

Iteration and Animation in Microsoft Excel 2003™

Introduction

When a formula on an Excel worksheet refers back to its own cell (either directly or indirectly) it is called a *circular reference*. A simple example of such a formula would be **=A1+1**, held in cell A1. This indicates that the current value held in A1 should be incremented by 1 and that this new value should in turn be increased by 1 again. This is called *iteration*. Excel continues the process until a criteria or limit is reached. Iteration is used, for example, to solve equations and optimization problems - see [Goal Seek and Solver in Microsoft Excel](#) for further details.

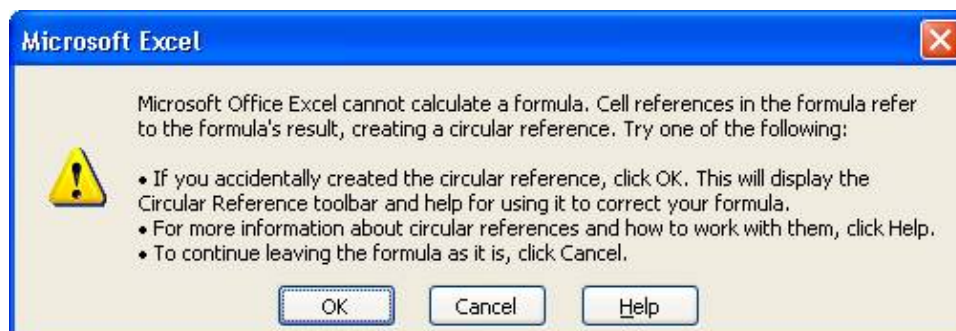
You can control the iteration either by setting a fixed number of iterative steps or by limiting the degree any cell can change within a single iteration. By definition, a circular reference is never completed, so you can re-run the iteration by a similar amount over and over again.

Fine control of the iterative process can be achieved through the use of special controls - spin buttons, scroll bars, sliders etc. By adding these to your worksheets, you can make iteration very simple to use, even by those who know nothing of the process. If these are combined with graphical output of the results then the effects can be spectacular. Your charts will suddenly become animated.

Simple Iteration

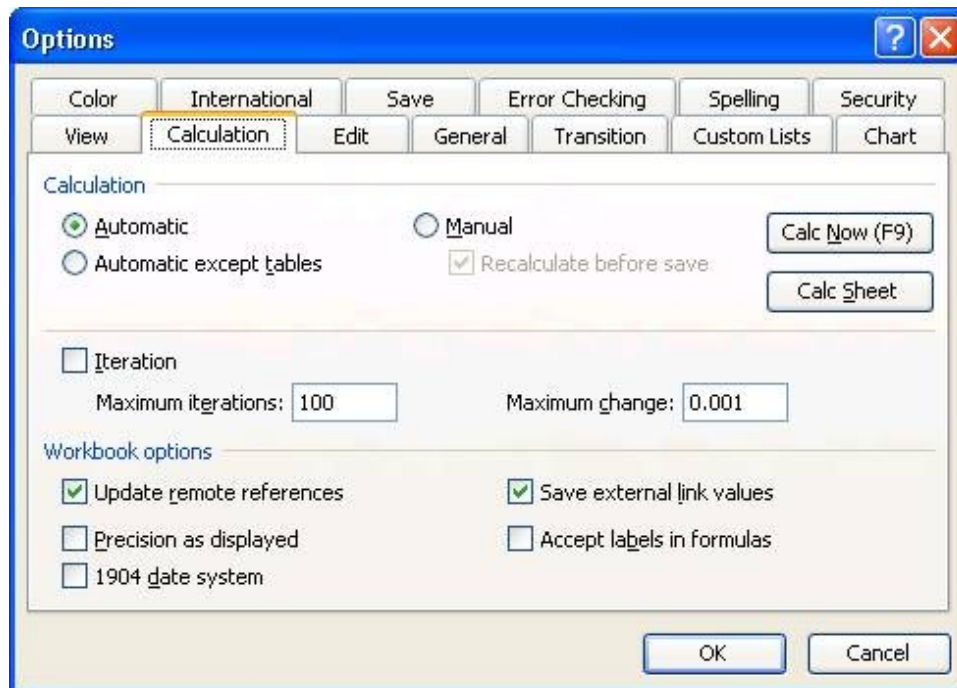
The first exercise introduces you to circular references and iteration, and how to control them.

1. Start up Excel as usual or click on **[New]** to start with a new file
2. In cell A1 type **=a1+1** then press **<right arrow>**



A warning now appears because you have entered a circular reference. More often than not, you have typed in a formula incorrectly and don't want the circular reference (and you would click on **[OK]** to resolve it). Here, however, you do want it so:

3. Click on the **[Cancel]** or press **<Esc>** to cancel the warning message
4. Next, open the **Tools** menu and choose **Options...** then move to the *Calculation* tab



When carrying out iterations, it's a good idea to turn automatic calculation off. If you don't then every time you enter a new value or formula into any cell, the iterative process runs.

5. Set *Calculation* to **Manual** by clicking in the option button provided
6. Next, turn on **Iteration** by clicking the check box and reset *Maximum iterations:* to 1
7. Press **<Enter>** for **[OK]** then press **<F9>** and note what happens

You should find that the value held in A1 changes from 0 to 1.

8. Hold down **<F9>** to recalculate over and over again - the value in A1 should steadily rise
9. Repeat steps 4 to 7 and change *Maximum iterations:* to 10
10. Repeat step 8 - the values in A1 should increase by 10 each time

Though the values shown jump by 10, in fact the value held in *A1* increases in steps of 1 each time. The recalculation stops after 10 iterations but the process is so quick you don't see it happening. To prove this:

11. In cell *B1* type `=if(b1<17,b1+1,b1)` - ie only increase *B1* if its value is <17
12. Press **<left arrow>** then **<F9>** once - *B1* jumps to 11
13. Press **<F9>** again - the iteration stops with *B1* equal to 17 (and will remain so)

By setting a condition with the **IF** function, the circular reference only runs up until the criteria is met. Meanwhile, the value in *A1* continues to rise indefinitely as there is no such limitation. You can also see iteration taking place if the number of iterations is large:

14. Repeat steps 4 to 7 and change *Maximum iterations:* to 10000
15. Press **<F9>** once and watch what happens - note also the iteration count on the *Status Bar* in the bottom left corner

There's another way to limit iteration (apart from setting a maximum number of iterations) and that's to limit the degree of change which takes place in a cell.

16. Repeat steps 4 to 7 but this time change *Maximum change:* to 1.001
17. Press **<F9>** and watch what happens

The formula in cell *A1* increases the value in the cell by just 1 each time. Because the maximum change allowed (1.001) is larger than the result of each iteration (add 1), the calculation stops after only one iteration. It isn't quite so obvious what's happening here, so try the following:

18. In *A1* type 100 then in *B1* type `=(a1+b1)/2` and press **<Enter>** - the result is 50
19. Press **<F9>** and the next result is 99.21875

This isn't $(100+50)/2$, which would be 75. Excel has taken this value for the next iteration (ie $175/2$) because neither has the maximum change (1.001) been exceeded nor the maximum number of iterations (1000). In fact, four iterations were carried out before the maximum change allowed stopped the process. Thereafter, only one iteration will take place each time. To see this:

20. Keep pressing **<F9>** and watch what happens - the calculation ends with a value of 100

Note that only one set of iteration criteria can be set at any one time - you can't have different criteria for different cells.

Resetting the Starting Values

To reset the starting values, you simply have to re-enter or edit the recursive formula:

1. Move to cell *B1* and press **<F2>** to enter edit mode
2. Change the formula to read $= (a1+b1)/3$ then press **<Ctrl Enter>** - if you didn't know it already, **<Ctrl Enter>** enters the formula but also maintains the position of the active cell
3. Press **<F9>** a few times and watch what happens - the final result this time should be 50

You do not have to enter a new formula to reset the starting values:

4. With *B1* still the active cell, press **<F2>** then **<Ctrl Enter>** without changing the formula - the first iterative value of 33.33333 appears (press **<F9>** if you want to check iteration still works)

Resetting the starting values by having to re-enter the recursive formula isn't immediately obvious and you might like to provide a simple mechanism for this, particularly if the spreadsheet is being used by people other than yourself:

5. Press **<F2>** and edit the formula in *B1* to read
`=if(b2="yes",0,(A1+B1)/3)`
6. Press **<Enter>** and in cell *B2* type *yes* (press **<Ctrl Enter>**)
7. Press **<F9>** - *B1* is reset to 0
8. Press **<Delete>** to clear *B2* followed by **<F9>** - the iteration process starts up again

Obviously you would need to provide instructions (eg text in cell *A2* or a comment attached to cell *B2*) to explain how to carry out the above.

Chart Animation

Iteration shows up best when the values it generates are plotted on a chart. This next example traces the **SIN** and **COS** functions - these give values between 1 and -1 in a wave motion. Begin by resetting the iteration limits and cell values/formulas:

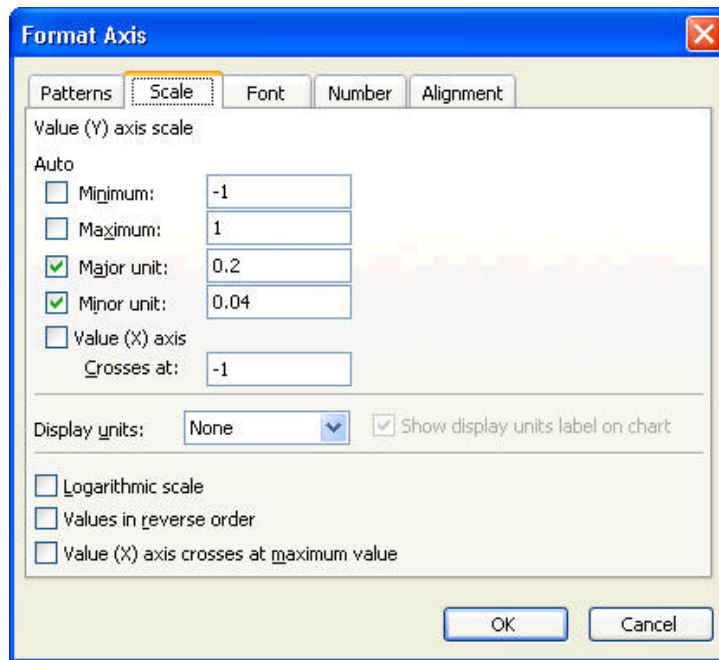
1. Open the **Tools** menu and choose **Options...** then move to the *Calculation* tab
2. Set *Maximum iterations:* to 1 and *Maximum change:* to 0.001 - press **<Enter>** for **[OK]**
3. Move to cell A1 and type *x* - press **<right arrow>**
4. Continue by typing *sin* and *cosine* into cells B1 and C1
5. Move to cell A2 and type *=if(a2<100,a2+1,0)* - press **<right arrow>**
6. Continue by typing *=sin(a2/10)* and *=cos(a2/10)* into cells B2 and C2 and press **<Enter>** - note that these functions work on radians, not degrees

Now plot these values on a graph:

7. Select cells A1 to C2 by dragging through them using the mouse
8. Click on the **[Chart Wizard]** toolbar button
9. At *Step 1* of the wizard choose **XY (Scatter)** - press **<Enter>** for **[Next>]**
10. At *Step 2*, set *Series in:* to **Columns** - press **<Enter>** for **[Next>]**
11. There's no need to add titles etc at *Step 3*, just press **<Enter>** for **[Next>]**
12. At *Step 4*, set *Place Chart:* to **As new sheet:** - press **<Enter>** for **[Finish]**

Your graph will appear on a new *Chart1* chart sheet. You now need to modify the axes settings:

13. *Double click* on the vertical Y-axis and move to the *Scale* tab in the *Format Axis* window



14. Under the *Auto* settings, for **Minimum:** turn off the *Auto* check box and type a value of -1
15. For **Maximum:** turn off the *Auto* check box and type a value of 1
16. Change the **Value (X) axis Crosses at:** to -1 - the settings should now be as shown above, press **<Enter>** for **[OK]**
17. Now, *double click* on the horizontal X-axis
18. Repeat steps 14 and 15 (turning off *Auto*) but set **Minimum:** to 0 and **Maximum:** to 100
19. Finally press **<Enter>** for **[OK]** - your chart is ready for animation
20. Hold down **<F9>** and watch what happens

It would be nice if the points were plotted in full on the screen. To do this, you need to plot the complete set of values, not just a single pair. First, you need to calculate them:

21. Move back to the data by clicking on the *Sheet1* tab
22. In cell A3 type $=a2+1$ then position the mouse cursor over the *cell handle* and drag the formula down to cell A101

The resultant values look wrong (they are all the same) but this is because automatic calculation has been switched off. The correct values will appear when you restart the iteration.

23. Press **<up arrow>** then move back to cell A3 and type $=a2+1-100$ and press **<Enter>**

24. Next, select cells *B2* and *C2* then *double click* on the *range handle* to copy these formulae down the columns - press **<F9>** to recalculate them
25. Next, move back to the chart - click on the *Chart1* tab
26. Open the **Chart** menu and choose **Source Data...**
27. Amend the *Data range*: to read `=sheet1!A1:C101` - press **<Enter>** for **[OK]**
28. Hold down **<F9>** and watch what happens

Using Controls with Animation

Having to press **<F9>** to run iterations isn't very user-friendly. More importantly, it doesn't give you full control if you want to run an iteration backwards. To do this, you need to use special controls such as a *spin button*, *scroll bar* or *slider*. These are held in the *control toolbox*. To display this:

1. Open the **View** menu and choose **Toolbars** and select **Control Toolbox** - the toolbar appears



There are a couple of hundred different controls available - the most commonly-used are shown on the toolbar, while others can be accessed via the **[More Controls]** button - the last one on the toolbar. In fact, the toolbar is split into two sections - the first three buttons are used to set up what happens when you use the controls on the rest of the toolbar.

There's one disadvantage in using controls, namely that they can only be used on worksheets, not on chart sheets. Before you try them out, move the current chart onto *Sheet1*:

2. Open the **Chart** menu and choose **Location...**
3. Select the option to *Place chart: As object in: Sheet1* - press **<Enter>** for **[OK]**
4. Enlarge the chart by dragging out the bottom right *corner handle*

One major advantage of using controls is that they perform all the iterations for you - you don't need manual calculation set on. This also means that you can have more than one control with different settings - ie you are not restricted by the iteration criteria settings.

5. Click on any cell away from the chart (to deactivate it)
6. Open the **Tools** menu and choose **Options...** then move to the *Calculation* tab
7. Set *Calculation:* to **Automatic** and turn off *Iteration:* - press **<Enter>** for **[OK]**
8. **[Cancel]** the circular recursion warning message if it reappears

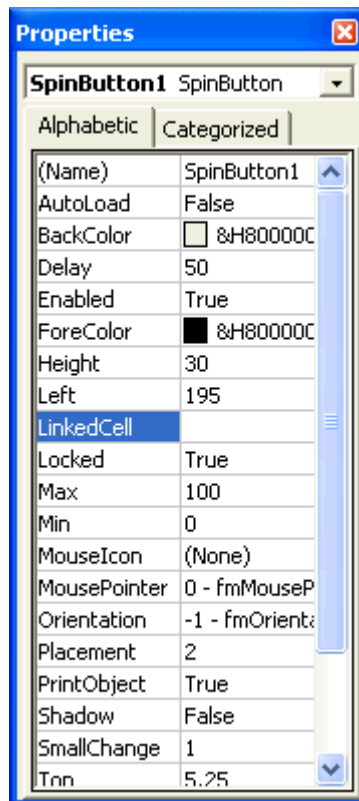
The sections which follow show you how to make use of some of the tools.

Spin Button Controls

Spin Button  Properties  Design Mode / Exit Design Mode 

Start with a spin button control. This can be used to change the value in a specified cell between a *maximum* and *minimum* value.

1. Click on the **[Spin Button]** icon in the *Control Toolbox* - a small *Exit Design Mode* toolbar appears and the corresponding (first) button in the *Control Toolbox* is activated
2. Move the mouse cursor into an empty cell (eg *E1*) then hold down the mouse button and drag out a suitably-sized spin button control (eg covering three rows deep and up to half a column wide) - release the mouse button
3. Once the spin button has appeared (it can take a few seconds), click on the **[Properties]** button on the *Control Toolbox* (the second from the top) - the *Properties* window appears:



4. Set the **LinkedCell** to `a2` then [**Close**] the *Properties* window
5. Close the design by clicking on either of the [**Exit Design Mode**] toolbar buttons
6. Click on cell `A2` and replace the formula by the value `0` (press **<Enter>**)
7. Finally, point to the **increase** (*up arrow*) spin button and hold down the mouse button
8. Also try the **decrease** (*down arrow*) spin button

You'll find you can run the animation forwards or backwards, though it stops when it reaches `100` or `0`. If you look at the picture of the *SpinButton Properties*, above, you'll see that these are the default values for *Max* and *Min*, respectively.

9. Finally, repeat steps **1** to **5** to create a second button but, at step **4**, also change the **SmallChange** setting from `1` to `10`
10. Test out the new button - you'll find you get `10` iterations at a time

A Scroll Bar Control

Scroll Bar 

A scroll bar control offers the same features as a spin button, but additional ones too:

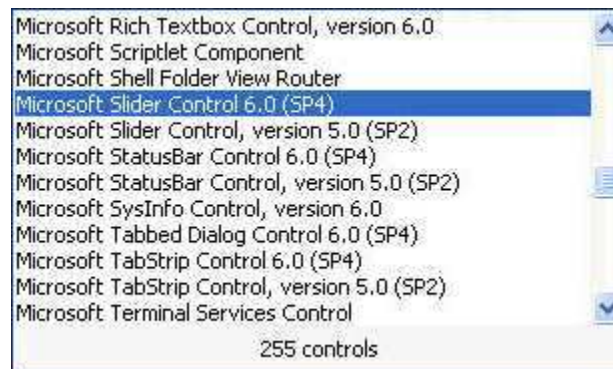
1. Click on the **[Scroll Bar]** button in the *Control Toolbox*
2. Move the mouse cursor into an empty cell (eg G2) then hold down the mouse button and drag out a scroll bar control (eg covering three or four cells horizontally)
3. Next click on the **[Properties]** button in the *Control Toolbox*
4. Set the **LinkedCell** to a2 then, **Max** to 100 and **LargeChange** to 10
5. **[Close]** the *Properties* window then click on the **[Exit Design Mode]** toolbar button
6. Use the scroll bar as you would any other scroll bar, ie:
 - a) Position the mouse cursor over either end and hold down the mouse button or
 - b) Drag the *slider block* to the left or right, or
 - c) Click to the left/right of the block to jump in steps of 10 (the **LargeChange** setting)

A Slider Control

More Controls  Build Code 

Another control which is sometimes used is a slider. This isn't nearly so simple to use, however, as not all the settings you require are present in the *Properties* window. You have to write your own effects using *Microsoft Visual Basic!*

1. Click on the **[More Controls]** button in the *Control Toolbox* - a list of controls appears:



2. Scroll down to find **Microsoft Slider Control 6.0 (SP4)** and click to select it
3. Move the mouse cursor into an empty cell (eg *G4*) then hold down the mouse button and drag out a horizontal control covering four or five cells
4. Next click on the **[Properties]** button on the *Control Toolbox*
5. Set **LargeChange** to 10, **Max** to 100 and **TickFrequency** to 10 - note there is no **LinkedCell** property
6. **[Close]** the *Properties* window then click on the **[View Code]** button on the *Control Toolbox*

This takes you into the *Visual Basic Editor*, with a *Subroutine* ready for you to type in the programming code to set up the *Linked Cell*. Just follow the instructions below.

7. Type `Range("a2") = slider1` then close the *Editor* by clicking on the red **[Close]** button
8. Press the **<down arrow>** key at least once then click on the **[Exit Design Mode]** toolbar button
9. If you find a second slider has appeared on the *Formula Bar* click on **[Undo]** - this was the only reason for moving the slider in step 8 (it looks like there's a bug in Excel)
10. End by testing out the slider:
 - a) Drag the *slider block* to the left or right, or
 - b) Click to the left/right of the block to jump in steps of 10

Note how movements of the slider are reflected by the scroll bar control.

Slider controls aren't nearly as useful as the others - nor are they easy to install. However, it has introduced you to another whole area of complexity. The subroutine you wrote could be much more complicated and could be used to set different starting values in A2 and other cells, depending on various conditions.

Other Controls

There isn't time to discuss all the other controls - just be aware of their existence. Ones which might be of particular use include:

- **Toggle Buttons, Check Boxes** and **Option Buttons** - these can be used to switch a value in a cell between *TRUE* and *FALSE* and could be used to reset the starting values for an iteration, for example
- **List Boxes** - these display a list of possible values, from which you choose to set a value in a cell. If the list is longer than the drawn box, a scroll bar appears
- **Combo Boxes** - these are the same as *List Boxes* except that the list is hidden by default (as such, they take up less space). You only open up the list when you want to select the required value

Try setting up a control, if you like, following the same instructions as for the other controls.

Adding Controls to Charts

Although control buttons do not work on chart sheets, they can be added to charts on ordinary worksheets. To do this:

1. Click on the **[Design Mode]** button then select one of the existing controls - eg a *spin button*
2. *Right click* on the control and choose **Order** then **Bring to Front**
3. Using the mouse or *arrow* keys, move the control onto the chart (eg to the bottom right corner)
4. Click on **[Exit Design Mode]** to return to normal working
5. Test out the control to check that it still works

You can, if you like, group the chart and its control into a single entity. This has the disadvantage that the chart then becomes an object such that when you select it, the **Chart** menu no longer appears (so don't try it here). To make a group, use *shift click* to select both objects in *Design Mode* then *right click* and under **Grouping** choose **Group**.

Note that charts and controls do not have to be on the same worksheet as the data. If you move them to a new sheet then all you need to do is set up the *Linked Cell* so that it references the data sheet (eg *Sheet1!A2*).

A Final Example

In this final example, three curves will be used, each moving in different directions. Don't worry about the mathematics:

1. Click on cell *A2* then position the mouse cursor on the border (a four-headed arrow appears)
2. Hold down the mouse button and drag the cell to *E5* then release the mouse button

Cell *A2* is the *Linked Cell* for the spin button and scroll bar controls.

Dragging and dropping it like this will have changed the corresponding property for these controls

3. Move to cell *B1* and type y_1 , press **<right arrow>** and in cell *C1* type y_2
4. Press **<right arrow>** again and in cell *D1* type y_1+y_2 - press **<Enter>**
5. In cell *D2* type $=b_2+c_2$ then *double click* on the *cell handle* to copy the new formula down the column
6. Press **<left arrow>** and in cell *C2* type $=\sin((\$E\$5-a_2)/10)$ - you need to fix cell *E5* here, hence you must use an *absolute reference* (**Tip:** press **<F4>** after you type *E5* to add the \$ signs automatically)
7. Press **<left arrow>** and change the formula in *B2* to $=\sin((\$E\$5+a_2)/10)$
8. Press **<left arrow>** and type the number 0 into cell *A2* - press **<Enter>**
9. Select cells *B2* to *C2* then *double click* on the *range handle* to copy the new formulae down the columns
10. Finally, move to cell *A4* and **[Copy]** the formula to *A3* (use **<up arrow>** then **<Enter>**)

Your data is now complete, but a few changes need to be made to the chart:

11. Click on the chart, to activate it, then open the **Chart** menu and choose **Source Data...**
12. Change *Data range:* to read $=\text{sheet1!}\$A\$1:\$D\101 then press **<Enter>** for **[OK]**
13. Next open the **Chart** menu and choose **Chart Type...**
14. Select *Scatter with data points connected by smooth Lines without markers* - press **<Enter>** for **[OK]**

15. Finally, *double click* on the vertical y-axis and, on the *Scale* tab set **Minimum:** to -2, **Maximum:** to 2 and **Value (X) axis Crosses at:** to -2
16. Press <Enter> for [OK] then use either the *spin button* or *scroll bar* to run the iteration

You should find that the one graph moves backwards, the other forwards, while the sum of the two moves up and down. This set of results does have considerable scientific significance, but these notes are not the place to discuss this.

In step **16**, above, either the spin button or scroll bar could be used; the slider, however, cannot. This is because the *Visual Basic* code still refers to A2 as the linked cell. To rectify this:

17. Try using the *slider* to run the animation - part of the curve appears but it's static
18. Open the **Tools** menu and choose **Macro...** then **Visual Basic Editor**
19. Change *Range("A2") = Slider1* to read `Range("E5") = slider1`
20. Close the *Editor* then reset cell A2 to 0
21. Try out the *slider* - it should now be working, though isn't nearly as exciting as using the other controls