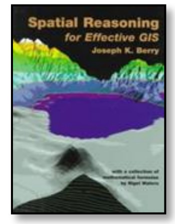
*Beyond Mapping II*

# Topic 7 – Organizing the Map Analysis Toolbox



***Spatial Reasoning*** ***book***



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# What Does Your Computer Really Think of Your Map?

***(GeoWorld, November 1994)***

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To a human, a map is an image composed of colorful symbols. When you see a couple of red lines cross, your graphical intuition says, “a road intersection." When two blue lines combine into one, you think, "fork in a stream." As your eyes wander across a soil map, you easily grasp which soil unit is adjacent to which. Such truths are self-evident.

But that's not the case for a computer-compatible map. To the computer, a map is simply an organized set of numbers— no colored lines, no patterned globs. All of the relationships among map features must be captured in the number set, or the computer can't "see" the map. The term *spatial topology* describes the concept of this linkage, and can be thought of as information added to the pile of map coordinates.

Take a look at the map of the United States shown in figure 1. It's easy for you to detect the characteristic bumps for Florida, New England, and Texas. But the computer only sees thousands of "on-and-off" dots. If an individual dot is on, the computer assigns the appropriate color; it's totally unaware, however, of any patterns formed. This myopic rendering is characteristic of a *graphics package*. They're great for painting maps, but fail to offer the spatial topology needed for map analysis. A graphics package can't tell the difference between a map and the graphical rendering of a rose petal-both are just a pile of unrelated dots.

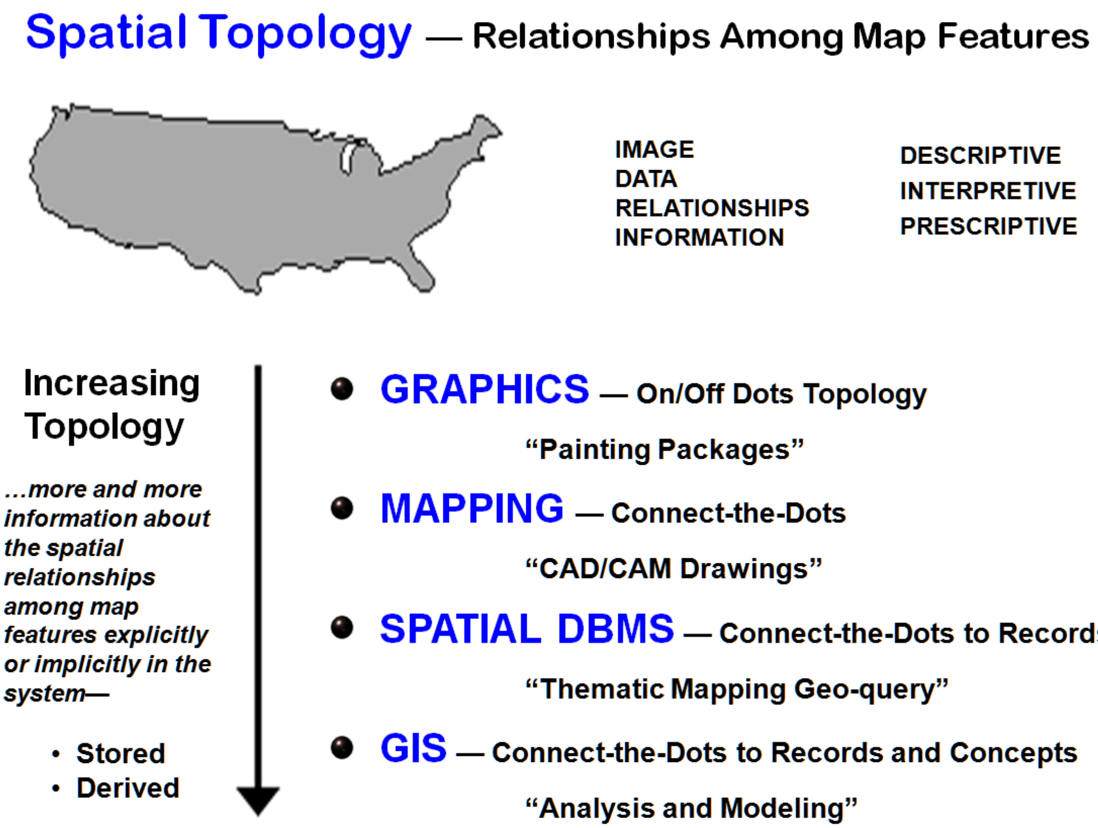


*Figure 1. Spatial topology indicates the degree to which relationships among map features are known to the computer.*

A *mapping package* is a bit more sophisticated, as it has "connect-the-dots" topology that outlines a distinct object. The data structure divides the set of all coordinates into piles, with a separate group for each distinct feature. One approach uses a "header" to identify the number of following coordinates that define the feature. If a point feature is indicated, only a pair of coordinates will follow. For a line feature, the header is followed by a string of coordinates connected sequentially. A polygonal feature marks a string of connected coordinates that closes on itself. That's the basic structure for an AutoCAD .DXF file— whether it's a blueprint for a sewage plant or a map of the world.

A *spatial database management system* extends this ca>based structure to a "connect-the-dots-to-records" relationship. These packages link a CAD-like database, identifying the location of each map feature (spatial record), to another database containing information about each of the features (thematic records). The linkage is made through a common identification number (ID#) for each feature contained in the spatial and thematic datasets.

If you want to know which countries have a population greater than 200 million, the computer searches the appropriate field in the thematic database (thematic entry), then uses the ID#s to find the appropriate coordinates to draw each country that satisfies the query. Similarly, a user can "mouse-click" on a country (spatial entry) and pop up a particular record, a summary of records, or all informational records from the thematic database. A spatial database management system isn't your typical dumb map. The computer knows a lot about each map feature (maybe more than you do, or at least more than you can remember).

However, there are still several gaps in the computer's full understanding of the map. To be a GIS, the computer needs "connect-the-dots-to-records-and-concepts" topology. It needs to keep track of the relationships among connecting and adjacent map features. For example, the common boundary (termed an *arc*) between two polygons includes its "from and to" starting points (termed *nodes*) and the "left and right" polygons it divides. A network of linear features, such as roads or streams, notes which arcs connect to each other and the cost of traversing each arc in either direction. All this extra baggage of spatial topology does nothing to enhance the graphical rendering of a map; it merely gets in the way.

We go to all this trouble, however, because the computer can't find its way around on a non-topological map. A CAD-based road map might look good to you, but your computer sees a disorganized jumble of line segments. To determine an optimal path (or any path for that matter), the computer must have the connections you see stored in the dataset it manipulates. To determine the visual connectivity from one location to another, the computer needs to know the relative intervening elevations. To determine cover type diversity, it needs to quickly identify adjoining cover types around a location.

Each GIS package strikes a balance between stored and derived spatial topology. *Vector systems* tend to <u>store</u> a lot of their topology in the spatial tables linked to the thematic database. A simple "hit to disk" tells the computer the adjacent soil polygon or the next line segment along a road. *Raster systems* tend to <u>derive</u> their topology "on the fly', while processing the data. Finding an adjacent polygon or the next road cell involves a search of eight neighboring cells. In both vector and raster systems, intricate spatial relationships (e.g., point in polygon, intersecting lines, or effective buffers) are derived using the basic analytics in the GIS tool kit. Complex relationships involve spatial models containing several lines of code.

A GIS needs full spatial topology (connect the dots to records and concepts) to perform spatial analysis. As more information about the relationships among map features is bundled into the data structure or GIS tool set, the GIS can perform more work for you. If the system is kept in the dark, it can only draw a map-a simple picture of its database.

# Classifying the Analytical Capabilities of GIS

***(GeoWorld, March 1996)***

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*"It's like nailing jelly to a tree."*

Classifying GIS analytical operations is a bit sticky. Tremendous inroads have been made toward a common understanding of data exchange formats, data structures, and even data content standards. However, agreement on a common, conceptual structure for GIS functionality remains elusive.

In part, that's due to the diverse disciplines claiming title to GIS and to their varied perspectives on what it should do. Coupled with these user differences is the vendor community's desire for product differentiation. The result is a quagmire in communicating GIS capabilities and freely exchanging application models.

Most GIS textbooks identify an essential set of GIS components as data input (encode), data management (store), manipulation/analysis (process), and product output (display). Discussions on the manipulation/analysis component tend to sort GIS operations into two broad categories: thematic and spatial. *Thematic operations* focus on what, or the attributes that describe map features. They involve processes such as data reclassification, aggregation, query, and conditional statements. For example, locating all of the management parcels (map features) containing Cohassett soil and Douglas fir trees ("what" attributes) involves a simple query to the management database, followed by a map display of the results.

*Spatial operations* focus on where, or location, and involve processing such as geometric translations, measurement, coincidence, and spatial statistics. These operations go beyond repackaging descriptive map data to creating entirely new spatial information and/or map features. For example, you could overlay a map of management parcels with a map of terrain steepness to derive an entirely new map identifying the average slope for each of the management parcels. As a result, you have new information (average slope) that didn't previously exist in the database. Or, the overlay could generate a new map with the management parcels partitioned into a subset of new map features based on the relative terrain steepness within the parcel.

At first, the distinction between thematic and spatial operations might seem trivial— merely semantics among the academics. However, the distinction is a major determinant of current GIS applications. Thematic operations reflect well-established database procedures that follow standard Structured Query Language (SQL) protocol. As a result, these applications have a large following of users within the greater computer community.

Spatial operations, however, present new concepts and foreign procedures.  To a confused GIS-neophyte, there appear to be as many organizational schemes for spatial operations as there are GIS products and textbooks.  However, there are a few common threads among the different taxonomies.  First, they all differentiate spatial analysis from "house-keeping" (encoding and storage) and "visualization" (query and display).  Second, they all agree that spatial analysis implies creating new mapped data— either new feature characteristics or new spatial partitioning.

The differences in organizational schemes tend to arise from the taxonomical structure itself- primarily a dichotomy between the developer and user camps.  Developer-oriented schemes group the various spatial operations by how they work.  This approach is well-suited for GIS developers, programmers, and specialists, because it rerates to the algorithmic approaches ingrained in GIS processing.  For example, Tomlin's comprehensive book on spatial analysis identifies three "functional groups" based on how the computer algorithm obtains mapped data for processing (see Author's Note):

1. **Local** functions involve single *individual locations*.
2. **Focal** and incremental functions involve values of immediate or extended *neighborhoods*.
3. **Zonal** functions involve entire or partial zones, or *regions*.

User-oriented schemes, however, focus on input and output products.  The approach is appropriate for general GIS users because it "relates to familiar manual map processing procedures."  My favorite identifies four functional groups (see Author's Notes):

1. **Reclassification** operations *assign a new value to each map feature on a single map* based on the feature's position, initial value, size, shape, or contiguity (clumps).
2. **Overlay** operations *assign new values summarizing the coincidence of map features* from two or more maps based on a point-by-point, region-wide, or map-wide basis.
3. **Distance measurement** operations *assigns map values based on simple or weighted connections among map features* including distance, proximity, movement, and connectivity (optimal paths, line-of-sight, and narrowness).
4. **Neighborhood** operations *assign map values that summarize conditions within the vicinity of map locations* (roving window) based on surface configuration or statistical summary.

From a developer's perspective, calculating "average slope" for each management parcel is a zonal operation (summary of slope data within each parcel), whereas the "partitioning" of individual parcel/slope subdivisions is a local operation (intersecting vector lines or raster cells). From a user's perspective both are simply overlay operations that involve the coincidence of two maps.  The distinctions arise because the developer relates to the differences in the two algorithms, while the user relates to manually superimposing the two maps on a light table.

A third perspective, “application-orientation,” also is used to organize spatial operations. For example, Environmental Systems Research Institute, Inc.'s GRID cell-based modeling toolkit contains more than 200 operations organized into 20 functional groups. The scheme draws from focal and zonal functions (reclassification and distance functions), and identifies application-specific groups to include geometric transformation, statistical, surface and shape analysis functions. Most of the groups, however, distinguish among map-ematical operations to include arithmetic, Boolean, relational, bitwise, combinatorial, logical, accumulative, assignment, trigonometric, exponential, and logarithmic.

Two things should be apparent: (1) we aren't clear about what GIS can do, and (2) we desperately need to be more clear. Before GIS can become a useful button on everyone's computer, there needs to be a level of consistency in processing structure that approaches what's being established in data structures. Without such consistency, we might be able to exchange data, but our spatial reasoning with the data will be fragmented and incomplete-a GIS Tower of Babel. Of course, data considerations aren't nailed down either. But that's another story.

# *Resolving Map Detail*

***(GeoWorld, December 1994)***

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What determines a map's accuracy? There are a lot of factors, but some important ones hinge on the concept of *resolution*. That's not a reference to the determination or tenacity of the cartographer, but a measure of the “level of detail” captured in a map. If a map captures more detail than another map, it has a higher (or finer) resolution.

In one sense, resolution can be related to map scale. We all know that more detail is seen in a map at 1:24,000 (large/local scale) than one of the same area at 1:2,000,000 (small/global scale). The effect is that we have only a few inches of space on a sheet of paper, and if each inch on the paper represents 24,000,000 inches on the ground (2,000,000 feet nearly 400 miles), there isn't much room for details— hence, low resolution.

But scale only mathematically relates map measurements to actual ground distances. It doesn't fully account for the informational scale of a map. *Minimum mapping resolution* (MMR) notes the "level of spatial aggregation," which can be thought of as the smallest area that can be circled and called one thing. For example, the MMR for a l:24,000 vegetation map is typically less than five acres. Sure you can discern a single tree, but would you circle it and call it a timber stand? What's it take-two trees, 10 trees ...?

The MMR for a l : 24,000 soils map is often six to 20 acres, with abundant disclaimers about possible "pockets" of other soils (globs of different soils smaller than the MMR). This informational scale is left to the discretion of the photo interpreter or field technician— largely a function of experience, the pen's width, air photo scale, and the discernability and homogeneity of the forest and soil units.

Another scale-related consideration is *spatial resolution*, identifying "the smallest addressable unit of space" used in delineating map features. In a vector system, the smallest addressable unit is the implied line segment connecting two points. If a point feature is denoted, the length of the line segment is zero, and the spatial resolution is at coordinate accuracy of the reference grid + digitizing error.

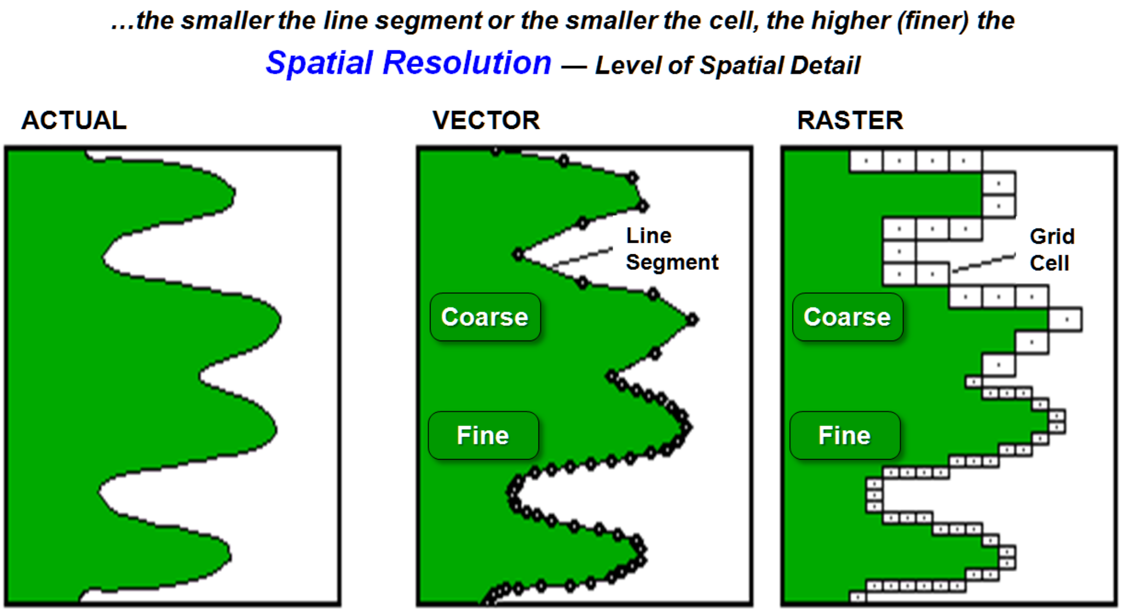


*Figure 1. Spatial resolution identifies the smallest addressable unit of space. It's the line segment in a vector system, and it's the cell size in a raster system.*

As shown in figure 1, the spatial resolution of an arc is a function of the spacing of the digitized points— the closer the points, the higher the spatial resolution (especially on curved segments). A measure of the spatial resolution for a line involves the ratio of deflections in the X and Y directions to line segment length.

The spatial resolution for a raster system is simply the size of cell implied by the analysis grid— the smaller the cell, the higher the spatial resolution (see figure 1). Point features, such as a spring on a water map, are assumed to be contained in a single cell, with the minimal positional accuracy of one-half the diagonal of the cell.

Feature size and positioning aren't the only determinants of map detail. *Thematic resolution* identifies the smallest classification grouping of a map theme (see figure 2). In some applications, a simple forest/non-forest map might provide a sufficient description of vegetative cover. For years, this coarse classification has appeared as green on U.S. Geological Survey topographic sheets. Resource managers require a higher thematic resolution, however, and expand the classification scheme to include forest species, age and stocking level.

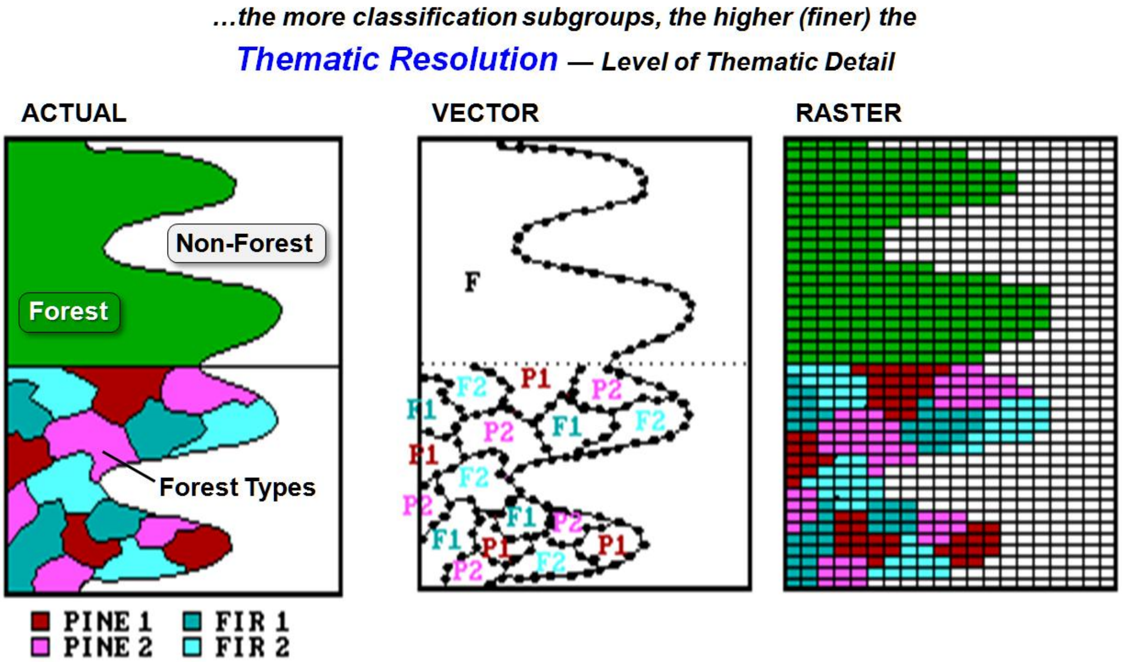


*Figure 2. Thematic resolution identifies the smallest classification grouping of a map theme.*

Another dimension of resolution, termed *temporal resolution*, identifies the frequency of map update. For example, a county planner might be content with a land-use map that's updated every couple of years. The farm agent for the county, however, needs the agricultural land-use theme broken into farm production classes (finer thematic resolution), and these areas need to be updated a couple of times each year (finer temporal resolution).

The concept of informational scale is important in GIS database design. A corporate database requires consistency among its mapped data, or at least specification and translation procedures to track and adjust for inconsistencies. That's a far cry from the traditional plethora of personal paper maps.

For 8,000 years, geographic scale has been the de facto indicator of map detail. But times have changed, and measures of mapping, spatial resolution, thematic resolution and temporal resolution should be integral parts of the modern map's legend and processing procedures. Just keep in mind, the next time your GIS slams a few maps together, that simply translating to the same geographic scale and projection doesn't ensure consistent informational scales. And we all know what happens when you mix scales (ahhhhha!).

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