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 Microsoft Excel 2013: Goal Seek and Solver 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 press \(<\text{Ctrl} \ n>\) to start with a new file
2. In cell A1 type \( =a1+1 \) then press \(<\text{right arrow}>\)
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 edit the formula to resolve it). Here, however, you do want it so:

3. Click on [OK] or press <Enter> to create the circular reference and continue
4. Next, move the FILE tab, click on Options then choose Formulas

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 Workbook Calculation to Manual by clicking in the option button provided
6. Next, Enable iterative calculation 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 an IF function, the circular reference only runs until the criteria is met. Meanwhile, the value in A1 continues to rise indefinitely as there is no such limitation.

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.

14. Repeat steps 4 to 7 but this time change Maximum change: to 1.001
15. 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. Usually, several iterations occur before any limits are met. Try the following:

16. In A1 type 100 then in B1 type = (a1+b1)/2 and press <Enter> - the result is 50
17. Press <F9> and the next result is 99.21875 (and not (100+50)/2, which would be 75)
Excel has used the value 75 for another iteration (i.e. 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 stopped the process. Thereafter, only one iteration takes place each time. To see this:

18. 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 in force 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 \( \frac{a1+b1}{3} \) 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 - if you didn't know it already, <Ctrl Enter> enters the formula but also maintains the position of the active cell
5. Press <F9> - B1 is reset to 0
6. Press <Delete> to clear B2 followed by <F9> - the iteration process starts up again

Obviously you would need to provide instructions (e.g. 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 \text{SIN} and \text{COS} functions - these give values between 1 and -1 in a wave motion. Begin by resetting the iteration limits and cell values/formulas:

1. Move to the FILE tab, click on Options then choose Formulas
2. Set Maximum iterations: to 1 and Maximum change: back to 0.001 - press <Enter> for [OK]
3. Move to cell A1 and type \( x \) - press <right arrow>
4. Continue by typing \text{sin} and \text{cosine} into cells B1 and C1
5. Move to cell A2 and type \( \text{if}(a2<100,a2+1,0) \) - press <right arrow> (this resets A2 back to 0 after 100 iterations)
6. Continue by typing \( \text{sin}(a2/10) \) and \( \text{cos}(a2/10) \) 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. Move to the INSERT tab and click on [Insert Scatter (x,y) or Bubble Chart] in the Charts group
9. Choose [Scatter with only Markers] - the first button in the group of subtypes
10. If the graph has 3 markers and a legend which says Series 1, click on [Switch Row/Column]
You now need to modify the axes settings:

11. **Right click** on the vertical Y-axis and choose **Format Axis**… - the Task Pane appears on the right
12. Under **Bounds** in the **Axis Options** settings, set **Minimum**: to a fixed value of **−1**
13. Set **Maximum**: to a fixed value of **1**
14. Change the **Horizontal axis crosses**: to an **Axis value** of **−1**
15. Now, **click** on the horizontal X-axis to view its settings in the **Task Pane**
16. Repeat steps 12 and 13 setting **Minimum**: to **0** and **Maximum**: to **100**
17. [Close] the **Task Pane** - your chart is ready for animation
18. Click on any cell (ie away from the chart) then 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:

19. 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.

20. Press <up arrow> then move back to cell A3 and type **=a2+1−100** and press <Enter>
21. 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
22. Next, click on the chart to activate the **CHART TOOLS** tabs and move to the **DESIGN** tab
23. Click on the [Select Data] button – a dialog box appears
24. Amend the **Chart data range**: to read **=Sheet1!$A$1:$C$101** - press <Enter> for [OK]
25. Click on any cell away from the chart then 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 - you can’t run an iteration backwards, for example. To do this, you need to use special controls such as a **spin button**, **scroll bar** or **slider**. These are held on a special **DEVELOPER** tab on the **Ribbon**. To display this:

1. Move to the **FILE** tab and choose **Options** then **Customize Ribbon**
2. In the panel on the right, turn on **Developer**

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.

3. Still in Excel Options, click on **Formulas** then set **Workbook Calculation**: to **Automatic** and turn off **Enable iterative calculation** - press <Enter> for [OK]
4. Press <Esc> to [Cancel] the circular reference warning message if it reappears
5. Move to the **DEVELOPER** tab then click on **Insert** in the **Controls** group to display the controls:
There are well over a hundred different controls available - the most commonly-used are shown here, while others can be accessed via the [More Controls] button - the one in the bottom row on the far right.

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

**Spin Button Controls**

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 (ActiveX Control)] icon - the one on the far left in the bottom row
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, click on the [Properties] button in the Controls group - the Properties window appears:

![Spin Button Properties Window]

4. Set the **LinkedCell** to A2 then [Close] the Properties window
5. Move out of design mode by clicking on the [Design Mode] button on the Ribbon
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

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

1. Click on the [Insert] button in the Controls group and select the [Scroll Bar ActiveX Control] button – the one on the far right in the first row of ActiveX Controls
2. Move the mouse cursor into an empty cell (e.g., G2) then hold down the mouse button and drag out a scroll bar control (e.g., covering three or four cells horizontally)
3. Next click on the [Properties] button
4. Set the LinkedCell to A2 then, Max to 100 and LargeChange to 10
5. Close the Properties window then click on [Design Mode] to move back to normal working
6. Use the scroll bar as you would any other scroll bar, i.e.:
   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)

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 of 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 placed on charts on ordinary worksheets. To do this:

1. Click on the [Design Mode] button then select one of the existing controls - e.g., 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 (e.g., to the bottom right corner)
4. Click on [Design Mode] to return to normal working
5. Test out the control to check that it still works

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 (e.g., 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 move to the DESIGN tab and click on [Select Data]

12. Change Chart data range: to read \=Sheet1!$A$1:$D$101\ then press `<Enter>` for [OK]

13. Next click on the [Change Chart Type] button

14. Select Scatter with Smooth Lines (third in the set of XY Scatter charts) - press `<Enter>` for [OK]

15. Finally, right click on the vertical y-axis, choose Format Axis…


17. Press `<Enter>` for [Close] and click away from the chart

18. 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 (frequency modulation), but these notes are not the place to discuss this.

19. End by closing the file – it’s your choice as to whether you want to save the file or not

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