3.1 System Dynamics Tool:
***Nova* Tutorial 1**

Introduction to Computational Science:
Modeling and Simulation for the Sciences

Angela B. Shiflet and George W. Shiflet
Wofford College
© 2006 by Princeton University Press

Nova Revision by Elizabeth Lockman

Introduction

We can use the software *Nova* created by Richard Salter, to model dynamic systems. For more examples and more detailed tutorials on building models in Nova, visit www.novamodeler.com. **Dynamic systems** are usually very complex, having many components with involved relationships. For example, we can use *Nova* to model the competition among different species for limited resources or the chemical reactions of enzyme kinetics.

To understand the material of this tutorial sufficiently, we recommend that you do everything that is requested. While working through the tutorial, answer Quick Review Questions in a separate document.

In the first tutorial on *Nova*, we consider an example on unconstrained growth. In this example, the rate of change of the population is equal to 10% of the number of individuals in the population, and the initial population is 100 individuals. Thus, we have the following **differential equation**, or equation involving a derivative:

$$\frac{dP}{dt} = 0.1P, \quad P_0 = 100$$

Start running the software, perhaps by double-clicking the *Nova* icon ( ). A window will appear, as in

Figure 3.1.1.

Figure 3.1.1   **Nova Model Canvas**
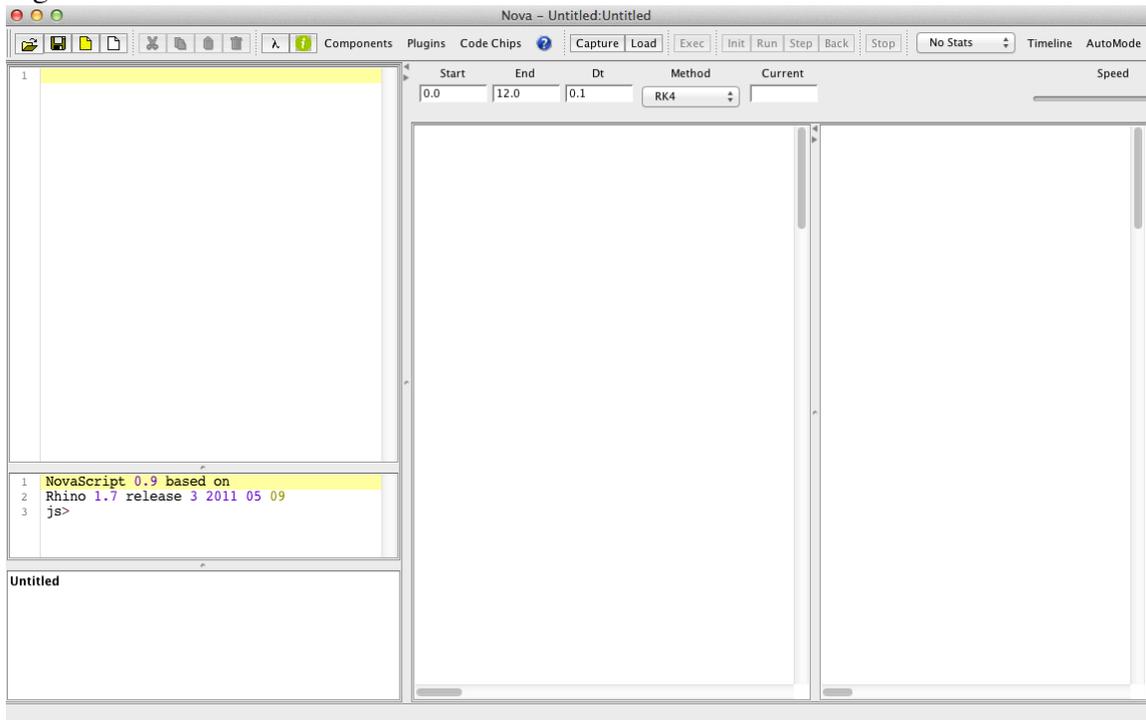
In the left-hand section of the model, you can enter code or equations to build the model. In the center section, we'll build the model. The right third of the screen is for output.

Figure 3.1.2   Modeling Space

The most important icons for building a model appear under the components section of the tool bar. Click on "Components" and a floating window will pop up. The most important components for this tutorial are shown in Table 3.1.1. We describe the meaning of each of these building blocks in the following sections.

Table 3.1.1   Basic building blocks of *Nova*

| Building Block	Icon	Meaning
Stock		noun, something that accumulates
Flow		verb, activity that changes magnitude of stock
Term		converts, stores equation or constant, does not accumulate
Arrow		connects inputs and information

Stock

In *Nova* terminology, a **stock** is a noun and represents something that accumulates. Some examples of stocks are population, radioactivity, enzyme concentration, self-esteem, and money. At any instant, the magnitudes of the stocks give us a snapshot of the system. The most common type of stock is a reservoir, which the green stock square represents.

Quick Review Question 1 In the *Nova* components section, click on the green stock icon. Without holding down the mouse button, move the cursor towards the top-middle of the window. What is the shape of the cursor?

Click in the center section of the Nova window to insert a stock object. When prompted, type the name of the stock, *population*. The contents of the window should be as in Figure 3.1.3.

Figure 3.1.3   Contents of window after insertion of stock called *population*
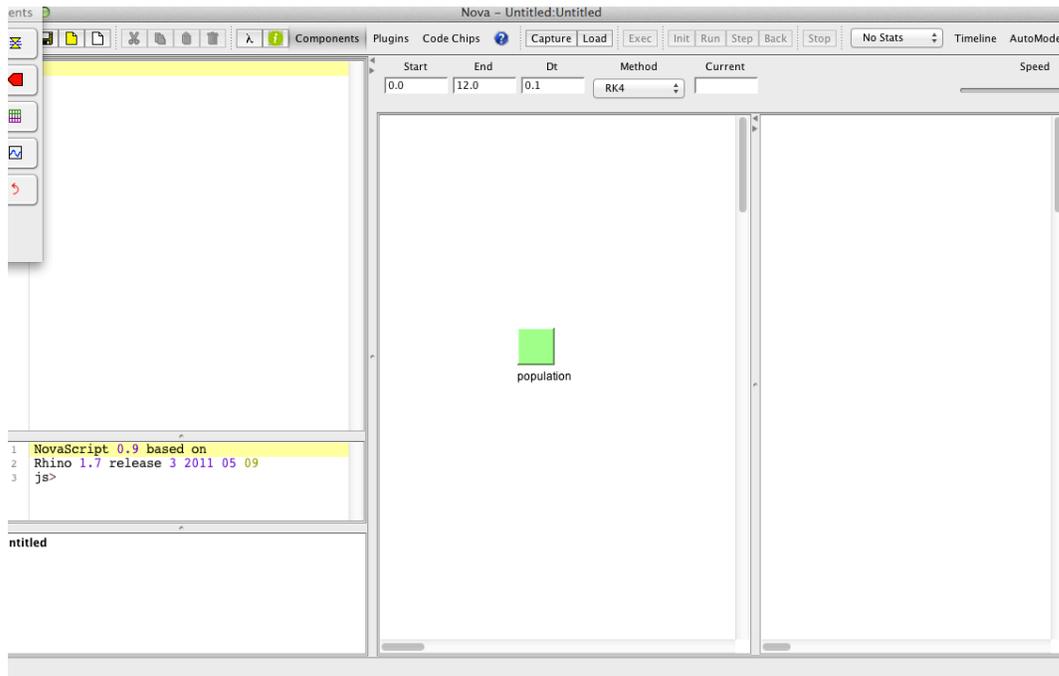
Quick Review Question 2 Click on the stock, *population*, and attempt to drag it around the screen. Describe where the stock can be dragged.

Under the *File* menu, select **Save**, or the floppy disk icon in the toolbar (or **ctrl-s** on a PC or **command-s** on a Macintosh) to save your work on a disk. Use a meaningful name for the file, such as *NovaTutorial1*. Save your work frequently. Thus, if there is a power interruption, you will not lose much of your work. Also, sometimes if you make a mistake, it is easier to close the file without saving and open the recently saved version.

Flow

While a stock is a noun in the language of *Nova*, a **flow** is a verb. A flow is an activity that changes the magnitude of a stock. Some examples of such activities are births in a population, decay of radioactivity, formation of an enzyme, improvement of self-esteem, and growth of money. The flow icon represents a directed pipe with in and out arrows and flow regulator.

Click on the flow icon. Click on the model canvas a couple inches to the left of the stock to place the flow. We'll call it *growth*. Click on the cloud to the right of the white arrow, and drag it towards the stock until the arrow connects directly to the stock and the cloud goes away. The diagram should appear as in Figure 3.1.4.

Figure 3.1.4   Diagram after addition of *growth* flow
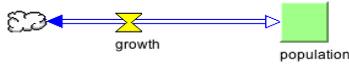
Quick Review Question 3 Drag the *population* stock around the right of the screen. What happens to the diagram?

If moving the *population* stock does not result in the flow arrow moving, too, but reveals another cloud, you need to attach the flow to the stock. Drag the stock over the cloud at the point of the arrowhead until the cloud goes away. Perform the task of Quick Review Question 3 again.
   Save your work.

Converter

We can use a **term** to modify an activity. A term can store an equation or a constant. For example, with the population model, a term might store the constant growth rate, say $10\% = 0.1$.
    As an example for radioactive decay, radioactive substance bismuth-210 decays to radioactive substance polonium-210. With A representing the amount of bismuth-210 and B the amount of polonium-210, the ratio B/A is significant in the model of decay. A term can store this ratio.
    Select the term icon from the components window, which is a pink circle. Click below and to the left of the flow name, *growth*. Name the term *growth rate*. Blanks are permissible. The diagram should appear similar to Figure 3.1.5.

**Figure 3.1.5**   Diagram after insertion of term *growth rate*
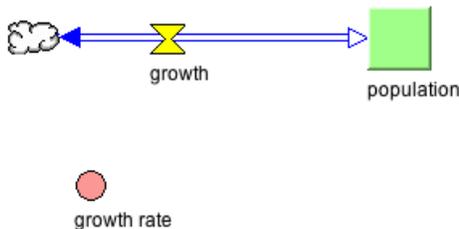
Arrow

An **arrow** connects components of a model and transmits an input or an output. For example, in a population model, a arrow can transmit the growth rate value from the growth rate term to the growth flow.

In a radioactive decay model, arrows from the bismuth-210 (*A*) stock and from the polonium-210 (*B*) stock to a term for the ratio of *B* over *A* transmit the respective amounts of radioactivity for use by the term.

Because they transmit data, arrows do not have numerical values.

In the population model, both the growth rate and the current population affect the current growth. For example, if the growth rate is higher, so is the growth. Moreover, a larger population exhibits a greater change in population. We indicate these relationships by connecting the *growth rate* term and the *population* stock to the flow *growth*. Select the arrow icon, click on the *growth rate* circle and drag the arrow towards the *growth* flow, then click on the growth flow. Click on the arrow icon from the components window again. Connect *population* to *growth* as in Figure 3.1.

Figure 3.1.6   Arrows drawn to *growth* flow
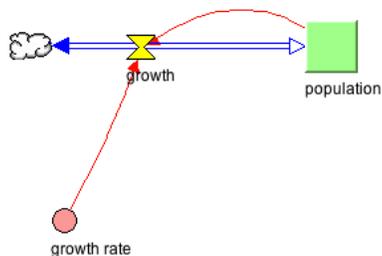
Quick Review Question 4 For the arrow from the stock to the flow, click on it until you see a see a small circle along the length of the arrow. Drag it around. Where can you drag it?

Quick Review Question 5 What happens to the arrow as you drag the stock *population* around the window?

Save your work.

Delete

To remove a component from the diagram, we use **delete** (🗑). At the top of menu select the trashcan icon, or select delete from the edit menu.

Quick Review Question 6 Add another term to the model canvas. Call it test1. Click the trashcan icon. What happens to that term?

Quick Review Question 7 What happens when you delete the flow?

**Quick Review Question 8** What happens when you delete the connecting arrow?

Quick Review Question 9 Click on *population*, then click the trashcan to remove the stock. What is eliminated?

When we delete an item, the process eliminates the item and all connected connectors and flows. Restore the model to its previous form by repeatedly clicking undo in the Edit menu. If a component is missing, recreate the model to appear as in Figure 3.1.6.

<div align="center">

Equations and Initial Values

</div>

We are now ready to enter equations and initial values. To begin defining an initial population, right click on the *population* stock and view a popup menu as in Figure 3.1.7. For an initial population of 100 bacteria, type 100. The value replaces the shaded text "0.0".

Figure 3.1.7   Popup menu after right-clicking *population* stock
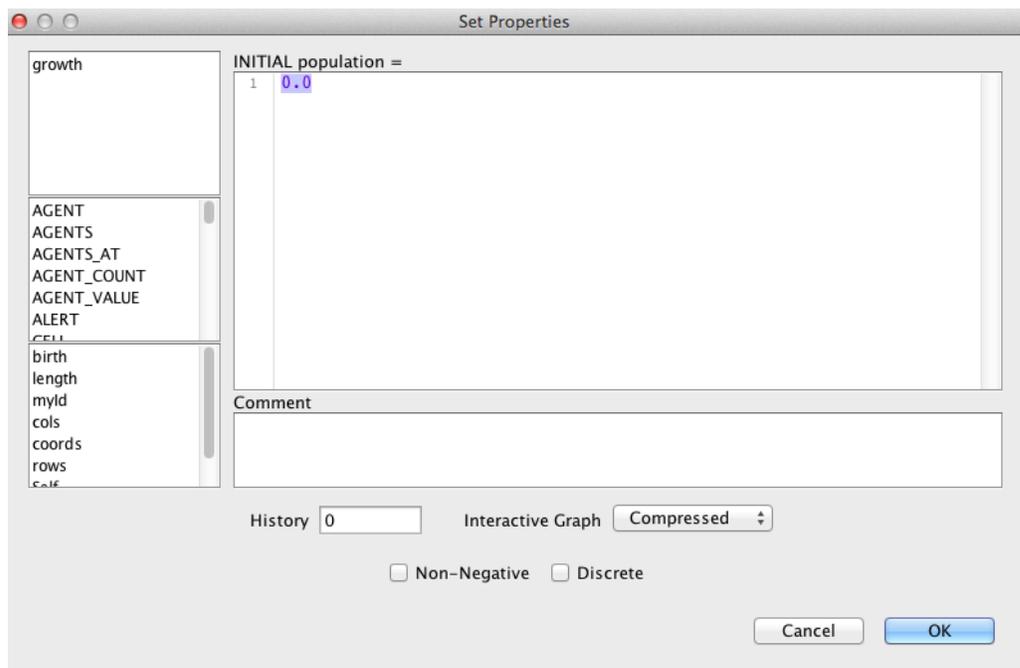
Notice in the bottom of the box, there is a checkbox labeled ***Non-negative***. Check this box, because populations cannot be negative. However, sometimes a stock can store a negative amount, such as money in the case of debt or velocity in the case of a falling object with up being positive. In such situations, we should leave the *Non-negative* checkbox unchecked.

Click *OK*.

Quick Review Question 10   To establish the growth rate as $10\% = 0.1$, first, right-click the term. What name does *Nova* give for the term?

Type 0.1 in place of the highlighted "0.0" and then click *OK*.

For equations, *Nova* can either use an underscore or a blank in a name. Nova automatically translates the names to include the underscore. Thus, "growth rate" in a diagram (see Figure 3.1.6) becomes "*growth_rate*" in a *Nova* equation (see Figure 3.1.7). We employ such replacement of blanks with underscores in the text and tutorials to avoid confusion with component names.

Unlike *growth_rate*, the flow *growth* is not a constant; but the growth in the population changes with time as the population changes. For our example, at any instant, the rate of change in the population, or *growth*, is 10% (*growth_rate*) of the current population (*population*). In calculus terminology, the instantaneous rate of change of population is the derivative of *population* with respect to time *t*, so that we have the following formula:

$$\frac{d(population)}{dt} = growth\_rate \cdot population$$
$$= 0.1 \cdot population$$

Right-clicking on the *growth* flow, we see a popup menu as in Figure 3.1.8.

Figure 3.1.8   Popup menu for *growth*
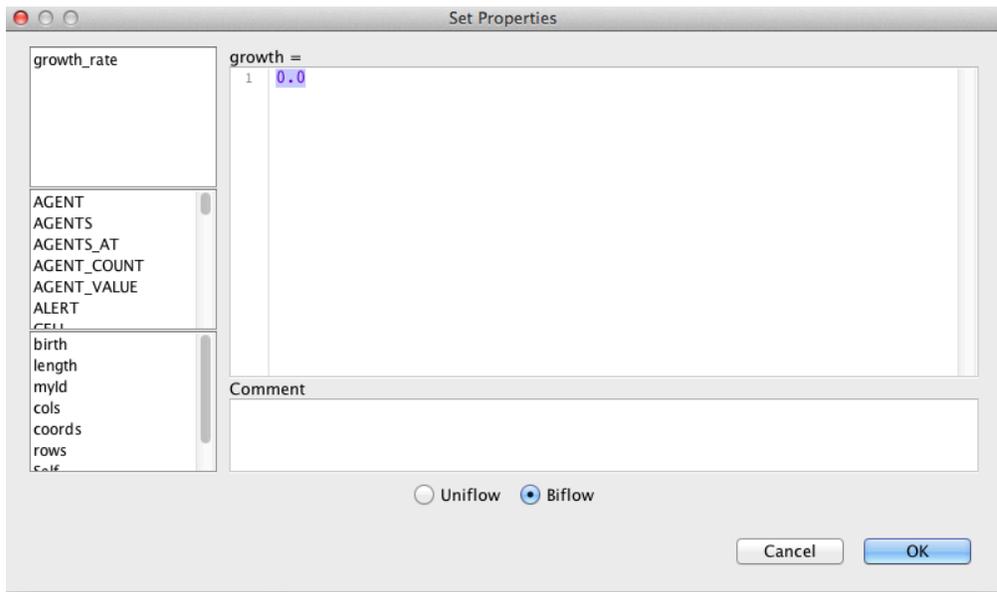
Quick Review Question 11   The menu in the upper left-hand corner of the popup
   menu contains the items that have arrows connecting them to *growth*, namely
   population and *growth_rate*. We include these variables in the formula for *growth*.
   For our example, this instantaneous rate of change of population is 0.1*population*
   bacteria per unit of time. Using * for multiplication and clicking on the appropriate
   variables in *Required Inputs*, enter the formula for growth. What is the resulting
   formula? Click *OK*.

   As Figure 3.1.8 shows, the popup menu for a flow has two radio buttons,
UNIFLOW and *BIFLOW* in the top left corner. The default is *BIFLOW*, which indicates
that growth can only flow in two directions, in and out of the stock *population*. Should
we wish to allow values to only flow in one direction, we would check *UNIFLOW*. In
this case, the flow would appear as in Figure 3.1.9, with only the open arrowhead
indicating the primary direction into *population*.

Figure 3.1.9   Uniflow
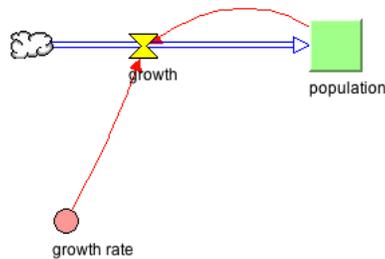
At this point, let's run the model so we can see the code behind our model. In the top tool bar, click these buttons in the following sequence: "Capture," "Load," "Exec."

Now click on the lambda symbol (λ) in the toolbar.
This will take us to the **Equation/NovaScript Level** and reveals the resulting formulas, which Equation Set 1 displays. On the model, we had established a value for *growth_rate* (0.1), an initial value for *population* (100), and the equation for *growth* (*growth_rate* * *population*). The variable **dt**, which appears in the formula for *population*(*t*), represents the **change in time** between time steps. The variable **t** represents **time**; and ***population*(*t*)** is the **population at time** *t*; while ***population*(*t* − *dt*)** is the population at the previous time step, *t* − *dt*. As we discuss in detail in Module 3.2 on "Unconstrained Growth," the first equation indicates the population at one time step is the population at previous time step plus the change in population over that time interval:

(new population) = (old population) + (change in population)
            = (old population) + *growth* * *dt*
            = (old population) + (growth over 1 unit) * (length of time step)

Equation Set 1 Formulas

```
population(t) = population(t - dt) + (growth) * dt
INIT population = 100
INFLOWS:growth = growth_rate * population
growth_rate = 0.1
```

Quick Review Question 12   For current time *t*, give the meaning of each of the following:
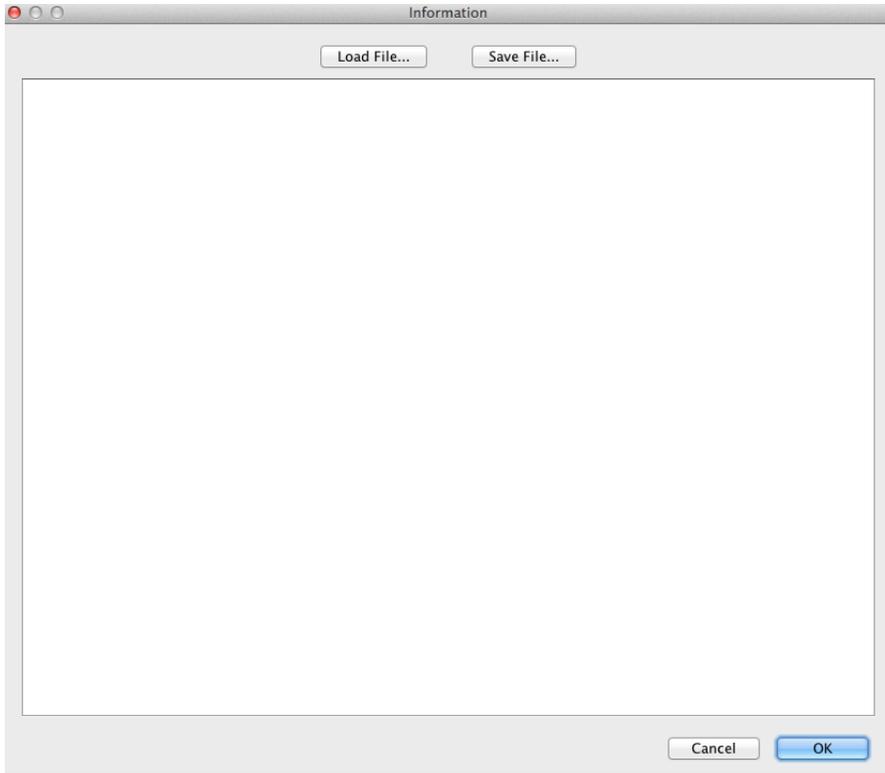
a. $t - dt$
b.   *population*($t - dt$)
c.   *growth* * *dt*

Save your work and continue saving frequently.

Comments

Click the information icon ( ) in the top toolbar of the *Nova* window to go to the **Information Window**. Figure 3.1.10 displays the information window.

Figure 3.1.10   Information Window

Documenting our work is extremely important. We want other people to be able to understand the model as quickly as possible. Moreover, we can very easily forget what we intended just a few days or hours ago. We may have several very similar versions of the same model that we need to distinguish one from another. We do not want to waste our own or someone else's time by having to dig deeply into the different levels and equations to understand the model.

Quick Review Question 13   To enter a comment, click the **Label** icon in the components window ( ) to get a **label**. What is the shape of the resulting cursor?

Click towards the top middle of the window to insert the label. Type "Unconstrained Growth Population Model" on one line and your name and date on the

next. Type an explanation that the model is for growth of a population with no limiting factors.

**Quick Review Question 14**   Click on the outside lines of the label. What appears?

Drag on one of the small shaded rectangles, called **handles**, at a corner to resize or display all of the text. Drag on one of the box's lines to move the box without resizing.

Graphs

In the components window, the **graph** icon ( ) appears as a picture of a small graph. After clicking this icon, click somewhere in the center panel of the model canvas to place the graph connections. Right click on the graph to get the Graph Properties window.

The "Graph 1" icon will remain in the window unless you delete it. Right-click on the "Graph 1" icon to redisplay the graph popup window. To see the graph itself, we'll need to do some wiring. Right-click on the graph icon to display the **Graph Properties Window** (see Figure 3.1.11).

Figure 3.1.11   Graph Properties Window with Graph Icon in background
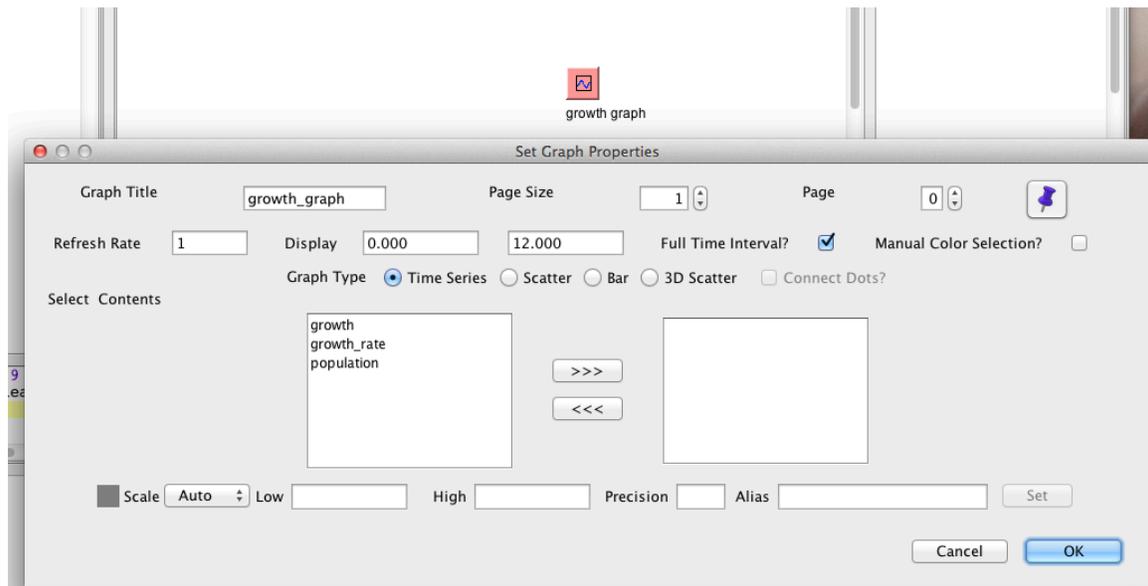
In the text box for *Title:* in the upper left-hand corner, type "Population vs. Time" so that the title appears on the graph's window. Leaving the graph type as the default *Time Series*, time will appear on the horizontal axis. To have *Nova* graph the population with respect to time, we click once on the *population* line under the contents box, and click ">>". When we click OK, we'll see a dotted line in the center panel of the model canvas connecting the population stock to the graph icon. In the right panel of the model, we'll see the graph "Population Vs. Time."

Run the model by clicking (in the following order): "Capture," "Load," "Exec" from the top tool bar to obtain the graph of Figure 3.1.12. Notice that the bottom left corner of the graph indicates an initial population (at time 0.0) of 100.

Figure 3.1.12   Graph of *Population vs. Time* using the default run specifications

growth graph
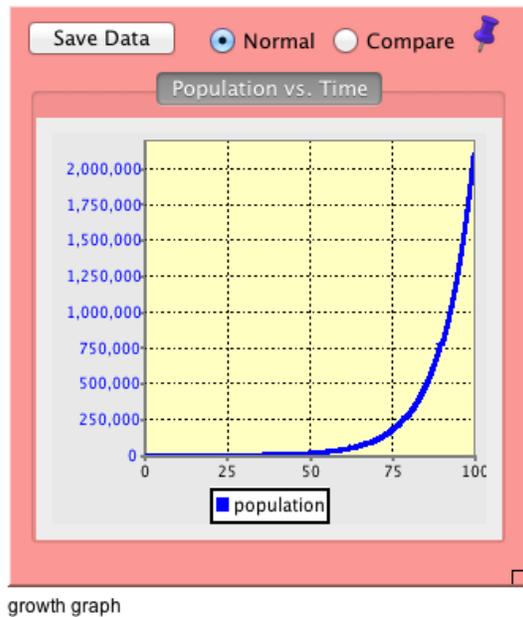
Quick Review Question 15   How many time units does the simulation run?

Quick Review Question 16   About how many time units does it take for the initial population to double?

To change the default time specifications, from the bottom of the tool bar change the value in the "End" box shown in Figure 3.1.13. Have the simulation run for 100 time units. If we are modeling the growth of a population of bacteria, the time unit would probably be an hour; while for a larger animal, the unit might be a month. Supposing the model is for a colony of bacteria, change the *Unit of Time* to *Hours*. Change *DT* to 0.1. Thus, calculations for the simulation will be every 0.1 hour instead of every 0.25 hour. Usually, a smaller *DT* generates more accurate results but causes the simulation to take longer. Although the computations take longer, we can also obtain better results with the Runge-Kutta 2 or the Runge-Kutta 4 integration method. For the time being, switch from the Nova default Runge-Kutta 4 (RK4) method to Euler's Method. Chapter 5 on "Simulation Techniques" discusses these methods.

Figure 3.1.13   *Run* toolbar

Start	End	Dt	Method	Current
0.0	12.0	0.1	RK4 ↕	12.000

Quick Review Question 17   After making the above changes, how many time steps (*DT*s) will be in the simulation?

Click *OK*, and run the simulation. Notice in Figure 3.1.14 that *Nova* changes the range on the time axis to 0.00-100.00 and on the population axis to 0-3000000.

Figure 3.1.14   Graph of *Population vs. Time* after editing the *Run specs* in the toolbar from Figure 3.1.13


growth pop
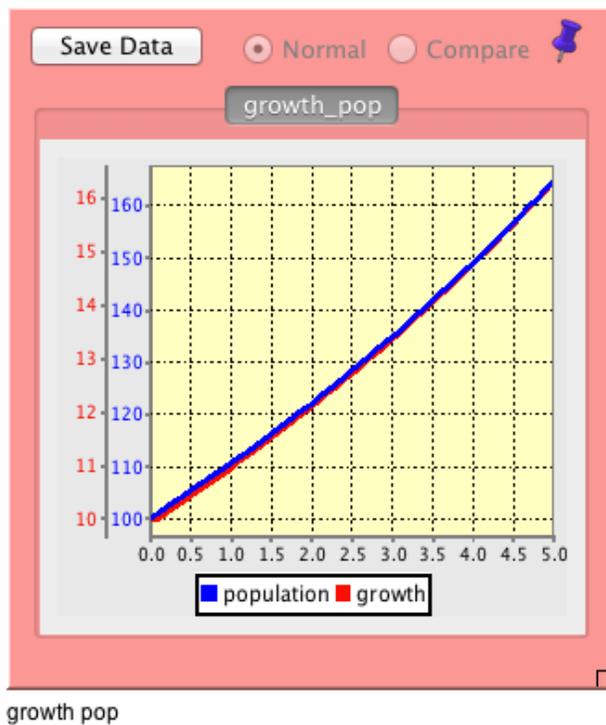
Right-click the graph to display the Graph Properties Window once again (see Figure 3.1.11). To generate a new graph, click on the graph icon on the components page again. For this graph, make the proper specifications to plot *population* and *growth* from 0 to 5 hours on the same graph by changing the default Display range values to 0 and 5(see Figure 3.1.15). Run the simulation. Notice that you can only really see one line on the graph. Right-click on the graph once again. We'll change that in the next step. In Figure 3.1.16 you'll see that that the graphs are numbered and colored with different scales on the vertical axis. The ranges are such that the graphs appear almost horizontal at 0.

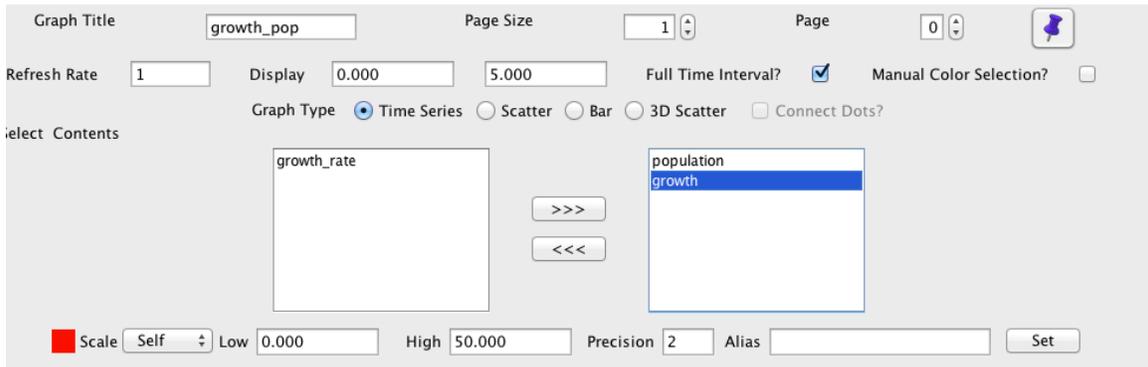**Figure 3.1.15**   *Run Specs* for graphs of *population* and *growth*
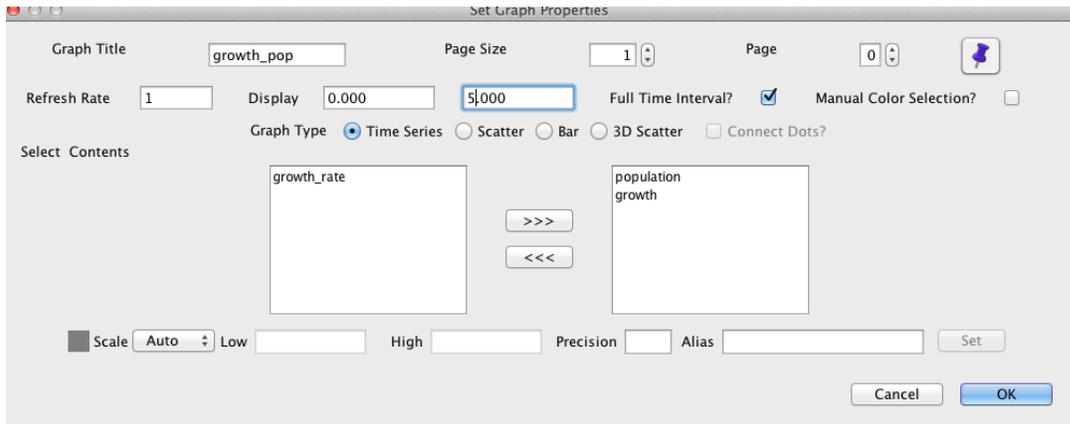
Figure 3.1.16   Graph of *Population & Growth vs. Time*


growth pop
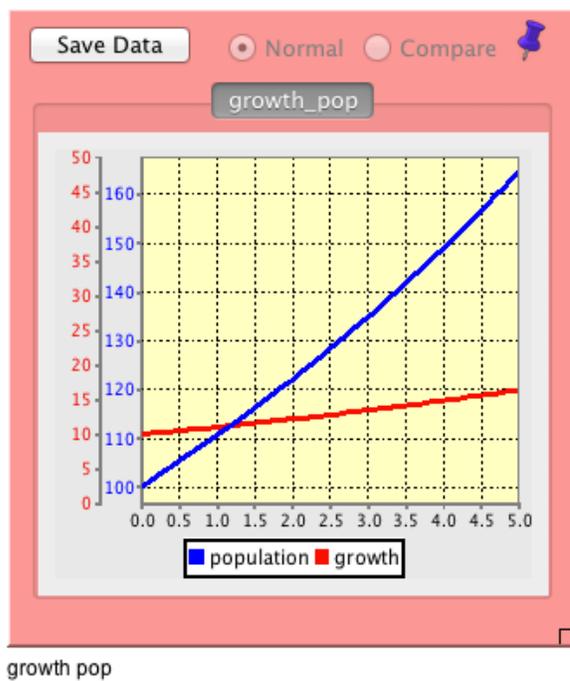
Right-clicking the graph, we can change the scales in the Graph Properties Window (see Figure 3.1.17). On the click on the variable *population*. You'll see the minimum (*Low*) and maximum (*High*) values on the *Scale* towards the bottom left. Change the scale from "Auto" to "Self." Repeat for the variable *growth*. Change the range to from 0 to 150, and click *Set*. Similarly, set the scale for *growth* to from 0 to 150, and click *Set* and *OK*. Without re-running, the graph, which is in Figure 3.1.18, immediately reflects the scale changes.

Figure 3.1.17   Graph Properties Window to change scales

Graph Title	growth_pop	Page Size 1 ⬍ Page 0 ⬍ 📌

Refresh Rate   1   Display   0.000   5.000   Full Time Interval?   ☑   Manual Color Selection?   ☐

Graph Type   ⦿ Time Series   ◯ Scatter   ◯ Bar   ◯ 3D Scatter   ☐ Connect Dots?

Select Contents

growth_rate		population
	>>>	growth
	<<<	

🟥 Scale [Self ⬍]   Low [0.000]   High [50.000]   Precision [2]   Alias [   ]   [Set]

Figure 3.1.18   Graph of *Population & Growth vs. Time* for scales of 0 to 150 for
   *population* and *growth*

growth pop
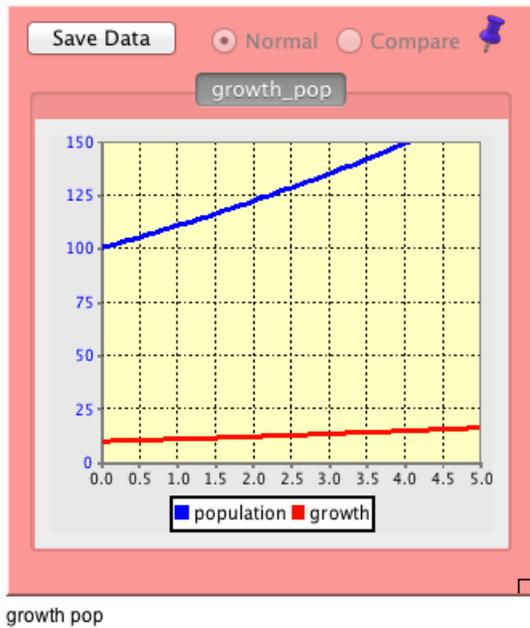
Quick Review Question 18 Notice that we still cannot see all of the *population* graph for
the time period. What maximum to the nearest 10 (160, 170, 180 etc.) shows the
entire graph from 0 to 5?

      Change the range for *population* and *growth* to be the same and so that both graphs
appear completely.

Tables

Besides a pictorial view, we may want a table of values from the simulation. The **Table** icon (▤) appears to the left of the Graph icon in the components window (see Figure 3.1.10). Click this icon and place a table object below the graph object. Name the table "Population Changes." Right-click the table to display the **Table Properties Window** as in Figure 3.1.19. Move *growth* and *population* to the *Selected* submenu.

Figure 3.1.19   Table Properties Window
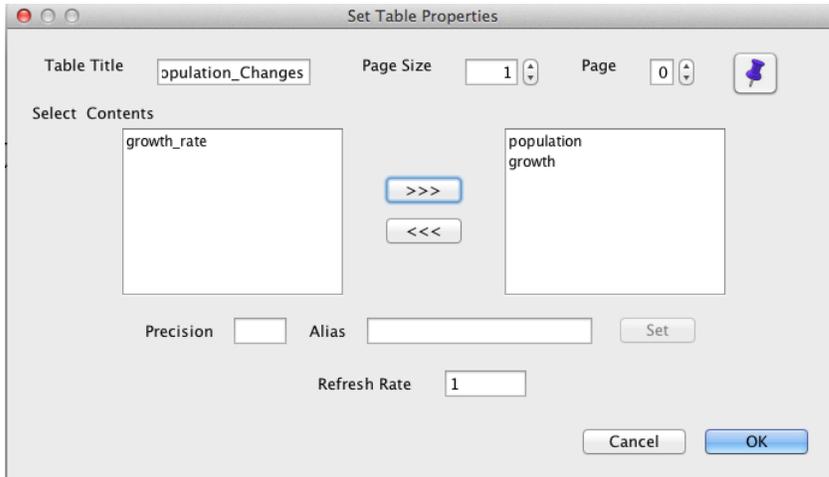
Quick Review Question 19 **How many rows of values appear in the table?**
    Click on the table in the output section of the model canvas. Drag the square in the bottom right corner to adjust the spacing and display larger values.
    It is more appropriate to have the growth and population in whole numbers. To change the format of the population values, right-click the *table* icon.

Quick Review Question 20   What do we do to display the population in whole numbers?

    Select the terms in the graph "population" and "growth." Change the precision of each term to 0, click *Set*, then click *OK* and run the model to view the result.

Input/Output Tools

We can change initial values and constants in the model by going back to the model in the middle section, right-clicking the stock or term, and changing the value. In running our model for several situations, this process is tedious. Moreover, we cannot detect the values immediately by looking at the screen or printout. However, *Nova* has a variety of tools for input and output values that can help us perform an assortment of simulations quickly and view the results readily.

One of the most useful such tools, is the **Slider** for defining constants and initial values. Click its icon ( ) in the Components Window (see Figure 3.1.10). Place a Slider on the model canvas and call it "population1". A window titled "Set Slider Parameters" will pop up. Chose the appropriate minimum and maximum values, for population such 1-2000. Click *OK*. Create another slider called "growth_rate1," with a minimum and maximum of 0 and 0.9. Click *OK*.. At this point, we need to do a little rewiring. Delete the "growth rate" term. Right click on the "growth" flow. Change the equation in the growth flow to "growth_rate1 * population." To change the value of the Population stock to the population1 slider, right-click on the stock and select "population1" for the Initial Population value. You'll notice that there are now two sliders in the right-hand output panel of the model canvas. Set these sliders so the initial population is 15 and the growth rate is 0.2 Run the simulation. If a graph does not display properly, double-click the graph and change the scale.

Quick Review Question 23   Insert a Slider Input Device for *growth_rate*. Give two ways to designate the growth rate with this device.

The final output window is displayed in **Figure 3.1.20**.

Figure 3.1.20
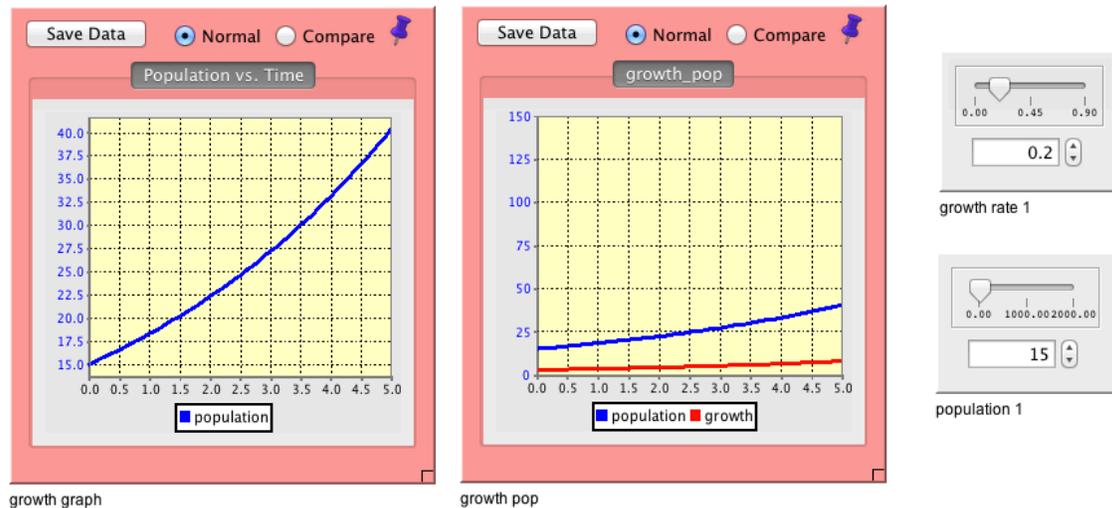
Save and Quit *Nova*.

Reference

Nova Tutorials, 2013. Nova. http://www.novamodeler.com/tut/