



IIT Madras

ONLINE DEGREE

Computational Thinking
Professor. G. Venkatesh
Indian Institute of Technology, Madras
Professor. Madhavan Mukund
Department of Computer Science
Chennai Mathematical Institute

Representation of a graph as an adjacency matrix to find shortest distance and time

Professor. Madhavan Mukund: So, we have been looking at these stations and how they are connected. So, first we check whether you can go from one station to another station directly.

Professor. G. Venkatesh: If there is a train which goes from this station.

Professor. Madhavan Mukund: There is one train which connects directly, then we said whether you can change at one station and go. Then we also try to see if there is a way of going by more than one train by drawing that graph connecting the thing. But so far I think we have not really looked at these other quantities which are there on this cards like the time, how long it takes or you know, some of the, each of these trains has distance measure.

(Refer Slide Time: 0:50)



Professor. Madhavan Mukund: So, it might be interesting to keep track of that, what is time it will take. For instance, if I can go from Pune to Secunderabad or Pune to Kolkata, then what would be the...

Professor. G. Venkatesh: Many trains.

Professor. Madhavan Mukund: What would be the best way to go in terms of time or distance or .

Professor. G. Venkatesh: Both. We have to both, I think sometimes distance is relevant sometimes time is relevant.

Professor. Madhavan Mukund: It depends on and also it depends how many times you are connecting it, it may be a short distance, but you might have...

Professor. G. Venkatesh: But the thing is that this processing that is finding out the distance between Pune and Delhi or whatever it is, we need only do it ones, I mean if you have done it ones, then doing it again and again and again, meaningless to do it.

Professor. Madhavan Mukund: So, we should kind of...

Professor. G. Venkatesh: Try to store it somehow?

Professor. Madhavan Mukund: Do it and record it.

Professor. G. Venkatesh: Record it. So, what is the good way to record it? Is that a graph like what we did earlier?

Professor. Madhavan Mukund: If we use a graph, in principle we could do that but then for every connection that we have on the edge we have this labels. So, earlier we had written some, so we have to put all this extra information. Label it might be messy to...

Professor. G. Venkatesh: Graph make sense only probably if you put a few edges. If every node is connected to everything else.

Professor. Madhavan Mukund: Then it will be very messy, I mean to look it up.

Professor. G. Venkatesh: Too many edges. There has to be few edges for the graph. So, in this case, do you want to take let us say these 5 stations and work with these 5 stations, find all the trains in it.

Professor. Madhavan Mukund: So, we want to say for example, what is the Pune to Kolkata, what is it from Pune to Nagpur, so we have a many 5 times, or 20 and of course.

Professor. G. Venkatesh: See, we are not looking Pune to Pune.

Professor. Madhavan Mukund: Pune to Pune.

Professor. G. Venkatesh: But anyway we can make a table of 5 by 5 table.

Professor. Madhavan Mukund: 5 by 5. We can make a table. That is a good idea, table.

Professor. Madhavan Mukund: So, we can have an entry for each starting point and each ending point and then in this table at that position we can...

Professor. Madhavan Mukund: So, we could write down these stations. So, should we write down these stations? In some, so let us write it down in say alphabetical orders.



The Maths Project

Page No. _____

Date _____

Station

Adra

Train No.	Arr	Dep	Days
12382	03:40	03:50	Th
12381	14:00	14:05	W

Train

12259

Station	Arr	Dep	Days
Kolkata	21:50	21:55	Th
Dumraon	22:20	22:25	Th
Kanpur	00:20	00:25	Th
Varanasi	11:30	11:35	Th
New Delhi	14:00	14:05	Th
Lahore	15:00	15:05	Th
Srinagar	16:00	16:05	Th
Chennai	17:00	17:05	Th
Bangalore	17:40	17:45	Th
Sri Ganganagar	18:15	18:20	Th
Bombay	18:30	18:35	Th

Station

Kolkata (2/2)

Train No.	Arr	Dep	Days
12382	03:40	03:50	Th
12381	14:00	14:05	W

FROM **TO** **K** **NA** **ND** **P** **S**

KOLKATA = 12382 12381 12381 12382 12382 12381 12381 12382 12382 12381 12381 12382

NAGPUR = 12382 12381 12381 12382 12382 12381 12381 12382 12382 12381 12381 12382

NEW DELHI = 12382 12381 12381 12382 12382 12381 12381 12382 12382 12381 12381 12382

PUNE = 12382 12381 12381 12382 12382 12381 12381 12382 12382 12381 12381 12382

SECUNDERABAD = 12382 12381 12381 12382 12382 12381 12381 12382 12382 12381 12381 12382

Professor. G. Venkatesh: New Delhi.

Professor. G. Venkatesh: Pune.

Professor. G. Venkatesh: And then Secunderabad.

Professor. G. Venkatesh: We can say it starts from, starting from. Is it? row is....

Professor. Madhavan Mukund: Staring from and on the top you will have the same thing and I will just write one letter so that we do not have to write everything. So, Nagpur, New Delhi, Pune, and Secunderabad.

Professor. G. Venkatesh: So, this is going to.

Professor. Madhavan Mukund: Going to.

Professor. G. Venkatesh: Staring from.

Professor. Madhavan Mukund: So, this is from and to.

Professor. G. Venkatesh: So, I want to go from Kolkata to Kolkata, does not make sense. I want to go from Kolkata, so if you draw the matrix, so let me just draw this table.

Professor. Madhavan Mukund: So, we have a table, so we have these kind of rows and we have one column for each place we want to go to from each of the places on the rows. So, we end up with this.

Professor. Madhavan Mukund: 5 by 5 table.

Professor. G. Venkatesh: Which the diagonal that is this one. You just put a cross.

Professor. Madhavan Mukund: So, you can just block it off.

Professor. G. Venkatesh: Because it is meaningless.

Professor. Madhavan Mukund: Because we are not going to go from one station back to itself.

Professor. G. Venkatesh: Unless you like stations. Now we are not into that.

Professor. Madhavan Mukund: So here for instance, this is Kolkata to Nagpur and this is Nagpur to Kolkata, now they may be the same but it may not be the same because the other direction and then there are various other things like timing and all might all be different.

Professor. G. Venkatesh: Time will be different, definitely different, distance also may be different, we do not know. We will see. So, what you want to write in this box?

Professor. Madhavan Mukund: So, I think we would certainly want to write down, so what is our goal? Let us suppose we want to look at distance. Now we would like to write down the distance it takes, but there maybe more than one train.

Professor. G. Venkatesh: So, let us write down the train and distance.

Professor. Madhavan Mukund: So, we write the train number and the distance on that train. Then we can choose the one which is best for whatever.

Professor. G. Venkatesh: You can choose the less, least.

Professor. Madhavan Mukund: Normally the least one.

Professor. G. Venkatesh: Alright so we have to do 20, 5 into 4 20. So, do we start Kolkata to Nagpur?

Professor. Madhavan Mukund: So, how do we do that? Start with Kolkata or start with Nagpur? Kolkata?

Professor. G. Venkatesh: And look at trains starting at Kolkata or passing through Kolkata?

Professor. Madhavan Mukund: So, we are now looking only for trains which directly connect.

Professor. G. Venkatesh: Depart from?

Professor. Madhavan Mukund: No, but also only direct connections.

Professor. G. Venkatesh: We are right now looking only for direct connections.

Professor. Madhavan Mukund: So, basically we need to look at the trains here and then the trains which are also there in that.

Professor. G. Venkatesh: Overlapping. So, we have to see Kolkata, Nagpur, compare the two and see if there are any overlaps. So, 022, 022.

Professor. Madhavan Mukund: Maybe I can, you can call out the numbers and I can check the Nagpur list.

Professor. G. Venkatesh: So, 2202.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 2214.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 14222.

Professor. Madhavan Mukund: 1 triple 2, that is there.

Professor. G. Venkatesh: 1222.

Professor. Madhavan Mukund: So, that is there.

Professor. G. Venkatesh: So, that departs Kolkata at 8:20.

Professor. Madhavan Mukund: So we can write so let me put, so 122...

Professor. G. Venkatesh: So, what we need to look in that train? What are we looking in that train? We are looking at the distance.

Professor. Madhavan Mukund: Distance. So, we have...

Professor. G. Venkatesh: Starting from Kolkata, it is going further than Nagpur.

Professor. Madhavan Mukund: So, Nagpur is 1131.

Professor. G. Venkatesh: 1131.

Professor. Madhavan Mukund: So, the train number, so we should may be write it in two different colours. So, the train number is 12...

Professor. G. Venkatesh: 12, 1 4 2s.

Professor. Madhavan Mukund: And the distance is 1131. So, this is one train.

Professor. G. Venkatesh: And then there is 12262.

Professor. Madhavan Mukund: That is also there.

Professor. G. Venkatesh: 12262, there are multiple trains.

Professor. Madhavan Mukund: But it is apparently following the same route because that also has the same distance.

Professor. G. Venkatesh: No, need to write?

Professor. Madhavan Mukund: So, 12262 and it is also 1131.

Professor. G. Venkatesh: Same track?

Professor. Madhavan Mukund: Same track.

Professor. G. Venkatesh: Are the stations are same also?

Professor. Madhavan Mukund: We can look. 12...

Professor. G. Venkatesh: May be, Should be know, if it is taking the distance between stations is,

Professor. Madhavan Mukund: Kolkata, Tata Nagar, Bilaspur, Nagpur and this one is going to Mumbai, this one is going, so at Bhusawal they split. Bhusawal, Igathpuri. This is Bhusawal, Manmad, so they go the same up to Bhusawal and then they take different direction.

Professor. G. Venkatesh: Interesting. Bhusawal is interesting station.

Professor. Madhavan Mukund: So, we done that.

Professor. G. Venkatesh: 12273.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 7, 74 is not there. 86802245.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: Then 12259.

Professor. Madhavan Mukund: 12259, no. So, there are only 2 trains.

Professor. G. Venkatesh: 02201.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 02201 and 02213.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: So, we have taken all the trains departing from Kolkata.

Professor. Madhavan Mukund: Checked those which pass through Nagpur.

Professor. G. Venkatesh: Pass through Nagpur.

Professor. Madhavan Mukund: There are two of them and we have noted down the distance on both of them.

Professor. G. Venkatesh: They are the same.

Professor. Madhavan Mukund: Happens to be the same.

Professor. G. Venkatesh: So, in this case the distance from Kolkata to Nagpur is 1131.

Professor. Madhavan Mukund: 1131 by direct train.

Professor. G. Venkatesh: By direct train.

Professor. Madhavan Mukund: And we now know this so later on if we need to refer to this we just have to look up this row for Kolkata and the column for Nagpur and we are done.

Professor. G. Venkatesh: Done and do not need to look at the cards. So, this is the way of processing the information storing it.

Professor. Madhavan Mukund: So, let us do one more.

Professor. G. Venkatesh: Let us do Secunderabad, Nagpur. We need Kolkata to Nagpur, what is ND, New Delhi, that is good, we have lot of trains.

Professor. Madhavan Mukund: So, let us do maybe Nagpur to Secunderabad.

Professor. G. Venkatesh: Nagpur to Secunderabad. There maybe no trains maybe, let us see.

Professor. Madhavan Mukund: Let us see.

Professor. G. Venkatesh: Let us see. Departure Nagpur. 12261.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 12221.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 02286.

Professor. Madhavan Mukund: Yes, 02286 is there. So, let us see what is 02286, Nagpur to Secunderabad, so now we have to do some subtraction because it is not starting from Nagpur. So, the train number is 02286 and the difference is so 1660 is the distance from Delhi, 1083 is the distance from Delhi, so we have to subtract 1083 from 1660, 6 so we get 577 I think, that make sense.

Professor. G. Venkatesh: 9 minus 7, 5 minus 8 7.

Professor. Madhavan Mukund: So, this is 577.

Professor. G. Venkatesh: 577.

Professor. Madhavan Mukund: So, distance from Nagpur.

Professor. G. Venkatesh: Then where have we come to, 02286. Then 12270.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: Then 12290.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 12269.

Professor. Madhavan Mukund: Nope.

Professor. G. Venkatesh: 02285.

Professor. Madhavan Mukund: That is a pairing train, but it is going in the other direction.

Professor. G. Venkatesh: No, we do not want that. 12222.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 12262.

Professor. Madhavan Mukund: No. So, there is only this one train, so we have this....

Professor. G. Venkatesh: 577. Let us do something with Pune.

Professor. Madhavan Mukund: Let us do something with Pune. So, Pune to Delhi or Delhi too many trains, let us see. Let us try with Pune trains.

Professor. G. Venkatesh: Pune to Delhi. 12219. We have to check both the cards.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 122, this is this are all arriving 12220

Professor. Madhavan Mukund: 12220, I do not see.

Professor. G. Venkatesh: 12263.

Professor. Madhavan Mukund: No. There it is. So, 02263. 12263 is actually, it is good, no subtraction required because it is running from Pune to Delhi via Mumbai. So, we now put this in the Pune to Delhi box, 12263 and says it is 1520, so 1520.

Professor. G. Venkatesh: Then there is 12221.

Professor. Madhavan Mukund: 12221, I do not see. No.

Professor. G. Venkatesh: Then it is 12298.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: So, there is only one train.

Professor. Madhavan Mukund: One train and...

Professor. G. Venkatesh: It is distance of 1520.

Professor. Madhavan Mukund: 1520.

Professor. G. Venkatesh: See, what are we not considered so far, which place have we not update so far.

Professor. Madhavan Mukund: So, we have done Kolkata to Nagpur, we have done Secunderabad to Nagpur, and we have done Delhi Pune. So, all stations have been checked in one, at least ones but we.

Professor. G. Venkatesh: Delhi Kolkata we did not do.

Professor. Madhavan Mukund: Delhi Kolkata might be very interesting, although there may be many trains. Let us try it. Kolkata has fewer so let us try the Kolkata again.

Professor. G. Venkatesh: So, I will start with Kolkata departure. 1 4 2s.

Professor. Madhavan Mukund: 1 with 4 2s, I think does not go this side at all. We have seen that before.

Professor. G. Venkatesh: We have seen that before. 12262.

Professor. Madhavan Mukund: 12262, 63 is there, no not 62.

Professor. G. Venkatesh: Really? 12273.

Professor. Madhavan Mukund: 73 is there, it is actually Kolkata to Delhi. So, 12273 and it is 1529.

Professor. G. Venkatesh: The next one is arrivals I am giving. 02245.

Professor. Madhavan Mukund: 02245, no.

Professor. G. Venkatesh: This two are arrivals. Then 12259.

Professor. Madhavan Mukund: 12259 I think should be there.

Professor. G. Venkatesh: 12259, it is passing through Delhi, not stopping at Delhi. Interesting.

Professor. Madhavan Mukund: It is actually going to Bikaner. So, it is 12259 is actually a different, so we should find out why it is 14, it is a shorter route, 1453.

Professor. G. Venkatesh: It is via Kanpur.

Professor. Madhavan Mukund: So, this is via Kanpur the other one is via so Kolkata, so this is very different route. So, Kolkata, Dhanbad, Kolkata, Akansol, Jasid, Patna, Varanasi, Kanpur, and this is so this is doing an extra detour where this Varanasi, Kanpur and this is going via Patna, Varanasi, Kanpur, so I think this extra stretch here, so Varanasi if you look, this is 667 and here it is 744. So, it is already accumulating somewhere.

Professor. G. Venkatesh: Because it is going through Patna, it has added some more distances. So, that is not going to Patna.

Professor. Madhavan Mukund: That is not going to Patna. And that should be roughly so this point about 67, 744 about 70 kilometres difference and that is around 70 kilometres difference here. So, that is. So, we have found at least some interesting thing here between Kolkata and Delhi, there are at least two trains which...

Professor. G. Venkatesh: Two trains.

Professor. Madhavan Mukund: 610...

Professor. G. Venkatesh: 022, this is our arrival. 02201.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: 02213.

Professor. Madhavan Mukund: No.

Professor. G. Venkatesh: So, there are only two trains.

Professor. Madhavan Mukund: Two trains but they have different routes.

Professor. G. Venkatesh: That have different routes.

Professor. Madhavan Mukund: So, they actually, so here we actually have....

Professor. G. Venkatesh: Finally find something very two trains with two different distances.

Professor. Madhavan Mukund: So, here we would possibly record that this is a better one. So, this is useful to know. So, in this way we could populate this whole thing in terms of distances.

Professor. G. Venkatesh: Distances.

Professor. Madhavan Mukund: And then we would know for every pair by a direct route what is the best way to go? And of course if we do it for all the train...

Professor. G. Venkatesh: Because this case all the trains every station and every station here is connected.

Professor. Madhavan Mukund: Is connected by direct train.

Professor. G. Venkatesh: Direct train therefore this table will have...

Professor. Madhavan Mukund: Every entry will have something.

Professor. G. Venkatesh: Suppose the train, there was a station another station which is not connected....

Professor. Madhavan Mukund: Then we will have basically have a blank space.

Professor. G. Venkatesh: Blank spot. So, in a sense it is like a graph. We think in this case, this is a what we called a clique everything is correct, everything else. But if something were not connected, there would not be an edge and on the edge what do we have? We have their label, label is now in this case?

Professor. Madhavan Mukund: The train number and the distance, but as a is a list of these train number distance pairs.

Professor. G. Venkatesh: You could have more than one edge also.

Professor. Madhavan Mukund: You could have more than one edge.

Professor. G. Venkatesh: One train one edge.

Professor. Madhavan Mukund: You could do that, you could for every train, you could draw one edge which.

Professor. G. Venkatesh: Normally a graph as only one edge between two nodes.

Professor. Madhavan Mukund: Normally, there is a just a question of becoming messy. Because you would like to two edges. You could write two edges, but I think that there...

Professor. G. Venkatesh: There we put, you remember we did this maths, physics and all that, this is possible that one student can mentor another students in maths and physics, so there can be two edges.

Professor. Madhavan Mukund: Two different labelled edges.

Professor. G. Venkatesh: Of course you could have one edge and label it maths comma physics or you can put two edges, one with maths, one with physics. But so assume for a moment that these are two edges so that it is easier to understand. So, edges are train in that case.

Professor. Madhavan Mukund: And on the train we are now putting the train number and the distance.

Professor. G. Venkatesh: Distance you are putting.

Professor. Madhavan Mukund: And we could also have put the time in the same way, we could have calculated based on...

Professor. Madhavan Mukund: Some of these we can at least try doing this time.

Professor. Madhavan Mukund: The ones that we know for instance, we could do that.

(Refer Slide Time: 17:25)

The image shows a person's hands interacting with a set of train schedule cards and a printed schedule on a table. The cards are purple and blue, with some showing station names like 'Adra', 'New Delhi', and 'Kolkata'. The printed schedule is a table with columns for station, train number, and time. The person is pointing at a specific entry in the printed schedule.

Station	Train No.	Time
Adra	12260	14:58
Adra	12261	15:00
Adra	12262	15:02
Adra	12263	15:04
Adra	12264	15:06
Adra	12265	15:08
Adra	12266	15:10
Adra	12267	15:12
Adra	12268	15:14
Adra	12269	15:16
Adra	12270	15:18
Adra	12271	15:20
Adra	12272	15:22
Adra	12273	15:24
Adra	12274	15:26
Adra	12275	15:28
Adra	12276	15:30
Adra	12277	15:32
Adra	12278	15:34
Adra	12279	15:36
Adra	12280	15:38
Adra	12281	15:40
Adra	12282	15:42
Adra	12283	15:44
Adra	12284	15:46
Adra	12285	15:48
Adra	12286	15:50
Adra	12287	15:52
Adra	12288	15:54
Adra	12289	15:56
Adra	12290	15:58
Adra	12291	16:00
Adra	12292	16:02
Adra	12293	16:04
Adra	12294	16:06
Adra	12295	16:08
Adra	12296	16:10
Adra	12297	16:12
Adra	12298	16:14
Adra	12299	16:16
Adra	12300	16:18



So, let us see for instance this, shall we look at these two train, the ones that we have already found.

Professor. G. Venkatesh: Kolkata and Delhi.

Professor. Madhavan Mukund: So, we know the trains, so 1259, so this is one of them. So, this starts at Kolkata at 18:31 on day 1 and reaches New Delhi at 11:45 on day 2.

Professor. G. Venkatesh: Departure, arrival is 6:23.

Professor. Madhavan Mukund: 11:31, 11:31 on day 2. So basically it starts at 6:31 pm and reaches the next morning at 11:31 am. So, here it is 11:31 and this is from 6:31, so 29 minutes, 29 minutes it will be 7 o'clock. So, another 5, so 5 hours 29 minutes there and 11 hours 31 minutes here. So, 16 plus 17 hours it is taking.

Professor. G. Venkatesh: 17 hours.

Professor. Madhavan Mukund: Exactly 17 hours. So, we can write so I will kind of split over this is 59, so this is right now let us assume the...

Professor. G. Venkatesh: If you put that also, that information is also put, but is it every day?

Professor. Madhavan Mukund: No, this is Monday, Wednesday, Thursday, Sunday.

Professor. G. Venkatesh: That gives another complication.

Professor. Madhavan Mukund: So, you can go in 17 hours provided you start on those 4 days. Let us look at the other train 73 and just see whether it goes more frequently and what is the

time it takes? Since it takes longer distance, it presumably takes longer time also. But we cannot be sure about that. so, let us see.

(Refer Slide Time: 18:55)



Professor. Madhavan Mukund: This now leaves that first of all it is only on Monday, Friday. So, on Monday both are there, so you can compare others, Friday and Wednesday, Thursday, Sunday are two different days. 8:35 and it reaches at 6:25 so it is almost 24 hours. So, it is like 6:35 will be 22 hours. Be it is day 1 at 8:35 as 21 hours and 50 minutes.

Professor. G. Venkatesh: So, 21 hours and 50 minutes.

Professor. Madhavan Mukund: And notice that actually the distance is not that much more, on the distance scale...

Professor. G. Venkatesh: But it maybe going to Patna and stopping, see you can see even...

Professor. Madhavan Mukund: Because it is not even 10 percent, because if it was 145, 1453, another 145 kilometres would be 1600 so it is less than 10 percent of extra distance, but it is talking good amount of extra time, almost one third is much time.

Professor. G. Venkatesh: So, very slow train, so not only is this faster train, it is also a shorter train.

Professor. Madhavan Mukund: Shorter in distance and much faster

Professor. G. Venkatesh: The only problem is that if you leave on Friday,...

Professor. Madhavan Mukund: Then it will be much better.

Professor. G. Venkatesh: You have to wait till Sunday.

Professor. Madhavan Mukund: Sunday. So, you leave.

Professor. G. Venkatesh: Not even Saturday.

Professor. Madhavan Mukund: So, you will have two full days and then you would have the pleasure of taking a shorter train. So, you would decide to be....

Professor. G. Venkatesh: Then you miss for a, for some reason if you miss this train, which is at 6:30 on Thursday, let us say you landed in the station at 7 o'clock.

Professor. Madhavan Mukund: Then you might as well this train. Friday morning rather than wait till Sunday. So, that is an extra factor which we have not yet recorded there. So, it is a bit misleading without that information. So, we could then take this edge and we can write all this information that we know about the train on that edge.

So one thing is that we have also, we have only said the time, but we have said when it reaches so that might also be relevant if we are looking at say, connections.

Professor. G. Venkatesh: Though, maybe we should look at connections. So this is interesting. what we have said basically is that you can digest all these complex information into a simple table. Do you like tables, using tables?

Professor. Madhavan Mukund: So, for earlier we did a graph and then we said the graph will become messy, but so this is like a graph as we said each of these entries is like an edge. It is just that instead of writing it in this picture form and having to squeeze and all the information in the small space that we have, we have kind of a louder cells. So, here we lose some information about pictorially looking at it but we gained this organization.

Professor. G. Venkatesh: I was thinking this matrix, if you really had it between all stations and all stations, you could do something more interesting, you could use the matrix to figure out how to go via one station to another station.

Professor. Madhavan Mukund: That for sure because.

Professor. G. Venkatesh: Can you do it?

Professor. Madhavan Mukund: So, let us give an example, maybe we can find an example.

(Refer Slide Time: 21:48)



Professor. Madhavan Mukund: So, supposing we know, so last time we had calculated that for example if you wanted to go, so we said that if you wanted to go from Pune to let us whole, so we had this graph and we had said that Kanpur had this peculiar situation where none of these 5 stations were directly connected to Kanpur. So, you would have to go from via Delhi or via Kolkata to go from here to there.

Professor. G. Venkatesh: So, now if we look at this table there would be no entries say between Pune and Kanpur.

Professor. Madhavan Mukund: So, that square or that cell in that table would be blank. So, now you have to look for some station which is connected to Pune and which is connected to Kanpur, so you have to find such a an entry.

Professor. G. Venkatesh: So, you can look in the matrix between Pune and something, some station X where there is an entry.

Professor. Madhavan Mukund: Where there is an entry?

Professor. G. Venkatesh: And from that entry, from that X there are several entry to Kanpur. And therefore, I can find out. So, if there is a X such that Pune to X and X to there are entries I can go.

Professor. Madhavan Mukund: So, so systematically...

Professor. G. Venkatesh: I can do that with two stations also. I can do Pune to X and X to Y.

(Refer Slide Time: 23:03)



Professor. Madhavan Mukund: So, basically so if you had this Pune thing, then it would have...

Professor. G. Venkatesh: Graph, it makes actually this is a better thing to do with graph because it basically means that I can go from Pune to something of an edge and from that you can go with an edge.

Professor. Madhavan Mukund: So, if you look at the row for Pune for instance, so there would be some entries which are there and some entries which are not there, I mean where I write an X, it is blank. So, in particular we know that the column for Kanpur is blank because we know no train going from Pune to Kanpur.

Professor. G. Venkatesh: But Pune to Delhi is there.

Professor. Madhavan Mukund: So, for instance here we might have found little further down, you might have found New Delhi.

Professor. G. Venkatesh: In fact, actually this was the direct, only the only way is to go by Delhi.

Professor. Madhavan Mukund: Go by Delhi. So, what we would have to do is now, if you do it systematically, for each of these...

Professor. G. Venkatesh: So, you will see that there is a Pune to Delhi and then will be another like,...

Professor. Madhavan Mukund: So, there will be a line for Delhi and in this row you will have to check that the corresponding column for Kanpur is marked with a tick.

Professor. G. Venkatesh: So, we are saying that there is a path from Pune to Delhi, an edge from Pune to Delhi.

Professor. Madhavan Mukund: And then a edge from that...

Professor. G. Venkatesh: Edge from Delhi to Kanpur. But now we have more information in our graph. We know the distance.

Professor. Madhavan Mukund: So, now you know that this is some D_1 and this is some D_2 ,

Professor. G. Venkatesh: So we can find the distance by adding.

Professor. Madhavan Mukund: So, therefore, I will get D_1 plus D_2 .

Professor. G. Venkatesh: I can?

Professor. Madhavan Mukund: You can do that. Because you will take that much, you would travel that much distance to get from Pune to Delhi, then you would get the ...

Professor. G. Venkatesh: And there are two trains over here, then I can take the shorter of those two.

Professor. Madhavan Mukund: And the shorter of these and get the shortest distance from Pune to Delhi.

Professor. G. Venkatesh: But you know what then, there is, now there is a possibility that not just daily, there may be something else also. Right now in this case, Pune to Delhi, only one way. Are there where there 2 ways?

Professor. Madhavan Mukund: Well, not directly but for instance, you can say Secunderabad, you can go to Pune, you can go to Secunderabad, you can go via Delhi to Kanpur, but you can also go to Vijayawada and go via Kolkata to Nagpur.

Professor. G. Venkatesh: Say for example Secunderabad I can go to Pune or I can go to Nagpur and then Nagpur to Pune.

Professor. Madhavan Mukund: And then you can ask whether they are the same distance or different distances.

Professor. G. Venkatesh: I think this will be shorter anyway I think.

Professor. Madhavan Mukund: So, I think Secunderabad Pune because this is a direct train, I am pretty sure that to go via Nagpur, it will be longer.

Professor. G. Venkatesh: So try?

Professor. Madhavan Mukund: You can try that.

Professor. G. Venkatesh: So, here again what we are doing basically is that if you do not have a direct route, in this case there is a direct route, nothing much to do, but there is no direct route, there may be multiple alternate ways of going from one place to another. So, we have to take all the alternate ways, find the distance of all the alternate. How do we find the distance? Add, add this distance, add that distance, this and this. So, like that we will find all the ways, add all the ways and chose the one which has the shortest.

Professor. Madhavan Mukund: Shortest.

Professor. G. Venkatesh: If you are looking at distance. Distance also means fare.

Professor. Madhavan Mukund: Usually the train fare is based on the distance that you travel.

Professor. G. Venkatesh: So, if you have only limited amount of money, it is very useful thing. We do not care about how much time you spend in the station. We take long time, but shortest distance. So, in that case based on shortest amount, money. In that case basically you just, so in this case, we can just write. Let us just try this. What are we trying to do?

Professor. Madhavan Mukund: We wanted to try from Secunderabad....

Professor. G. Venkatesh: You have the train numbers in this.

(Refer Slide Time: 26:40)



Professor. Madhavan Mukund: So, we have Secunderabad to Pune directly is 12220. So that is Secunderabad to Pune directly.

Professor. G. Venkatesh: It is 597.

Professor. Madhavan Mukund: So, let us write maybe, should we write it on this graph itself? In one bracket or something. 597. And if you want to go Secunderabad to Kanpur,...

Professor. G. Venkatesh: Nagpur.

Professor. Madhavan Mukund: Nagpur, that is 85, so Secunderabad Nagpur as already 578, so, you are already in bad shape because in most your distance is already used up in this. And then you want to go from Nagpur to Pune by this 1222.

Professor. G. Venkatesh: Here is Nagpur.

Professor. Madhavan Mukund: So, it is almost 900 kilometres so it is 900 minus 11, 889 kilometres. So, this is a huge detour because now if you go by Nagpur, then...

Professor. G. Venkatesh: You have to add up.

Professor. Madhavan Mukund: 578 plus 889 which is...

Professor. Madhavan Mukund: 13....

Professor. G. Venkatesh: 1467. Am I correct?

Professor. Madhavan Mukund: So, you are doing 1467 versus 597. So, this actually no.

Professor. G. Venkatesh: But something it may turn out like that, you may have to go like that. So, you can, so basically this matrix, this graph and matrix are the same, we have written it using a table. Do we have a name for this table, I mean this table, if we are writing using a table for this graph.

Professor. Madhavan Mukund: So, usually we are looking now at these stations which are connected to each other, so if you look at the connected ones and you ignore the ones which are not connected, rather it tells you which stations are connected, which are next to so it is called adjacency.

Professor. G. Venkatesh: Adjacency.

Professor. Madhavan Mukund: Adjacency matrix.

Professor. G. Venkatesh: This one is called? So the table is called an adjacency matrix?

Professor. Madhavan Mukund: For adjacency matrix basically is ticks and crosses, it tells you is it connected or not connected, and then you add this extra information which gives you some more information about the connection like the train number, the length, the distance, the time it takes and so on.

Professor. G. Venkatesh: So, we can use this matrix, adjacency matrix like equivalent of the graph in a sense? Whatever we want to do on the graph, we can do on the matrix.

Professor. Madhavan Mukund: Essentially.

Professor. G. Venkatesh: Essentially. And which is a table, so it is much easier to process in some sense?

Professor. Madhavan Mukund: Computer.

Professor. G. Venkatesh: So, now the point is that two things we saw we can do, one is that find out whether there is a direct train, just look in the adjacency matrix for tick and now we also found out that you can find out whether there is a say one hop.

Professor. Madhavan Mukund: So, basically for every tick, you go to the row for that tick and see if there is a tick to your destination.

Professor. G. Venkatesh: Like that.

Professor. Madhavan Mukund: So, you check this guy, go to that row and if that row has a tick for Kanpur, you can go via this place to Kanpur. So, you keep checking for each of these

and then if you have multiple search routes, then you can do this thing that we just said of comparing the...

Professor. G. Venkatesh: Comparing the routes.

Professor. Madhavan Mukund: For each route, once we know that we can do this minimum.

Professor. G. Venkatesh: Each route you have to add the distances.

Professor. Madhavan Mukund: We know this. For each route, we can just look up the distances of the two legs and add it up.

Professor. G. Venkatesh: Add it up.

Professor. Madhavan Mukund: And we can now take the minimum across all these different routes to get the best possible.

Professor. G. Venkatesh: Is there possibility that your 3 hops, instead of 1 hop, 2 hops, 3 hops like that?

Professor. Madhavan Mukund: You go from, you could certainly have 3 hops.

Professor. G. Venkatesh: Pune to Delhi.

Professor. Madhavan Mukund: So, then you would again have to look for some tick in the...

Professor. G. Venkatesh: So, in this case, if you look at this guy, we already saw Bangalore if you want to go to, this is...

Professor. Madhavan Mukund: So, in this case, if you look at this graph, we already saw Bangalore if you want to go to Kanpur, this is...

Professor. G. Venkatesh: Or you could go to Vijayawada, Kolkata and Kanpur. Do you want to compare the distances? We were doing it, Bangalore, Secunderabad, Delhi, Kanpur. Bangalore, Vijayawada, Kolkata, Kanpur.

Professor. Madhavan Mukund: Yes. So, first let us look up Kanpur.

Professor. G. Venkatesh: So that is like you know in this table what we are doing then is, this is Bangalore, then you are checking that there is a tick mark to Secunderabad, then the Secunderabad row you are going.

Professor. Madhavan Mukund: Checking a tick mark to Delhi. And Delhi row will have..

(Refer Slide Time: 31:37)



Professor. Madhavan Mukund: So, we have, so what are the stations we are interested in?
Bangalore, Secunderabad,...

Professor. G. Venkatesh: Delhi, Kanpur.

Professor. Madhavan Mukund: New Delhi, Kanpur and Vijayawada.

Professor. G. Venkatesh: Vijayawada Kolkata.

Professor. Madhavan Mukund: Actually we are, we want to go from Bangalore to Secunderabad, Bangalore to Vijayawada, then we want to go from Secunderabad to Delhi. And we want to go from,...

Professor. G. Venkatesh: You can put some tick mark, some indicator that you want that box.

Professor. Madhavan Mukund: So, we want this box.

Professor. G. Venkatesh: We want that box.

Professor. Madhavan Mukund: We want this box.

Professor. G. Venkatesh: We want that box.

Professor. Madhavan Mukund: Secunderabad to Delhi we want.

Professor. G. Venkatesh: Want that box.

Professor. Madhavan Mukund: Delhi to Kanpur we want. And then we also have a Kolkata there. So, Delhi to Kanpur we want a box, Kanpur to anywhere we are not interested. Kolkata to Kanpur we want a box. And then we want from Vijayawada to Kolkata we want this box.

Professor. G. Venkatesh: Not that many. Good.

Professor. Madhavan Mukund: So, once we have this, then we will hopefully...

Professor. G. Venkatesh: Then we can do our problem what we want to do.

Professor. Madhavan Mukund: So, let us do Bangalore Secunderabad we already know there is only train, so it is 12213. So, we can just look it up and sort it out. So, that we had already calculated last time. So, let us do the, once we already know so 12213 from Bangalore to Secunderabad is 688.

Professor. G. Venkatesh: We should put this thing backside, let lost again.

Professor. Madhavan Mukund: I will put back. So, this this is 122 Bangalore to Secunderabad, is 12213 and distance is 688. And now what is the other one? Bangalore to Vijayawada is 02245. Let me put this train back in its place. 02245 so this is, no it is not

02245, 02246. Bangalore to Vijayawada 728. So, this is the only thing that we know actually right now. Then Secunderabad to Delhi, so we did not do that before I think. So, we will have to look at Secunderabad and see what all trains go to Delhi.

Professor. G. Venkatesh: We will compare.

Professor. Madhavan Mukund: So, Secunderabad.

Professor. G. Venkatesh: You can ..

Professor. Madhavan Mukund: So, departure 12213. So, that is 688 2374 so...

Professor. G. Venkatesh: 2374 minus 688.

Professor. Madhavan Mukund: So, that is 1686?

Professor. G. Venkatesh: 1686.

Professor. Madhavan Mukund: So, that is one option. Secunderabad to New Delhi. 12213 1686, then 1222, no, 02285, is that a train?

Professor. G. Venkatesh: So, we have two trains.

Professor. Madhavan Mukund: So, let us see how this goes. So, this is a straight train, 16667. So, slightly shorter. 16667.

Professor. G. Venkatesh: Very very close, 1686 and 1667.

Professor. Madhavan Mukund: Then 22204.

Professor. G. Venkatesh: No.

Professor. Madhavan Mukund: And...

Professor. G. Venkatesh: 12214.

Professor. Madhavan Mukund: 12214.

Professor. G. Venkatesh: 1223 is there. 14.

Professor. Madhavan Mukund: So, it is strange, both these trains go in the same direction is very strange, so this should be going the opposite way, so I think there is some problem with this.

Professor. G. Venkatesh: Leave it, drop it. 12220?

Professor. Madhavan Mukund: 12220 is not there. So, we have these two train. So, we have 1667 is the best way to go from Delhi to Secunderabad to Delhi. Then we have to do Vijayawada to Kolkata. So, Vijayawada with you or I have to take out Vijayawada from this?

Professor. G. Venkatesh: I have Kolkata. Let us compare.

Professor. Madhavan Mukund: 22203.

Professor. G. Venkatesh: 222, no.

Professor. Madhavan Mukund: Then, 222?

Professor. G. Venkatesh: 222 is not there.

Professor. Madhavan Mukund: 02245? So, 46 actually it should be. So, 02246 Vijayawada to Kolkata is 1946 minus 728, so that is 1218, 1218.

Professor. G. Venkatesh: Correct.

Professor. Madhavan Mukund: Then 12270 or 12269?

Professor. G. Venkatesh: No.

Professor. Madhavan Mukund: Fine, only 1 train. So that is done. So now we only one..

Professor. G. Venkatesh: Two more boxes,...

Professor. Madhavan Mukund: So we have to do Kanpur. So, let us look at Kanpur Delhi first.

Professor. G. Venkatesh: Kanpur Delhi? You start with Kanpur and go to Delhi?

Professor. Madhavan Mukund: Do you want to go from Delhi to Kanpur, so let us look at arrivals at Kanpur. So, 12260 does it come from Delhi?

Professor. G. Venkatesh: 12260?

Professor. Madhavan Mukund: 12260

Professor. G. Venkatesh: I was looking at exists from Delhi, it is passing.

Professor. Madhavan Mukund: Bikaner.

Professor. G. Venkatesh: Bikaner.

Professor. Madhavan Mukund: So, here it is a direct thing from Delhi to Kanpur, it is 439 I think?

Professor. G. Venkatesh: 902 minus 463, so 439.

Professor. Madhavan Mukund: So, 1260.

Professor. G. Venkatesh: It is not that far, Delhi Kanpur, 439.

Professor. Madhavan Mukund: 439. Then 73, 12273?

Professor. G. Venkatesh: 73? It is there.

Professor. Madhavan Mukund: So, here it is arriving, so it is going the other way, so there must be a matching 74. 74 is 440, it is shorter. 12274, no it is not shorter, it is 1 kilometre longer 440. Then,...

Professor. G. Venkatesh: 1 kilometre, maybe just a platform, I do not know.

Professor. Madhavan Mukund: 12281?

Professor. G. Venkatesh: 12281, it is here.

Professor. Madhavan Mukund: That is also arriving at Delhi, so there must be a matching 12282 is probably the correct one. 12282 is also 440.

Professor. G. Venkatesh: 12282 where is it? It is here.

Professor. Madhavan Mukund: So, these are both the same, 440. So, it is some 439 or 440. So, those are the trains. So, now Kolkata to Kanpur, so presumably one of these trains also goes to Kolkata, so...

Professor. G. Venkatesh: You want to look at Kolkata to Kanpur.

Professor. Madhavan Mukund: So, this 6061 come. I think this 12260 61 I think seems to be...

Professor. G. Venkatesh: 6061.

Professor. Madhavan Mukund: So, we want to go from Kolkata to Kanpur. So, 60 leaves, it does not go to Kolkata, so, how it is? Kolkata to Kanpur. So, there is some problem here. So, 12260 does not go through Kanpur at all. It does go through Kanpur. Here it is, sorry 61 is the correct one or 59. 59 is Kolkata to Kanpur and it is 1014 kilometres that is 59. 73 we saw?

Professor. G. Venkatesh: 73 is there.

Professor. Madhavan Mukund: So, 73 is departing from Kolkata again. It is 1090, 12273 is longer. 1090. And 81, 82 do you have?

Professor. G. Venkatesh: No.

Professor. Madhavan Mukund: So, now we have done, got everything.

Professor. G. Venkatesh: Now, we do not need the cards.

Professor. Madhavan Mukund: Now we do not need the cards. So, now..

Professor. G. Venkatesh: We will deal the graph, we only need the table.

Professor. Madhavan Mukund: So, now we know that I we do Bangalore Vijayawada Kolkata Kanpur, so then we have...

Professor. G. Venkatesh: Vijayawada? Is that what we want to do, Bangalore, Vijayawada, Kolkata, Kanpur.

Professor. Madhavan Mukund: So, then we have 728...

Professor. G. Venkatesh: Plus.

Professor. Madhavan Mukund: Then Vijayawada is 1218, then Kolkata Kanpur, the shorter one is 1014 and the other version is Bangalore, Secunderabad, New Delhi, Kanpur. So, Secunderabad here will be 688 already shorter, Secunderabad to New Delhi was 1667, so this is a little longer but New Delhi Kanpur is only 439. So, if you look at this, it is almost..

Professor. G. Venkatesh: Clearly, it is really longer.

Professor. Madhavan Mukund: It is about 3000, if you look at this, it is more like 2000, even it is not a huge difference but we could add it up. So, this is 8 16 20, 4 5 6, 7 9 or a...

Professor. G. Venkatesh: 12820, 2 1 3 1 4 and 2 6 2 and 2, 4, 0 plus 2 plus 7, 9. And 1 plus 1 2. 2960.

Professor. Madhavan Mukund: Now, here we have 8 7 15 and 9 24, 5, 11 and 8, 19, 5 11 and 6, 17. It is kind of close. 2794.

Professor. G. Venkatesh: So, it is worth doing it, we will see worth doing. 2794 and 2960, so what did we find? Actually we found that Bangalore, Secunderabad, New Delhi, Kanpur...

Professor. Madhavan Mukund: Is slightly shorter route.

Professor. G. Venkatesh: Slightly shorter route than going via Kolkata.

Professor. Madhavan Mukund: But of course one thing which we had observed the other day which is that if you look at the Secunderabad Bangalore train, it runs only one day a week. So, that is an issue. So, that train is,...

Professor. G. Venkatesh: If you are lucky going on that day..

Professor. Madhavan Mukund: Going on that day, it is a better go.

Professor. G. Venkatesh: Otherwise, go by Vijayawada.

Professor. Madhavan Mukund: Vijayawada I think is more than ones a week, so you can go more often via Vijayawada, but this is interesting.

Professor. G. Venkatesh: You know, with this business of putting, stringing together like this, then adding the distances with this table, with matrix, adjacency matrix you called it, there is some matrix operation which does this, something which?

Professor. Madhavan Mukund: I think you can actually do that. So, basically if you look at matrix multiplication, so what that does is it takes the spares in this row and that column and adds them up, so this is what you want to do? You want to take the entry from here to there and there from there to there.

Professor. G. Venkatesh: So, it is like multiplying?

Professor. Madhavan Mukund: You can get it through some kind of matrix multiplication.

Professor. G. Venkatesh: So, there are some very interesting mathematical stuff going on.

Professor. Madhavan Mukund: So even this thing that we said earlier about this, is there without calculating.

Professor. G. Venkatesh: Without Calculating?

Professor. Madhavan Mukund: Like if we just want to know is there a one short route, one change, 2 hop route, 3 hop route that also you can get by this multiplication.

Professor. G. Venkatesh: Multiplication method. So, multiply the matrices and if the entry is non-zero, it means there is, the entry is 3 it means that,...

Professor. Madhavan Mukund: After you multiply 3 times, of you get a tick, then you have done it in 3 hops, after 4 times you will get it in 4 hops and so on. So, you can actually do this thing abstractly using the matrix without having to do this tedious searching and doing that and get it.

Professor. G. Venkatesh: Because matrix multiplication is not like.

Professor. Madhavan Mukund: Effectively it is doing the same thing but it is doing it in the sense blindly, you are not analysing it specifically.

