Spatial Analysis of Raster Data

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

0 = shale
1 = limestone
2 = fault
4 = no fault

0 = Fault in shale
1 = Fault in limestone
2 = no Fault, shale
3 = no Fault, limestone

\[
\begin{align*}
&0 & 0 & 1 & 1 \\
&0 & 0 & 1 & 1 \\
&1 & 0 & 1 & 1 \\
&1 & 1 & 1 & 1 \\
\end{align*}
\]

\[
\begin{align*}
&2 & 4 & 4 & 4 \\
&4 & 2 & 4 & 4 \\
&4 & 4 & 2 & 4 \\
&4 & 4 & 4 & 2 \\
\end{align*}
\]

\[
\begin{align*}
&2 & 4 & 5 & 5 \\
&4 & 2 & 5 & 5 \\
&5 & 4 & 3 & 5 \\
&5 & 5 & 5 & 3 \\
\end{align*}
\]

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 cell contains a value of 1 to 18:
  - 1 = water
  - 4 = Huckleberry R. Tuffs
  - 12= Plio-Pleist. Rhyolite etc.
Ordinal Raster – e.g. Erosion Ranking

- Each raster cell 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 cell 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)
Map Analysis of Raster Data I

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

Geology
Hydrography
Parcels

What Gets Stored?

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

<table>
<thead>
<tr>
<th>VAT for Geology raster</th>
<th>Value</th>
<th>Count</th>
<th>Type</th>
<th>Porosity</th>
<th>Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>Limestone</td>
<td>10</td>
<td>Calcite</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>Sandstone</td>
<td>22</td>
<td>Quartz</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td>Mudstone</td>
<td>2</td>
<td>No data</td>
</tr>
</tbody>
</table>

What Are the Tools & Techniques?

- **Map Algebra** employing:
  - Raster Operators
  - Raster Functions

Map Algebra is an algebraic system for working with raster data. It takes one or more rasters as input and returns 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

<table>
<thead>
<tr>
<th>0 = shale</th>
<th>1 = limestone</th>
<th>2 = well in shale</th>
<th>3 = well in limestone</th>
<th>4 = no well, shale</th>
<th>5 = no well, limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 1 1</td>
<td>2 4 4 4</td>
<td>2 4 5 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 0 1 1</td>
<td>4 2 4 4</td>
<td>4 2 5 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0 1 1</td>
<td>4 4 2 4</td>
<td>5 4 3 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1 1 1</td>
<td>4 4 4 2</td>
<td>5 5 5 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Map Algebra Operators

2. Relational

- , >, >=, <, <=

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

| 5 5 5   | 4 0 0   |
| 5 5 2   | 0 4 4   |
| 5 2 3   | 0 3 3   |
| 5 2 2   | 0 3 3   |

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

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.

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

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.

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.
Map Algebra Operators

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

   +=       Value = 13

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

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 gives
  - Special Types

- 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 0 or 1 (=binary masking) e.g. Boolean 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:
  2 2 2 2 2 5 5 5 5 5
  2 2 2 2 2 2 2 2 8 8
  2 2 2 2 2 2 2 2 8 8
  2 2 2 2 2 2 2 2 8 8
  2 2 2 2 2 2 2 2 8 8

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

Reclassification - Weighting

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

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Old Value</th>
<th>Weight</th>
<th>New Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone</td>
<td>2</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Sandstone</td>
<td>5</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Granite</td>
<td>8</td>
<td>5</td>
<td>40</td>
</tr>
</tbody>
</table>

- Granite is weighted 4x sandstone and 2x limestone

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

![Raster Overlay Diagram](image)

E.g. “Find faults cutting limestone OR shale”

Line-in-Polygon Query

<table>
<thead>
<tr>
<th>0 = shale</th>
<th>2 = fault</th>
<th>4 = no fault</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 1 1</td>
<td>4 4 4 4</td>
<td>2 4 5 5</td>
</tr>
<tr>
<td>0 0 1 1</td>
<td>4 2 4 4</td>
<td>4 2 5 5</td>
</tr>
<tr>
<td>1 0 1 1</td>
<td>4 4 2 4</td>
<td>5 4 3 5</td>
</tr>
<tr>
<td>1 1 1 1</td>
<td>4 4 4 2</td>
<td>5 5 5 3</td>
</tr>
</tbody>
</table>

![Line-in-Polygon Query](image)

![Operator Examples](image)

- 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: Computing Slope

- Use 8 neighboring cells to compute slope of cell #5.

- Find slope in x direction
  - \( b = \tan(\text{slope}_x) = \frac{(z_3 + z_4 + z_5 - z_1 - z_6 - z_7)}{8D} \)

- Find slope in y direction
  - \( c = \tan(\text{slope}_y) = \frac{(z_1 + z_2 + z_3 - z_7 - z_8 - z_9)}{8D} \)

- Find slope in steepest direction
  - \( \tan(\text{slope}) = (b^2 + c^2)^{1/2} \)

Focal Functions: Aggregation

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

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

<table>
<thead>
<tr>
<th>Original raster</th>
<th>3 m Buffer raster</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 4 4 4</td>
<td>4 4.5 5.0 5.7</td>
</tr>
<tr>
<td>4 2 4 4</td>
<td>3 3.6 4.2 5.0</td>
</tr>
<tr>
<td>4 4 2 4</td>
<td>2 2.8 3.6 4.5</td>
</tr>
<tr>
<td>4 4 4 2</td>
<td>1 2 3 4</td>
</tr>
</tbody>
</table>

Filtering effective for:
- removing noise
- revealing linear trends

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

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

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.