Berkeley Madonna Tutorial

Version 8.0.1

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Modeling a Harmonic Oscillator

This tutorial illustrates many of the basic techniques for constructing and executing models in Berkeley Madonna. We'll begin by creating a simple model using the equation editor and exploring its run-time behavior. Then, in Building a Visual Model, we'll create a graphical model using Madonna's new flowchart editor.

1. Launch Berkeley Madonna. Choose **New** from the **File** menu. Madonna creates a new model and opens its equation window. Edit the equations to appear as follows (changes are in **bold**):

   METHOD **Euler**

   STARTTIME = 0
   STOPTIME = 10
   DT = **0.1**

   init A = 0
   init B = 1
   d/dt(A) = -k1*B
   d/dt(B) = k2*A
   k1 = 1.0
   k2 = 1.0

   Tip: choose **Equation Help** from the **Help** menu for a summary of Berkeley Madonna's equation syntax.

2. Choose **Run** from the **Compute** menu (or click the **Run** button). Berkeley Madonna runs your model and plots the results for variables A and B.

3. Note that the amplitude of oscillation for both A and B increase over time. This instability is due to the fact that Euler's method is accurate to only the first order. Using the **Compute** menu, change the integration method to **Runge-Kutta 2** and run the model again. Now the amplitude is almost perfectly stable.

4. Open the parameter window by choosing **Parameter Window** from the **Parameters** menu. Select STOPTIME and change it to 1000. (Hint for Windows users: if you double-click a parameter in the list, you can immediately type in a new value without having to select the text in the edit field.) Run the model again. You'll see that the amplitude is actually increasing over time, albeit very slowly. If you change the integration method to **Runge-Kutta 4**, the amplitude will be absolutely stable (try it).

5. With over ten thousand data points shown in the plot, it's hard to see the individual oscillations. With the zoom-in feature, you can magnify any portion of the plot to fill

the entire screen. Using the left mouse button, drag a rectangle over a small portion of the plot, then release the mouse button. You can repeatedly zoom-in as many times as you want.

6. While you're zoomed in, try clicking some of the buttons in the toolbar above the plot:

   Table: displays the results of the run in tabular form. Tables can be saved and copied to the clipboard.

   Legend: displays a legend showing the correspondence between variables and colors used in the plot.

   Parameters: shows the parameter values that were in effect when the run was performed.

   Colors: toggles the use of different colors on and off.

   Dashed Lines: toggles the use of different line styles on and off.

   Data Points: draws a dot corresponding to each computed point.

   Grid: toggles the grid lines on and off.

   Readout: displays coordinates of the selected point when the mouse is clicked and dragged over the plot.

   When you're done trying out these buttons, click the (Zoom Out) button until the original scale showing all of the data is restored.

7. When you have an oscillatory solution such as this, you may want to know the frequency and amplitude of the oscillations. You can use Berkeley Madonna's Fast Fourier Transform feature to get this information. Click the (FFT) button. Berkeley Madonna computes the FFT of each variable in the plot and displays the resulting amplitude over the frequency spectrum. In this example, you can see a clear peak at f=0.16. If you use the Readout feature while FFT mode is active, both the frequency and the period corresponding to the readout cursor's position are displayed. Click the FFT button again to return to the time-based plot.

8. In the parameter window, select STOPTIME and click the **Reset** button to reset it to it's original value. Then, change the value of k1 to 0.01 and k2 to 100. Then, run the model. At first glance it appears that the amplitude of A and B are the same. However, if you look closely you'll see that A and B are plotted on separate scales (A on the left, B on the right) and that their actual amplitudes are quite different.

9. While holding the shift key, click on the button labeled **B** below the plot. Now, A and B are plotted on the same Y axis with the same scale. Shift-clicking a "variable button", as

the buttons at the bottom of the plot are known, moves the selected variable from one Y axis to the other.

10. While holding down the option key (Macintosh) or control key (Windows), click the **A** button. Now the scales are adjusted to optimally display the A variable. As a result, the B variable is now going past the boundaries of the plot. Option/control-clicking a variable button adjusts the scale of the X and Y axes to match the range of the selected variable.

11. You can manually set axis scales using the **Scales** page of the **Axis Settings** dialog (**Graph** menu). This dialog can also be displayed by double-clicking on any of the plot's axes. In this case, you'll see that the X and left Y axis scales have been manually set (this happened when you optimized the scaling for the A variable). Turn on Auto-scale mode for the X and left Y axes and click **OK**. Now both curves fit entirely within the boundaries of the plot.

12. Berkeley Madonna can display the results of multiple runs simultaneously on the same plot. This makes it easier to see how a parameter change affects your model. In the parameter window, set STOPTIME to 100 (not 1000). k1 and k2 should still be set to 0.01 and 100, respectively. Run the model. Next, change the k1 parameter to 0.02. Then, click the  (Overlay Plots) button in the graph. Run the model again. You'll see the results of both runs in the graph. If you turn on the legend, you'll see that four curves are plotted, two (A and B) for each run. Click the **A** button below the plot to remove A from the plot, leaving only the two B curves. Finally, click the FFT button to see how the frequency of oscillation increased in the second run.

13. As long as Overlay Plots remains enabled, Berkeley Madonna will continue to add new runs to the plot instead of removing the old run(s) first. You can manually remove old runs while leaving Overlay Plots enabled by using the **Discard Last Run** and **Discard All Runs** commands in the **Graph** menu.

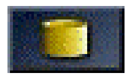
14. Changing parameters from the keyboard can be tedious, so Berkeley Madonna provides an alternative called sliders. Choose **Define Sliders** from the **Parameters** menu and add both parameters (k1 and k2) to the list. Enter reasonable minimum, maximum, and increment values for each (0.0, 2.0, 0.1). Berkeley Madonna displays a floating window with one slider for each parameter. Try dragging one of the sliders. When you release it, Berkeley Madonna adjusts the parameter value and automatically runs your model. If you hold down the option key (Macintosh) or control key (Windows) while releasing the slider, Berkeley Madonna adjusts the parameter value but does not run your model.

Building a Visual Model

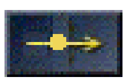
In the previous section, you learned how to create models by entering text into Berkeley Madonna's equation window. In this section, we'll construct a model graphically using the flowchart editor. The model will consist of three elements: a reservoir icon (integrator) representing the population, a flow icon representing deaths in the population, and a formula icon representing the rate of decay.

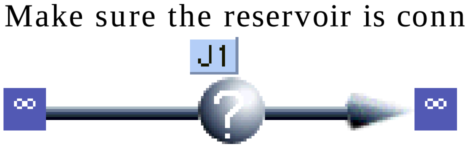
Before starting, verify that the flowchart editor is functioning properly. To do this, choose **About Berkeley Madonna** from the **Help** menu and look for text that reads "Flowchart version 8.0.1". If it says "Java not loaded", click the **Load Java** button. If Java fails to load, you need to install (or perhaps reinstall) Java support on your system. See the *Read Me* document for details.

1. Choose **New Flowchart** from the **File** menu. An empty flowchart window appears.

2. Position the mouse over the reservoir tool , press the mouse button, drag the reservoir to the flowchart, and release the mouse button. You've now placed a reservoir on the flowchart with the default name "R1". Note that the reservoir is colored red which means it's selected.

3. Change the name of the reservoir to "Population" by typing the new name. It is not necessary to first click the reservoir since it is already selected.

4. Click the flow tool , move the mouse over the Population reservoir, press the mouse button, drag the mouse to the right a few inches, and release the mouse button. This places a flow icon on the flowchart which drains the Population reservoir into an infinite sink.

5. Make sure the reservoir is connected to the flow. If the flow looks like this:


it's source end is not connected to the reservoir. In this case, drag the infinite source to the reservoir and drop it. This connects the flow's input to the reservoir instead of an infinite source.

6. You may find that the icons are not positioned the way you want. They can be repositioned by clicking and dragging. Note that Berkeley Madonna maintains the connection between the reservoir, flow, and sink.

7. Change the name of the flow to "Deaths" by clicking the flow if it is not already selected and typing the new name.

8. Place a formula icon  on the flowchart approximately halfway between the reservoir and flow icons (use the same click and drag technique as you did for the reservoir). Change the name of the formula icon to "Death Rate".

9. Click the arc tool  and create an arc going from the reservoir icon to the flow icon (use the same technique as you did for the flow). This creates a dependency relationship between the flow and the reservoir: the number of deaths depends on the population.

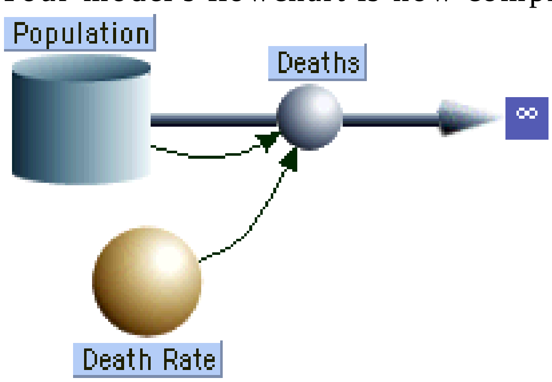
10. Create another arc going from the formula icon to the flow icon. This makes the number of deaths depend upon the death rate constant in addition to the population.

11. Double-click the Population reservoir. This opens a dialog box for the reservoir. In this dialog, you specify the reservoir's initial value. In this case, enter 1000 and click OK. Note that the question mark inside the reservoir icon disappears after the dialog has been dismissed. This means that the equations for this reservoir are fully specified.

12. Double-click the Death Rate formula to open it's icon dialog. Enter 0.02 for the formula's right-hand side and click OK.

13. Double-click the Deaths flow. Note that "Population" and "Death Rate" are *required inputs*. This means that these variables must be used in the right-hand side of the equation defining the icon's value. Enter the following formula for the right-hand side: "Population * Death_Rate". Note that instead of typing names of required inputs, you can double-click on the input's name in the list to insert that name. And you can use the calculator keypad to insert digits and common arithmetic operators. Click OK when done.

14. Your model's flowchart is now complete and should now appear something like this:



Now run your model by choosing **Run** from the **Compute** menu. Berkeley Madonna runs your model and displays the results in a graph window.

15. You can change the curvature of the dependency arcs by dragging their control points. To do this, first select an arc by clicking somewhere along its trajectory. The arc will turn red and a small square handle (control point) will appear. Click and drag the control point to change the arc's trajectory.

16. Icons and arcs can be removed by selecting them and choosing **Clear** (Macintosh) or **Delete** (Windows) from the **Edit** menu. You can also remove selected objects by holding down the control key while pressing the delete or backspace key. Try deleting the arc from the Population reservoir to the Deaths flow. Note that a question mark reappears in the flow icon. That's because the icon's equation refers to the Population variable which is no longer a dependent. You can easily reestablish this dependency by drawing a new arc from the reservoir to the flow.

17. Now that you've seen how easy it is to create a model, you should take a look at the equations Berkeley Madonna generated for you. To do this, choose **Equations** from the **Model** menu. Position the equations along side the flowchart so that you can see both windows simultaneously.

18. Select an icon in the flowchart with the mouse. When you select a single icon, Berkeley Madonna highlights its equation(s) in the equation window. This makes it easy to see an icon's equations without opening its icon dialog.

19. Berkeley Madonna can show you which icon corresponds to an equation in the equation window. To do this, position the equation window's insertion point (caret) within one of the equations, then choose **Show Icon** from the **Edit** menu. Berkeley Madonna activates the flowchart window and selects the corresponding icon.

20. Now try editing your equations in the equation window like you did in the first section of this tutorial. Berkeley Madonna won't let you. When working with a visual model (i.e., one that has a flowchart), you cannot edit the equations directly in the equation window. Instead, you edit each icon's equations using its icon dialog. The icon dialog can be opened by double-clicking an icon or choosing **Icon Info…** from the **Flowchart** menu. You can also open the icon dialog directly from the equation window by double-clicking an equation. For example, double-clicking anywhere within the line "Deaths = Population * Death_Rate" opens the icon dialog for the Deaths flow.

21. Select the Population reservoir, type "Molecules" and press return. The name of the icon changes and Berkeley Madonna updates the name in all equations that depend on it. To see this in action, change the name again and keep your eye on the equation window as you press the return key.

That's it for this tutorial. You now know enough to get started building your own models with Berkeley Madonna.