Maps as Numbers: Data Models

- Vertices
- Nodes
- Arcs

S - Start node
E - End node

Reality
Conceptual Models
Logical Models
Physical Models
The Task

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

Translate:

Real World Locations, Paper Map ➔ Computer Files

Spatial Data Models, Topology

Entity Info. ➔ Queriable 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**
- 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.

**Conceptual Models**
- Store well locations with a particular file structure, relationships in a dBase table. Associate table with location.
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. = “fields” of values
  - **Field-based models**
- Organize objects and fields by a common theme; e.g. geology, hydrography, transportation
  - **Thematic layers**
VECTOR MODEL

Discrete objects are represented by points and vectors, continuous fields by irregular tessellation of triangles (A Triangulated Irregular Network: “TIN”)

RASTER MODEL

Discrete objects and continuous fields are represented by an array of square cells (pixels)
How should discrete objects be coded?

- Raster Model
- Vector Model
Logical Models

Vector Model

AREAS (Polygons) consisting of...

LINES (Arcs) consisting of...

POINTS consisting of...

COORDINATES (in projected or geographic units)

\[(x, y)\]

\[(1, 5)\]

\[(5, 1)\]

\[(7, 2)\]

\[(5, 7)\]

\[(3, 8)\]
Continuous Phenomena As Surfaces

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

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

**Vector Line**

- **P1**
- **P2**
- **P3**
- **P4**
- **P5**

**Table of Points**

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

(in UTM coordinates)
Simple Raster Data Structure:

**Raster Line**

-24.56°W

74.24°N

“Dimension” = 5x6

“Resolution” = 12m

**Equivalent Binary “Flat File”**

(Plus “Header” with Raster dimension, resolution and location)

```
1 1 0 0 0 0
0 0 1 0 0 0
0 0 0 1 0 0
0 1 0 0 0 0
0 1 1 1 1 1
```
Vector Models (Raster Next Time...)

- “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 arcs 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
Topological Properties

- **Contiguity**: Adjacency
- **Connectivity**: What’s connected
- **Containment**: What’s inside or outside of a region

 zar Unchanged by translation, scaling, rotation
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**
  - Survey A
  - Survey B
  - Survey C

- **Topologic**

```
<table>
<thead>
<tr>
<th>Polygons</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey A</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Survey B</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>0</td>
</tr>
<tr>
<td>Survey C</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
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after Bonham-Carter, 1994
Lines: Graphic vs. Topologic

- **Graphic (Spaghetti):**
  - Vertices
  - Overshoot ("dangle")
  - Table of (x,y) coordinates

- **Topologic (with meatballs):**
  - Vertices
  - Nodes
  - Table of (x,y) coordinates
  - Table of arcs with IDs, starting and ending nodes

S – Start node
E – End node

1/30/2020
Lines: Arc-Node Topology

### Vertex 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>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>19</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

### Node 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>.</td>
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<tr>
<td>.</td>
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<td>.</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>5</td>
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</table>

### Arc Table

<table>
<thead>
<tr>
<th>ID</th>
<th>FID</th>
<th>F Node</th>
<th>T Node</th>
<th>Vertices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>1</td>
<td>2</td>
<td>1, 2</td>
</tr>
<tr>
<td>2</td>
<td>102</td>
<td>3</td>
<td>2</td>
<td>3, 4, 5, 6, 7</td>
</tr>
<tr>
<td>3</td>
<td>103</td>
<td>3</td>
<td>4</td>
<td>null</td>
</tr>
</tbody>
</table>

**F = “Start” node (F: “From” node)**

**T = “End” node or (T: “To” node)**
Polygons: Polygon-Arc Topology

Arc Table

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

Polygon 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>..., v8</td>
<td>N1</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 (= “Area Definition”)**
  - What proportion of an area is underlain by a specific rock type?
  - What is spatial density of specific feature(s)?
Vector Models

- Graphical ✓
- Topologic/”georelational” ✓
- T.I.N.
- Network
Triangulated Irregular Network -TIN

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

Colorado River at Bright Angel Creek
Triangular Irregular Network

- Network ("tessellation") of edge-sharing 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 – advantages for file size.
- Triangle sides are constructed by connecting adjacent points so that the minimum angle of each triangle is maximized (see “Delaunay Triangulation” for details); a "fat" triangle, not a “sliver” triangle.
- Can render faces, calculate slope, aspect, surface shade, hidden-line removal, etc.
- Practical limit for computation on desktop is ~ 10-15 million nodes.
How Are Triangle Created?
Find the Delaunay Triangulation

- Find the set of circumcircles such that no point lies within a circumcircle
  - Circumcircle is the circle that passes through all 3 corners of a triangle
  - For 4 or more points on the same circumcircle (e.g. a rectangle) the D. Triangulation is not unique
  - For a set of points on a line, the D. Triangulation is degenerate (no triangle)
- D. Triangulation avoids sliver triangles – better represents average slopes and aspects

Triangle
Circumcircle
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>
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</tr>
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</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, -</td>
</tr>
<tr>
<td>E</td>
<td>5, 1, 6</td>
<td>A, C, D</td>
</tr>
</tbody>
</table>

Node Elevations

After Zeiler, Modeling our World, p. 165
TIN for Seiad Valley, CA

- Triangle edges symbolized
- Faces symbolized for elevation & aspect

Seiad Fault
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