Raster Analysis

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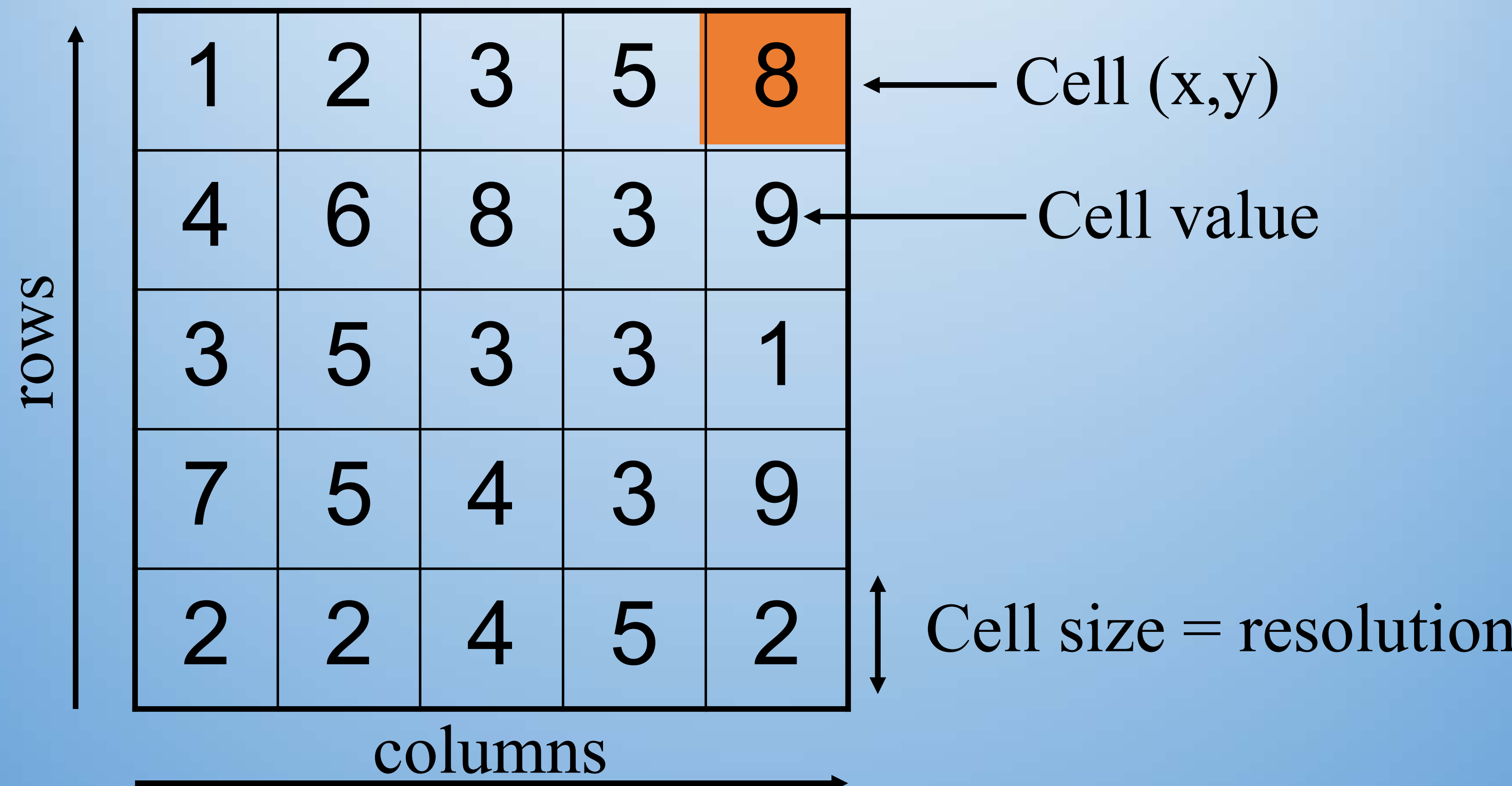
A few synonyms for raster

- Surface
- GRID – the ArcInfo raster type
- Image (generic) – usually relates to satellite imagery
- Image (.img) – Raster data structure used by Erdas Imagine, a common image-processing software package
- Array – more technical term associated with how raster data are managed by computer programmers
- Matrix – rarely used because of it's association with mathematics, but it does occasionally come up

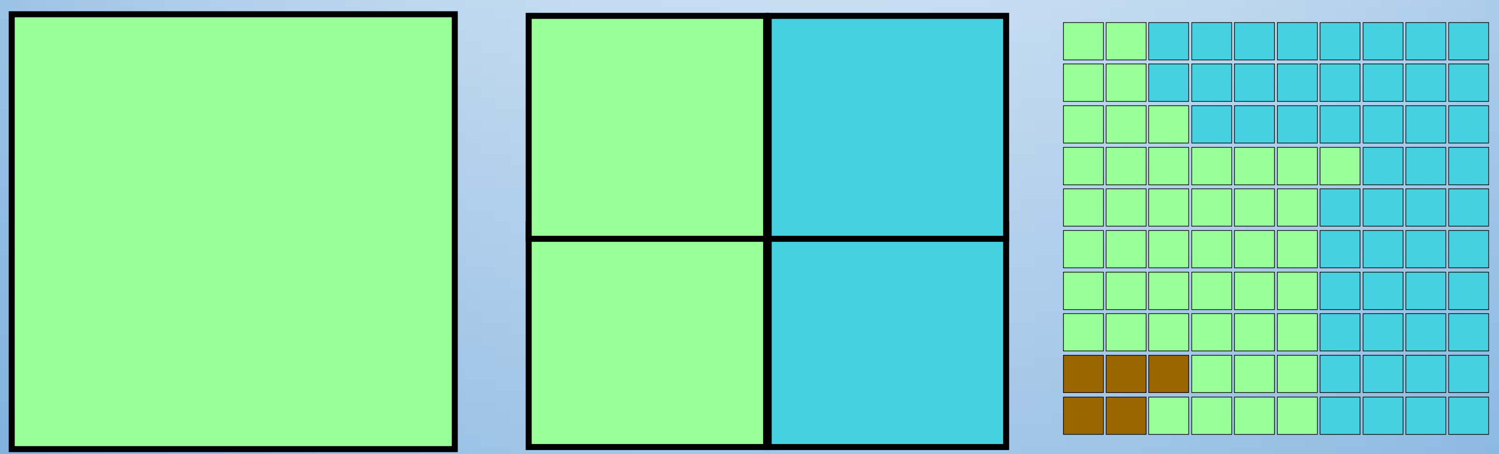
Raster Data Model

- The raster data model represents the Earth's surface as an **array** of two-dimensional grid cells, with each cell having an associated value:



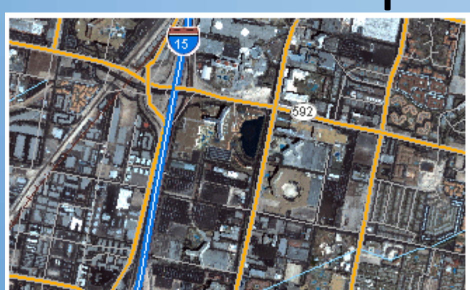
Cell Size & Resolution

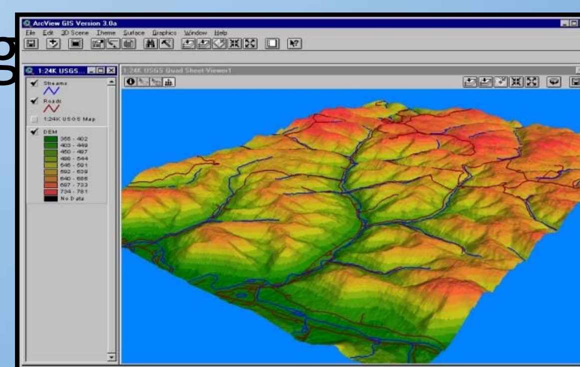
- The size of the cells in the raster data model determines the resolution at which features can be represented
- The resolution can have an effect on which features are represented in what locations:



10 m Resolution 5 m Resolution 1 m Resolution

- Raster GIS is often used because:
  - Raster is better suited for spatially continuous data like elevations
  - Raster is better for creating visualizations and modeling environmental phenomena
  - Other continuous data may include: air pressure, temperature, salinity, etc..
  - Raster data is a simplified realization of the world, and allows for fast and efficient processing
- A raster GIS perf…ing
  …on





Examples of Raster Analysis

- Predict fate of pollutants in the atmosphere
- The spread of disease
- Animal migrations
- Crop yields
- EPA - hazard analysis of urban superfund sites
- Market analysis
- Watershed analysis
- Terrain analysis

How Raster Analysis done?

Raster analytical functions are performed in a number of different ways:

- The Spatial Analyst toolbar
- ArcToolbox tools
- Scripting
- Command line

Types of Raster Analysis

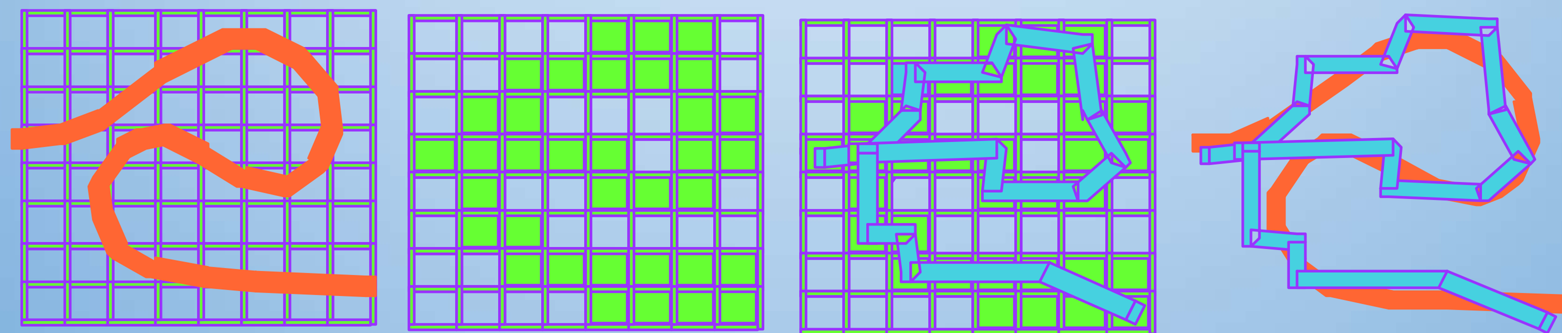
- Math
- Distance
- Surface analysis
- Extraction
- Change cell values
- Statistical Analysis
- Conditional
- Weighted overlay

Raster Data Model - Storage

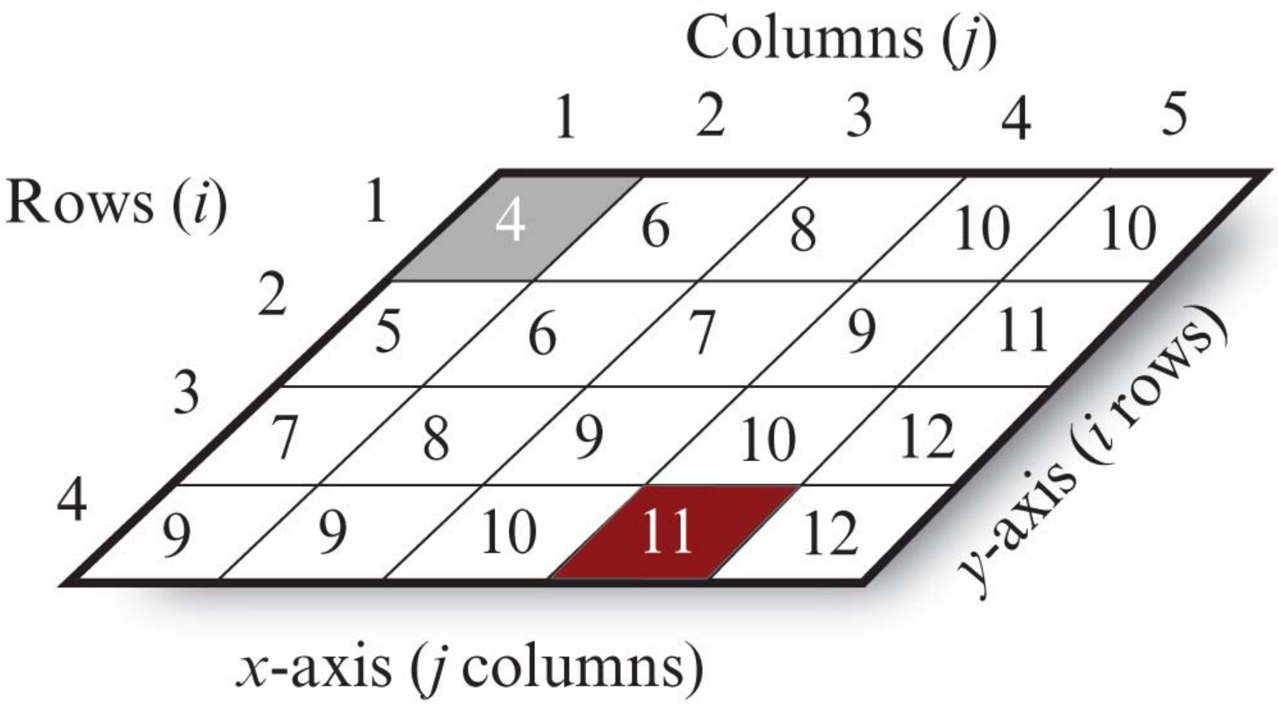
- There is a **trade-off** between **spatial resolution** and **data storage** when we use the raster data model, e.g.
  - 60 km satellite image with 10m cell size
    - 6000 X 6000 = 36,000,000 cells
    - 1 byte of attribute value (i.e. values 0-255)
    - ~36 MB of disk storage!
  - 60 km satellite image with 100m cell size
    - 600 x 600 = 360,000 cells
    - 360 KB of data… **1%** the size of the other one

Vector to Raster Transformations

- Quite often, data in the **vector and raster** models need to be **used together**
- One dataset is generally **transformed** to be represented in the other model, introducing **distortion.**



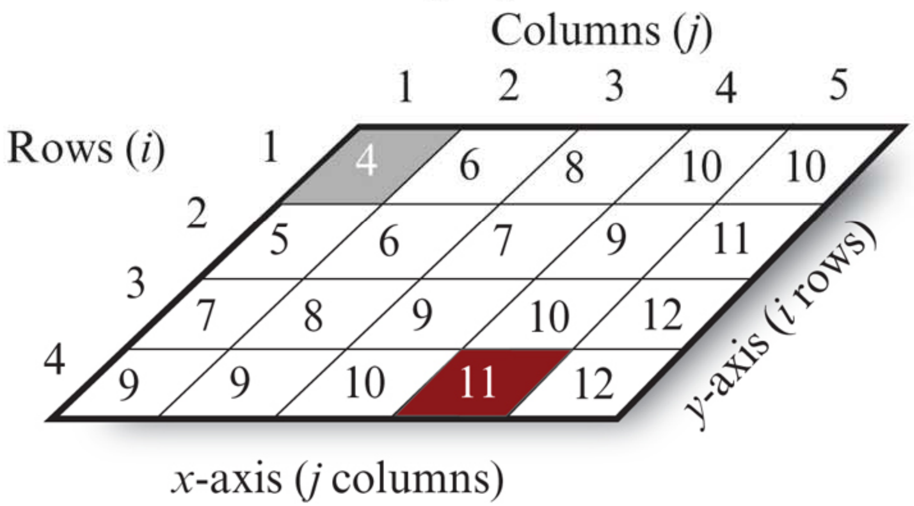
Display of Raster Data



Cell (pixel) at location row 1, column 1 has a value of 4, i.e., $C_{1,1} = 4$.

a.

Display of Raster Data



Cell (pixel) at location row 1, column 1 has a value of 4, i.e., $C_{1,1} = 4$.

a.

Black-and-white continuous-tone look-up table

	R	G	B	
0	0	0	0	**Black**
1	1	1	1	
2	2	2	2	
3	3	3	3	
4	4	4	4	
•				
127	127	127	127	**Mid-gray**
•				
•				
•				
•				
255	255	255	255	**White**

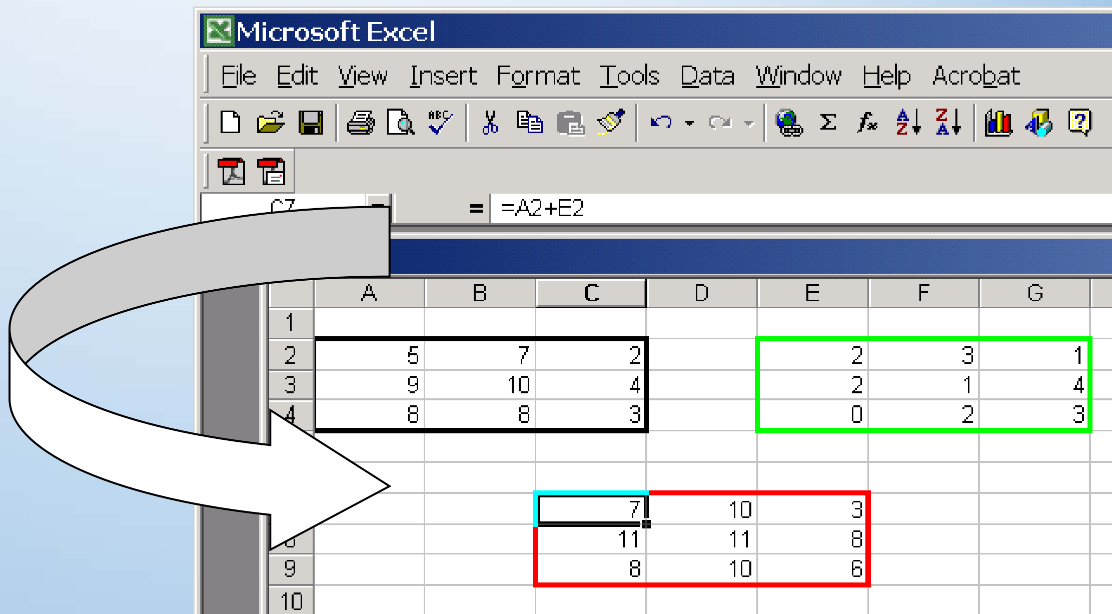
b.

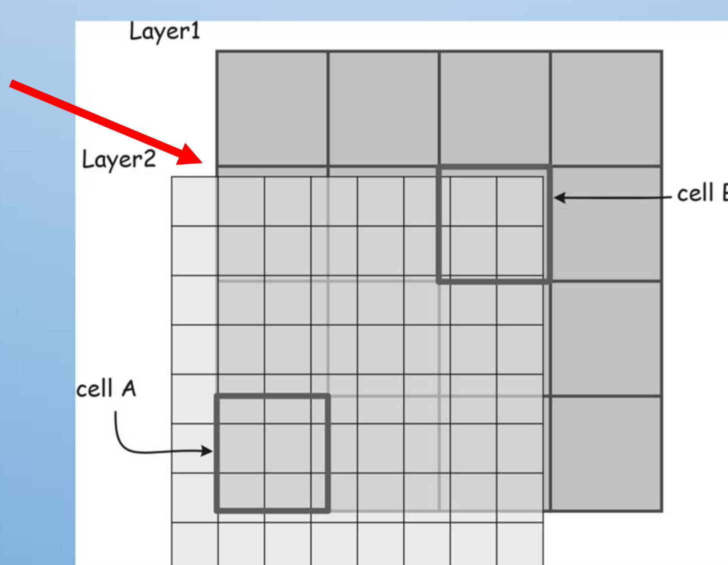
User-specified color look-up table

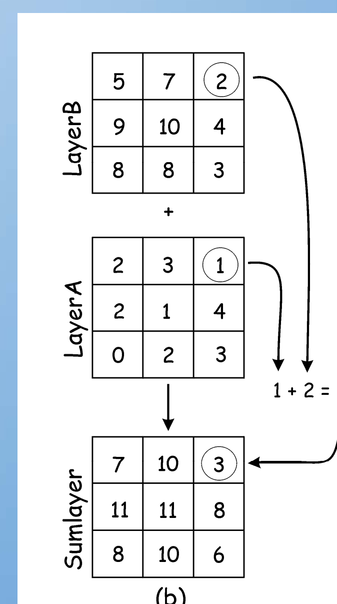
	R	G	B
1	175	240	233
2	176	245	188
3	220	250	177
4	210	232	137
5	82	184	59
6	5	133	58
7	100	148	52
8	186	171	34
9	240	157	2
10	189	70	2
11	140	11	1
12	115	23	5

c.

- Map algebra and raster GIS is quite simple to visualize in a spread sheet. An example of multiplication and addition
- The use of arrays make map algebra and raster GIS very computationally efficient
- But, be careful of:
  - Layers that are not coincident
  - Different cell sizes



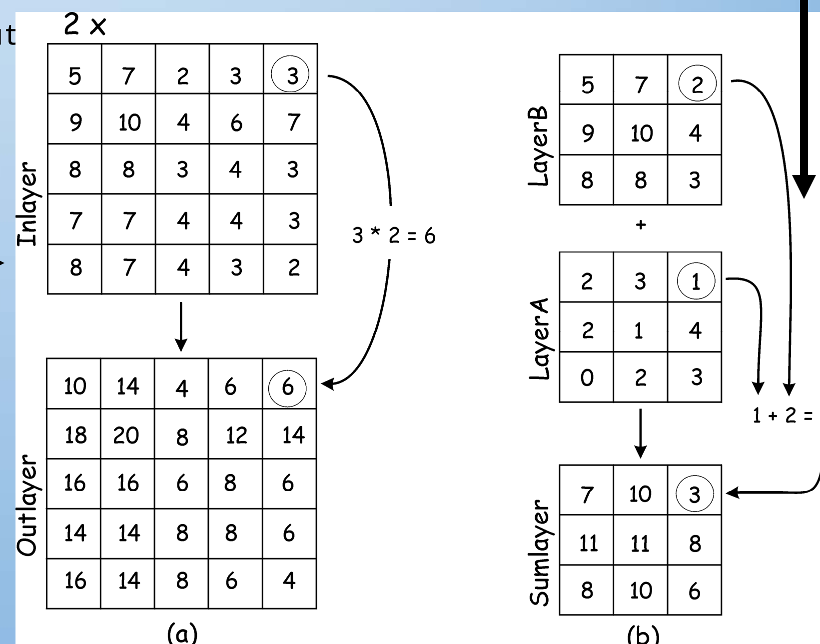




Map Algebra

- Map algebra is a cell by cell combination of raster layers using mathematical operations
- Basic Mathematical Operations
  - Addition, subtraction, division, max, min, virtually any mathematical operation you would find in an Excel spreadsheet
- Strong analytical functions

- Some Map Algebra Commands in ARC/INFO
- `Outgrid = grid1 + grid2`
- `Outgrid = grid1 * 2`
- `Outgrid = sin(grid1)`
- `Outgrid = costallocation(sourcegrid, costgrid, accumgrid, backgrid)`
- `Outgrid = con(>5 (ingrid1),0,ingrid1)`
- `Out`



Logical Operations: AND

Non-zero values are “true”, zero values are “false”
N = null values

Input

1	3	1	1
0	N	2	-1
1	2	5	0
0	1	N	N

AND

0	1	0	9
0	5	2	5
0	2	N	2
0	-3	4	8

=

Output

0	1	0	1
0	N	1	1
0	1	N	0
0	1	N	N

Logical Operations: OR

Non-zero values are “true”, zero values are “false”
N = null values

1	3	1	1
0	N	2	-1
1	2	5	0
0	1	N	N

OR

0	1	0	9
0	5	2	5
0	2	N	2
0	-3	4	8

=

1	1	1	1
0	N	1	1
1	1	N	1
0	1	N	N

Logical Operations: NOT

NOT

1	3	1	1
0	N	2	-1
1	2	5	0
0	1	N	N

=

0	0	0	0
1	N	0	0
0	0	0	1
1	0	N	N

More Local Functions – logical comparisons

a)

Input

1	3	1	1
0	N	2	-1
1	2	5	0
0	1	N	N

less than

0	1	0	9
0	5	2	5
0	2	N	2
0	-3	4	8

=

Output

0	0	0	1
0	N	0	1
0	0	N	1
0	0	N	N

b)

1	3	1	1
0	N	2	-1
1	2	5	0
0	1	N	N

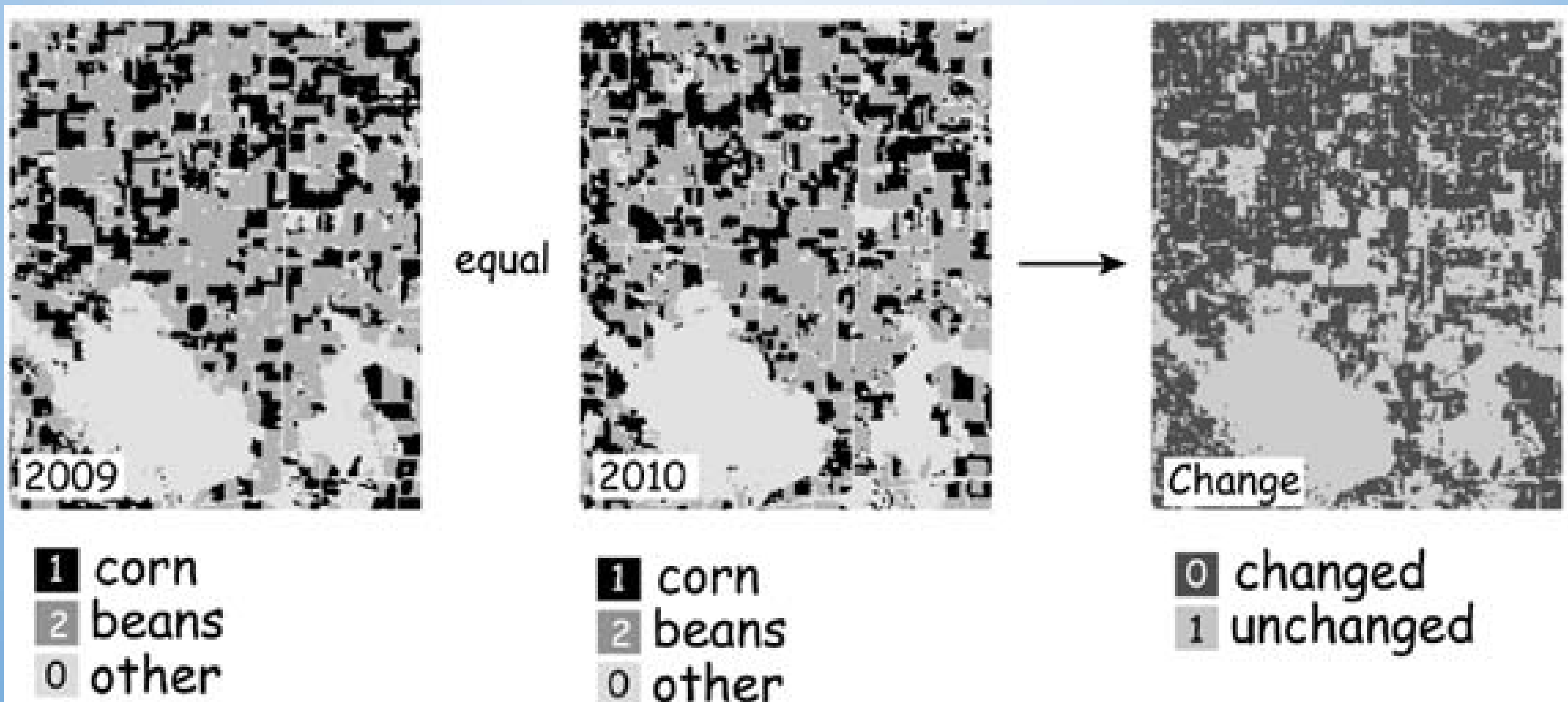
equal

0	1	0	9
0	5	2	5
0	2	N	2
0	-3	4	8

=

0	0	0	0
1	N	1	0
0	1	N	0
1	0	N	N

An Example of a Logical Operation



Reclassification

a)

Input

1	3	1	1
0	N	2	-1
1	2	5	0
0	1	N	N

Reclass by table

in	out
0	a
1	x
2	b
3	f
4	c
5	s

=

Output

x	f	x	x
a	N	b	N
x	b	s	a
a	x	N	N

b)

1	3	1	1
0	N	2	-1
1	2	5	0
0	1	N	N

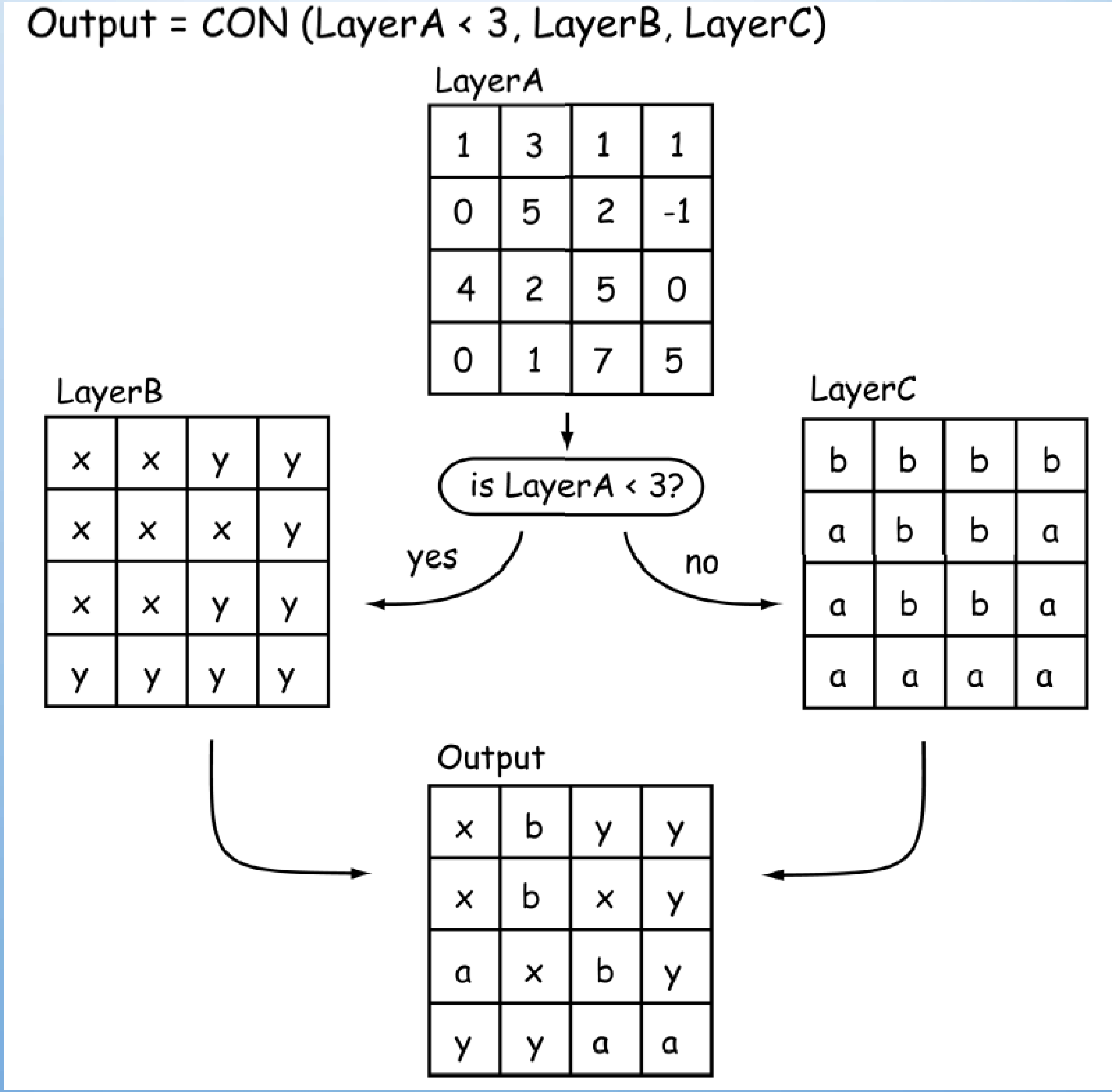
Reclass by ranges

in range	out
0 to 1.5	a
1.5 to 3.5	b
3.5 to 10	c
N	d

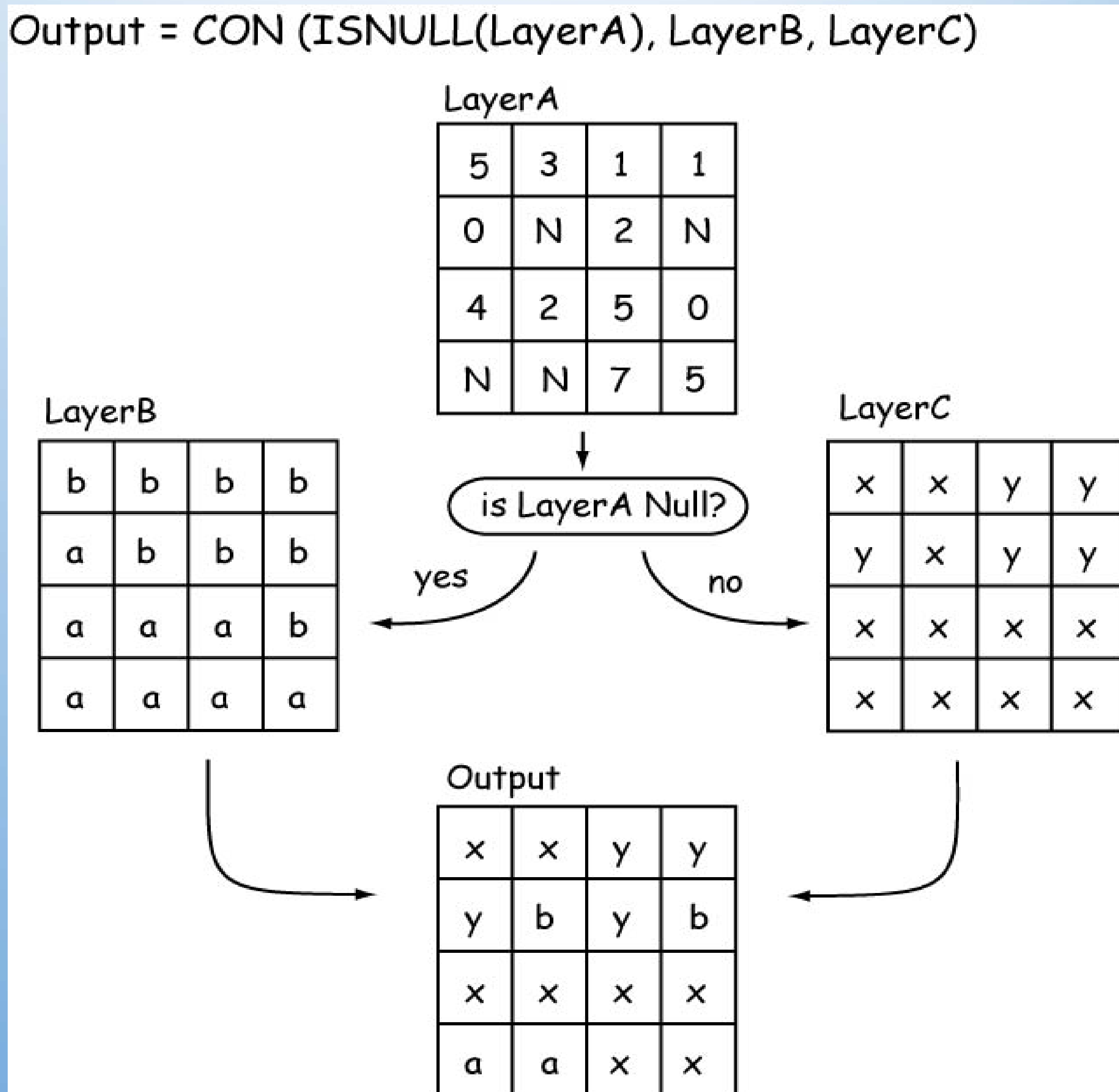
=

a	b	a	a
a	d	b	N
a	b	c	a
a	b	d	d

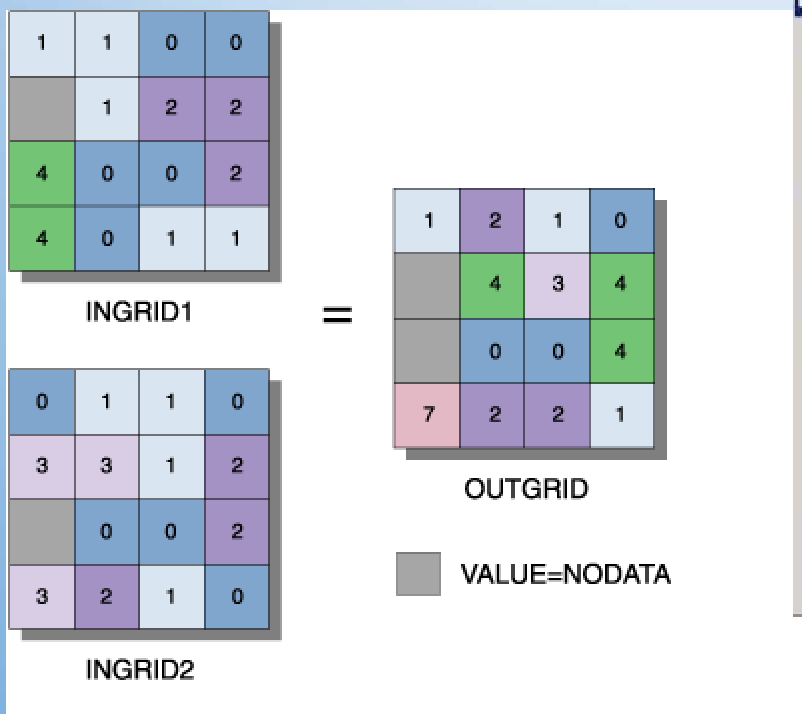
Conditional Function



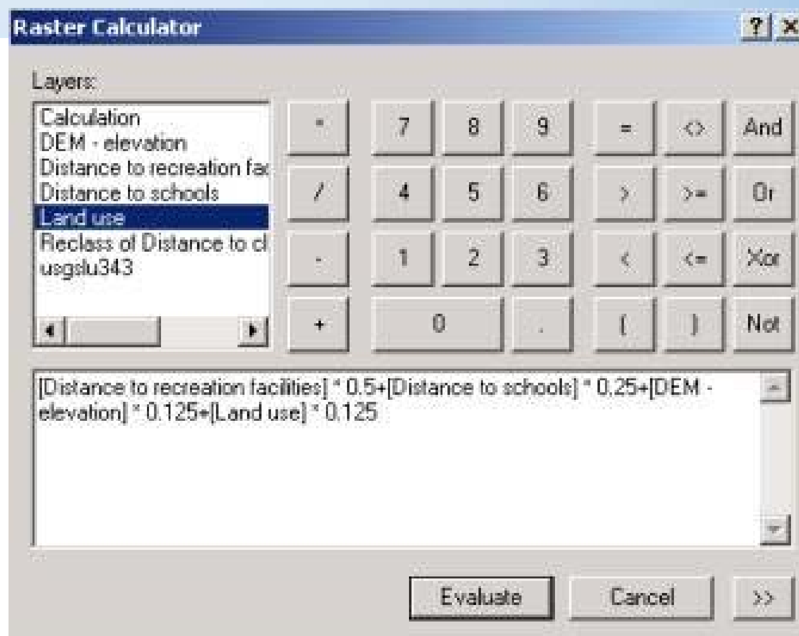
Nested Functions



Raster Calculator



Expression:
OUTGRID = INGRID1 + INGRID2



Raster Operations

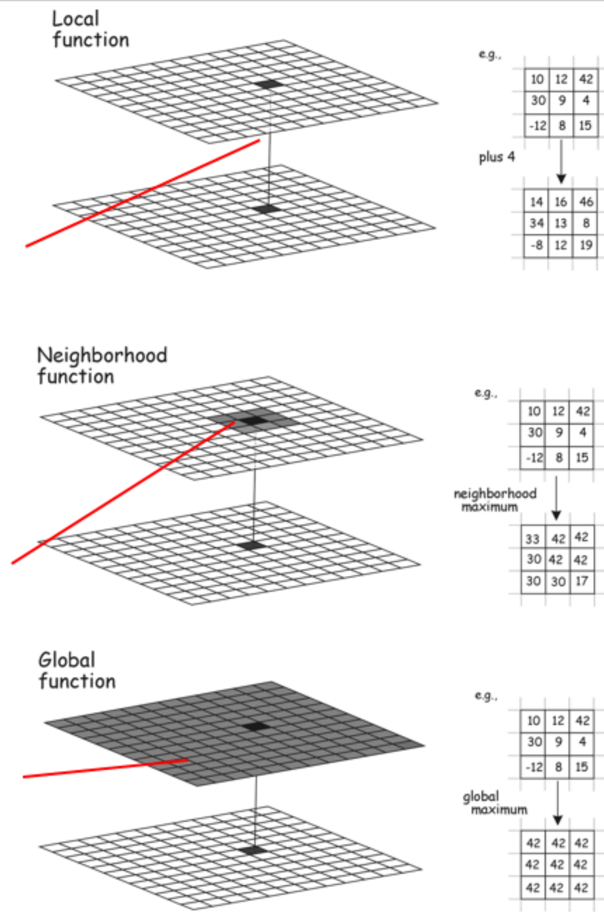
Raster Operations

Raster operations can be local, neighborhood (focal), zonal, or global

***Local*: Operate on individual cells, one-at-a-time, relative to the ones directly "below"; e.g., add layers together or subtract a number from each cell**

***Neighborhood (focal)*: "Moving window" operates on a cell, considering its immediate neighbors**

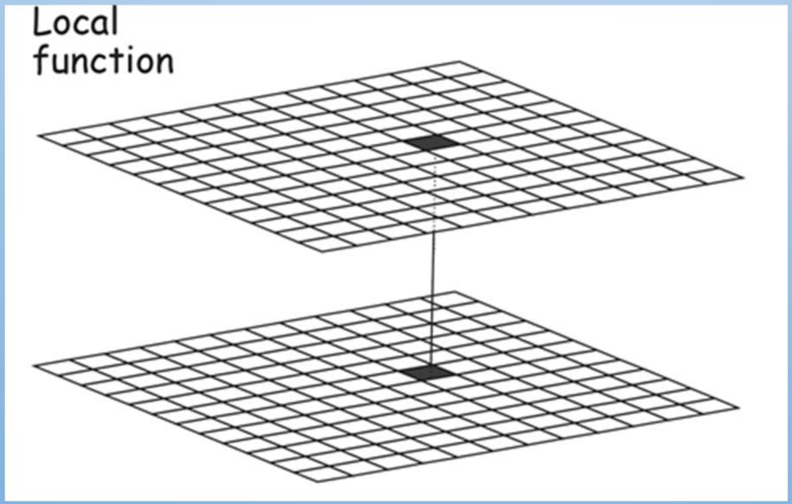
***Global*: Operate the same on all cells; e.g., calculate all cells to the maximum value in the map**



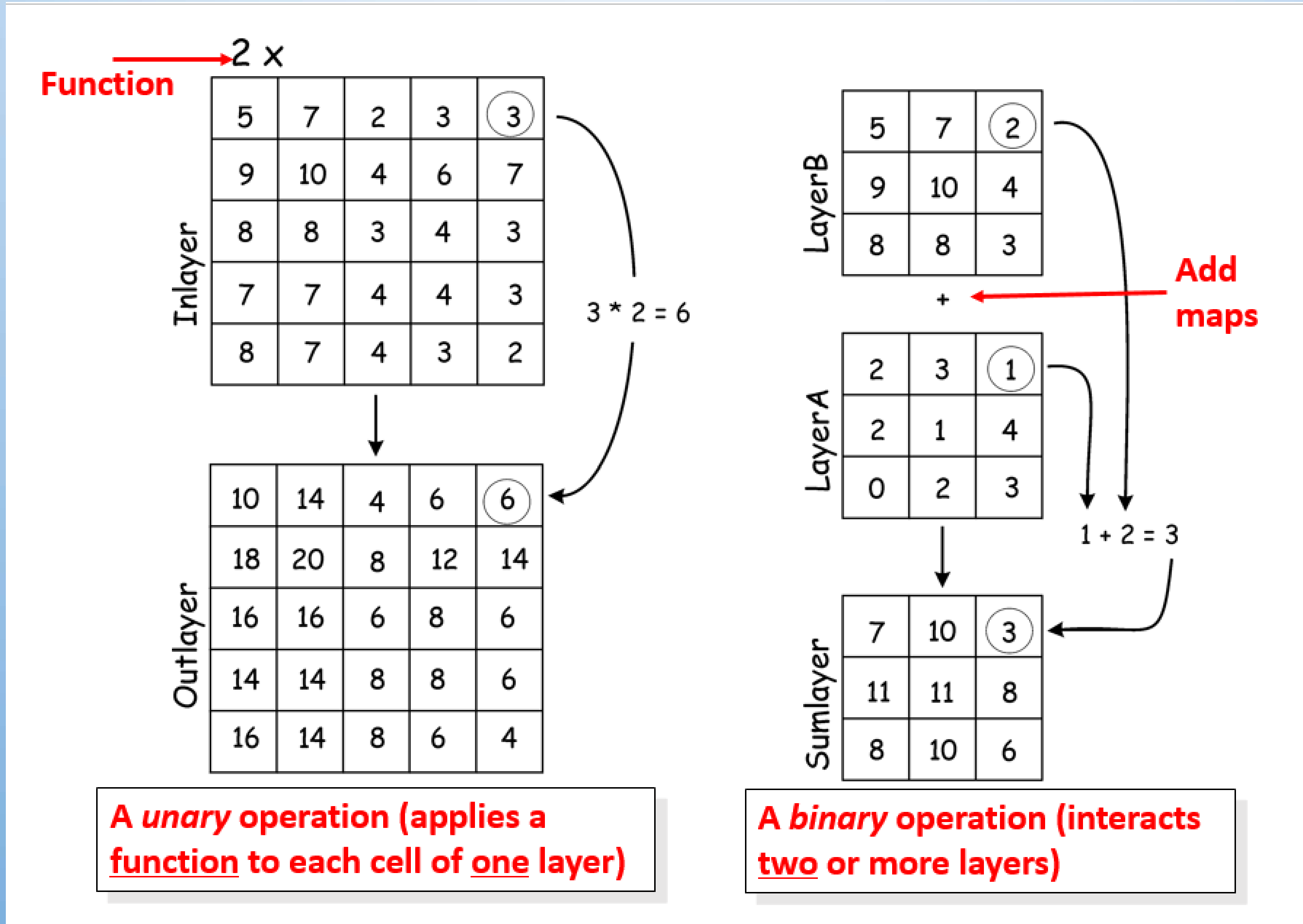
Local Operations

- Work on single cells, one after another, value assigned to a cell depends on this cell only

- Examples:
  - arithmetic operations with a constant, or with another grid
  - also logical operations, comparisons (min, max, majority, minority, variety, etc.) – same location but different layers
  - Reclassification



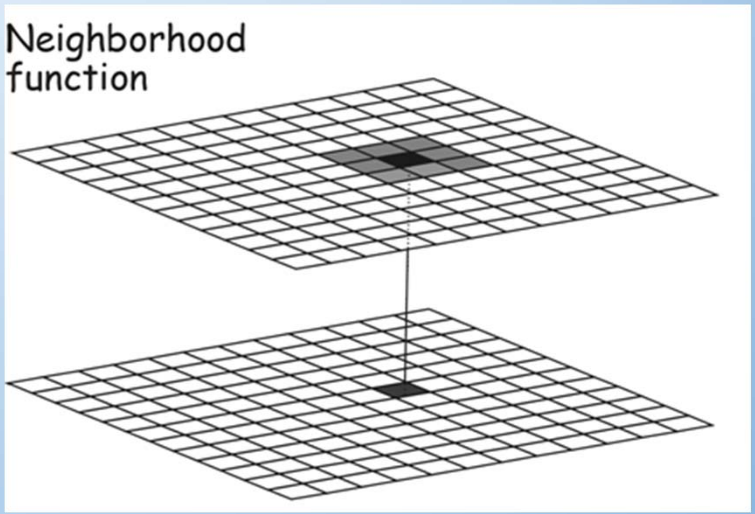
Local Operations



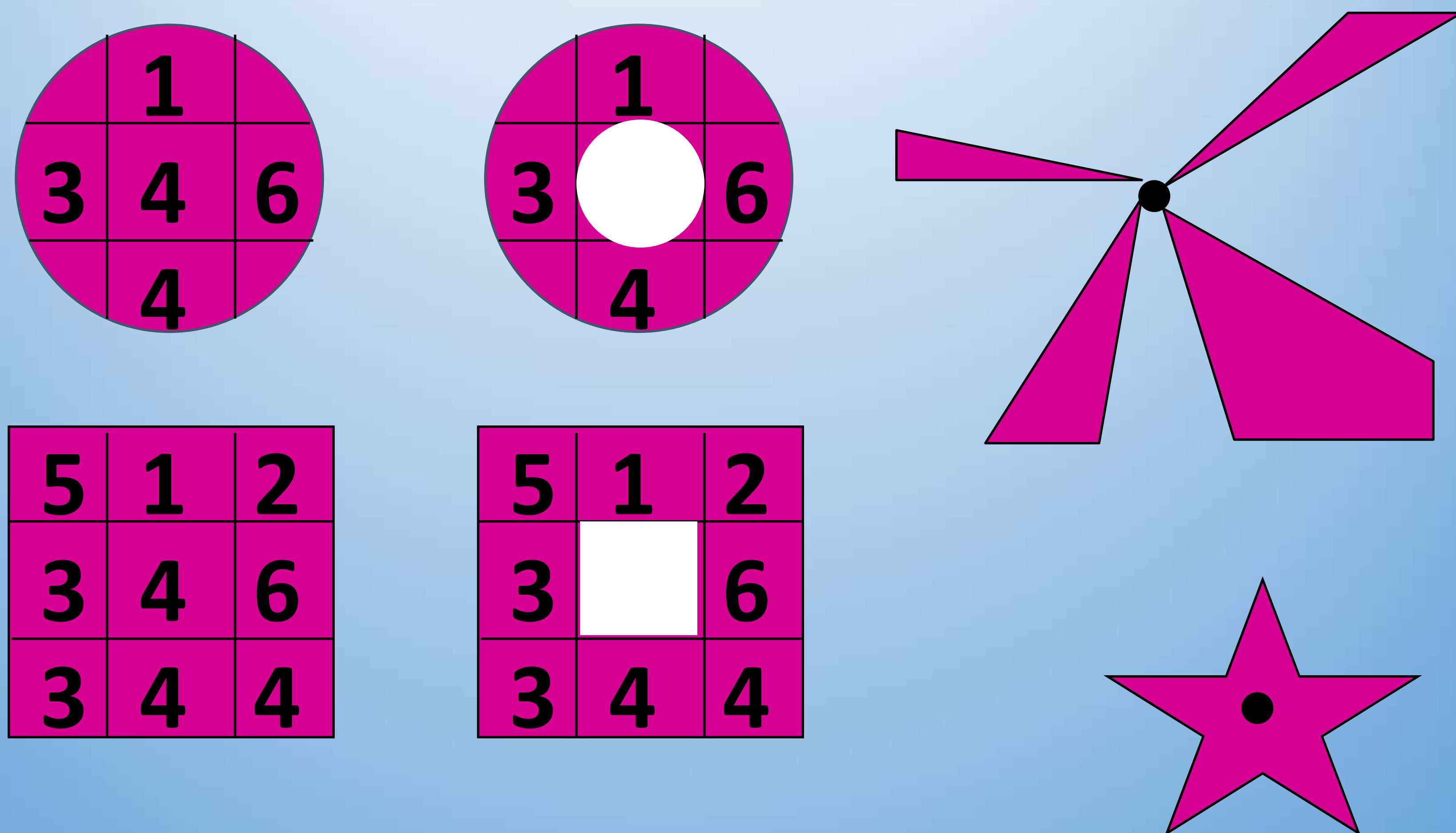
Focal Operations

- Assign data value to a cell based on its neighborhood (variously defined)

- Neighborhood: a set of locations each of which bears a specified distance and/or directional relationship to a particular location called the neighborhood focus (D. Tomlin)
    - distance and directional neighbors
    - immediate and extended neighbors
    - metric and topological neighbors
    - neighbors of points, lines, areas...



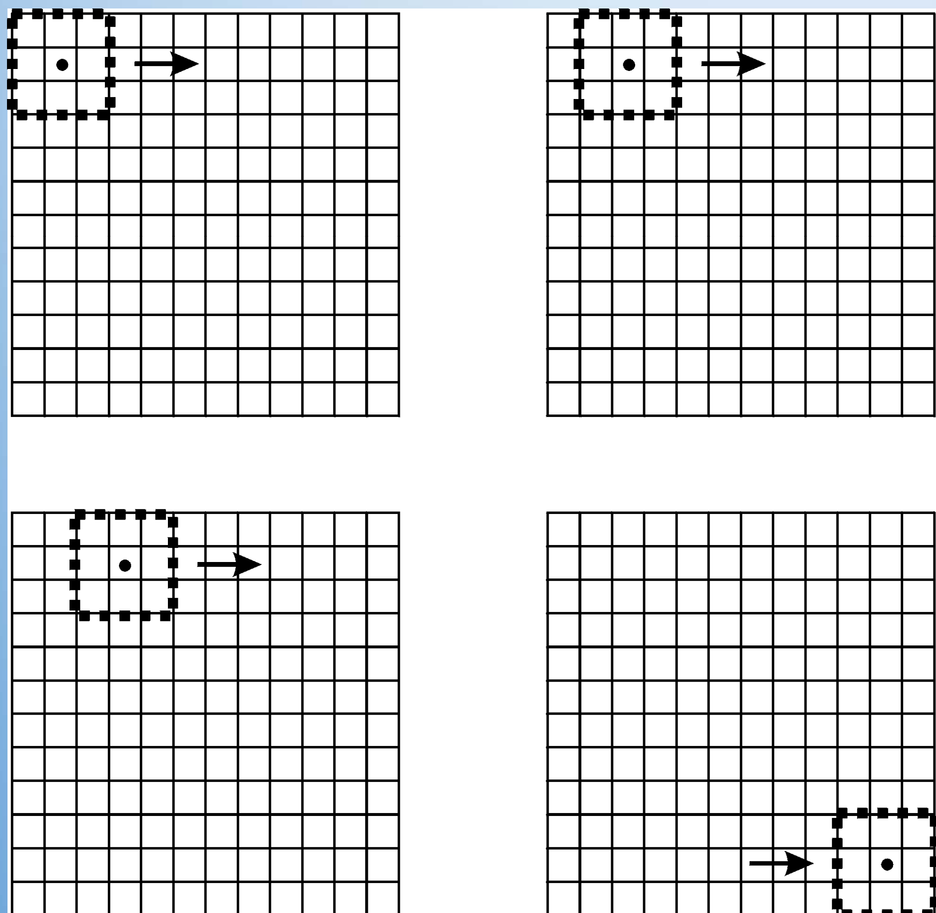
Define Neighborhoods: Shapes



Neighborhood Statistics in Spatial Analyst

- shape of neighborhood: | Circle | Rectangle | Doughnut | Wedge | Star
- size of neighborhood: radius (circle), inner and outer radius (doughnut), radius, start and end angles (wedge), width and height (rectangle)
- Operation: | Minimum | Maximum | | Mean | Median | Sum | Range | Standard Dev. | Majority | Minority | Variety |

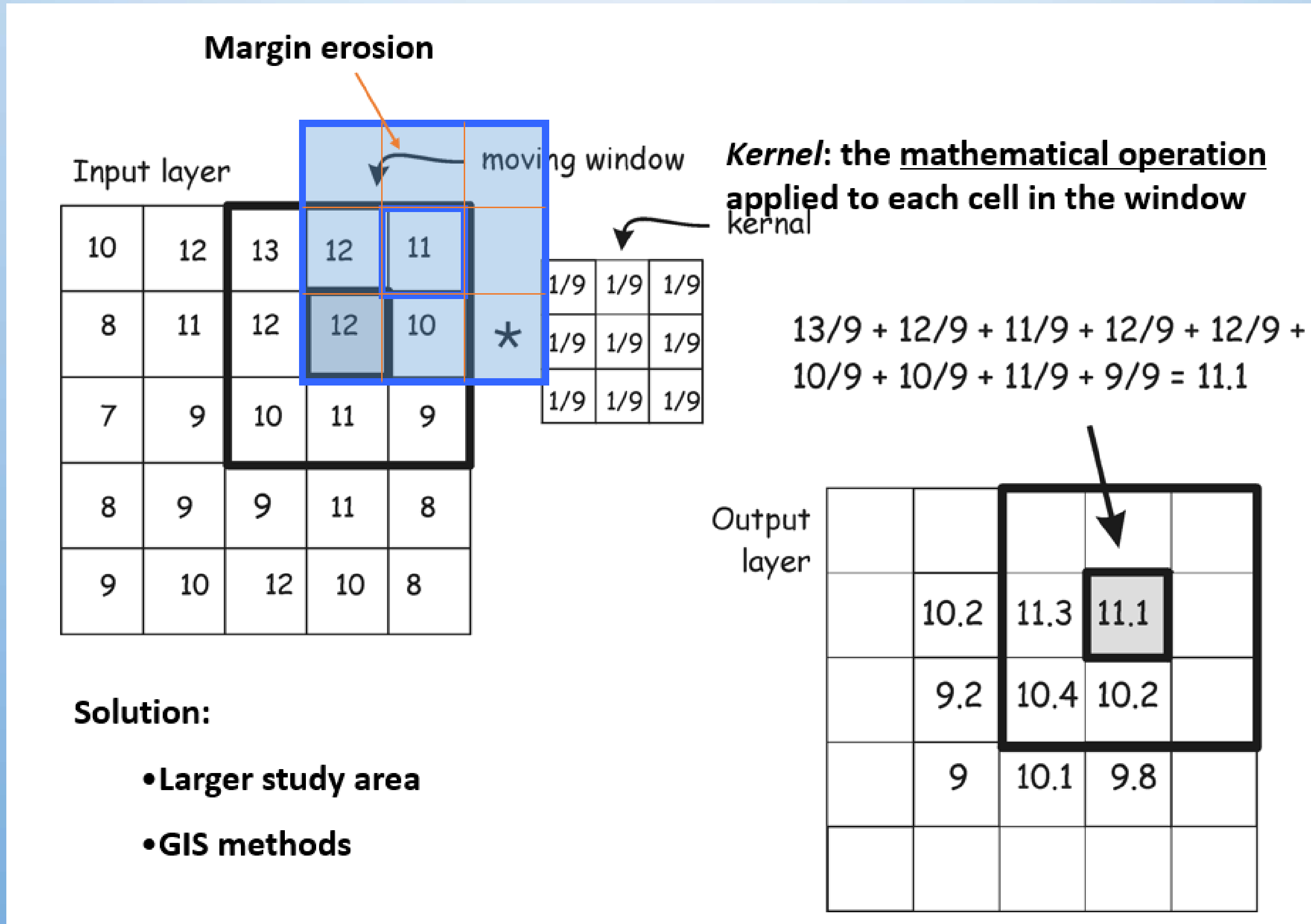
Define Neighborhood: Moving Window



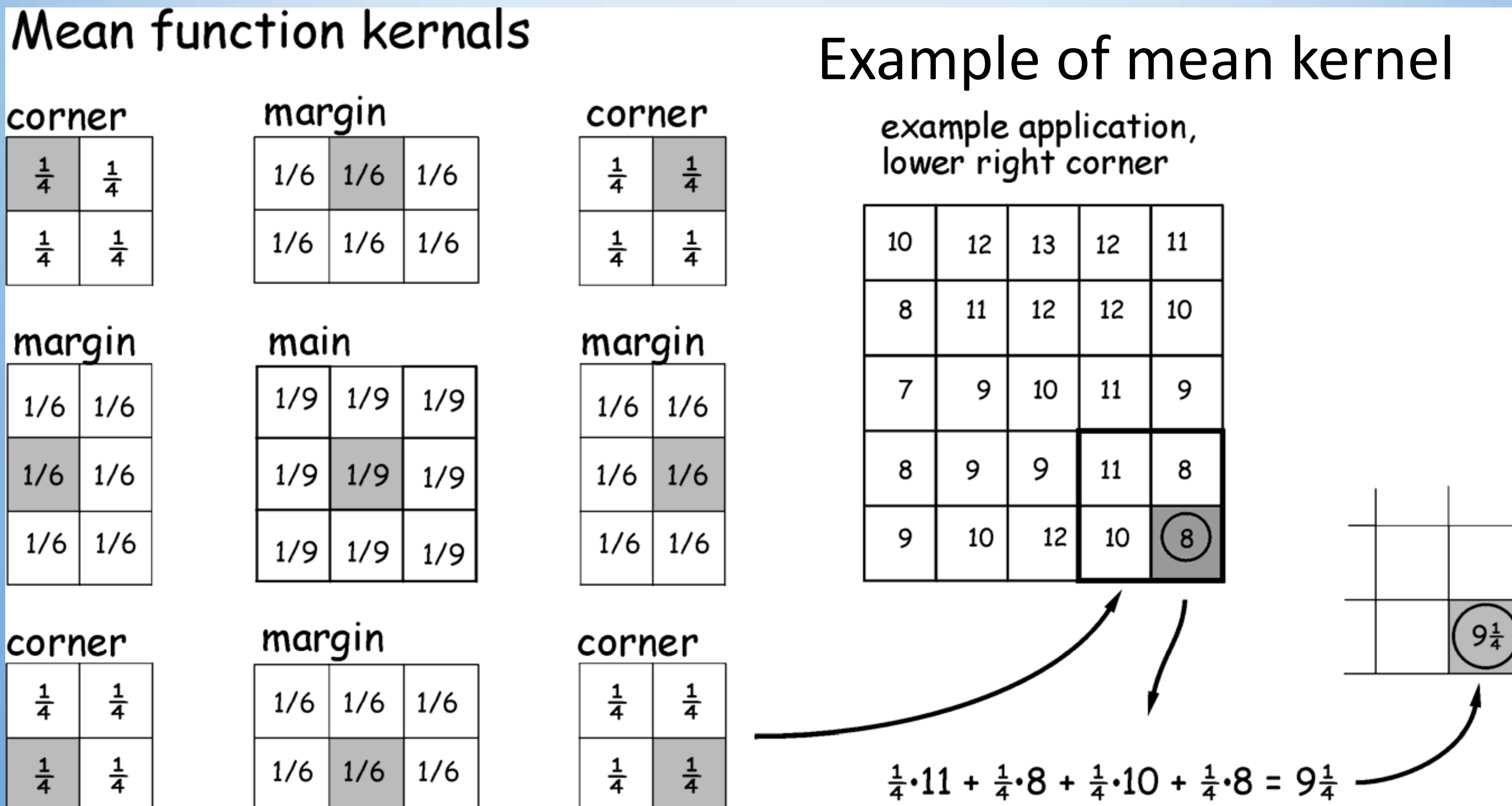
Moving Window:

A "window": cells used to specify the input values for an operation.

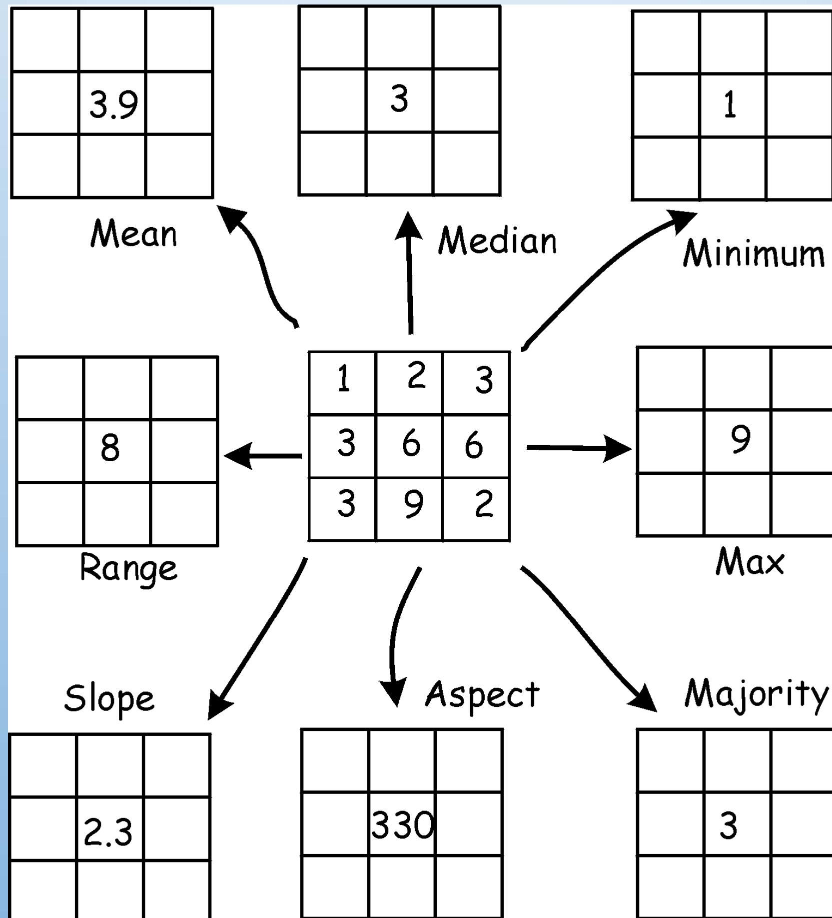
Focal Operations



GIS Solution to Margin Erosion



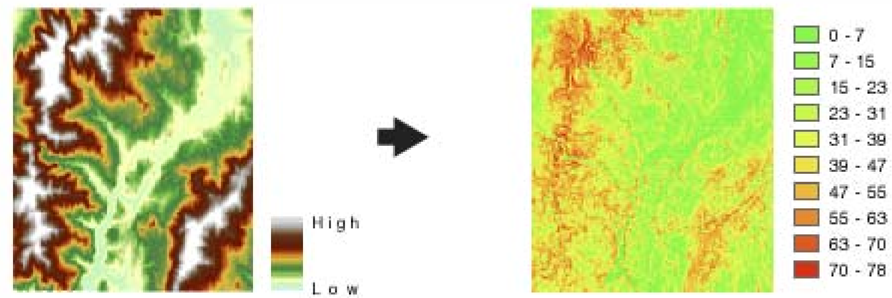
Neighborhood Operations



Slope

a	b	c
d	e	f
g	h	i

Surface scanning window



Input elevation raster

Output slope raster (in degrees)

The slope algorithm can also be interpreted as:

```
slope_degrees = ATAN (rise_run) * 57.29578
```

- where:

```
rise_run = √ ([dz/dx]² + [dz/dy]²]
```

The rate of change in the x direction for cell *e* is calculated with the following algorithm:

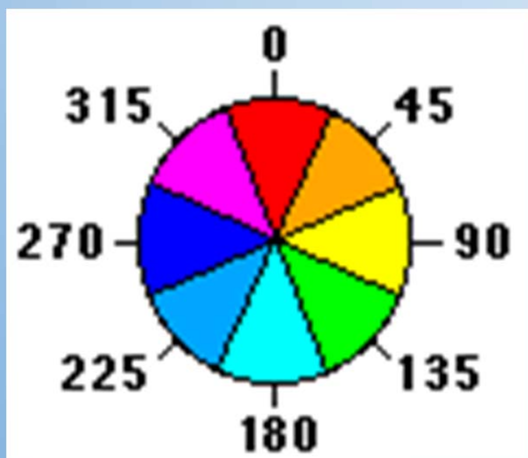
```
[dz/dx] = ((c + 2f + i) - (a + 2d + g) / (8 * x_cellsize)
```

The rate of change in the y direction for cell *e* is calculated with the following algorithm:

```
[dz/dy] = ((g + 2h + i) - (a + 2b + c)) / (8 * y_cellsize)
```

Aspect

- Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors.



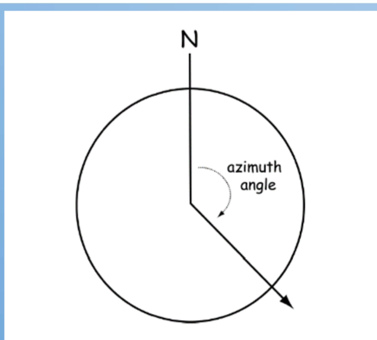
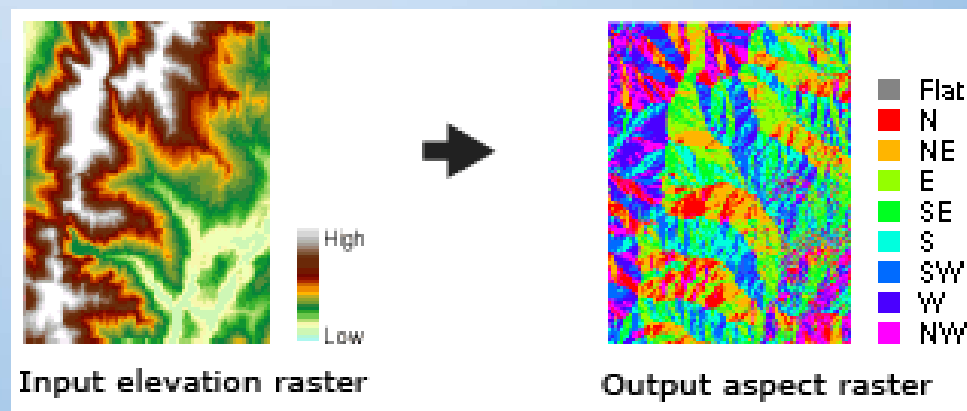


Figure 11-7: Aspect may be reported as an azimuth angle, measured clockwise in degrees from north.



Neighborhood Operations

- smoothing - moving averaging
- edge detection
- Grade (slope)
- Orient (aspect)
- Profile
- High pass filter
- assessing variety, etc.

Noise Highlight (high-pass filter)

Input Layer with "noise"

1065	1068	929	864	960	1113	974	896	890	841	759	719	705	696	720	708
1038	963	947	950	999	1021	1011	1015	995	1044	870	773	734	703	676	684
1142	1005	1151	310	1117	1056	1007	1002	902	954	935	913	789	756	724	700
1116	1114	1270	1165	1097	1025	922	917	821	829	860	838	807	810	758	760
1275	1170	1295	1114	1009	942	953	847	835	729	738	797	723	718	694	670
1441	1263	1196	1055	913	869	829	771	736	765	766	688	694	1676	684	698
1348	2900	1056	969	948	951	940	867	818	863	784	732	704	733	776	804
1377	1238	1122	1019	1089	950	956	896	2000	800	760	698	779	867	896	744
1489	1320	1188	1152	1050	942	922	952	815	841	721	780	852	28	845	738
1432	1415	1196	1100	1001	974	924	911	914	756	809	861	898	830	746	710
1412	1474	1240	1100	1001	982	873	835	829	853	931	937	845	706	685	680
1493	1368	1201	1090	1064	970	902	902	958	952	1015	841	782	803	786	711
1437	1407	118	1145	1070	1107	982	1047	1077	1052	954	884	44	940	828	771
1349	1369	1267	1247	1194	1196	1077	1214	1145	999	906	894	1024	1046	923	862
1319	1292	1378	1400	1367	1276	1162	1088	961	930	872	985	1010	1178	1148	1000

spikes ■ pits □

kernal for high-pass filter

$$\frac{1}{9} * \begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

$$\frac{\left(\begin{array}{l} (-1)*1065 + \\ (-1)*1068 + \\ (-1)*924 + \\ (-1)*1038 + \\ (9)*963 + \\ (-1)*947 + \\ (-1)*1142 + \\ (-1)*1005 + \\ (-1)*1151 \end{array} \right)}{9}$$

= 35.7

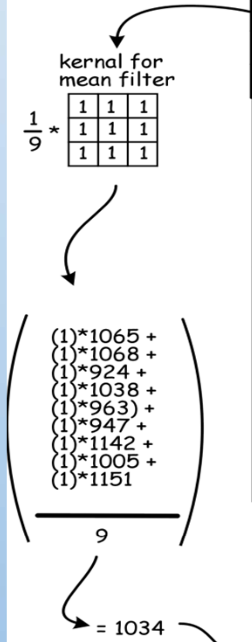
Ouput Layer

35	142	141	177	105	112	162	156	250	99	59	61	58	43
33	292	-657	270	145	121	158	60	147	148	179	85	89	74
66	345	235	237	124	61	107	41	76	111	108	102	146	110
62	256	114	100	95	161	93	122	23	41	117	-58	-43	-59
-35	-7	110	40	37	35	12	14	68	88	28	-59	1039	-69
1784	-140	35	79	118	152	-16	-38	37	109	79	-59	-54	-14
-74	-83	66	202	83	131	-23	1238	-45	69	18	179	243	281
158	125	178	135	68	88	25	-82	-1	20	71	214	-718	227
220	86	108	78	119	102	126	159	10	66	108	249	207	165
278	135	111	80	125	50	33	42	57	150	161	105	-3	21
281	207	207	123	83	46	68	119	99	192	130	115	179	105
340	-1004	228	68	167	47	129	158	162	115	166	-758	247	67
306	227	253	104	169	69	265	215	121	64	151	248	257	59

Noise Reduction (low-pass)

Input Layer with "noise"

1065	1068	929	864	960	1113	974	896	890	841	759	719	705	696	720	708
1038	963	947	950	999	1021	1011	1015	995	1044	870	773	734	703	676	684
1142	1005	1151	310	1117	1056	1007	1002	902	954	935	913	789	756	724	700
1116	1114	1270	1165	1097	1025	922	917	821	829	860	838	807	810	758	760
1275	1170	1295	1114	1009	942	953	847	835	729	738	797	723	718	694	670
1441	1263	1196	1055	913	869	829	771	736	765	766	688	694	1676	684	698
1348	2900	1056	969	948	951	940	867	818	863	784	732	704	733	776	804
1377	1238	1122	1019	1089	950	956	896	2000	800	760	698	779	867	896	744
1489	1320	1188	1152	1050	942	922	952	815	841	721	780	852	28	845	738
1432	1415	1196	1100	1001	974	924	911	914	756	809	861	898	830	746	710
1412	1474	1240	1100	1001	982	873	835	829	853	931	937	845	706	685	680
1493	1368	1201	1090	1064	970	902	902	958	952	1015	841	782	803	786	711
1437	1407	118	1145	1070	1107	982	1047	1077	1052	954	884	44	940	828	771
1349	1369	1267	1247	1194	1196	1077	1214	1145	999	906	894	1024	1046	923	862
1319	1292	1378	1400	1367	1276	1162	1088	961	930	872	985	1010	1178	1148	1000

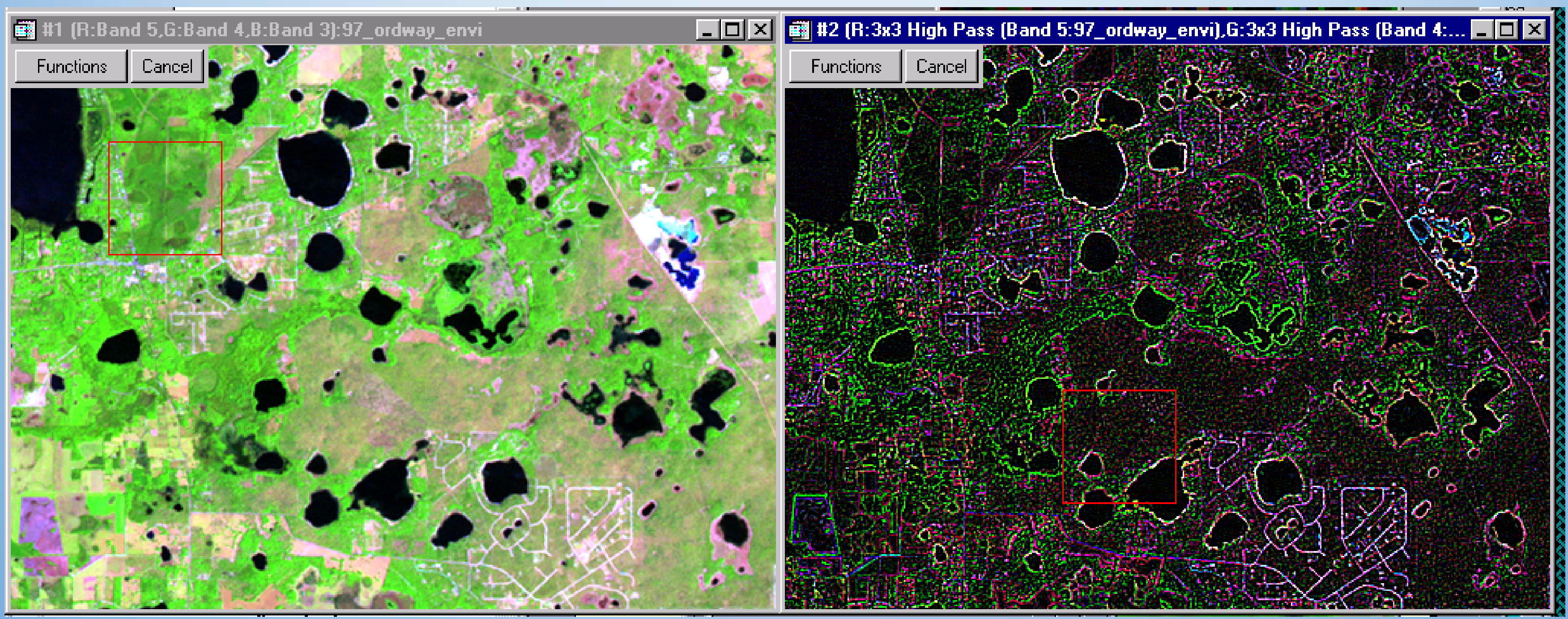


smoothed spike or pit

Ouput Layer

	1034	909	914	932	1028	1010	965	948	910	867	799	754	722	707	
	1082	986	1000	971	1028	997	954	942	912	890	835	791	750	730	
	1170	1066	1058	981	1014	963	911	870	844	843	822	794	753	732	
	1237	1182	1123	1021	951	897	847	805	786	778	767	861	840	829	
	1438	1335	1061	974	928	885	844	803	781	762	736	829	822	828	
	1437	1313	1040	973	938	892	979	946	921	761	733	841	867	875	
	1448	1329	1065	1007	972	930	1018	983	933	775	756	685	720	714	
	1308	1194	1101	1030	978	936	1032	987	935	780	795	732	749	711	
	1351	1242	1114	1033	963	923	886	856	829	832	848	748	715	663	
	1359	1242	1110	1031	965	919	894	878	890	883	879	833	786	739	
	1238	1127	1003	1058	994	955	933	945	957	935	803	753	713	767	
	1223	1134	1044	1120	1062	1044	1033	1038	1006	944	816	806	797	852	
	1215	1180	1131	1222	1159	1127	1083	1057	988	941	841	889	904	966	

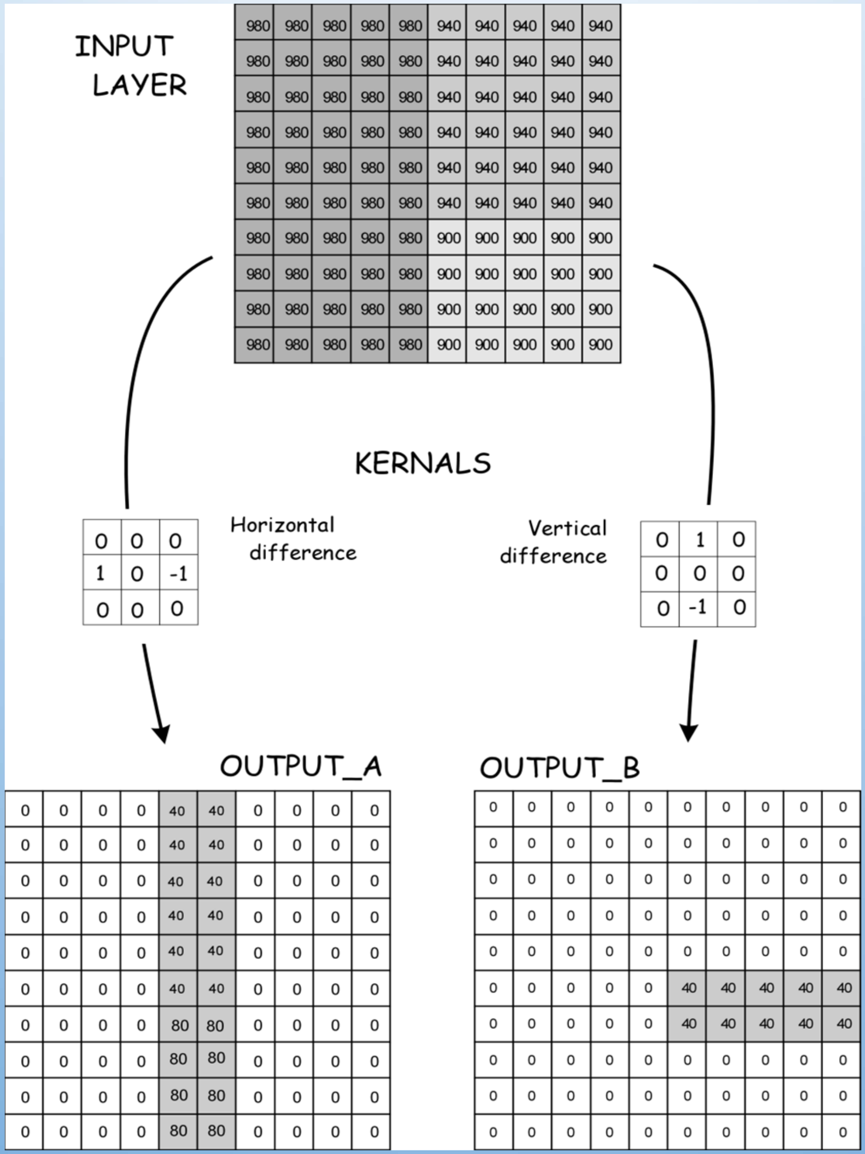
Spatial Filtering - Low and High Frequency Detail and Edges



543 Composite Result of ENVI 15x15 High Pass Filter – Edge Finding

High-Pass filters emphasize high texture, low pass filters suppress, or minimize texture

Directional Edge Detection



- Make a new map of the area of interest with cell value = 1, others cell value = 0 or NODATA
- Multiply by existing map

Source

1	3	4	7
6	3	2	-1
1	2	5	0
0	1	3	2

Clip

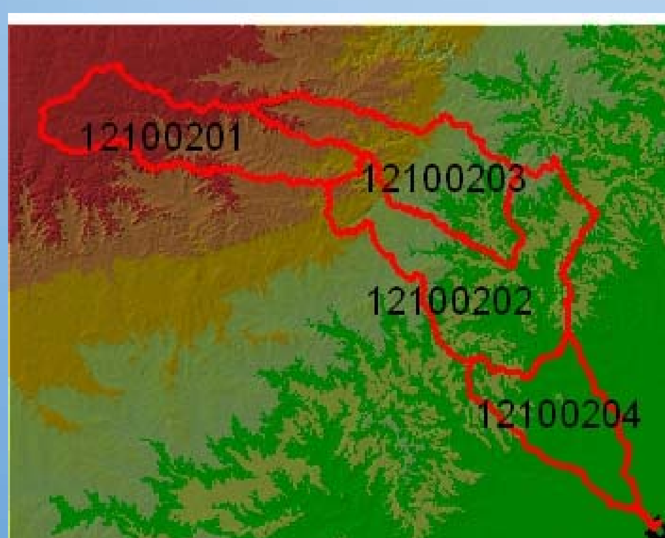
Template

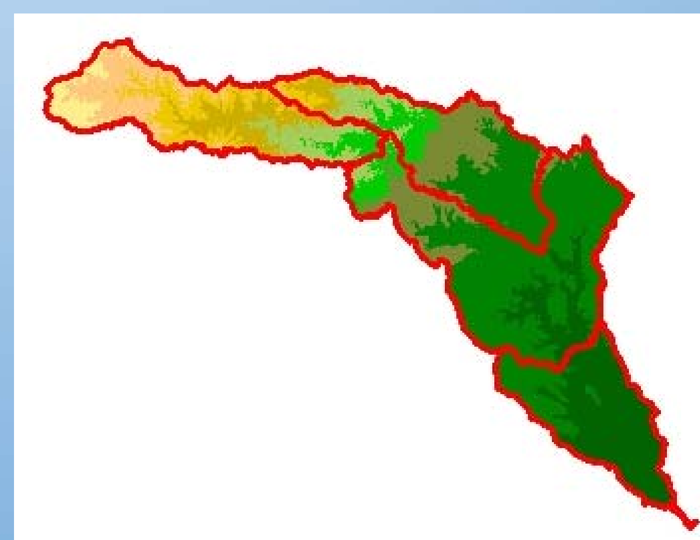
0	0	0	1
0	0	1	1
0	1	1	1
0	1	1	0

=

Output

N	N	N	7
N	N	2	-1
N	2	5	0
N	1	3	N





Common Raster Command: CON

- Con: Condition, a command in ArcGIS

```
If (layer1>5) then
        Output = 1
else
        Output = 0
End if
```

Con(layer1>5, 1, 0)

0	0	1
0	2	0
0	0	0

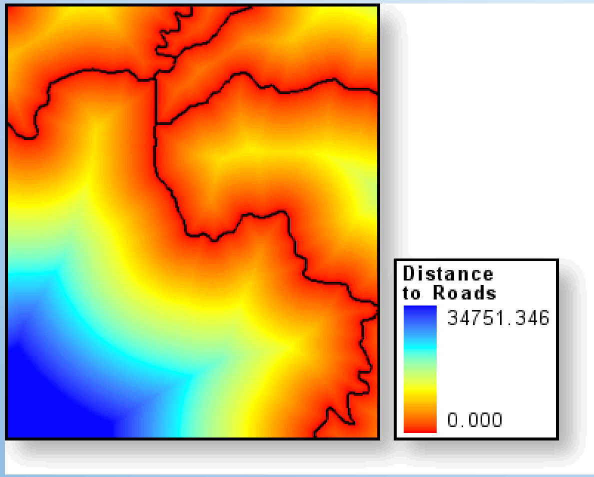
Nested Con operation:

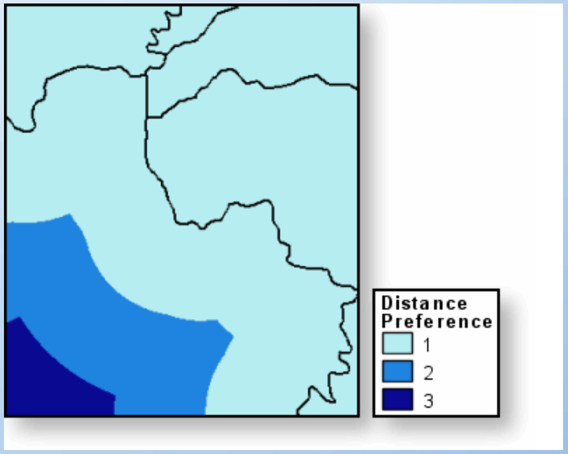
Con(layer1>5, Con(Layer1>10,2,1), 0)

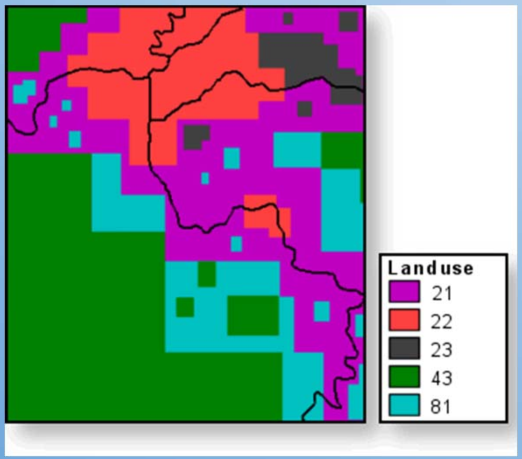
```
If (layer1>5) then
   if (layer1>10) then
       output = 2
   else
       output =1
   end if
Else
   output = 0
End if
```

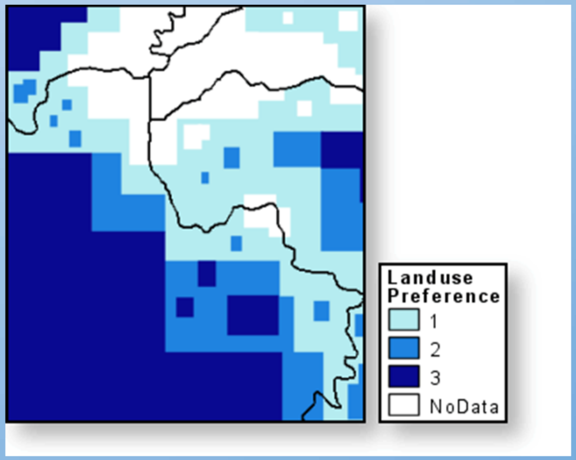
3	4	7
5	11	4
4	2	3

CON is used for re-classification







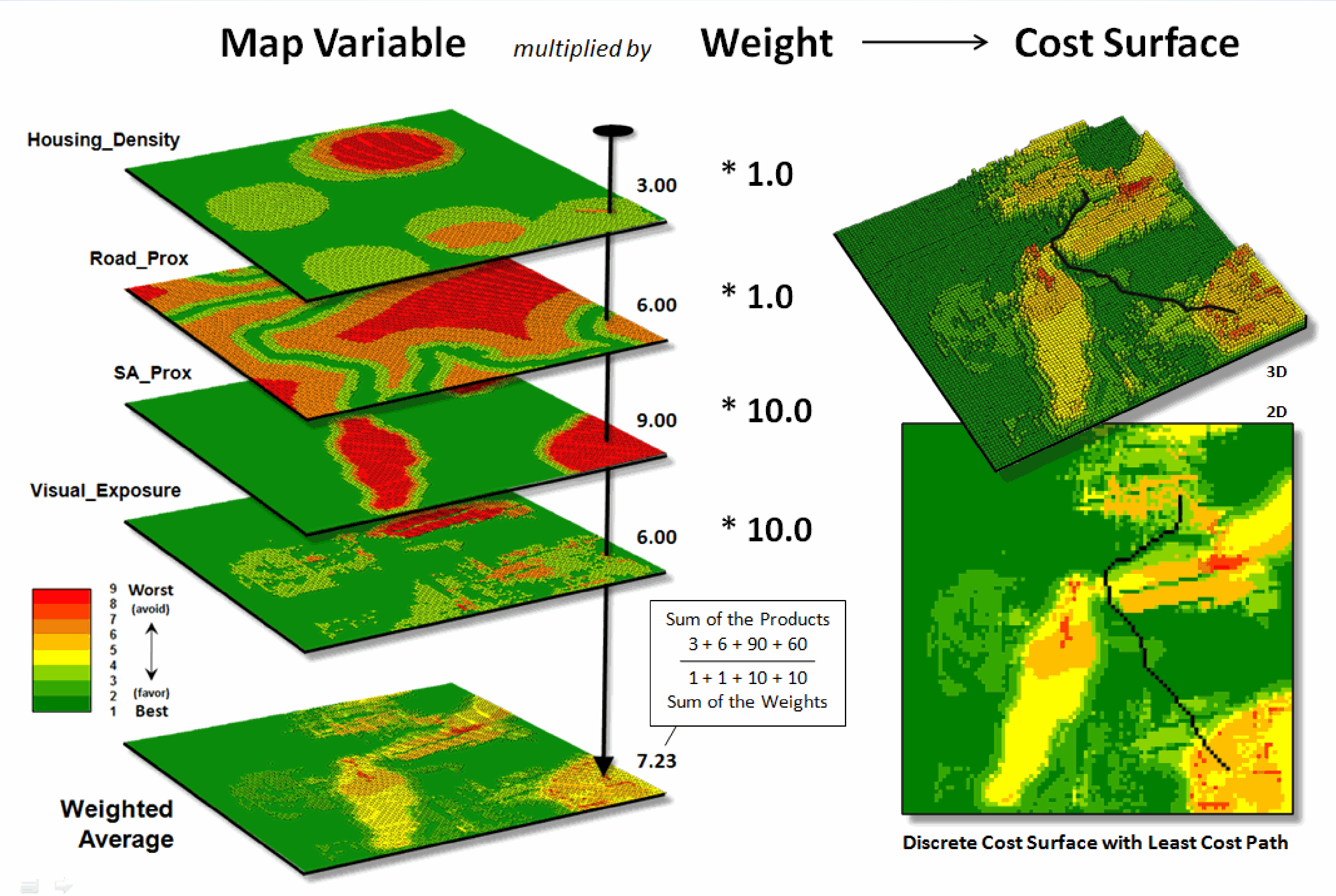


Cost Surfaces – Global Operation

- Contain the minimum cost of reaching cells in a layer from one or more source cells.
- The cost may be expressed in different units: $ money, time, or other units of merit.
- Cost = distance * cost per unit of distance (frication surface)
  - The distance from a source cell is combined with a cost per unit of distance (variable or fixed) to calculate a travel cost.
- Think simple:

Distances—in cell dimension units— are measured to/from cell centers and calculated using RMS formulae that keep values positive.

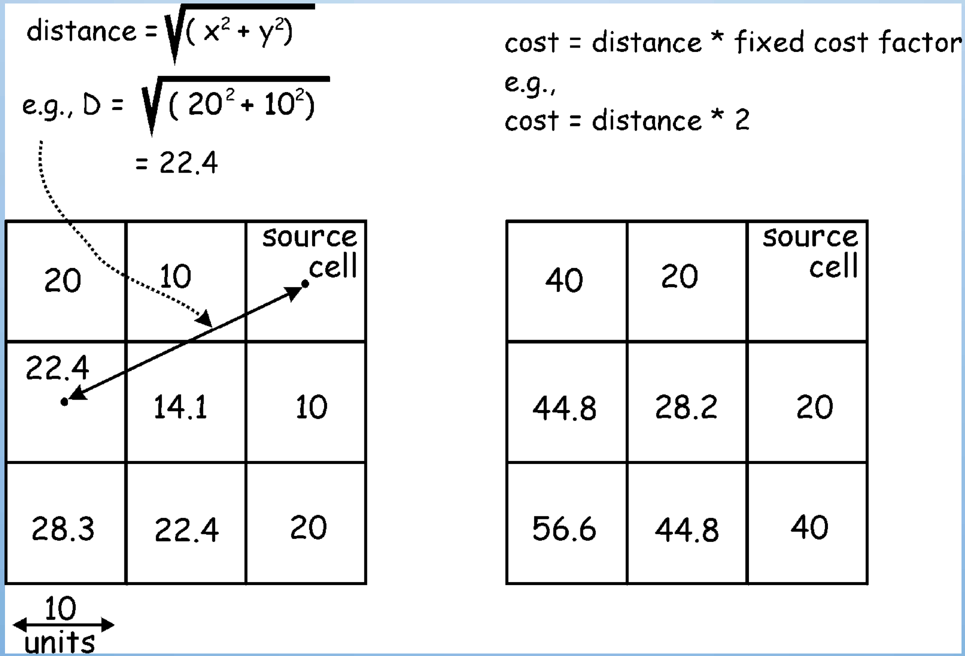
Example



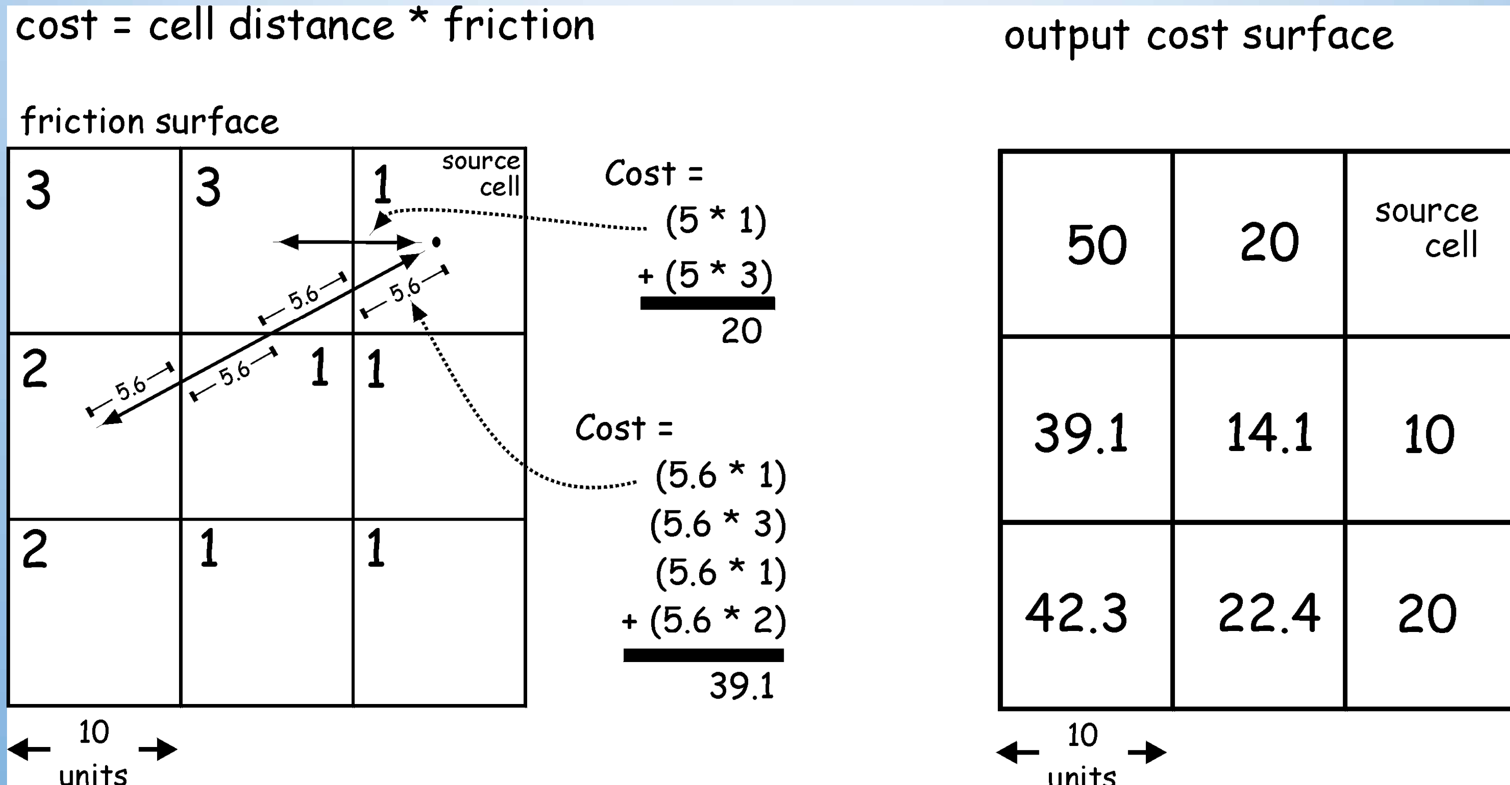
Map Variable
multiplied by
Weight
Cost Surface
Housing_Density
Road_Prox
SA_Prox
Visual_Exposure
3.00
6.00
9.00
6.00
* 1.0
* 1.0
* 10.0
* 10.0
9 Worst
(avoid)
(favor)
1 Best
Sum of the Products
3 + 6 + 90 + 60
1 + 1 + 10 + 10
Sum of the Weights
7.23
Weighted Average
3D
2D
Discrete Cost Surface with Least Cost Path

Friction Surface: Cost per unit Distance

- Another way to calculate travel costs
- Cell values of a "friction" surface represent the (***variable***) cost per unit travel distance for crossing each cell.
- Define cell friction on elevation, land cover, etc. (or even friction: icy slopes!)



Cost Surface: varied cost



Cost of a new power line

Land Use	**Friction or Cost**	**Explanation**
Agriculture	1	Base Cost
Deciduous Forest	4	Cut trees, removed and sold
Coniferous Forest	5	Cut trees, less return
Urban	1200	Conversion very expensive
Pavement	1	Base Cost
Suburban	1000	See Urban
Barren/Gravel	1	Base Cost

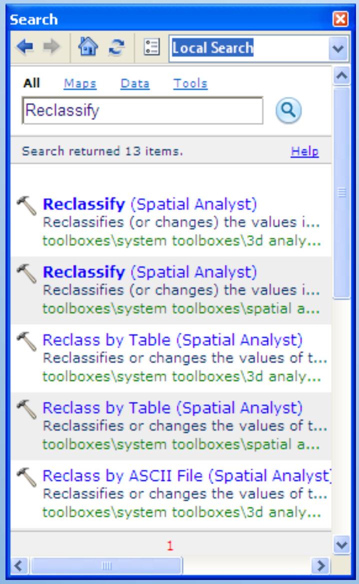
Cost Surface

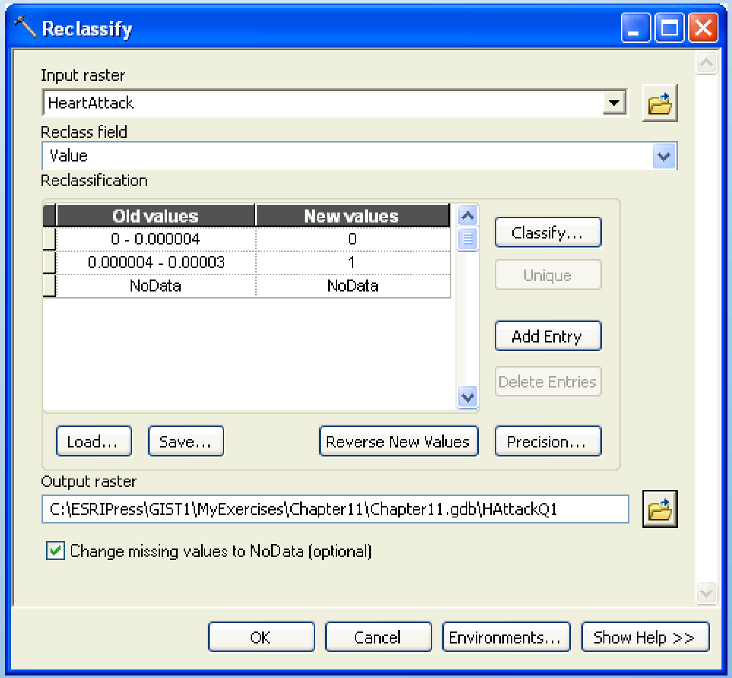
1000	1000	1000	5	11	5	5	4	4	4	4
4	1	4	4	1	5	5	4	4	4	4
4	1	1	1	1	5	5	4	4	4	4
4	1	5	5	1	5	5	5	5	5	5
4	1	5	5	1	5	5	5	5	5	5
1000	1	5	5	1	5	1000	5	5	5	4
1	1	5	4	4	1000	1000	1000	4	4	4
1	1	1000	5	5	1000	5	1000	1	1000	1000
1	5	1000	1000	1000	1000	1	1	1000	1000	1000
1	5	1000	1000	1000	5	1	Power Plant	1	1000	1000
1	5	1000	1000	1000	4	1	1	1	1000	1

Existing Trunk Power line

Reclassify settings

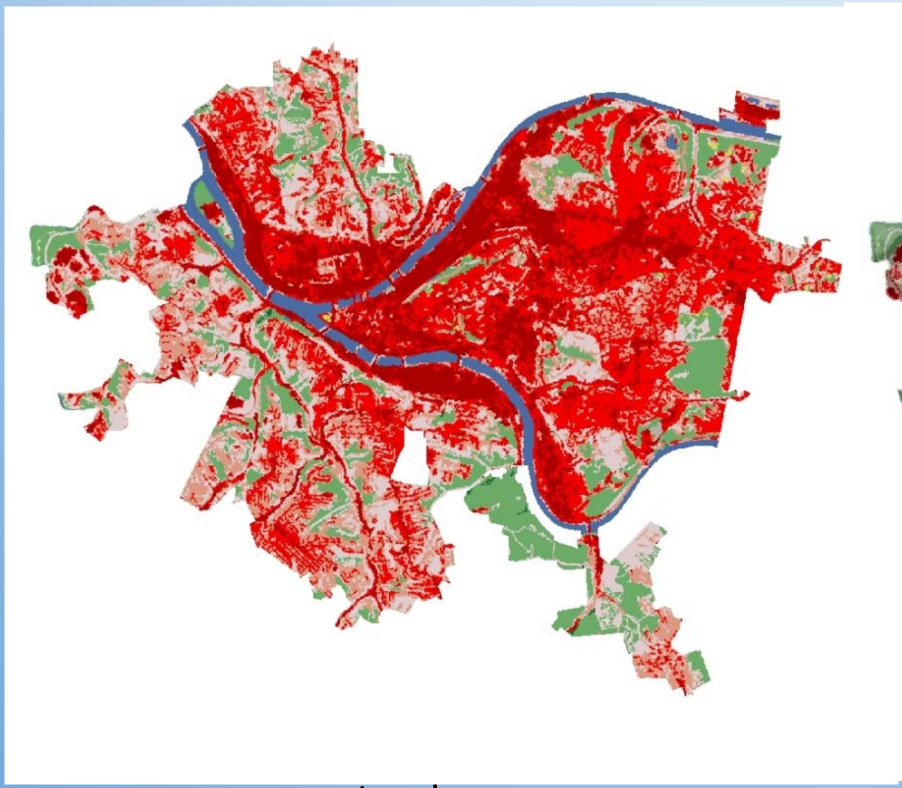
- Reclassify tool to query for high heart-attack densities



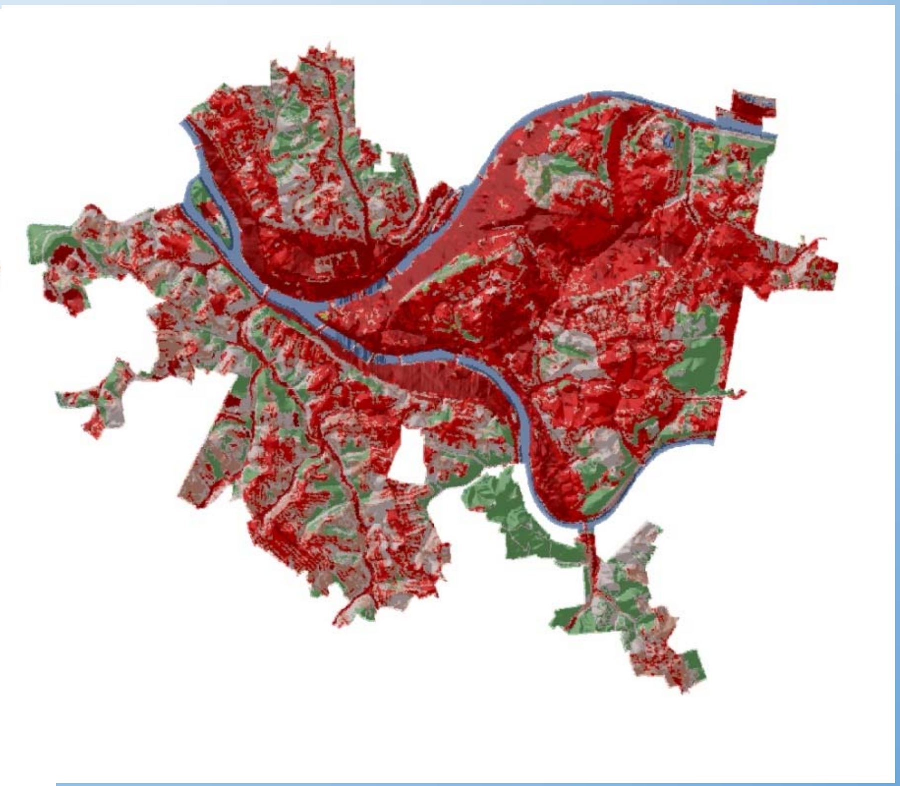


Using hillshade

To make a raster layer appear 3D, give it 35% transparency and place hillshade below it



Land use

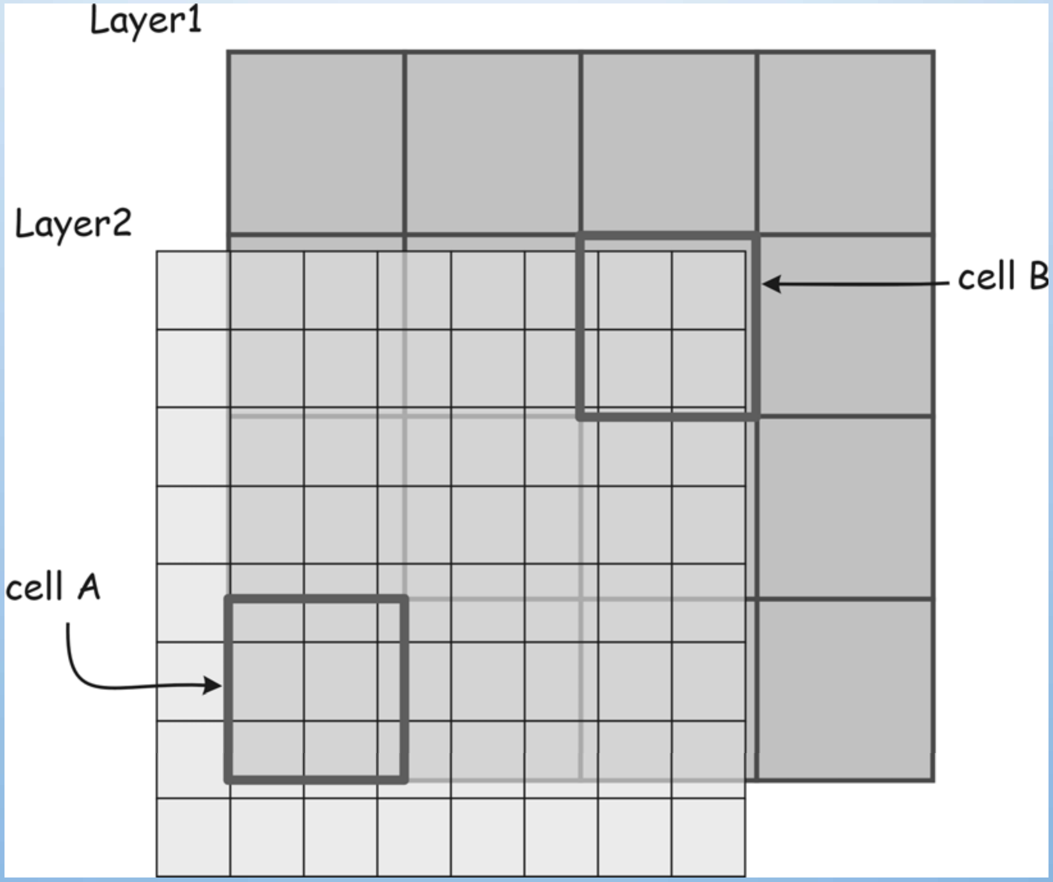


Land use with hillshade

Comparing Two Maps

- Map comparison is easily facilitated using the Tabulate Area function in ArcGIS (or any decent raster based GIS)
  - Determines the cross tabulation between two grid themes on a cell-by-cell basis
- Once the tabulations are made, the data is displayed in a simple matrix
  - Map one is the X axis and Map two is the Y axis

Incompatible Cell Sizes



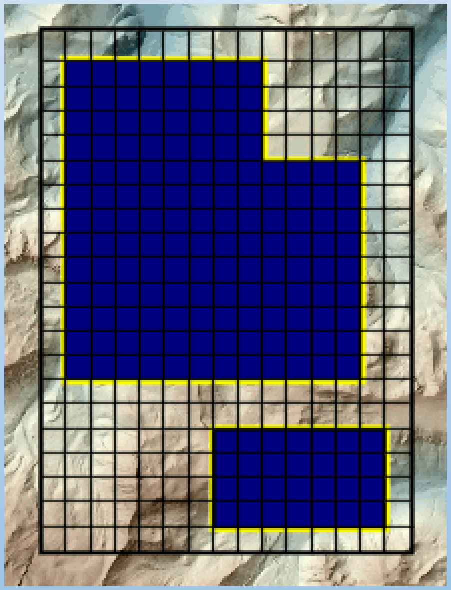
Solution: *Resample* one map (or both?), so layers have same cell size and are aligned

Analysis Mask

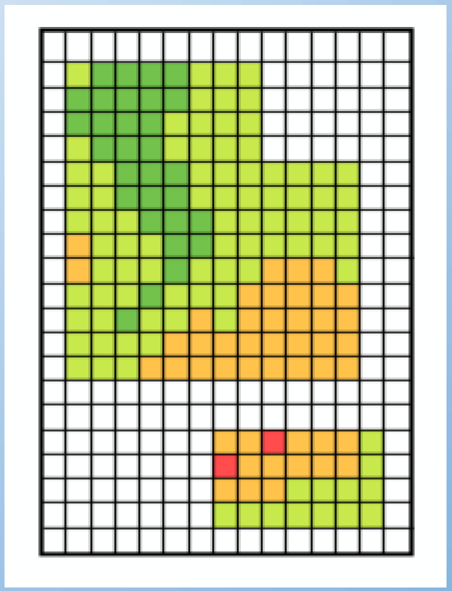
- You can specify a processing mask (either a raster or vector layer) to identify cells that will be set to NoData in the output.

Input Raster

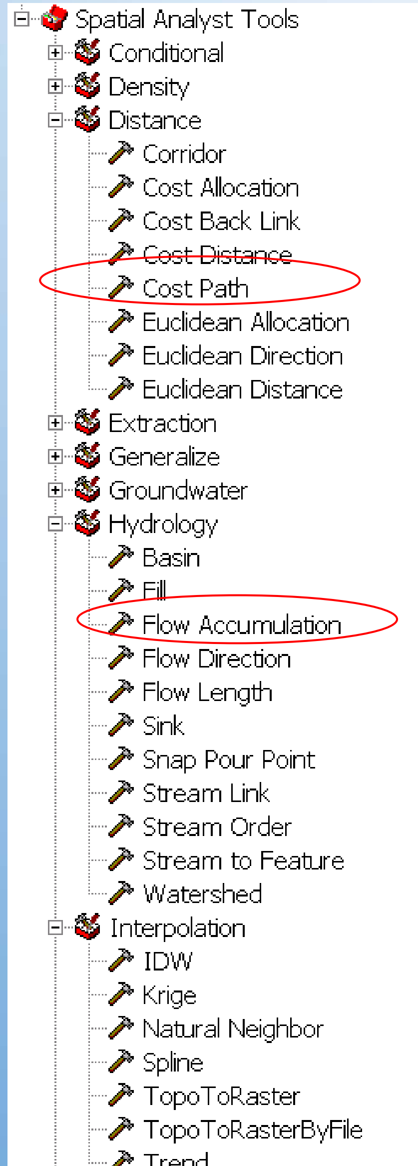
Analysis Mask

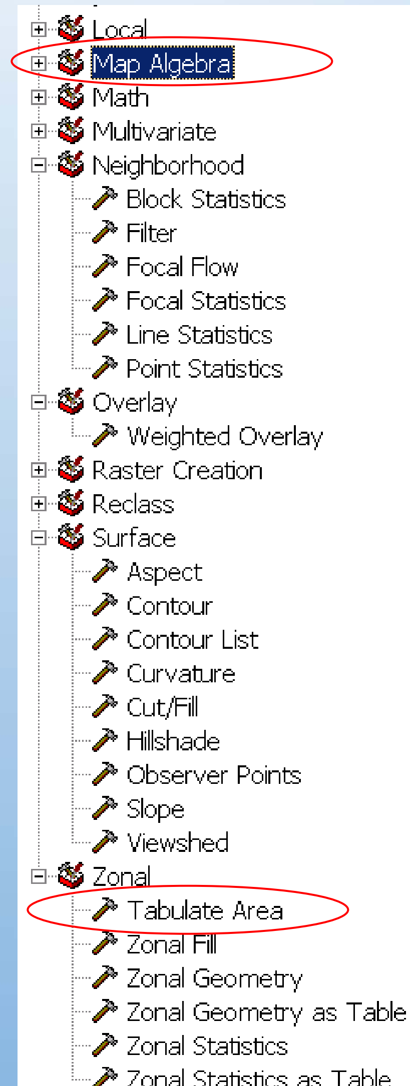


Output Raster



A tour of raster functions in ArcGIS





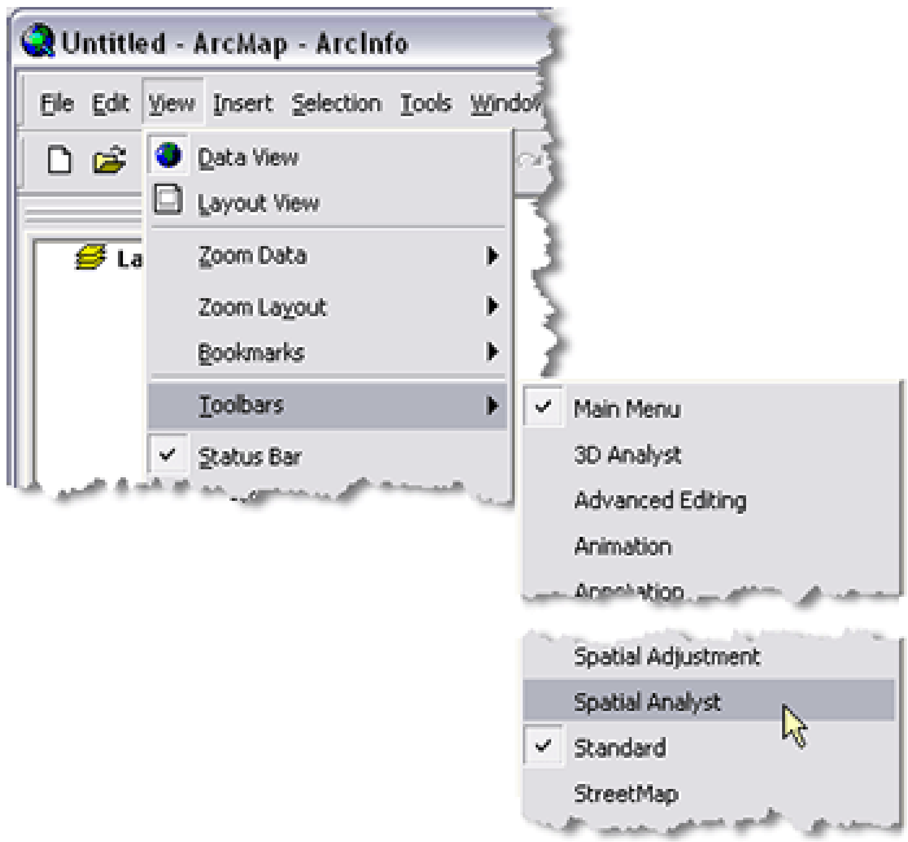
ArcGIS Spatial Analyst Extension

- Raster processing extension to ArcGIS
- It has tools for performing a broad variety of spatial analyses, and is especially well-suited to surface analysis.
- Used to
  - Create Data
  - Identify Spatial Relationships
  - Locate Suitable Sites
  - Execute sophisticated Path-finding
- Comprehensive modeling and raster analysis capabilities
- Requires separate license from ESRI than ArcGIS

Spatial Analyst capabilities

- Convert vector features (point, line, or polygon) to grids
- Calculate distance from every cell to objects of interest (similar to buffers)
- Generate density maps from point features
- Create continuous surfaces from scattered point features
- Derive contour, slope, aspect maps, and hillshades for these features
- Perform cell-based map and discrete cell-by-cell analyses
- Simultaneously execute Boolean queries and algebraic calculations on multiple raster layers
- Perform neighborhood and zone analysis
- Perform raster classification and display
- Use data from different image formats

Spatial Analyst Toolbar



You should now see the Spatial Analyst toolbar in your ArcMap window:

Quick Check Spatial Analyst

- ArcGIS Desktop Help (local computer)
- ArcGIS Desktop Resource Center (ESRI website)