Introduction to System Dynamics Modeling
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Lecture – 16.1
Second Order Systems
Romeo & Juliet Model

So, today we are going to look at dynamics of love; each one of us going to be affected by it at some point or are already are affected. But how we are going to react to it depends on each of our personalities? Right. Some people are going to you know love your partners more if they love you more and you may get discouraged if they do not love you back. Some people may get annoyed if their partners love them too much and they may be attracted to people who are not attracted to them right.

So, what you are going to do is try and model the different personalities and understand how the relationship unfolds by building system dynamic models. So, that is what we are going to do in today's class and we are going to capture the personalities by using different parameters in the model and see how it goes ready?

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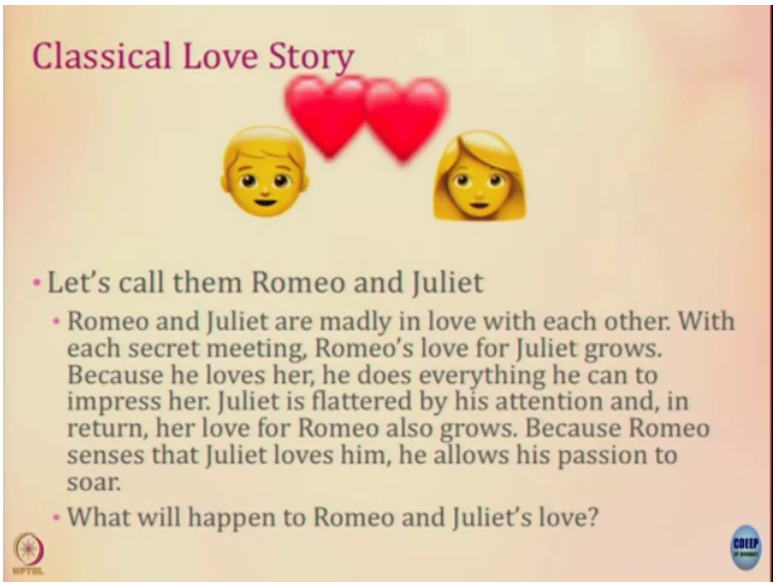

Let us go for it. Let us start with the classical love story boy meets girl, sparks fly and they both like each other and his love grows which makes her love gross for him, he she likes him even more which makes him likes her even more which keeps growing probably much than annoyance of others, but still it grows, let us call this Romeo and Juliet model.

So, Romeo and Juliet are madly in love with each other with each meeting Romeo's love for Juliet grows because he loves her, he does everything to woo her. Juliet is flattered by the by his attention and in return her love for Romeo also grows because Romeo senses that Juliet loves him, he loves his allows his passion to soar right.

So, now what will happen to Romeo and Juliet's love ok. So, now, we need to see how we can model this in our; a as a system dynamic model, but before that; so what do you think is happening here? Each other's love seems to reinforce the others love on the partner right.

So, what we are expecting here is it is a reinforcing love which is going to result in a exponential growth in their love for each other. So, but question is if we want to model it what is going to be the stock? Love is the stock.

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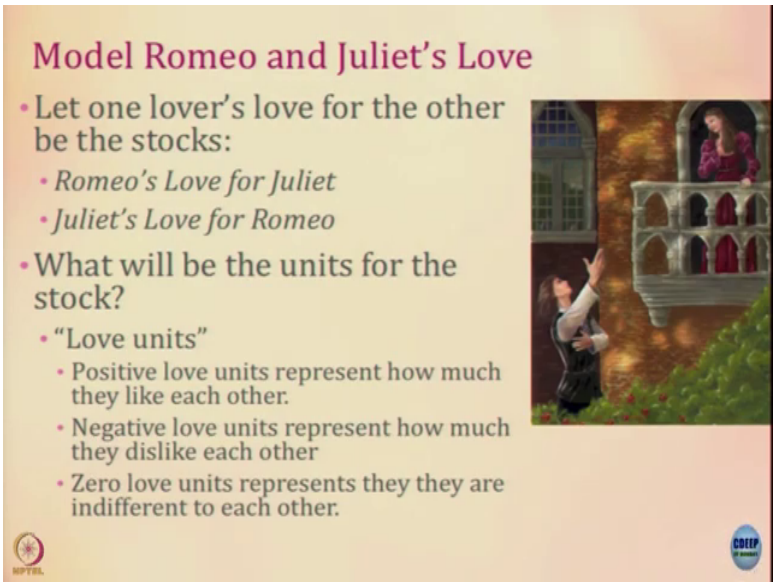

So, let us simply define it as let one lovers love for the other be the stocks right. Let us have two stocks one called Romeo's love for Juliet and Juliet's love for Romeo; let us define two different stocks.

Now, what will be the units for the stock? Units has to match, we are engineers we just come up with some love units; let us say arbitrary let us call it love units. I do not know how it will be measured maybe it is number of what can you say messages they exchange per day or number of times they think about each other a day or yeah anything like that.

So, number of likes they put in Facebook on each other or something ah. So, let us say that will measure a some love units which is somewhat measurable which you just saw. And let us make some simple assumptions like positive love units represent how much they like each other and negative love units represent how much they dislike each other and if it is zero; they are indifferent to each other right ok.

So, now we are getting somewhere; we are defined two stocks and we are defined the units, stock changes through what? Flows. So, that has to be two stocks, then there has to be two flows; it is not a material system, it is not like one love is transferred to other and there is no conservation of flows etcetera happening ah; each can grow as much as it wants. And we just saw that Romeo's love for Juliet grows based on how much Juliet loves him and Juliet's love for Romeo grows based on how much Romeo loves her right. So, they are feeding of each other; we can represent it as a stock flow diagram as shown here.

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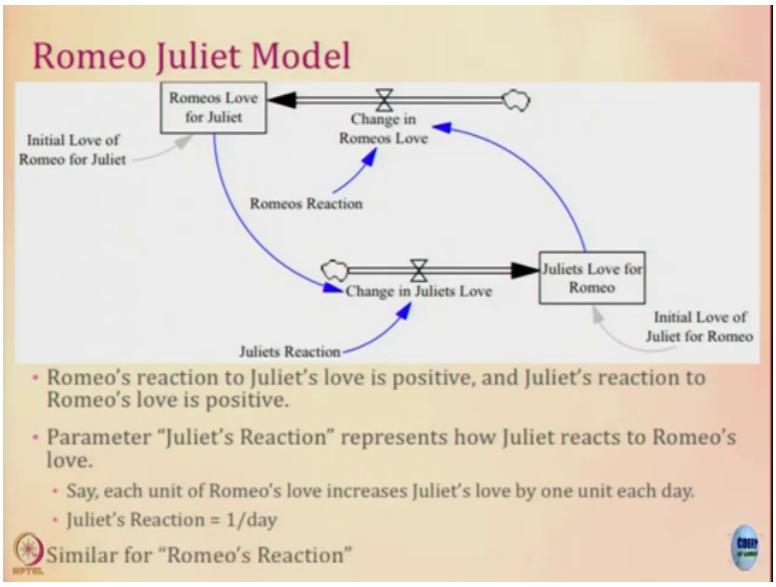

So, let us define two stocks Romeo's love for Juliet and Juliet's love for Romeo and we have of course, any flow that changes it; we just simply call it as changes in Romeo's love and the changes in Juliet's love affects the; the stock of Juliet's love. Now, you can observe; so this is the basic I think you can get it, the key thing that we have brought in is something called as two parameters one is Romeo's reaction and second is Juliet's reaction right.

So, here we are trying to capture the personalities where what is the Romeo's reaction to Juliet's love for him and what is Juliet's reaction to Romeo's love for her? In this particular case, we just saw that if Juliet's loves Romeo then Romeo's reaction is to gets reinforced; it increases right; same similar with Juliet's reaction. So, it is a Romeo's reaction Juliet's love is positive, Juliet's reaction to Romeo's love is also positive ok.

So, let us simply capture it by this parameter Juliet's reaction; let us say each unit of Romeo's love increases Juliet's love by one unit right. So, then we can just said Juliet's reaction is just 1; plus 1 ok. So, now we have a nice looking HD model. The initial; the initial love of Romeo for Juliet and initial love of Juliet for Romeo they are just to denote the initial value of the stocks, it does not change the stock it just sets the initial value; I just wrote it outside for you know convenience.

So, what we are going to do is see what happens when their initial reactions are different when they meet right ok; so the Romeo's reaction similar to Juliet's reactions, so both is plus 1. So, let us go to the Vensim.

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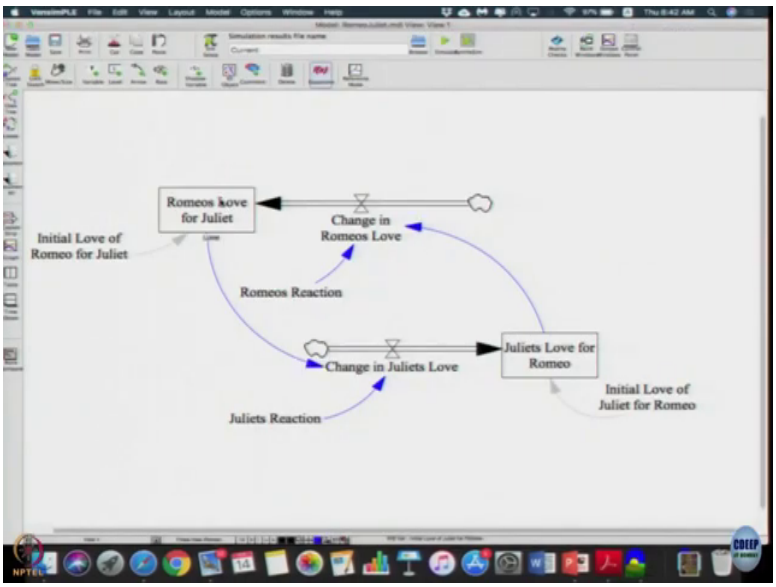

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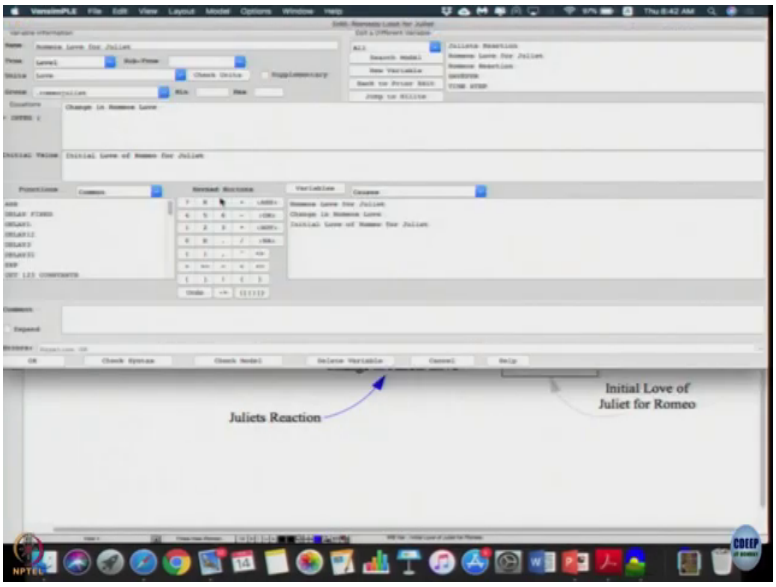

So, we just try to show one show one of the stocks; Romeo's love for Juliet initial values initial love of Romeo for Juliet.

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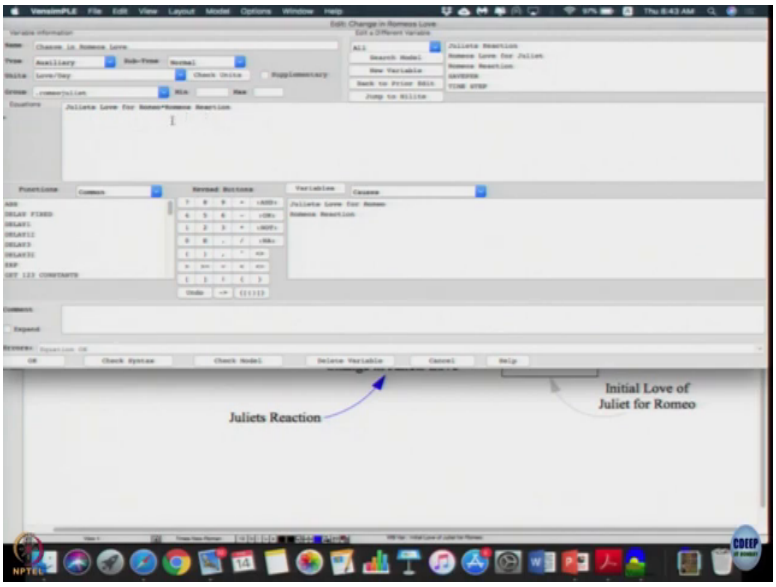

And changes in Romeo's love is nothing, but Juliet's love for Romeo multiplied by Romeo's reaction. So, for each unit of Juliet's love, his Romeo's reaction is going to multiply that by a factor of 1 in this case.

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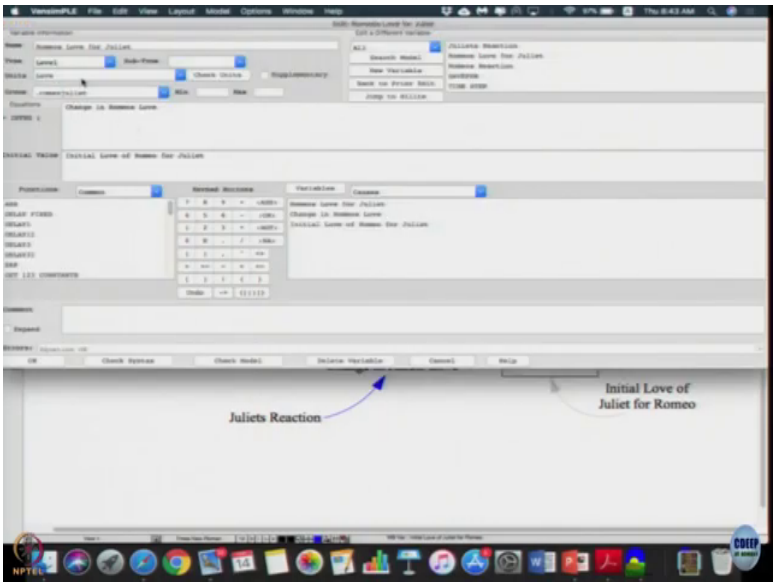

And Romeo's reaction is 1 and units is 1 per day, the units of stock is love.

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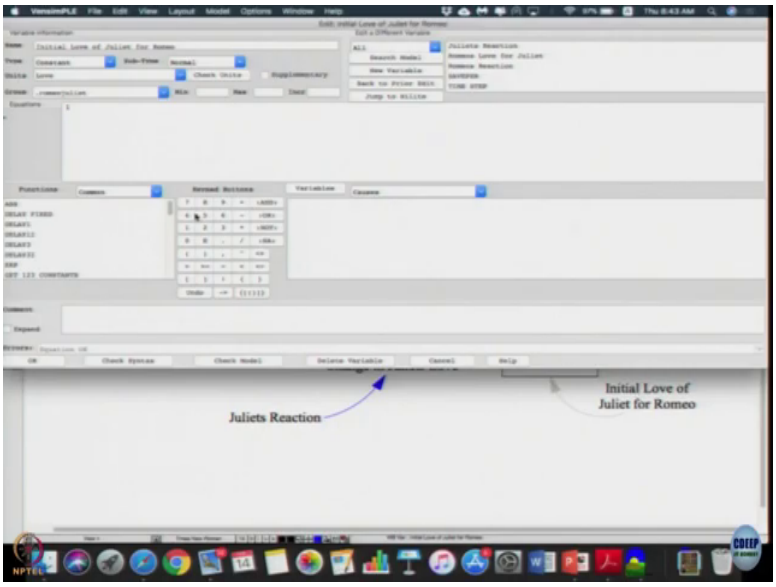

And the initial love of Romeo is 1, initial love of Juliet is 1. So, what we are assuming is when they meet each other first time; sparks fly and they love each other love at first sight both sides, let us go for it.

Let us simulate the model and what do you expect the behaviour to be? I am just going to plot the stocks.

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You can observe both the stocks increase; it is identical both the lines overlap. So, you do not see the other one, but both are overlapping and in a matter of 12 days, they have accumulated 150000 love units and it has grown exponentially right. So, in this; so why does it grow exponentially then there has to be a positive feedback or is it cannot grow exponentially?

So, let us just trace it; exponential growth. So, here as Romeo's; Romeo's love for Juliet increases, the change is in a positive direction; so Juliet's love for Romeo also increases and because of that Romeo likes Juliet even more. So, it is a reinforcing positive feedback system that we have here which is causing a exponential growth with both their love ok.

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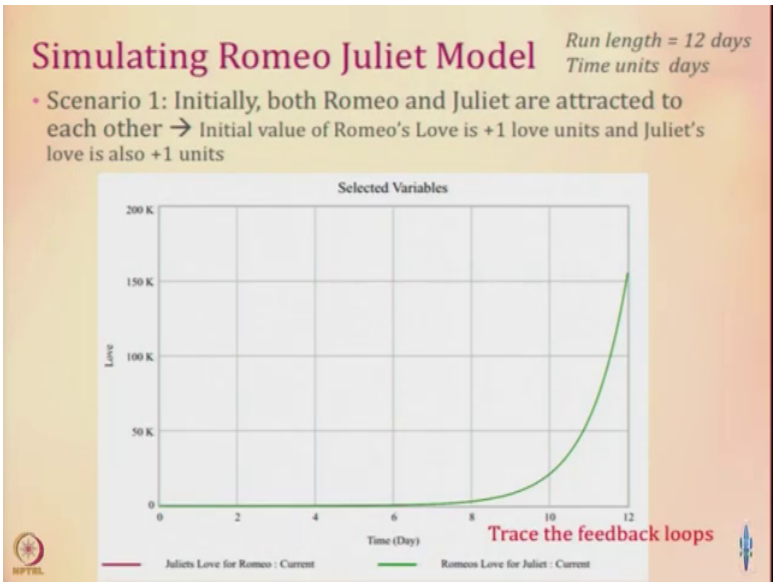

Let us take this case as we just saw initially both Romeo and Juliet attracted to each other. So, we just do that by setting the initial value of Romeo's love to plus 1 and Juliet's love is also plus 1 units initially and we have seen this exact same behaviour exponential growth and we trace the feedbacks of both has to be a positive feedback loop because the reaction; reaction is positive. So, whatever amount of love units you are just multiplying with plus 1; so direction of change is still positive.

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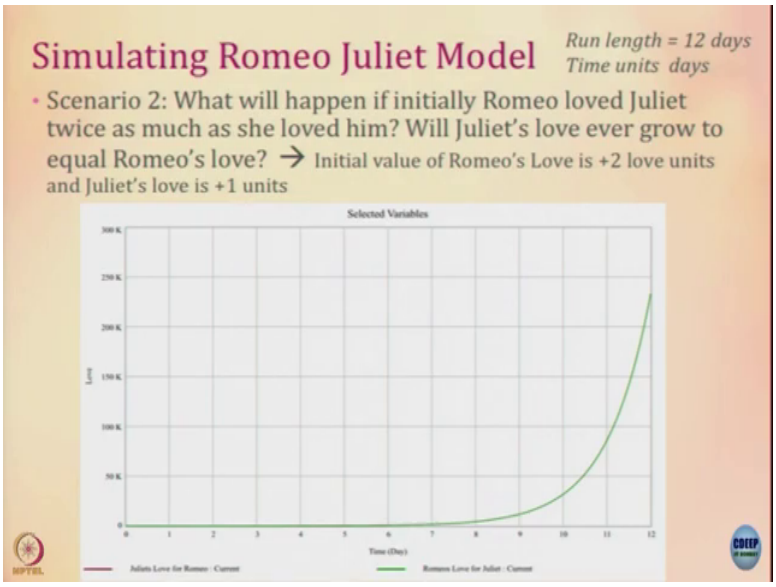

Now, let us do some interesting scenarios and plot changes in the basic storyline. What will happen if initially Romeo loved Juliet twice as much as she loved him? Will Juliet's love ever grow to equal Romeo's love? What do you think? But if the simulated we can set the initial value of Romeo's loves to plus 1 love units and Juliet's love to plus 1 love units and if I simulated.

So, actually dynamics is as seen here both their love for each other is going to grow exponentially and it is going to still overlap, that is because when we started Romeo's love was 2 units that cause Juliet's love to increase twice as much as before which caused Romeo's love to increase same 1 times more which again cause Juliet's love to increase.

So, both; so whatever settings they are going to have the same amount of love for each other, but since Romeo loved her twice as much initially, their love grows to 40000 units to 40000 love units much more than 150000 love units we started right.

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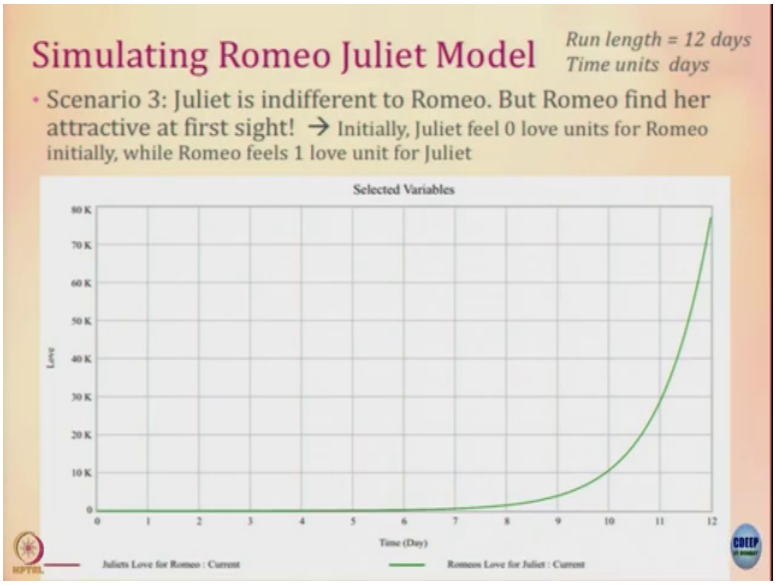

Let us suppose more changes, let suppose Juliet is initially indifferent to Romeo, but Romeo finds her attractive at first sight that is Juliet initial love units is 0, while Romeo feels 1 love unit for Juliet. What do we expect the dynamics to be? It has to increase exponentially, just think about it there is initial Romeo loves her. So, with 1 unit; based on that the change in Juliet's love will also increased to 1.

Initially, Romeo's still may not change because Juliet is indifferent to her, but once Juliet sees Romeo's love for him; her love start or if she will start reciprocating it; maybe a little later,

but once both have start having positive values, it become a positive feedback system which has reinforcing each other.

Let us see how many love units accumulate in 12 days not as much as original, but still 70000 love units is what they have because Juliet was initially indifferent to Romeo, but Romeo feels 1 love unit for Juliet right. Now, still we can experience exponential growth; as long as a positive feedback system and we are going to have non zero values, system is going to grow exponentially; it cannot grow otherwise.

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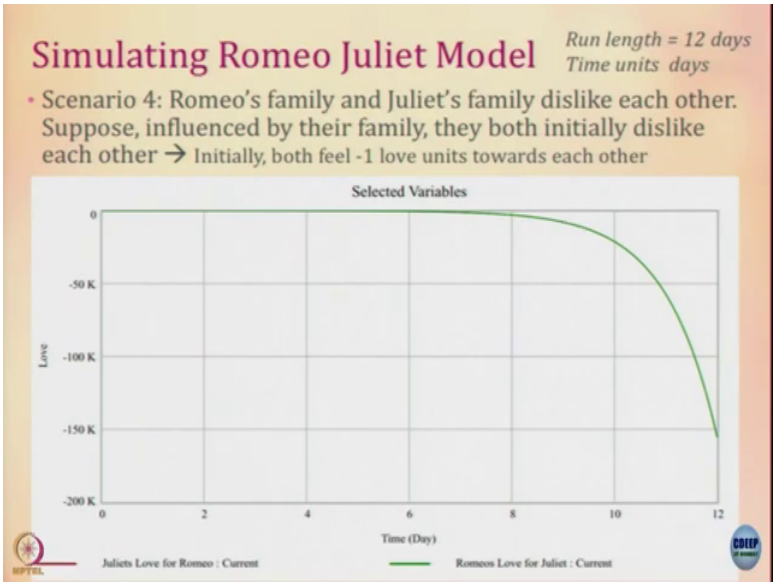

Let us skip it those who remember the story will know that Romeo's and Juliet's family fight with each other; they do not like each other. Suppose influence by their family, they also initially dislike each other that is both initially both feel minus 1 love units towards each

other; they see each other and they start hating them immediately, then what kind of dynamics can we expect.

People are drawing in the air; so it is also going to have exponential behaviour, but it is going to be accelerated decay or exponential collapse is what we can expect. And just like we anticipated some of us ah; their hate for each other will continue to feed off each other. So, with every unit of time Juliet; I mean Romeo hates Juliet. So, Juliet hates for Romeo is going to increase and because that hate increases, Romeo's hates for Juliet will further increase and that going to get reinforce each other. So, direction of change is continues to be the same, but it says in an exponential collapse among them; both going to hate each other forever.

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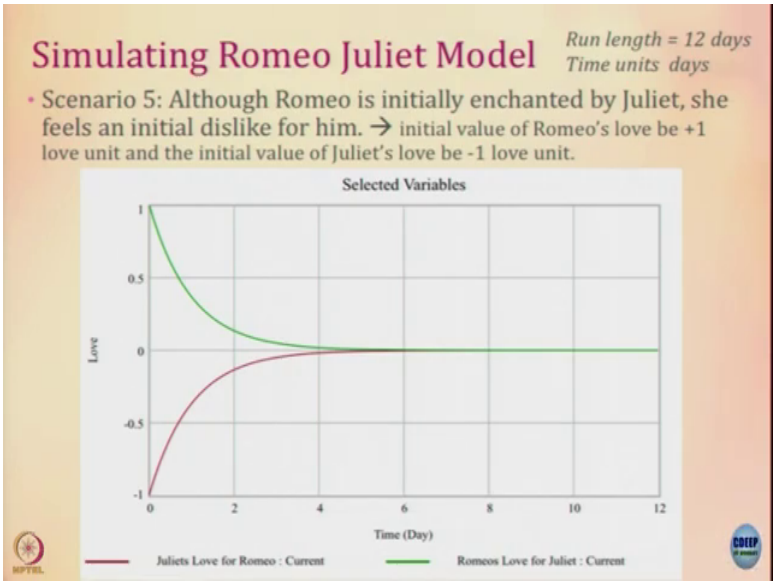

How about if its more complicate things? Although Romeo is initially enchanted by Juliet, she feels a initial dislike for him right. We simply model it by saying initial value of Romeo's

love is plus 1 love unit and Juliet is minus 1 love unit she; she dislikes him, but he likes her, then what do you think will happen?

So, it cancel each other; after sometime it will you have seen too many movies, if we try and simulate it we actually get a very surprising dynamics. So, the red line is Juliet's love for Romeo, green line is Romeo's love for Juliet is actually very surprising dynamics because here we have positive feedback system which is displaying a goal seeking behaviour ok. Entire semester, we saw that positive feedback system is exponential growth, negative feedback system results in goal seeking behaviour; now we see that love changes everything.

So, let us see let us try to understand why that happens right. So, as we just told or just saw Romeo's reaction as the positive direction to whatever Juliet's love for him is right; so let us start there. So, Romeo likes Juliet, but his figures out that Juliet does not like him. So, his stock of love falls he gets discouraged, but for Juliet; if you see, she finds out that he loves him and her; her dislike only reduces and hence you are getting a and this happens over time and they find that they eventually reach a point of indifference towards each other at least as per this model.

So, that is a very surprising behaviour; we just had a positive feedback system, just by setting the initial parameters we never change the model; we are only playing the initial parameters right that is quite fun. Just by changing parameter setting, we are getting different dynamics; some very hyper exponential growth or I mean exponential growth and the final values keep changing depending on where we are at the initial values and now with one parameter combination we are actually getting a goal seeking behaviour which is counterintuitive and very interesting.

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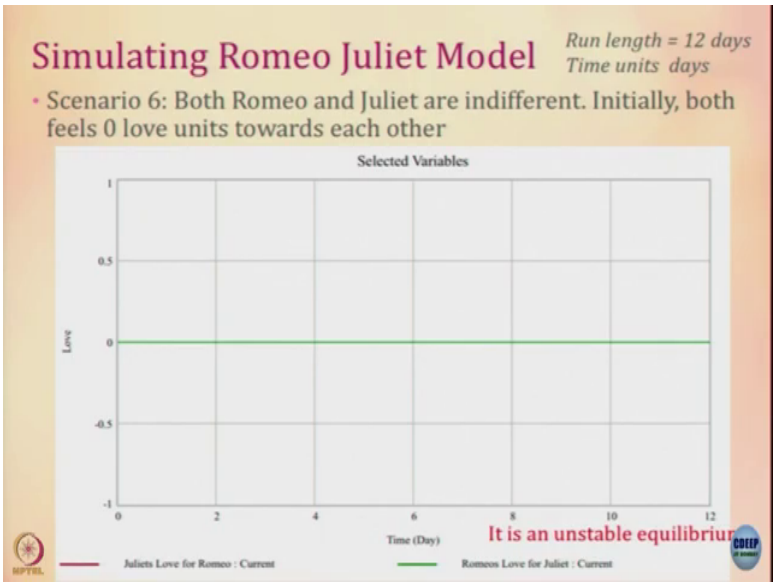

So, expanding that if both Romeo and Juliet are indifferent that is both feel 0 love units; that means, initial stock is 0; so net change is also going to continue to be 0. So, they are going to be continued to be indifferent to each other right; they are going to continue to be indifferent to each other. So, for this but this is a very unstable equilibrium; even if one feels some like some amount of like to the other person, we are going to start off a reinforcing loop or a classical love story is going to start right.

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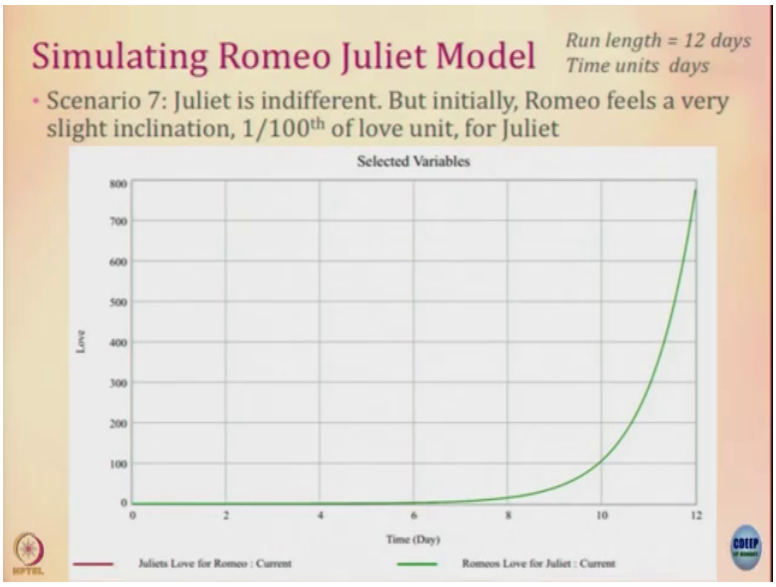

Whatever, even if you assume whatever a small number assume Juliet is indifferent, but Romeo feels a very very slight 1 by 100th feeling of whatever of love unit for Juliet very very tiny amount. But still if you simulate it; you will still get an exponential growth because it is a saturates at a much smaller love units, but still nevertheless over time; they are going to have exponential growth they love.

So, that is very unstable equilibrium and even a small change in; in the positive direction is going to result in a exponential growth in their love and works the other way also; if you are going to have very slight dislike for the person that might also get reinforced over time.