

CREATING & RUNNING A VERY SIMPLE MODEL

Goal: This activity introduces a simple analog model of population change using dynamic systems modeling terminology and diagrams. It will serve as a launching point for discovery and exploration of the complexity of variables, models, theories, and solutions that surround global change modeling issues.

Objectives:

- To understand the concept of a model
- To be able to construct and explain a simple conceptual model of population change using dynamic systems modeling diagrams (i.e., "Stella" diagrams)
- To be cognizant of, and sensitive to, the complexity of variables involved in real-world population change, and recognize the variables needed to construct more sophisticated models
- To be able to critique the usefulness and limitations of modeling

PART I. CONCEPTUALIZING & "RUNNING" A SIMPLE MODEL "BY HAND"

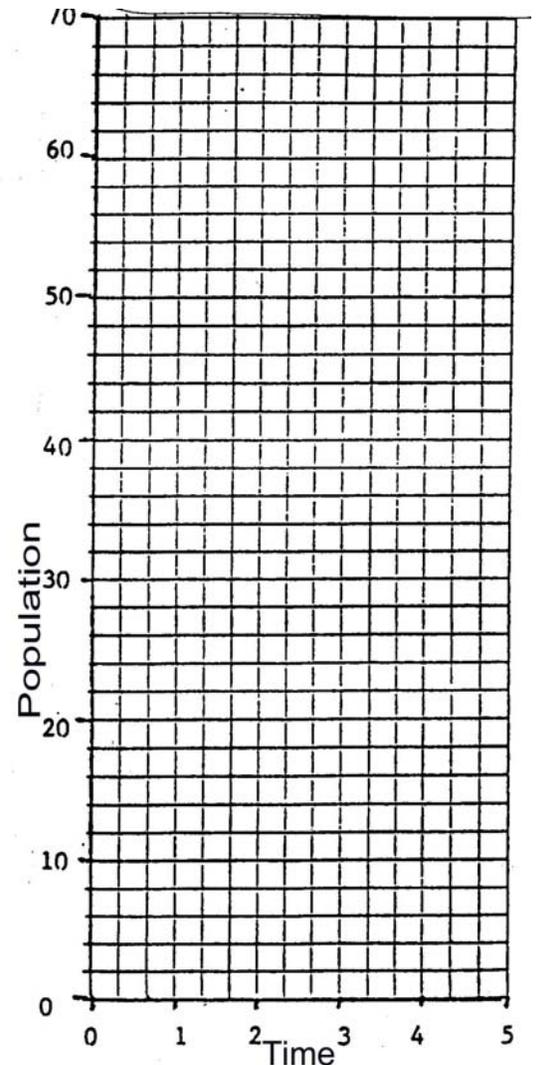
Exponential Growth of an Imaginary Population

Imagine that a glass jar contains a very unique and prolific type of organism (a "Critter") that has the ability, by mating, to reproduce and generate two new mature (and ready to mate) organisms every minute. One new male and one new female critter are always produced in each mating session between a critter couple. Based on this conceptual model, you will describe the change in population of these prolific critters each minute for a 5 minute period. Your observations will begin as soon as you introduce two ready-to-mate critters to the jar, hence the **initial conditions of your model will be 2 critters.**

- a) Complete the table below by indicating the # of **New Critters** to be added to the jar at the end of each minute, based on how many "couples" are in the jar at the beginning of the minute.
- b) Also indicate what the **TOTAL Critter Population** is in the jar at the end of each minute.
- c) As the jar is filling, note when it is **HALF FULL** in your table.
- d) Plot the data in the table on the graph provided at right.

Here are the table and graph needed to record your results:

| | # of New Critters (births) added to the jar each minute | TOTAL Population (# of Critters) in jar at end of each minute |
|---------------|---|---|
| initial state | -- | 2 |
| 1 min | | |
| 2 min | | |
| 3 min | | |
| 4 min | | |
| 5 min | | |



What's the ratio of the # of new births each minute to the total # of critters in the population at the end of the *previous* minute? _____

(This ratio is called the BIRTH RATE)

For our purposes, express it as a decimal: _____

PART II. MAKING A "SYSTEM DIAGRAM" OF POPULATION GROWTH

What is a Model?

The "Critters in a Jar" exercise you just completed was a conceptual *modeling* activity. What is a model? The concept has many dictionary definitions, but the kind of model used in scientific studies is typically one that is "a description or analogy to help visualize something that cannot be directly observed," or "a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs." The imaginary process of "reproducing critters" was represented by conceptualizing how many new critters would be born each minute (or *time step*) and how the number of critters in the jar would increase each minute as a result. Through this analogy (*analogue model*) of a controlled exponential population growth process your results showed a classic exponential curve when graphed. Note that you could have also plotted the same data on semi-log graph paper to obtain a straight line. In either case, an equation can be written for the curve or line to provide a mathematical representation of the exponential growth process. One advantage of modeling is that future growth can be predicted by applying the equation. Another advantage of modeling is that it allows you to understand the system you are analyzing in an entirely new way, i.e., by breaking it into its component parts and figuring out how these parts of the system work together. It is here that exciting discoveries can be made. The real value of modeling is as an investigative technique. In Global Change studies in particular, models are often used to test the effects of *changes* in individual system components on the overall behavior of a dynamically changing system.

System -- A selected set of interacting components usually small enough that its behavior can be understood or modeled. (after Few, 1991)

System model -- A set of assumptions or rules, data, and inferences that define all of the interactions among the components of a system and the significant interactions between the system and the "universe" outside the system. (after Few, 1991)

One other way of modeling a dynamic process -- such as population growth -- is to *diagram* the process or system. To do this, various symbols are used to represent different elements or components of the system, as well as the connections between these elements.

System diagram -- A diagram of a system that uses graphic symbols or icons to represent system components in a depiction of how a system works. (after Few, 1991).

Thinking About the Components of the Model

To gain an understanding of the modeling process, we will start with the very simple example of the "Critters in a Jar" and construct a model of that system using diagrams. In this activity you'll use "STELLA" diagramming symbols that were first developed by Jay Forrester at the Massachusetts Institute of Technology.¹

First, fill in the following information which will allow you to pinpoint the main components and variables of the critter's population growth system and how they changed:

a) As you did the exercise, what two components of the system changed over time?
_____ & _____

b) What was the time step of this change? _____

c) What assumption, or "rule" was used to determine how much change occurred at each time step?

¹ These symbols have been modified and incorporated into a software program called STELLA[®] (isee Systems, Inc.) so that model diagrams can be transformed easily into working computer models. See their website at: <http://www.iseesystems.com/index.aspx>

- d) What were the initial conditions of the jar? _____
- e) What was the critter birth rate? (birth rate =) _____
- f) Did the BIRTH RATE of the critters change from minute to minute? _____
- g) Write an **equation in words** to describe how you figured out *the number of new critters (critter births)* to add at the beginning of each new time step

new critter births = _____ * _____

- h) Write an equation in words to describe how you figured out the *TOTAL number of critters (critter population)* in the jar at the *end* of each time step

ending critter population = _____ + _____

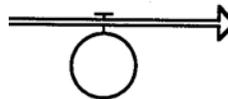
Expressing the Model Components in a SYSTEM DIAGRAM:

Thinking about the basic steps and parts of the critter exercise allows you to conceptualize it in model form. The *population* (the number of critters in the jar at each point in time) is one main system component which changed or varied over time. This population component can be viewed as a **stock** or **reservoir** that stores or accumulates quantities of critters. We can symbolize the population stock in our exercise as a **box** symbol which can store or accumulate critters:



POPULATION

The population of critters inside the jar changed over time. This part of the critter system can be viewed as a **flow** or **flux** of new critters into the jar (symbolized by an arrow). But we cannot separate the flow of critters into the jar from the mechanism that specifies how that flow behaves (i.e., how many critter births occurred in a given time step). This aspect of the critter system can be viewed as a **valve** or **regulator** on the flow. It is symbolized as a circle attached to the flow arrow with a little valve on it. The flows is labeled to show what is "flowing" in the system, in our case, *critter births* are being added to the stock or reservoir:



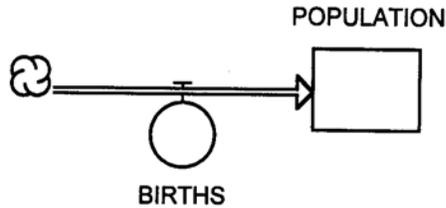
BIRTHS

Finally, to start off the whole critter population explosion process, recall that we first introduced two ready-to-mate critters into the jar. We can specify this origin for critters "outside" the jar system as a **source** that supplies a variable to a system. Since the nature of this source was not specified in detail, we symbolize it in a diagram as an undefined "cloud" shape -- or an aspect of the system that is somehow separate or larger and unaffected by the system being modeled:



SOURCE CLOUD

We can now piece together our diagram to show how all the components of the system work together:



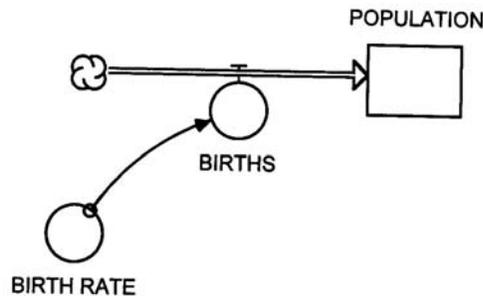
But wait! There's some information missing to make this model exactly like the critter-in-the-jar exercise. To make the critter population grow, a simple "rule" or assumption was made to specify how the valve on the flow of critters should work to increase the population. We assumed that a critter couple was able to mate and reproduce two new offspring every minute. We could have changed this assumption, or made a different one, so this is a varying part of the critter system model above. The assumptions or guidelines that were defined to describe the way the flow-part of the system should behave represent a way of refining our model and converting it into a more detailed representation of the process. We symbolize this "converting" element of our model (a **converter**) as a circle, and give it a label that describes the thing the converter is adding to, defining, or computing for the system:



To make a converter useful to the other components of the system, we need to have a way to pass the information in it to the flow & valve or to another converter. This information transfer takes place through a **connector** which passes information from one component of the system to another. The symbol used is a thin line with an arrow at the end pointing in the direction of the information transfer:

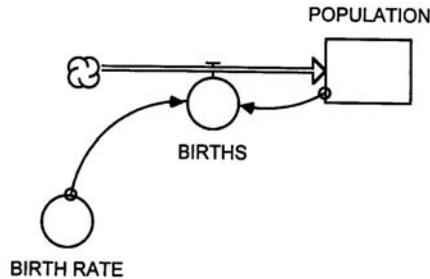


Now we can refine our critter population model diagram to include the assumptions about the critter birth rate through a converter and a connector:



Will the model now work exactly the way the Critter-in-the-Jar exercise worked? What was the thing that determined how many new critters you added at each time step???

Yes, you first needed to know **how many critter couples were in the jar** in order to apply the "two births per critter couple" birth-rate formula and compute the population at each time step. In our critter exercise, the information about the number of critter couples available was obtained from counting up the critter population already in the jar. In our systems diagram, this information is obtained from the population reservoir. Connectors can be used to transfer information from a stock or reservoir to a converter or to a flow & valve. In our critter exercise, we figured out the number of new births going into the jar population (a flow) by multiplying the number of critter couples (obtained from information in the jar population) times the birth rate per critter couple (an assumption residing in our free-floating converter). Hence information transferred from both the population reservoir and the birth rate converter was used to compute the number of critter newborns at each time step. Here's how it would look in the systems diagram:



You will soon create and run this model using STELLA software to see if you get the same results as you computed "by hand."

Critiquing the Simple Model

As with the critters-in-the-jar analogue, there are some major problems with so simple a model. Probably the most severe critique of the model is that -- unlike the real world -- none of the critters die!

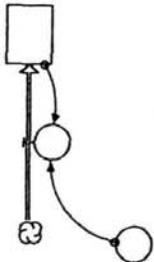
How could we add deaths to the model? We could illustrate the flow out of the population reservoir with a DEATH flow & valve. This flow has to end up somewhere, so we will introduce one last systems diagramming component -- a **sink**. Sinks, like sources, can be represented as unspecific clouds. The sink in a Stella model may seem a lot like a stock or reservoir that is receiving flow from the system, but the difference is that a sink is so large that it remains largely unaffected by the system.



Obviously many other critiques could be made for this model, but given the very restricted assumptions we based it on, it is probably a valid model for the imaginary critter situation.

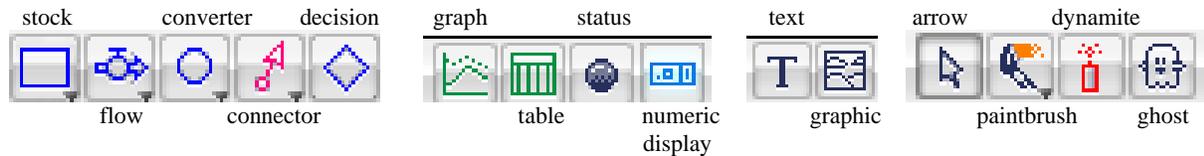
After you learn how to use the Stella Software to duplicate and run the critter model, you will be able to envision and understand more complex Stella models of global change processes. For example, inflows and outflows of carbon to the atmosphere (viewed as a stock) could be described in a Stella Model, as could inflows of solar energy to the Earth's surface and outflows of terrestrial energy from the Earth's surface back to space. You should begin thinking about what a Stella Diagram of these processes would look like in preparation for our next class.

TABLE OF PRIMARY DYNAMIC SYSTEMS DIAGRAMMING COMPONENTS
(Definitions adapted from Few, 1991)

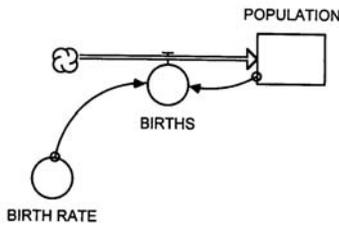
| TERM | DEFINITION | SYMBOL |
|--|---|---|
| System | A selected set of interacting components usually small enough that its behavior can be understood or modeled. System diagram -- A diagram of a system that uses graphic symbols or icons to represent system components in a depiction of how a system works. System model -- A set of assumptions or rules, data, and inferences that define all of the interactions among the components of a system and the significant interactions between the system and the "universe" outside the system. |  |
| Reservoir (stock, pool) | In systems terminology, a component of a system that can store or accumulate a quantity of one of the system variables and/or can act as a source of that variable. By analogy, a water reservoir stores the stream feeding it and supplies water to users downstream. |  |
| Flow (flux) | In systems terminology, the rate at which a variable enters or leaves a reservoir. By analogy, water in streams flows into or out of reservoirs. Also -- the rate of flow of some quantity, often used in reference to the flow of some form of energy. |  |
| Valve (control, regulator) | In systems modeling terminology, the mechanism that specifies the flow through a specific path in a system. By analogy, a valve controls the flow of water from a faucet. Flow and valves are always depicted together on a systems diagram. |  |
| Converter | In systems terminology, a free-floating element on a system diagram within which new variables or constants may be defined, computations performed, assumptions defined, or decisions made. |  |
| Connector (inter-connections & coupling) | Parts of a system are coupled if information from one part is provided to, and influences the behavior of, the other parts. The information being passed is the interconnection . On the systems diagram, the interconnection is called a connector . <i>[Note that connectors are not named and they must be attached on both ends.]</i> |  |
| Source | A reservoir that supplies a variable to a system. Sources are usually large reservoirs that are unaffected by the system being modeled. |  |
| Sink | A reservoir that receives a variable from the system under consideration. Usually sinks are large reservoirs that are unaffected by the system being modeled. |  |

PART III. HOW TO CREATE THE CRITTER POPULATION GROWTH MODEL IN STELLA SYSTEMS MODELING SOFTWARE

1. Download and install the STELLA 9 (trial/save-disabled version) from: <http://www.iseesystems.com/community/downloads/STELLA/STELLADemo.aspx>
2. Open STELLA. If the program doesn't open in MAP mode, click on the MAP tab → along the left side of the screen to get into Map Mode.
3. Along the top of the screen, you'll see a row of icons in groups – here are most of them:



4. Your task is to put the STELLA symbols (stock, flow, converter, connectors) together in MAP MODE to make the critter population model below:



a) First put the **STOCK** in. Click on the stock symbol in the row of icons at the top of the screen to select it, then move your cursor to the center of the blank screen and click. Next **give the stock a name** (e.g., “Population,” “Critter Population” etc.) by deleting “Noname 1”(with a backspace) and typing in a new name. Then click anywhere in the white background to see the changes.

b) Next send a **FLOW** into the Critter Population stock from a **source cloud**. Click on the flow symbol in the row of icons to select it, move your cursor an inch or two to the LEFT of the stock, **CLICK AND HOLD** as you slide the cursor toward the stock to direct the flow into it. (You’ll see the **source cloud** appear when you first click.) You may **RELEASE** the click when contact occurs between the flow’s arrow and the stock – the stock will temporarily change its appearance to look shaded to indicate that the connection has been made. If you release too soon, you will not have properly connected the flow to the stock. Now give the **flow a name**, such as “births” or “Critter births.”

c) Next put in a **CONVERTER** to represent the information on Birth Rate needed to operate the flow and valve at the proper rate. Click on the converter symbol in the row of icons, move your cursor to somewhere near the flow & valve and **CLICK** to place the converter. Now **give the converter a name**, such as “Birth Rate” or “Critter Birth Rate.”

d) Next put in a **CONNECTOR** to connect the information in the Birth Rate converter to the Births flow so that the flow knows at what rate to “give birth to” new critters with each time step of the model. Click on the connector icon to select it than click again on the Birth Rate converter (be sure the connector’s arrow starts inside the converter) then **CLICK AND HOLD** as you slide the cursor toward the flow symbol. When the arrow at the end of the connector makes proper contact with the circular part of the flow symbol, the flow will temporarily change its appearance to look shaded. When the connection has been made, **RELEASE** the mouse button .

e) Lastly you need to put in a **second CONNECTOR** to connect the information contained in the Critter Population stock with the Birth flow. (Recall that the number of new babies born every minute (each time step) is dependent on **BOTH** the birth rate (the converter) **AND** the current population of critters (the stock).

- Now switch to MODEL MODE by clicking on the MODEL tab along the left side of the screen. As soon as you switch into MODEL MODE, Question marks (?) will appear on the symbols where INPUT is needed to make the model run.
- DOUBLE CLICK each symbol that is asking for input (?) and fill in the pop-up window with the requested input inside the brackets { . . . } as follows:

STOCK: **INITIAL (Population) = . . . delete the phrase { Place initial value here. . . }**
and in its place enter **2** for the initial value in the population stock (then click OK)

CONVERTOR: **Birth_Rate = . . . delete the phrase { Place right hand side of equation here... }** and in its place enter **1.0** for the birth rate (then click OK)

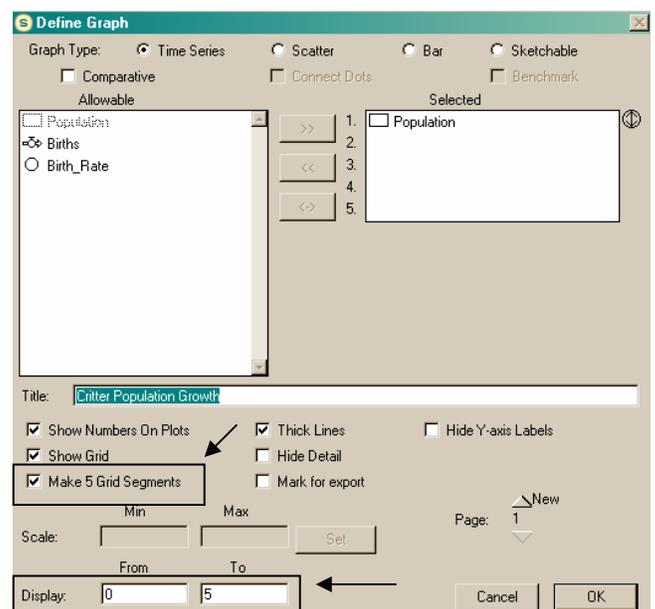
FLOW: **Births = . . . delete the phrase { Place right hand side of equation here. . . }**
and in its place create the equation that will compute the number of births at each time step by clicking on the first required variable (**Population**), then the multiplier in the numeric pad (*), and then the second required variable (**Birth_Rate**). Your right hand side of the equation should look like this: **Population * Birth_Rate** (then click OK)

NOTE: The above values will re-create the critter model you produced “by hand” in the first part of the assignment but you can change the variables to try out different scenarios by changing the Birth rate and the Initial value of the stock.

- Once you have filled in all the information required by the question marks, a little of the magic of STELLA can be revealed! Using the relationships represented by your model diagram, the STELLA software will automatically produce the necessary equations to make the model run with the input you just provided. **To see the equations, CLICK on the EQUATION tab** along the left side of the screen. The equation that computes the number of new births each time step and adds them to the number of critters already in the stock is revealed. Return to MAP or MODEL mode to continue.

You’re getting closer to running the model, but first you have to set up a way to view the model results . . .

- Create a **GRAPH** to show the results. Click on the **Graph** icon on the toolbar to select it and click again to deposit a graph in a spot on the screen. Then click on the graph to open it. You’ll see a graph, but no variable will appear on the y-axis. Double click on the graph to get to a window (shown at right) where you can select the variable you want on the y-axis (a Time Series graph is the default and time will be on the X axis). **Select the variable you want (Population)** by clicking on it and then move it to the right side of the box by clicking on >> **Give the graph a title**, such as “Critter Population Growth,” by filling in the Title box. Then to match the 5-minute run of your hand-plotted graph exactly, click on “**Make 5 Grid Segments**” and set the Display to go from **0 to 5**. Click OK and then close the graph by clicking in the upper corner of the graph. *(You will view the results later.)*



9. Next, create a **TABLE** to show the results. Click on the **Table** icon and deposit it on the screen, then double click on the table (as you did with the graph) to set up the table the way you want it. **Include these 3 variables: Critter Population, Births and Birth rate. Give the Table a title,** such as “Model Run Results” or something like that. Then close the Table by clicking in the upper corner of the table.

You're almost ready to RUN the model!! A few more steps:

Before running, some **specifications** (SPECS) of the model need to be defined.:

10. First, click on RUN in the toolbar at the top of the screen and select **RUN SPECS . . .** A window will open up.

Enter the **RUN SPECS** to match exactly the Critter Model you simulated by hand by using the following values:

Length of Simulation:

From: **0**
 To: **5**
 DT = **1.00** (for a one minute time step)

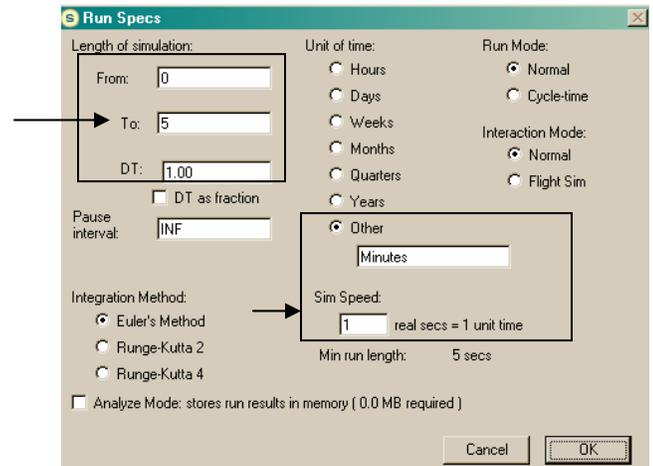
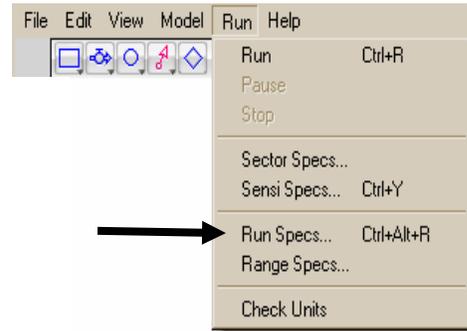
Unit of time:

Select “Other” and enter: **Minutes**

Sim Speed:

Enter **1**
(to simulate at the speed of 1 second = 1 minute)

Then click OK to close the window.

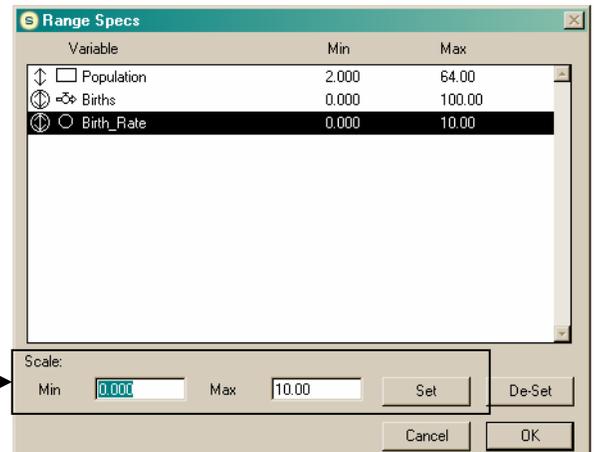


11. Next, click on RUN in the toolbar at the top of the screen again and select **RANGE SPECS . . .**

Enter **RANGE SPECS:** min max

Population: 2 64
Births: 0 100
Birth rate: 0 10

To do this, select the variables one at a time and enter the Min and Max values at the bottom of the window. Click **SET** after each variable entry has been made and go to the next variable. *(If you don't click SET, you will get an error message.)* When all the ranges for each variable have been set, click OK to close the window.

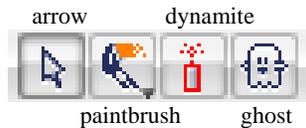


12. FINALLY to RUN the model, **CLICK on the right-pointing triangle RUN symbol:**  at the bottom left of the screen OR select **Run** from the RUN tool in the toolbar at the top of the screen.

13. To see the results, click on the **TABLE** and then the **GRAPH**. If you did everything properly, the table should show the same results that you hand-calculated and the graph you get should look like the graph you hand-plotted.

14. Now have fun playing with the model and trying out more model runs, e.g., you can put the Critters on birth control by reducing the birth rate, make the Critters sterile by changing the birth rate to 0, or make the Critters very prolific by increasing the birth rate. You can change the initial value of the population in the stock. You can fool around trying out different Run and Range settings and adjust your table and graph to better show these new results. Observe that because the growth rate is EXPONENTIAL, small changes in the input variables can make very large changes in the growth response.

A FEW MORE STELLA TRICKS:



If you make a **mistake**, you can “dynamite” it away!! Click on the **DYNAMITE** icon to select it, then move the stick of dynamite so that the “fuse end” lines up on the item you want to delete and click again. **BLAST!** It’s gone! [NOTE: when blasting away **CONNECTORS**, you must put the fuse on the connector at its start – the tiny little circle where it is attached to the stock or converter that it is connecting.]

You can use the **ARROW** to draw a box around an entire model diagram (or part of one) and select all the components inside the box at once. You can also reposition things with the arrow .

The **GHOST** is used to make a copy of a component of your model and paste a “ghosted” copy of this same component elsewhere in the model or in a related model. This is useful in more complex models where a specific calculation (such as the conversion of degrees C to degrees F) may need to be made over and over again.

You can use the **PAINTBRUSH** to change the color of your model, add text by clicking on the **TEXT** icon to enter explanatory text in a block, and set up a **NUMERIC DISPLAY** to show the final value of different variables in your model after it has completed its run

To **clear the results of a Table or Graph**, click on the **dynamite** symbol that is located in the corner of the table or graph.

You can “**push-pin**” a Table or Graph **to keep it open** so you can watch it change *during* the model run by clicking on the little push pin symbol at the upper left corner of the Table or Graph.

GC TOOLKIT ASSIGNMENT IN PREPARATION FOR FEB 13th CLASS:

Now that you know how to construct a Stella system diagram and run a Stella Model you are ready to apply Stella to a global change model. Your assignment is to sketch out the Stella Diagram for a **simple radiation balance at the Earth’s surface which can also be used to compute the Earth’s mean surface temperature**. Your model will consist of an incoming solar radiation (inflow) and an outgoing terrestrial radiation (outflow) with energy accumulating in, and being released from, the Earth’s “stock” or reservoir of stored surface energy.

At right are the model components you should use. Start with the arrangement of the stock and flow symbols first, then try to figure out how to arrange as many of the converters and connectors as you can. *In class next week we will go through the explanation of the correct model and actually run the model.*

