IIT Madras

ONLINE DEGREE

Computational Thinking
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Introduction to graph data structure

Professor Madhavan Mukund: So, let us come back to this problem we did earlier about students helping each other. So, we had tried to find two who could match each other in two subjects, so that one student is better in physics, the other one better in maths and they could study together and help each other, so each person is getting something out of it, each person was also doing something useful for the other person.

But supposing that there is a larger group, maybe it could be that, we did it only for maths and physics, but it could be that one student can help another student with maths, that student could help a third student with chemistry, the third student may be able to help the first student with physics. So, do we find those kind of study groups which are not just two people but may be…

Professor G Venkatesh: It seems even, we discussed this earlier also, since that we are trying to setup a relationship between students. We are trying to see which student can mentor another student in a subject. So, there must be some neat way of representing this relationship where one student, if there is a student A that can help a student B in a subject S, it can just say that, I mean I can just say that A can help B in S and write that, represent that in some way...

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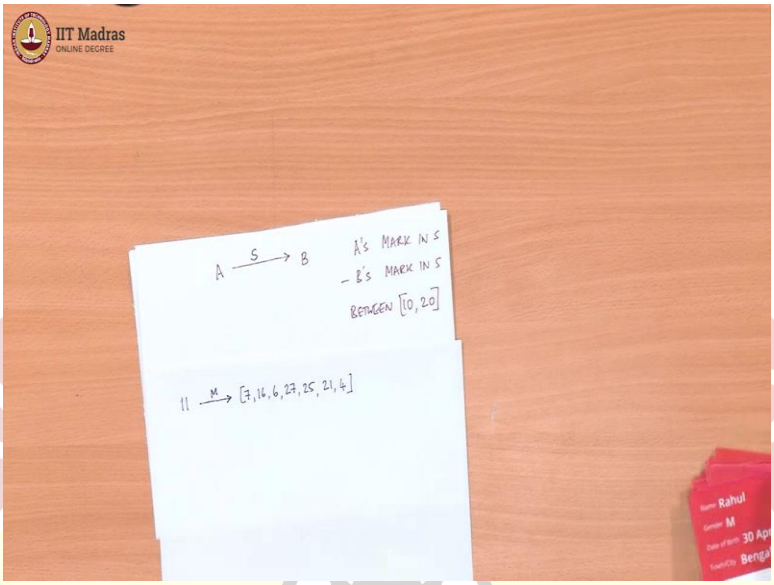

Professor Madhavan Mukund: So, you are saying something like if I have A student and say another student B, and I want to represent that A can help B in S.

Professor G Venkatesh: A can help B in a subject S.

Professor Madhavan Mukund: So, I kind of draw this.

Professor G Venkatesh: Put an arrow and put S on that arrow.

Professor Madhavan Mukund: And then because I want to know which subject it is, I will write, label on top of it something like this.

Professor G Venkatesh: Yeah, if I can do this…

Professor Madhavan Mukund: Then you think from this information, we can do something…

Professor G Venkatesh: I feel that this is very useful information for us to digest how these cards into some diagrammatic graphical, diagrammatic.

Professor Madhavan Mukund: So, then when do we make this connection now? So, in a subject…

Professor G Venkatesh: We have to say then A can help B. I would say that A can help B, if his marks is more than B.

Professor Madhavan Mukund: Therefore, A must be knowing more than B, otherwise this will not make point.

Professor G Venkatesh: Much more than, not just simply 1 or 2 marks more. I will say 10 marks more.

Professor Madhavan Mukund: But should not be too much, because otherwise that difference will be too high, A might not be able to…

Professor G Venkatesh: So, how about if we say between, the difference is between 10 and 20? A's marks in S. S is a subject right? A's marks in S.

Professor Madhavan Mukund: A's marks in S.

Professor G Venkatesh: Subtract B's mark in S from it, that is the difference basically we are saying.

Professor Madhavan Mukund: Minus these…

Professor G Venkatesh: Minus these marks in S, so if you subtract the two marks in S, it should be between 10 and 20, including 10 and 20 let us say. It should be between 10 and 20 inclusive, can be 10, 11, 12, 13, up to 20. We are saying at least 10 because…

Professor Madhavan Mukund: Yeah, there should be some substantial…

Professor G Venkatesh: Some gap must be there, right?

Professor Madhavan Mukund: A must know…

Professor G Venkatesh: And if it is 20 and all that, then if it is more than 20 then, so much better than B.

Professor Madhavan Mukund: A will be not able to appreciate, may not even understand B's difficulties.

Professor G Venkatesh: B's difficulties. So this is a good, I think this may be good better gap.

Professor Madhavan Mukund: So, let us try and see that, so let us do it may be for one subject first and then or should be, so let us try and do it same A before maths.

Professor G Venkatesh: We will do it for maths?

Professor Madhavan Mukund: Yeah.

Professor G Venkatesh: So, we are finding all pairs, means, all pairs means nested iteration, right?

Professor Madhavan Mukund: Yes.

Professor G Venkatesh: We will see, maybe we can do it better because we can reject quickly. So first, Rahul we need to only find people within 9.

Professor Madhavan Mukund: So, I will write down the card number, so that I do not have to write down long names. So it will be easier to…

Professor G Venkatesh: So, only those people who are within.

Professor Madhavan Mukund: Yeah, so we are doing now only for maths.

Professor G Venkatesh: Maths, so 97 means we are starting with 87 just 10.

Professor Madhavan Mukund: And 77, so anybody who is…

Professor G Venkatesh: Between 77 and 87.

Professor Madhavan Mukund: Between 77 and 87 will be, candidate…

Professor G Venkatesh: Rahul, candidate for Rahul to mentor.

Professor Madhavan Mukund: Nobody is going to mentor Rahul because nobody can be…

Professor G Venkatesh: So, it is not possible. So, Rahul is going to be, does not need matric. So, we have to look 77 to 87, so that should be fast to do I hope. So we reject this, we reject this, we keep this.

Professor Madhavan Mukund: 87, 77 yeah. So, we had only Rahul's number.

Professor G Venkatesh: The Rahul's number is 11.

Professor Madhavan Mukund: So we say that…

Professor G Venkatesh: For 11 the list, we are making a list, so 7 is in the list. This is out 97, 63 is out, this is 87 just about; 16. This is out, 81 is in the list.

Professor Madhavan Mukund: 6.

Professor G Venkatesh: This is out, this is out, this is out. This is in the list, 27.

Professor Madhavan Mukund: 27.

Professor G Venkatesh: This is just in the list 25, this is out, this is out, this is out, this is also out, this is in the list.

Professor Madhavan Mukund: 21.

Professor G Venkatesh: 21. This is also out, this is also out, this is just in the list, 4. We are comparing 77 to 87. 52 this is out, this is out, this is also out, this is also out, also out, out, out, out.

Professor Madhavan Mukund: So, Rahul can mentor, number 11 can mentor all these case.

Professor G Venkatesh: Now like that we have to do for everything, we have finished, you have to do for Harish. But when we do Harish, we do, we can look at it again, we have to look at it again.

Professor Madhavan Mukund: Rahul we know cannot get it, but for other people they may be. So let us do.

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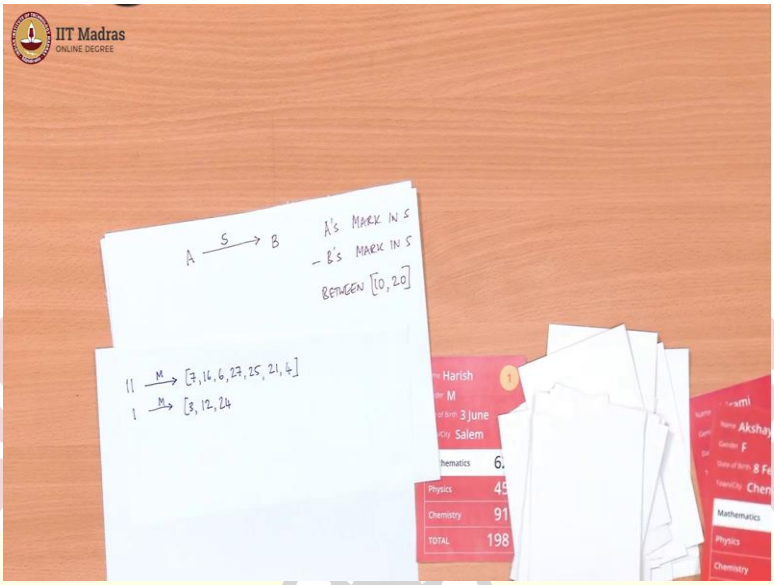

Professor Madhavan Mukund: So, Harish is 1.

Professor G Venkatesh: So 62, so whom can Harish mentor?

Professor Madhavan Mukund: 42 to 52.

Professor G Venkatesh: 42 to 52. So, Rida 3, this is out, this is out, this is out, out, out, 12. See this is a lot of work but once you do this it will be useful for us afterwards. That is the idea. This is out, this is out, this is gone, this is gone, 42 to 52, right?

Professor Madhavan Mukund: Yeah.

Professor G Venkatesh: This is gone, this one is there, 24. This is gone, this is gone, this is gone, this is gone, gone, this is gone, gone, gone, then nothing. This is a small number. So, Harish is done. We have done Rahul and Harish. Now we come to Rida.

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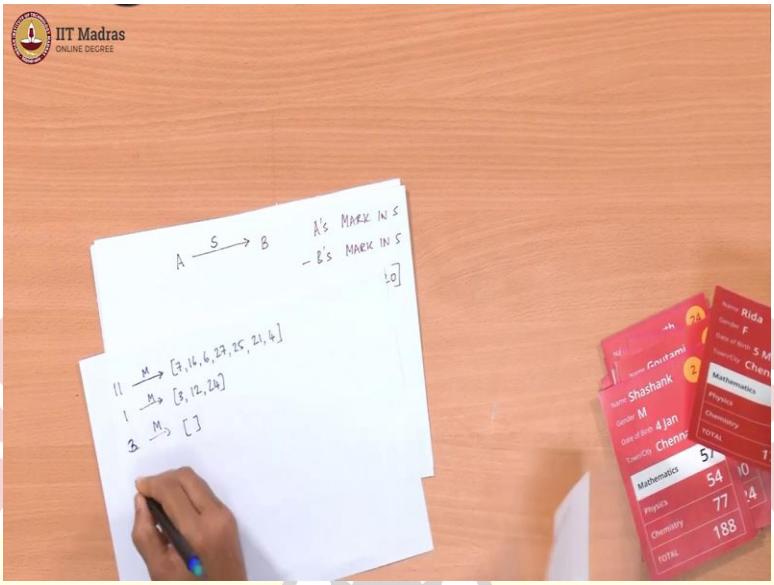

Professor Madhavan Mukund: So, I think 42 was the lowest marks, I do not think anybody has got 32. So, Rida is going to I can just put it as, I will just draw it as an empty list.

Professor G Venkatesh: Rida is done, then Shashank.

Professor Madhavan Mukund: Shashank will be, 37 to 47. So, I think one of them is this one. So, Shashank's number.

Professor G Venkatesh: Shashank is 2.

Professor Madhavan Mukund: Shashank was 2, then Rida is 3 okay, I made a mistake.

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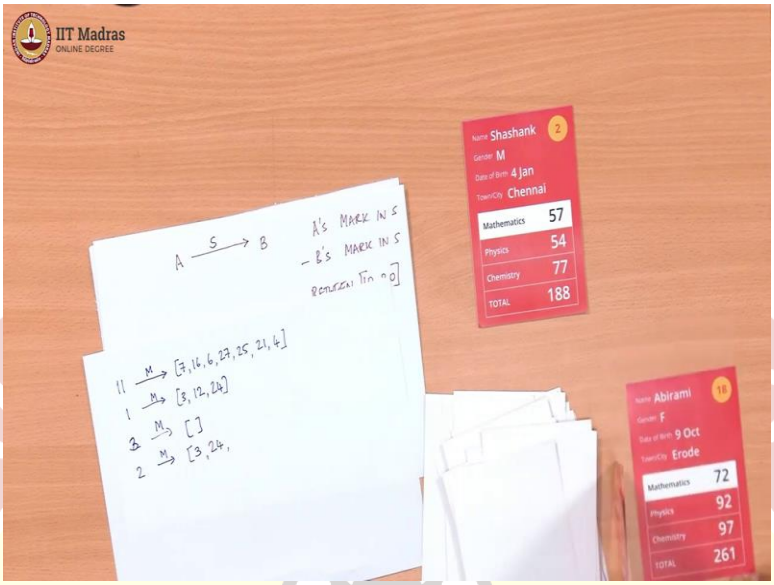

Professor Madhavan Mukund: So, 2 can now mentor 3.

Professor G Venkatesh: And so 2, so 97, 62 are anyway out. 57, so we are looking at 47…

Professor Madhavan Mukund Maybe we will keep that this over here, so we remember which number is left. So, now we going 37 to 47.

Professor G Venkatesh: 37 to 47.

Professor Madhavan Mukund: They are not many.

Professor G Venkatesh: I think we can go fast. 37 to 47. Probably none, okay one is there, it is 24. 37 to 47.

Professor Madhavan Mukund: Okay, done. So, we have done 11, 1, 3 and 2.

Professor G Venkatesh: So, move on to 15.

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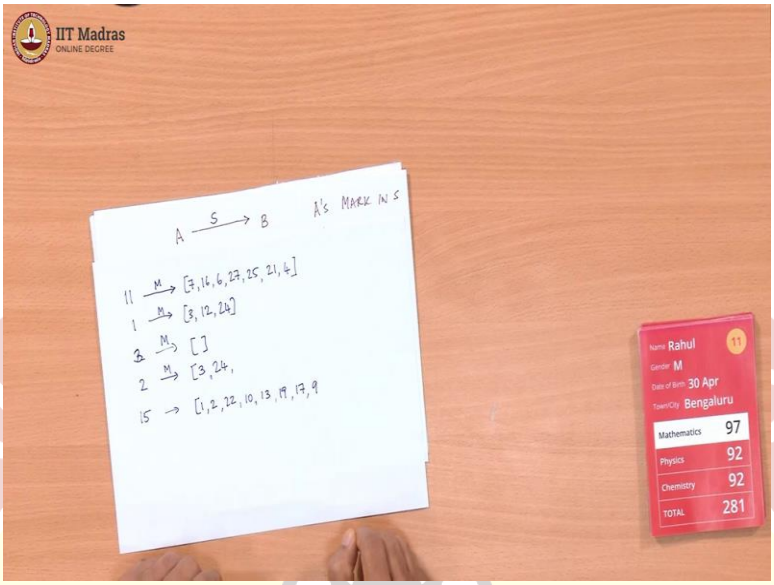

Professor Madhavan Mukund: So this is 76, we are looking at 56 to 66.

Professor G Venkatesh: 56 to 66 you have to go back here. 56 to 66, Harish 1. This is there 2. This is also there 22. Not this, not this, not this, not this.

Professor Madhavan Mukund: No 66.

Professor G Venkatesh: 10, 13.

Professor Madhavan Mukund: What is it one? 81, 56.

Professor G Venkatesh: 19, 17, 9, that is it.

Professor Madhavan Mukund: So, we have done 11, 1, 3, 2, 15.

Professor G Venkatesh: We can like that we can do others presumably.

Professor Madhavan Mukund: So maybe we can, so instead of doing the rest for now, let us see within these 5 that we have found, some groups for whether we can find some, for some other subject, should we do something? Not take this but maybe start with the next group.

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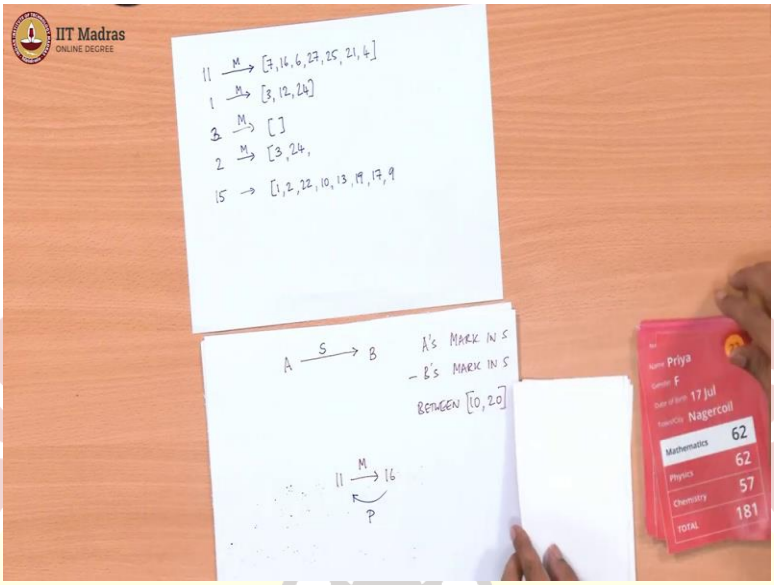

Professor. Madhavan Mukund: So what we want to do is, we want to find out, we will come to find out, whether if we go for example say 11 who can mentor say number 16. So, 11 can mentor 16 in maths. Then we want to find out whether it is…

Professor G Venkatesh: 16 can mentor 11 for example.

Professor Madhavan Mukund: Is it possible? So, it cannot be in maths because this…

Professor G Venkatesh: 11 is greater than 16. So 16…

Professor Madhavan Mukund: Cannot be there. But it could be for example in physics.

Professor G Venkatesh: Physics or chemistry.

Professor Madhavan Mukund: So, this is what we want to find out.

Professor G Venkatesh: So let us, took physics and chemistry we will do also. But do it only for these sets.

Professor Madhavan Mukund: For, we should maybe leave out these 5 and start with the next five and see what we can do.

Professor G Venkatesh: What do you mean by next 5?

Professor Madhavan Mukund: That is in this sequence 11, 1 we have already looked at the first 5 cards. So, start with the sixth card and look for now physics neighbors of the sixth card, which includes the 5 five but.

Professor G Venkatesh: Okay, let us do that.

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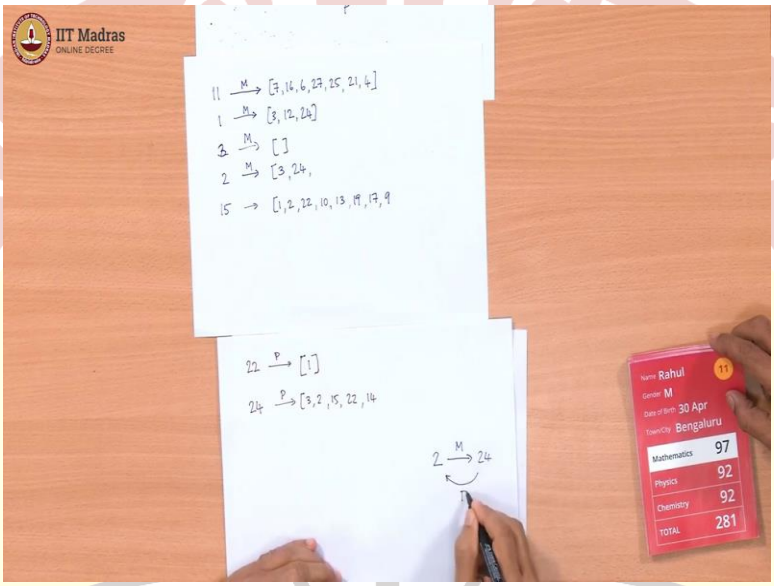

Professor G Venkatesh: So, Priya 22

Professor Madhavan Mukund: Now we are doing for physics.

Professor G Venkatesh: This is finish, offline we will do it, I think we will do it.

Professor Madhavan Mukund: So, 22.

Professor G Venkatesh: 22.

Professor Madhavan Mukund: So in physics, so she has 62.

Professor G Venkatesh: So, we are looking for?

Professor Madhavan Mukund: 42 to 52.

Professor G Venkatesh: So, again we have to see these also.

Professor Madhavan Mukund: In fact, they are particularly interested. So 1, alright.

Professor G Venkatesh: 42 to 52. Not. 64, 64, 68, 69, 71, 72, 72, 73, not likely to find I think. People have scored well in physics, 66, 81, 82, 83, 88, 91, 92, 92, 92. So, we have just only 1. So, we have found I think some pair. See 1 is got, no 1 does not have 22.

Professor Madhavan Mukund: So 15, goes to 22 for example, 22 goes to 1. That does not help.

Professor G Venkatesh: Okay, let us see Chemistry, should we see chemistry? How we do? What some of Physics we do?

Professor Madhavan Mukund: We can do some more physics.

Professor G Venkatesh: Okay, so we start now.

Professor Madhavan Mukund: So we start, maybe little further down, we do not have to start at the next one.

Professor G Venkatesh: These are 62, 64. They will go to some slightly higher.

Professor Madhavan Mukund: So I think, physics marks would be roughly increasing, so we go somebody who has gotten the 70s or 80s.

Professor G Venkatesh: That is 71.

Professor Madhavan Mukund: Yeah JK 26, 26 does not appear here, so let us take that one.

Professor G Venkatesh: We count from there.

Professor Madhavan Mukund: 10 is okay.

Professor G Venkatesh: 10 will…

Professor Madhavan Mukund: 10 or 24? Let us go for 24 then.

Professor G Venkatesh: 24 okay. 72 Siddharth. 72 is you want to do, 52 to 62.

Professor Madhavan Mukund: Yeah.

Professor G Venkatesh: We got to go back here. Not this, not this, this one 3, this 2, Gautami 15, this one Priya 22, Sophia 14, not this, not this, not this, not this, not this, not this, not, not. I think all of these are going to be higher.

Professor Madhavan Mukund: Yeah and beyond that they are going to be above.

Professor G Venkatesh: So, if you had sorted it, it has been made a job to be easier looks like?

Professor Madhavan Mukund: Yeah, looks like.

Professor G Venkatesh: Sorting it would have helped. Okay, here 66 is ruled out.

Professor Madhavan Mukund: 42 to 62 we are looking at.

Professor G Venkatesh: So, this is sorted by physics marks I think, so that is why it is very easy to do it. So, that is it we are done.

Professor Madhavan Mukund: So, I am just trying to see whether…

Professor G Venkatesh: You are already finding a pair forming?

Professor Madhavan Mukund: So, here for instance we have a pair…

Professor G Venkatesh: Which is?

Professor Madhavan Mukund: Which is that…

Professor G Venkatesh: 2 is 24, 24 is 2.

Professor Madhavan Mukund: So, 2 can mentor 24 in maths.

Professor G Venkatesh: 2 is 24 and 24 is in 2.

Professor Madhavan Mukund: And 24 can mentor 2 in physics.

Professor G Venkatesh: Alright, so it looks like the way it works is that once you find these lists, make you some structure here, something like that. We have to see what the structure is it, looks like an interesting structure. We are connecting every node to every other node.

Professor Madhavan Mukund: Correct, so we could actually draw out this thing as a picture instead of these lists like we have started.

Professor G Venkatesh: How do you draw it? I mean what is the structure?

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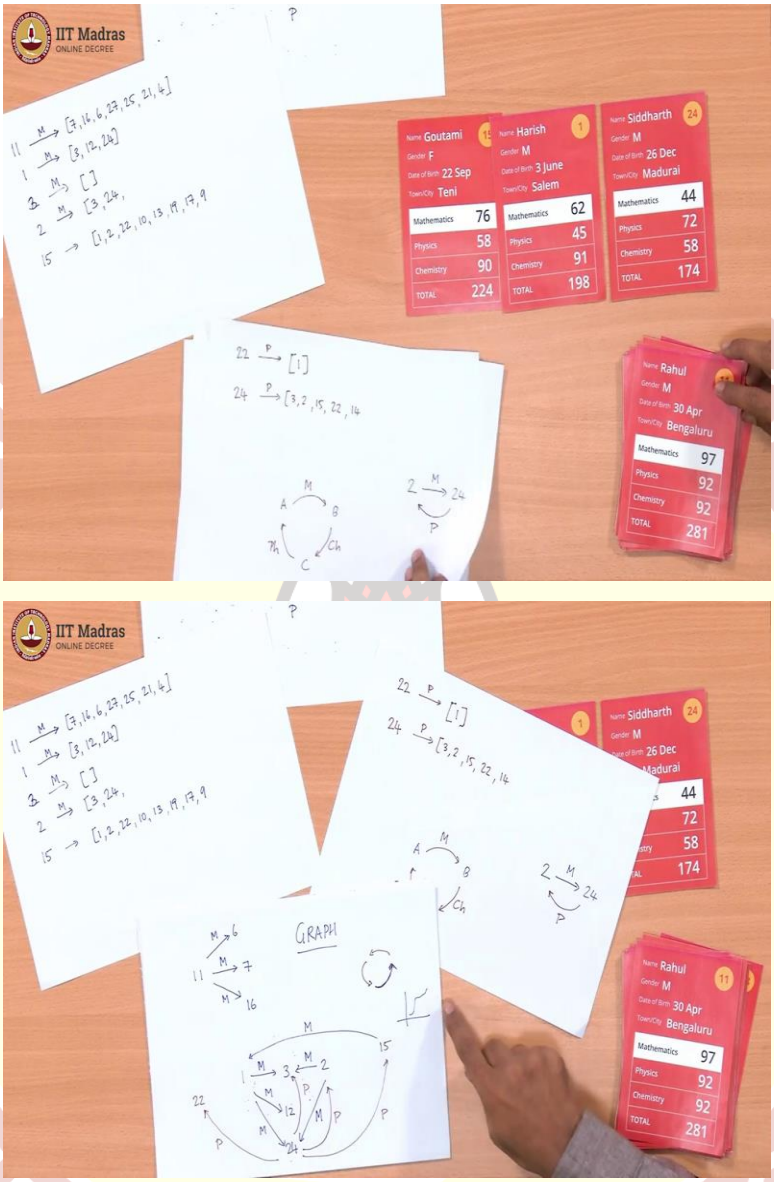

Professor Madhavan Mukund: So I will, just like we have started doing there, so I could draw this whole thing out, so let us keep this. So, I would say for instance, let us just write these numbers. So, I have 11, say 1, so I would say for example 11 connects to 7. And separately it also connects to 16.

Professor G Venkatesh: 16. And then it connects to 6.

Professor Madhavan Mukund: Connects to 6.

Professor G Venkatesh: There are many connections.

Professor Madhavan Mukund: So, 11 has many connections like this. But, let us look at the other ones, so 1 2.

Professor G Venkatesh: So 2, because 2.

Professor Madhavan Mukund: So, let us start with, these are smaller lists, so this is probably easier to draw, so 1 connects, so this is all the maths connections, so 1 connects to 3, 1 connects to 12, 1 connects to 24. And now 2 also connects to 3. So, 1 connects to 3, 2 also connects to 3.

Professor G Venkatesh: I see again.

Professor Madhavan Mukund: And 2 also connects to 24.

Professor G Venkatesh: I see. Like that.

Professor Madhavan Mukund: So, we will have one of these for every because this, every card has one number, so it will come only once in this. And now when we go back and do the physics marks, for instance for 24, 24 is the same 24 then we will say that from 24 we will draw a physics line or physics arrow back to 3.

Professor G Venkatesh: 2 3 was there?

Professor Madhavan Mukund: So, 3, 2 and then 15 which we have not drawn yet but somewhere there is going to be 15. And a 22.

Professor G Venkatesh: 15 is there.

Professor Madhavan Mukund: No, 15 is not yet drawn in my picture here.

Professor G Venkatesh: Okay, okay.

Professor Madhavan Mukund: And 14 also I have …

Professor G Venkatesh: 15 is connected to 1, 1 is connected to 24, 24 is connected to 15.

Professor Madhavan Mukund: 15 is connected to 1, yes, by maths.

Professor G Venkatesh: So, 15 can mentor 1 in maths, 1 can mentor 24 in maths, and 24 can mentor 15 in physics. You notice that there is a cycle here, like this, this is a cycle, this is also cycle.

Professor Madhavan Mukund: Yeah a longer cycle, so like they can form a group.

Professor G Venkatesh: So a cycle, but this is not a cycle, 1 is mentoring 3, 1 is mentoring 24, 24 is mentoring 3 but this is not a cycle.

Professor Madhavan Mukund: Because you go backwards across this arrow.

Professor G Venkatesh: You should go only in the forward direction of arrow. So, similarly 2, 3, 1 is…

Professor Madhavan Mukund: Is not good. You cannot go from 2 to 3 to 1.

Professor G Venkatesh: 2, 3, 1, 24 to, it looks like a cycle, it is connected, but it is not connected in the same direction, it is going in the opposite direction. But here if you look 15 to 1 along the direction of the arrow, 1 to 24 along the direction of the arrow.

Professor Madhavan Mukund: Correct.

Professor G Venkatesh: 24 to 15.

Professor Madhavan Mukund: So, we have this, basically this kind of…

Professor G Venkatesh: So, is that correct? I mean 15, who is 15?

Professor Madhavan Mukund: 15 is the fifth card, hopefully it is still the fifth card.

Professor G Venkatesh: I did not shuffle it so.

Professor Madhavan Mukund: Yeah after 2.

Professor G Venkatesh: 15 Gautami.

Professor Madhavan Mukund: So, Gautami has 76 in maths.

Professor G Venkatesh: And is able to mentor Harish, who has 62. And Harish is able to mentor…

Professor Madhavan Mukund: 24, which was way down.

Professor G Venkatesh: 24, 24 Siddharth. I am going to take out these cards. Interesting. So…

Professor Madhavan Mukund: 1, 15 and 24. You need to get 15 out which is after the 2.

Professor G Venkatesh: After 2 is 15.

Professor Madhavan Mukund: So, these are the 3 cards.

Professor G Venkatesh: How did we say it does, 76?

Professor Madhavan Mukund: I think you are outside the view of the thing. So, we should probably put them here. So, now what we claimed is that 15 can mentor 1 in maths.

Professor G Venkatesh: 15 can mentor 1.

Professor Madhavan Mukund: That is because this difference is between 10 and 20. 76, 66, 56, so this is in the right range. Now 62 can mentor something between 42 and 52, so this can mentor this.

Professor G Venkatesh: I see.

Professor Madhavan Mukund: But now 72 can mentor somebody who has got between 52 and 62. So, coming back physics.

Professor G Venkatesh: So, Gautami can mentor Harish in maths; Harish can mentor Siddharth in maths; and Siddharth can mentor Gaotami in physics.

Professor Madhavan Mukund: Yes.

Professor G Venkatesh: Interesting. Interesting, so we are finding cycles, right?

Professor Madhavan Mukund: So, we are finding these kind of cycles, and the cycles typically will have different colors in the sense of different subjects.

Professor G Venkatesh: In this case, of course both are same.

Professor Madhavan Mukund: Two are in maths.

Professor G Venkatesh: This is not a desirable cycle, because…

Professor Madhavan Mukund: Yeah, so ideally you would like a cycle which looks like…

Professor G Venkatesh: You put different colors.

Professor Madhavan Mukund: Yeah, we would have, I have only two colors, but you would like somebody say three people A, B and C.

Professor G Venkatesh: A mentoring B in one subject.

Professor Madhavan Mukund: So, supposing A is good in maths and mentors B. And maybe B is good in chemistry and mentors C. And C is actually good in physics.

Professor G Venkatesh: So, cycles of length.

Professor Madhavan Mukund: Two also is okay. So, length 2 we already say like this one, maths and physics.

Professor G Venkatesh: So, length 2 or 3 cycles…

Professor Madhavan Mukund: Will form study groups.

Professor G Venkatesh: Form study groups.

Professor Madhavan Mukund: Where they can help each other.

Professor G Venkatesh: So, is there a name for the structure which you created, this kind of diagram which you have made, this diagram?

Professor Madhavan Mukund: This diagram. So, this actually is what we call a graph.

Professor G Venkatesh: I see.

Professor Madhavan Mukund: So, this is not the kind of graph that we study in maths.

Professor G Venkatesh: x, y. you draw x, y axis.

Professor Madhavan Mukund: So this is not a graph like this of some function or something like that. This is a graph which has these…

Professor G Venkatesh: But though this is also a relation that is also a relation.

Professor Madhavan Mukund: Yeah.

Professor G Venkatesh: In that sense…

Professor Madhavan Mukund: So what we have is, we have these…

Professor G Venkatesh: Perhaps it is a discrete. This is something not continues thing.

Professor Madhavan Mukund: Correct.

Professor G Venkatesh: This is a very discrete thing.

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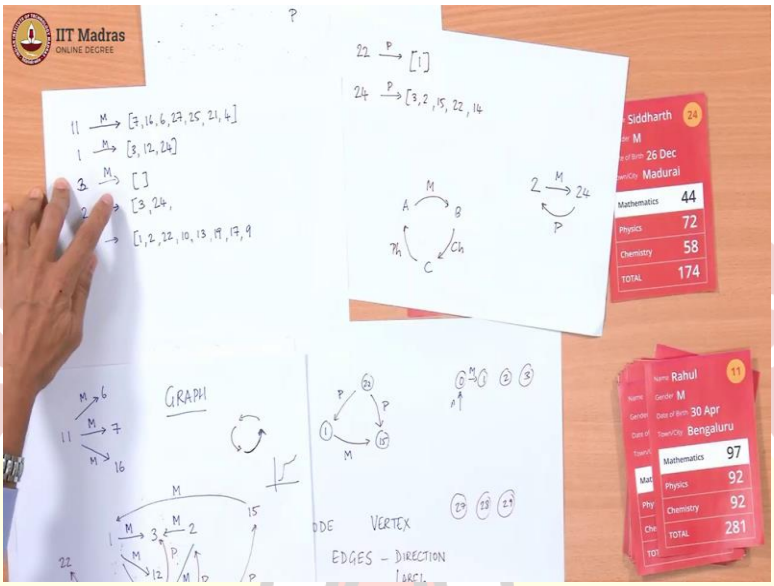

Professor Madhavan Mukund: So, you have these things were we now take these as students. So we put some labels like 1, 15, 22…

Professor G Venkatesh: What are they called, these things normally?

Professor Madhavan Mukund: As a normally we will call them, either we can call them a node or we can call them a vertex.

Professor G Venkatesh: Of the graph?

Professor Madhavan Mukund: Of the graph. So, these are the items that we are trying to connect, these are the things we are trying to relate. So here for us the items are the cards corresponding to the students. And then we draw these connections between them in different directions and so on. And these are called edges. So, edges connect these nodes.

Professor G Venkatesh: And I notice that you put a arrow, so presumably these edges have a direction.

Professor Madhavan Mukund: So, here these edges have a direction, which says that 1 can mentor 15. So, there is with a direction in this case. We might also have situations where you do not have a direction. So, we can maybe look at that in some other problem.

Professor G Venkatesh: In this one there is a direction, and the direction means something. It means 1 to 15, that 1 can mentor 15. And you, you also put a label, where…

Professor Madhavan Mukund: And the last thing we put is a label. So, we put something here like maths or physics.

Professor G Venkatesh: So, it is a labelled edge. So, you have an edge with a direction and a label.

Professor Madhavan Mukund: Yes.

Professor G Venkatesh: So, graph which has nodes or vertices connected, the nodes are connected by directed edges which have labels on them.

Professor Madhavan Mukund: Yeah. So, the nodes themselves have labels, in the sense that the nodes have names which identify the, otherwise you cannot tell…

Professor G Venkatesh: Which node is what, right?

Professor Madhavan Mukund: And then you connect pairs of nodes by edges, so you can say from 1 to 15, there is an edge labelled M or from 22 to 15, there is an edge labelled P.

Professor G Venkatesh: And what we have looked so, the graph is easy to construct because all you have to do basically is inspect the cards and if you find that in any subject between the cards the marks is lying between 10 and 20, then you draw the edge.

Professor Madhavan Mukund: Yes.

Professor G Venkatesh: That does not, then you do not draw that. So, it is easy to draw these edges and it is possible that between 22 and 15 there are more than one edges.

Professor Madhavan Mukund: Correct.

Professor G Venkatesh: So, you could have physics, maths and chemistry all pointing the same direction.

Professor Madhavan Mukund: Correct, yes.

Professor G Venkatesh: For example, if we take Rahul, chances are that there may be many edges going out from Rahul.

Professor Madhavan Mukund: Yeah, because he has high marks, so there will be…

Professor G Venkatesh: Everything, right? It is possible but also it is possible that there are edges going back from 15 to 22 also.

Professor Madhavan Mukund: Yes.

Professor G Venkatesh: But you cannot have one P going from 22 to 15, another P going from 15 to 22.

Professor Madhavan Mukund: Because one, if it is bigger than one direction, it has to be very smaller than the other direction, so then the edge cannot…

Professor G Venkatesh: So it is not, it is not possible also that there is a cycle with all Ps.

Professor Madhavan Mukund: Correct.

Professor G Venkatesh: 22 to 15, 15 to 1, 1 to 22, not possible because…

Professor Madhavan Mukund: This cycle for instance has 2 maths and one then physics…

Professor G Venkatesh: That is possible.

Professor Madhavan Mukund: But you cannot have 3 maths because that could mean that 15 is bigger than 1 is bigger than 24 it is again bigger than 15. That is not possible.

Professor G Venkatesh: Not possible, it is a paradox, it is a contradiction. So…

Professor Madhavan Mukund: So any cycle in this particular graph that we are drawing with this subject thing, will have…

Professor G Venkatesh: Cycle will have some fix length only here because you know, I mean you are increasing by 10 marks, so…

Professor Madhavan Mukund: Yes, you cannot go indefinitely because if you go across this, you are at least 10 marks less, at least 10 marks less, at least 10 marks less. So, if you have crossed say 6 steps, then you have gone down 60 marks and probably nobody has got less than 40.

Professor G Venkatesh: So, you will have some numbers of edges 10 and then after you can do physics some numbers of edges like that. So, you will have only some length cycles but anyway

it could be quite long, we do not know. But right now we are interested in finding cycles which are may be of length 2 or length 3, ideally three.

Professor Madhavan Mukund: Yeah, 3, but 3 we would actually like this kind of…

Professor G Venkatesh: Different edges.

Professor Madhavan Mukund: We like this kind of cycle, it is not very useful I think to have a study group where a student, say the number 1, is both learning maths from 1 and also teaching maths to 1.

Professor G Venkatesh: And also teaching maths because this guy will feel bad.

Professor Madhavan Mukund: Yeah.

Professor G Venkatesh: But in the study group 24, is going to feel terrible, right?

Professor Madhavan Mukund: Because he is already getting second hand information... So, this is a kind of group we would really like to…

Professor G Venkatesh: Highly like to be a group. So, since we are looking for cycles of length 3.

Professor Madhavan Mukund: In the big graph, which we have done this whole calculation…

Professor G Venkatesh: Cycles of length 3 with all 3 different labels.

Professor Madhavan Mukund: With 3 different labels.

Professor G Venkatesh: Or cycles of length 2. Because cycles of length 2 will always be different labels.

Professor Madhavan Mukund: So, in this graph for instance we know that all the cards are numbered 0 to 29. So we would have, effectively we would have these 30 different vertices all the way up to 27, 28, 29. So, we would have this and then as we examine the cards, we will start inserting these edges, this is maths or this is physics and so on. And then in this picture that we build from this, we would then start looking for these interesting cycles.

Professor G Venkatesh: So if want to find so what is the method of finding the cycle?

Professor Madhavan Mukund: Well you can start in some way.

Professor G Venkatesh: Randomly we can start?

Professor Madhavan Mukund: Start somebody and see, pick a neighbor.

Professor G Venkatesh: Pick a neighbor in the sense that it…

Professor Madhavan Mukund: Somebody whom it can mentor, student whom that person can mentor.

Professor G Venkatesh: By looking at this graph?

Professor Madhavan Mukund: Yeah.

Professor G Venkatesh: Graph itself here looks like it is easy way to maintain the graph, because I will just keep the lists.

Professor Madhavan Mukund: Correct.

Professor G Venkatesh: It is a bunch of list.

Professor Madhavan Mukund: For each label, we keep a list of neighbors on outgoing mentor possibilities for that label. So, these are all the maths students whom 11 can mentor, similarly, these are all the physics students whom 24 can mentor.

Professor G Venkatesh: So it is just a bunch of…

Professor Madhavan Mukund: So, we have just 3 lists for everybody. The list could be empty like 3 cannot mentor anybody in maths, this could be only one item or the list could have many items like this, depending on how many…

Professor G Venkatesh: So, you have 3 lists, so three basically has, if you take 3 it will have a list of students that 3 can mentor in maths, can mentor in physics and can mentor in chemistry. So, 3 lists. Like that for every node, which means for every node, node being a student, for every student or every node we have three lists of, is it called adjacencies or what is it called?

Professor Madhavan Mukund: It is called, yeah adjacency…

Professor G Venkatesh: Adjacency list, neighbor list, list of neighbors?

Professor Madhavan Mukund: Yeah, adjacent people who are next door.

Professor G Venkatesh: Next door, adjacent door. So neighboring list, so neighbor, list of neighbors of things. And now you are also labelling the neighbors, not only the maths neighbors, or physics neighbors and so on. So, you have 3 lists of neighbors for every node and that is a graph.

Professor Madhavan Mukund: Yeah, then we can draw it as a graph.

Professor G Venkatesh: You can draw it out as a graph because 3 may have a neighbor which is 4, and 4 may have a neighbor who is 7, 7 may have a neighbor who is somebody else, and that guy might have a neighbor who is again this person again. So it can come back, that is how we get a cycle, you get a cycle, going round. And what we are interested in is finding these cycles, because we want cycles of length 2 or cycles of length 3.

Professor Madhavan Mukund: So, these are the study groups.

Professor G Venkatesh: So, it was a study group. So to do that, if you want to do that systematically, I think you start with some random node.

Professor Madhavan Mukund: Well this is one way, start with the first node for instance.

Professor G Venkatesh: Okay.

Professor Madhavan Mukund: Then you pick, say a maths neighbor of that node.

Professor G Venkatesh: Find the maths, find the neighbor.

Professor Madhavan Mukund: So that will have some subject, so now we want to find a neighbor of the next person which is not the same subject because we said we do not want this kind of a group which has two edges on the same time. So, if you have chosen maths the first time, you have to find a neighbor who is, say a physics neighbor. Then you have to see whether one of those guys has a chemistry neighbor back.

Professor G Venkatesh: So, basically you are searching for cycles.

Professor Madhavan Mukund: You are searching for cycles. But you have to try it out for every…

Professor G Venkatesh: First you can try two pair cycles of like two, which is easy actually. Then I just have to find a neighbor in whose neighbor list I am lying.

Professor Madhavan Mukund: Yeah, in a different subject. Obviously, it has to be a different subject as…

Professor G Venkatesh: I has to be in a different subject. So if I start with a neighbor in maths, then I look in the physics and chemistry neighborhood list of that node, to see whether I am present in that. If I am present in that just like the train we saw, if I am present in that, then I can form a pair.

Professor Madhavan Mukund: Then we can form a group.

Professor G Venkatesh: And I, so once I form a pair I take that pair out. I can take it out.

Professor Madhavan Mukund: Take it out.

Professor G Venkatesh: Like that I can keep taking out. And which will hopefully everything will get caught.

Professor Madhavan Mukund: Yeah.

Professor G Venkatesh: Some of the guys may have left out. We do not know.

Professor Madhavan Mukund: Yes, then you had to go back and start again

Professor G Venkatesh: We had to start again.

Professor Madhavan Mukund: Yeah, but that is a different question, I mean how do you found the best, best kinds of groups with this to make sure nobody is left out.

Professor G Venkatesh: So, if you want to find the best groups one way would be to find us a group, first find a group. Find a study group, get this all this pairing cycles you find, extract all the cycles, write down the cycles somewhere, then come back and do the whole thing again. Start from another node.

Professor Madhavan Mukund: Yeah start with a different, start with a different place and see how it…

Professor G Venkatesh: How it evolves, right?

Professor Madhavan Mukund: Yes.

Professor G Venkatesh: Maybe this is better than that, maybe this is worse than that, I do not know. If it is better than that, discard that and keep this.

Professor Madhavan Mukund: Yes. So, for each starting point, so we can even do it once for every starting point, so you can, it will take a lot time depending on how many nodes we have. But in principle we can try and do this for every possible…

Professor G Venkatesh: See this is interesting, I mean what we have created is an interesting data structure. I mean this looks like a very interesting thing because a lot of information is stored here in a very compact form.

Professor Madhavan Mukund: Yes. So, this picture actually captures a lot of information, these relationships between these cards, the cards are our nodes and the different types of relationships. So not just one type of relationship, but different types of relationships we have.

Professor G Venkatesh: They are all captured and they are using all of it together to find something.

Professor Madhavan Mukund: Yes, so, so what we are trying to calculate or compute is actually something to do with structure of this relationships. So that is and we can do it much neater when you that relationships drawn out for us, rather than go back and look at each card. That is what we have done the first time and we are doing this mentoring, we were trying to look at two cards and decide whether this is bigger than that, that is bigger than this. So, once and for all that information is captured in this picture and then we can…

Professor G Venkatesh: As a form of a graph.

Professor Madhavan Mukund: Yes. So, these graphs are very useful.

Professor G Venkatesh: Okay.