

*Beyond Mapping I*

## **Introduction – an overview of basic terminology and structure**



[Beyond Mapping](#) book

[Coming to Terms with Terminology](#) — describes the underlying theory of how point, line and areal features are stored in Vector and Raster GISs

[GIS Maps Are Dumb](#) — compares the basic Vector and Raster data structure approaches for storing individual map layers

[Terminology Accelerates Your Intellectual Depletion Allowance](#) — introduces the concepts and organization used in GIS databases comprised of multiple map layers

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## **Coming to Terms with Terminology**

*(GIS World, July 1993)*

*...sticks and stones may break my bones, but terminology will never hurt me*

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Geographical Information Systems (GIS) technology has its roots in computer mapping and spatial data base management. It allows users to effectively organize, update and query mapped data. More recently, GIS has moved from graphic inventory of the landscape to modeling potential uses of the land. The evolution from mapping to data management to modeling is the result of the digital map format and increasing quantification of map analysis procedures. The new procedures and resulting decision-making environment require a rethinking of traditional mapping concepts. Notions of error propagation, weighted distance measurement, visual exposure surfaces, N<sup>th</sup> optimal path, spatial statistics and fragmentation indices form some of the new tools confronting the users of GIS.

To some, the unfamiliar terminology, concepts and capabilities of map analysis represent the "darker side" of GIS technology. Traditional mapping and data base management are comfortable turf. You use the computer to link your file cabinets to your map sheets— it's automation of your daily routine. Your current concepts are easily transferred. But the analytic capabilities of GIS take us well beyond mapping. It challenges old assumptions and suggests new applications. In many respects, GIS is more different than it is similar to traditional map processing. The most obvious changes are in the GIS maps

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themselves. New terms and concepts abound. To go beyond mapping, you must first become comfortable with the basic GIS terminology and organizational structure. This, and the two sections to follow, is designed to develop this foundation.

Like other new technologies, often GIS is guilty of concealing its basic concepts in unfamiliar terminology. The concepts are simple; it's the terms that are complicated. Once you cut through the hyperbole, GIS is a lot like what you do now. In the real world, the landscape is composed of rocks, dirt, trees and fine feathered friends. In your "paper world," these things are represented by words, tables and graphics.

### The "Paper Map World" (*analog*)

#### POINTS



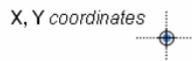
#### LINES



#### AREAS



### The "GIS Map World" (*digital*)



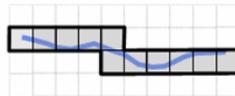
(Vector)



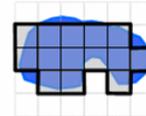
(Vector)



(Raster)



(Raster)



**POINTS** are stored as individual X, Y coordinates (Vector) or as individual Column, Row cell entries in a grid (Raster)

**LINES** are stored as a set of mathematically connected X, Y coordinates (Vector) or as a set of connected grid cells (Raster)

**AREAS** are stored as a set of mathematically connected X, Y coordinates defining the boundary (Vector) or as a set of contiguous cells defining the interior (Raster)

*Figure 1. Basic Map Features. Point, lines and areas are stored as organized sets of coordinates or cells.*

Your maps are graphical abstractions, in which inked lines, shadings and symbols are used to locate landscape *features*. Technically speaking, all maps are composed of three basic features— *points*, *lines* and *areas*. For example, a typical water map identifies a spring as a dot, a stream as a squiggle and lake as a blue glob. GIS can reproduce a similar graphic, but that isn't how it stores the data. In the GIS world, map features most often are represented by X, Y coordinates, as shown in figure 1. Points are identified as a single coordinate pair. Lines are identified as a connected set of points (like "connect-the-dot" pictures). Areas, such as an ownership parcel, are identified by the coordinates defining their borders. This comfortable data format is termed *Vector*.

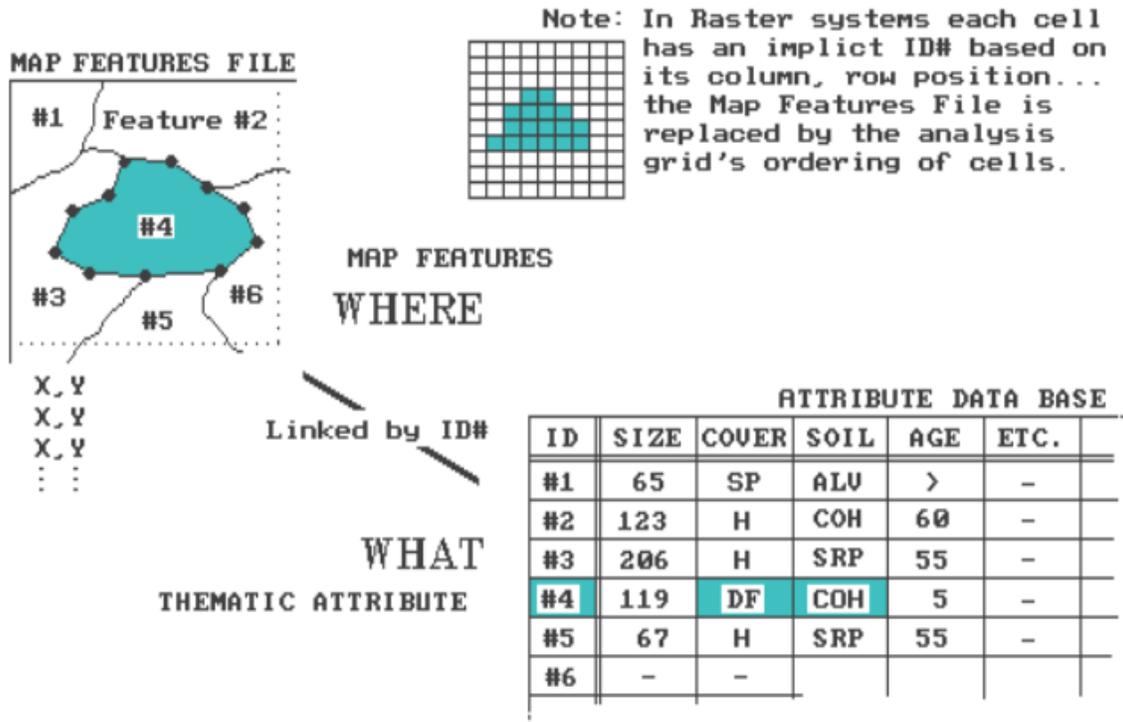
A less familiar format, termed *Raster*, uses an imaginary grid of cells to represent the landscape. Points are stored as individual *Column, Row entries*. Lines are stored as a set of connected cells. Areas are

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identified as all of the cells within the interior of each feature. Although this data structure has several advantages, it has a major disadvantage— lack of precision. If a stream passes through an acre cell, the whole cell is identified as "a stream." You don't know if it is at the top, bottom, or wiggles several times through the center of the cell. Further discussion of data structure is best reserved for later.

For now, let's see how maps are linked to data. In the paper world you are the link, running back and forth between a map and your file cabinets. If you want to know which timber stands have Douglas fir and Cohasset soil, you flip through your files and note the stand numbers of those you're after. You go to the map to locate them. If you wonder what the forest/soil type is for a neighboring stand, you run back to the files look it up.

That's a lot of work for you, but not for your GIS. The map and file cabinets are electronically linked as shown in figure 2. A common *identification number* (ID#) is part of the *map features* and the *thematic attribute* tables. Actually, these tables are just plain old data bases— one stores the X, Y's, while the other stores the information about each stand. Each row of the attribute table (termed a *record*) is divided into several columns termed *items*).



*Figure 2. Linking Features and Attributes. Tables of map feature location (WHERE) and characteristics (WHAT) are linked by a common identification number or column, row grid position.*

This organization is similar to the old days when foresters kept data (items) on a 4x5 card (record) for each stand. In confusing techy-speak, the items COVER= DF and SOIL= COH are searched. In the figure, stand #4 is the only one that meets the joint condition. Its coordinates are plotted to the screen and filled with a vibrant color of your choice. The GIS searches the remaining 40,000 stands and all of the "hits" plotted in less than a minute. If you "mouse click" anywhere on the map, the data about that stand

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pops-up in less than a second. Think of the shoe leather you could save.

The raster world has an analogous link. Each cell has an implicit ID# based on its column, row position. By convention, the analysis grid is ordered as you read a book— from left to right, top to bottom. By implication, the first cell (ID# 1) is in the upper right corner. The next cell (ID# 2) is the adjacent cell to the right. The sequential numbering continues through the last column of the first row. It then picks up with the first column of the second row, and continues the left to right sequence for each successive row. It finally finishes with the lower right cell. Most raster systems store the "what" information in a separate attribute table for each map.

Some systems store the information as one large table with each record indicating a cell and each item describing a separate thematic attribute. If you think about it (and look at Figure 2) the similarities between the vector and raster formats should be apparent. The attribute databases are nearly identical with the exception of the ID#s— explicit for vector, implicit for raster. The map features file for vector stores irregular features, whereas for raster, it is an implied analysis grid of regular cells. There are a lot of similarities between the two but there are also some significant differences... as we will soon see.

## GIS Maps Are Dumb

(GIS World, August 1993)

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When you view a map, all sorts of things are apparent. If two blue lines come together you instantly recognize it as a fork in a stream. As your eye moves along a set of blue lines, you easily comprehend which stream networks are connected, and which are not. Your interpretation of the contour lines even tells you which way the water is flowing.

The GIS isn't as lucky. With your map view, you see it all and bring to bear years of experience, insight and intuition. When a GIS "views" a map, it does it a piece at a time— you're holistic, it's myopic. The relationships among the pieces (termed *spatial topology*) have to be contained in the data's organization. The GIS may know that a coordinate pair (X, Y location) is identified with a stream, but without topology it has no idea how that location relates to all of the other map locations.

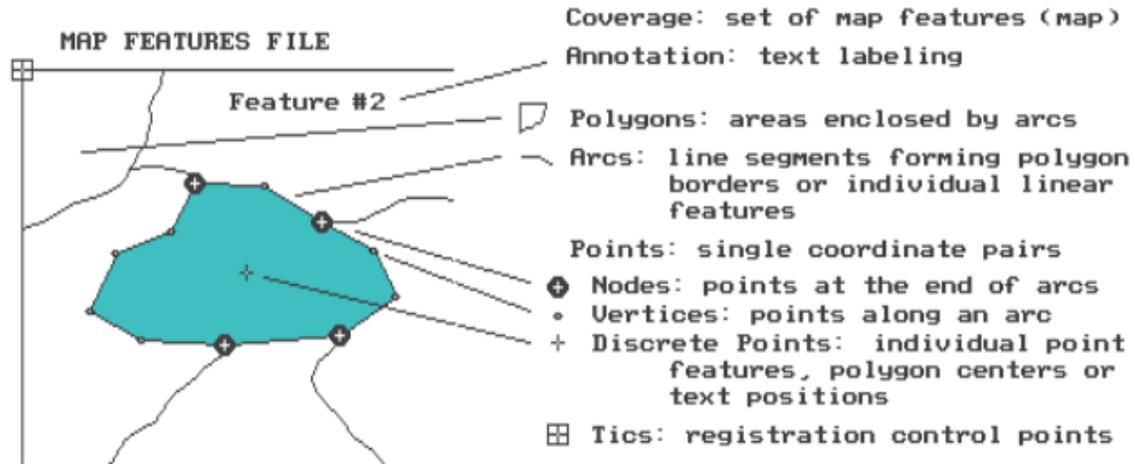
The fundamental element of map structure is the *point*, which is represented by a pair of X, Y values. These coordinates usually relate to a standard referencing grid such as latitude and longitude or UTM meters. There are several types of points, as shown in Figure 1. *Tics* are geographic control points used in registering a map. *Discrete* points are used to represent information such as wells. Also, they are used to associate data with polygons and to the positioning of text. *Vertices* and *Nodes* are used to construct lines and polygons. This process is similar to the "connect-the-dots" drawings from your childhood. You started with the first dot, and then drew from one to the next until things took shape. Vertices are merely passed through, whereas nodes identify the special points where more than two lines meet.

The set of line segments between two nodes is referred to as an *Arc*. In the case of linear features, such as a stream network, the GISs keep track of which arcs are connected. Also it notes the up/down stream nodes of each arc. When the stream flows into a lake the node is tagged as an inlet. The stream node at the other end of the lake is identified as an outlet. You see this stuff— the computer has to be told.

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## GIS MAP STRUCTURE (Vector)



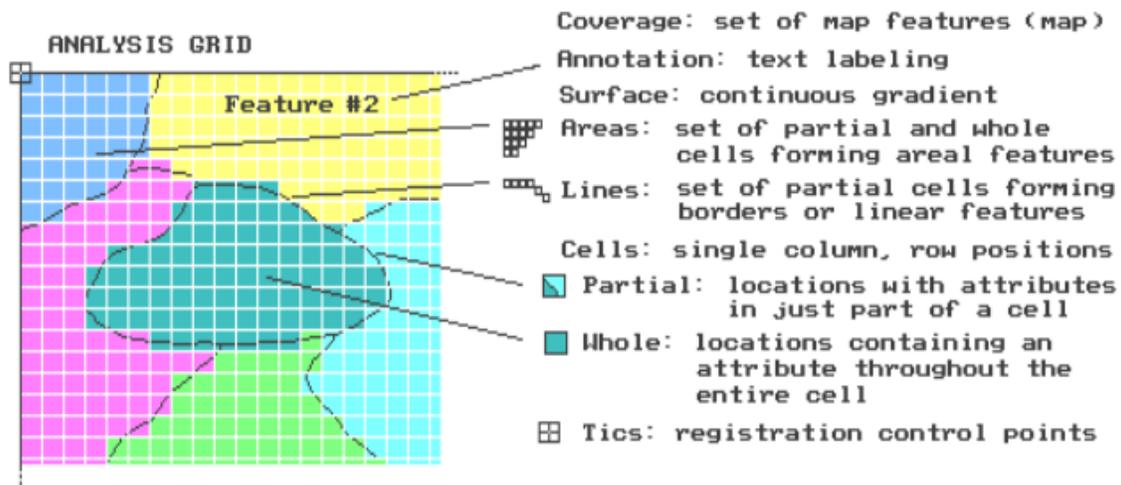
*Figure 1. Vector Organization of Map Features. Map features are formed by organized sets of points (coordinate pairs).*

*Polygons* are areas enclosed by arcs. Just as several points form an arc, a closed series of arcs form polygons. There is a discrete point inside each polygon which serves as a link to the information about it (e.g., size, cover, soil, age). When polygons are adjoining, such as timber stands, their shared arcs are tagged with a special code identifying the linkage. In this manner, the GIS knows the adjoining polygons, and their adjoining polygons, and so on.

With minimal guidance from map *annotations*, you see all this. However, the GIS must incorporate it into its data structure. When it jumps into the middle of a map (termed a *Coverage*), it has to be able to sequentially construct all of the relationships among the map features. Yep, GIS maps are dumb. It's a good thing the computer keeps track of all the details.

Figure 2 shows the same area expressed in raster format. The entire landscape is covered by an imaginary grid of *cells*, the basic unit of this data structure. There are two types of cells. A *whole cell* contains a single map characteristic throughout its interior (e.g., soil or forest type). A *partial cell* contains a mixture of characteristics (e.g., part soils A and B) or just a portion of an individual characteristic (e.g., road or spring). It's the partial cells that account for the lack of precision of raster data. The entire area of a cell is the smallest addressable unit and all spatial detail smaller than a cell is lost. If a finer analysis grid is used, precision increases. In theory, the grid could be as fine as the X, Y coordinates in a vector system, yielding identical precision. However, the storage and processing demands at such a high resolution exceed the capacities of most modern computers.

## GIS MAP STRUCTURE (Raster)



*Figure 2. Raster Organization of Map Features. All map features are formed by organized sets of cells (column, row in analysis grid).*

Until there is a super computer on every desk, an oversized partial cell must be used to identify a single point in space. Connected series of partial cells are used to identify *lines*. And, a set of whole (interior) and partial (border) cells are used to identify *areas*. To simplify things, the characteristic dominating a border cell can be assigned, thus making it a whole cell (and a whole lot easier to store).

The raster structure allows us to extend the basic map features from just points, lines and areas, to *surfaces*. A surface describes the continuous distribution of gradient data. Elevation is a good example, at least in hilly terrain. Each cell is assigned an elevation value that typifies the elevation within its boundary. The raster format of elevation data is termed a digital elevation model (DEM) and contains radically different information than the traditional contour map. Atmospheric pressure, temperature and cost surfaces are other examples of this new type of map feature. When you think about it, we have just "scratched the surface" of this strange beast called GIS.

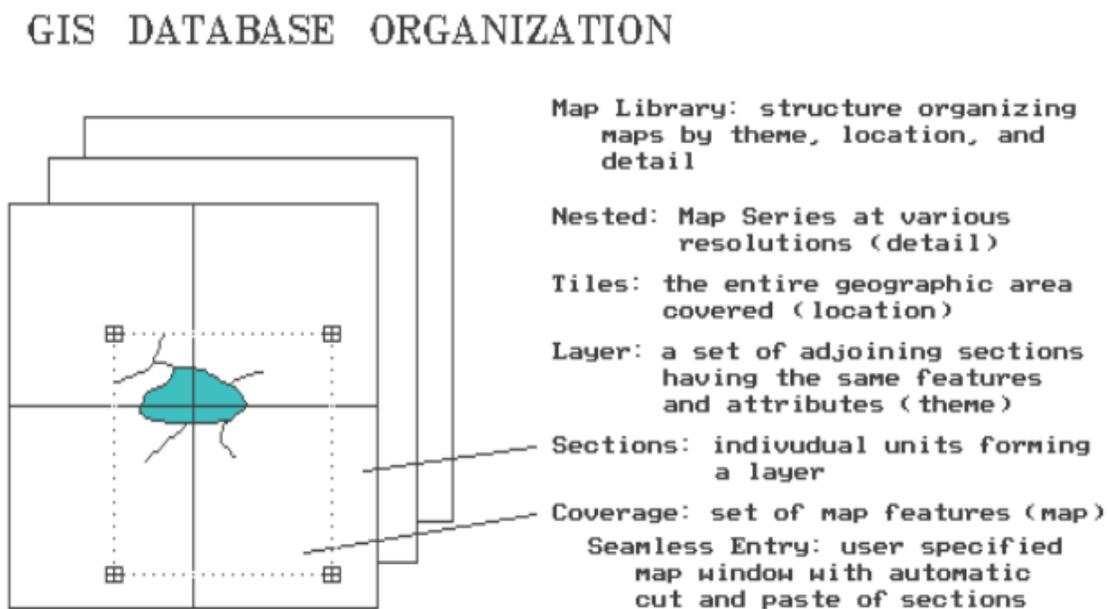
*Author's Note:* As with all *Beyond Mapping* articles, allow me to apologize in advance for the "poetic license" invoked in this terse treatment of a complex subject. The specific terms may vary from system to system, however, the basic concepts presented hold for most systems. For more information see "Cartographic Data Structures," by Pueker and Chrisman, *American Cartographer*, Vol. 2, No. 1, and "Arc/Info: A Geo-Relational Model for Spatial Information," by S. Morehouse, ESRI, 380 New York Street, Redlands, CA, 92373.

## **Terminology Accelerates Your Intellectual Depletion Allowance**

(GIS World, September 1993)

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The last two sections discussed the basic terminology and approaches in data structure. However, before we can jump into the implications of treating maps as data and data structure alternatives, there is a bigger picture that has to be covered— *workspace* organization. Recall that a coverage is the proper term for a GIS map (vector or raster format alike). Three things make a GIS coverage different from a traditional map— it's digital, it represents only one theme and it's *seamless*. By being seamless a user can specify a set of corner coordinates and the GIS will automatically "cut and paste" data from the appropriate storage *sections* (see Figure 1). This process is similar to you locating four adjoining topographic sheets, identifying your project area boundary on each, whacking away with your scissors, and then taping the pieces together. Like sections in the Public Land Survey System (PLSS), a GIS section is simply a means of dividing a large area into regular blocks for efficient referencing. Most users are unaware of the computer's fundamental organization of sections, as the seamless database structure allows them to define any project area they please.



*Figure 1. GIS Data Base Organization. In the computer, maps are stored as sets of adjoining sections.*

A *Layer* is a set of adjoining sections having the same features and attributes. For example, a GIS database might contain separate layers for political jurisdictions, roads, elevation, hydrography, and vegetative cover. In contrast, the familiar USGS topographic map depicts all these plus other themes on a single map sheet. That's what you see, but that's not really the case. Actually, each theme is actually stored as a printer's separate and printed as a sandwich of inked layers.

It is imperative that great care is taken in encoding each section or they might not *edge-match*. As shown in Figure 1 the boundaries of features must continue from section to section. Misalignment of edges is the most frequent cause of pre-mature GIS death. Obviously, your registration and digitizing must be extremely precise, but that may not be enough. A couple of uncontrollable problems can arise. The

original maps you're encoding might not align. If so, adjust them the best you can. Or, more subversive, the classification scheme may not be consistent. For example, you might encode two abutting forest maps with one having six levels of stocking/age classes, and the other having eight. No matter how carefully you digitize they will never edge-match (and your GIS is doomed from the start).

A layer describes the informational content of each GIS map. A *Tile* describes the basic geographic area represented in each of the layers. Although tiles are generally rectangular, they may be any shape, such as a county or forest administration unit. You can think of them as the digital analogue for the map sheets of a conventional map series.

A *nested* map series contains maps at various resolutions over the same geographic area. This concept is particularly applicable to raster databases containing different satellite data. Frequently, a user will store two or more analysis grid resolutions of the same area—a coarse one for strategic and fine one for tactical studies. The familiar USGS's 7.5 and 15 minute topographic series is a "paper product" example of nesting.

One final concept ties it all together—the *map library*. A map library refers to a listing of all GIS maps in a system. The listing is simultaneously organized by location, theme and detail. In a full-featured GIS, you can specify a project area, select the maps you need, then store them in your own workspace. With a healthy understanding of the errors introduced, you can transform maps of various geographic scales and projections, resample maps of various levels of detail, as well as exchange vector and raster maps.

### Data Characterization

- Column, row entries
- Features
- Identification number
- Items
- Map features
- Points, lines, areas (polygons)
- Raster
- Records
- Thematic attribute
- Vector
- X,Y coordinates

### Data Organization

- Edge-match
- Layers
- Map Library
- Nested
- Seamless
- Sections
- Tiles
- Workspace

### Raster Data Model

- Area cell set
- Cell (column, row)
- Line cell series
- Partial cell
- Surfaces
- Whole cell

### Vector Data Model

- Annotation
- Arcs
- Coverage
- Discrete points
- Nodes
- Point
- Polygons
- Tics
- Topology
- Vertices

Whew! All this has been an overload in both mundane and arcane terminology. Some of it makes common sense; some of it may make no sense at all. Keep in mind that you're the intellectual superior of the GIS. You simply see things, while it has to organize everything in excruciating detail. Although

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fundamentally different, you and your GIS need to be agreeable partners. The tabular listing above identifies the “terms” of the agreement in the previous discussions... are you comfortable with them all?

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