Spatial Analysis of Raster Data

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

+

2	4	4	4
4	2	4	4
4	4	2	4
4	4	4	2

=

2	4	5	5
4	2	5	5
5	4	3	5
5	5	5	3

0 = shale

1 = limestone

2 = fault

4 = no fault

2 =Fault in shale

3 = Fault in limestone

4 = no Fault, shale

5 = no Fault, limestone

What is Spatial Analysis?

- Spatial Query:
  "Where is…?"

- Spatial Analysis (e.g. suitability analysis):
  "Where is the best place for…?"
  "What is the least costly path between…?"

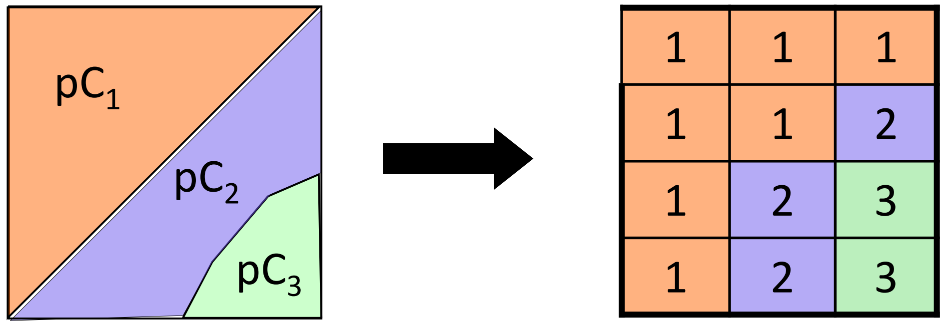
- *"… a set of methods with results that change when the location of objects being analysed changes"*
  –the spatial aspect of this form of analysis sets it apart

Why Rasters?

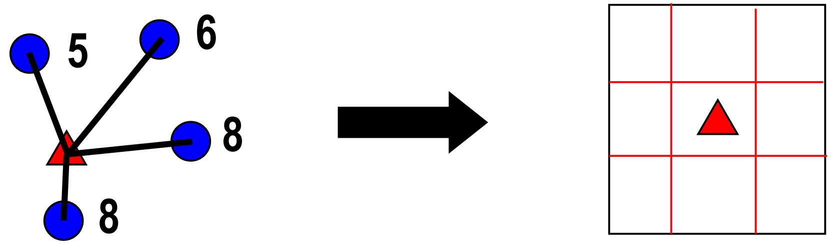
- Conceptually simple, easy to implement
- Well-suited for surface- and field-related phenomena (e.g. elevation, gravity, rainfall, etc.) and for discrete features
- Wide availability of data-sets; all remotely sensed data of this sort
- *De facto* standard approach – oldest, most widely implemented, mature, widest suite of tools and software
- Best suited for “Where” rather than “What” questions

Where do rasters come from?

- Converted vector files, e.g. shapefiles, coverages – Tools available



- Created from interpolations of point values – Tools available



- Directly from raster sources; remotely sensed data, DEMs, meteorological measurements, etc.

What gets stored?

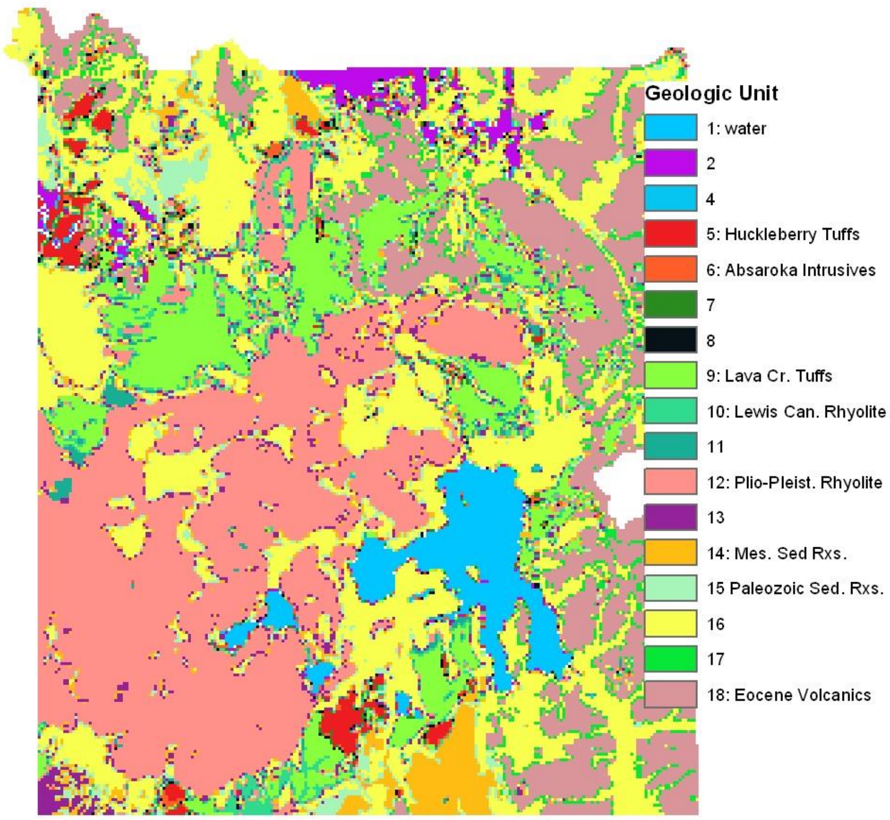
- Cell values may be:
  - *Nominal* – integers are attribute codes (tags)
  - *Ordinal* – integers are ranks
  - *Ratio* – Ratio of values makes sense, e.g. 300 m elevation is twice as high as 150 m; magnitude of ratio has some physical meaning

What gets stored?

- Cell values may be:
  - *Nominal* – integers are attribute codes (tags). Though numbers, they are dimensionless and without scale.
  - Numbers as qualitative descriptors.

Mathematical operations on cell values are not meaningful as a measure of scalar magnitudes.

Nominal Raster – e.g. Geologic Map

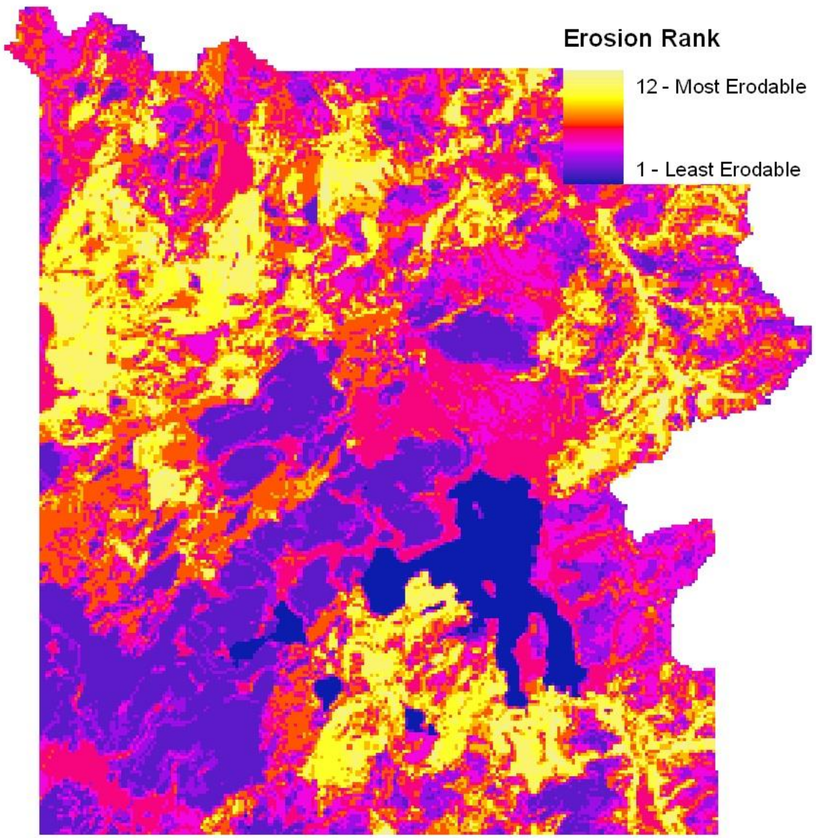


- Each raster cells contains a value of 1 to 18:
- 1 = water
  4 = Huckleberry R. Tuffs
  12= Plio.-Pleist. Rhyolite
  etc.

What gets stored?

- Cell values may be:
  - *Ordinal* – integers are **ranks**
    - e.g. 1=excellent, 2=good, 3=poor;
      1=low, 2=medium, 3=high
    - Ranking scheme used for hazard rating, density measures, etc.
    - Mathematical & most statistical operations meaningless; Median might be useful measure of central value

Ordinal Raster – e.g. Erosion Ranking



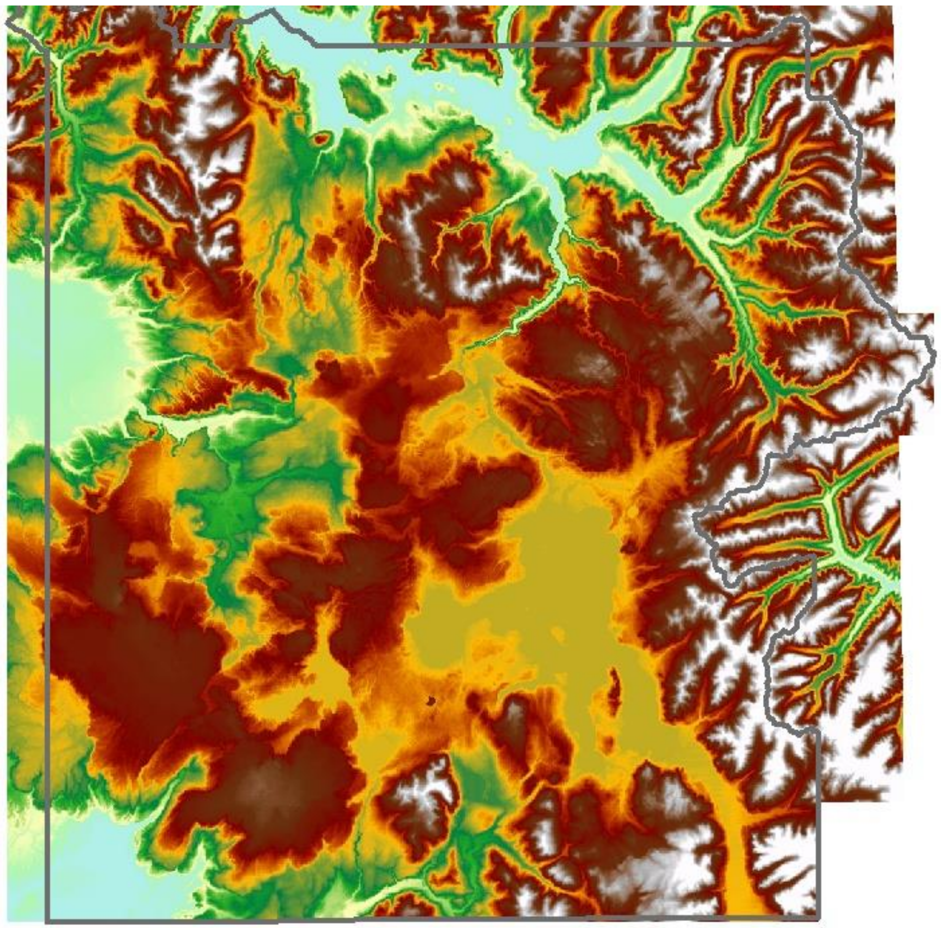
- Each raster cells contains a value of 1-12
- Yellow = 12 = Most Erosive
- Blue = 1 = Least Erosive

What gets stored?

- Cell values may be:
  - *Ratio* – data are organized along a continuum and numbers do have an absolute meaning
    - e.g. lengths, volumes, heights, concentrations, etc.

Multiplication/Division, Subtraction/Addition make sense for arriving at meaningful new cell values**.**

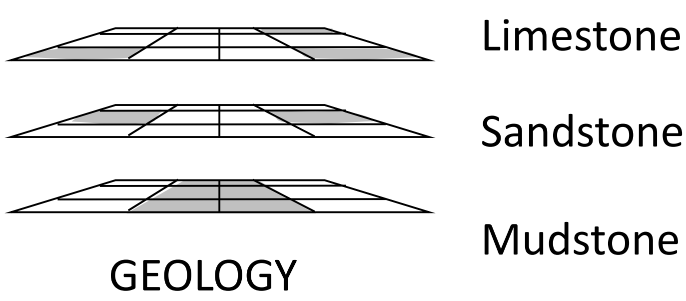
Ratio Raster – e.g. Elevation above MSL



- Each raster cells contains a value of 1544-3578 (meters)
- White = 3578 m
- Pale Blue = 1544 m

What Gets Stored?

- Depends on raster data model: 2 types-*Simple* and *Extended*:
  - *Simple Raster* – Binary (nominal values)
    - 0 or 1 stored; feature present or not. B & W image. E.g. Limestone or not Limestone.
    - requires a different raster for each attribute (e.g. rock type) within a single theme (e.g. Geology)

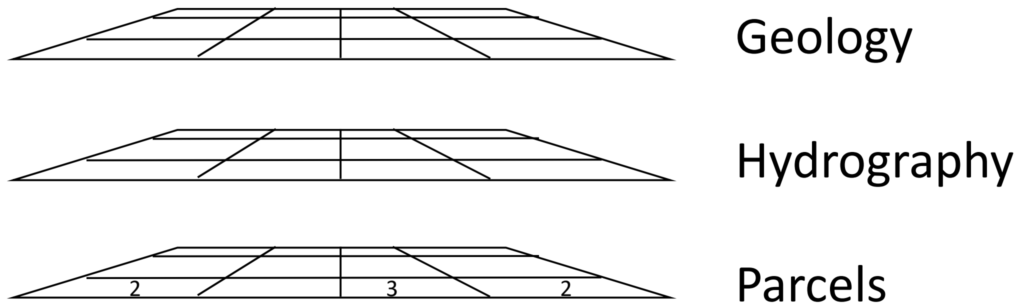


What Gets Stored?

- Raster data model:
  - *Simple Raster* – Non-binary, one nominal value per cell

    - integer is a code for categorical attribute e.g. limestone = 1, sandstone = 2, mudstone = 3

    - requires one raster per theme



What Gets Stored?

- Raster data model:
  - *Extended Raster* - One value per cell but multiple attributes per value in *value attribute table* (VAT)

1	1	1
1	1	2
1	2	3
1	2	3

VAT for Geology raster				
Value	Count	Type	Porosity	Cement
1	7	Limestone	10	Calcite
2	3	Sandstone	22	Quartz
3	2	Mudstone	2	No data

What Are the Tools &Techniques?

- Map Algebra employing:
  - Raster Operators
  - Raster Functions

- *Map Algebra takes raster(s) as input and return a result as a new raster*.

Map Algebra Operators

1. Arithmetic
   - +, -, *, / ; for pairs of rasters
   - Trigonometric, Log, Exponential, Powers for single rasters

Example: Raster Overlay

- E.g. “Find wells within limestone”
  - Point-in-Polygon Query

0 = shale

1 = limestone

Geology

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

+

2 = well

4 = no well

Wells

2	4	4	4
4	2	4	4
4	4	2	4
4	4	4	2

=

2 = well in shale

3 = well in limestone

4 = no well, shale

5 = no well, limestone

2	4	5	5
4	2	5	5
5	4	3	5
5	5	5	3

Map Algebra Operators

2. Relational (e.g. raster comparisons)
   - <, >, =, >=, <=, <>

   Compare two rasters. Create a new raster such that if condition is false, return 0, if true 1.

5	5	5
5	5	2
5	2	3
5	2	3

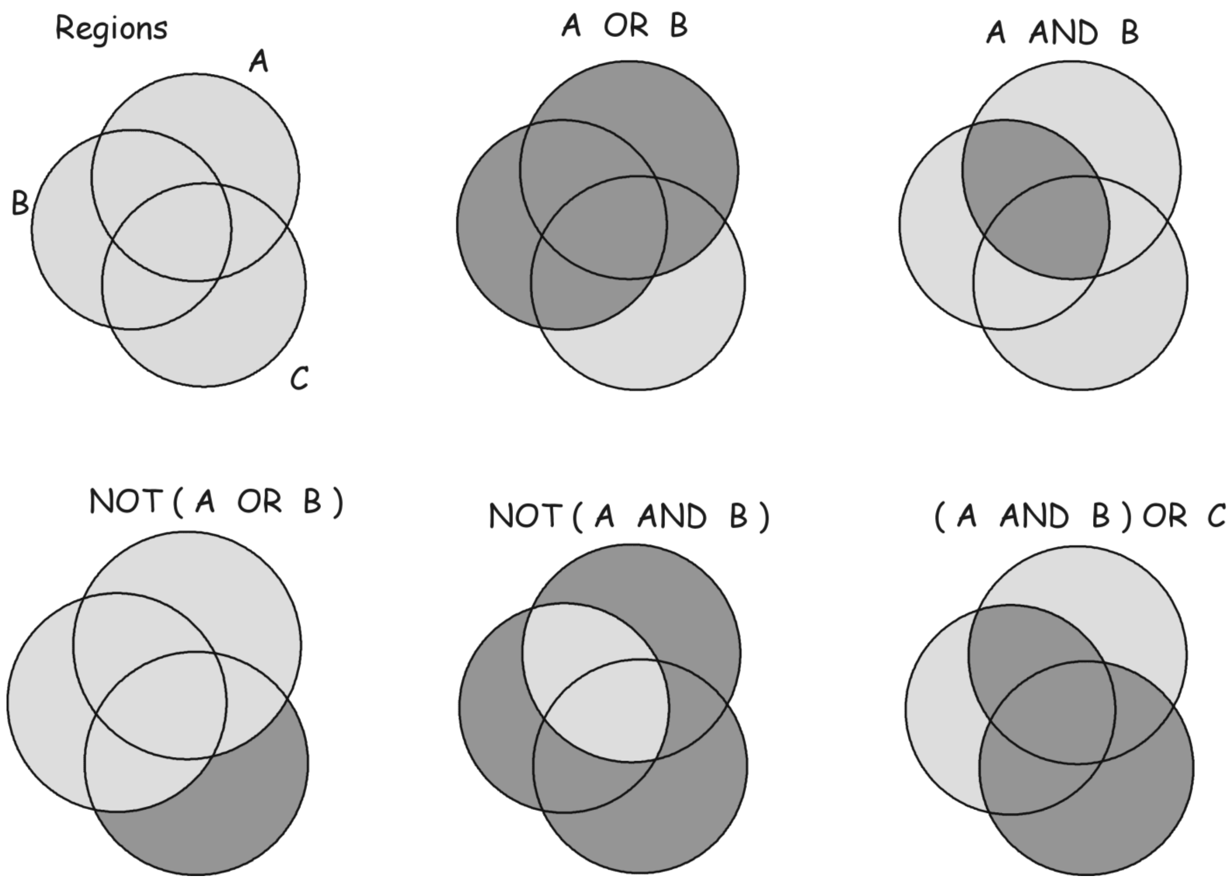
>=

4	0	0
0	4	4
0	3	3
0	3	3

=

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

Boolean Selections; Or, And, Not



From Bolstad, 4th edition

Map Algebra Operators

3. Boolean
   - And, Or, Not
     - And – both true
     - Or- either true
     - Not – switches true for false

Search, compare and/or identify where there are non-zero values in two rasters

a) Input AND = Output

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

=

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

b)

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

c)

NOT

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

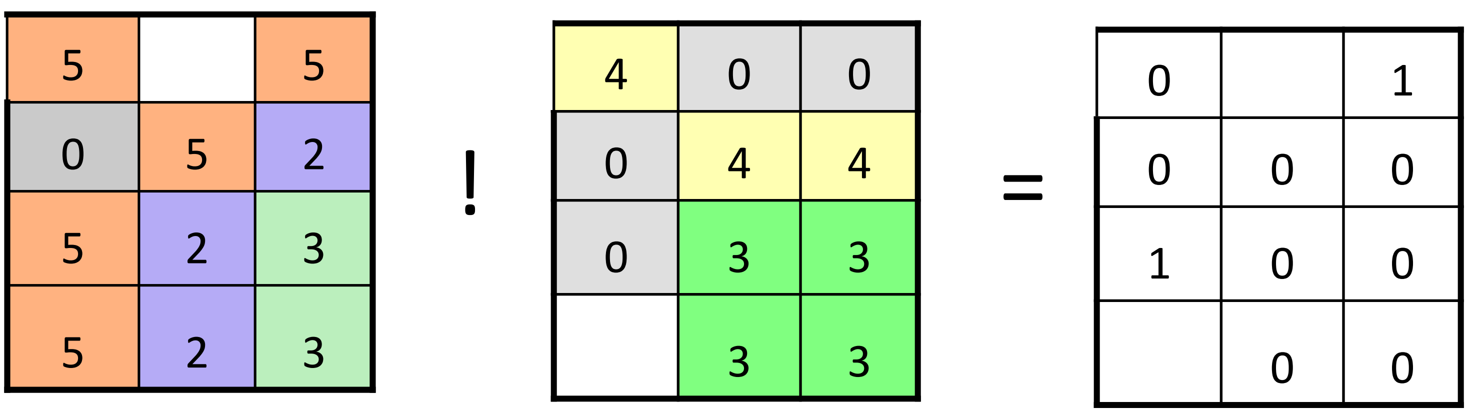
=

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

From Bolstad, 4th edition

Map Algebra Operators

3. Boolean
    - And, Or, Not, Xor
        - E.g. “Xor” (Exclusive Or) finds where there are nonzero values in one or the other raster, but not both.



Map Algebra Operators

4) Combinatorial

- Assign value in new raster on basis of the combination of values in compared rasters

R 1	R 2	Out
1	1	0
1	4	1
2	3	2
2	4	3
3	3	4

1	1	1
1	1	2
1	2	3
1	2	3

Raster 1

COR

4	1	1
1	4	4
1	3	3
1	3	3

Raster 2

=

1	0	0
0	1	3
0	2	4
0	2	4

Output

Map Algebra Operators

- Logical
  - Difference (DIFF), Contained In (IN) and OVER
  - E.g. OVER searches for zeros. All nonzeros from first raster returned; if zero, returns value from second raster.

1	1	1
1	1	0
1	0	3
1	0	3

OVER

4	1	1
1	4	4
1	3	3
1	3	3

=

1	1	1
1	1	4
1	3	3
1	3	3

Map Algebra Operators

4. Combinatorial - Logical

- Conditional Statement – CON – highly versatile; generalized "Over"
- Format is: {Condition to be met; Output value if True, Output value if False}. If no False value specified then "null" is recorded.
- E.g. CON {R1>0, R1, 0.5}; If Raster 1 cell is greater than zero, then write the cell value to the output, otherwise write 0.5 to that cell in the output

4	1	1
1	4	-4
1	-3	3
1	-3	3

R1: Raster 1

CON {R1>0, R1, 0.5}

4	1	1
1	4	0.5
1	0.5	3
1	0.5	3

Output

Map Algebra Operators

5) Accumulative

- +=, *=, -=
- Add, subtract, multiply, raster values in specific order.

1	1	1
1	1	0
1	0	3
1		3

+=

Value = 13

Map Algebra Operators

6. Assignment
   - =
   - Assign all cells in a new raster a value by performing operation on old raster

1	1	1
1	1	0
1	0	3
1		3

$* \ 5 =$

5	5	5
5	5	0
5	0	15
5		15

Raster Functions

- Higher-order operations built up of operators just listed; relationship of input to output cells:
  - Local – cell-to-cell functions: 1 input cell per output cell
  - Focal – by-neighborhood functions
  - Global – entire raster
  - Special Types

Raster Functions

- Local Functions
  - Each cell in first raster operated on by an expression or by cell at same location in another raster
  - Used in:
    - Reclassification
    - Overlay Analysis

Local Functions: Reclassification

- Make new raster by performing function on old.
  - Nominal values reclassed as O or 1 (=*binary masking)* e.g. Boolian operators
  - Reduce range or number of values
    - floating point to integer values
  - Change measurement scale to weight values; convert nominal values to rank (ordinal or ratio values).

Reclassification – Binary Masking

- Beginning Raster:

5	5	5	5	5	5	5	5
5	5	5	5	2	2	5	5
5	5	5	5	2	2	8	8
5	5	5	5	2	2	8	8
2	2	2	2	2	2	8	8
2	2	5	5	5	5	5	5
2	2	2	2	5	5	5	5
5	2	2	2	5	5	5	5

- Simplify to raster with granite and non-granite cells to produce binary raster.

2 = limestone

5 = sandstone

8 = granite

Local Functions: Reclassification

- Binary Raster – composed of 0 and 1

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

- Replaced nominal 2 and 5 by 0; 8 by 1.
- Simplified raster can be saved and used for further analysis

Reclassification - Weighting

- Reclassify to assign weighting factor for further analysis; nominal values become ordinal values for later calculation

5	5	5	5	5	5	5	5
5	5	5	5	2	2	5	5
5	5	5	5	2	2	8	8
5	5	5	5	2	2	8	8
2	2	2	2	2	2	8	8
2	2	5	5	5	5	5	5
2	2	2	2	5	5	5	5
5	2	2	2	5	5	5	5

Lithology	Old Value	Weight	New Value
Limestone	2	10	**20**
Sandstone	5	2	**10**
Granite	8	5	**40**

- Granite is weighted 4x sandstone and 2x limestone

Local Functions: Raster Overlay

- All entities represented by cells;
  - point = single cell
  - line = chain of cells
  - polygon = group of cells
- Nominal values identify a related group of cells as an entity
- Rasters of continuous variables (e.g. rainfall, temp., elevation) have cells with ratio values

Local Functions: Raster Overlay

- Compare cell value among layers by *Map Algebra*
  - generate new raster as sum, difference, product, etc. of cells within two layers

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

+

2	0	0	0
0	2	0	0
0	0	2	0
0	0	0	2

=

2	0	1	1
0	2	1	1
1	0	3	1
1	1	1	3

Local Functions: Raster Overlay

- E.g. "Find faults cutting limestone OR shale"

  - Line-in-Polygon Query

2 =Fault in shale

3 = Fault in limestone

0 = shale

1 = limestone

2 = fault

4 = no fault

4 = no Fault, shale

5 = no Fault, limestone

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

+

2	4	4	4
4	2	4	4
4	4	2	4
4	4	4	2

=

2	4	5	5
4	2	5	5
5	4	3	5
5	5	5	3

Local Functions: Raster Overlay

- Operators include nearly all previously listed:
  - Arithmetic
  - Relational
  - Logical
  - etc.

Focal Functions

- Neighborhood functions: uses values in adjacent cells to return values for new raster.
- Used for:
  - Aggregation
  - Filtering
  - Computing slope and aspect

Focal Functions

- Aggregation
  - "Down-sampling" – combining cells (average, central cell, median) to produce raster with fewer cells.

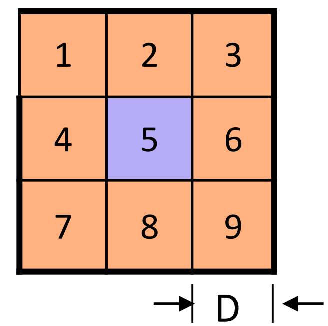
3	3	2	1	2	2	2	2
3	3	3	3	2	1	1	2
3	2	1	3	1	3	1	1
2	1	0	2	0	0	1	1
4	3	2	0	0	0	1	1
0	2	3	0	2	2	2	1
2	0	2	3	4	1	2	0
0	2	1	1	1	2	2	3

Average

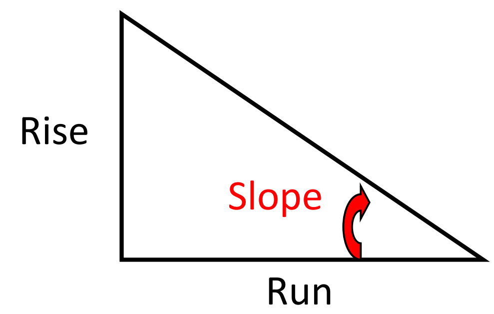
2	1
1	1

Focal Functions: Computing Slope

- Use 8 neighboring cells to compute slope of cell #5. Rise/run = tan (slope)
  - Find slope in x direction
    - $b = \tan(\text{slope}_x) = (z_3 + z_6 + z_9 - z_1 - z_4 - z_7)/8D$
  - Find slope in y direction
    - $c = \tan(\text{slope}_y) = (z_1 + z_2 + z_3 - z_7 - z_8 - z_9)/8D$
  - Find slope in steepest direction
    - $\tan(\text{slope}) = (b^2 + c^2)^{1/2}$



z = elev.



Focal Functions: Filtering

- Filtering – assign new value to cell on basis of neighboring cells. Save as new raster.
  - Define filter window as a group of cells ("*kernal*") around a target cell; size and shape can be specified.
  - Step window across entire raster, calculating new value for center of filter on basis of neighboring values within the filter and filter rule.

Neighborhood Functions: Filtering

- Rule – replace target cell (in center) with mean value encountered in filter
- Define square filter of 3x3 cells

3	3	2	1	2	2	2	2
3	3	3	3	2	1	1	2
3	2	1	3	1	3	1	1
2	1	0	2	0	0	1	1
4	3	2	0	0	0	1	1
0	2	3	0	2	2	2	1
2	0	2	3	4	1	2	0
0	2	1	1	1	2	2	3

Target 1: mean = 18/9 = 2
- replace target with 2

Target 2: mean = 15/9 = ~1.7
- replace target with 2

- Filtering effective for:
  - removing noise
  - revealing linear trends

Neighborhood (Proximity) Functions

- Buffering – calculate buffer zone based on proximity. Save as new raster.
  - Cell value of new raster is a measure of distance via proximity.

Original raster

2	4	4	4
4	2	4	4
4	4	2	4
4	4	4	2

A

3 m Buffer raster

4	4.5	5.0	5.7
3	3.6	4.2	5.0
2	2.8	3.6	4.5
1	2	3	4

A