Maps as Numbers: Data Models

The Task
- An accurate, registered, digital map that can be queried and analyzed.

Translate:
- Real World, Paper Map → Computer Files
  - Spatial Data Models, Topology
  - Entity Info. → Queryable Database Files
  - Relational or Object-Oriented Databases
- Relate Spatial Coordinates to Entity Info.

“Spatial DBMS” software = GIS software!

Data Models
- How is reality abstracted and codified?
  - Reality
  - Conceptual Models
  - Logical Models
  - Physical Models

Wells produce from rocks that contain oil and gas
- Wells are points, rock units are polygons (both are objects)
- Well A penetrates Fm. 1; produces oil. Well B penetrates Fm. 3; produces gas. Fm 3 overlies Fm. 1.
- Store well locations with a particular file structure, production stats. in a dBase table. Associate table with location.

Conceptual Models
- Characterized all features or phenomenon as:
  - Discrete objects; e.g. wells, roads, rock bodies, etc.
    - Object-based models
  - Continuous phenomena; e.g. gravity, magnetic intensity, topography, temperature, snowfall, soil pH, etc.
    - Field-based models
**Logical Models**

**VECTOR MODEL**
- Discrete objects are represented by points and vectors, continuous fields by irregular tessellations of triangles (TINs)

**RASTER MODEL**
- Discrete objects and continuous fields are represented by an array of square cells (pixels)

**Continuous phenomena as surfaces**

**Raster Topography**
- Regular tessellations, e.g. DEM

**Vector Topography**
- Irregular tessellations, e.g. T.I.N.
Simple Vector Data Structure

Vector Line

Table of Points

<table>
<thead>
<tr>
<th>ID</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>503200</td>
<td>3200522</td>
</tr>
<tr>
<td>P2</td>
<td>503250</td>
<td>3200522</td>
</tr>
<tr>
<td>P3</td>
<td>503300</td>
<td>3200460</td>
</tr>
<tr>
<td>P4</td>
<td>503245</td>
<td>3200410</td>
</tr>
<tr>
<td>P5</td>
<td>503350</td>
<td>3200410</td>
</tr>
</tbody>
</table>

(in UTM coordinates)

Simple Raster Data Structure:

Raster Line

Equivalent Binary Flat File

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

Physical Models

Vector Models

- "Graphical"
- Topologic/georelational
- T.I.N.
- Network

"Graphical" Vector Model

- Lines have arbitrary beginning and end, like spaghetti on a plate
- Common lines between adjacent polygons duplicated
- Can leads to "slivers" of unassigned area = "sliver polygons"
“Graphical” Vector Model

**Shortcomings for maps:**
- No real world coordinates required
- No identification of individual objects; no way to attach attributes
- Details of relationships among object (e.g. what’s adjacent) not stored, but needed for spatial analysis

Graphical Vector Structure

**Contains no explicit information about adjacency, containment or contiguity** i.e.
- Which polygons are adjacent?
- Which polygons are contained within other polygons?
- Which lines are connected? Where are they connected? Where do lines begin and end?

= “Spaghetti Data Model”

Topological Vector Model

**Store pts. as x,y geographic coordinates**
**Store lines as paths of connected pts.**
**Store polygons as closed paths**

Also explicitly store ....
- Where lines start and end (connectivity)
- Which polygons are to the right and left side of a common line (adjacency)

Topology

**The geometric relationship(s) between entities (e.g. points, lines, areas); where is one thing with respect to another?**
Topological Properties

- Spatial characteristics that are unchanged by transformations like scaling, rotation and translation are topologic
  - Non-topological: x, y coordinates, area, distance, orientation
  - Topological:
    - Contiguity – what’s adjacent
    - Connectivity – what’s connected
    - Containment – what’s inside or outside of a region

Maintaining Topology: Planar Enforcement

- One and only one feature at every x, y location
  - Lines cross at nodes; polygons space-filling, exhaustive, mutually exclusive (no overlaps or gaps)
  - Sum of the area of all individual polygons equals the area of extent of all polygons
  - Common boundaries stored only once
- A PLANAR GRAPH meets these conditions
- Allows spatial queries for adjacency, containment and rapid what-is-where
- All raster data is of this sort

Non-Planar vs. Planar Graphs

- Spaghetti
- Topologic

after Bonham-Carter, 1994
Maps as Numbers

1/28/2016
M. Helper, GEO 327G/386G, UT Austin

Lines: Graphic vs. Topologic

- **Graphic (Spaghetti)**
  - vertices
  - overshoot
  - Table of (x,y) coordinates

- **Topologic (with meatballs)**
  - vertices
  - Table of (x,y) coordinates & Table of arcs with IDs, starting and ending nodes
  - S – Start node
  - E – End node

Lines: Arc-Node Topology

<table>
<thead>
<tr>
<th>ID</th>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ID</th>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

- **Vertex Table**
- **Node Table**
- **Arc Table**
  - F = "Start" node (F: "From" node)
  - T = "End" node or (T: "To" node)

Table of (x,y)

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

Arc Table

<table>
<thead>
<tr>
<th>ID</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>v7,...,v11</td>
<td>v2</td>
</tr>
<tr>
<td>2</td>
<td>v8</td>
<td>v11</td>
</tr>
<tr>
<td>3</td>
<td>v1, v2,...,v6</td>
<td>N2</td>
</tr>
</tbody>
</table>

Polygons: Polygon-Arc Topology

<table>
<thead>
<tr>
<th>Arc</th>
<th>L.</th>
<th>Poly</th>
<th>R.</th>
<th>Poly</th>
<th>Poly</th>
<th>Arcs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>World</td>
<td>P1</td>
<td>N1</td>
<td>N2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>P1</td>
<td>P2</td>
<td>N2</td>
<td>N1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>P2</td>
<td>World</td>
<td>N2</td>
<td>N1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Poly ID</th>
<th>FID</th>
<th>Arcs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>100</td>
<td>A1, A2</td>
</tr>
<tr>
<td>P2</td>
<td>102</td>
<td>A2, A3</td>
</tr>
</tbody>
</table>

Arc Coordinates Table

<table>
<thead>
<tr>
<th>Arc</th>
<th>Start</th>
<th>Vertices</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>N1</td>
<td>v7,...,v11</td>
<td>N2</td>
</tr>
<tr>
<td>A2</td>
<td>N2</td>
<td>...</td>
<td>v8</td>
</tr>
<tr>
<td>A3</td>
<td>N2</td>
<td>v1, v2,...,v6</td>
<td>N1</td>
</tr>
</tbody>
</table>

Why bother with topology?

| Provides a way of error trapping and geometry validation after data entry |
| All lines must meet at nodes, all polygons must close, polygons can’t overlap, all lines in a network must join |
| Permits spatial queries, precise measurements |
What kind of queries does topology permit?

- **Connectivity**
  - What is shortest path between features or locations? (networks, flow)
  - Find all fault trace intersections

- **Contiguity**
  - What's adjacent: e.g. Show all granite/limestone contacts
  - Combine all contiguous units with a specific attribute (e.g. lithology) into a single unit

- **Containment (eq. “Area Definition”)**
  - What proportion of an area is underlain by a specific rock type?
  - What is spatial density of specific feature(s)?

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**Logical Models**

**Vector Models**

- **Graphical**
- **Topologic/“georelational”**
- **T.I.N.**
- **Network**

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**Triangulated Irregular Network - TIN**

- Topological 3-D model for representing continuous surfaces using a tessellation of triangles

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**Triangular Irregular Network**

- Network (“tessellation”) of interlocking triangles made from irregularly spaced points with x, y and z values
- Density of triangles varies with density of data points (e.g. spacing of contours) - c.f. raster with uniform data density
- Triangle sides are constructed by connecting adjacent points so that the minimum angle of each triangle is maximized (see “Delaunay Triangulation” for details)
- Can render faces, calculate slope, aspect, surface shade, hidden-line removal, etc.
TIN Topology

Node Table

<table>
<thead>
<tr>
<th>Node</th>
<th>x</th>
<th>y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>9</td>
<td>12</td>
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<tr>
<td>3</td>
<td>11</td>
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<tr>
<td>4</td>
<td>11</td>
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<td>5</td>
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<td>16</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

Tin Topology Table

<table>
<thead>
<tr>
<th>Triangle</th>
<th>Node list</th>
<th>Neighbors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1, 2, 6</td>
<td>C, E</td>
</tr>
<tr>
<td>B</td>
<td>2, 3, 4</td>
<td>C</td>
</tr>
<tr>
<td>C</td>
<td>2, 4, 6</td>
<td>B, D, A</td>
</tr>
<tr>
<td>D</td>
<td>4, 5, 6</td>
<td>E, C, D</td>
</tr>
<tr>
<td>E</td>
<td>5, 1, 6</td>
<td>A, C, D</td>
</tr>
</tbody>
</table>

After Zeiler, Modeling our World, p. 165

3-D TIN Scenes of Seiad Valley fault

3-D TINS, Grand Canyon
Vector Models

- Graphical ✓
- Topologic/"georelational" ✓
- T.I.N. ✓
- Network - not discussed, see Help files