### Algorithms\_week3\_lecture2\_3-20240914

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You are worrying about this is too difficult, probably. Will the examples be very difficult? For now? I only say the algorithm analysis task, not a babysitter, just didn't see that yet, but another part, basically, the major goal is to let you know how to analyze areas. Not design evidence. Do you remember? This is very different because design is more difficult than analyzing water. Sometimes more difficult because you think about the reasonable average. That's not so easy. The focus will be on analyzing, which means usually i'll give you aa problem. I tell you this is an algorithm, please. And I hope that this algorithm is in terms of approximation ratio, or in terms of running time, et cetera.

Okay. So this will be very likely one question in midterm or final exam. All right, only one. And then later on, in the game theory, you will know, actually, for game theory part, some subjects are very easy. There is some standard calculation possible. Those are easy parts, right? Let's come to the independence. Now, I will show you the same figure this and show you the same solution. I how likely it could be the same thing again.

Now I tell you, now please treat the blackness as a solution. What's the nature of the blackness? Why don't this right as well text up? What is the blackness? What's the nature of the black notes? Are there any edges in these letters? No. Why not? Because if there's an edge between black rules, then one goes on the local vertex cover, right? Ok do you know? Every edge? You need to have one little one white vertex, right? Ok so if there is actually black, not possible, then why is not that accelerate? You didn't have a reaction. So that's why there's no edge between black notes. Then we call the graduates independent set, no connection between each other. Right? So independent set is trying to find a maximum number of vertices or notes that, right? It's called maximum independent set problem.

Now, again, you can do three d I want to see that as many nodes as possible. And the first known as that I do not want, there's no you catch too many other notes, right? I wanted my selection catch very few notes. They don't have more choices to see out of those, right? Ok so the greedy now, because of what people know, which actually is very few notes, right? Ok so let's see. This week, every time I pick the vertex, will know that has a minimum degree in the remaining class. This method, actually, it is not good. Why are we gonna see? This is bigger. Then in this figure, we have one vertex x on the left, and n nodes and vertex vertices in the middle. Then x connects to all these n there is a so called clique on the right kn what is knkn means you have n nodes. Each pair of nodes have connection.

It's a very good dense graph, many edges in this area, every pair as a dash. And then I left book, sorry. I let the v any vi connect to all the nodes in km this is only I I only draw one, but actually, it is many. I connect any node in cayman.

So in this scenario, if it's really, then which node do you see that? First? You see, like a node with the minimum number of we know the name around. So which one do you see at first? V one, v one. I remember, I said, from vi right? V one, v two, they connect to every node in kn we connect every node in here, their degree as well. As x very good. X has a degree n but all the vi has degree n plus one, because there are n edges here, one edge here. Every di has n minus n plus one x kn even more, right? Kn the inside, or the n minus one edges, they also can outside. You want to be three, two, n therefore, the first one is that is x how does it? X the middle layer is not there. Right? Because they have mentioned.

All right. And then you are left with the one on the right here. But pm is a so called clique. So all connections inside. You see that one node, you can no longer say that any other, right? Because we know that every two has an x right? You see that one, then other than other things will be just not possible, right? You cannot see that. Now, you see greedy algorithm can only say I have two nodes, right? How many optimism? And very good optimal set for the middle layer, they have no connection with each other, right? With each other. Select orderly will be optimal solution.

Now you see, optimal is m right? Everything's up to what's the ratio? I remember, this is a maximization. The ratio is reverse, right? The two over n that is arbitrary close to zero. It's a very bad issue, ok it's a very bad issue. And actually, for true, why when you see the table heading. Yeah. So actually, people prove that you cannot do better than maybe ii partly products. So basically, it tells you you cannot do better than this kind of approximation. Okay? One over n to the power, something if optimal solution can see that a lot of those you can use their feet. N roughly one over n this is the best thing to do. Roughly, I then there is a very strange thing here. First of all, when you see this figure, the many set problem is the opposite of the textile track. We already know indiana set is opposite of the textile, but we know the texture has a very good approximation time. But I also told you independent seven has very bad proximity.

The first one, this question is, why is what happened? Why burton server has a very good confirmation, but intensive has a very bad confirmation, although they are optimal solutions correspond to each other. So if I have multiple solutions to the next level, I reverse. It becomes optimal solution for intensity for sure, because you are minimizing the vertex for the size, you are maximizing the intensive size. If limits of reach possible, it depends that also reaches oftentimes optimal solution corresponds to each other. But why approximation ratio can differ that much? Right? Is the first one's question? Any idea? I know it's time.

Now, the second one is question. They are just second, okay. You see the prosecution issue for independent said is very bad, right? But independent said can be solved very quickly in some special graphs. Did you remember, what can you recall any special ground where the intensive problem can be solved? Very easy? Right? Disabled expression can have more than one answer. The reason I asked you this is because we somehow covered it in the first lecture, is not out of this time, is something that can be referred to.

Now, 1 million bonus time. You can't say any question, either explain why they differ a lot, right? Tell me which graphs you can say is easy. That's why I say, better know what I will explain last time or in the previous lectures that will help you to get a bonus point in the future. Anyone to let me try? I think the very good tree.

So the opposite the second bonus, right? Because the last time in the last lecture we talked about, so you still remember that terminology we use in that example tree, we can use cp right? Dp on tree, you can solve some problems. What do we call it a very informing? Right? Want to say that somebody can join a party. Right? What do we call it? But you get all the story trees on the grounds you're talking about maximum convertible, the maximum comfortable group, right? Okay. Right? Actually, that one is exactly independent set, because we said we do not want any connection between the two people we selected, right? In the group. That's exactly independent set, right? Ok so this is one thing. Now there is the second thing, but it's okay, not to catch. The. Second thing is a bit, too, to advance, although we also mentioned that, but we didn't mention that graph. We also only mentioned the tree. All right. But feel free to let me know if you have any idea about the some topics we cover in the first lecture, which they also allowed men set to be solved fast, even though you didn't attempt to do that yet.

So now we come to the first one this question. Why the constitution can be heard that much possibility of approximation. It's just too different for the two versions of the problem. This one is really not so easy on us. There's a a it's a challenging bonus, but let me write down something. This is a hint. What do I like? This is approximation ratio. Then 81, let me ask you only stuff often very good, ok 81. You have what is able to hold for profit situation. And also this is okay, right? Now it's this one. This is independent set. This is the test, right? Because they come from each other, right? The text server invested as a then, both of them might say, right? Okay, so this is true so that you must have to be very bad, which means o can be a big value or maybe relatively good value for the only half hand. But a is very small. So a is very, very small area, ok and o is a normal man ok only, this is the case. Then your ratio will be very bad, right?

So it's more, no. Now you go to vertex cover. N minus a becomes very close to n this is a big number, very close. How about n minus all? This is still normal, right? Because always normal, no means could be n half n then if you do n minus half n it is still half n this is simple n over a normal value.

This has to be very well. Will this be very bad? No, right. It will not be bad. That's why approximation ratio, because the comparison base is different. The other is one of them you're comparing with a but we told them the other way you can do with n minus the base is different. So one problem being difficult does not mean the other one. Is it right? Or is it bad? All right. So that's the the reason why. Okay. Now, this one, I will see this part of it. This basically says that if your degree of the graph is small, then dependent sets probably has it approximation. And the element is very easy. Every time you pick up the test, I don't know. And then remove the neighbors of the default of this vertex, and then the remaining graphic, another vertex and remove your neighbours.

This method. When it's a general graph, it's very bad, but if the graph has a bounded degree. In other words, if the the degree of the number of neighbors of any node is, at most delta, then it is a delta plus one approximation. This approximation is very easy to derive. Basically, it says, I just let optimal solution take everything. I assume optimal solution can take everything, but actually, it cannot. Right? Ok but the best optimal solution can do is, yes. And then what is the greedy algorithm doing? The greedy algorithm says, whenever I pick one vertex, I only sacrifice delta, other words, right? And pick one sacrifice sale and then another one sacrifice sale, right?

And then how many can I pick altogether animals, right? So I can comment it's very i'm gonna pick so many notes, because I pick one sacrifice delta, pick one sacrifice delta. That means for every delta plus one vertices, I can pick one vertex in my solution. I just divided n by this delta plus one. This is the number of vertices I can pick in my reading solution. This is rather than equal to optimal divided by delta plus one. Right? Because I said optimal in the best case, we think of it, right? Okay. So that's enough.

That's very easy, right? The other plus one approximation. Ii think it will be the easiest ever approximation you will analyze. Iii I will not be spending too much time here. Now, it's time to come back to that problem to see whether we can have a fast algorithm, but slightly worse solution. Because knapsack has a f penis or penis, right? It takes a long time to get a good approximation, right? And then scenarios, pizzas, even after class, they are not realistic. They have a hidden, big concept there. So in practice, people will not use those, although they have a good guarantee, right? But usually the order is, here we are trying to see whether we can design a better algorithm, faster algorithm. But although the performance is slightly worse, but still, it's not too bad.

Let's see what you can do. Now we are going to formalize the nasa problem also in a linear program. Here, this is the integer program. We have we want to see that some items, xi equal to one means I see that I I make sure the summation of cost is m os b I want to maximize the value of the select items, maximize the value subject to the budget restrictions.

Okay? Now, we realize it to be fresh, the normal linear program. Now let me write down something. What is the optimal solution? If you can cut items, define item value 100 and coming to half, I have value 50. If I do this, what's optimal solution? I can't. What's the institution? You choose the largest density point. We can call it density ok per cost is very valuable. Then you choose those items first. Right? Because you can't so that we call, we divide value by the cost, you call the point density of ice. You start with the largest density island first. If I can take it all, then take it. All right. In the second month, take it third, take it. That at some moments, you cannot take the whole item into your collection. What do? You mean? I just come back tonight, thickly fit the budget, and then take that part, right?

That's the best solution you can ever imagine. Right? Starting from the largest vi over ci a this is a element fraction solution. This is the album one. Example. Suppose item one has a cost one, value two, and item two has a cost end, value end. You see the ratio, the density item one is two, right? That is to divide by + 1. Item two is one. Right? Anybody? If you compare this density, I don't want is more valuable, right? So take anyone first. You take the higher than one. And if I have two ok how much do you take? You can take the fraction, right? You can take this fraction, m minus one divided by m that will fit the whole next exercise, right?

Next budget.

And then that is very but this structural solution, there's no way to get an integral solution, because if you still do rounding, what happens? You run this n minus one over m to one. That means you take all items. But that must not make sense, right? If you take both sides, your budget is violated, right? It's gone. So you cannot be running here. Then what can you do? Here? Iii think this is a very important message. You will take home after the lecture. Okay? This is very, very interesting technique.

Let me show you the the okay, two ways, right? If you give up the second item which is cut, then the average is very bad, right? If you only take the first item, 221, sort of a second item, the proposition, which is very bad. So you cannot do that. Right? Now, we look at the optimal value of the linear program, v one plus v two plus v three. So remember, this v is sorted according to vi over ci this sorted by this. If taking some v and in the end the last item, you can only take a fraction of v this xi can be half or 1/3 or 14, right? It's a fraction. Okay? Now, there is some good news about the optimal value of this media program is definitely less than this. This means you take the whole item, buy, right? Because in fractional solution, you can only take possible, right? But if I allow you to take hold of, I then definitely this solution is better than optimism, right? Even larger optimal solution, you see the optimal solution value will be bounded from above like this.

Now, before I go on to the solution, I would like to ask whether some of you have heard about the some machine learning, classifier, methods, which assembles multiple weak class fires.

And it comes aa stronger after aggregation. For example, each of the classical, remember, classifier is give us an input. It will tell you whether it's true or not, right, true or false, true or false. Right? And then you have multiple, they are very weak, each of them is weak. Their answer may not be accurate. Maybe this one tells one. This one tells zero. This one tells you it's also one. This one tells you this one. How do you get the answer from all the weak class? 5 years? You make every decisions, then I think this class should be one. Now, if you make the collective decision, this huge classifier, the performance could be very good, although each individual component is weak. All right? Now, if I remember correctly in another class, so maybe it's called other groups or something. It's kind of boost. You are boosting weak classifier to be a strong classifier. So here we are using similar methodology. So we know that throw throwing away the second item or the last fraction item. It will give you a very bad approximation, right?

Now I say then maybe I can choose the better solution of two algorithms. The first algorithm is, I I do throw away the last item. Only do you want me to enter the island ok so the last the second everyone says, I believe the last as well with it. The black piece, take the mask.

So now you see, actually your two solutions. One of them is taking this part, right? The other one is taking this part. Right? Although I don't know which one is better, I can compare it, right? I can compare these two species to see which one is better. I think this is something like ii designed two algorithms for the same problem.

These two algorithms of different pieces, they have different performance. In some instance. This is better, right? In some instances, this is better. All but no matter which one is better, I just keep it better and run both errors among the business and take a better solution. And i'm going to show this better solution is very good. It's just like 2 week algorithms, right? Each one of them is not good, right? If you just apply everyone, how much time? If you just apply everything too, it's also not true, right? But if I combine them, it becomes now see what's my solution. My first algorithm takes this part, your performance that better than this, right? Or at least the same as this. My second algorithm. I take this part, but take this part, I can be even more ambitious. I say I would take the most valuable item from my collection, because vi is one, right? One item of the possibility of possible selection.

Now I take the best item, I take the one with the largest value. It must be better than the iron. Ok I take the largest anyone, it must be better than the iron. And this algorithm, too, we will have this quality. Right? That was the tools out there. It's better than five.

Now. What do you have? Error one is better than e one plus e two plus ei minus one. L two is better than ei so how about if I act after the monday I was into together? What is that? It's better than optimal union pronunciation? Is that right? Because you see this is better than right, ok so you have the valuable algorithm one and algorithm two together. It's better than optimal. The optimal lp is better than the true optimal, because optimal lp means you can cut items, right? It can't happen. You get so much that if you cannot cut, you can only get few. Right?

So now you have two algorithms stand up to be better than optimal. Then if I take a better solution within the issue, then how good it can be? I return this maximum of algorithm and evolution. This must be larger than at least half of the optimal solution. Is that right? The algorithm, the two algorithms act together. That's an help. If I take the best version of these two, it must be larger than half of them. Right? That's very encouraging, because using this very simple method, you are able to achieve two of us or half of us.

This is something which ii don't want, because it uses the single elements, combine together to become a strong empire. Right? What you need to do is just take the best solution returned by all the individual algorithms. Right?

Now, I believe that maybe in the near future, you you probably can also use some similar idea in your audience. Any questions here? If no question, we'll move on to the last problem, traveling salesman problem. So this is also a very classic problem. I believe that some of you have learned it before. And so for completeness, it just explain a better. Basically, you have a network or a graph on this graph. Notes means cities. And the edges means roads. And the numbers on the edge means how long does it take on to reach on b to d right here? Right? This is a business. This is a now, what is the tsbtsb says, I want to start from a note like this, like a all right? I want to go through every node in the middle, and then finally go back to the starting point. I guess I want to do this kind of traveling, okay, across the visiting every node, every city in the middle, and then going back to the signs, I want the traffic distance to be as soon as possible.

You have many such tools, all kinds of smaller.

Assume the graph satisfy the so called triangle in policy. In other words, if you go from a to g and g to c it will be more costly compared to going on acr now, when you have this, then it means that if you have a detour like going like this, it's always worse than going from a to b although some edges I didn't draw, actually is there.

You see, this is another complete graph, but the cost of the triangle is policy. It should be a complete one, right? Going to some middle notes. And then somewhere, it is not as good as the insurance. Right? All right. Now, one thing you notice is that how to generate a so called tool, right? Visiting every noting exactly wants to go back to the beginning. If I remove one edge from the two, it becomes a so called spanish, especially. All right. What is benefit of benefit means? I guess I will catch every rule, right? And at the same time, i'm connected. I'm also a tree. I remember there's a tree, the 77. I will not deliver into the concept, because that belongs to the infrastructure costs.

Now, remove one edge, it becomes a minimum span about a spanning tree. And among all the spanning tree, there is one called minimum spanning tree. Ok there is a minimum spanning tree, which means that spanning tree has the smallest cost or smallest travel time of all the edges. Now, we can show that tfb the length of tsb is at least the length of minimum symmetry, because you see psp. After removing one edge from pspi have a news. I have a spanning tree, right? That means your psp must be one edge more compared to the spanning tree.

This direction is very straightforward. Now we focus on another direction, the other direction. The other direction is like a tape of minimum spanning tree. Then I try to visit all the notes according to some traversing sequence. For example, I start with one and then go from 1 to 2, and then two back to one, and then to three, and then 3 to 44, back to three, and then to five, et cetera. So I can visit all of the edges twice and make it a so called tool entry, and then did what edges in some way that they can close to. All right. So the picture you see here, right? It's according to some search, that's a search for something.

So now, what the, let's say this is not a problem, not atsp solution, because one vertex, right? You visited too many times. I don't want to go visit no, once exactly in the right. But I can do that. Why do you see 1 to 2 and then two back to one? This is not necessary. Instead of two back to one, I can let two over this three, like this 2 to 1 or 3, maybe 2 to 3. By doing this, I only reduce the total traveling, right? Because of what? Triangle inequality. Right? Okay. I can do similar things, 34, and 42. Now here is 4 ~ 33 ~ 5, and then make it 4 ~ 5. So eventually, I have this kind of general. Right? This tool has a shorter lens. Compare this, right? What's the length of this? One has a length two times opc or two times the nst take me, show you the population. Okay? This is 2 times of this, right? And by doing some shortcuts, I get this one. And this was held, right? Everything is less than equal to two times mst now, because mst is less than obt a algorithm is less than two times obt this gives you a two approximation for tsdr okay?

And then later on, with aaa smarter analysis, people can improve the two to be 1 . 5. This 1 . 5 remains the best result until very recently. It's broken by some scientists. And that this this basically is a very important. My phone, although this improvement is tiny, somebody told me hope is great. It is the equivalent is ten to the power of - 26, which means that improvement is 0 . 0001. The ratio will be 1 . 4999 about 9.

Okay, so anyway, it's an improvement indeed. And although the improvement is a tiny, the result is very simple. Now, so I guess this part, some right now, we also have a general case where the triangle inequality does not hold. Ok the general case, what can we do? Can we still do the two of our mission? If not, can you do log in approximation, or we do an approximation? In the remaining time, i'm going to show you, actually, you cannot do any approximation. Right? No matter how bad it is. Can I do that? You will be the first time learning how to prove in approximately with us, because learning any lower balance, which means this problem do not have a better than two minus epsilon approximation. All of these slow downs are only tell you as a knowledge, right? Some people show this if somebody shows, I never tell you these days because it's too complicated, but this one, we can't do it, because it's not complicated. It's the first ever, right? Only 50 and go on, which can be proved in the proper sense in this or maybe in this course.

Okay? The answer I already told you, there's no point of time fn approximation. If this fn can be computed employment, so basically, it could be, there is no 10 billion approximation. Anything is better, not do that. Right? So how to prove it? In order to prove it, we need to know another problem for hamiltonian cycle problem. What is that? It's just an easy version of tip remember, charlie salesman, you need to visit everyone every once you want to make the travel events as small as possible. Came to cycle says, I don't worry about travel s this is between two nodes. Every distance is one, okay? This one is a hamiltonian cycle. It is every node in the middle exactly once. But every such cycle is the same, because there's no edge, no weight on the edges, right? No weight on the edge. Right?

This one has, I mentioned the cycle, and this one does not have, because this one no way to find it. Now let me show something. Now this is one graph. This is a directed graph. Then there may be such a incident cycle, direct incident cycle, like this in the graph. Then there's also related problem of hamiltonian path. This problem. It means that I do not need to go back to the starting point. I start here, go to all vertices and stop here. You can do that. It doesn't come back. Ok this time in the past. So we know have a 20 cycle or have any past, but the past only complete, because you can check whether it's bad enough for a cycle. It's only complete in both directed and undirected works.

So we are going to use this harness of having recycled to prove the harness of tsp in general measure.

Let's see. How does it say you have? We do not. Let me show you the step in order to show ps ps on behalf, you need to do a reduction from an anti heart problem. Here is kind of a cycle. We transform hamilton cycle to your tsp problem, then show the solution for chemical cycle, and your solution for tsp correspond to each other. If you can solve one, can solve the other, there is corresponds. And then that means if you can solve psp then you can solve them in a second. But that's not possible. Therefore, the psp is hot. Basically, you do a reduction. How do the reduction? This is a graph. In this graph, I I want to check whether there is a hamilton inside. And then in the new graph for tsd because remember, tsd it has to be a complete graph, a complete graph. Everything is stable.

Now, in the psp graph, I will change. I I will be at those edges, which are not there in the beginning and make their weight higher than the weight of the edges that exists.

For example, in this graph, g there are four edges. Then in this new graph, these four edges will have weight one ok or this is one. For the two edges that do not exist. In the original graph, I assign ways to more possible. Right? So by doing this, what can you say? Okay, if this graph has an hamiltonian cycle, then what's the length of tsd here? The best tsd solution in the probability? What is that? That's easier, because you just follow him in a second. Everything is one, man, one, one. Everything is one. I will come back, right? That will be lengthen. Right? Then not, on the other hand, if the original graph does not have a family inside, then there's no way to start from somewhere, and also every node in between in the middle and come back to the originals. For we only through edges between, right? It's almost, it's not possible to have one. No, because that means you finally have it on the cycle, right? Because I told you there is no hand to the cycle. Right? Second one.

So if there's no capital cycle, then you will not be in that market to go through one every time, right? There must be one edge. You go through its cost two, right? That means your tsp cycle length is at least n plus one, in case, have an insightful test lines. If the cycle doesn't exist, your cost is at least 10 months n plus one.

Now, you can do some art. You say, if i'm able to solve psb exactly, what does it mean? It means I can immediately know whether you have an intercycle exist in the original part. Because if my solution they talk about psp is n then I can very safely tell you your original graph has coming in the cycle. If your solution returns to me at n plus one, they are table, no chemicals. That means if you solve casey, you can solve chemical insider. But that's not possible is coming in cycles in hardware. So that means your psp is also it's not possible. It's not possible to be easy. One. Your problem cannot be easier than happen inside ok so that means to prove that tsb is np hard.

Now, the major thing, although we don't have much time. So the major thing here is that in order to prove, it cannot be approximate within some factor.

Actually, we need to play around with these two, because this two is arbitrary. Right? When I say it's two, maybe you already have some fashion in mind why it has to do. Can I do 1 . 5 or 3? 100? Yes. You can do it any better the route, because you can make it any better that allows to prove some stronger bounds.

For example, you can make this two, n plus one. I make this nonexistent edge to cost anyone. Then when that happens, what can you do? So now, if g has come into the cycle, then the length is still n that's right. But if g does not have an eminent cycle, they are less is at least two n right? N minus one edges is one and one edge, n plus one, also to. You see, then there's a huge difference between these two, right? This I you see the clock. There's boss. So this is n and n to them. They differ a lot. Right? So let's see how to use it. Now it comes in + 1, right? Okay. Now suppose you have an approximation algorithm, which can get an approximation ratio, alpha. This alpha is two minus epsilon. Those means you can do better than two approximation. I suppose you can do better than two approximation.

Then what can you say? So I run it on this. Psp instance, transform psp instance. If we've obtained apsp cycle larger than or equal to two n then what does it mean? Because your ratio is less than two minus epsilon. It really ratio is two minus epsilon. If your lens is two m that means your best tsv is larger than m think about it. If your spsp is n then multiplying two minus x you cannot reach to n right?

Ok if you return to me a solution whose lessons to n with this knowledge, with this two minus epsilon approximation assumption, you can conclude your tsp fast es events is not a name. If stsp is not an s what does it mean? It means have it to the cycle that's like this, because if it exists, your best gsp should be in. Right? All right. So, in other words, on the other hand, right? If you return, this is less than then that is, you have come to say, right? If the return is less than two m your base cannot be, it cannot be allowed. You pay your base cannot be n right? Sorry. My bad. If you return, that is less than two n that means your base, your base problem a there must be a hamiltonian cycle, because your optimal solution here, the optimal solution here, if it's not n it's n plus one, for example, then multiplying this two minus epsilon will go beyond that. To make it short if the original graph hasn't happened in the cycle, that means your tsd length is n because of the approximation guarantee I have the final return value must be less than ten.

But remember in that our conclusion here, your tsds is either in Or at least two m right? Only these two options. If it gives you atsd less than two m then tsp must be n it cannot be the other channel. Right? So that's why you said, okay, based on the return result, I can vary safely known whether the original graph has come to decide or not. Given the knowledge that it is a two minus test, then I I can further extend. Is it? Okay? I can further extend the solution that the answer to the following. Say, okay, I make a function like this if there's no edge. So that is this. And then you will have two classes possible. The other one is, if you have cabin cycle, the letters to mean, if you do not have it, the length is at least n times fn now, the gap between these two extremes, it becomes a factor of fn so that's why we say, actually, you cannot have a better than fn approximation in this time.

I guess I will not talk about the details here, just a brief summary, sorry, for overrun a bit.

Now, a brief summary is we have many different methods to solve different problems, right? Especially reading and providing linear programming for surrounding, and also sometimes to use the structures together with the relationship, with the key problem here, this one, right? But come in a a metric PSP and then also we study the competition of multiple algorithms to solve an asset, giving two approximation. And there are also other methods. So there are some general tips. Whenever you are facing some problems, you first understand the structure of the problem, and then also understand difficult. They try to prove whether it's gonna be hard or not. Right? And then you'll start with some context is like really what I program. Then you try to improve the approximation ratio. Then you can show that goal. My concentration ratio to it is time for my error.

Basically give you one example. They are. I have one example where my errors cannot do better than that issue. So the analysis of my errors in this time, there are 2 types. One is analysis of algorithm. The other is the real lockdown means no evidence can do better than a certain ratio, right? So that's even stronger guarantee of your album be good. Right? And then you can use examples to show your conjecture and also disprove the conjecture. Whenever you have a terrorism research, you can always try to improve it as long as nobody show. Better than this is not possible. The last one is finding the economy or limits of the approximation probably change. Ok so I guess this is the oi the charity a bit quick to the last part, but I hope you can still follow, in some sense, apply on the global questions. I wish you a enjoyable holiday, the coming days. Back next week. Thank you.