3.1 System Dynamics Tool: *Vensim PLE* Tutorial 1

Introduction to Computational Science: Modeling and Simulation for the Sciences

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Introduction

We can use the software *Vensim® PLE* from Ventana Systems, Inc. (http://www.vensim.com/) to model dynamic systems. **Dynamic systems** are usually very complex, having many components with involved relationships. For example, we can use *Vensim* to model the competition among different species for limited resources or the chemical reactions of enzyme kinetics.

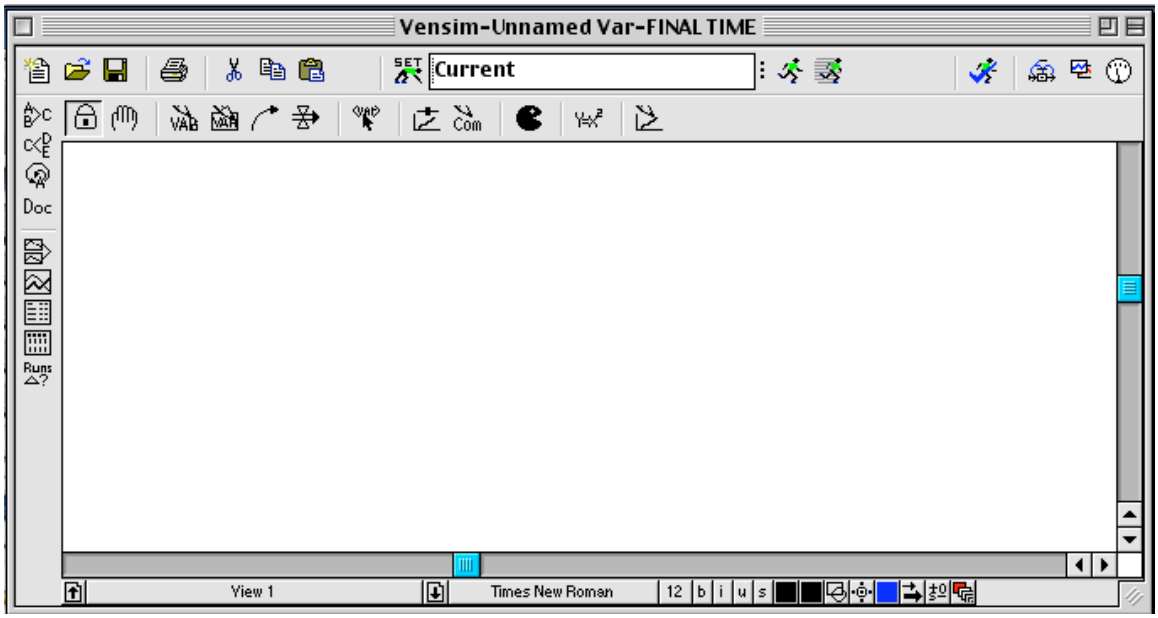
To understand the material of this tutorial sufficiently, we recommend that you do everything that is requested. While working through the tutorial, answer Quick Review Questions in a separate document.

In the first tutorial on *Vensim PLE*, 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 *Vensim PLE* icon (). Then, select ***New*** from the ***File*** menu. A ***Model Settings*** popup menu appears (see Figure 3.1.10). Usually, when starting a new model, we change some of the values in this window. However, until we have had time to consider some of *Vensim*'s features, accept the default settings by clicking ***OK***. A window appears as in Figure 3.1.1. In this window, we can construct a diagram model with equations.

Figure 3.1.1 *Vensim PLE* window



The **title bar**, which is at the top of Figure 3.1.1, contains the text "Vensim-Unnamed Var-FINAL TIME." The **main toolbar** is beneath the title bar and contains typical icons for *Open Model*, *Save*, *Print*, *Cut*, *Copy*, and *Paste*, among others. The most important icons for building a model, the **sketch tools**, appear towards the left, below the main tool bar, and immediately above the large, currently blank ***Build* (*Sketch*) *Window***. Table 3.1.1 lists the sketch tools, and the following sections describe the meanings of these building blocks.

Table 3.1.1 Basic building blocks of *Vensim*

Building Block	Icon	Meaning
Box Variable or **Stock**		noun, something that accumulates
Rate or **Flow**		verb, activity that changes magnitude of stock
Variable or **Converter**		converts, stores equation or constant, does not accumulate
Arrow or **Connector**		transmits inputs and information

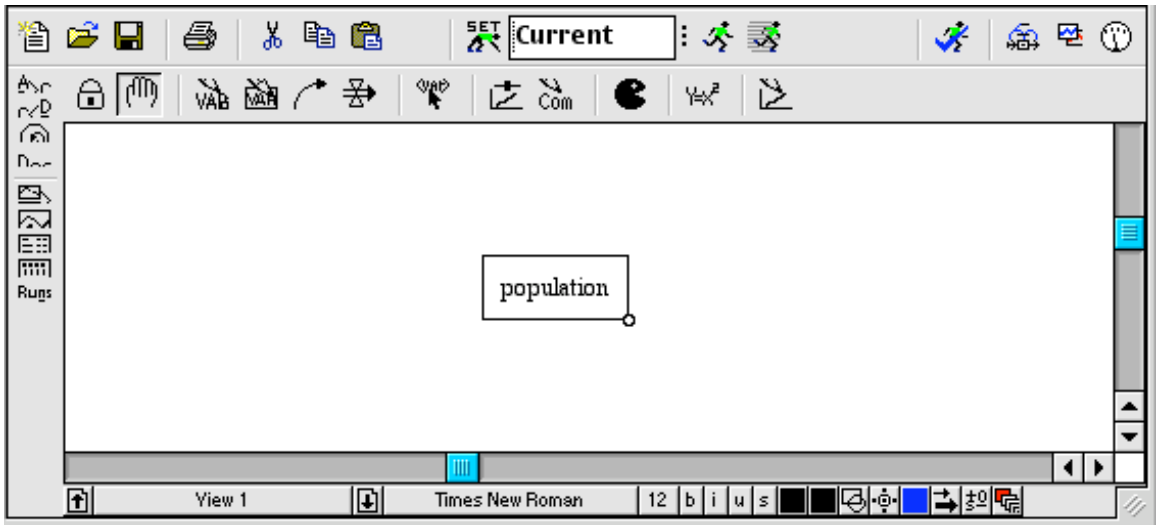
Box Variable or Stock

In *Vensim PLE* terminology, a **box variable** or **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.

Quick Review Question 1 In *Vensim*, click on the rectangular 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 *Build Window* to insert a stock object. Without clicking again, type the name of the stock, *population.* The contents of the window should be similar to Figure 3.1.2. To change the name later, click once on the stock with the box variable icon and type the new name and press *RETURN* or *ENTER*.

Figure 3.1.2 Contents of window after insertion of stock called *population*



Quick Review Question 2 Select the **hand tool** ( ) on the left of the sketch toolbar and then click on the stock's name, *population*, and attempt to drag the name around the screen. Describe what happens.

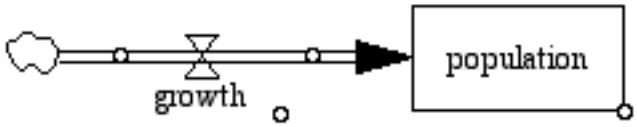
Under the *File* menu, select ***Save*** (or **ctrl-s** on a PC or **command-s** on a Macintosh) or click the ***Save* icon** on the main toolbar to save your work to a disk. Use a meaningful name for the file, such as "*Vensim for Tutorial 1*." Save your work frequently. Thus, if there is a power interruption, 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.

Rate or Flow

While a stock is a noun in the language of *Vensim*, a **rate** or **flow** is a verb. A rate is an activity that changes magnitude of stock. Some examples of such activities are births in a population, decay of radioactivity, formation of an enzyme, improvement of self-esteem, or growth of money. The rate (flow) icon represents a directed pipe with a valve.

Click on the flow icon. Click a couple of inches to the left of the stock; and then without dragging, click the stock so that a rectangular with a cursor appears. Type its name, *growth*, in the rectangle and press *RETURN* or *ENTER*. The diagram should appear similar to Figure 3.1.3 with the flow beginning in a cloud, the ether, which in this example is a source.

Figure 3.1.3 Diagram after addition of *growth* rate (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 delete the flow and create another that attaches to the stock.

We can change the direction of flow from being only into *population* to being into and out of this reservoir so that population can increase or decrease. Thus, we are changing the flow from a uniflow having one direction to a biflow going in two directions. To change the direction, we first select the hand tool. Then, on the small circle to the left of the valve for *growth*, **right click** with a Windows computer or **ctrl-click** with a Macintosh computer. Should we wish to allow values to flow in both directions through the arrow, we click the top left checkbox for ***Arrowhead*** and then *OK* in the popup menu (Figure 3.1.4). In this case, the flow would appear as in Figure 3.1.5 with arrowheads at both ends representing the possibilities of addition to and removal from the population.

Figure 3.1.4 Popup menu for the arrow

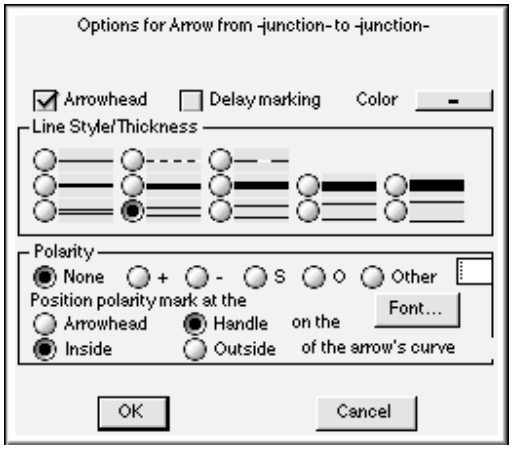
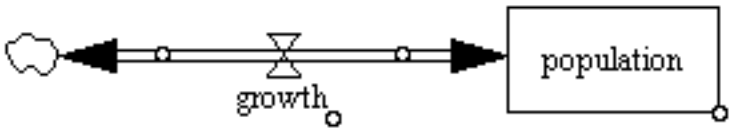


Figure 3.1.5 Biflow for *growth*



If you changed the flow to be a biflow, restore the arrow to be uniflow as in Figure 3.1.3 by right clicking (Windows) or ctrl-clicking (Macintosh) and unchecking *Arrowhead* in the arrow popup menu (Figure 3.1.4).

Save your work.

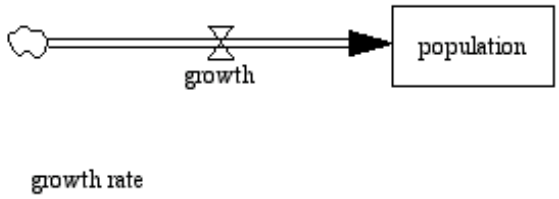
Variable—Auxiliary/Constant or Converter

We can use an **auxiliary/constant variable** or **converter** to modify an activity. A variable can store an equation or a constant. For example, with the population model a variable 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 converter can store this ratio.

Select the ***Variable—Auxiliary/Constant*** **icon**, which has **"VAR"** and a pencil but no box. Click below and to the left of the flow name, *growth*. Name the converter *growth rate*. Blanks are permissible. The diagram should appear similar to Figure 3.1.6.

Figure 3.1.6 Diagram after insertion of converter *growth rate*



Arrow or Connector

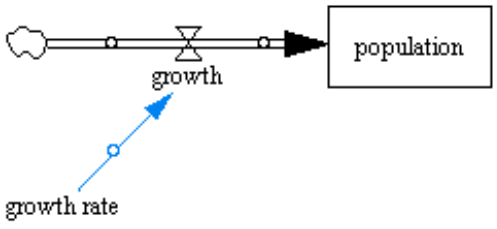
An **arrow** or **connector** transmits an input or an output. For example, in a population model, a connector can transmit the growth rate value from the growth rate auxiliary/constant variable (converter) to the growth flow.

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

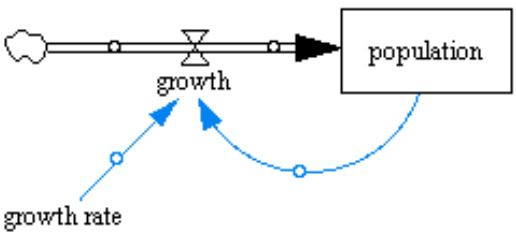
In the population model, both the growth rate and the current population affect the current growth. For example, if the growth rate is higher, so is the growth. Moreover, a larger population exhibits a greater change in population. We indicate these relationships by connecting the *growth rate* converter (variable) and the *population* stock (box variable) to the flow *growth*. After selecting the connector icon, click *growth rate* and then *growth*. The resulting diagram is as in Figure 3.1.7a. Without selecting another tool, we can use the same tool again. Connect *population* to *growth* as in Figure 3.1.7b by clicking *population*, clicking below and between *population* and *growth* to create an arch, and then *growth*. Small circles indicate anchors that we can drag to create arches. Save your work.

Figure 3.1.7 Connectors drawn to *growth* flow

a



b



Quick Review Question 4 For the connector from the stock to the flow, select the hand tool and then click on the small circle on the arrow and drag it around. What happens to the arrow?

Quick Review Question 5 What happens to the arrow as you drag box variable *population* around the screen?

Delete

To remove a component from the diagram, we use the **delete tool** ( ) or *Cut* from the *File* menu. Using the delete key does not completely eliminate the item from the model. Select the delete icon, which is the second-to-the-last icon on the right in the sketch toolbar.

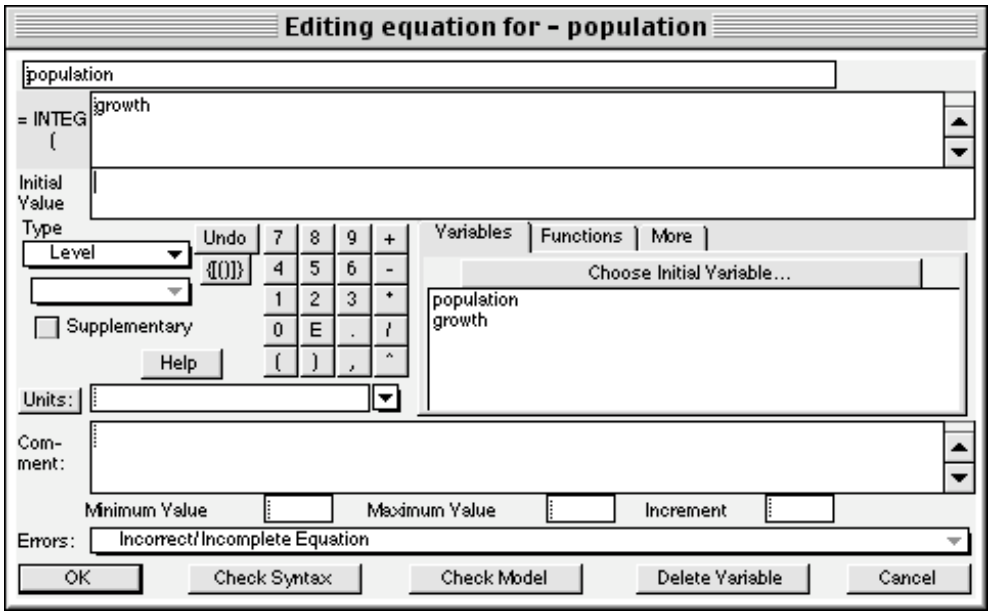
Quick Review Question 6 With the delete tool, click on *population* to remove the variable. What is eliminated?

When we remove an item with delete tool, the process eliminates the item and all connected connectors and flows. Restore the model to its previous form by closing the current document *without saving* and reopening the document. If a component is missing, recreate the model to appear as in Figure 3.1.7b.

Equations and Initial Values

We are now ready to enter equations and initial values. To begin defining an initial population, click on the **equation tool** ( ), which is next-to-the last icon on the right of the sketch tools toolbar. The three items that can have values or equations (*population*, *growth*, and *growth rate*) turn black. Click the *population* variable, and view a popup menu as in Figure 3.1.8. For an initial population of 100 bacteria, type 100 at the location of the cursor in the *Initial Value* text box. Click the ***Check Syntax*** button at the bottom left of the panel. In the ***Errors:*** box immediately above the button, *Vensim* responds *Equation OK*.

Figure 3.1.8 Popup menu after clicking the equation icon and *population*



The dropdown menu for *Units:* lists several alternatives, including ***Dmnl*** for **dimensionless**, which we should use when a value has no units. Because the appropriate unit for *population* is not in the list, we type *bacteria* after *Units:*.

The boxes and text of the equation panel (Figure 3.1.8) indicate that *population* is the integral (***INTEG***) of *growth* and the initial value of *population* is 100 bacteria. Hence, *Vensim* is saying the following, where time (*t*) goes from *a* to *b:*

$$P = \int_a^b growth\ dt$$

We do not need to understand integration to use *Vensim*. As we discuss in detail in Module 3.2 on "Unconstrained Growth," in computer simulation terms, the statement is equivalent to the following:

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

To complete input for *population*, click *OK* on the bottom left of the panel.

Quick Review Question 7 To establish the growth rate as 10% = 0.1, first, click the variable (converter) with the equation tool. What precedes the text box containing the cursor?

Type 0.1 in the text box. In the *Units:* text box, type 1/*Hour*, and click *OK*. Notice that after entering a growth rate and an initial population, the diagram elements no longer appear black.

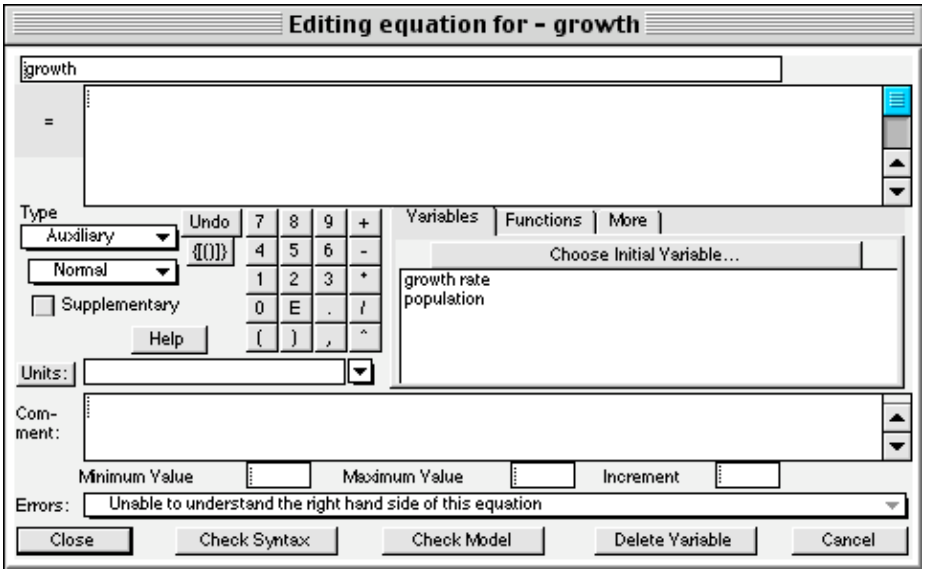
We often employ replacement of blanks with underscores in the text to avoid confusion with component names. Thus, *growth rate* is equivalent to *growth_rate* in this tutorial and the text.

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:

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

Clicking on *growth*, we see a popup menu as in Figure 3.1.9.

Figure 3.1.9 Popup menu for *growth*



Quick Review Question 8 The submenu ***Choose Initial Variable…*** of the Popup menu for *growth* (Figure 3.1.9) lists the items that have connectors 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 hour. Using * for multiplication and clicking on the appropriate variables in *Choose Initial Variable…*, enter the formula for growth. What is the resulting formula? For the units, type *bacteria/Hour*. Click *OK*.

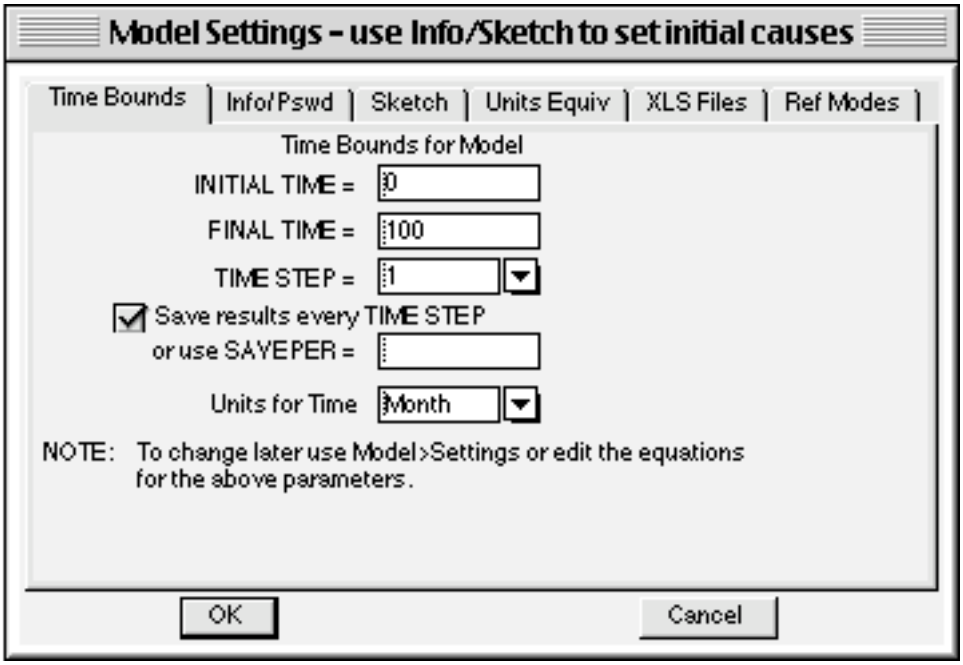
We can verify that our units are consistent from the ***Model*** menu by selecting ***Units Check***. Unfortunately, *Vensim* indicates that we have one error. The *Units Checking* popup menu displays the following analysis:

```
Error in units for the following equation:
population  =
        INTEG( growth ,
             100)
population  --> bacteria
growth  --> bacteria/Hour

Analysis of units error:
Right hand and left hand units do not match
population
 Has units:  bacteria
INTEG( growth ,
     100)
 Has units:  Month*bacteria/Hour
```

An inconsistency (in boldface here) in the time units between *Hour* and *Month* exists. The problem arises from the fact that *Vensim* uses a default unit of *Month* for time. To override the default, from the ***Model*** menu we select ***Settings....*** In the resulting ***Model Settings*** popup menu (Figure 3.1.10), we change the ***Units for Time*** to be *Hours*. This change should correct the inconsistent units, so click *OK*.

Figure 3.1.10 *Model Settings* popup menu



Quick Review Question 9 After making the change of units, perform a units check from the *Model* menu. Give the displayed message.

For this example, let us also change the length of the simulation and the time between steps of the simulation. Once more, select ***Settings...*** from the ***Model*** menu. In the ***Model Settings*** popup menu (Figure 3.1.10), leave the ***INITIAL TIME*** as 0 *Hours*, but change the ***FINAL TIME*** to be 12 *Hours* so that the simulation does not run as long. Also, in the dropdown menu for ***TIME STEP***, select 0.125. Thus, calculations for the simulation will be every 0.125 Hours instead of every hour. Usually, a smaller *TIME STEP* generates more accurate results but causes the simulation to take longer. Click *OK*.

Clicking the **document icon** (***Doc***) to the left side of the *Build Window* reveals the formulas, which Equation Set 1 displays. We established values for the *FINAL TIME* (12), *INITIAL TIME* (0), *TIME STEP* (0.125), and units for time (*Hour*) in *Model Settings* popup menu. Using the equation tool, we set a value for *growth_rate* (0.1), its unit (1/*Hour*), an initial value for *population* (100), its unit (*bacteria*), and the equation for *growth* (*growth_rate* * *population*).

Save your work and continue saving frequently.

Equation Set 1 Formulas

```
(1)FINAL TIME  = 12
   Units: Hour
   The final time for the simulation.

(2)growth=
      growth rate*population
   Units: bacteria/Hour

(3)growth rate=
      0.1
   Units: 1/Hour

(4)INITIAL TIME  = 0
   Units: Hour
   The initial time for the simulation.

(5)population= INTEG (
      growth,
         100)
   Units: bacteria

(6)SAVEPER  =
       TIME STEP
   Units: Hour [0,?]
   The frequency with which output is stored.
```

```
(7)TIME STEP  = 0.125
   Units: Hour [0,?]
   The time step for the simulation.
```

Comments

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 10 To enter a comment, click the **comment icon** (), which is the fourth icon from the right on the sketch toolbar, to get a **text box**. What is the shape of the resulting cursor?

Click towards the top middle of the *Build Window* to insert the text box. Type "Unconstrained Growth Population Model," your name, the date, and an explanation that the model is for growth of a population with no limiting factors. Press *RETURN*, *ENTER*, or *OK*. Drag on the small circle, called a **handle**, at the right bottom corner to resize the text box.

Quick Review Question 11 What occurs when you click the text box with the comment icon?

Run Simulation

To generate a simulation dataset that we can display and graph, we click the ***Run a Simulation*** **icon** (), which appears as a running man immediately to the right of the text box containing *Current*. A display of the times appears as the simulation progresses. When complete, the name of the resulting dataset is *Current*, the name in the text box. We can change the simulation setup, such as the *TIME STEP* or length of the simulation, and generate another dataset using a different name.

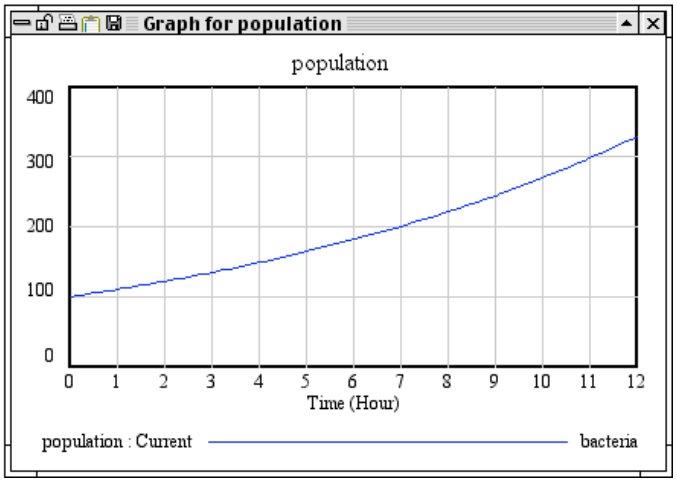
Quick Review Question 12 How many time units does the simulation run?

Quick Review Question 13 Click on the *Run a Simulation* icon again. Give the message that appears. Click *Yes* to run the simulation again and overwrite the dataset.

Graphs

The ***Graph* icon** () appears as a picture of two small graphs to the middle, left of the *Build Window*. After clicking this icon, a graph popup window of *population* versus *Time* appears immediately (see Figure 3.1.11). Adjust the placement of the graph by dragging on its title bar. Drag on an edge to change the size of the graph popup window.

Figure 3.1.11 Graph of *population* versus *Time*



Quick Review Question 14 About how many time units does it take for the initial population to double?

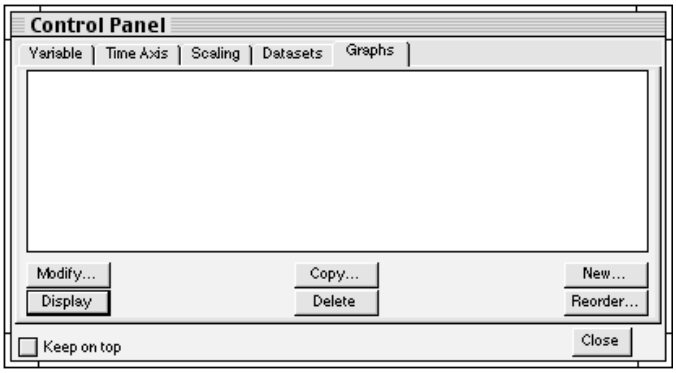
Quick Review Question 15 Click outside of the graph popup window. What happens?

To redisplay output, such as a graph or table that no longer appears because we clicked outside its window, click the ***Output Windows - show/circulate*** icon (), which is the second icon from the right on the main (top) toolbar. We can close an output window so that *show/circulate* does not reactivate the display by clicking the horizontal bar on the top left of the window or clicking the X on the top right of the window.

Frequently, we want more control over a graphical display, such as designating a title or having more than one plot appear on the same graph. To do so, click on the

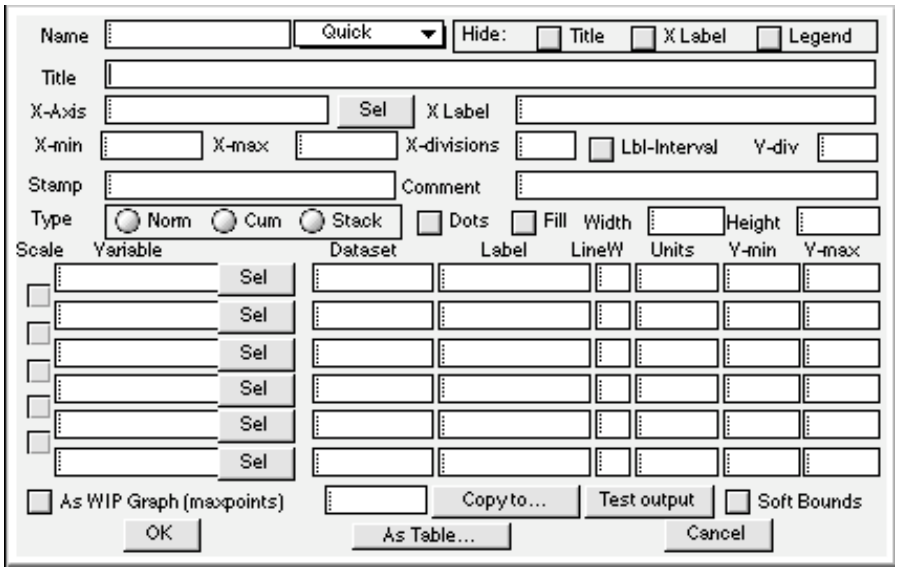
control panel icon ( ) in the far right of the main toolbar. Click on the ***Graphs*** tab on the right, top of the resulting **Control Panel** so that the panel appears as in Figure 3.1.12.

Figure 3.1.12 Control panel



To start a new graph, click the ***New*** button towards the right, bottom of the control panel. A **graphics panel** (Figure 3.1.13) appears that enables us to specify a number of graph characteristics. For the title, type "Growth and Population" in the ***Title*** text box. Under ***Variable*** on the left bottom, click the ***Sel*** button and select *growth* in the popup menu. Repeat the process, selecting *population*, for the variable in the next row. Click *OK* to return to the control panel.

Figure 3.1.13 Graphics panel

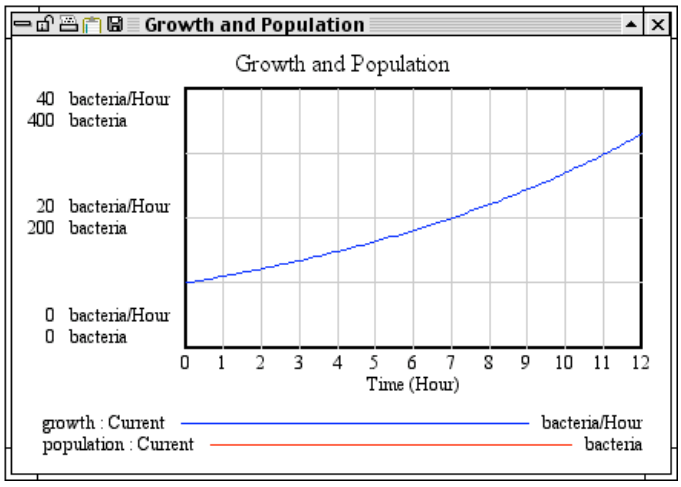


Quick Review Question 16

a. What name appears in the large control panel text box?
b. How is this name related to the title of the graph?

To view the graph, which appears in Figure 3.1.14, click the ***Display*** button on the left bottom of the control panel. Because the graphs of *growth* and *population* have the same shape and the scales are different, the two graphs appear on top of each other. To show the graphs on the same scale, return to the control panel and click ***Modify***. In the resulting graphics panel, click on the ***Scale*** checkbox between and to the left of the variables *growth* and *population*. So that your name appears on the graph, place your name in parentheses at the end of the title. Click *OK* and then *Display* in the control panel.

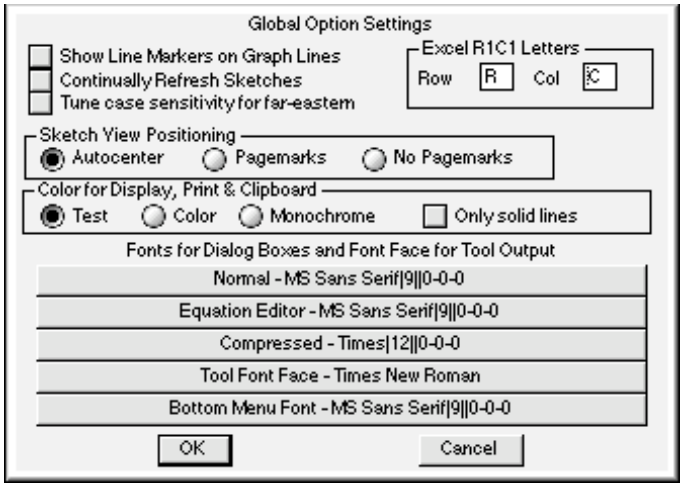
Figure 3.1.14 Graph of *growth* and *population* using different scales



Quick Review Question 17 Describe the differences in the current graph, which employs the same scale for both variables, and the graph of Figure 3.1.14.

By default, *Vensim* uses different colors to distinguish between the graphs. To print with a black-and-white printer, we have several alternatives available through ***Options...*** on the ***Options* menu** (Figure 3.1.15). To have *Vensim* number each plot, click ***Show Line Markers on Graph Lines*** checkbox at the top left. Other useful options in the ***Color for Display, Print & Clipboard*** section in the middle of the panel are ***Monochrome*** for black-and-white graphs and ***Only solid lines*** for solid lines instead of dotted and dashed ones.

Figure 3.1.15 Options panel



Quick Review Question 18 By making one change at a time in the options panel and then redisplaying the graph from the control panel, describe the change(s) caused by clicking each of the following:

a. *Show Line Markers on Graph Lines*
b. *Monochrome*
c. *Only solid lines*

To preserve this graph regardless of what other changes we make, click the **lock icon** at the top left of the graph window (see Figure 3.1.14). Click the next icon, and **print** the graph. The ***Export window contents*** **icon** copies the table to the clipboard for pasting into another application, such as a word processing document. To toggle between a larger and smaller graphical display, click the **triangle(s)** towards the right top of the window.

Tables

We start generating a table in the same way we did graphs by clicking on the control panel icon on the right of the main toolbar. From the control panel, we can develop a new table or modify an existing one. For this example, select the graph's title, *Growth_and_Population*, and click ***Copy***. The resulting panel has a copy of the information to create a graph of *growth* and *population*. Click the ***As Table...*** button in the middle bottom of the control panel to see the **table panel**, Figure 3.1.16. In the ***Table Name*** text box on the top left, change the name of the table from *Growth_and_Population_0* to *Growth_and_Population_Table*. Click the ***Running down*** check box in the ***Time*** section on the right so that the time values appear in a column down the page. Click *OK*. The resulting table appears as in Table 3.1.2.

Figure 3.1.16 Table panel

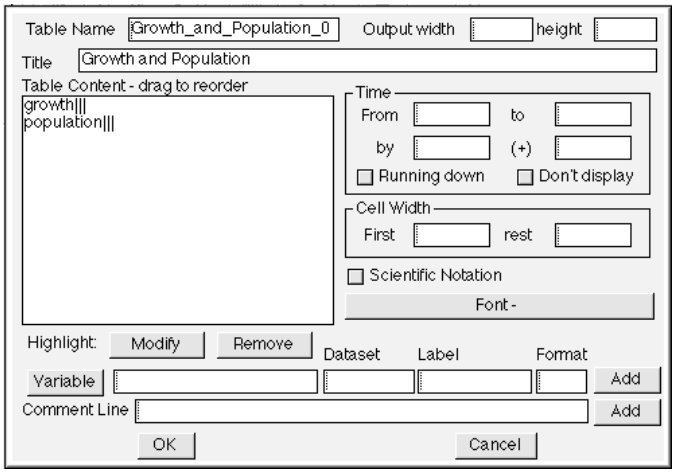


Table 3.1.2 Table of *growth* and *population*

Time (Hour)	growth	population
0	10	100
0.125	10.12	101.25
0.25	10.25	102.51
0.375	10.37	103.79
0.5	10.50	105.09
0.625	10.64	106.40
0.75	10.77	107.73
0.875	10.90	109.08
1	11.04	110.44
1.125	11.18	111.82
1.25	11.32	113.22
1.375	11.46	114.64
1.5	11.60	116.07
1.625	11.75	117.52
1.75	11.89	118.99
1.875	12.04	120.48
2	12.19	121.98
2.125	12.35	123.51
2.25	12.50	125.05

Quick Review Question 19 Give the last row of the table.

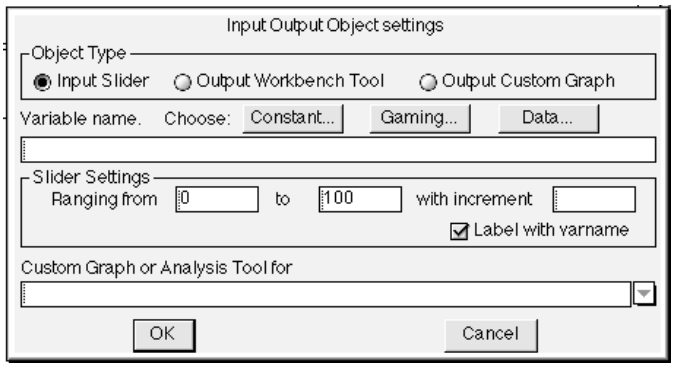
Quick Review Question 20 In the control panel after selecting *Modify* for *Growth_and_Population_Table*, make the following changes: Have *Time* go from 5 to 10; have the *Cell Width* of the *First* column be 20 and of the *Rest* be 14; and in the *Table Content* window drag to have *growth* appear after *population*. Describe the first and last two lines of simulated data in the resulting table.

Print the table.

Input/Output Tools

We can change initial values and constants in the model by selecting the equation tool and then clicking the desired variable. For a visual display, click the ***Input Output Object* icon** ( ) to the right of the sketch tools. Click in the model work area to place the object. Immediately, the ***Input Output Object Settings* panel** appears (see Figure 3.1.17). Click ***Constant*** and select *growth rate*. Have values range from 0 to 0.2. After clicking *OK*, we see a slider bar for *growth rate*. The ***SET* icon** ( ) to the left of the dataset name activates the slider bar.

Figure 3.1.17 *Input Output Object Settings* panel



Quick Review Question 21 After clicking *SET*, Give the appearance of each of the following:

a. The slider bar
b. *growth_rate*

Type or drag to obtain 0.09 as an alternative value for *growth_rate*. Change the name of the dataset to *Current09*. Click the *Run a Simulation* icon to the right of the dataset name to run a simulation with the new value for *growth_rate*. Click the *Run a Simulation* icon again. To end the setup without running a simulation and return *growth_rate* to its default value, click the ***STOP* icon** ( ) to the left of the dataset name.

Print the model diagram and the equations viewed by clicking *Doc* on the left. You have already printed a graph and table. Save and Quit *Vensim*.

Reference

Kirkwood, Craig W., updated by Jennifer Cihla Vender, *Vensim® PLE Quick Reference and Tutorial*,Ventana Systems, Inc., 2002. Available from: http://www.public.asu.edu/~kirkwood/sysdyn/VenPLE.pdf

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