

Professor. Madhavan Mukund: Then it will be Thursday there, Friday there and so on. So, that is very difficult to capture in one graph. But statically if we capture all the days

Professor. G. Venkatesh: We do not care about the number of days.

Professor. Madhavan Mukund: Then still you know that minimum of three trains you need will to go.

Professor. G. Venkatesh: So, I want to ask you also, you know, people do this, pilgrimage, right? They go, they say, I want to visit these two or three cities where they some, they want to visit some

Professor. Madhavan Mukund: Standard places.

Professor. G. Venkatesh: Whatever it is.

Professor. Madhavan Mukund: And they want to do one place, two or three places like that and like that, they want to come back home. So, let us say I want to go like that, I want to visit, let us say I want to go to Nagpur, Kanpur, Pune and come back from Bangalore. I am in Bangalore. I want to do Pune, Nagpur and Kanpur. 3 cities I want to visit. And come back. So, with this graph tell me how to do it? I mean, is it, is it a good way of doing that?

(Refer Slide Time: 19:41)

Professor. Madhavan Mukund: We will certainly tell you the different ways of doing it. For instance, I mean, first of all you know that to get to any of these places, you have to go via Secunderabad.

Professor. G. Venkatesh: Secunderabad. Okay

Professor. Madhavan Mukund: Or via Vijayawada and hit Kanpur from the top.

Professor. G. Venkatesh: Okay.

Professor. Madhavan Mukund: But then having got here, for example, suppose, you get here. Now you can either go to Nagpur and then go to Kanpur.

Professor. G. Venkatesh: Okay.

Professor. Madhavan Mukund: Or you can come to Pune and then go to Kanpur. So, you can do Kanpur, Pune, Nagpur in any order, I mean, not any order but you can do it.

Professor. G. Venkatesh: It seems that it is better to do Pune to Nagpur because direct train is there.

Professor. Madhavan Mukund: Yeah, but then for Nagpur to Kanpur, a Delhi train you have to use.

Professor. G. Venkatesh: I have to…

Professor. Madhavan Mukund: Somewhere you have to do a Delhi train. So, and you are coming back also…

Professor. G. Venkatesh: I have to use two times Delhi train…

Professor. Madhavan Mukund: We will have to do it. Either you have to come back to Nagpur via Delhi train or you will…see, once you go to Kanpur, you have to visit Delhi and or you have to come via Kolkata and come back this way. So, Kanpur is giving you this, in this, this collection of cities, Kanpur has this extra overhead. However, you go to Kanpur, you have to make a stop.

Professor. G. Venkatesh: Stop in Delhi two times.

Professor. Madhavan Mukund: Yeah, so, there are two trains in both directions.

Professor. G. Venkatesh: I have to go Delhi to Kanpur and Kanpur back to Delhi.

Professor. Madhavan Mukund: So, then you might as well avoid this extra thing and go straight to Pune. So, at least avoid doing…

Professor. G. Venkatesh: But you know, whatever it is, it is better than looking at the trains.

Professor. Madhavan Mukund: Absolutely.

Professor. G. Venkatesh: Right? It looks compact.

Professor. Madhavan Mukund: Right.

Professor. G. Venkatesh: At least, I can see the options much more easier…

Professor. Madhavan Mukund: And, in fact you can, in a sense, if I follow this this, if I look at some train, for instance, which, so, maybe we should pick up a train. Let us look at, for instance, one of these trains which is say, goes to Kolkata like this. 02…

Professor. G. Venkatesh: Vijayawada to…

Professor. Madhavan Mukund: So, let us look at this 00246, for instance.

Professor. G. Venkatesh: Two four six.

Professor. Madhavan Mukund: So, if we have drawn the full graph, right, then this would have had these in- between stations. So, there would have been an edge from Bangalore to Renigunta, label two two four six. There would have been edge for Renigunta to Vijayawada, label two two four six. There would have been an edge for Vijayawada to Vijaynagaram. Then, Vijaynagaram to Bhubaneswar. Bhubaneswar to Kolkata. So, by tracing this edge with this same label, we actually follow this path.

Professor. G. Venkatesh: Path.

Professor. Madhavan Mukund: So, all the information that is there in this card can actually be reconstructed from the…

Professor. G. Venkatesh: Graph.

Professor. Madhavan Mukund: The graph, if we keep this edge labels. Not the timings because we do not have the timings here. But at least the sequence in which each train goes, we will get that. And, if you ignore that sequence, we just want to know if I can go from here to there, you can just say okay, how many hops I need to take? So, this is definitely a nice way of…

Professor. G. Venkatesh: Compact way.

Professor. Madhavan Mukund: Yes, instead of all these separate cards with a lot of data scattered between them, this is one way of doing it directly. And, then, all our computations…

Professor. G. Venkatesh: Can be on this graph.

Professor. Madhavan Mukund: Is done only on this graph.

Professor. G. Venkatesh: It is much more, much more easy it looks like to me, because you just have to, to navigate the graph, we saw that you just have some lists, right?

Professor. Madhavan Mukund: Yes.

Professor. G. Venkatesh: So, Bangalore will have list of…

Professor. Madhavan Mukund: List of all the outgoing edges.

Professor. G. Venkatesh: Outgoing edges, incoming edges.

Professor. Madhavan Mukund: Yes, and, then you have to have a systematic way of finding out…

Professor. G. Venkatesh: Go through the list.

Professor. Madhavan Mukund: Yeah.

Professor. G. Venkatesh: Systematically, which we know how to do, iterate.

Professor. Madhavan Mukund: Yes.

Professor. G. Venkatesh: For all the elements in the list.

Professor. Madhavan Mukund: Correct.

Professor. G. Venkatesh: Right?

Professor. Madhavan Mukund: So, finally we have to do a kind of search though this graph to find the best path or to find there is a path. But, that we can do systematically just by keeping track of labels that we have recorded on the graph. So, so that is, that is one advantage of moving from these explicit tables to this kind of combined representation.