EXERCISE 4: USE OBJECTS, OPERATORS, AND COMMANDS

Map Algebra is the most powerful feature of ArcGIS Spatial Analyst. By combining its operators and functions, you can perform very sophisticated analysis.

This is a two-part exercise. In Exercise 4A, you will work with Map Algebra objects and operators. In Exercise 4B, you will work with Map Algebra functions. Both exercises will help you learn to build expressions, and you will learn some practical processing tricks as well.

STEP 1: USE ARITHMETIC OPERATORS IN EXPRESSIONS

The arithmetic operators are mostly self explanatory. The addition (+), subtraction (-), multiplication (*), and division (/) operators behave exactly the way you expect. Only the modulus (MOD) operator might be unfamiliar; you will work with it in this step. To start. you will open a new empty map.

- □ Start *ArcMap* and open a new empty map.
- □ Click *Show/Hide ArcToolbox* Window to open the *ArcToolbox*.
- □ Add the *Wind1.lyr* layer to your map from your ... *Exercise05* folder.
- □ Expand the legend for *Wind1*.

The Wind1 layer is a raster of fictitious wind directions in each cell. You will now visualize these direction values using the Cell Tool toolbar. This toolbar is useful for visualizing raster data that stores directions (e.g., flow direction in hydrologic analysis or a direction raster created by a distance function).

- □ On the *Main Menu*, click *View> Toolbars > Cell Tool* to open the toolbar.
- □ In the *Cell Tool* toolbar, click the *Boundary button*
- □ In the map, drag a box from inside the upper-left cell to inside the lower-right cell.

This adds the boundaries of the cells as graphics to your map to aid in visualization.

- □ In the *Cell Tool* toolbar, click the *Direction button*.
- □ In the map, drag another box like the one before.

This draws arrows in the cells oriented according to the cells direction values.

NOTE: There is a series of red cells from the center of the map and westwards that appear without arrows. There is a known bug in the Direction tool that turns zeros into NoData. The Value tool displays ND for these cells as well.

□ Zoom in on the map to see the arrows and then zoom back to the full extent.

□ In the *Cell Tool* toolbar, click the *Clear Graphics* button.

Next you will set the analysis environment, before you create new data using a Map Algebra expression.

□ Right-click in the *ArcToolbox* background and click Environments.

□ Make these Environment Settings:
- Current Workspace: .. *Exercise05*
- Scratch Workspace: ... *Exercise 05*
- Output Extent: Same as Layer "*Wind1*"
- Cell Size: Same as Layer "*Wind1*"

NOTE: The geoprocessing environment settings made in the ArcToolbox are not shared by the Spatial Analyst toolbar.

The Map Algebra Mod (modulus) operator returns the remainder for integer division. For example, dividing 3 into 16 returns 5, with I left over. The expression 16 MOD 3 will return the remainder of].

The modulus is useful when you are dealing with cyclical data, such as angles, which start at 0, increase to 360 and then start over at 0 again. For example, if you add 50 degrees to 330 degrees, the resulting direction should be 20, not 380.

Wind1 is a fictitious raster of wind direction. The arrows show the direction of the wind in each cell. The wind is changing direction in every cell: it is rotating clockwise around the center of a circle. The actual cell values are compass directions from 0 to 360 degrees, expressed as integers.

You could find the direction of the center of rotation for each cell by simply adding 90 degrees to its angle. However, that results in values greater than 360 for many of the cells (e.g., 350 + 90 = 440). The results of the addition can be adjusted with MOD so all values remain in the range of 0 to 360 degrees (e.g., 440 MOD 360 = 80).

Now use the Single Output Map Algebra tool to add 90 degrees to each cell and then adjust the angles back into the 0 to 360 range with the modulus operator.

□ *Run > Map Algebra > Single Output Map Algebra*:

- □ Map Algebra expression: type
    - (Wind1 + 90) MOD 360

- □ Output raster: type **Wind2**

You use the Map Algebra tools to write and execute Map Algebra expressions. You may cut and paste text directly into the expression box. For example, you might cut the syntax of a complicated function from the online Help and paste it (using Ctrl+V keys) into the expression, where you would edit it to provide the appropriate arguments.

NOTE: Click the Usage button for learning more about the Map Algebra function and its arguments. Click Show Help to get help on how to use the tool. You can create a layer list by clicking the Input raster or feature data to show in ModelBuilder if you are using it.

If a Warning message appears when you evaluate, you most likely have a syntax error. Look for misspelled object names, objects that are not blank delimited or illegal function arguments.

Now use the Copy/Paste Raster Symbology utility to transfer the symbology from Wind Ito Wind2.

- □ Right-click *Wind1* and click *Copy Raster Symbology*.

- □ Right-click *Wind2* and click *Paste Wind1 Symbology*.

- □ Turn *Wind2* on and off to see the 90 degree shift in the colors.

Normally, it is not valid to add angles together as you have done here. Adding angles together is generally a vector sum problem, like adding ocean currents with wind currents, and you consider not only direction but magnitude (velocity) as well.

Now you will use the Cell Tool for visualizing the directions in the Wind2 layer.

- □ Ensure that Wind2 is at the top in the Table of Contents.

NOTE: The Cell Tools work on the raster layer that is closest to the top of the ArcMap Table of Contents.

- □ In the *Cell Tool* toolbar, click the *Boundary* button.

- □ Drag a *box* over the map as you have done before.

- □ Click the *Direction* button and drag another, similar box over the map.

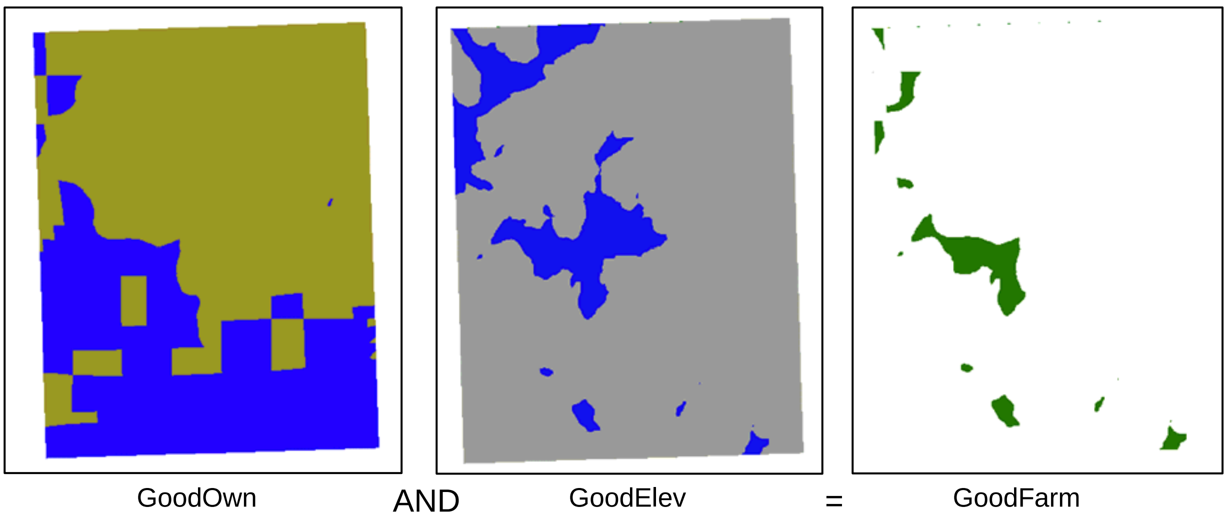
All the arrows point to the center of the Wind2 raster layer, demonstrating that the angles have been shifted by the 90 degrees you added to the Wind I angles.

☐ Zoom in to view the arrows. Zoom back to the full extent when you are done.

While the Cell Tools are useful for exploring cell attributes, you must be careful to only apply them to small areas of a raster.

STEP 2: USE RELATIONAL OPERATORS IN EXPRESSIONS

In this step, you will write a simple model to find suitable sites for a tree farm. You intend to raise pine and fir trees for decorative purposes. You know that these trees grow best above 2,400 meters elevation. Also, you have an agreement with the United States Forest Service that will allow you to grow the trees on their land. You will use relational operators to find areas of suitable elevation and land for your tree farm.



You will start the model using the relational equality operator (either EQ or = =) to test the Ownership layer for values that equal 200 (USFS lands). The output raster will contain only values of 1 and 0 (true and false).

☐ Create a new map without saving your current map.

☐ Add the following layers from your... \Exercise05 folder.

- *Elevation.lyr*: Terrain elevations in meters
- *Ownership.lyr*: Land ownership

Creating the new map reset your analysis environment to its defaults. You will now set the environment to cover the full extent of your data and to a practical cell size.

☐ Make these Environment Settings:
- Current Workspace: ... *Exercise05*

- Scratch Workspace: ... *Exercise05*
- Output Extent: *Same As Layer "Elevation"*
- Cell Size: *Same As Layer "Elevation"*

□ Turn on Ownership and expand its legend. Review the ownership descriptions.

□ *Run ... > Math > Logical > Equal To*:
- Input raster or constant value 1: *select Ownership*
- Input raster or constant value 2: t**ype 200**
- Output raster: type **GoodOwn**

NOTE: This is the equivalent to the Map Algebra expression:
Ownership EQ 200

The Equal To tool (which implements the Map Algebra EQ operator) returned values of one for Forest Service lands and zero for all other ownerships.

NOTE: In expressions, all the relational operators may be entered either as abbreviations (e.g., EQ) or as arithmetic symbols (e.g., "==").

□ Turn off all layers and collapse their legends.

Next, you will make a layer for suitable elevations. Use the relational Greater Than operator (either GT or >) to test the Elevation layer for values greater than 2,400 meters above sea level.

□ Turn on Elevation and open its legend. Review the elevation ranges.
□ *Run ... > Math > Logical> Greater Than:*
□ Input raster or constant value 1: select *Elevation*
□ Input raster or constant value 2: type **2400**
□ Output raster: type *GoodElev*

NOTE: This is the equivalent to the Map Algebra expression:
Elevation GT 2400

The GT operator returns values of one for all cells with elevations greater than 2,400 meters and zero for all other elevations.

This step demonstrated the behavior of the EQ and GT relational operators. The remaining four relational operators (NE, LT, LE, and GE) behave in a similar manner, comparing numeric values and returning true and false.

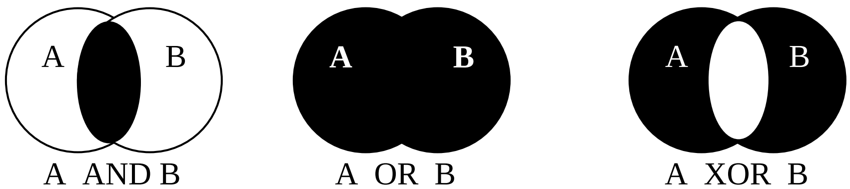
□ Turn off all layers and collapse their legends.

STEP 3: USE BOOLEAN OPERATORS IN EXPRESSIONS

Your tree farm model identified areas of good land ownership and areas of good elevation. But they are separate layers. You need to put them together to find only those areas with the right ownership and elevation.

The three Boolean operators (AND, OR, and XOR) compare the logical values of two objects against one another and return a true or false. Recall from the lecture that when Map Algebra logically compares values, nonzero values (negative or positive) evaluate as true, while a value of zero evaluates as false. Like the relational operators, the Boolean operators are often used in a CON function but can also be used alone.

Each Boolean operator has a rule that determines which cells will be returned as true. The diagram below explains the rules visually. In the diagram, the areas inside the two circles are all true. The dark areas pass the operator's test and are returned as true.



• A AND B: If both A and B are true, return true.
• A OR B: If either A or B are true, return true.
• A XOR B: If either A or B are true, but not both, return true.

As applied to your tree farm model, the expression [GoodOwn] AND [GoodElev] will return only those cells, where both the desired ownership and elevations are true.

- ☐ *Run ... > Math > Logical > Boolean And*:
- ☐ Input raster or constant value 1: select *goodown*
- ☐ Input raster or constant value 2: select *goodelev*
- ☐ Output raster: type **GoodFarm**

Note: This is the equivalent to the Map Algebra expression:
Goodown AND GoodElev

The new GoodFarm layer has values of one only for cells that have both good ownership and elevations. It should look like the graphic at the beginning of Step 2. Of course, you could have done the whole model with the following Map Algebra expression:
(Ownership EQ 200) AND (Elevation GT 2400)

Sometimes models of this type consider dozens of variables (raster layers), and it is easier to break the model up into several steps, as you have done.

☐ Turn off all layers and collapse their legends.

STEP 4: USE COMBINATORIAL OPERATORS IN EXPRESSIONS

So far, your tree farm model has identified the areas of good ownership and elevation. However, it should also consider soils, since the trees grow better in some soils than in others. In this step, you will combine your candidate farm sites with soils.

The combinatorial operators (CAND, COR, and CXOR) are the equivalent of a vector overlay because they combine the Value attributes of both inputs and write them to the output raster (a unique ID is generated for each combination, which becomes the output cell value). Also, they follow the same rules as the Boolean operators; that is, CAND only outputs combined attributes for those cells, where both inputs are true. (The COMBINE function has a similar result but combines many inputs at once).
Now you will use the CAND operator to find all the different types of soils in the potential tree farm sites you have identified.

☐ Add .. *Exercise05**Soil.lyr* to your map.

Your environment settings should still be valid, so you do not need to reset.

☐ Turn on *Soil* and expand its legend. Briefly review the soil descriptions, if necessary.

☐ *Run ... > Math > Logical> Combinatorial And*:
☐ Input raster or constant value]: select *goodfarm*
☐ Input raster or constant value 2: select *Soil*
☐ Output raster: type *FarmSoil*

Attributes of farmsoil

ObjectID	Value	Count	Goodfarm	Hrsoil
0	0	160361	0	0
1	1	2693	1	201
2	2	126	1	204
3	3	2517	1	401
4	4	1208	1	402

Record: 1 Show: All Selected Records (0 out of 5 Selected.)

NOTE: This is the equivalent to the Map Algebra expression:
GoodFarm CAND Soil

The effect of the CAND operator is not immediately obvious; you must examine the attribute table of the FarmSoil layer to see what it has done.

☐ Right-click on *farmsoil* and select *Open Attribute Table*.

These are the different soils that are found in the GoodFarm sites. Because all potential farm sites have the same ID (GoodFarm = 1), you cannot tell which soils describe which sites. You could fix this problem with the RegionGroup and ZonalStats functions (in ArcToolbox, Generalization> Region Group and Zonal> Zonal Statistics).

□ Close the *Attributes of farmsoil* table.

□ Turn off all layers and collapse their legends.

STEP 5: USE LOGICAL OPERATORS IN EXPRESSIONS

The OVER operator is useful for updating one raster with another. All nonzero values in the first input are 'pasted' over the corresponding cells in the second input. You will now use OVER to update the LandCover layer with your tree farm sites.

NOTE: The symbology of your output the input LandCover layer.

□ Add ... *Exercise05\LandCover.lyr* to your map.
□ Turn on *LandCover* and expand its legend.

Briefly review the descriptions.

□ *Run ... > Map Algebra > Single Output Map Algebra:*
□ Map Algebra expression: type **GoodFarm OVER LandCover**
□ Output raster: type **NewLand**

OVER has replaced the LandCover cells with the nonzero cells from GoodFarm. In reality, you would want to reclassify the GoodFarm layer before doing the update, replacing the cell values of I with an actual land cover code.

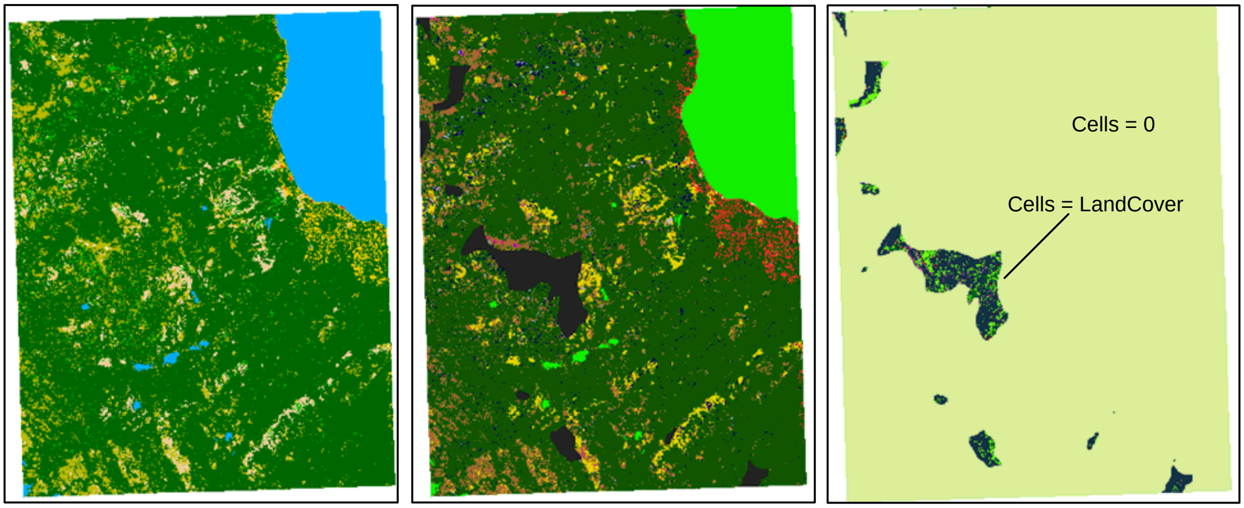
□ Turn off all layers and collapse their legends.

The DIFF operator finds the differences between two rasters. For cells, where both inputs are different, it returns the value from the first input. Where they are the same, it returns zero. layer will not match the symbology of DIFF is especially useful for performing time-series studies, like finding those places where land use has changed between 1980 and 1990. You will now use it to identify differences between your NewLand and LandCover layers.

□ *Run ... > Map Algebra > Single Output Map Algebra:*
□ *MapAlgebra* expression: type **LandCover DIFF NewLand**
□ Output raster: type **LandDiff**

DIFF has returned the LandCover values, where they are different than the NewLand values. All other cells are set to zero. Not only can you see where the layers are different, you can also see how they are different.

□ Turn off all layers and collapse their legends.



LandCover DIFF NewLand = LandDiff

The IN operator is useful for selecting cells based on their values and writing them to a new raster. It compares the input values to those in the provided list and, if there is a match, returns the value to the output cell. Otherwise, it returns NoData.

- ☐ Turn on Soil and expand its legend. Briefly review the descriptions.

For the purposes of this step, assume that soil codes of 201 (Loam, Cobbly) and 204 (Loamy Sand, Coarse And Stony) are best for growing fir and pine trees. You will now use the IN operator to create a new raster layer for just those cells.

- ☐ Run ... > *Map Algebra* > *Single Output Map Algebra*:
- ☐ MapAlgebra expression: type **Soil IN (201, 204)**
- ☐ Output raster: type **goodsoil**

IN returns the cells that had values in the list (201 and 204). All other cells were set to NoData. The IN operator provides a quick way to create a processing mask (you can also use the Con and Set Null tools from the Spatial Analyst Conditional tools in the ArcToolbox).

- ☐ Save your map as *MyMapAlgebra.mxd* in your ... *Exercise05* folder
- ☐ Exit ArcMap. This completes Exercise 4.

You have worked with representative Map Algebra operators from most of the categories. You have also compared how you use the operators in Map Algebra expressions (written in the Single Output Map Algebra tool) and how you use them individually with geoprocessing tools.

In the next exercise, you will work with Map Algebra functions and their equivalent geoprocessing tools from each function group (local, focal, block. zonal, and global).

EXERCISE END