Introduction to Dynamical Models in Biology

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Lecture 8
Examples of simulation in JSim

Hello, welcome to module 2 of week 2 of our course on Introduction to Dynamic Models in Biology. In the last module I introduced you to JSim the free software that you can use to simulate your ODEBS model, in that module we have discussed the basic features of how to use JSim that has been discussed. In this module I will take some example of ODEBS model and we will discuss how to write the code for that in JSim and then how to simulate that.

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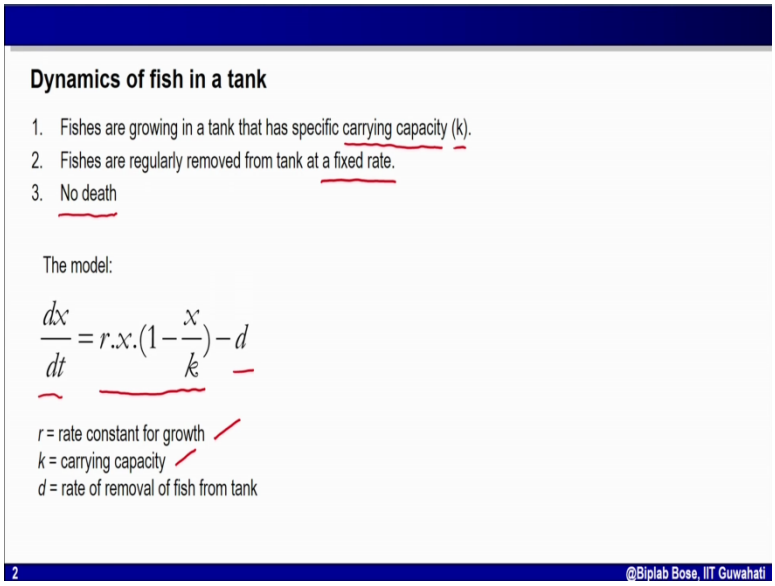

So let us take a model first, today I will discuss a model on Dynamics of Fish in Tank suppose we are going fish in a tank obviously the tank has a capacity that how many fish can be hold there so that means the fishes are growing in a tank that has a carrying capacity let us call it K. Let us make another assumption that we want to sell the fish in market so we are regularly removing the fishes from the tank at a fix rate and assume that there is no death of the fish, lucky fishes. So I can write a ODE to represent the dynamic of the fish in the tank as given here x is the size of the population of fish.

So $\frac{dx}{dt}$ rate in change in the population of fish ¿$r.x.\left(1-\frac{x}{k}\right)$ you can recognise that this first part is nothing but logistic growth model. So r is the rate constant for growth of the fish, k is the carrying capacity and x is the population size minus d. D is the rate of removal of fish from tank and is the constant unit. Now obviously you can analyse it analytically but we want to solve this numerically using JSim. So how do I write the code in JSim for this model?

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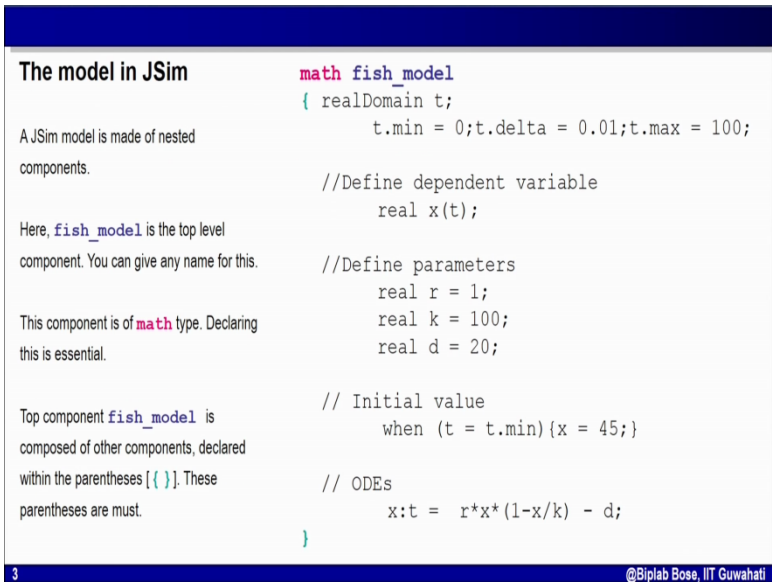

I have written down the code on the right hand side you can see and try to understand what each of these components means, remember JSim is a model in JSim a model has nested component, one nested into another. So in this model the main component is fish model, it is the name of my model that I have given, you could give any other name. Now each component of a JSim model has particular type for example the model that we are doing is a mathematical model and its name I have given as fish model.

So I will denote it as math type as shown here, so you have to write math so that JSim compiler can understand this is a mathematical model and it has to use all mathematical library functions that it has. Now fish model is the top most component, it has many components listed here nested under it and everything nested under this fish model are within this curly brackets shown here. Don't miss this curly brackets otherwise JSim will not understand where the model start and where the model ends, model starts with this curly bracket and ends with this curly model.

So the key feature that shown in this slide that you have to put a name, I have put a name fish model and you have to define the type so it is math type and everything else is within this curly bracket. Let us look into the other component, now in our model t is the independent variable so everything else the dependent variable changes in t domain, so we have to represent and tell JSim that t is a independent variable and that is done by this tag that real domain, so I have written real domain t that means JSim understand that t is the independent variable.

Once you have told JSim the independent variable then you have to tell it where it starts and where it ends that means the minimum value of that independent variable and what is the maximum value of that independent variable that you have to say. So for us time is the independent variable obviously time start at 0 so t min is equal to 0 and t max that is the maximum value is equal to 100 that I have decided. How time will change between 0 to 100, it will change at a time step up .01 and that is shown as t.delta. So what I have done here, I have defined t as a independent variable and marked it as a real domain.

I have provided JSim the minimum value of t i.e. 0, I have provided it the maximum value of t i.e. 100 you can change it to some other value and in fact you can change this value later on also while we do the simulation and you have to tell the increment in time i.e. t delta which I have defined at .01 you can change this value later on during simulation also. Note one important thing all these information has ended with semi colon, these semi colon tells JSim that your instruction has ended, if you miss semi colon there will be error in compilation so don’t miss them.

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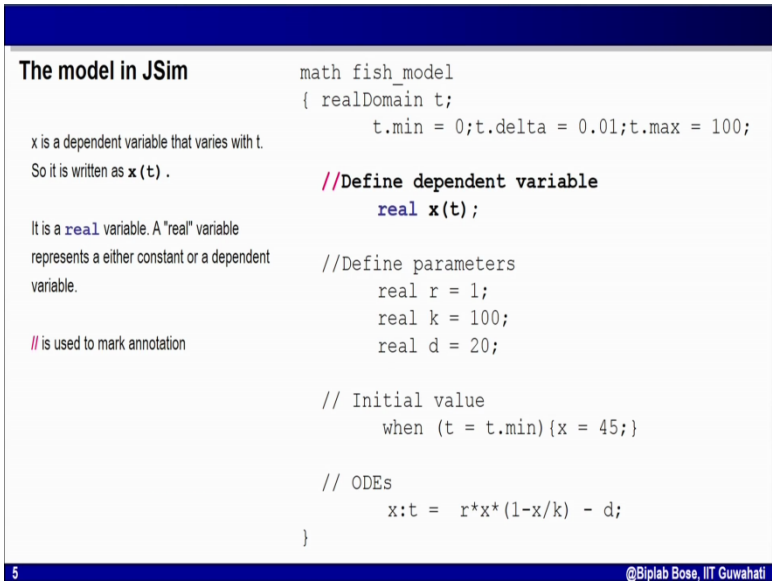

Now we have defined the independent variable so now we have to define the dependent variable, in our model the population of fish is only the dependent variable so that is x and I have defined it as x(t) so JSim understand that x depends upon t which I have defined here as an independent variable, and remember I have written real before it so it is a tag that represent that it is a real dependent variable. You can see this double slash marks these marks are used to tell JSim that the words written after these are not instructions but annotation, annotating your code is a good practice so that you can understand why you have written a particular instruction and somebody else looking at your code can also understand what is the meaning and purpose of a particular code block, so annotation starts with these double slashes.

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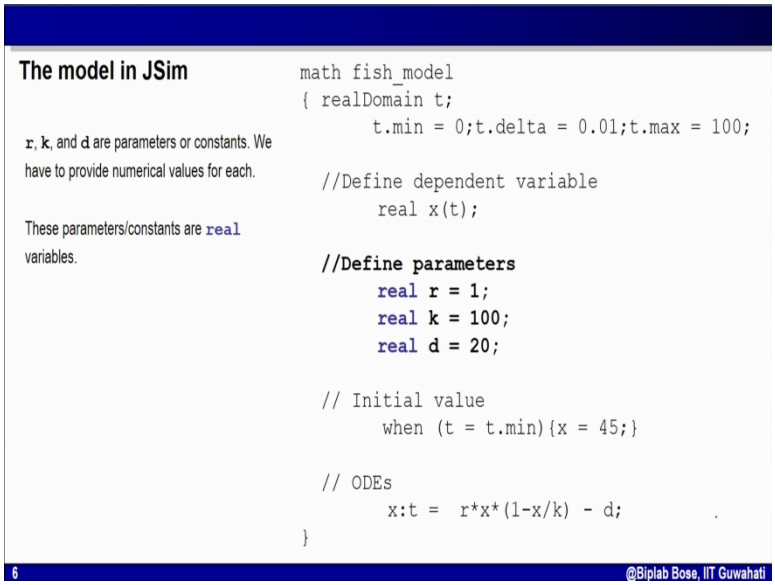

Next look into the other part, we have defined the dependent variable, the independent variable now we have to define the parameters the constant, remember our model have 3 constant or 3 parameter r, k and d. Here I have defined r = 1, k = 100, d = 20. You can choose any other value depending upon your purpose and in fact during the simulation also you can change the values. Now these parameters are real value so that's why term real is written in front of them.

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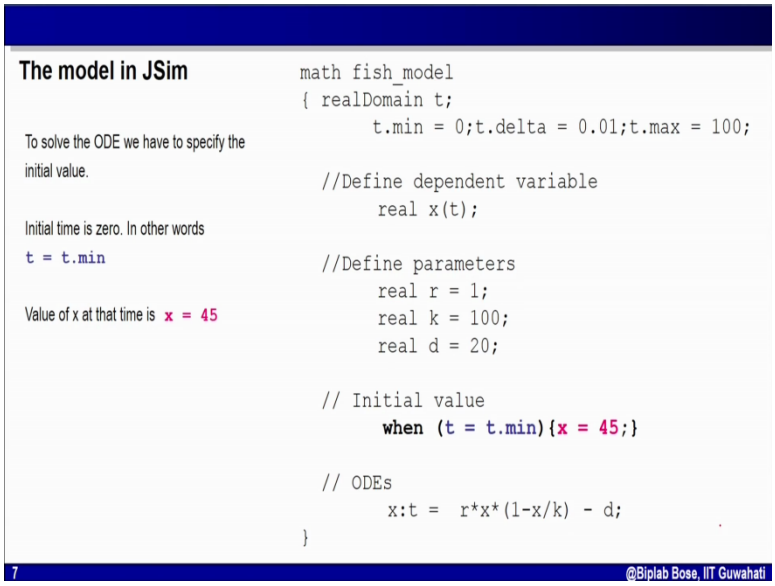

Let's look into other part, if you remember every ODE solver has to know the initial condition that is what is the value of dependent variable at t equal to 0, how should I tell that information to JSim? That is what is shown here. It is written as when t equal to t min, what is the value of t min, t min = 0 so that means this instruction is telling when t = 0 value of x = 45, that means I am telling there are 45 fishes at in the tank at t = 0, not that this value is within the curly bracket and I have a semi colon here, don't miss these semi colons.

So you have to define the initial value using this format when t = t.min curly bracket start x that there is a dependent variable is equal to some value semi colon close ups curly bracket. The rest what is left with is to define the ODE, remember the derivative of x is $\frac{dx}{dt}$ that is represented by x : t, x : t in JSim language and as you remember the equation is $r*x*\left(1-\frac{x}{k}\right)-d$ it is as it is as we have discussed earlier ending with semi colon that's all and JSim know your model once you have written it, compile it and run it, let's see how I have done it in a video.

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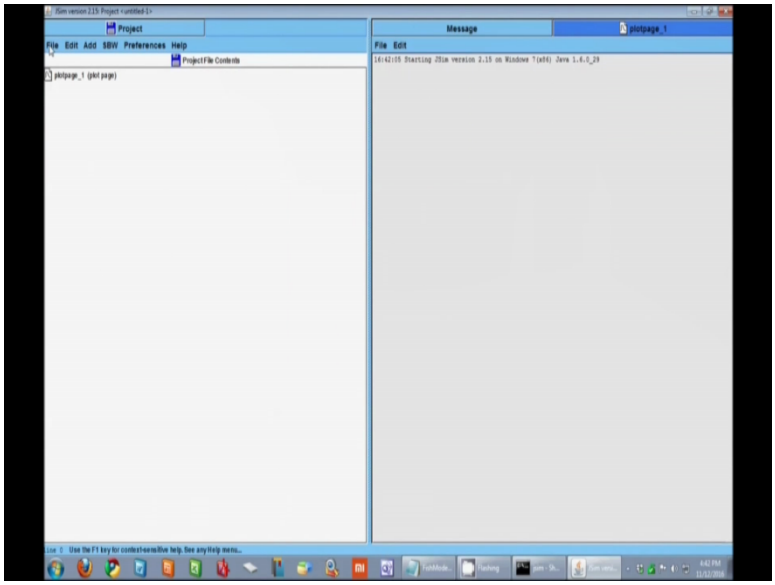

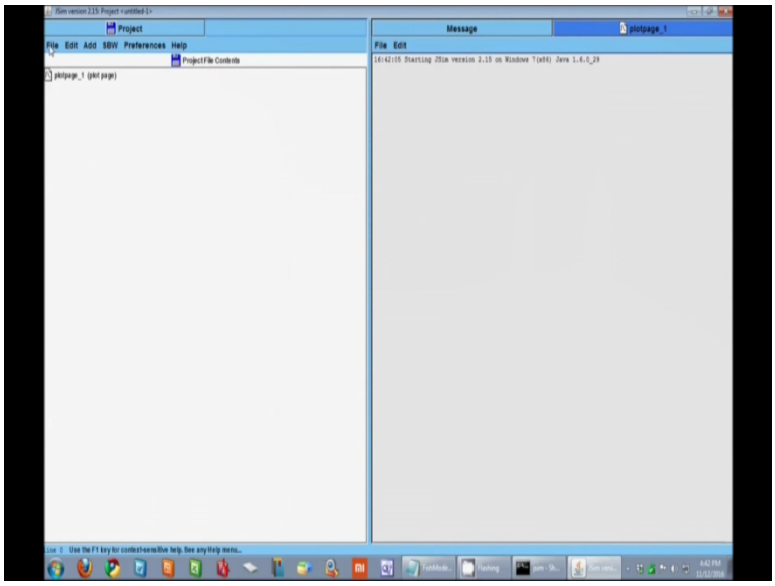
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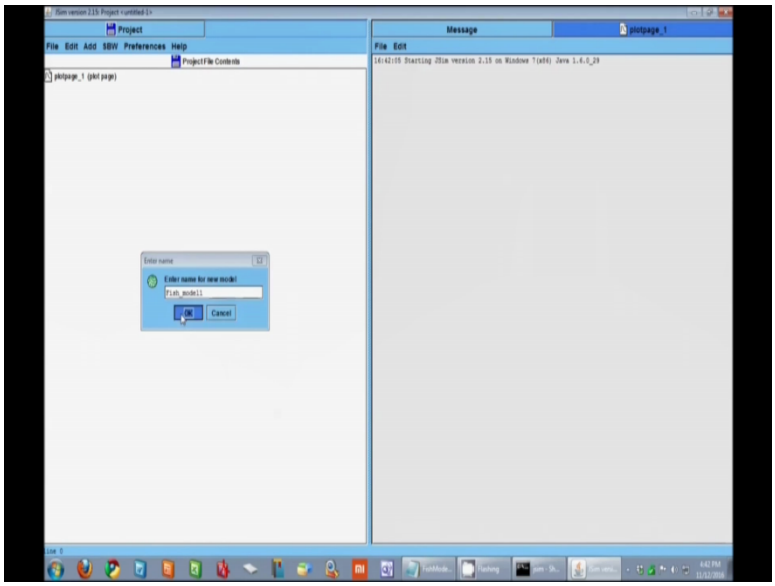
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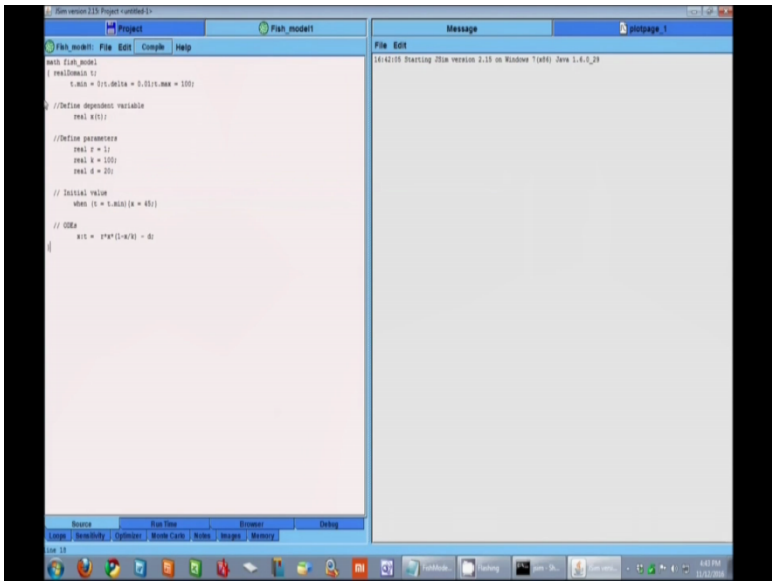
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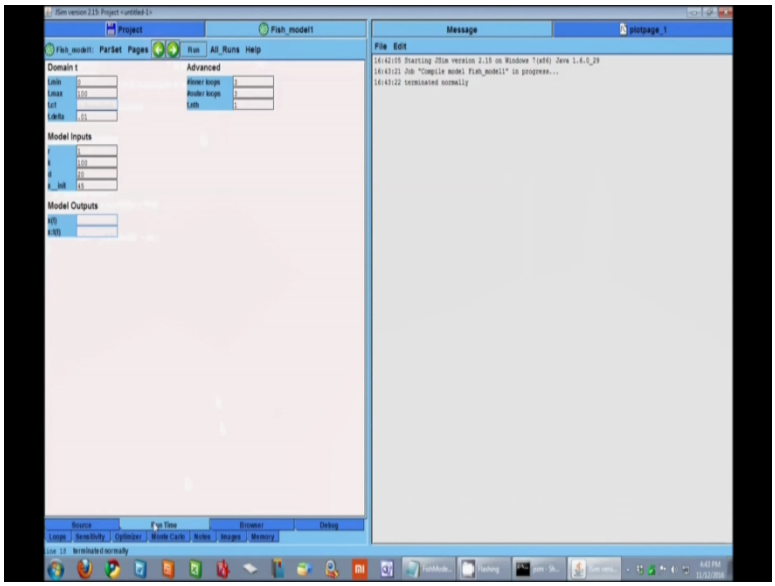
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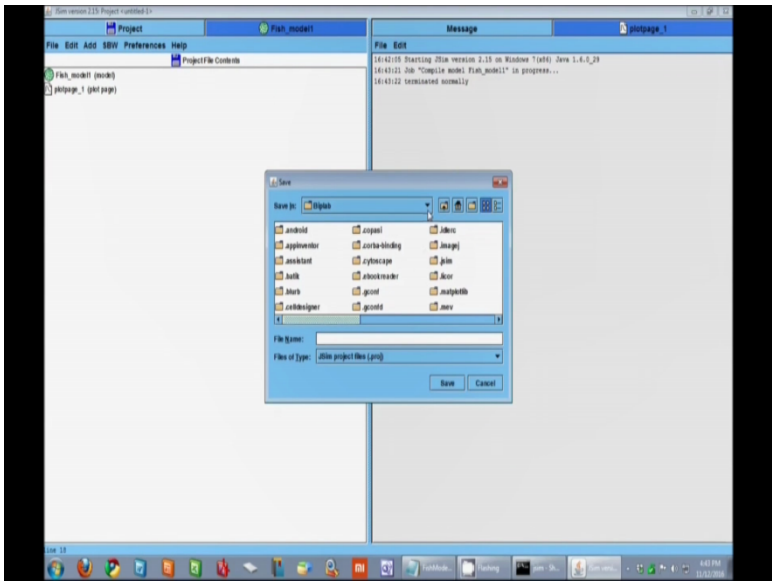

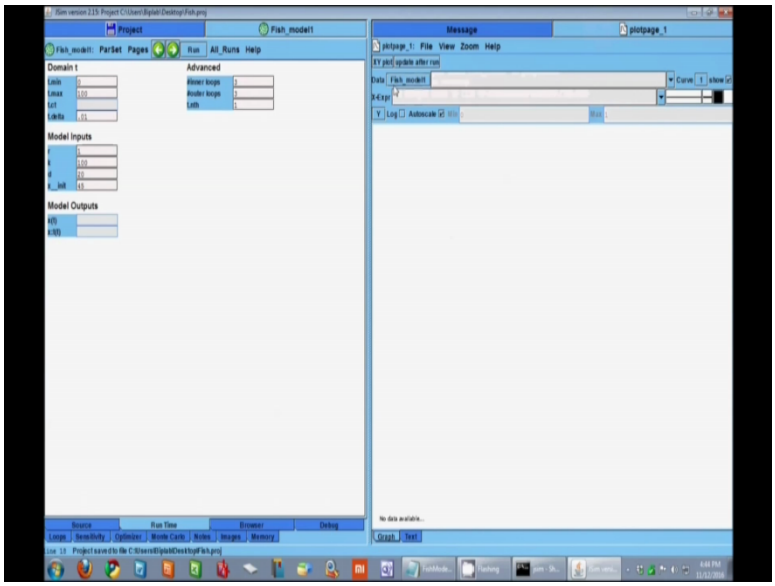

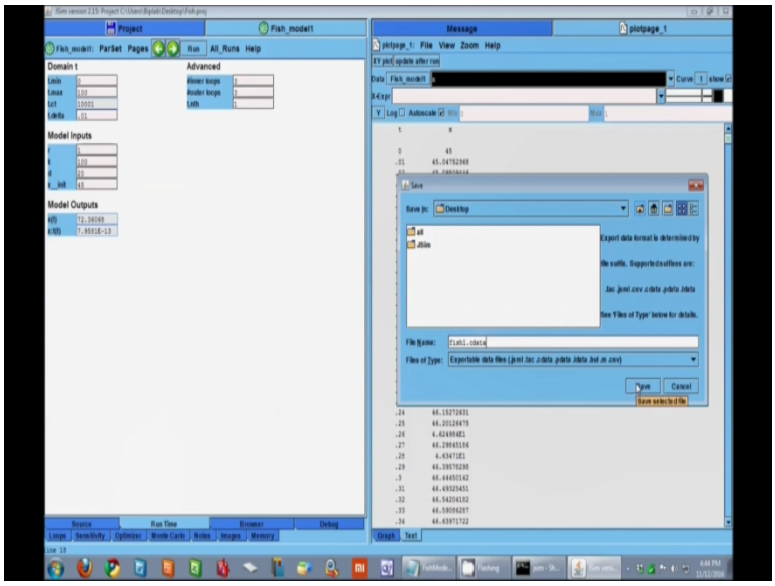

So start by double clicking the JSim shortcut, we have to create a new project. Already once you have opened a new project has opened, I have to add the model so that means I have to go to add tool and add in new model and put a good name for example here it is a fish model so I put fish_model1 so now new tab has come, this is my fish model where I have to define the model. This blank where I have to write down the model instructions, I have already written down in a text file so that I can easily copy and paste it, so I will simple copy it from here and paste in this window provided in JSim for source code, let us paste it here, so you have the code ready.

Now I can compile it, once you click compilation keep a watch on the message tab, here it is written in a message this turn it normally and the run time tab is active that mean my code is fine and it is compiled successfully, don't forget to save it. Let us put a name for this project so it is saved now, I will recommend you to frequently save your code, so I have a run time tab from which I can control the run and I can edit the values of the parameters and any other values. You can see initial value, final value of t, delta t everything there.

Let us activate the plot page, we have to select a variable that we want to plot, only one variable is there i.e. x, x : t is derivative we don't want that, so we plot x in the vertical axis, t in the horizontal axis, run it here you have your data. In the takes tab you have the takes data which you can save or export as a data file, I prefer saving it in C data so you write the name of the

file.C data, save it. Now in this model you had only one variable x that is the population of the fish but suppose you have more than one dependent variable, how to deal with that in JSim, let us see.

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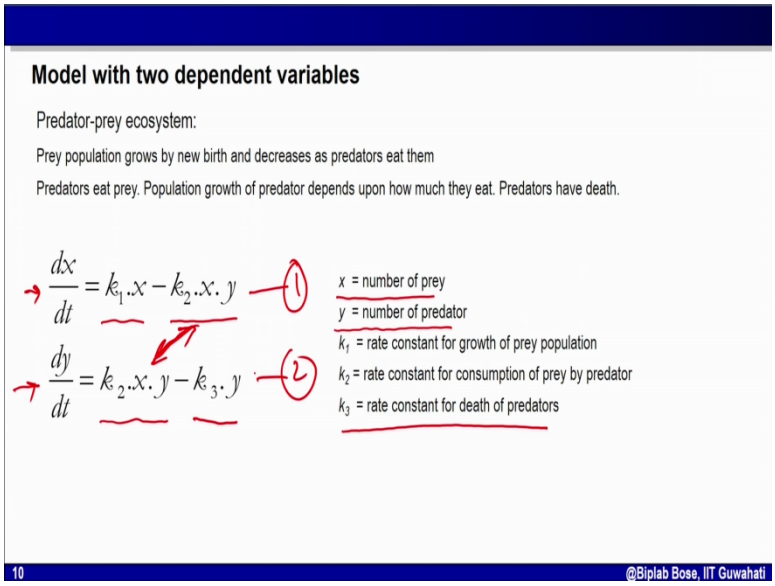

I have a model here with 2 dependent variable and this is a classic model called predator prey model. I have eco systems like a jungle where there are prey and predators, prey population grows by new birth and decreases as predator eat them, for example you can consider prey as a deer and predator as the tiger. Prey population grows by itself whereas the tiger grow and eat the prey so prey population decreases. As the predator eats prey its population grow and there is also death of the predator naturally.

So how we will model this using ODE, we have some simple ODE based model for that. X represent no. of prey in the eco system, y represent no. of predator so $\frac{dx}{dt}$ represent rate of change of prey in the population in the eco system that is equal to $k_1.x$, k_1 is the rate constant for growth of the prey population into the population at that time minus $k_2.x.y$, k_2 is the rate constant for consumption of prey by predator obviously prey and predator has to come in contact with each other that's why x*y, now remember y is representing the predator population so $\frac{dy}{dt}$ is the rate of change of that it is equal to $k_2.x.y$ this is the simplification.

We have assumed that the predator population increases only as it eats the prey, the tiger is eating the deer. So these 2 values are same, these 2 terms are same. Predators are dying by natural death so that has a fix rate $k_3.y$, k3 is the rate constant for death of predatory. So I have 2 ODE one and two and I have 2 dependent variable, so how should I code it in JSim?

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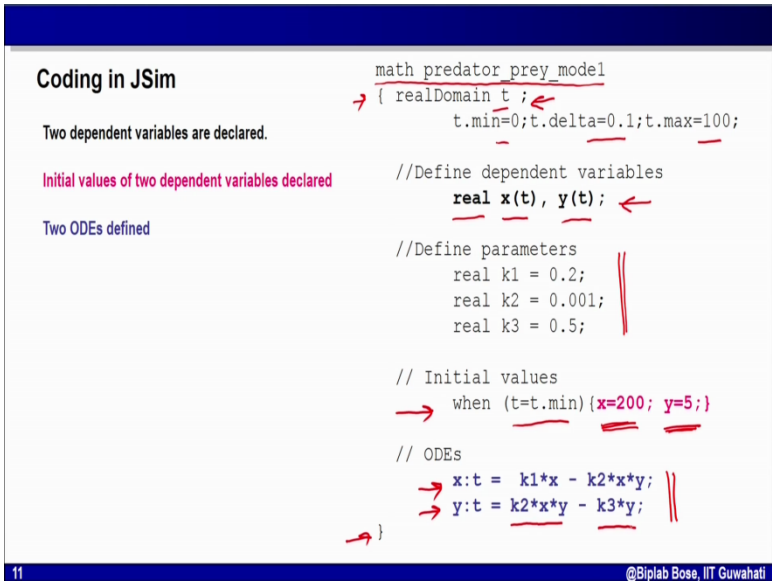

Here I have coded it. The first thing is math predator prey model so name of my model is predator_prey_model and I have told it is a top component and it is a math type. I have put everything else within this curly bracket and then I have defined time as the independent variable its minimum value, maximum value and delta is defined. I have 2 dependent variable x and y both of them depend upon time so x(t), y(t) both of them are real. Here I have the parameters you can choose different values and put different numbers and I have to define the initial values as usual. So at time t equal to t.min i.e. t equal to 0, I have to define value of x and y both.

So I consider initially I have 200 populations for prey that means 200 deer in the jungle maybe and y is the predator so I have 5 predators, usually number of predator is always less than the number of prey. You can choose different value and you can change those values later on during simulation also. Now I am left with defining the ODE's so I have to define 2 ODE one for $\frac{dx}{dt}$ and one for $\frac{dy}{dt}$, so x:t i.e. the $\frac{dx}{dt}$ and you have the components here k_1*x -

k_2*x*y second ODE is $\frac{dy}{dt}$ i.e. written as y:t and then k_2*x*y - k_3*y, that's all we have defined 2 variables, 2 ODE's and we are ready to simulate it, let's see how it works.

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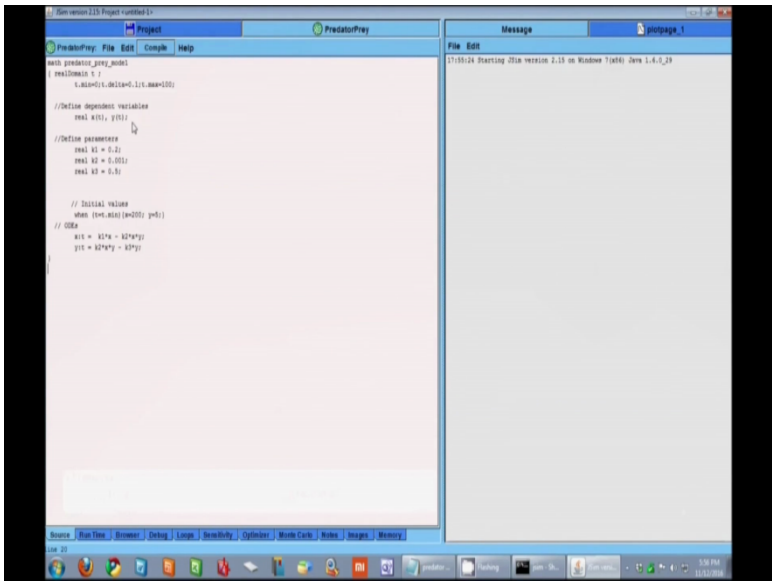

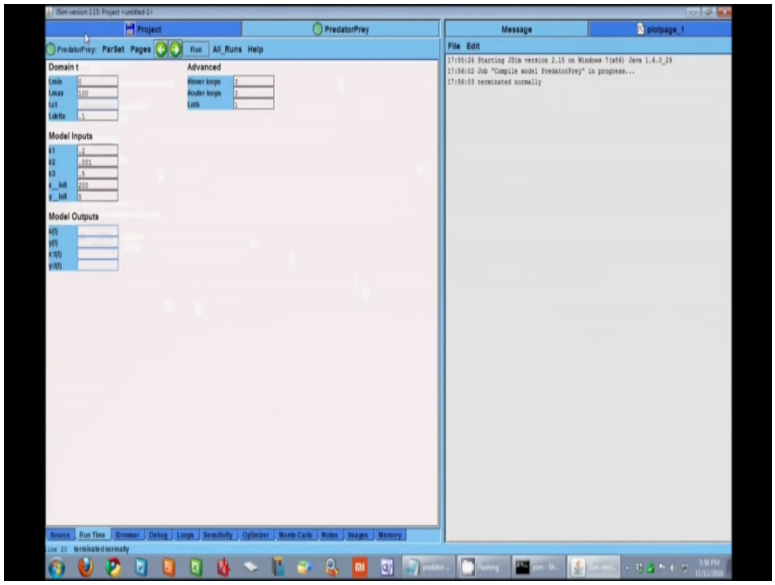

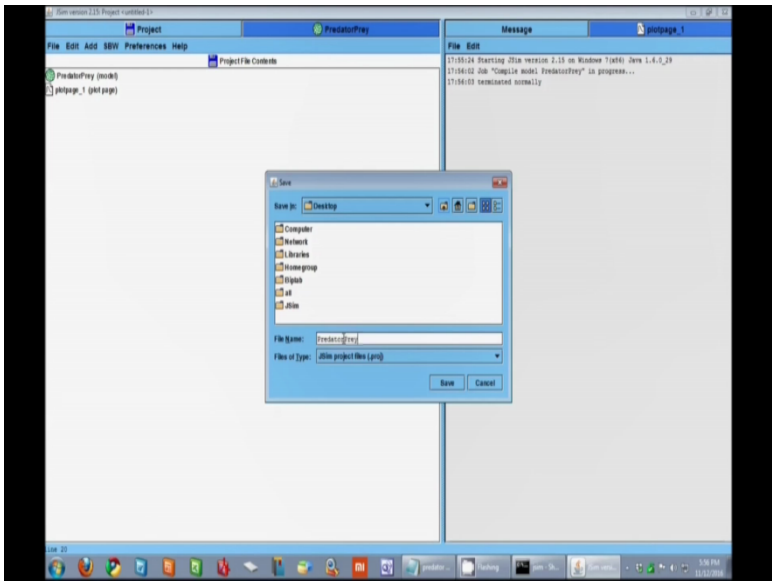
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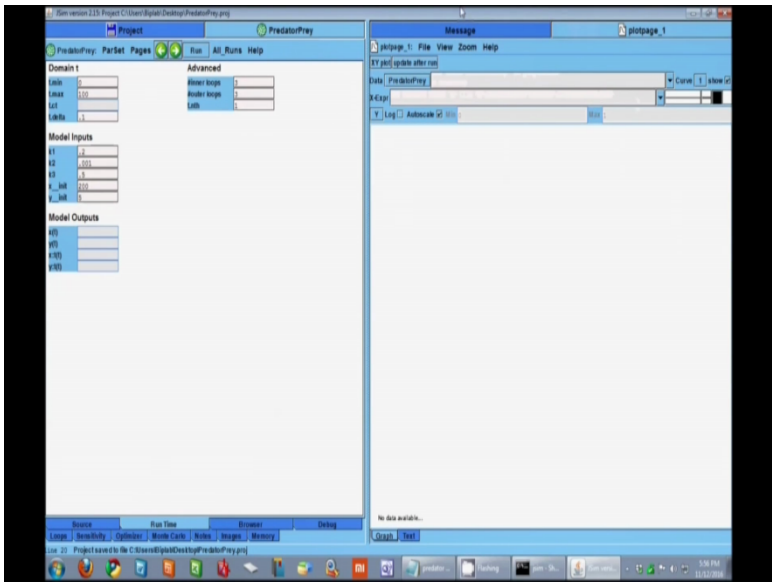
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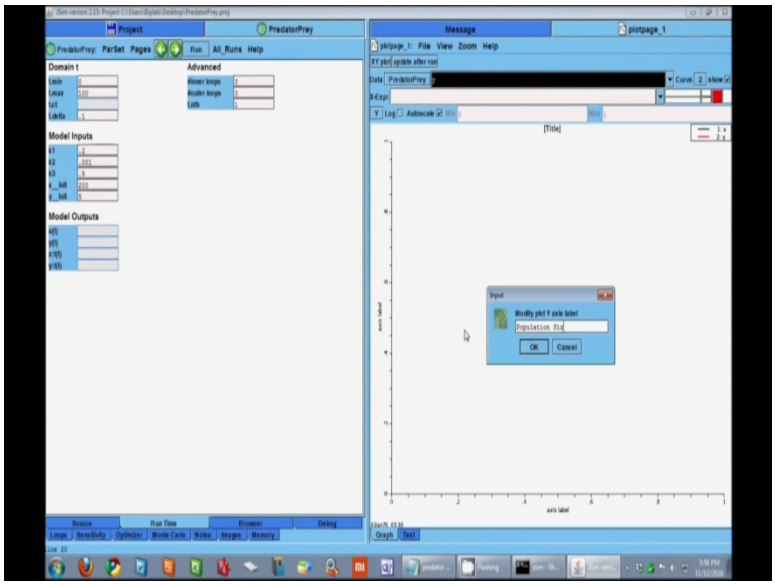
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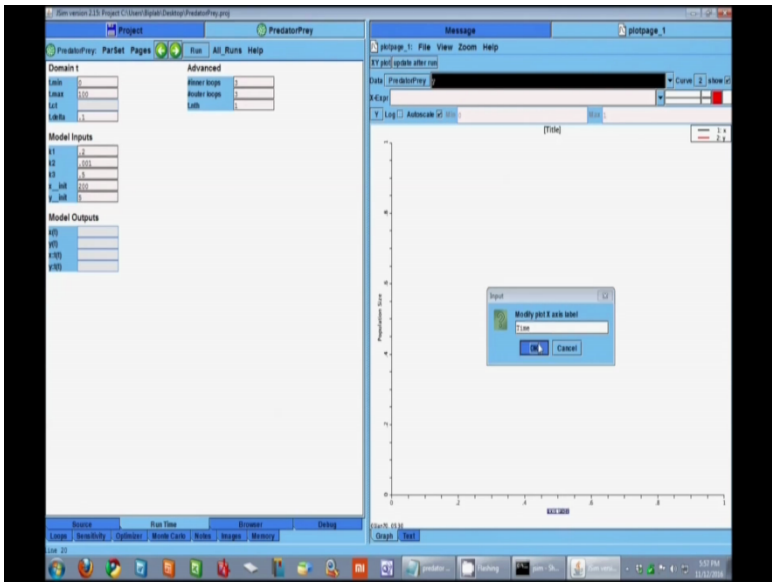
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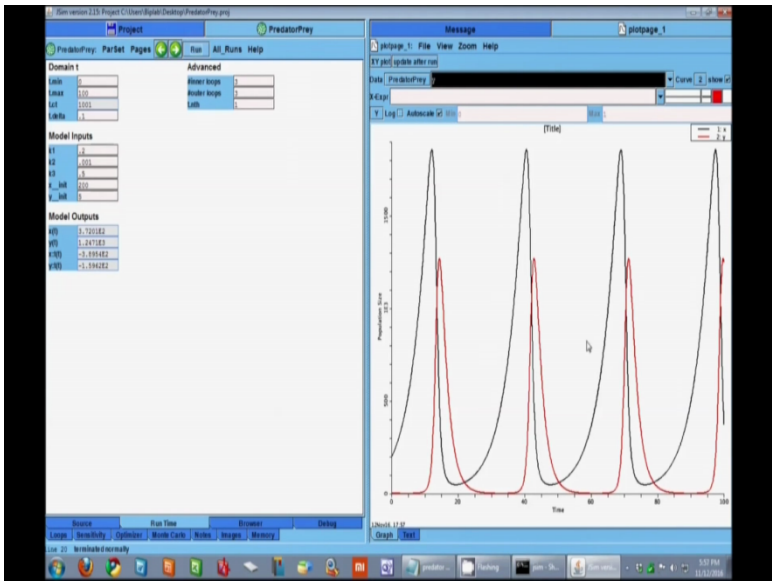

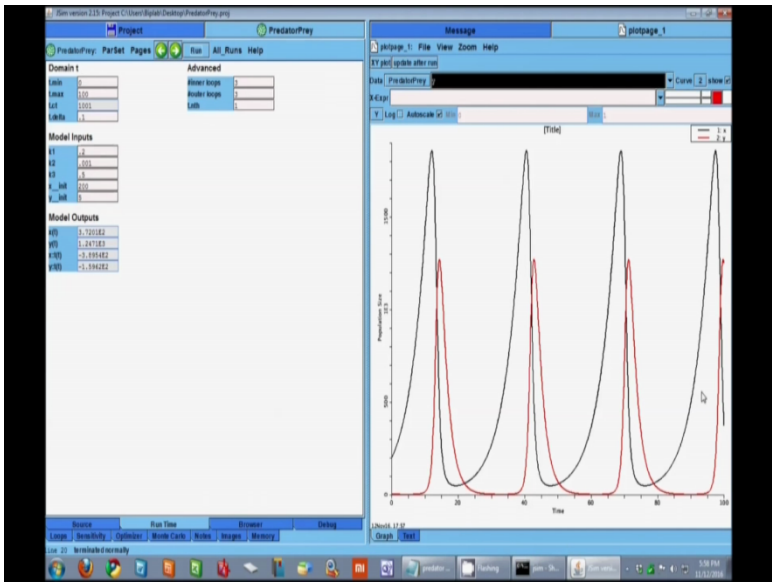

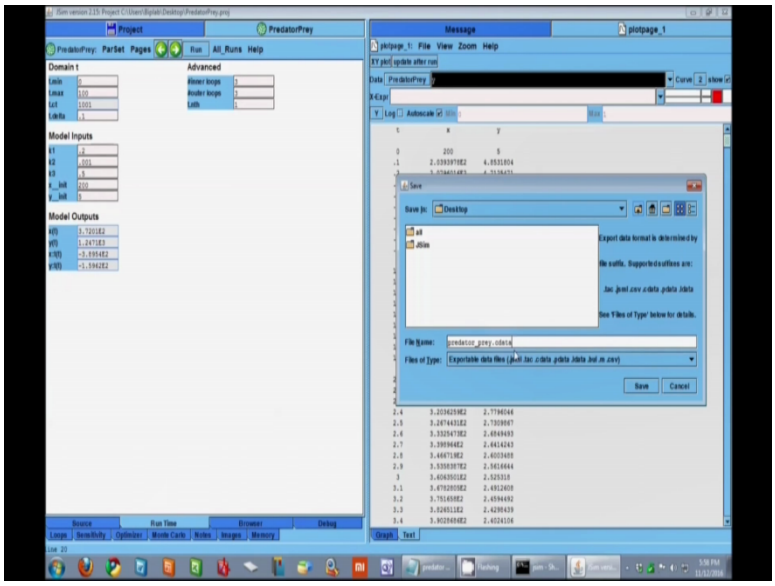

Again I will double click and start JSim, I have to add the model, I will name it as suitable corresponding name like predator prey, so I will go to the model source code page, I have already written down the code and I will paste that code on that empty space so here I have the code, I copy and paste it there. Paste it. Compile it. Notice the message is saying terminated normally the run turn time is ready, I save the file as a project, note the extension of a project is .proj, I have saved it. Now I have to run and see how the system behave i.e. x and y behave with time so I have to plot it for different values of the parameters.

So remember I have to choose the model I have only one model here predator prey but I have to choose variables, I have 2 dependent variable x and y, you can see both are there so I have chosen x in curve1 and in curve2 I am putting y, so x will be by black line and y will be by red line, let us put name and label on the axis, the vertical one is population size, the horizontal one is time. So now run it. Here you have got the data both x and y both predator and prey, one is in red and one is in black, you can see prey is starting from 200 then slowly with time it is increasing whereas the predator who was initially at 5 it increases very slowly and eats prey its population increases, as its population increases population of prey drops.

As prey drops, predator doesn't get any food so their growth also drops then one predator drops prey population gets another chance to increase, so it keeps on increasing on this black line and by that time predator increases prey population decreases so what we get is oscillation in population size of predator and prey, it is almost infinite oscillation. I can save this data, I can

save this data in text format from file export data file option. Put a name, don't forget to give the extension in the name i.e. C.C data here, save it. So you have saved it, remember in the horizontal axis we have time and in vertical axis we have population size for both x and y, this is by default JSim will plot time i.e. a independent variable in the horizontal axis but we can change that also, we can change and put something else in the horizontal axis, let us do that.

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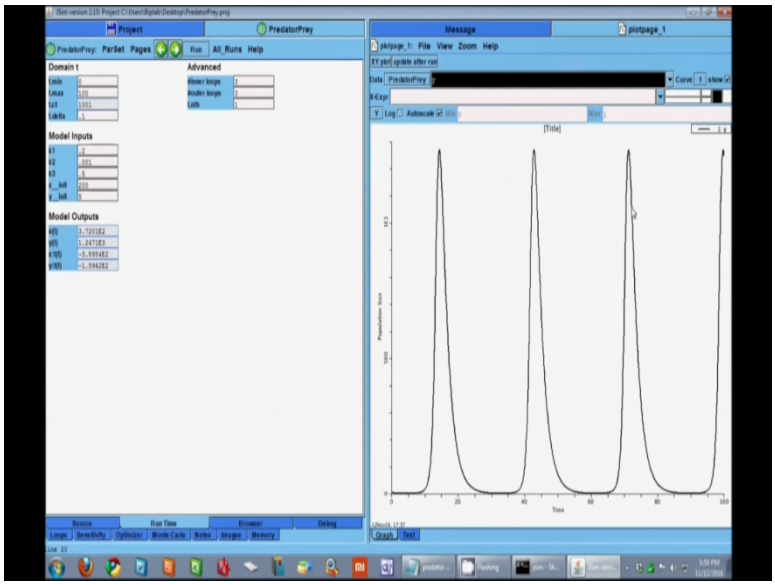

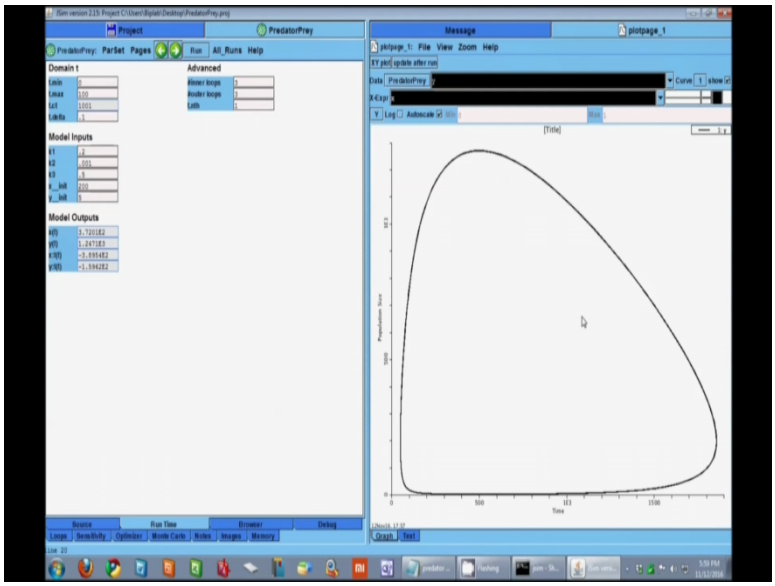

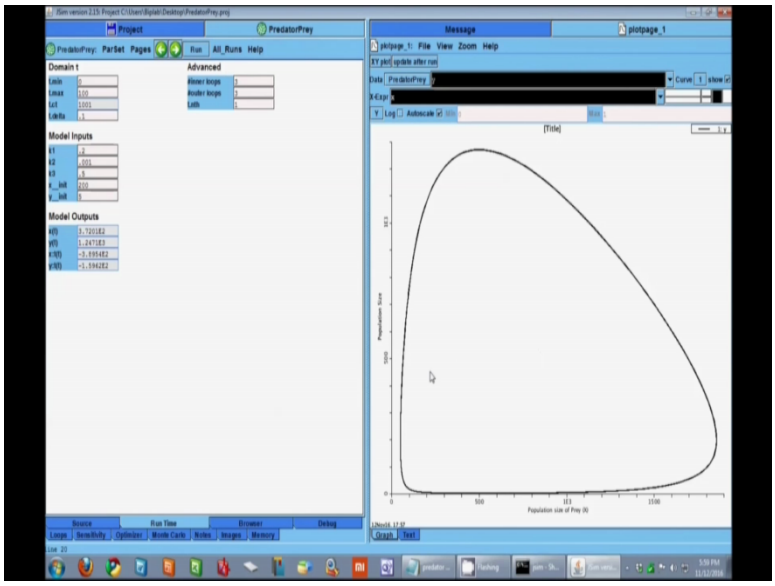

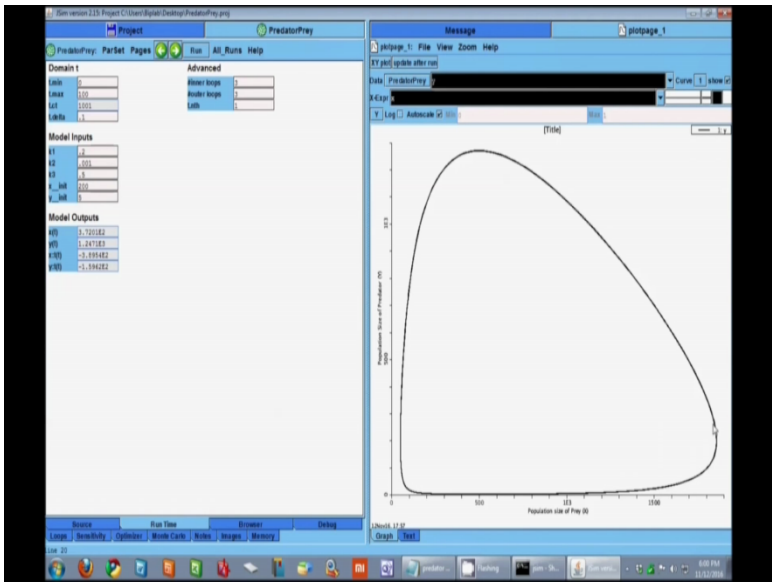

First remove the second curve, un-checking show change the first curve from x to y so we are plotting horizontal time and vertical is y only. Now you change the value of horizontal axis from time to x and press Enter. So now you have plot wherein horizontal axis you have population of the prey i.e. x so write it down there and the vertical axis will be the population size of predator, change that. So we have x in the horizontal and y in the vertical, you can see it is a closed loop as shown in the black line. Initially population of prey is around 200 then as time increases prey increases, predator increases slowly as prey decreases and you come back to the original value of prey and predator and you keep on circling in this closed loop. This type of plot is often called phase plot where both the dependent variable are plotted together.

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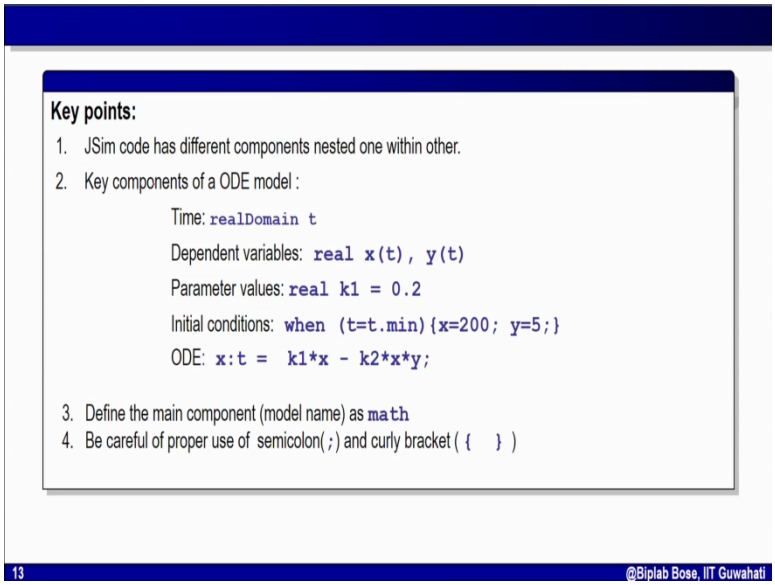

So what we have learned in this module is that we have seen 2 different model, one is for fish tank model with one dependent variable, we have seen another model of predator prey with two dependent variable and we have learned how to write down the code in JSim's own language and then compile it and run it, to get the result and how to plot that result. So just to jot down the key point JSim code has different component nested within each other that you have to remember, the key components of the model you should not forget is that time i.e. the independent variable that you define as real domain t, you have to define the dependent variable like define here as real x(t) and y(t), you have to define the parameter values and without parameter numerical parameter you cannot do numerical simulation.

You have to define the initial condition without that initial condition your numerical solution cannot be obtained, so it is done like this when t = 0 i.e. t = t.min and at that time x is 200 and y is 5, this is the format by which you write and tell JSim that this is the initial condition and you define the ODE and remember one key point the name component is the name of the model that you choose and define that as a math type otherwise JSim will not understand that it is a mathematical problem, be careful about semi colon and curly bracket. These are the common mistake sometimes very frequently we make where we miss a semi colon in a right position and we miss a curly bracket in a right position. Hope with this instruction you will be able to write your own JSim code and simulate it and enjoy. Thanks for watching see you in the next module.