GIS

The Geographic Approach for the Nation

ESRI Federal User Conference

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Spatial Analyst for Geospatial Intelligence

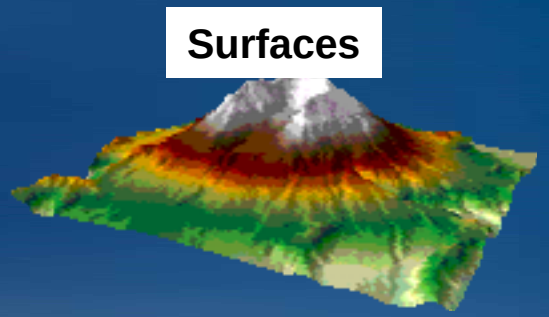
Chris Belson

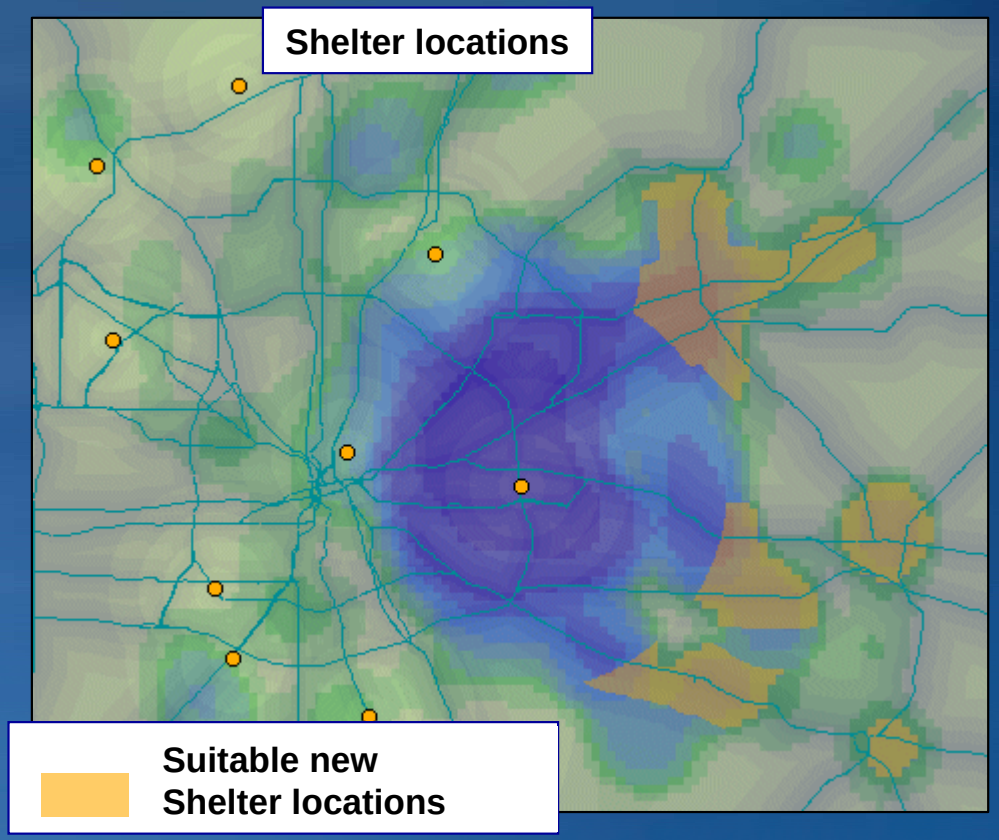
Overview

- Introduction to ArcGIS Spatial Analyst
  - What is Spatial Analyst
  - Why use raster data
  - Choosing an environment
- Accessing Spatial Analyst capabilities
  - The seven interfaces
  - Environment setting options
- Basic Spatial Analyst Concepts
  - The language of raster analysis
  - Spatial Analyst functions
- Modeling
  - What are models
  - Types of models
- Calculating risk
- Questions

ArcGIS Spatial Analyst

- Extension for ArcGIS Desktop
- Provides rich modeling environment
  - Derive new information
  - Identify spatial relationships
  - Find suitable locations
  - Calculate travel cost
  - Works with all cell-based GIS data



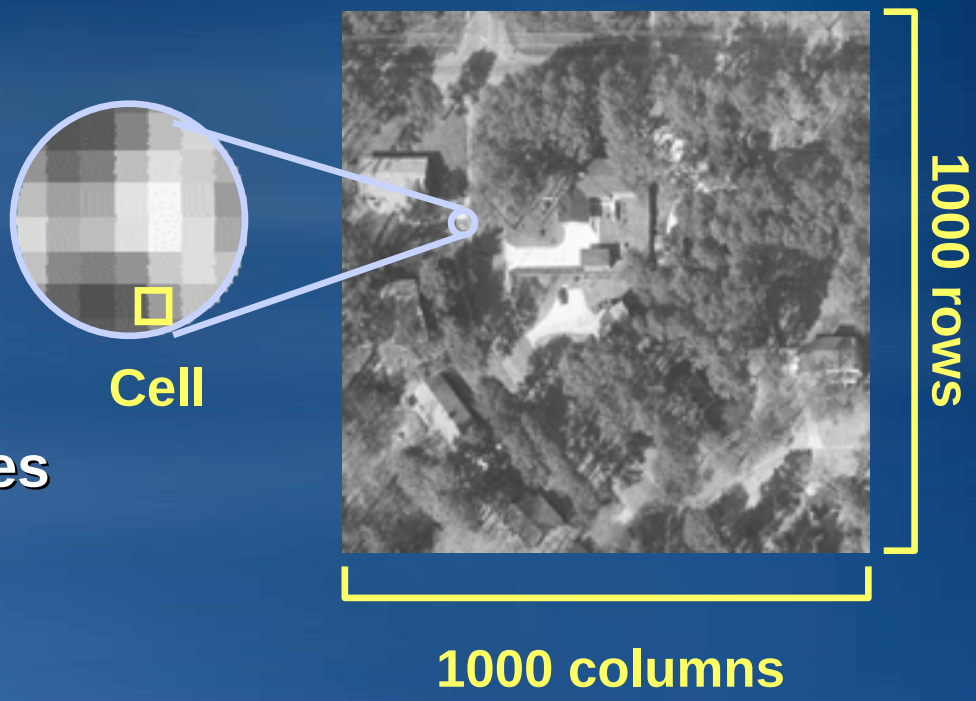


Why use raster data?

- Easier than vector in many analysis
- Efficient overlays with complex data
  - The ability to uniformly store points, lines, polygons, and surfaces
- More analysis options
  - The ability to represent continuous surfaces and perform surface analysis (visibility, slope, aspect, etc.)
  - Distance analysis (decay distances, weighted distance etc.)
- Can be faster then some vector analysis!

Raster datasets

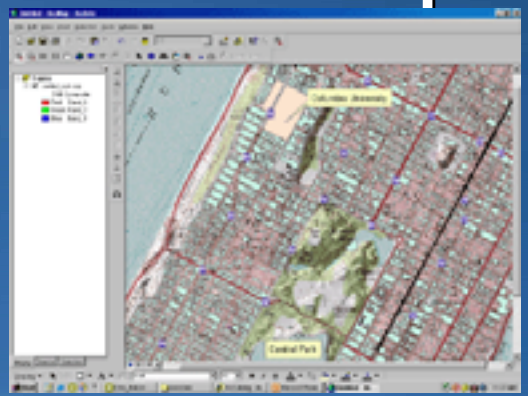
- **Raster data basics**
  - Smallest unit of data is the cell
  - Each cell has a numeric value
  - Cells are arranged in columns and rows
- **Each cell is independent**
  - No discrete features or attributes
  - Raster is arbitrarily subdivided for storage
- **Data type**
  - Discrete data indicates a quantity of a variable
  - Continuous data indicates a quality of a variable



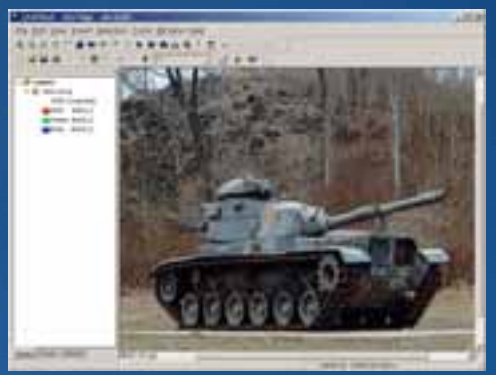
Raster formats

- The format is how cells are stored in a raster
- ArcGIS supports dozens of raster formats
  - Various image formats (SID, IMG, TIFF, and more)
  - ESRI grid and grid stack
  - ESRI ArcSDE raster
- All may be managed in ArcCatalog
- Majority can be used with ArcGIS Spatial Analyst tools

TacticalForce.jpg



CentralPark.img



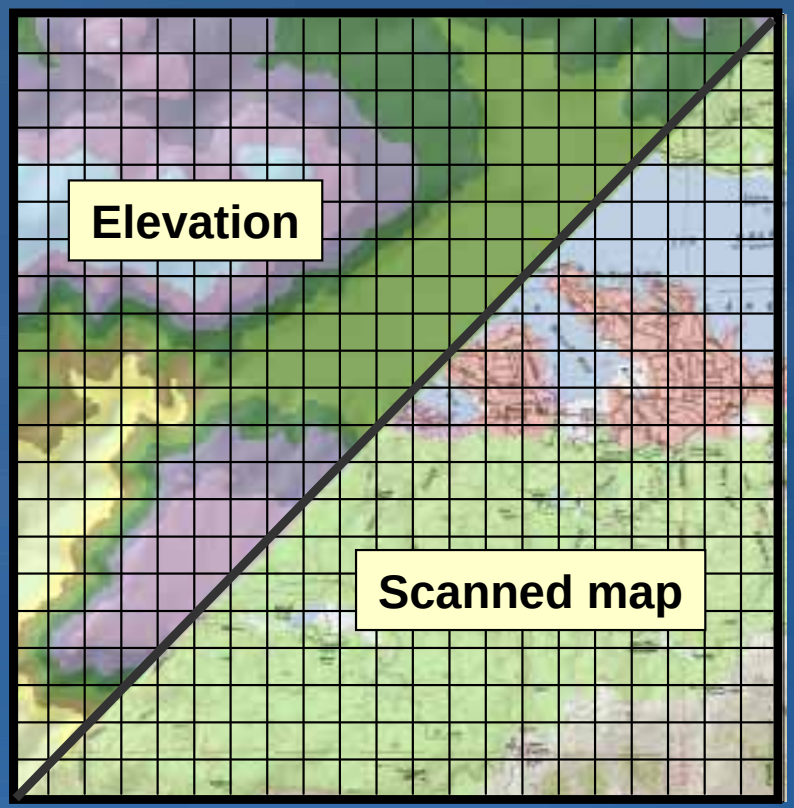
Tank.gif

Raster format essentials

- All raster formats are basically the same
  - Content is more important than format: data or picture?
  - Spatial Analyst does not know the difference

columns ➔

rows ➔



Raster data

- Elevation
- Land use codes
- Population density

Good for analysis

- Slope from elevation

Good for mapping

- Thematic layers
- Derivative products (like shaded relief)

Raster pictures

- Scanned maps
- Satellite images (unclassified)
- Photos of buildings

Good for mapping

- Backgrounds

Good for attributes

- Picture of house

Bad for analysis

A

Raster compression

- Reduces storage and speeds drawing
- Compression is a property of a format
  - Cannot just compress a raster; you must change its format
- Most raster formats support compression
  - TIFF and GIF: LZW compression (lossless)
  - ArcSDE: LZ77, JPEG (lossy), or JPEG 2000 comp. (lossy*)
  - MrSID: Wavelet compression (lossy or loss-less)
  - ESRI grid
    - Integer: Adaptive run-length encoding (loss-less)
    - Floating point: None

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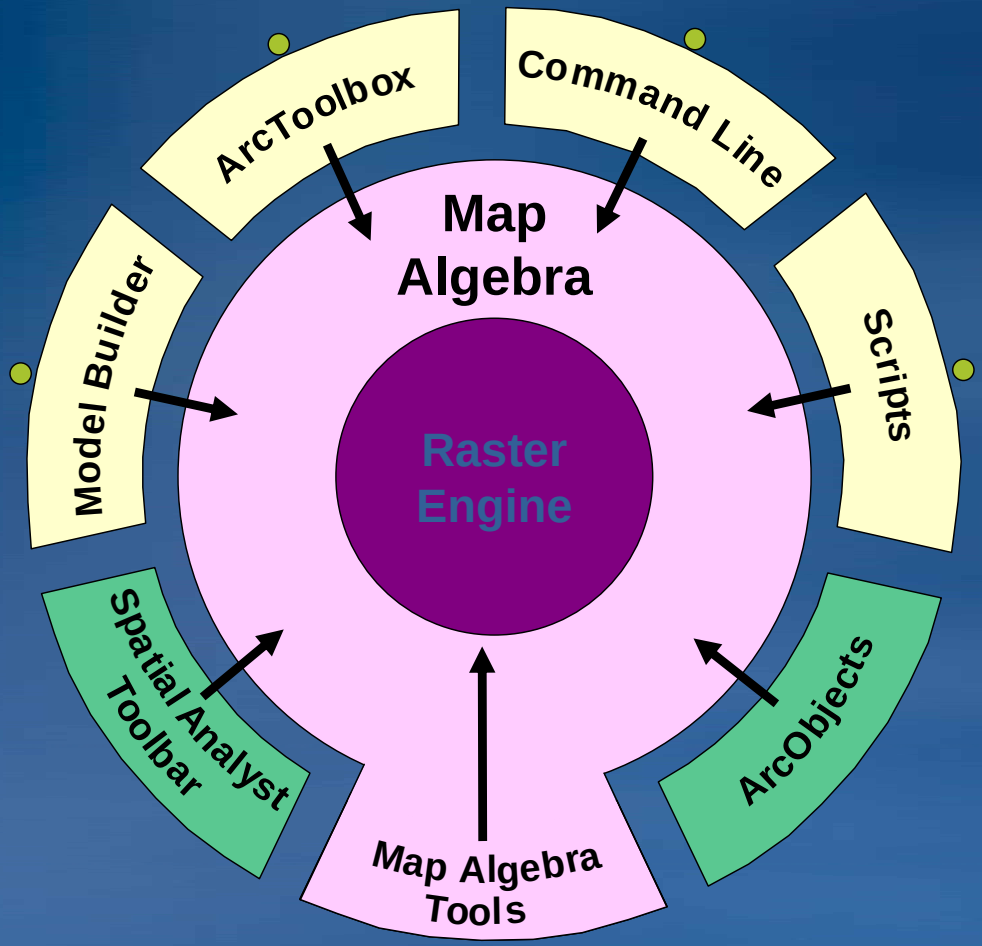
Seven interfaces for ArcGIS Spatial Analyst



- Part of the geoprocessing framework (share a common environment)

1. ArcToolbox
   Dialogs for all tools
2. Command Line
   Type commands
3. ModelBuilder
   Visual modeling
4. Scripts
   Write easy programs
5. Spatial Analyst Toolbar
   Dialogs for common tools
6. ArcObjects
   More programming power
7. Map Algebra Tools
   For all interfaces

- Most become Map Algebra
- Evaluated by Raster Engine

A

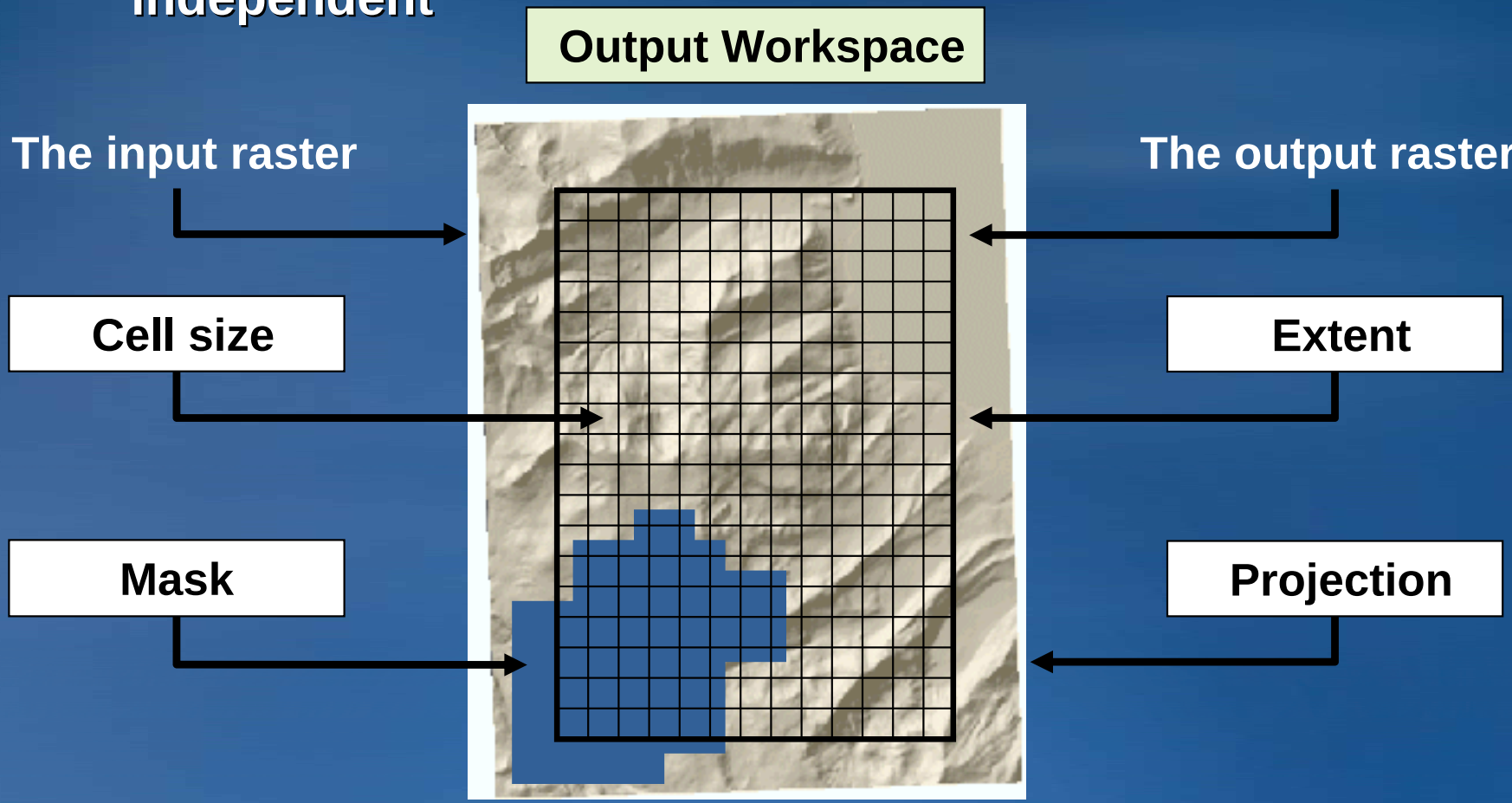
Choosing an environment

	Tool Dialog	Command Line	Model Builder	Script
Simple tasks	✓	✓		
Efficient		✓	✓	✓
Reusability		✓	✓	✓
Combine processes		✓	✓	✓
Batch operations	✓*			✓
Use logic			✓ **	✓
Schedule runtime				✓

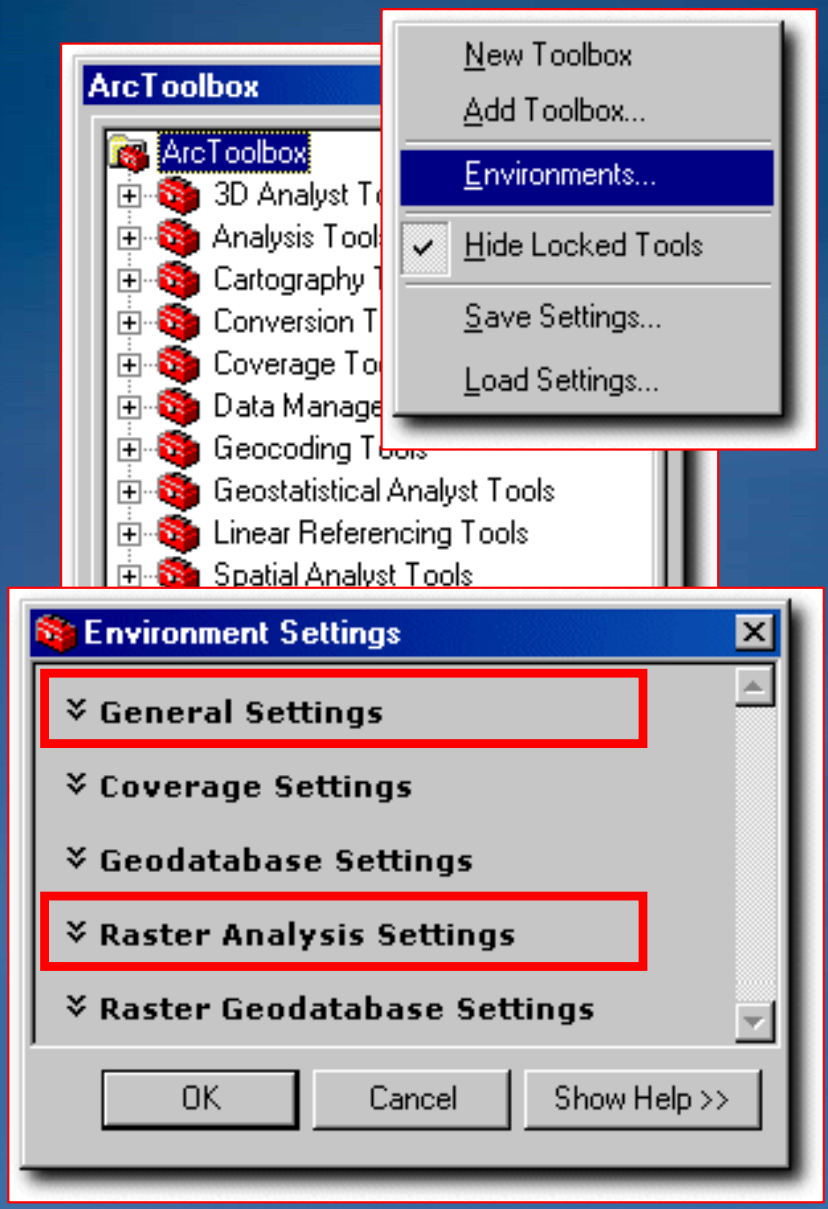
*** Some tools have batch options.**
**** Can set preconditions in model to set tool order.**

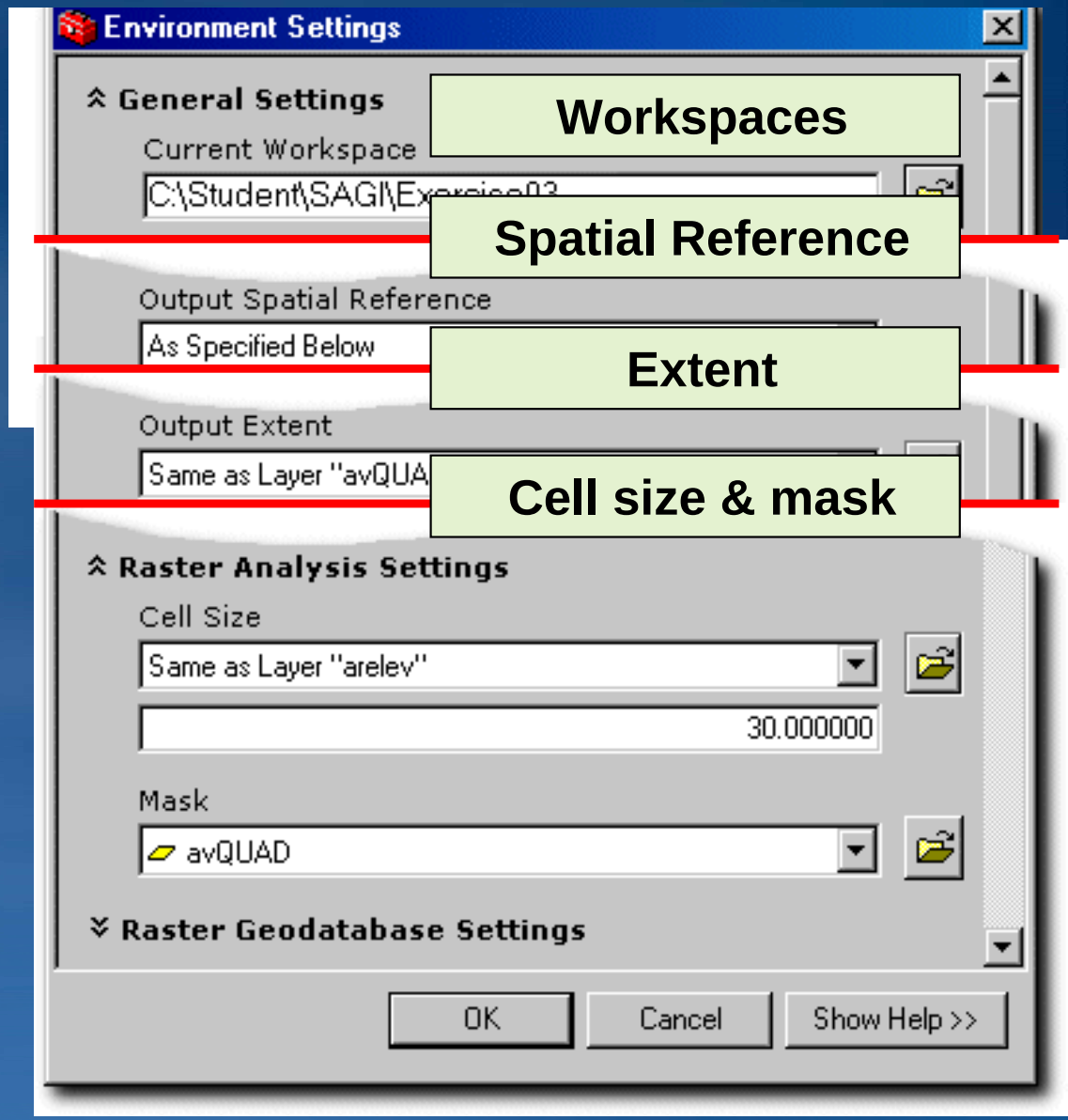
Raster analysis environments

- Control how an output raster is created
  - Set for geoprocessing and ArcGIS Spatial Analyst toolbar—independent



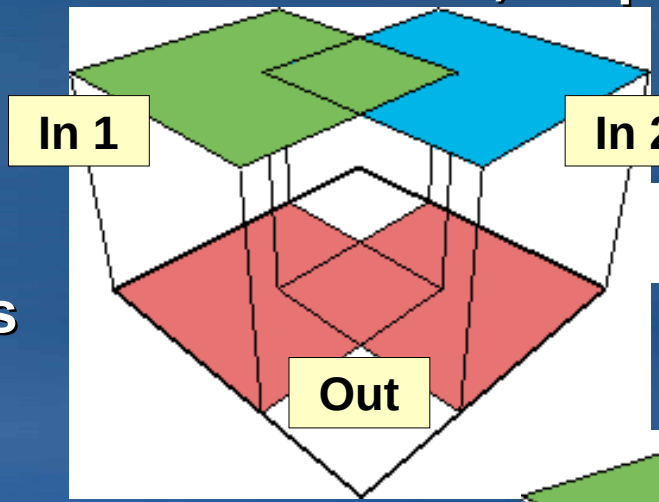
Setting geoprocessing environments



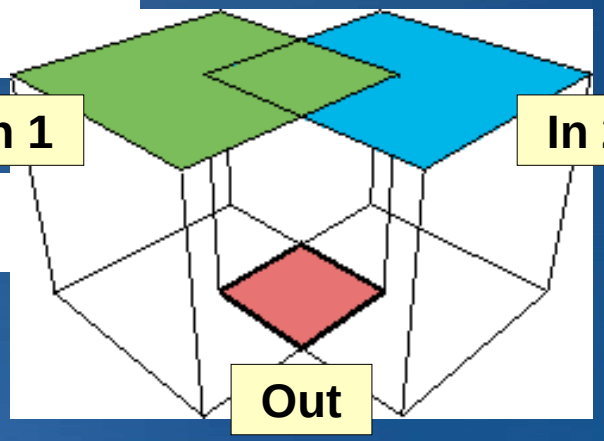


Setting output extent

- Controls the width and height of the output raster
  - Combine rasters with different extents; output another extent
- Output options
  - Union of inputs (default)
  - Intersection of inputs
  - Same as layer
  - Same as display
  - As specified



← Union of inputs

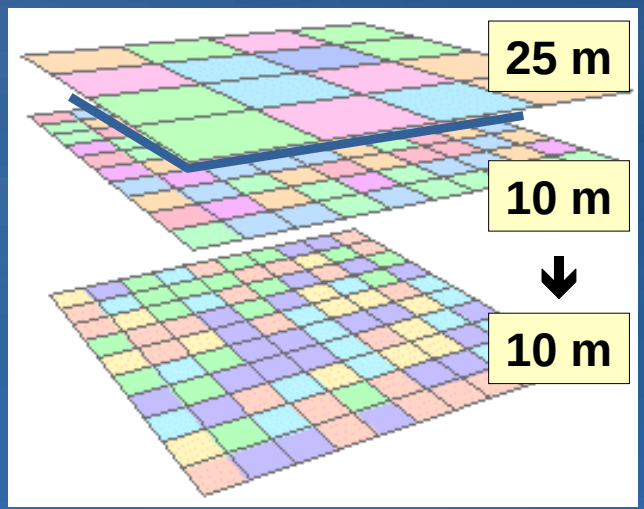


Intersection of inputs →

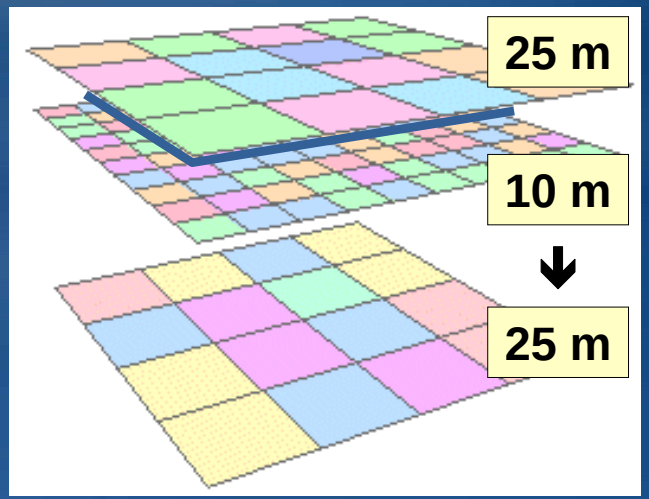
Setting output cell size

- Rasters are resampled during analysis
  - Combine rasters with different cell sizes, output another size
- Output options
  - Maximum of inputs (default)
  - Minimum of inputs
  - Same as layer
  - As specified

Minimum of inputs

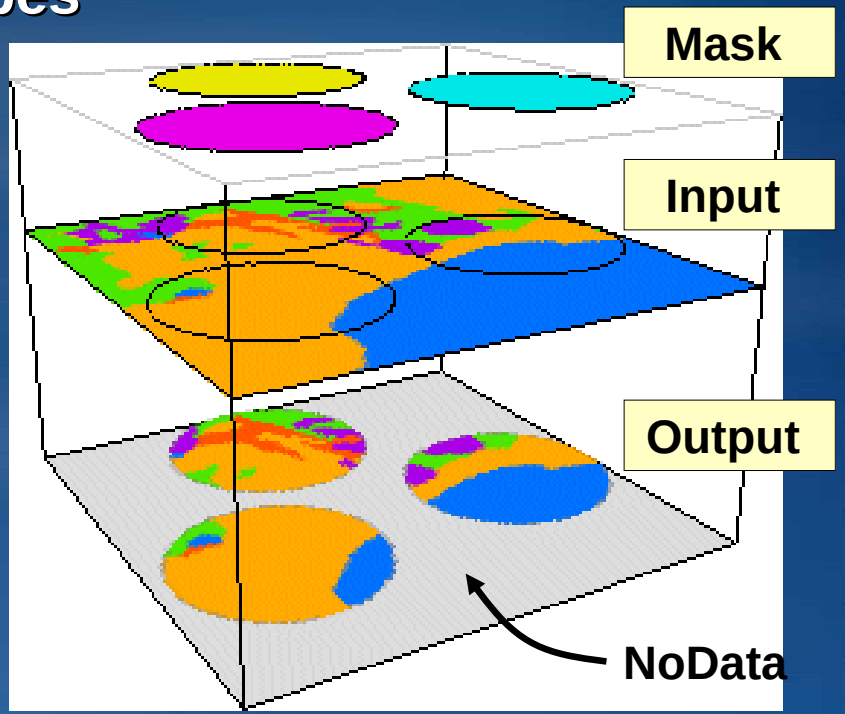


Maximum of inputs



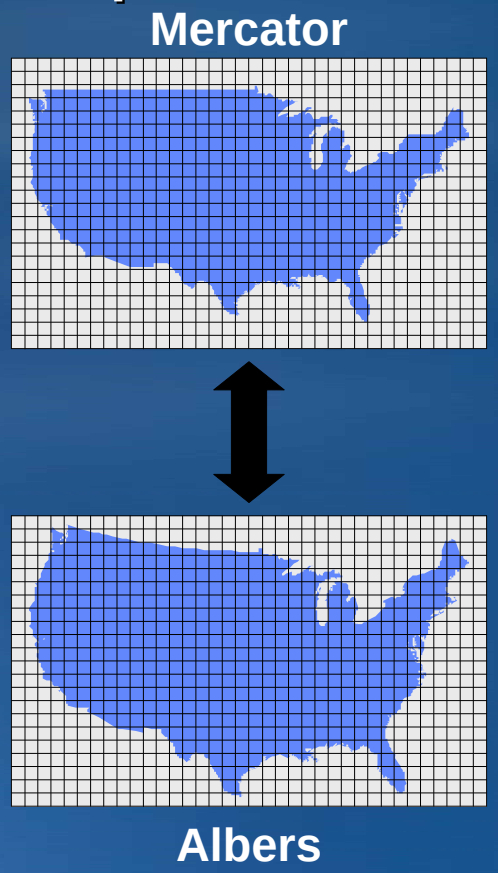
Setting analysis mask

- Defines areas where analysis is performed
  - Useful for clipping to irregular shapes
- Vector mask
  - Only cells covered by features are output (others set to NoData)
  - Creates a feature mask with selection and export
- Raster mask
  - Only cells covered by valued cells are output (others set to NoData)
  - Creates a raster mask with several ArcGIS Spatial Analyst techniques



Setting output projection

- Rasters can be projected during analysis
  - Combine rasters in different projections, output to another
- Output options
  - Same as input
  - Same as display
  - Same as layer (geoprocessing only)
  - As specified (geoprocessing only)
- Uses *Fast project*
  - Best for small areas at low latitudes



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Map Algebra: The language of raster

- A data manipulation language designed for raster
  - Math-like expressions

```
LandingSuit = ([SlopeSuit] * 0.75) + ([PowerSuit]  * 0.25)
```

Parts of the language:

- Objects: Raster, vector, numbers, constants,and variables
- Operators: “+”, “/”, “GT”, “LE”, “AND”, and “OR”
- Functions: Slope, FocalMean, and Sin
- Rules: For building expressions and using functions

- Most operators and functions are implemented as tools

Function syntax rules

- **Functions return values**
  - Use as objects in expressions

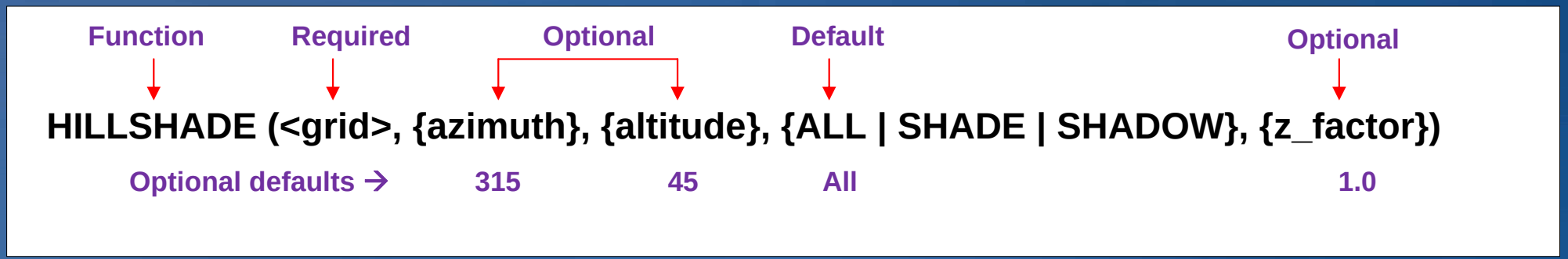
```
[PowerSuit] + CON([Slope] LE 15, 1, 0)
```

- **Arguments in parentheses and comma delimited**

```
SLOPE([Elevation], DEGREE)
```

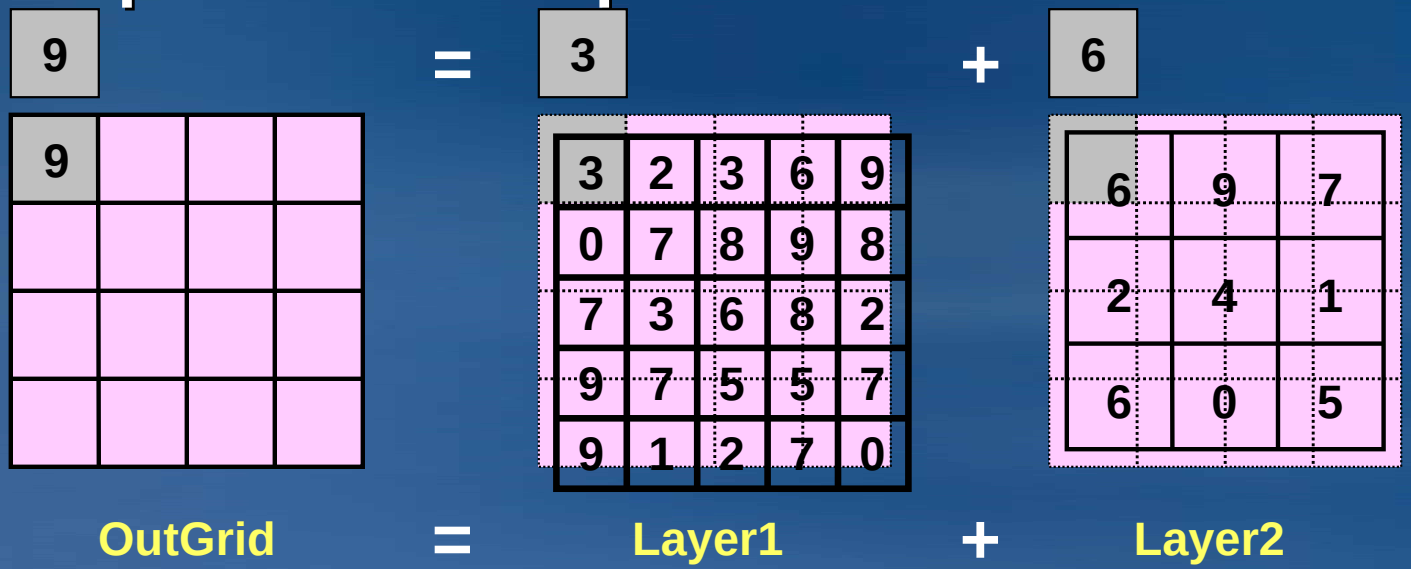
- **Arguments may be other functions or expressions**

```
SLOPE( IDW(C:\data\elevpoints, spot), DEGREE)
```



Expression evaluation

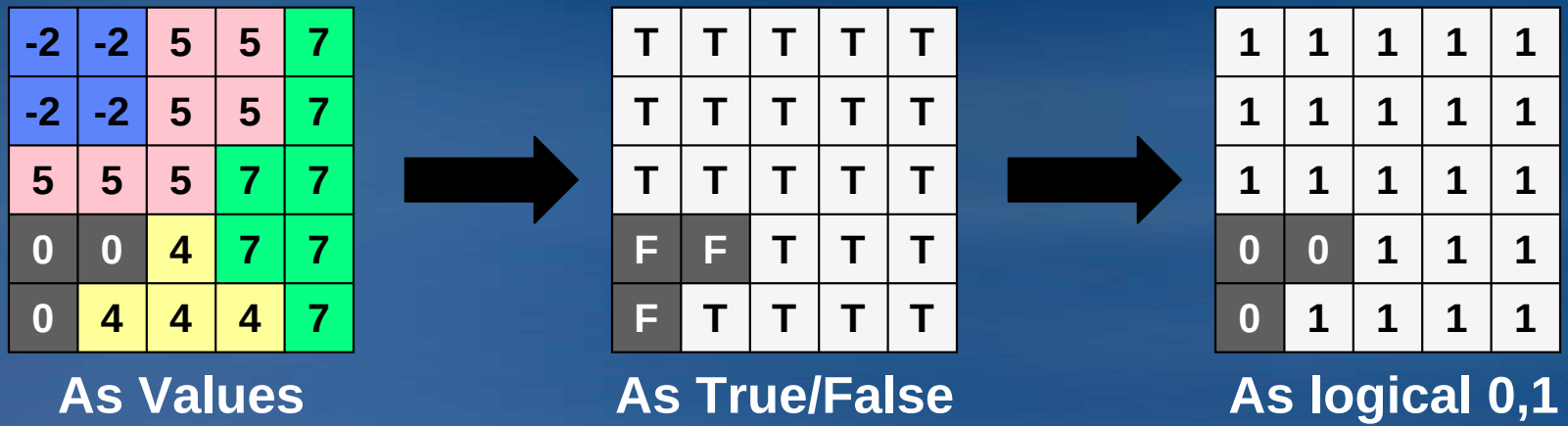
- **How expressions are processed**



1. Define an empty output grid based on the analysis environment
2. Position to the next output cell (start at row 0, column 0)
3. Resample input raster(s) to determine corresponding cell values
4. Evaluate the expression and write the result to the output cell
5. Repeat Steps 2–4 for all output cells

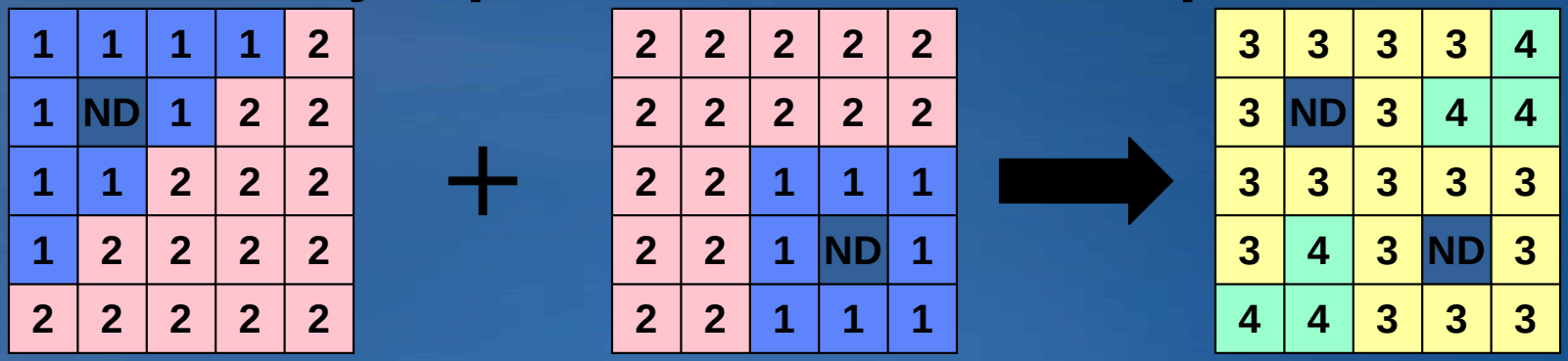
Special cell values in Map Algebra

- **Logical: Nonzero values are *True*; zero is *False***



As Values | As True/False | As logical 0,1

- **NoData: If any input is *NoData*, the output is *NoData***



Layer1 + Layer2 = Layer3

Map Algebra operators

- Work with two objects, such as **Slope GE 10**

Arithmetic

+	Addition
–	Subtraction
*	Multiplication
/, DIV	Division
MOD	Modulus
–	Unary minus

Boolean

^, NOT	Logical complement
&, AND	Logical And
|, OR	Logical Or
!, XOR	Logical Xor

Relational

==, EQ	Equal
^=,<>, NE	Not equal
<, LT	Less than
<=, LE	Less than or equal
>, GT	Greater than
>=, GE	Greater than or equal

Combinatorial

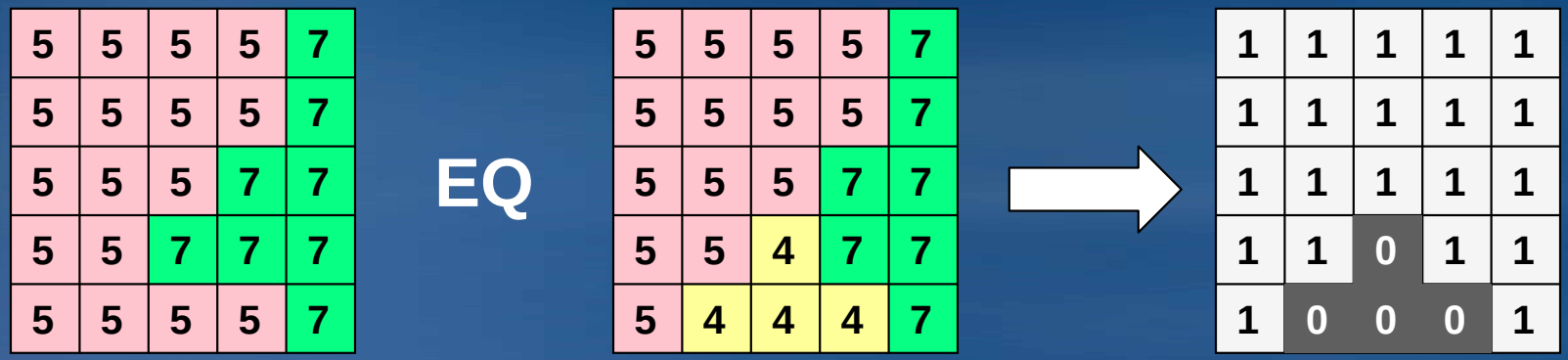
CAND	Combinatorial And
COR	Combinatorial Or
CXOR	Combinatorial Xor

Logical

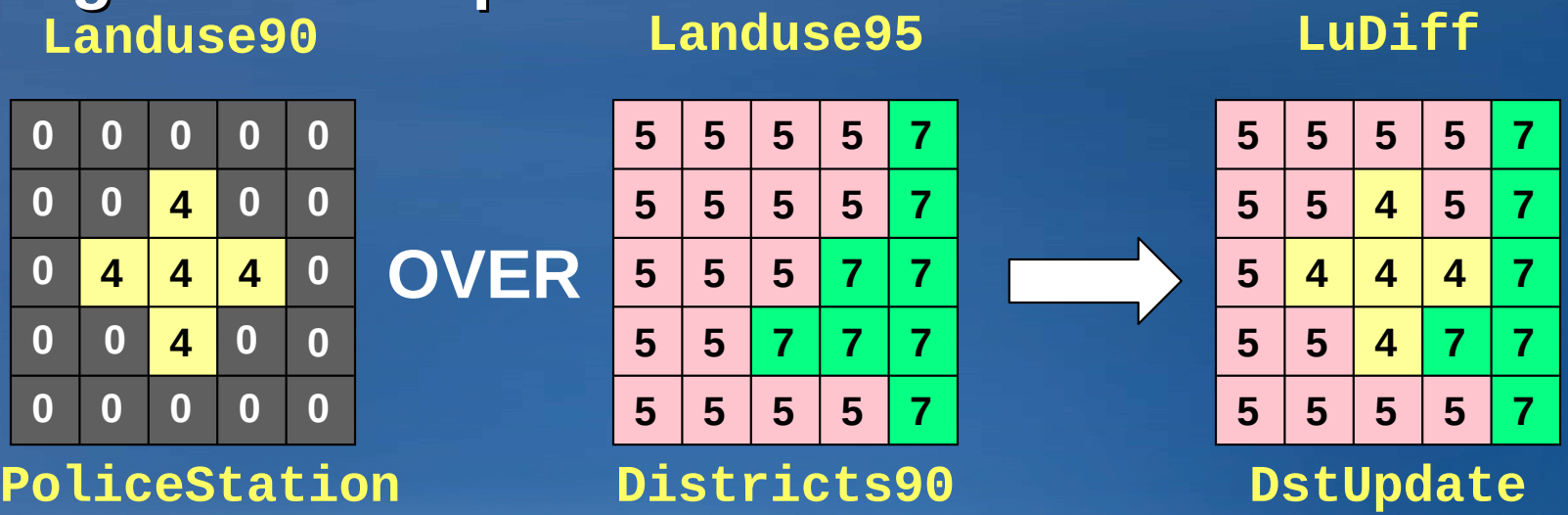
DIFF	Logical difference
IN {list}	Contained in list
OVER	Replace

Examples of operators

- Using EQ to find changes in land use

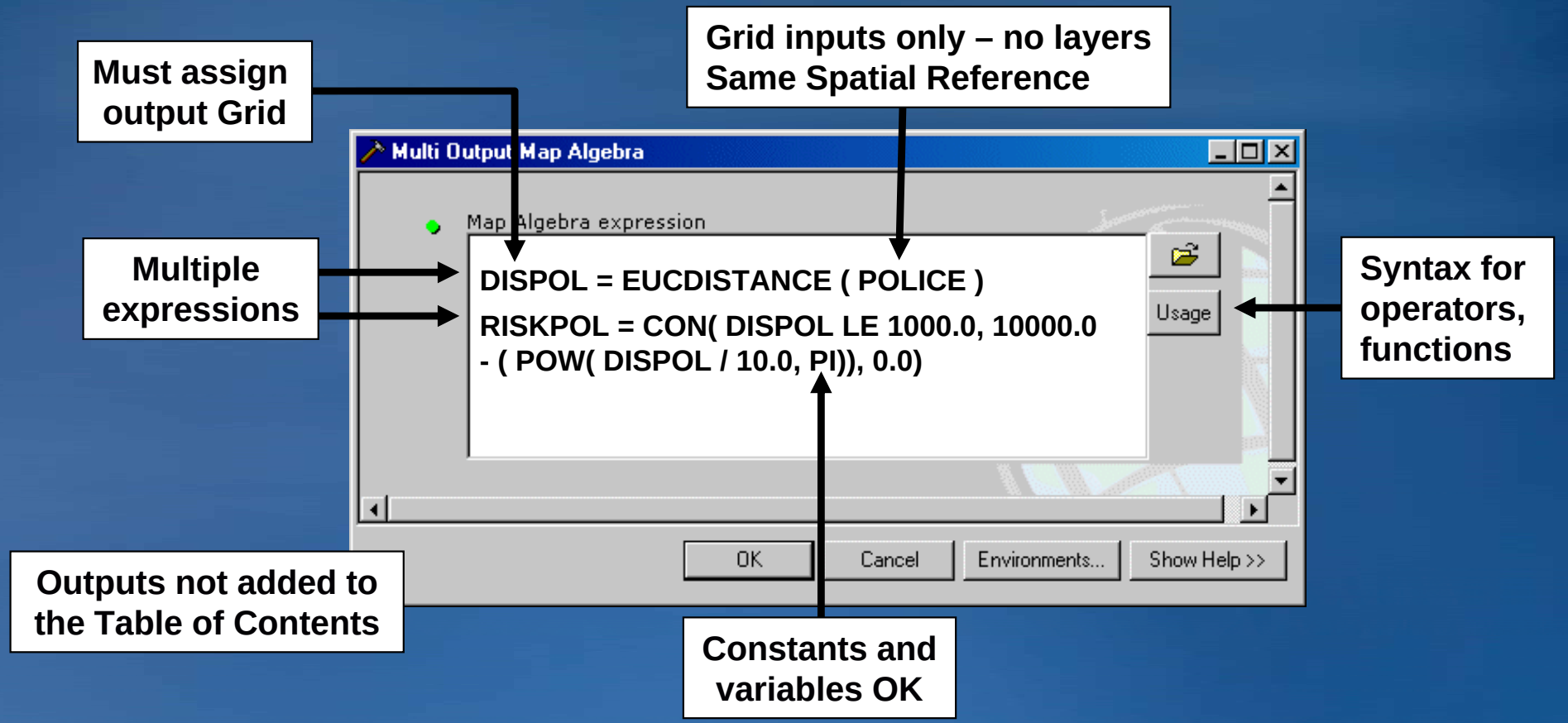


- Using OVER to update land use



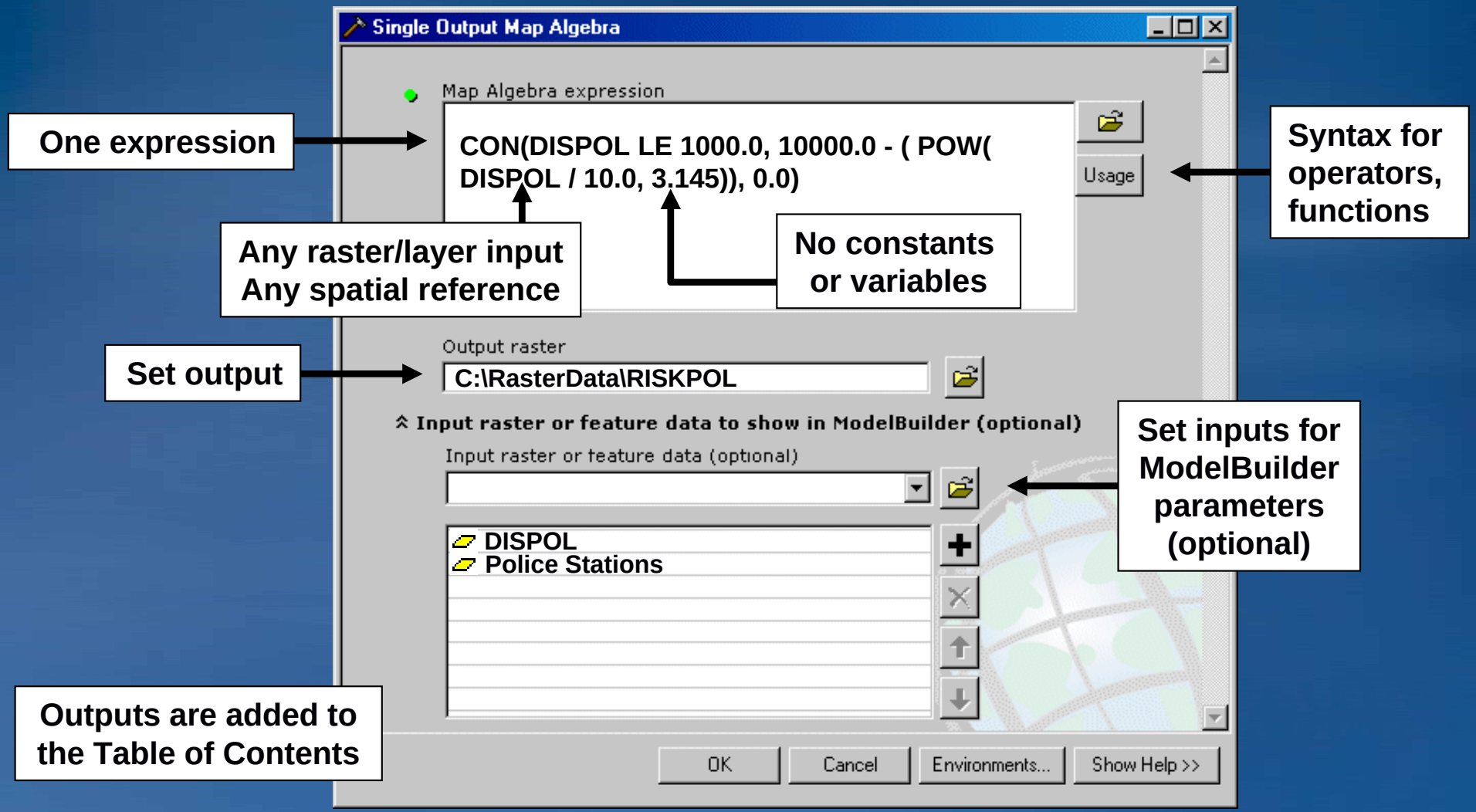
Multi Output Map Algebra tool

- Implements all Map Algebra capabilities
  - Lacks some normal tool capabilities



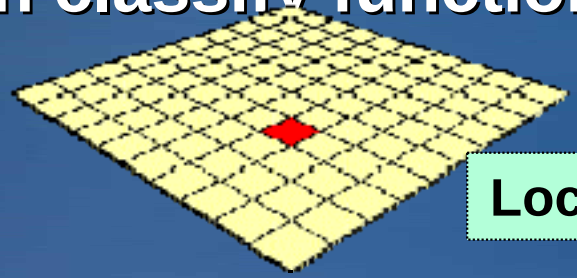
Single Output Map Algebra tool

- Designed for use with ModelBuilder



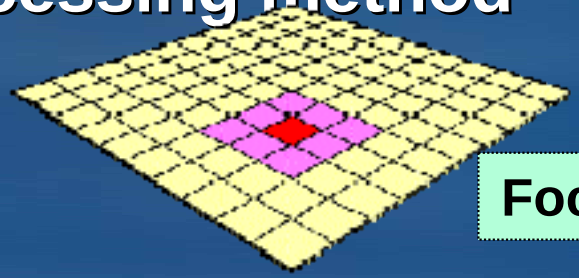
Map Algebra functions

- Do most of the work in Map Algebra
  - Approximately 168 functions
- Can classify functions by processing method



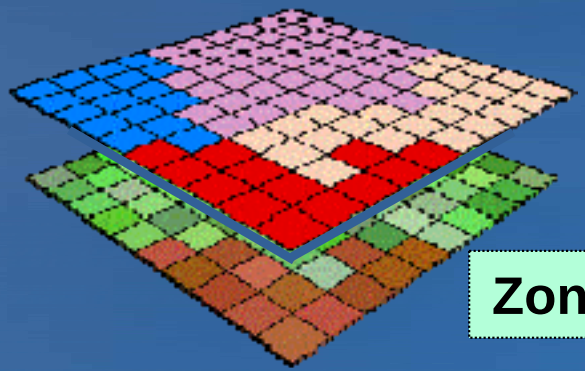
Local

By cell



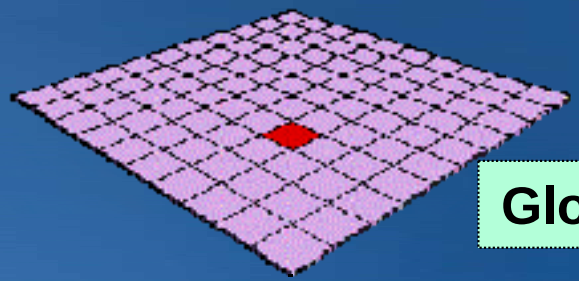
Focal

By neighborhood



Zonal

By zone

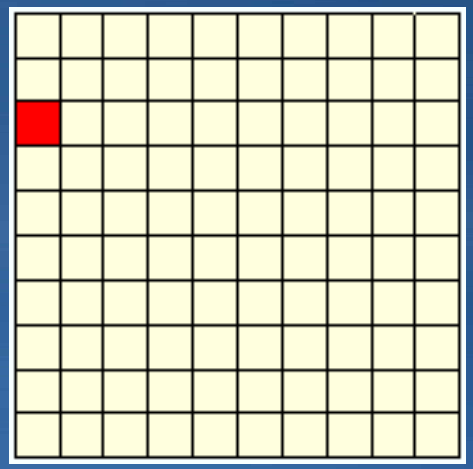


Global

By raster

Local functions

- Compute values based on the current output cell
  - Most functions are local
- Each cell is processed, starting at top left



CON function

- IF-THEN-ELSE function for Map Algebra

```
CON(<condition>, <true_expression>, {false_expression})
```

IF TEST THEN *(TEST = 1)* ELSE *(TEST = 0)*

- May be a simple IF-THEN-ELSE

```
CON(Slope < 20, 1, 0)
```

- Or nest CONs for an ELSE-IF

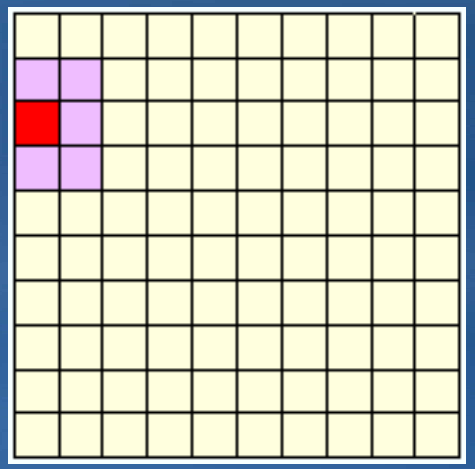
```
CON(Slope < 20, 1,
   CON(Slope < 40, 2,
     CON(Slope < 90, 3, 5) ) )
```

Second CON {false_expression}

Third CON {false_expression}

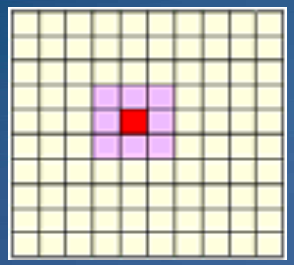
Focal functions

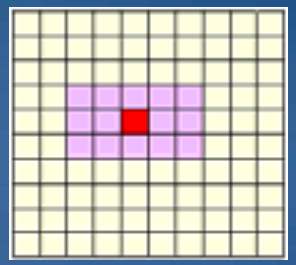
- Compute values by cell neighborhoods
  - Writes result to current cell in the output grid
- Neighborhood is a moving window over input

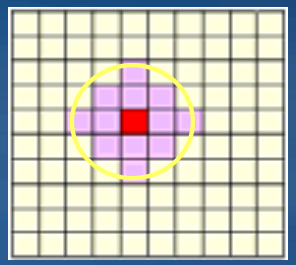


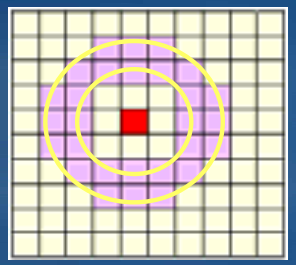
Neighborhood types

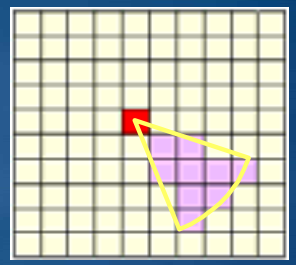
- You can define the neighborhood geometry


Default


Rectangle


Circle


Annulus


Wedge

- Create a custom neighborhood with a kernel file

```
FOCALSUM(Elev)
FOCALSUM(Elev, RECTANGLE, 5, 3)
FOCALSUM(Elev, CIRCLE, 2)
FOCALSUM(Elev, ANNULUS, 2, 3)
FOCALSUM(Elev, WEDGE, 4, 300, 330)
```

Kernel.txt

```
5 3
1 1 0 1 0
1 0 0 1 1
0 1 1 1 0
```

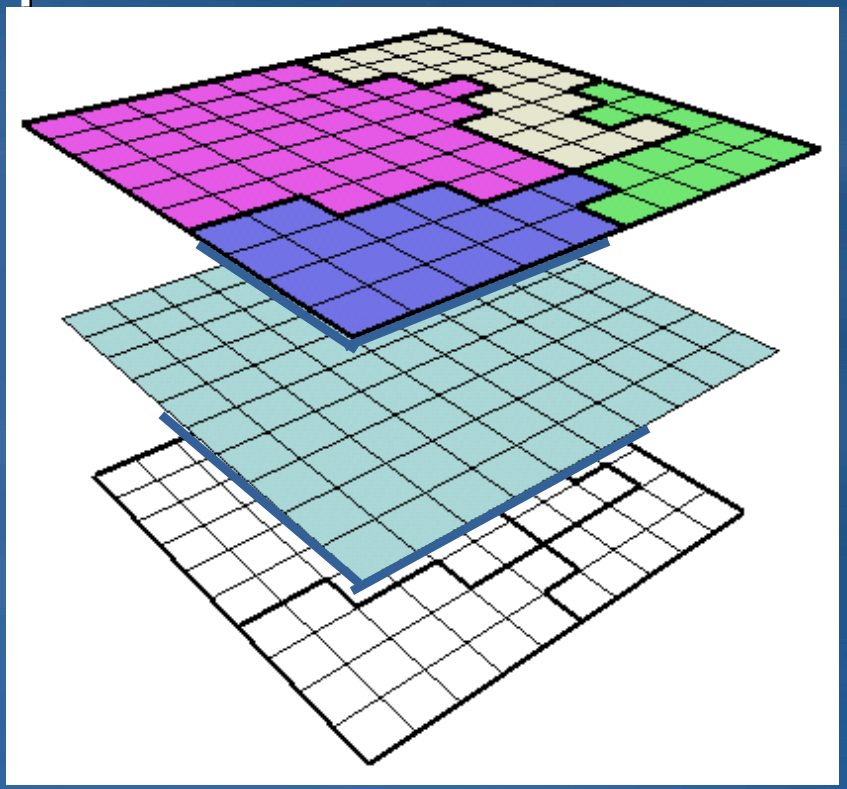
Zonal functions

- Most summarize values in a layer by zones in another
  - Require two input rasters: Zone and Value

District

Population

PopByDistrict



Zone layer

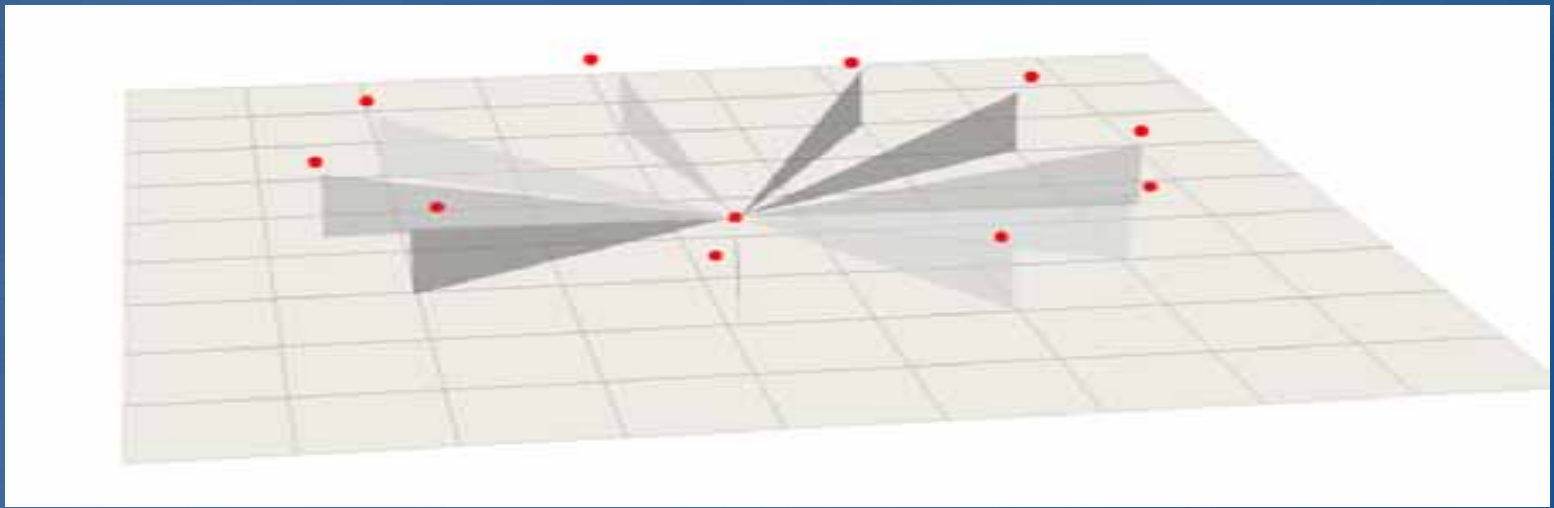
Value layer

Output layer

```
ZONALSUM(District, Population)
```

Global functions

- Can access all input cells to compute output cell value
  - Interpolators (IDW, Spline others)

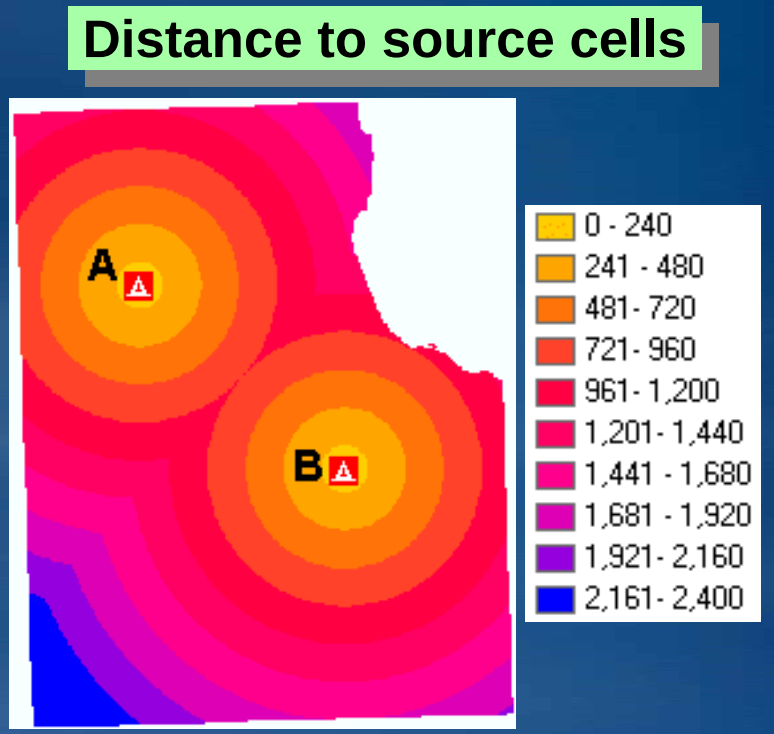


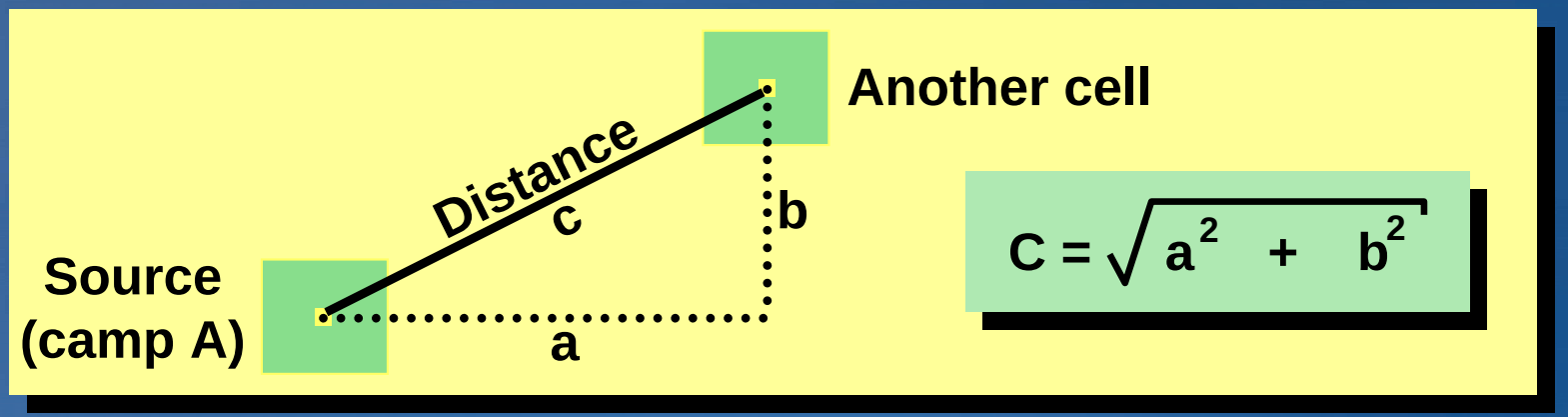
Distance functions

- Straight-line distance
  - Inputs: Sources (raster, point, line, or polygon)
  - Euclidean distance: Distance to threatened bridge
- Weighted distance
  - Inputs: Sources and cost surface
  - Cost distance: How long to drive to destinations
  - Cost path: Best paths to destinations

Calculating Euclidean distance

- Calculates straight-line distance
  - From each cell to nearest source
  - Cell center to cell center
  - Output in map units (e.g., feet)
  - Source cells are output as zero
- Must create sources first





Weighted distance measurement

- The shortest path between points is not always the best

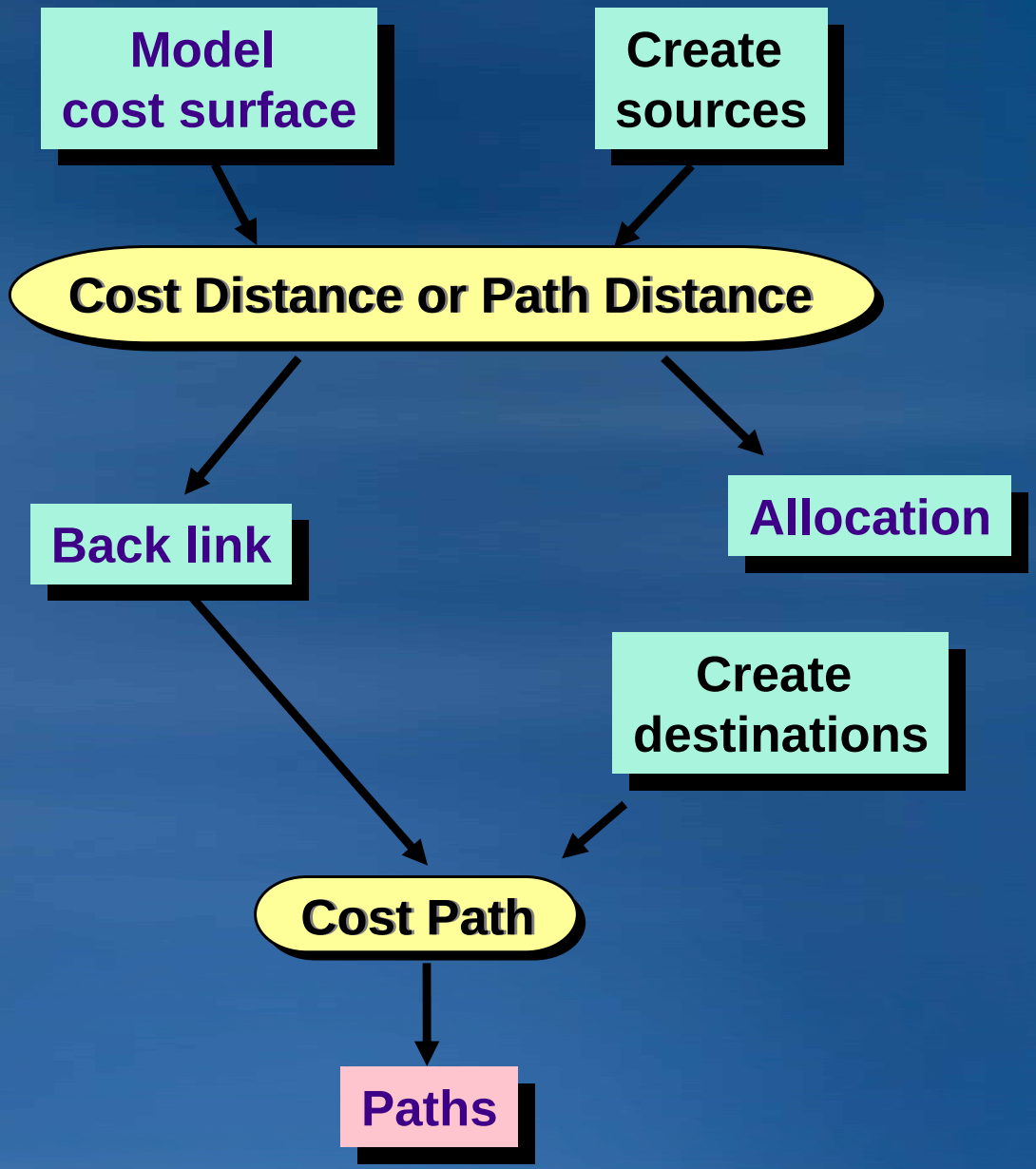
Five hours

Ten hours

- Ten hours to climb over the mountain
- Five hours to follow the trail around it

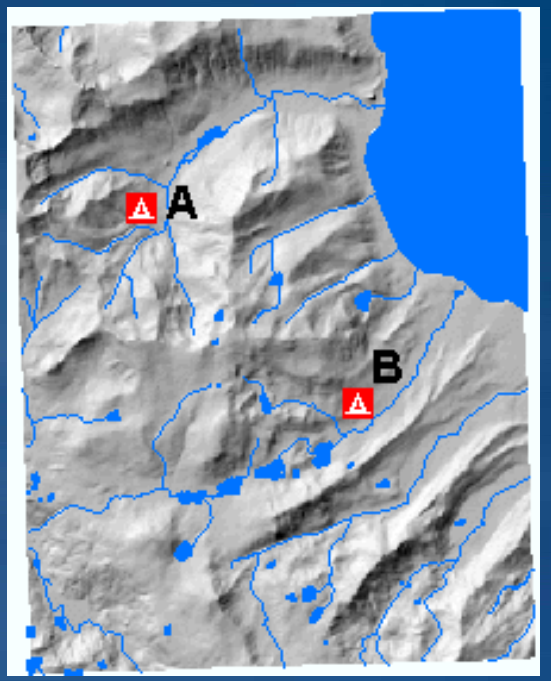
- Finds the least-cost path between cells and sources
  - Considers resistance to travel; an input cost surface
  - Weights distance with travel costs
- Result: Accumulated travel cost to every cell
  - Units are cost (e.g., time, risk), not distance

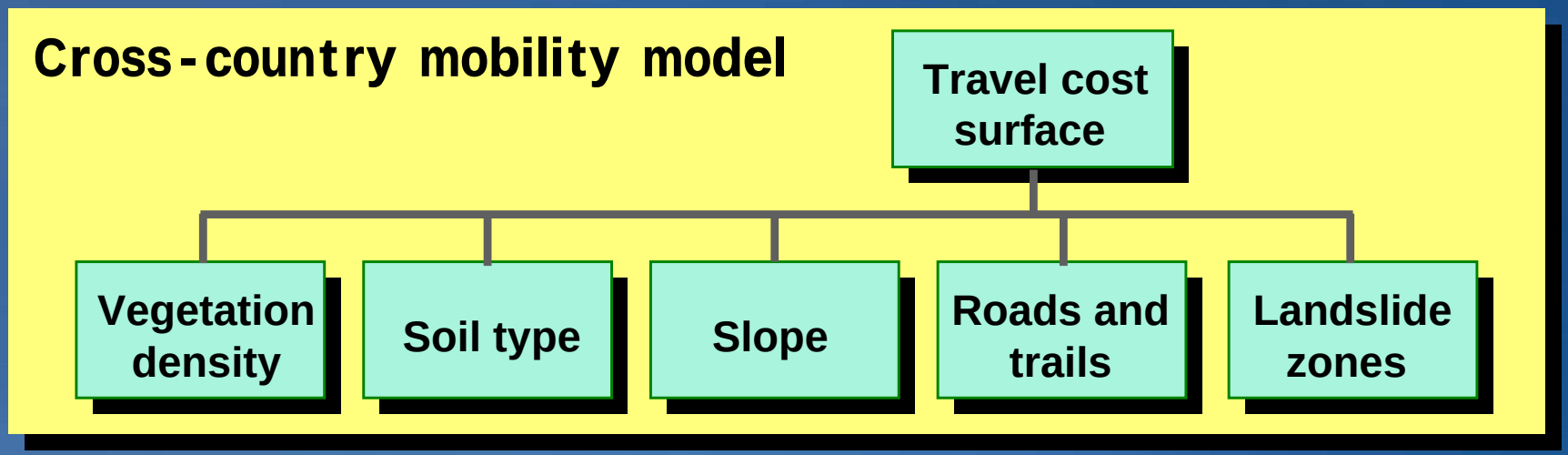
Roadmap: Weighted distance process



Creating the cost surface

- Cost to travel through each cell
  - High values = high travel cost
- Express as cost-per-unit distance
  - Dollars per foot, hours per meter, and so on
- Create by modeling
  - Often considers many variables



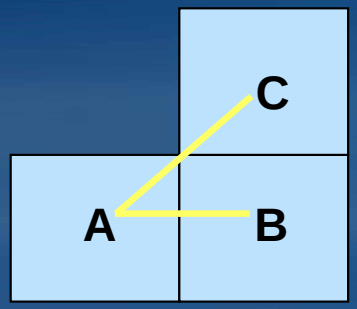


Calculating travel costs

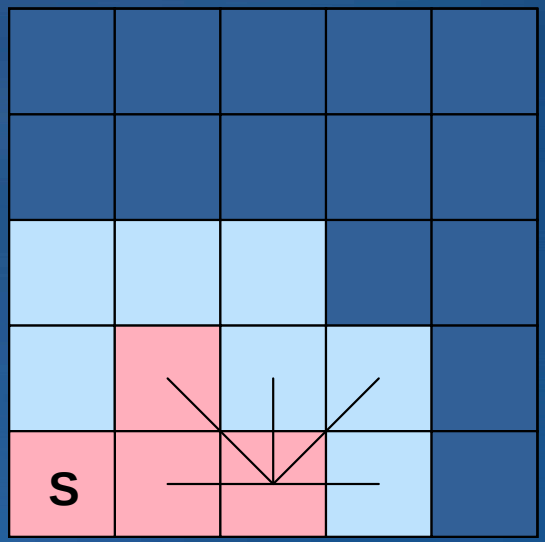
- **Calculating cell-to-cell travel cost**

$$CostAB = Cellsize \times 1 \times \frac{CostA + CostB}{2}$$

$$CostAC = Cellsize \times \sqrt{2} \times \frac{CostA + CostC}{2}$$



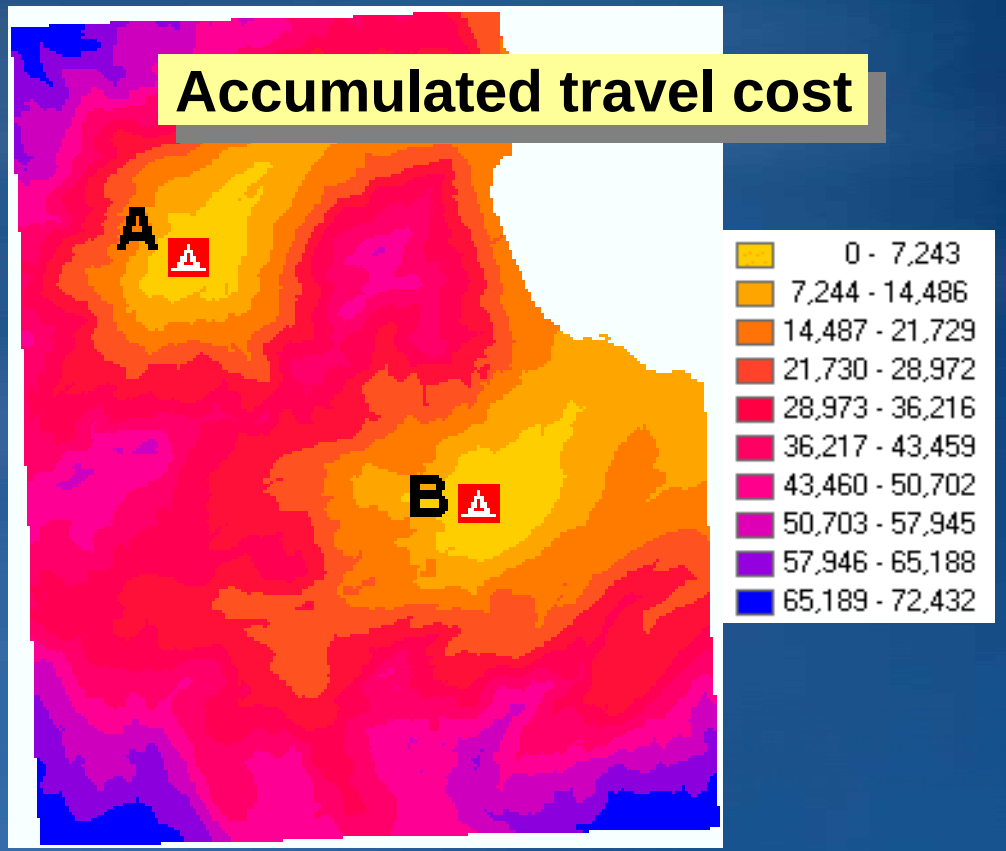
- **The process spreads from sources**
  - Start at a source cell
  - Find cost to each neighbor
  - Move to cheapest neighbor
  - Find cost to each neighbor
  - Repeat until all cells are reached



A

Accumulated travel cost output

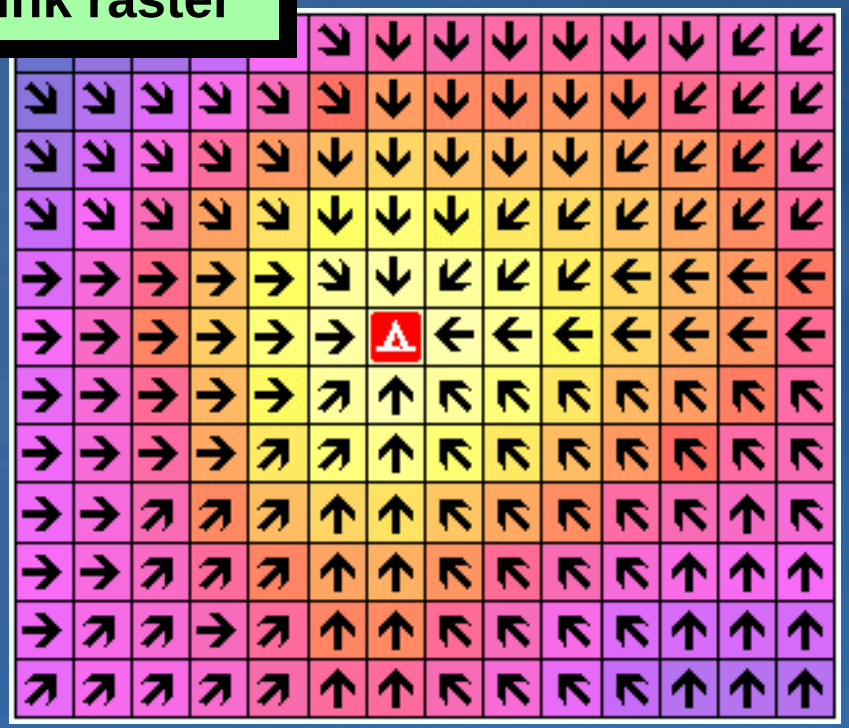
- Cost accumulates away from source cells
  - High values = Higher cost to travel
- Use as
  - A measure of accessibility
  - An input to Cost Path



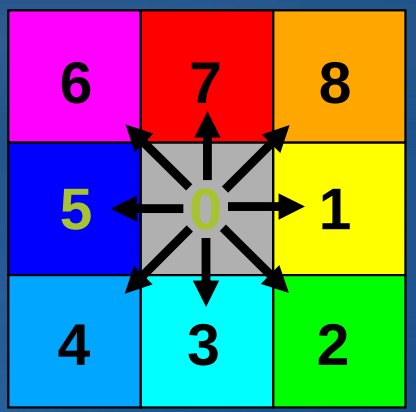
Back link output

- Direction codes point back to the nearest source
  - For each cell, points to the adjacent cell on least-cost path
- Required by the Cost Path tool

Backlink raster

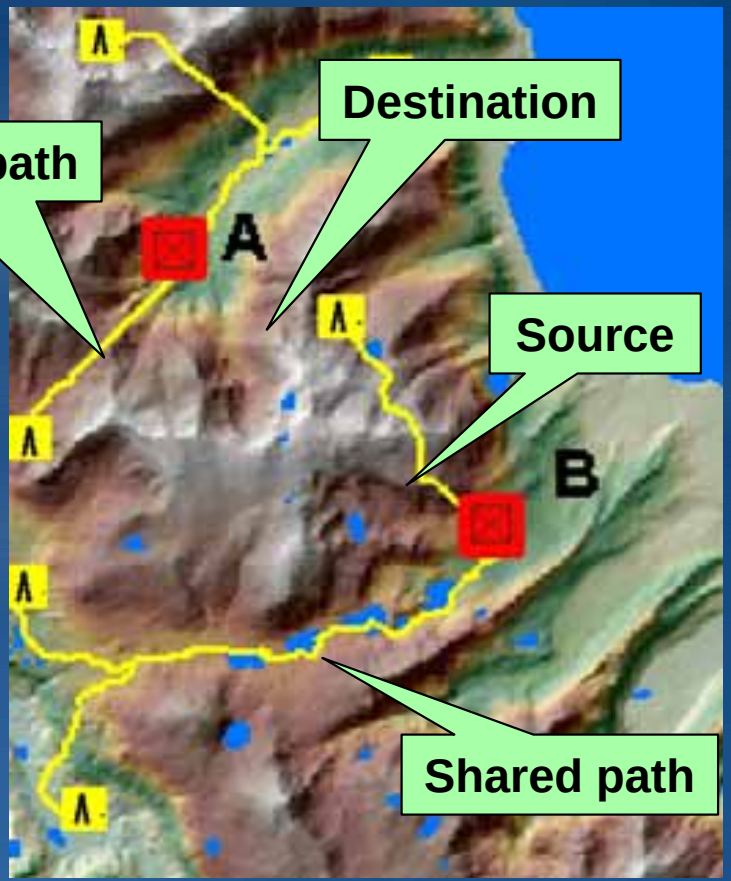


Backlink codes



Finding paths

- Finds least-cost paths from sources to destinations
  - User interface = line features
  - COSTPATH = raster lines (with attributes)
- Required inputs
  - Destinations
  - COSTDISTANCE outputs
    - Accumulated travel cost grid
    - Direction grid
- Shortest Path in user interface
  or COSTPATH function

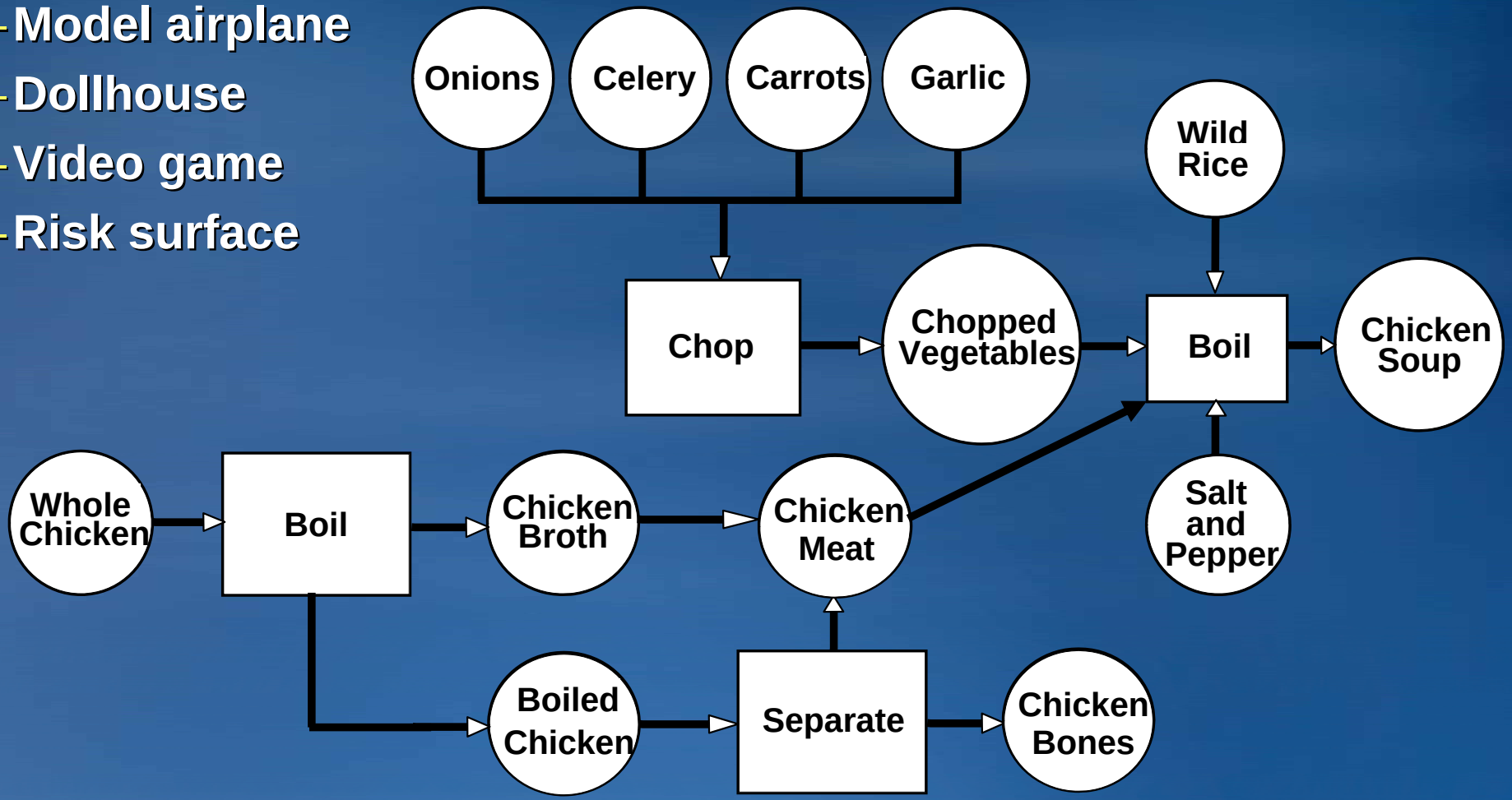


Overview

- Introduction to ArcGIS Spatial Analyst
  - What is Spatial Analyst
  - Why use raster data
  - What is raster data
- Accessing Spatial Analyst capabilities
  - The seven interfaces
  - Environment setting options
- Basic Spatial Analyst Concepts
  - The language of raster analysis
  - Spatial Analyst functions
- **Modeling**
  - **What are models**
  - **Types of models**
- Calculating risk
- Questions

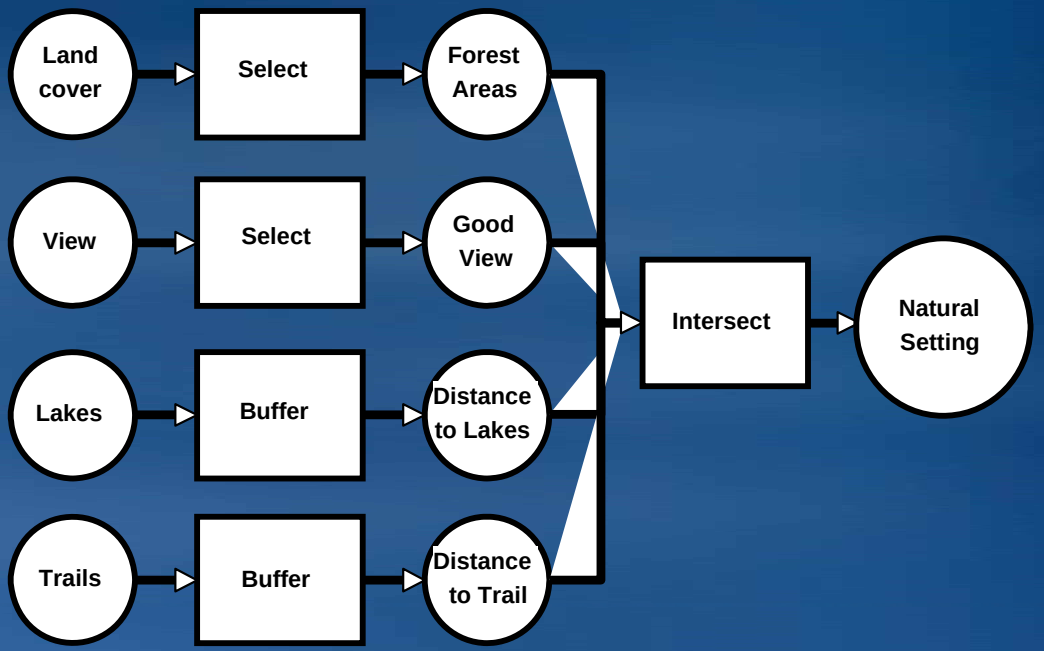
What is a model?

- A representation of reality
  - Model airplane
  - Dollhouse
  - Video game
  - Risk surface



Why use models?

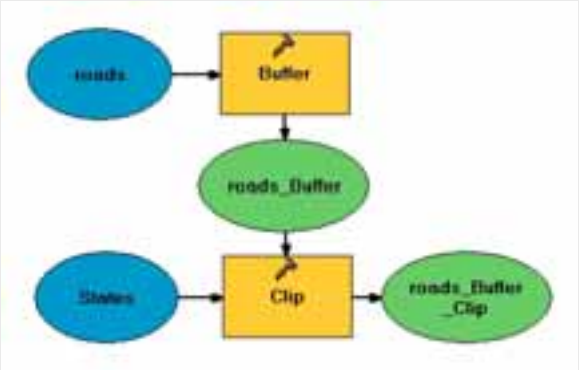
- Share process with others
- Document work
- Solve simple or complex problems
- Modify variables easily
  - Rerun
  - Explore what if scenarios
- Framework for understanding real-world processes



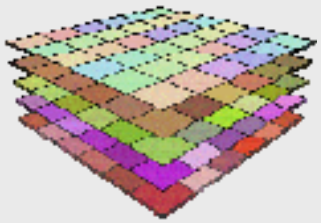
Types of models

Representation models

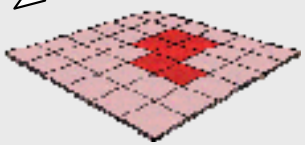
Automated workflows



Suitability models

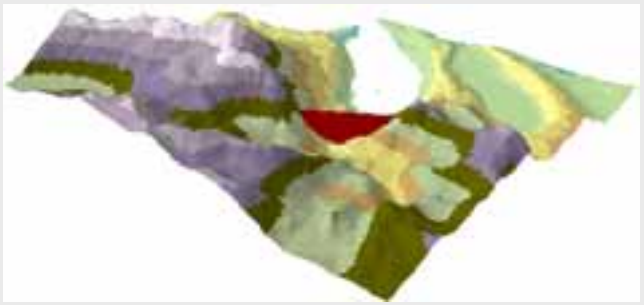


GIS data layers



Best Shelter location

Process models

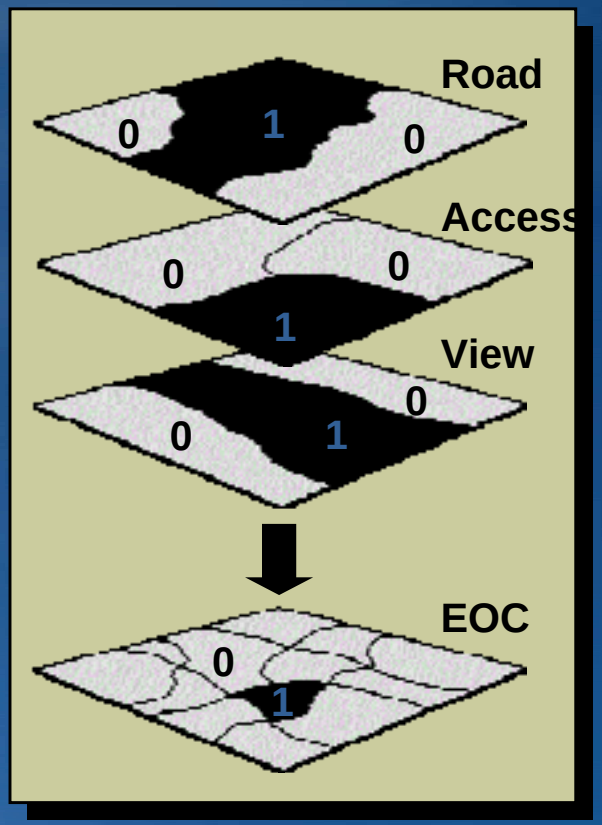


Filling a reservoir

Suitability: Binary models

- Use for simple problems
- Classify layers into good (1) and bad (0)
  - Combine with AND, addition, or multiplication

    `EOC = Road And Access And View`
- Advantages
  - Easy
- Disadvantages
  - No next-best sites
  - All layers have same importance
  - All good values have same importance

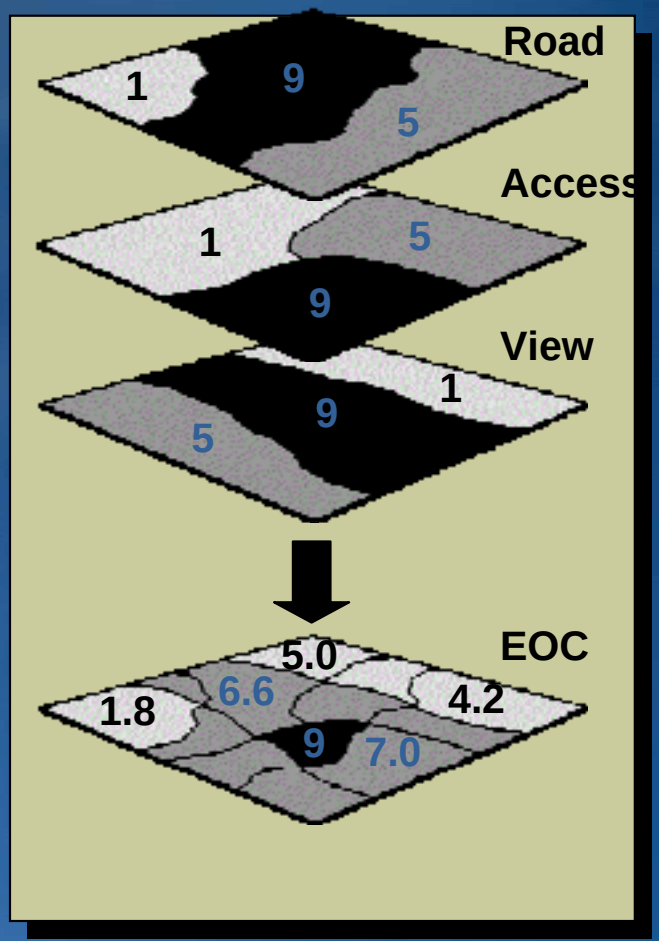


Suitability: Weighted models

- Use for complex problems
- Classify layers into suitability 1 – 9 (9 = best)
  - Weight each layer

```
EOC = (Road   * 0.5)
    + (Access * 0.3)
    + (View   * 0.2)
```

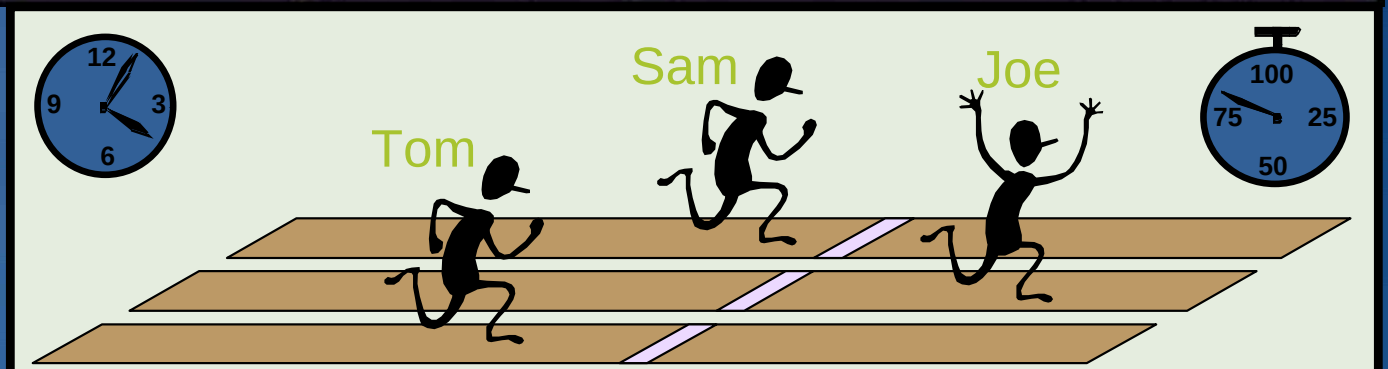
- Advantages:
  - All values have relative importance
  - All layers have relative importance
  - Returns suitability on a scale 1 – 9
- Disadvantages:
  - Preference assessment is harder



Suitability: Data types

- The type of data is important
- Data types
  - Nominal
  - Ordinal
  - Interval
  - Ratio

Type	Examples	Legal math
Nominal	ID, Landuse code, Phone number	=
Ordinal	Importance, Order of completion	<, =, >
Interval	Time of day, Temperature, pH level	<, =, >, +, -
Ratio	Age, Distance, Weight, Counts	<, =, >, +, -, *, /



Runner	#72 – Tom	#43 – Sam	#10 – Joe	Nominal
Finished	3rd	2nd	1st	Ordinal
Time of day	4:05:09	4:05:07	4:05:03	Interval
Elapsed time	81 sec	79 sec	75 sec	Ratio

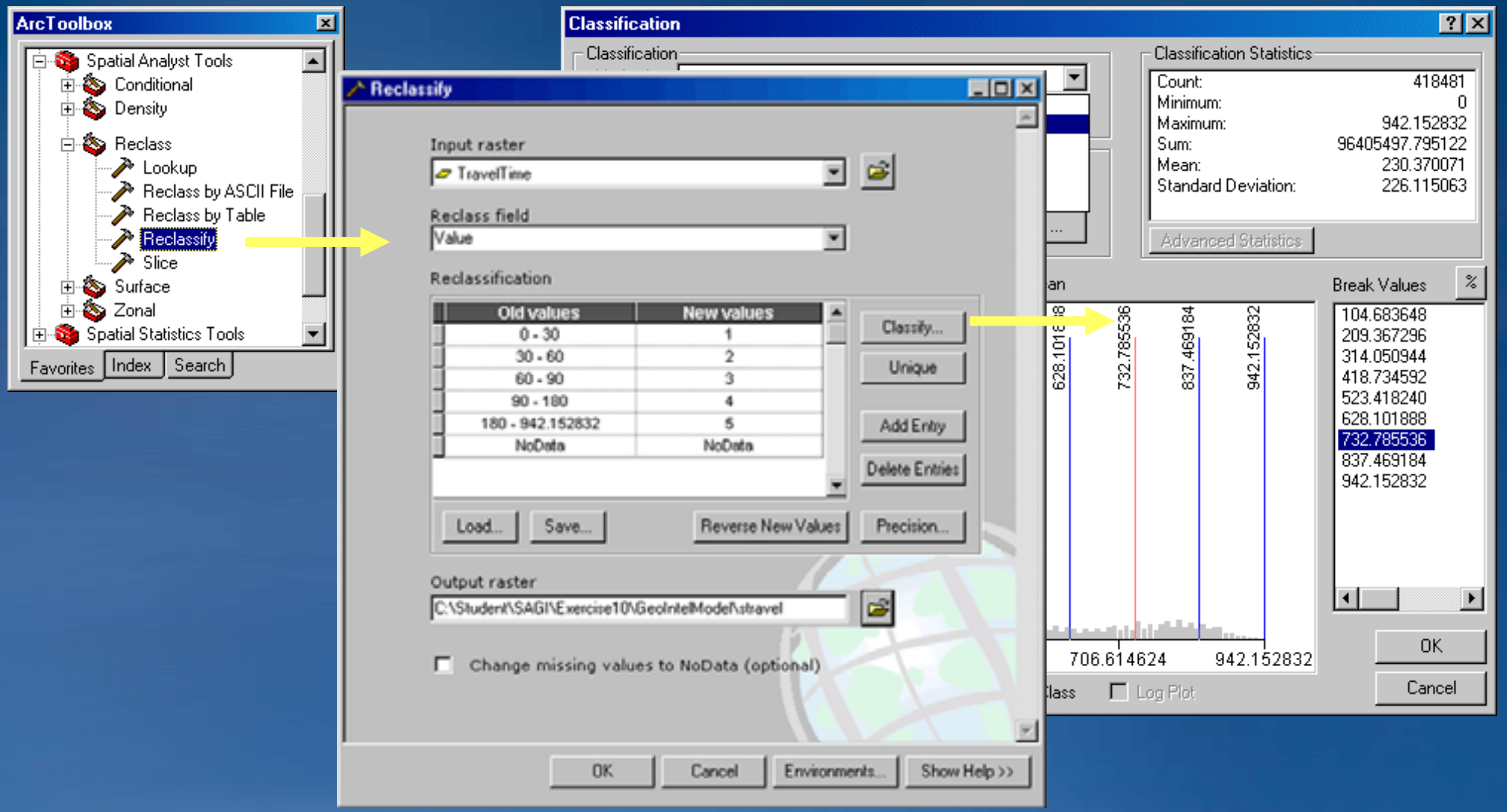
Suitability: Factors that influence models

- **Scale of suitability**
  - Use the same scale for all layers
  - Map values using the scale
- **Model calibration**
  - Tune to produce accurate results
  - Three main sources of error
    - Omitting important layers
    - Incorrect methods
    - Errors in weights
- **Sensitivity analysis**
  - Determine the importance of each layer

	Value priority	
Best	9	High plus
	8	High
	7	High minus
	6	Moderate plus
	5	Moderate
	4	Moderate minus
	3	Low plus
	2	Low
Worst	1	Low minus

Reclassify tool

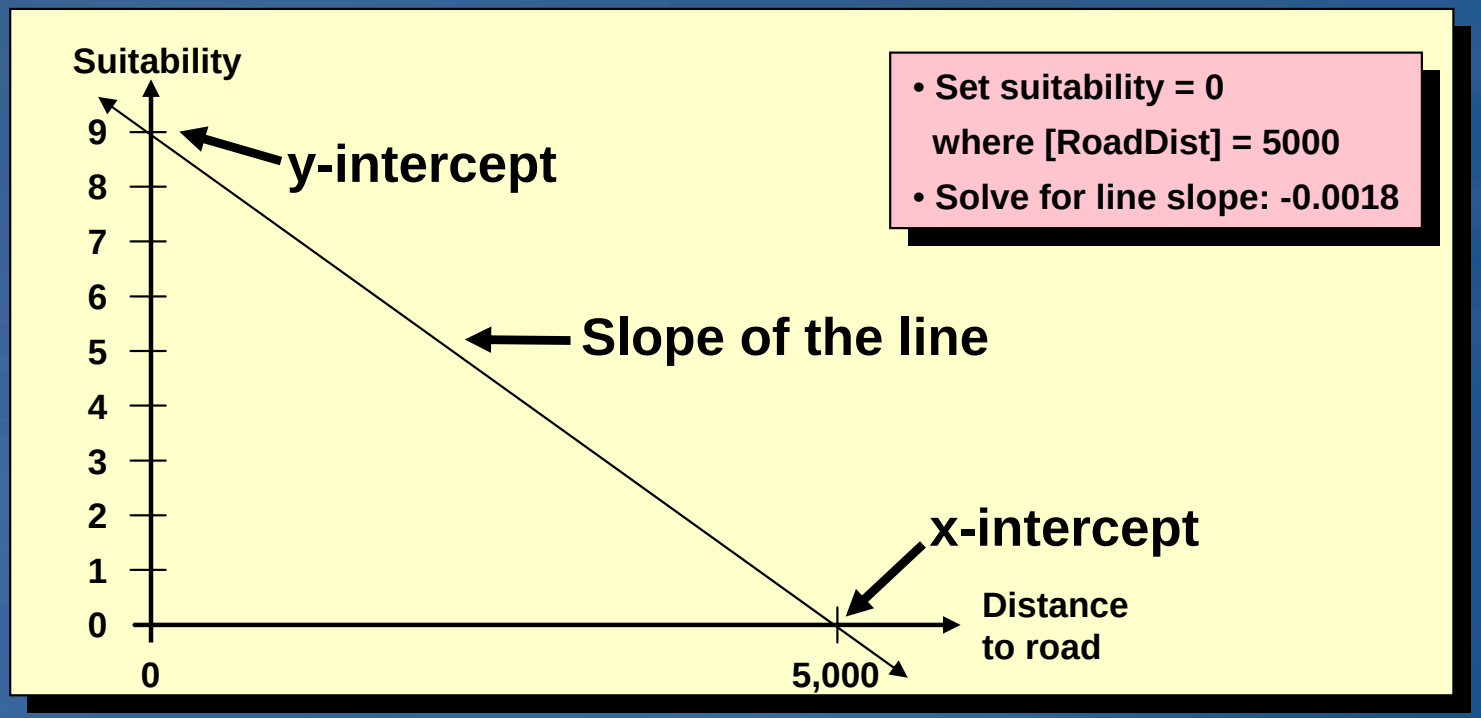
- Can use to convert measures to suitability



Reclassifying with equations

- An option with ratio data
  - Need a mathematical relationship between data and suitability

Example: Suitability decreases with distance to roads

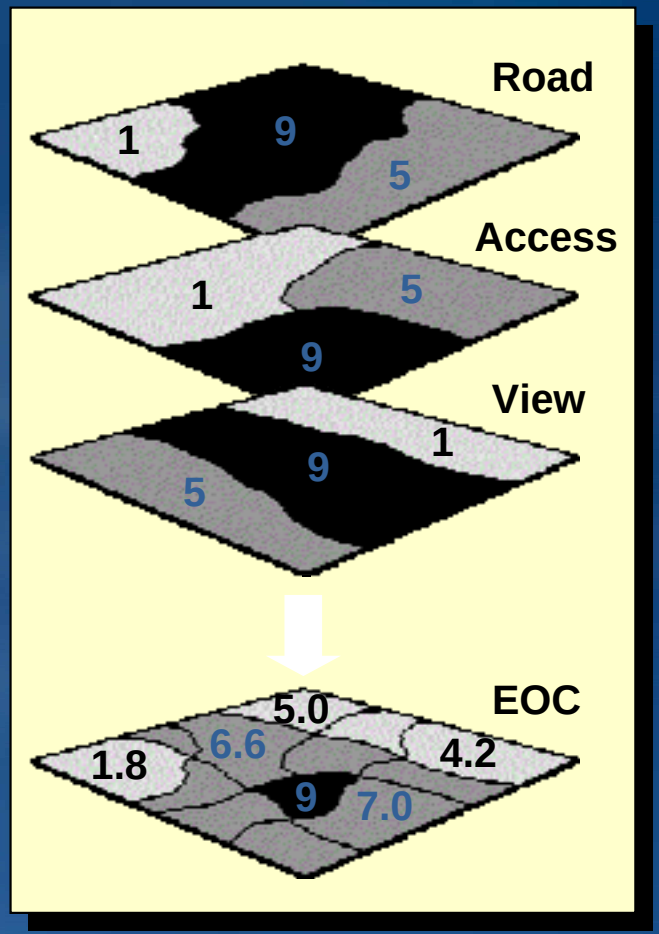


Implement with Map Algebra or a model:

```
RoadSuit = 9 + ( -0.0018 * RoadDist )
```

Weighting and combining the layers

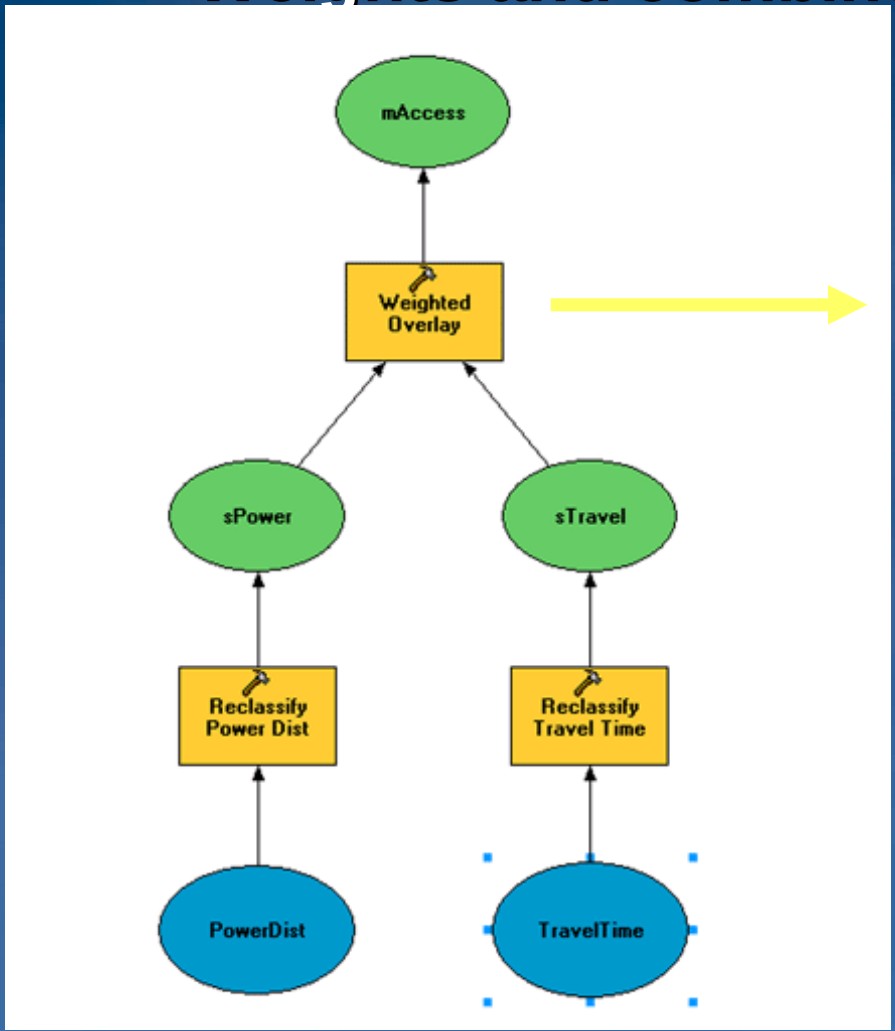
- For each submodel
  - Multiply suitability layers by weights
    - Weights must add up to one
  - Add the weighted layers together
- Repeat to combine submodels
- Uses one Map Algebra expression per submodel
- Use the Weighted Overlay tool

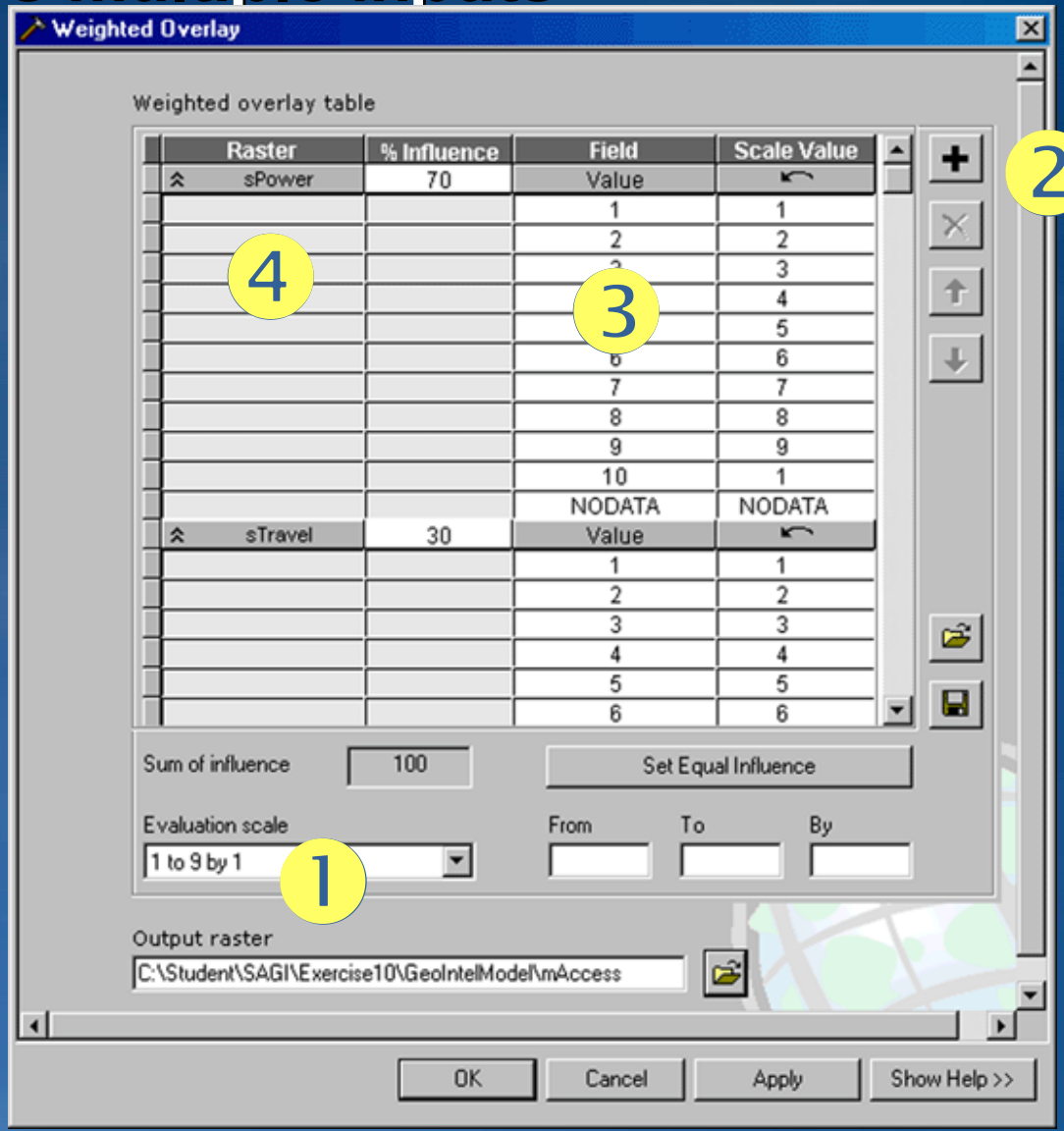



```
EOC = (Road * .5) + (Access * .3) + (View * .2)
```

Weighted Overlay tool

- Weights and combines multiple inputs





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Questions

Thank you !!