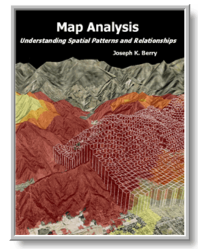
Beyond Mapping III



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Introduction: GIS Software's Changing Roles

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GIS Software's Changing Roles

(GeoWorld, September 1998, pg. 28-30)

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Although GIS is just three decades old, the approach of its software has evolved as much as its capabilities and practical expressions. In the 70's software development primarily occurred on campuses and its products relegated to library shelves of theses. These formative years provided the basic organization (both data and processing structures) we find in the modern GIS. Raging debate centered on "vector vs. raster" formats and efficient algorithms for processing— techy-stuff with minimal resonance outside of the small (but growing) group of innovators.

For a myriad of reasons, this early effort focused on GIS technology itself rather than its applications. First, and foremost, is the necessity of building a viable tool before it can be taken on the road to practical solutions. As with most revolutionary technologies, the "chicken and the egg" parable doesn't apply—the tool must come before the application.

This point was struck home during a recent visit to Disneyland. The newest ride subjects you to a seemingly endless harangue about the future of travel while you wait in line for over an hour. The curious part is that the departed Walt Disney himself is outlining the future through video clips from the 1950s. The dream of futuristic travel (application) hasn't changed much and the 1990s practical reality (tool), as embodied in the herky-jerky ride, is a long way from fulfilling the vision.

What impedes the realization of a technological dream is rarely a lack of vision, but the nuts and bolts needed in its construction. In the case of GIS, the hardware and software environments of the 1970s constrained its use outside of academia. Working with 256K memory and less than a megabyte of disk storage made a GIS engine perform at the level of an old skateboard. However, the environments were sufficient to develop "working prototypes" and test their theoretical foundations. The innovators of this era were able to explore the conceptual terrain of representing "maps as numbers," but their software products were woefully impractical.

With the 1980s came the renaissance of modern computers and with it the hardware and software environments needed by GIS. The research-oriented software gave way to operational systems. Admittedly, the price tags were high and high-end, specialized equipment often required, but the suite of basic features of a modern GIS became available. Software development switched from specialized programs to extensive "toolboxes" and subsequently spawned a new breed of software specialists.

Working within a GIS macro language, such as ARCINFO's Arc Macro Language (AML), customized applications could be addressed. Emphasis moved from programming the "tool" within generis computer languages (e.g., FORTRAN and Pascal), to programming the "application" within a comprehensive GIS language. Expertise broadened from geography and computers to an understanding of the context, factors and relationships of spatial problems. Programming skills were extended to spatial reasoning skills—the ability to postulate problems, perceive patterns and interpret spatial relationships.

From an application developer's perspective the floodgates had opened. From an end user's perspective, however, a key element still was missing—the gigabytes of data demanded by practical applications. Once again GIS applications were frustrated. This time it wasn't the programming environment as much as it was the lagging investment in the conversion from paper maps to their digital form.

But another less obvious impediment hindered progress. As the comic strip character Pogo might say, "…we have found the enemy and it's us." By their very nature, the large GIS shops established to collect, nurture, and process spatial data intimidated their potential customers. The required professional sacrifice at the GIS altar "down the hall and to the right" kept the herds of dormant users away. GIS was more often seen within an organization as an adversary competing for corporate support (a.k.a., a money pit) than as a new and powerful capability one could use to improve workflow and address complex issues in entirely new ways.

The 1990s saw both the data logjam burst and the GIS mystique erode. As Windows-based mapping packages appeared on individuals' desks, awareness of the importance of spatial data and its potential applications flourished. Direct electronic access enabled users to visualize their data without a GIS expert as a co-pilot. For many the thrill of "visualizing mapped data" rivaled that of their first weekend with the car after the learner's permit.

So where are we now? Has the role of GIS developers been extinguished, or merely evolved once again? Like a Power Rangers transformer, software development has taken two forms that blend the 1970s and 80s roles. These states are the direct result of changes in software programming approaches in general, and "object-oriented" programming in particular.

MapInfo's MapX and ESRI's MapObjects are tangible GIS examples of this new era. These packages are functional libraries that contain individual map processing operations. In many ways they are similar to their GIS toolbox predecessors, except they conform to general programming standards of interoperability, thereby enabling them to be linked easily to the wealth of non-GIS programs.

Like using a Lego set, application developers can apply the "building blocks" to construct specific solutions, such as a real estate application that integrates a multiple listing geo-query with a pinch of spatial analysis, a dab of spreadsheet simulation, a splash of chart plotting and a sprinkle of report generation. In this instance, GIS functionality simply becomes one of the ingredients of a solution, not the entire recipe.

In its early stages, GIS required "bootstrap" programming of each operation and was the domain of the computer specialist. The arrival of the GIS toolbox and macro languages allowed an application specialist to develop software that tracked the spatial context of a problem. Today we have *computer specialists* generating functional libraries and *application specialists* assembling the bits of software from a variety of sources to tailor comprehensive solutions.

The distinction between computer and application specialist isn't so much their roles, as it is characteristics of the combined product. From a user's perspective the entire character of a GIS dramatically changes. The look-and-feel evolves from a generic "map-centric view "to an "application-centric" one with a few tailored buttons that walk users through analysis steps that are germane to an application. Instead of presenting users with a generalized set of map processing operations as a maze of buttons, toggles and pull-down menus, only the relevant ones are integrated into the software solution. Seamless links to nonspatial programming "objects," such as pre-processing and post-processing functions, are automatically made.

As the future of GIS unfolds, it will be viewed less as a distinct activity and more as a key element in a thought process. No longer will users "break shrink-wrap" on stand-alone GIS systems. They simply will use GIS capabilities within an application and likely unaware of the underlying functional libraries. GIS technology will finally come into its own by becoming simply part of the fabric of software solutions.

Determining Exactly Where Is What

(GeoWorld, February 2008, pg. 14-15)

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The Wikipedia defines **Accuracy** as "the degree of veracity" (exactness) while **Precision** as "the degree of reproducibility" (repeatable). It uses an archery target as an analogy to explain the difference between the two terms where measurements are compared to arrows shot at the target (left side of figure 1). Accuracy describes the closeness of arrows to the bull's-eye at the target center (actual/correct). Arrows that strike closer to the bullseye are considered more accurate.

Precision, on the other hand, relates to the size of the cluster of several arrows. When the arrows are grouped tightly together, the cluster is considered precise since they all strike close to the same spot, if not necessarily near the bull's-eye. The measurements can be precise, though not necessarily accurate.

However, it is *not* possible to reliably achieve accuracy in individual measurements without precision. If the arrows are not grouped close to one another, they cannot all be close to the bull's-eye. While their average position might be an accurate estimation of the bull's-eye, the individual arrows are inaccurate.

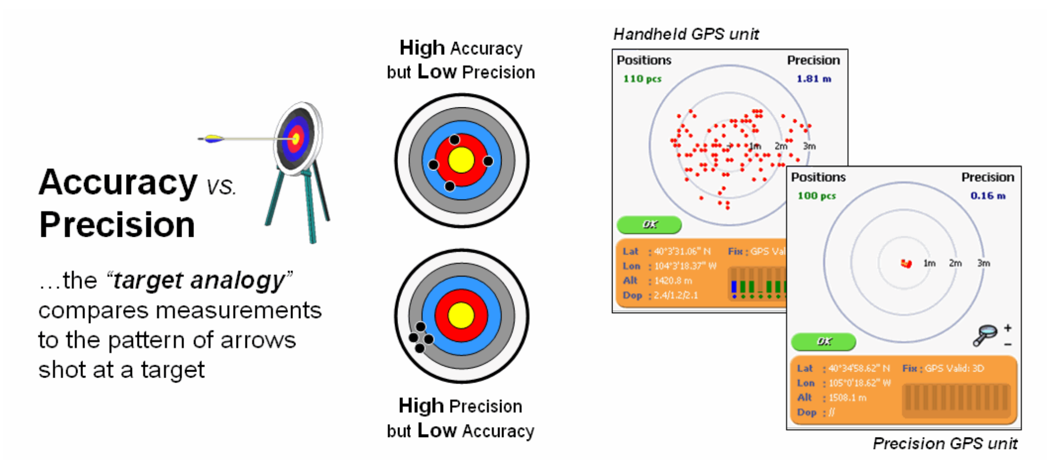

Figure 1. Accuracy refers to "exactness" and Precision refers to "repeatability" of data.

So what does this academic diatribe have to do with GIS, as all maps are accurate and precise, right? …chiseled in stone with a burning bush in the background, right? While that might be mapping's legacy belief, the digital map provides room for different perspectives depending on map type and application.

In GPS technology the target analogy is straight forward (right side of figure 1) and the scattering of GPS measurements over time forms patterns akin to target practice. The handheld GPS unit shows a dispersion of points within three meters of the bull's-eye. A precision GPS unit using a base station for differential correction shows a much tighter, sub-meter cluster at the bull's-eye (actual geographic location).

Whereas GPS readings tell us "where is where" (purely positional), accuracy and precision take on a somewhat different meanings in a GIS involving two informational dimensions—"where is what." Precision is concerned with "Where" (position) and accuracy is concerned with "What" (classification).

Figure 2 illustrates the two-fold consideration of *Precise Placement* of coordinate delineation and *Accurate Assessment* of attribute descriptor for three photo interpreters. The upper-right portion superimposes three parcel delineations with Interpreter B outlining considerably more area than Interpreters A and C—considerable variation in precision. The lower portion of the figure indicates differences in classification with Interpreter B assigning Ponderosa pine as the vegetation type—considerable variation in accuracy to the true Cottonwood vegetation type correctly classified by Interpreters A and C.

Many GIS map layers are precise/accurate, such as surveyed ownership parcels, pipelines and benchmarks. However, many more layers are less precise/accurate, such as interpreted vegetation parcels, fault lines and bird sightings. These differences in map sets, as well as mindsets, often divide the GIS community— those involved with precise/accurate maps and those involved with somewhat fuzzier mapped data.

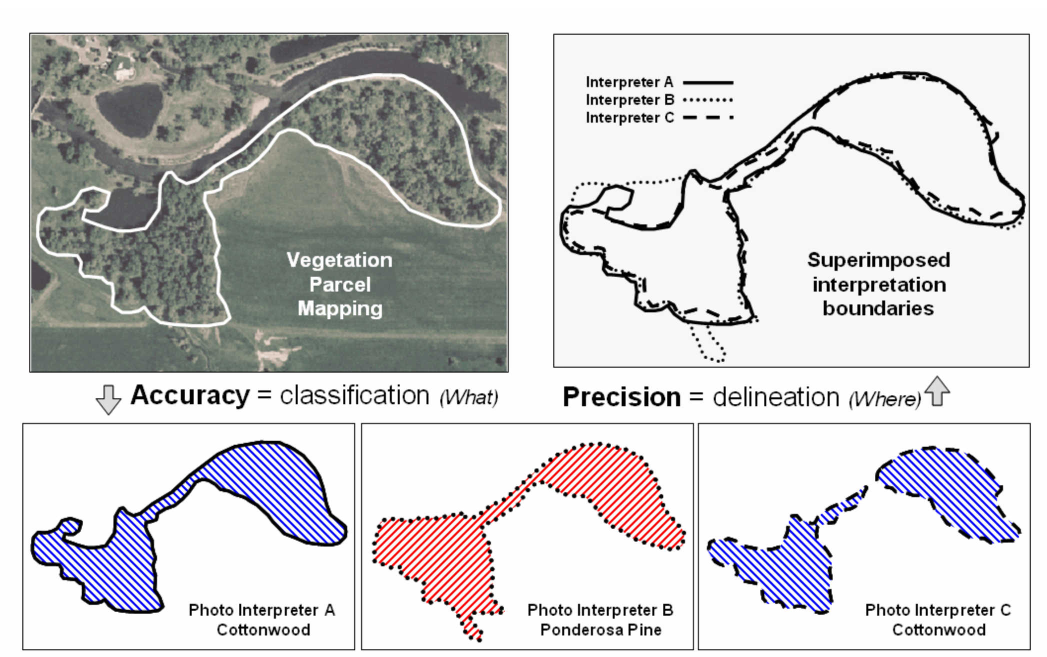

Figure 2. In mapped data, precision refers to placement whereas accuracy refers to classification.

In addition, our paper map legacy of visualizing maps frequently degrades precision/accuracy in detailed mapped data. For example, a detailed map of slope values containing decimal point differences in terrain inclination can be easily calculated from an elevation surface. But the detailed continuous spatial data is often aggregated into just a few discrete categories so humans can easily conceptualize and "see" the information—such as polygonal areas of gentle, moderate and steep terrain. Another example is the reduction of the high precision/accuracy inherent in a continuous "proximity to roads" map to that of a discrete "road buffer" map that simply identifies all locations within a specified reach.

Further thought suggests an additional consideration of GIS "exactness"—*Model Accuracy* reflecting how robust and complete a model is. For example, figure 3 summarizes the logic and results for a electric power line routing model (see Author's Notes). The simplified model seeks to identify the optimal route that avoids areas of high housing density, far from roads, within/near sensitive areas and high visual exposure to houses. The top portion of the figure shows the criteria maps that are calibrated on a scale of 1(most preferred) to 9 (least preferred) in terms of suitability for routing a power line.

As you might suspect, different groups have differing perspectives on the interpretation and relative importance of the routing criteria. For example, homeowners might be most concerned about Housing Density and Visual Exposure; environmentalists most concerned about Road Proximity and Sensitive Areas; and engineers most concerned about Housing Density and Road Proximity. Executing the model for these differences in perspective (relative importance of the criteria) resulted in three different preferred routes.

The lower-left portion of figure 3 shows the spread of the three individual solutions. One isn't more precise/accurate than another, just an expression of a particular perspective of the solution. The lower-right side of the figure suggests yet another way to represent the solution using the simple average of the three preference surfaces to identify an overall route and its optimal corridor—sort of analogous to averaging a series of GPS readings to approximate the bull's-eye. It might be argued that the overall solution is more precise/accurate as it incorporates more perspectives (average of multiple arrows in a cluster).

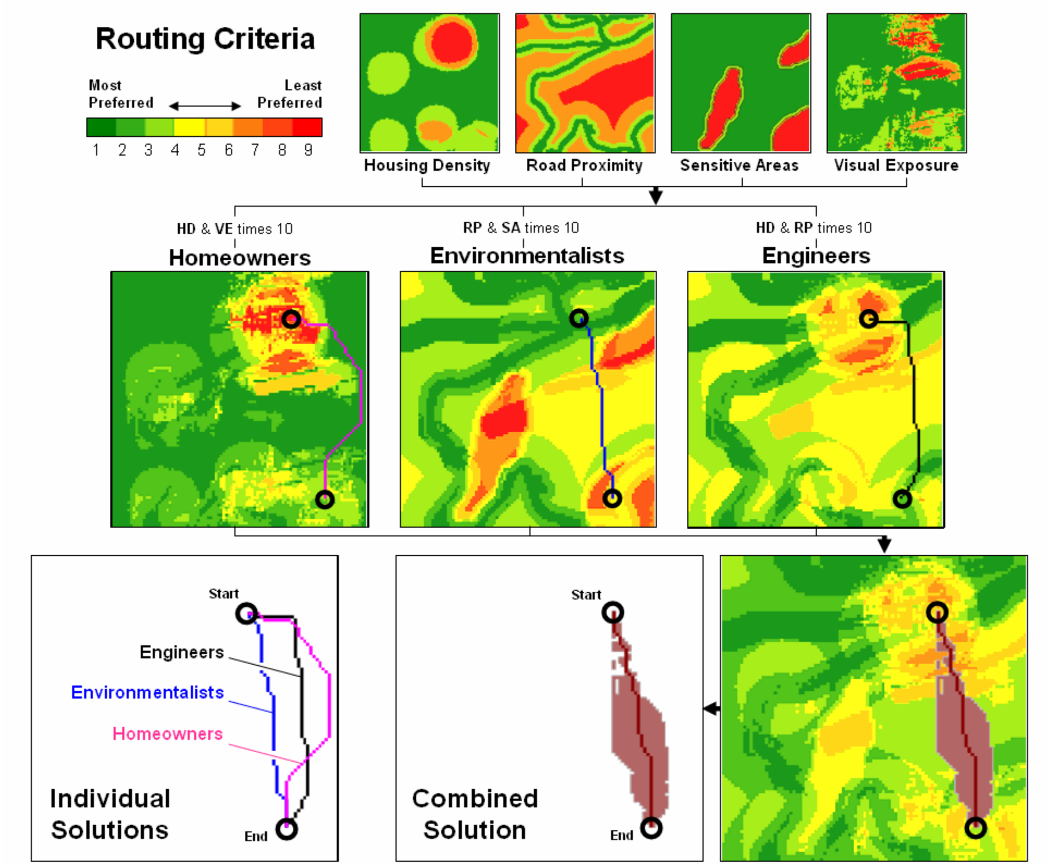

Figure 3. Maps derived by GIS modeling also involve accuracy of the interpretation, logic, understanding and judgment ingrained in the spatial reasoning.

The take home from this discussion is that precision and accuracy is not the same thing and that the terms can take on different meanings for different types of maps and application settings. There are at least three different levels of precision/accuracy—1) "*Where is Where*" considering just precise placement, 2) "*Where is What*" considering placement and classification, and 3) "*Where is What, if you assume…*" considering placement, classification and interpretation/logic/understanding/judgment ingrained in spatial reasoning. Before GIS can go beyond mapping we need to fully recognize that there are appropriate degrees of precision and accuracy—paraphrasing Voltaire, *perfect can be the enemy of good*, or at least good enough to be useful.

Author's Notes: *Related discussion of routing model considerations and procedures is in Topic 8, Spatial Model Example in the book Map Analysis (Berry, 2007; GeoTec Media, **www.geoplace.com/books/MapAnalysis**) and Topic 19, Routing and Optimal Paths in the online Beyond Mapping III compilation (**www.innovativegis.com/basis/MapAnalysis**).*

Finding Common Ground in Paper and Digital Worlds

(GeoWorld, February 2007, pg. 28-30)

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In the real world, landscapes are composed rocks, dirt, water, green stuff and furry/feathered friends. In a “paper world” these things are represented by words, tables and graphics. The traditional paper map is a graphical representation with inked lines, shadings and symbols used to locate landscape features using three basic building blocks— *Points*, *Lines* and *Areas*. For example, a typical water map might identify a well as a dot, a stream as a squiggle and a lake as a blue blob (figure 1). Each feature is considered a well-defined “discrete spatial object” with unique spatial character, positioning and dimension.

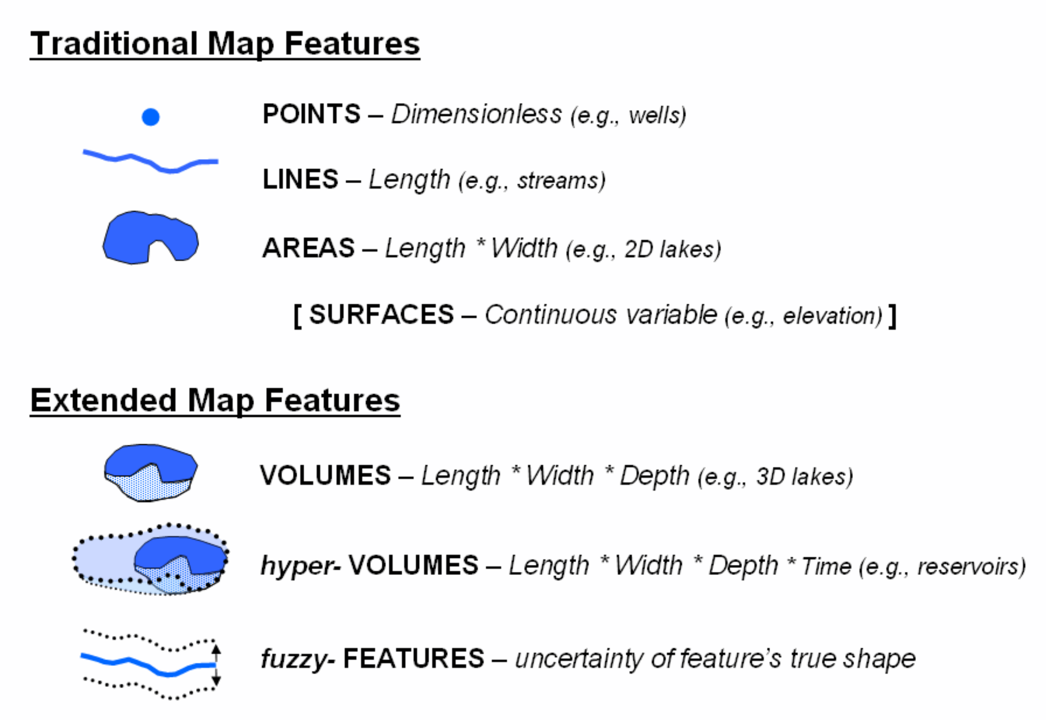

Figure 1. Traditional and Extended Map Features.

In geometry a point is considered dimensionless, however, the corresponding concept in cartography is a dot of ink having a physical dimension of a few inches to several miles depending on the scale of a paper map. Similarly, a line in mathematical theory has only length but is manually mapped as a thin serpentining polygon of the pen’s width. An area feature has both length and width in two-dimensional space. The interplay of mapping precision and accuracy in a digital world involves a discussion of scale and resolution reserved for the next section. For now, let’s consider the revolutionary changes in map form and content brought on by the digital map as outlined in the rest of figure 1.

For thousands of years, manual cartography has been limited to characterizing all geographic phenomena as discrete 2-dimensional spatial objects. However many map variables, such as elevation, change continuously and representation as contour lines suggests a nested series of flat layers like a wedding cake instead of the actual continuously undulating terrain. The introduction of a grid-based data structure provides for a new basic building block—a map *Surface* of continuously changing values throughout geographic space.

Another extension to the building blocks is *Volumes* that track length, width and depth in characterizing discrete or continuous variables in 3-dimensional space. For example, the L,W,D coordinates identify a specific location in a lake and a fourth value (attribute) can identify its temperature, turbidity, salinity or other condition.

A *hyper-Volume* (or hyper-point, -line, -area or -surface) introduces time as an additional abstract coordinate. For example, the weekly water volume of a reservoir might be tracked by L,W,D,T coordinates identifying a location in 3-dimensional space, as well as time combined with a fifth value indicating whether water is present or not. This conceptual extension is a bit tricky and provides discussion fodder about mixed referencing units (e.g., meters and minutes) for a later section. However, the result is a discrete volumetric map feature that shrinks and expands throughout a year—a dynamic spatial entity that at first appears to violate orthodox mapping commandments.

Another mind-bend brought on by the digital map is the concept of *fuzzy-features*. This idea tracks the certainty of a feature or condition at each map location. For example, the boundary line of a soil polygon is a subjective interpretation, while soil parcel's actual edge could be a considerable distance away—"the boundary is likely here (high probability) but could be over there (low probability)." Another fuzzy example is a classified satellite image where statistical probabilities are used to establish which cover type is most likely.

Taken to the hilt, one can conceptualize a data structure that carries L,W,D,T and A,P (attribute and probability) descriptors that identify a location in space and time, as well as characterize its most likely condition, next most likely, and so on—sort of a sandwich of probable conditions. Such a representation challenges the infallible paradigm of mapping but opens a whole new world of error propagation modeling.

Whereas volumes, hyper-volumes and fuzzy-features define the current realm of GIS researchers, an understanding of contemporary approaches for characterizing points, lines, and areas is necessary for all GIS users. Figure 2 outlines the two fundamental approaches—*vector* and *raster* (see Author's Notes).

A *Point* defined by X,Y coordinates in vector, and a *Cell* defined by Col,Row indices in raster, form the basic data structure units—the "smallest addressable unit of space" in a map. Lines are formed by mathematically connecting points (vector) or identifying all of the conjoined cells containing a line (raster). Areas are defined by a set of points that define a closed line encompassing a feature (vector) or by all of the contiguous cells containing a feature (raster).

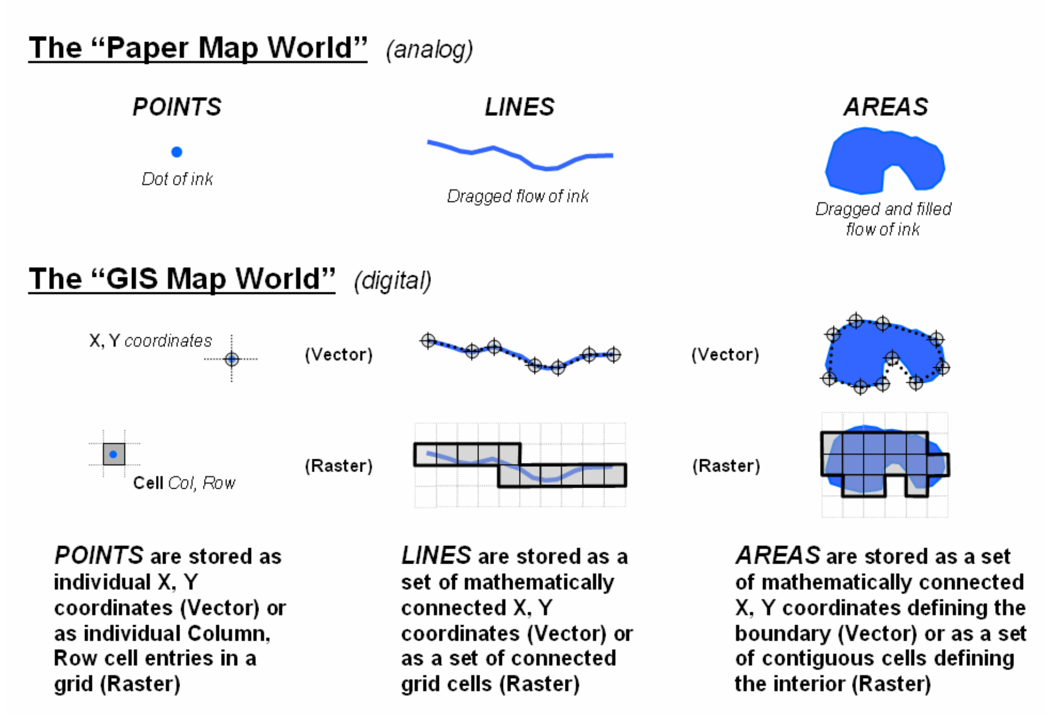

Figure 2. Basic Vector and Raster Data Structure Considerations.

While spatial precision is a major operational difference between vector and raster systems, how they characterize geographic space is important in understanding limitations and capabilities. Vector precisely identifies critical points along a line, but the intervening connections are implied. Raster, on the other hand, identifies all of the cells containing a line without any implied gaps. Similarly, vector precisely stores an area's boundary but implies its interior (must calculate); raster stores the interior but implies the boundary (must calculate).

The differences in "what is defined" and "what is implied" determine just about everything in GIS technology, except maybe the color pallet for display—data structure, storage requirements, algorithms, coding and ultimately appropriate use. Vector systems precisely and efficiently store traditional discrete map objects, such as underground cables and property boundaries (mapping and inventory). Raster systems, on the other hand, predefine continuous geographic space for rapid and enhanced processing of map layers (analysis and modeling).

So how do you think vector and raster systems store surfaces, volumes, hyper-volumes and fuzzy-features? …very poorly, or not at all for vector systems. However raster systems pre-define all of a project area (no gaps) by carrying a thematic value for each cell in a 2-dimensional storage matrix to form a *continuous map surface*. For volumes, a third geographic referencing index is added to extend the 2D cells to 3D cubes in geographic space defined by their X,Y,Z position in the storage matrix see Author's Notes).

A similar expansion is used for hyper-volumes with four indices (X,Y,Z,T) identifying the "position," except in this instance an abstract space is implied due to the differences in geographic and time units. Information about fuzzy-features can be coded into a compound attribute value describing any map feature, where the first few digits identify the character/condition at a location with the trailing two digits identifying the certainty of classification.

The bottom line is that tomorrow's maps aren't simply colorful electronic versions of your grandfather's maps. The digital map is an entirely different beast supporting radically new mapping approaches, perspectives, opportunities and responsibilities.

Author's Notes: *Topic 6, "Alternative Data Structures," in Spatial Reasoning for Effective GIS (Berry 1995, Wiley) contrasts vector and raster data structures and describes related alternative structures including TIN, Quadtree, Rasterized Lines and Vectorized Cells.*

Resolving Map Detail

(GeoWorld, March 2007, pg. 28-30)

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One of the most fundamental concepts in the paper map world is *Geographic Scale*—the relationship between a distance on a map and its corresponding distance on the earth. In equation form, $scale_{ratio}$= *map distance / ground distance* but is often expressed as a representative fraction (RF), such as $scale_{RF}$= *1:63,360* meaning 1 inch on the map represents 63,360 inches (or 1 mile) on the earth's surface.

However in the digital map world, this traditional concept of scale does not exist. While at first this might seem like cartographic heresy, note that the "map distance" component of the relationship is assumed to be fixed as ink marks on paper. In a GIS, however, the map features are stored as organized sets of numbers representing their spatial position (coordinates for "where") and thematic attribute (map values for "what"). One can zoom in and out on the data thereby creating a continuous gradient of geographic scales in the resulting display or hardcopy plot.

Hence geographic scale is a function of the display, not an inherent property of the digital mapped data set. What is important is the implied concept of informational scale, or *Resolution*—the ability to discern detail. Traditionally it is implicit that as geographic scale decreases, resolution also diminishes since drafted feature boundaries must be smoothed, simplified or not shown at all due to the width of the inked lines.

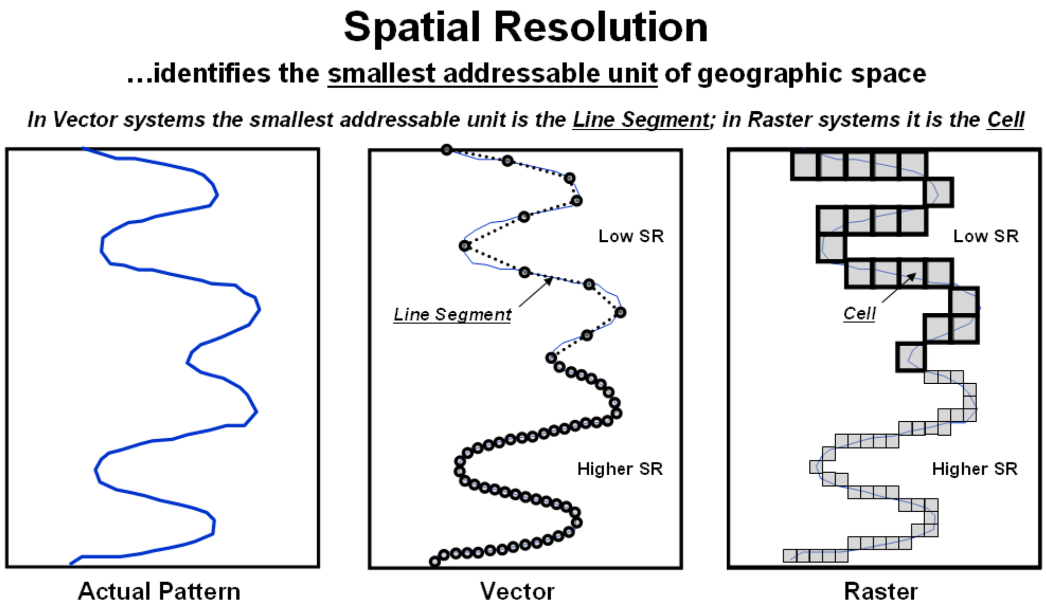

Figure 1. Spatial Resolution describes the level of positional detail used to track a geographic pattern or distribution.

However in a GIS, the concept of resolution is explicit. In fact there are five types of resolution that need to be considered—Spatial, Map, Thematic, Temporal and Model. *Spatial Resolution* is the most basic and identifies the "smallest addressable unit" of geographic space (figure 1). For point features, the X,Y coordinates (vector) and cell size (raster) determine the smallest addressable unit.

For line features in vector, however, the smallest addressable unit is the line segment with larger segments capturing less detail as the implied straight line misses the subtle wiggles and waggles of a pattern. Similarly, large grid cells capture less linear detail than smaller cells.

For polygon features in vector, an entire polygon represents the smallest addressable unit as the boundary needs to be completed before the implied interior condition can be identified. In raster, the smallest addressable unit is defined by the cell size as the condition is carried for each of the cells comprising the interior and edge of a polygon feature.

The concept of spatial resolution easily extends to the level of spatial aggregation or *Map Resolution* that identifies the "smallest physical grouping" of a map theme (figure 2). For example, a high resolution forest map might identify individual trees (very small polygons delineating canopy extent), whereas more generally, numerous trees are used to identify a forest parcel of several acres that ignores the scattered tree occurrences. The size of the minimum polygon is determined by the interpretation process with smaller groupings capturing more detail of the pattern and distribution.

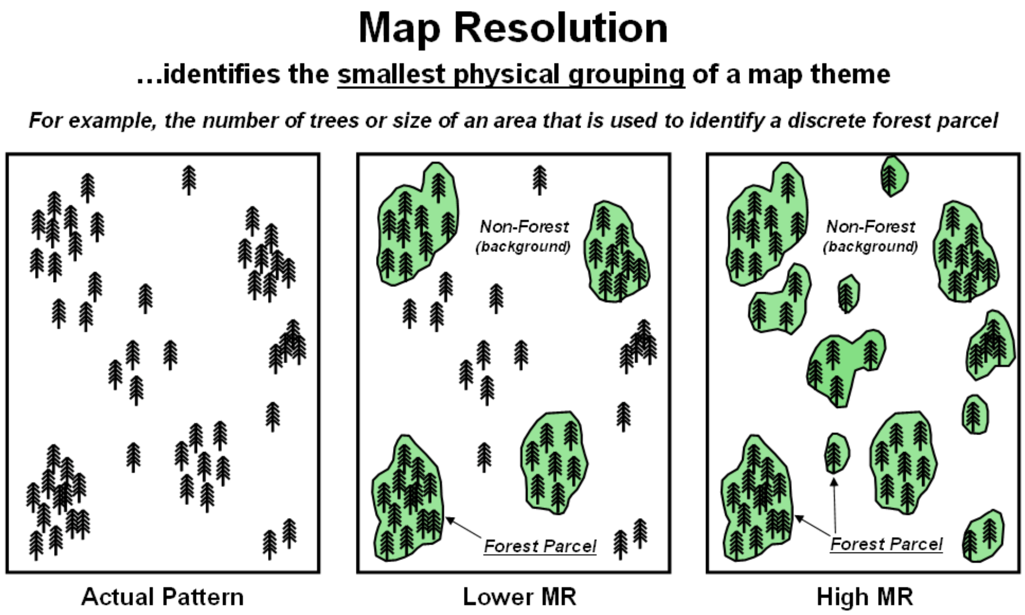

Figure 2. Map Resolution describes the level of physical aggregation used to depict a geographic pattern or distribution.

Thematic Resolution identifies the "smallest classification grouping" of a map theme. For example, a simple forest/non-forest map might provide a sufficient description of vegetation for some uses and this coarse classification has appeared for years as green on USGS topographic sheets. However, resource managers require a higher thematic resolution of vegetation cover and expand the classification scheme to include species, age, stocking level and other characteristics. The result is a finer classification categories of a generalized forest area into smaller more detailed parcels (figure 3).

A forth consideration involves *Temporal Resolution* that identifies the frequency, or time-step of map update. Some data types, such as geological and landform maps, change very slowly and do not need frequent revision. A city planner, on the other hand, needs land use maps that are updated every couple of years and include future development sites. A retail marketer needs even higher temporal resolution and will likely update sales and projection figures on a monthly, weekly or even daily basis.

Model Resolution is the least defined and involves factors affecting the level of detail used in creating a derived map, such as an optimal corridor for an electric transmission line or areas of suitable wildlife habitat. Model resolution considers detail ingrained in 1) the interpretation/analysis assumptions (logic) and 2) the algorithms/procedures (processing) used in implementing a spatial model. For example, a proposed transmission line could be routed considering just terrain steepness for a low model resolution, or extended to include other engineering factors (soils, road proximity, etc.), environmental concerns (wetlands, wildlife habitats, etc.) and social considerations (visual exposure, housing density, etc.) for much higher model resolution.

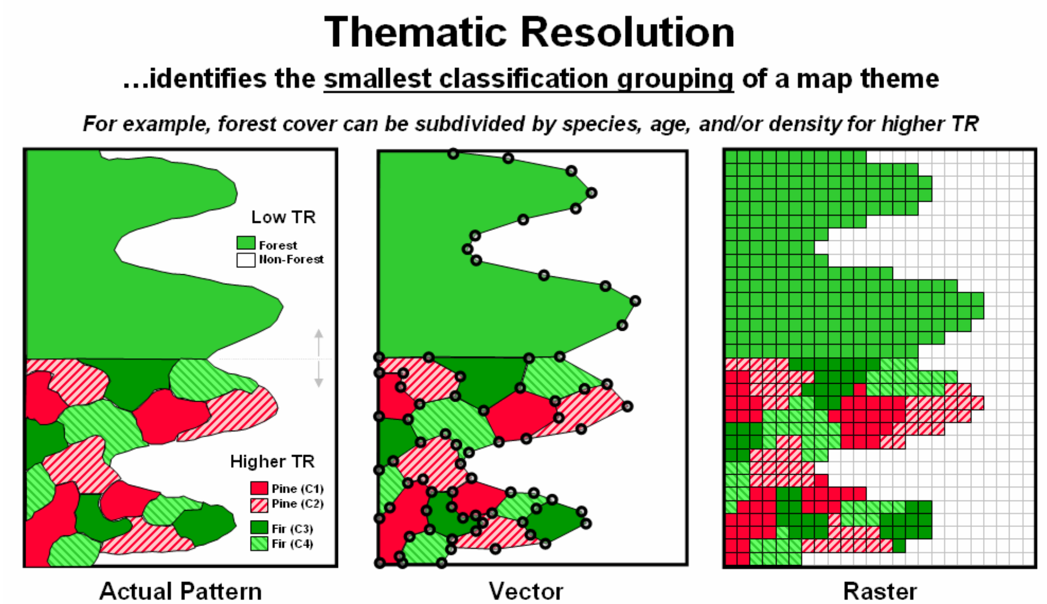

Figure 3. Thematic Resolution describes the level of classification aggregation used to depict a geographic pattern or distribution.

So why should we care about digital map resolution? Because accounting for informational scale is just as important as adjusting for a common geographic scale and projection when interacting with a stack of maps. Our paper map heritage focused on descriptive mapping (inventory of physical phenomena) whereas an increasing part of the GIS revolution focuses on prescriptive mapping (spatial relationships of physical and cognitive interactions). This "thinking with maps" requires a thorough understanding of the spatial, map, thematic, temporal and model resolutions of the maps involved or you will surely be burned.

Referencing the Future

(GeoWorld, April 2007, pg. 28-30)

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Geo-referencing is the cornerstone of GIS. In the mid-1600s the French mathematician, René Descartes established the Cartesian coordinate system that is still in use today. The system determines the location of each point in a plane as defined by two numbers—a *x-coordinate* and a *y-coordinate*.

A third *z-coordinate* is used to extend the system to 3-dimensional geographic space (see Author's Notes). In mapping, these coordinates reference a refined ellipsoid (geodetic datum) that can be conceptualized as a curved surface approximating the mean ocean surface of the earth.

The location and shape of map features can be established by X and Y distances measured along flattened portions of the reference surface (figure 1). The familiar

Universal Transverse Mercator (UTM) coordinates represent E-W and N-S movements in meters along the plane. The rub is that UTM zones are need to break the curved earth surface into a series of small flat, projected subsections that are difficult to edge-match.

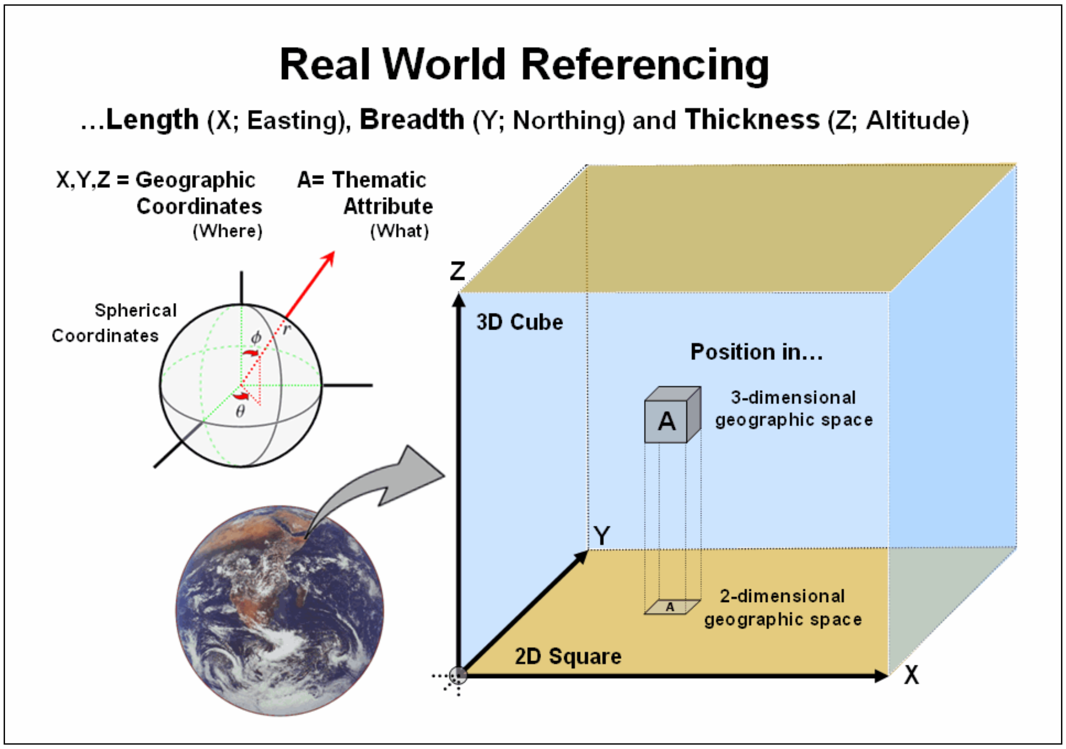

Figure 1. Geographic referencing uses three coordinates to locate map features in real world space.

A variant of the traditional referencing system uses spherical coordinates that are based on solid angles measured from the center of the earth. This natural form for describing positions on a sphere is defined by three coordinates—an *azimuthal angle* (θ) in the X,Y plane from the x-axis, the *polar angle* (φ) from the z-axis, and the *radial distance* (r) from the earth's center (origin). The advantage of a spherical referencing system is that it is seamless throughout the globe and doesn't require projecting to a localized flat plane.

Digital map storage is rapidly moving toward spherical referencing that uses latitude and longitude in decimal degrees for internal storage and on-the-fly conversion to any planar projection. This radical change from our paper map heritage is fueled by ubiquitous use of GPS and a desire for global databases that easily walk across political and administrative boundaries.

Since the digital map is a radical departure from the paper map, other alternative referencing schemes are possible. For example, hexagons can replace the Cartesian grid squares we have used for hundreds of years (top portion of figure 2). The hexagon naturally nests to form a continuous network like a beehive's honeycomb. An important property of a hexagon grid is that it better represents curved surfaces than a square grid—

a soccer ball stitched from squares wouldn't roll the same *[Note: actually a soccer ball is a composite of hexagons (white) and pentagons (black)]*.

However the most important property is that a hexagon has six sides instead of four. The added directions provide a foothold for more precise measurement of continuous movement— one can turn right- and left-oblique as well as just right and left. Traditional routing models using Least Cost Path would benefit greatly.

Expanding to 3-dimensional geographic space provides for polyhedrons to replace cubes. For example, a dodecahedron is a nesting twelve-sided object that can be used instead of the six-sided cube. Weather and ground water flow modeling could be greatly enhanced by the increased options for transfer from a location to its larger set of adjoining locations. The computations for cross-products of vectors, such as warp-speed cruise missiles, could be greatly assisted as they are affected by different atmospheric conditions and evasive trajectories.

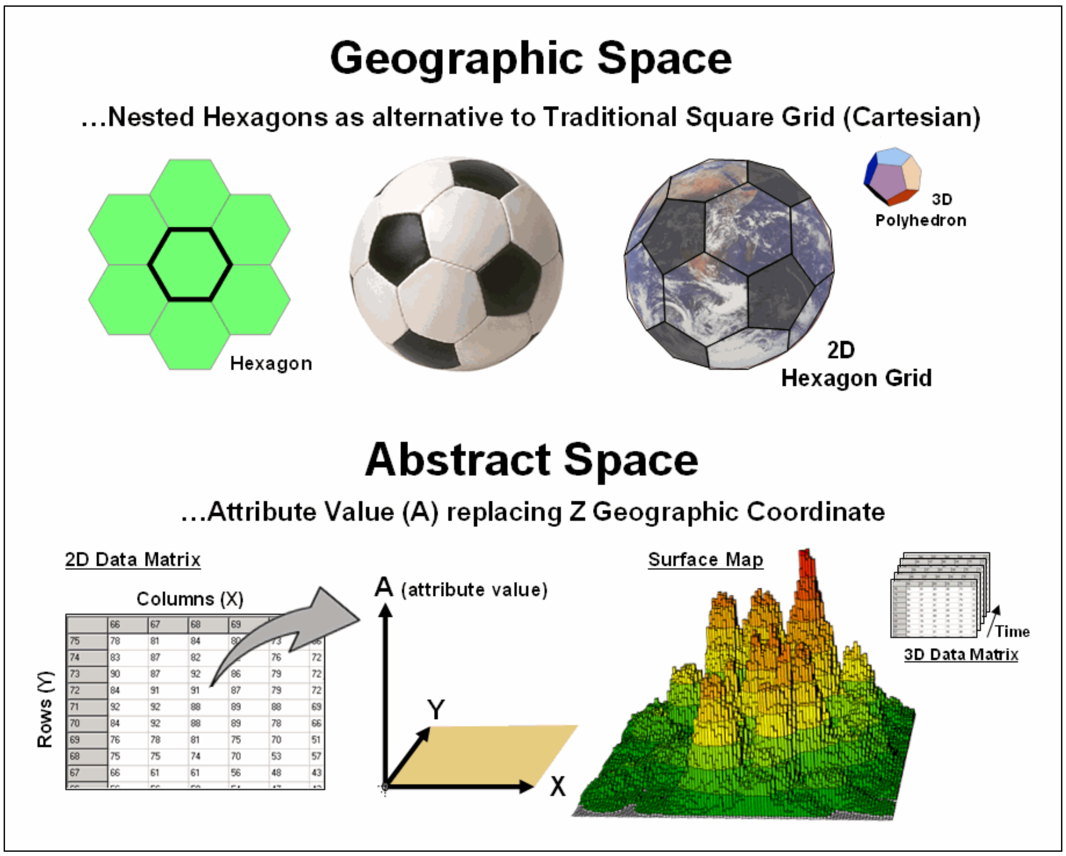

Figure 2. Alternative referencing systems and abstract space characterization are possible through the digital nature of modern maps.

Another extension involves the use of abstract space (bottom portion of figure 2). For example, the Z-coordinate can be replaced with an attribute value to generate a map surface, such as customer density. In this instance, the abstract referencing is a mixture of spatial and attribute "coordinates" and doesn't imply 3-dimensional, real word geographic occurrences. Instead, it relates geography and conditions in an extremely useful way for conceptualizing patterns. Normalization along the abstract coordinate axis is an important consideration for both visualization and analysis.

This brings us to space-time referencing. During a recent panel discussion I was challenged for suggesting such a combination is possible within a GIS. The idea has been debated for years by philosophers and physicists but H.G. Wells' succinct description is one of the best—

> *'Clearly,' the Time Traveller proceeded, 'any real body must have extension in four directions: it must have Length, Breadth, Thickness, and - Duration. But through a natural infirmity of the flesh, which I will explain to you in a moment, we incline to overlook this fact. There are really four dimensions, three which we call the three planes of Space, and a fourth, Time. There is, however, a tendency to draw an unreal distinction between the former three dimensions and the latter, because it happens that our consciousness moves intermittently in one direction along the latter from the beginning to the end of our lives.' (Chapter 1, Time Machine).*

The upshot seems to be that a fourth dimension exists (see Author's Notes), it is just you can't go there in person. But a GIS can easily take you there—conceptually that is. For example, an additional abstract "coordinate" representing time can be added to form a 3-dimensional data matrix. The GIS picks off the customer density data for the first "page" and displays it as in the figure. Then it uses the data on the on the second page (one time step forward) and displays it. This is repeated to cycle through time and you see an animation where the peaks and valleys of the density surface move with time.

So animation enables you to move around a city (X,Y) viewing the space-time relationship of customer density (A). In a similar manner you could evaluate a forest "green-up" model to predict re-growth at a series of time steps after harvesting to look into future landscape conditions. Or you can watch the progression over time of ground water pollutant flow in 3D space (4D data matrix) using a semi-transparent dodecahedron solid grid just for fun and increased modeling accuracy. In fact, it can be argued that GIS is inherently *n*-dimensional when you consider a map stack of multiple attributes and time is simply another abstract dimension.

My suspicions are that revolutions in referencing will be a big part of GIS's frontier in the 2010s. See you there?

Author's Notes*: an excellent online reference for the basic geometry concepts underlying traditional and future geo-referencing techniques is the Wolfram MathWorld pages, such as the posting describing the dodecahedron at http://mathworld.wolfram.com/Dodecahedron.html; a BBC posting at http://www.bbc.co.uk/science/space/exploration/timetravel/index.shtml contains an interesting discussion of the space/time reality. See the online book Beyond Mapping III, Topic 27, "GIS Evolution and Future Trends," for a discussion of 3-dimensional GIS posted at www.innovativegis.com/basis/MapAnalysis/.*

Is it Soup Yet?

(GeoWorld, February 2009)

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In the forty-odd years of computer-tinkering with maps our perspectives and terminologies have radically changed. My first encounter was in the late 1960s as an undergraduate research assistant at the University of California, Berkeley. The entry point was through photogrammetric interpretation in the pursuit of a high resolution contour map for the school's forest. In those days one stared at pair of stereo-matched aerial photos and marched a dot at a constant elevation around the three-dimensional surface that appeared. The result was an inked contour line drawn by a drafting arm that was mechanically connected to the stereo plotter— raise the dot and re-walk to delineate the next higher contour line.

The research effort took this process to a new level by augmenting the mechanical arm with potentiometers that converted the movements of the arm into X,Y coordinates that, in turn, were recorded by direct entry into a keypunch machine. After several months of tinkering with the Rube Goldberg device several boxes of punch cards were generated containing the digital representation of the contour lines that depicted the undulating shape of the terrain surface.

The card boxes then were transferred to a guru who ran the only large-bed plotter on campus and after a couple of more months of tinkering the inked lines emerged. While far from operational, the research crossed a technological threshold by replacing the analog mechanics of traditional drafting with the digital encoding required to drive the cold steel arm of a plotter—maps were catapulted from drawings to organized sets of numbers.

In the 1970's **Computer Mapping** emerged through the efforts of several loosely allied fields involved in mapping—geography for the underlying theory, computer science for the software, engineering for the hardware and several applied fields for the practical applications. As depicted in figure 1, some of the more important perspectives and definitions of the emerging technology at that time were:

- **Surveying** is the technique and science of accurately determining the terrestrial or three-dimensional space position of points and the distances and angles between them where these points are usually, but not exclusively, associated with positions on the surface of the Earth, and are often used to establish land maps and boundaries for ownership or governmental purposes. *(Wikipedia definition)*
- **Photogrammetry** is the first remote sensing technology ever developed, in which geometric properties about objects are determined from photographic images. *(Wikipedia definition)*
- **Remote Sensing** is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing device(s) that is not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, etc.). *(Wikipedia definition)*

– **Computer-aided Drafting and Computer-assisted Mapping (CAD/CAM)** is the mapping expression of Computer-aided Design that uses computer technology to aid in the design and particularly the drafting (technical drawing and engineering drawing) of a part or product. *(Wikipedia definition)*
– **Automated Cartography** is the process of producing maps with the aid of computer driven devices such as plotters and graphical displays. *(Webopedia definition)*
– **Image processing** is any form of signal processing for which the input is an image, such as photographs or frames of video with the output of image processing being either an image or a set of characteristics or parameters related to the image. *(Wikipedia definition)*

The common thread at the time was an inspiration to automate the map drafting process by exploiting the new digital map form. The focus was on the graphical rendering of the precise placement of map features—an automated means of generating traditional map products. For example, the boxes of cards containing the contour lines of research project were mothballed after the plotter generated the printer's separate used for printing multiple copies of the map.

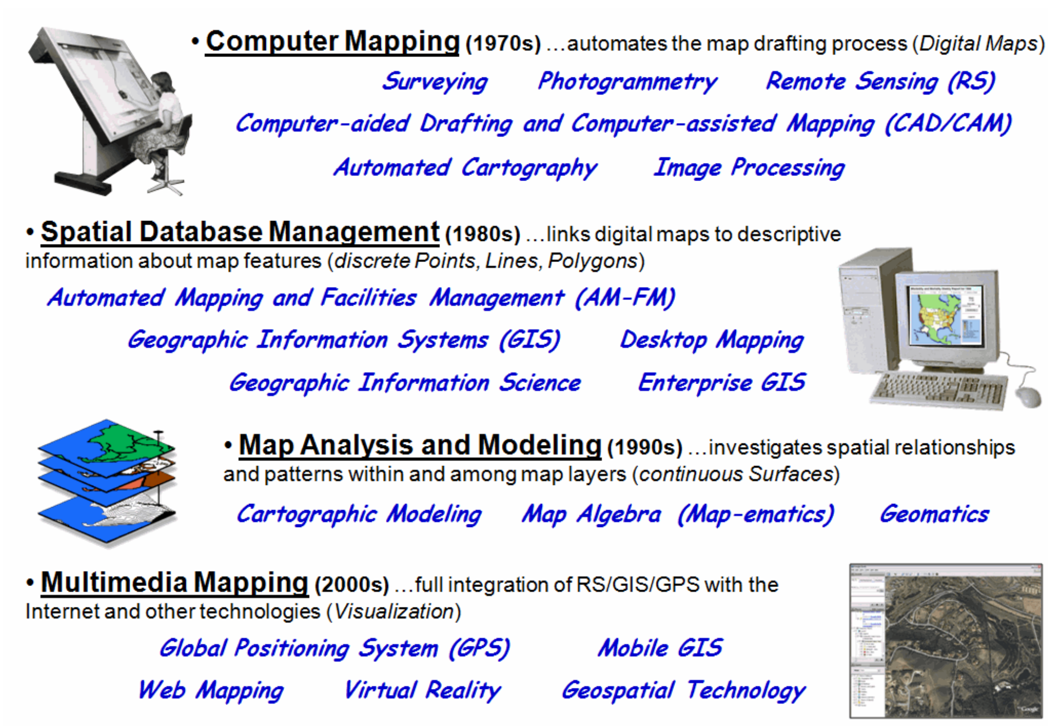

Figure 1. The terminology and paradigm trajectory of GIS's evolution.

Spatial Database Management expanded this view in the 1980s by combining the digital map coordinates (*Where*) with database attributes describing the map features (*What*). The focus shifted to the digital nature of mapped data and the new organizational capabilities it provided. Some of the perspectives and terms associated with the era were:

– **Automated Mapping and Facilities Management (AM-FM)** seeks to automate the mapping process and to manage facilities represented by items on the map. *(GITA definition)*
– **Geographic Information System (GIS)** is an information system for capturing, storing, analyzing, managing and presenting data which are spatially referenced (linked to location). *(Wikipedia definition)*
– **Geographic Information Science (GISc or GISci)** is the academic theory behind the development, use, and application of geographic information systems (GIS). *(Wikipedia definition)*
– **Desktop Mapping** involves using a desktop computer to perform digital mapping functions. (*eNCYCLOPEDIA definition*)
– **Enterprise GIS** is a platform for delivering organization-wide geospatial capabilities providing for the free flow of information. *(ESRI definition)*

Geo-query became the rage and organizations scurried to integrate their paper maps and management records for cost savings and improved information access. The overriding focus was on efficient recordkeeping, processing and information retrieval. The approach linked *discrete Point, Line and Polygon* features to database records describing the spatial entities.

Map Analysis and Modeling in the 1990s changed the traditional mapping paradigm by introducing a new fundamental map feature—the *continuous Surface*. Some of the more important terms and perspectives of that era were:

– **Cartographic Modeling** is a process that identifies a set of interacting, ordered map operations that act on raw data, as well as derived and intermediate data, to simulate a spatial decision making process. *(Tomlin definition)*
– **Map Algebra** (and **Map-*ematics***) is a simple and an elegant set-based algebra for manipulating geographic data where the input and output for each operator is a map and the operators can be combined into a procedure to perform complex tasks. *(Wikipedia definition)*
– **Geomatics** incorporates the older field of surveying along with many other aspects of spatial data management which integrates acquisition, modeling, analysis, and management of spatially referenced data. *(Wikipedia definition)*

While much of the map-*ematical* theory and procedures were in place much earlier, this era saw a broadening of interest in map analysis and modeling capabilities. The comfortable concepts and successful extensions of traditional mapping through Spatial Database Management systems lead many organizations to venture into the more unfamiliar realms of spatial analysis and statistics. The emerging applications directly infused spatial considerations into the decision-making process by expanding "*Where* is *What?*" recordkeeping to *"Why, So What and What If?"* spatial reasoning—thinking with maps to solve complex problems.

Multimedia Mapping in the 2000s turned the technology totally on its head by bringing it to the masses. Spurred by the proliferation of personal computers and Internet access, spatial information and some "killer apps" have redefined what maps are, how one interacts with them, as well as their applications. Important terms and perspectives of the times include:

- **Global Positioning System (GPS)** is the only fully functional Global Navigation Satellite System (GNSS) that enable GPS receivers to determine their current location, the time, and their velocity. *(Wikipedia definition)*
- **Mobile GIS** is the use of geographic data in the field on mobile devices that integrates three essential components— Global Positioning System (GPS), rugged handheld computers, and GIS software. *(Trimble definition)*
- **Web Mapping** is the process of designing, implementing, generating and delivering maps on the World Wide Web. *(Wikipedia definition)*
- **Virtual Reality** (**VR**) is a technology which allows a user to interact with a computer-simulated environment, be it a real or imagined one. *(Wikipedia definition)*
- **Geospatial Technology** refers to technology used for visualization, measurement, and analysis of features or phenomena that occur on the earth that includes three different technologies that are all related to mapping features on the surface of the earth— GPS (global positioning systems), GIS (geographical information systems), and RS (remote sensing). *(Wikipedia definition)*

The technology has assumed a commonplace status in society as people access real-time driving directions, routinely check home values in their neighborhood and virtually "fly" to anyplace place on the earth to view the surroundings or checkout a restaurant's menu. While spatial information isn't the driver of this global electronic revolution, the technology both benefits from and contributes to its richness. What was just a gleam in a handful of researchers' eyes thirty years ago has evolved into a pervasive layer in the fabric of society, not to mention a major industry.

But what are the perspectives and terms defining the technology's future? That's ample fodder for the next section.

Author's Notes: *a brief White Paper describing GIS's evolution is posted online at www.innovativegis.com/basis/Papers/Other/Geotechnology/Geotechnology_history_future.htm . An interesting and useful Glossary of GIS terms by Blinn, Queen and Maki of the University of Minnesota is posted at www.extension.umn.edu/distribution/naturalresources/components/DD6097ag.html.*

What's in a Name

(GeoWorld, March 2009)

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The previous section traced the evolution of modern mapping by identifying some of the more important labels and terminology that have been used to describe and explain what is involved. In just four decades, the field has progressed from an era of *Computer Mapping* to *Spatial Database Management*, then to *Map Analysis and Modeling* and finally to *Multimedia Mapping*.

The perspective of the technology has expanded from simply automated cartography to an information science that links spatial and attribute data, then to an analytical framework for investigating spatial patterns/relationships and finally to the full integration of the spatial triad of Remote Sensing (RS), Geographic Information Systems (GIS) and the Global Positioning System (GPS) with the Internet and other applied technologies.

While the evolution is in large part driven by technological advances, it also reflects an expanding acceptance and understanding by user communities and the general public. In fact, the field has matured to a point where the US Department of Labor has identified Geotechnology as "one of the three most important emerging and evolving fields, along with nanotechnology and biotechnology" (see Author's Notes). This is rare company indeed.

The Wikipedia defines *Biotechnology* as "any technological application that uses biological systems, living organisms, or derivations thereof, to make or modify products or processes for specific use," and *Nanotechnology* as "a field whose theme is the control of matter on and atomic and molecular scale." By any measure these are sweeping definitions that encompass a multitude of sub-disciplines, conceptual approaches and paradigms. Figure 1 suggests a similar sweeping conceptualization for *Geotechnology*.

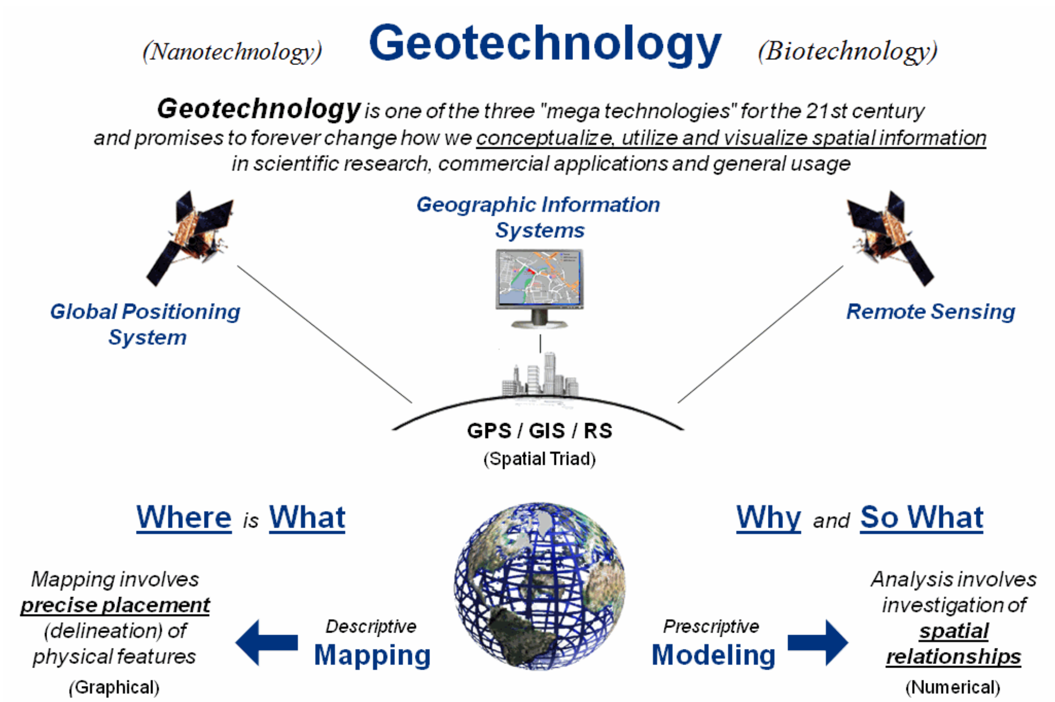
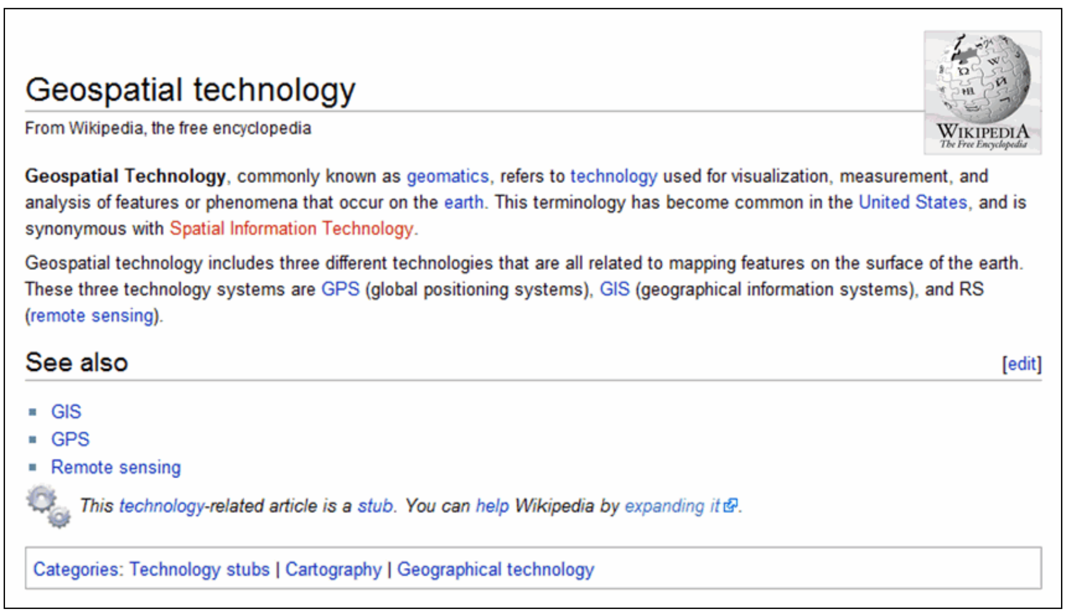


Figure 1. Conceptual framework of Geotechnology.

The top portion of the figure relates Geotechnology to "spatial information" in a broad stroke similar to biotechnology's use of "biological systems" and nanotechnology's use of "control of matter." The middle portion identifies the three related technologies for mapping features on the surface of the earth— GPS, GIS and RS. The bottom portion identifies the two dominant application arenas that emphasize descriptive Mapping (*Where* is *What*) and prescriptive Modeling (*Why* and *So What*).

What is most important to keep in mind is that geotechnology, like bio- and nanotechnology, is greater than the sum of its parts—GPS, GIS and RS. While these individual mapping technologies provide the enabling capabilities, it is the application environments themselves that propel geotechnology to mega status. For example, precision agriculture couples the spatial triad with robotics to completely change crop production. Similarly, coupling "computer agents" with the spatial triad produces an interactive system that has radically altered marketing and advertising through spatially-specific queries and displayed results. Or coupling immersive photography with the spatial triad to generate an entirely type of "street view" map that drastically changes 8,000 years of analog mapping.

To this point in our technology's short four decade evolution it has been repeatedly defined from within. The current "geospatial technology" moniker focuses on the interworking parts that resonates with GIS specialists (see figure 2). However to the uninitiated, the term is as off-putting as it is confusing—*geo* (Latin for the earth), *spatial* (pertaining to space), *technology* (application of science). Heck, it even sounds redundant and is almost as introvertedly-cute as the terms *geomatics* and *map-ematics*.


Geospatial technology

From Wikipedia, the free encyclopedia

Geospatial Technology, commonly known as geomatics, refers to technology used for visualization, measurement, and analysis of features or phenomena that occur on the earth. This terminology has become common in the United States, and is synonymous with Spatial Information Technology.

Geospatial technology includes three different technologies that are all related to mapping features on the surface of the earth. These three technology systems are GPS (global positioning systems), GIS (geographical information systems), and RS (remote sensing).

See also [edit]

- GIS
- GPS
- Remote sensing

This technology-related article is a stub. You can help Wikipedia by expanding it.

Categories: Technology stubs | Cartography | Geographical technology

Figure 2. Wikipedia Definition of Geospatial Technology.

On the other hand, the use of the emerging term "Geotechnology" for the first time provides an opportunity to craft a definition with a broader perspective that embraces the universality of its application environments and societal impacts along the lines of the bio- and nanotechnology definitions.

As a draft attempt, let me suggest—

Geotechnology *refers to any technological application that utilizes spatial location in visualizing, measuring, storing, retrieving, mapping and analyzing features or phenomena that occur on, below or above the earth. It is recognized by the U.S. Department of Labor as one of the "three mega-technologies for the 21st Century," along with Biotechnology and Nanotechnology. There are three primary mapping technologies that enable geotechnology—GPS (Global Positioning System), GIS (Geographic Information Systems) and RS (Remote Sensing). …etcetera, etcetera, etcetera… to quote a famous King of Siam.*

As with any controversial endeavor, the devil is in the details (the *etcetera*). One of the biggest problems with the term is that geology staked the flag several years ago with its definition of geotechnology as "the application of the methods of engineering and science to exploitation of natural resources" (yes, they use the politically incorrect term "exploitation"). Also, there is an International Society for Environmental Geotechnology, as well as a several books with the term embedded in their titles.

On the bright side, the Wikipedia doesn't have an entry for Geotechnology. Nor is the shortened term "geo" exclusive to geology; in fact just the opposite, as geography is most frequently associated with the term (*geo* + *graph* + *y* literally means *"to write the descriptive science dealing with the surface of the earth"*). Finally, there are other disciplines, application users and the general public that are desperate for an encompassing term and succinct definition of our field that doesn't leave them tongue-tied, shaking their heads in dismay or otherwise dumbfounded.

Such is the byzantine fodder of academics …any inspired souls out there willing to take on the challenge of evolving/expanding the definition of Geotechnology, as well as the perspective of our GPS/GIS/RS enabled mapping technology?

Author's Notes*: see* **www.nature.com/nature/journal/v427/n6972/full/nj6972-376a.html** *for an article in Nature (427, 376-377; January 22, 2004) that identifies Geotechnology by the US Department of Labor as one of the three "mega technologies for the 21st century" (the other two are Nanotechnology and Biotechnology).*

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