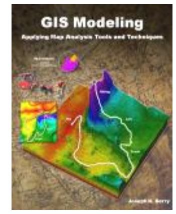
Beyond Mapping IV

Topic 10 – Future Directions and Trends



GIS Modeling book

<Click here> for a printer-friendly version of this topic (.pdf).

(*Back to the Table of Contents*)

GIS Innovation Drives Its Evolution

(GeoWorld, August 2007)

(*return to top of Topic*)

What I find interesting is that current geospatial innovation is being driven more and more by users. In the early years of GIS one would dream up a new spatial widget, code it, and then attempt to explain to others how and why they ought to use it. This sounds a bit like the proverbial "cart in front of the horse" but such backward practical logic is often what moves technology in entirely new directions.

"User-driven innovation," on the other hand, is in part an oxymoron, as innovation—"*a creation, a new device or process resulting from study and experimentation*" (Dictionary.com)—is usually thought of as canonic advancements leading technology and not market-driven solutions following demand. At the moment, the over 500 billion dollar advertising market with a rapidly growing share in digital media is dominating attention and the competition for eyeballs is directing geospatial innovation with a host of new display/visualization capabilities.

User-driven GIS innovation will become more and more schizophrenic with a growing gap between the two clans of the GIS user community as shown in figure 1.

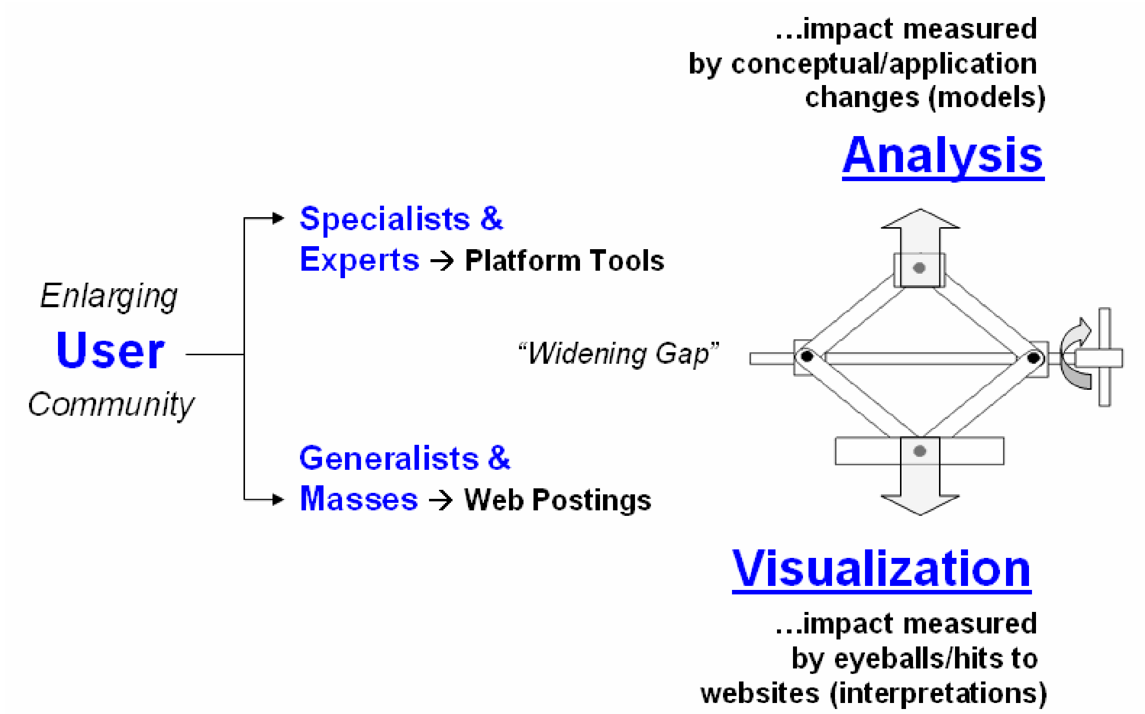


Figure 1. Widening gap in the GIS user community.

Another interesting point is that "radical" innovation often comes from fields with minimal or no paper map legacy, such as agriculture and retail sales, because these fields do not have pre-conceived mapping applications to constrain spatial reasoning and innovation.

In the case of *Precision Agriculture*, geospatial technology (GIS/RS/GPS) is coupled with robotics for "on-the-fly" data collection and prescription application as tractors move throughout a field. In *Geo-business*, when you swipe your credit card an analytic process knows what you bought, where you bought it, where you live and can combine this information with lifestyle and demographic data through spatial data mining to derive maps of "propensity to buy" various products throughout a market area. Keep in mind that these map analysis applications were non-existent a dozen years ago but now millions of acres and billions of transactions are part of the geospatial "stone soup" mix.

As shown in figure 2 the evolution of GIS is more cyclical than linear. My greybeard perspective of over 30 years in GIS suggests that we have been here before. In the 1970s the research and early applications centered on *Computer Mapping* (display focus) that yielded to *Spatial Data Management* (data structure/management focus) in the next decade as we linked digital maps to attribute databases for geo-query. The 1990s centered on *GIS Modeling* (analysis focus) that laid the groundwork for whole new ways of assessing spatial patterns and relations, as well as entirely new applications such as precision agriculture and geo-business.

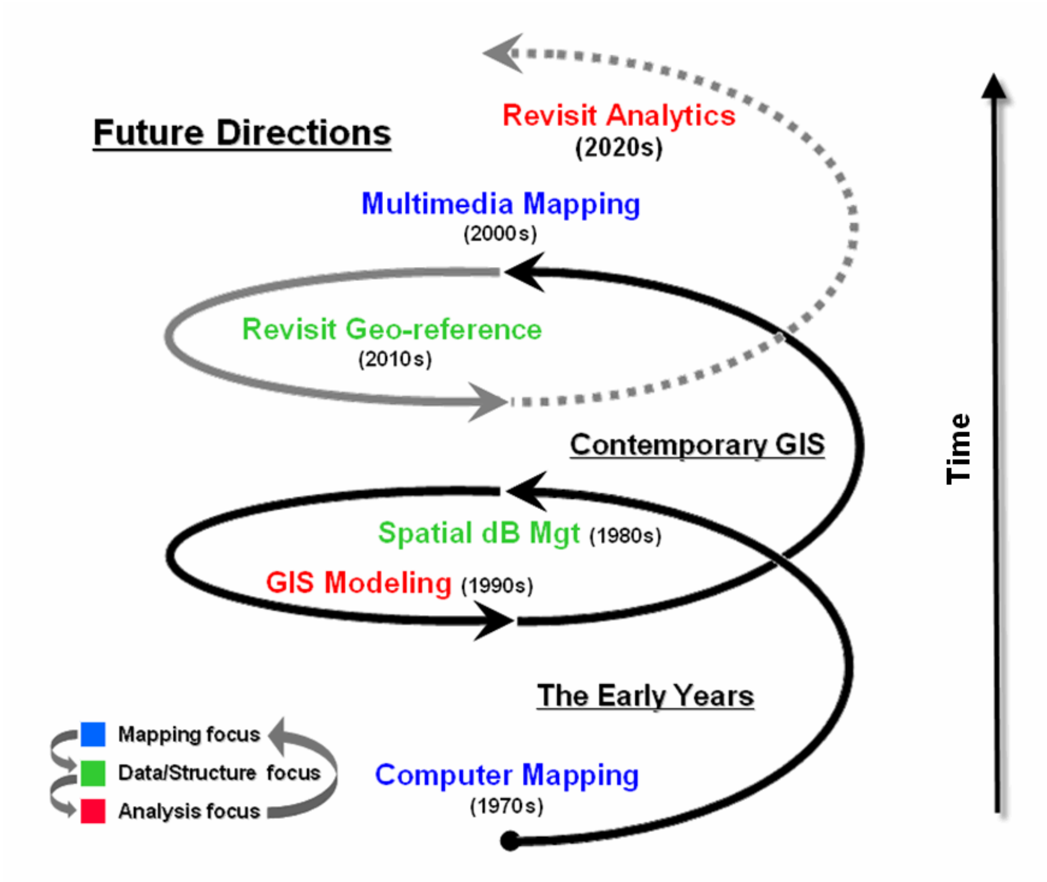


Figure 2. GIS Innovation/Development cycles.

Today, GIS is centered on *Multimedia Mapping* (mapping focus) which brings us full circle to our beginnings. While advances in virtual reality and 3D visualization can "knock-your-socks-off" they represent incremental progress in visualizing maps that exploit dramatic computer hardware/software advances. The truly geospatial innovation waits the next re-focusing on data/structure and analysis.

The bulk of the current state of geospatial analysis relies on "*static coincidence modeling*" using a stack of geo-registered map layers. But the frontier of GIS research is shifting focus to "*dynamic flows modeling*" that tracks movement over space and time in three-dimensional geographic space. But a wholesale revamping of data structure is needed to make this leap.

The impact of the next decade's evolution will be huge and shake the very core of GIS—the Cartesian coordinate system itself …a spatial referencing concept introduced by mathematician

Rene Descartes 400 years ago.

The current 2D square for geographic referencing is fine for "static coincidence" analysis over relatively small land areas, but woefully lacking for "dynamic 3D flows." It is likely that Descartes' 2D squares will be replaced by hexagons (like the patches forming a soccer ball) that better represent our curved earth's surface …and the 3D cubes replaced by nesting polyhedrals for a consistent and seamless representation of three-dimensional geographic space. This change in referencing extends the current six-sides of a cube for flow modeling to the twelve-sides (facets) of a polyhedral—radically changing our algorithms as well as our historical perspective of mapping (see Author's Note 1) April 2007 Beyond Mapping column for more discussion).

The new geo-referencing framework provides a needed foothold for solving complex spatial problems, such as intercepting a nuclear missile using supersonic evasive maneuvers or tracking the air, surface and groundwater flows and concentrations of a toxic release. While the advanced map analysis applications coming our way aren't the bread and butter of mass applications based on historical map usage (visualization and geo-query of data layers) they represent natural extensions of geospatial conceptualization and analysis …built upon an entirely new set analytic tools, geo-referencing framework and a more realistic paradigm of geographic space.

Author's Note*: 1) For more discussion, see Beyond Mapping Compilation Series, book IV, Introduction, Section 3 "Geo-Referencing Is the Cornerstone of GIS." 2) I have been involved in research, teaching, consulting and GIS software development since 1971 and presented my first graduate course in GIS Modeling in 1977. The discussion in these columns is a distillation of this experience and several keynotes, plenary presentations and other papers—many are posted online at www.innovativegis.com/basis/basis/cv_berry.htm.*

GIS and the Cloud Computing Conundrum

(GeoWorld, September 2009)

(return to top of Topic)

I think my first encounter with the concept of cloud computing was more than a dozen years ago when tackling a Beyond Mapping column on object-oriented computing. It dealt with the new buzzwords of "object-oriented" user interface (OOUI), programming system (OOPS) and database management (OODBM) that promised to revolutionize computer interactions and code sets (see Author's Note). Since then there has been a string of new evolutionary terms from enterprise GIS, to geography network, interoperability, distributed computing, web-services, mobile GIS, grid computing and mash-ups that have captured geotechnology's imagination, as well as attention.

"Cloud computing" is the latest in this trajectory of terminology and computing advances that appears to be coalescing these seemingly disparate evolutionary perspectives. While my technical skills are such that I can't fully address its architecture or enabling technologies, I might be able to contribute to a basic grasp of what cloud technology is, some of its advantages/disadvantages and what its near-term fate might be.

Uncharacteristic of the Wikipedia, the definition for cloud computing is riddled with techy-speak, as are most of the blogs. However, what I am able to decipher is that there are three distinguishing characteristics defining it (see figure 1)—

- it involves ***virtualized*** resources …meaning that workloads are allocated among a multitude of interconnected computers acting as a single device;
- it is dynamically ***scalable*** …meaning that the system can be readily enlarged;
- it acts as a ***service*** …meaning that the software and data components are shared over the Internet.

The result is a "hosted elsewhere" environment for data and services …meaning that cloud computing is basically the movement of applications, services, and data from local storage to a dispersed set of servers and datacenters— an advantageous environment for many data heavy and computationally demanding applications, such as geotechnology.

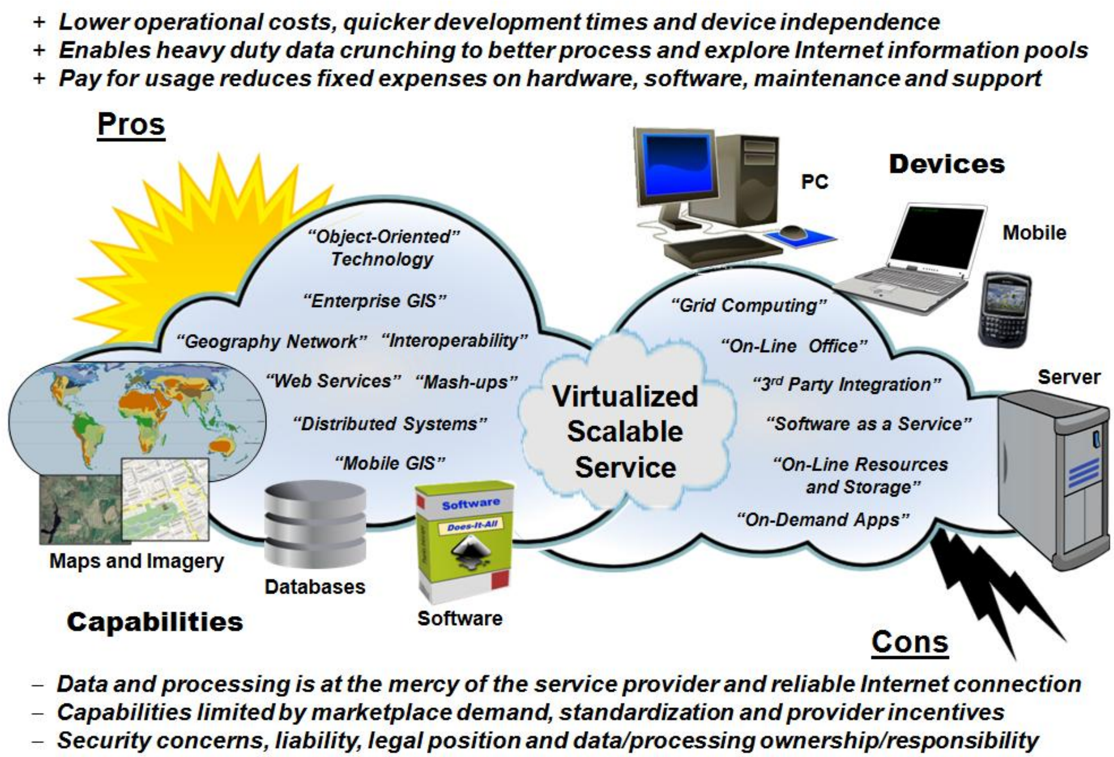


Figure 1. Cloud Computing characteristics, components and considerations.

A counterpoint is that the "elsewhere" conjures up visions of the old dumb terminals of the 70's connected to an all powerful computer center serving the masses. It suggests that some of the tailoring and flexibility of the "personal" part of the PC environment might be lost to ubiquitous services primarily designed to capture millions of eyeballs. The middle ground is that desktop and cloud computing can coexist but that suggests duel markets, investments, support and maintenance.

Either way, it is important to note that cloud computing is not a technology—it is a concept. It essentially presents the idea of distributed computing that has been around for decades. While there is some credence in the argument that cloud computing is simply an extension of yesterday's buzzwords, it ingrains considerable technical advancement. For example, the cloud offers a huge potential for capitalizing on the spatial analysis, modeling and simulation functions of a GIS, as well as tossing gigabytes around with ease …a real step-forward from the earlier expressions.

There are two broad types of clouds depending on their application:

- "*Software as a Service*" (SaaS) delivering a single application through the browser to a multitude of customers (e.g., WeoGeo and Safe Software are making strides in SaaS for geotechnology)— on the customer side, it means minimal upfront investment in servers or software licensing and on the provider side, with just one application to maintain, costs are low compared to conventional hosting; and,
- "*Utility Computing*" offering storage and virtual servers that can be accessed on demand by stitching together memory, I/O, storage, and computational capacity as a virtualized resource pool available over the Internet— thus creating a development environment for new services and usage accounting.

Google Earth is a good example of early-stage, cloud-like computing. It seamlessly stitches imagery from numerous datacenters to wrap the globe in a highly interactive 3D display. It provides a wealth of geography-based tools from direction finding to posting photos and YouTube videos. More importantly, it has a developer's environment (.kml) for controlling the user interface and custom display of geo-registered map layers. Like the iPhone, this open access encourages the development of applications and tools outside the strict confines of dedicated "flagship" software.

But the cloud's silver lining has some dark pockets. There are four very important non-technical aspects to consider in assessing the future of cloud computing: *1)* liability concerns, *2)* information ownership, sensitivity and privacy issues, *3)* economic and payout considerations, and *4)* legacy impediments.

<u>Liability concerns</u> arise from decoupling data and procedures from a single secure computing

infrastructure— what happens if the data is lost or compromised? What if the data and processing are changed or basically wrong? Who is responsible? Who cares?

The closely related issues of ownership, sensitivity and privacy raise questions like: Who owns the data? Who is it shared with and under what circumstances? How secure is the data? Who determines its accuracy, viability and obsolescence? Who defines what data is sensitive? What is personal information? What is privacy? These lofty questions rival Socrates sitting on the steps of the Acropolis and asking …what is beauty? …what is truth? But these social questions need to be addressed if the cloud technology promise ever makes it down to earth.

In addition, a practical reality needs an economic and payout component. While SaaS is usually subscription based, the alchemy of spinning gold from "free" cyberspace straw continues to mystify me. It appears that the very big boys like Google and Virtual (Bing) Earths can do it through eyeball counts, but what happens to smaller data, software and service providers that make their livelihood from what could become ubiquitous? What is their incentive? How would a cloud computing marketplace be structured? How will its transactions be recorded and indemnified?

Governments, non-profits and open source consortiums, on the other hand, see tremendous opportunities in serving-up gigabytes of data and analysis functionality for free. Their perspective focuses on improved access and capabilities, primarily financed through cost savings. But are they able to justify large transitional investments to retool under our current economic times?

All these considerations, however, pale in light legacy impediments, such as the inherent resistance to change and inertia derived from vested systems and cultures. The old adage "*don't fix it, if it ain't broke*" often delays, if not trumps, adoption of new technology. Turning the oil tanker of GIS might take a lot longer than technical considerations suggest—so don't expect GIS to "disappear" into the clouds just yet. But the future possibility is hanging overhead.

Author's Note: *see online book Map Analysis, Topic 1, Object-Oriented Technology and Its GIS Expressions posted at www.innovativegis.com/basis/MapAnalysis/; a good online discussion of Cloud Computing is posted at www.appistry.com/cloud-info-center.*

Visualizing a Three-dimensional Reality

(GeoWorld, October 2009)

(return to top of Topic)

I have always thought of geography in three-dimensions. Growing up in California's high Sierras I was surrounded by peaks and valleys. The pop-up view in a pair of aerial photos got me hooked as an undergrad in forestry at UC Berkeley during the 1960's while dodging tear gas canisters.

My doctoral work involved a three-dimensional computer model that simulated solar radiation in a vegetation canopy (SRVC). The mathematics would track a burst of light as it careened through the atmosphere and then bounce around in a wheat field or forest with probability functions determining what portion was absorbed, transmitted or reflected based on plant material and leaf angles. Solid geometry and statistics were the enabling forces, and after thousands of stochastic interactions, the model would report the spectral signature characteristics a satellite likely would see. All this was in anticipation of civilian remote sensing systems like the Earth Resources Technology Satellite (ERTS, 1973), the precursor to the Landsat program.

This experience further entrenched my view of geography as three-dimensional. However, the ensuing decades of GIS technology have focused on the traditional "pancake perspective" that flatten all of the interesting details into force-fitted plane geometry.

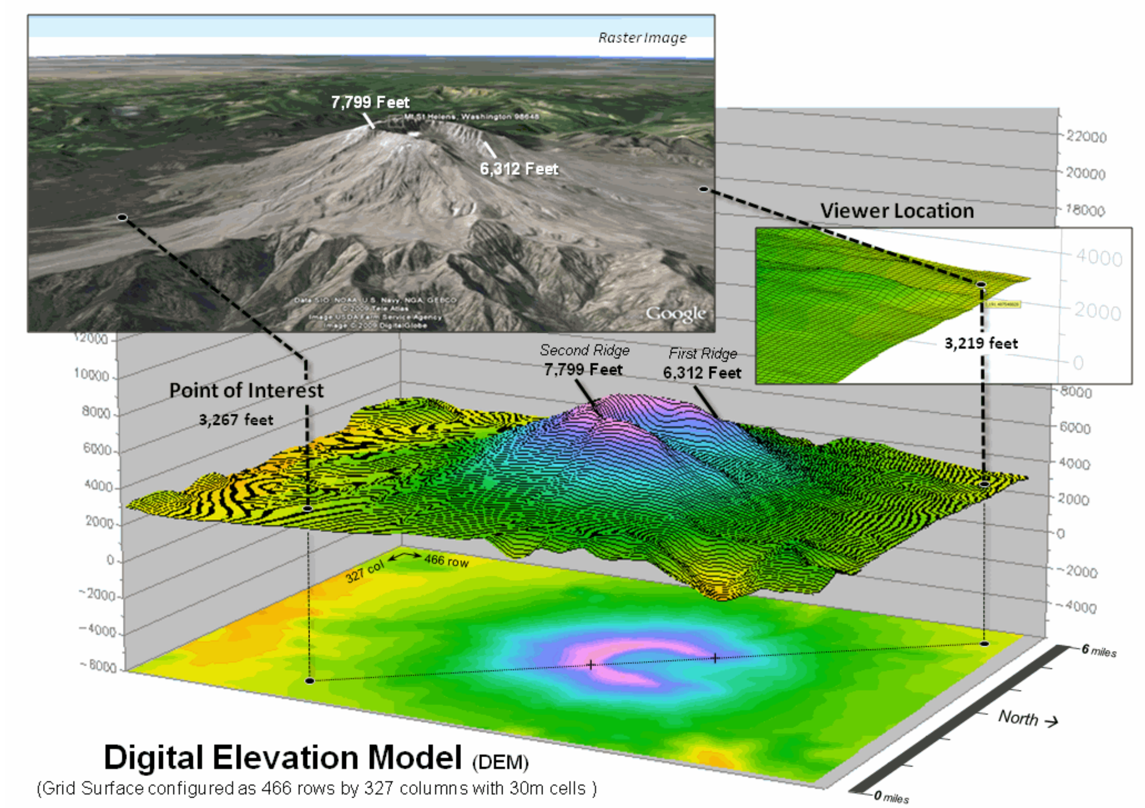


Figure 1. Mount St. Helens topography.

Even more disheartening is the assumption that everything can be generalized into a finite set of hard boundaries identifying discrete spatial objects defined by points, lines and polygons. While this approach has served us well for thousands of years and we have avoided sailing off the edge of the earth, geotechnology is taking us "where no *mapper* has gone before," at least not without a digital map and a fairly hefty computer.

Consider the Google Earth image of Mount St. Helens in the upper-left portion of figure 1. The peaks poke-up and the valleys dip down with a realistic land cover wrapper. This three-dimensional rendering of geography is a far cry from the traditional flat map with pastel colors imparting an abstract impression of the area. You can zoom-in and out, spin around and even fly through the landscape or gaze skyward to the stars and other galaxies.

Underlying all this is a Digital Elevation Model (DEM) that encapsulates the topographic undulations. It uses traditional X and Y coordinates to position a location plus a Z coordinate to establish its relative height above a reference geode (sea level in this case). However from a purist's perspective there are a couple of things that keep it from being a true three-dimensional GIS. First, the raster image is just that— a display in which thousands the "dumb" dots coalesce to form a picture in your mind, not an "intelligent" three-dimensional data structure that a computer can understand. Secondly, the rendering is still somewhat two-dimensional as the mapped information is simply "draped" on a wrinkled terrain surface and not stored in a true three-dimensional GIS—a warped pancake.

The DEM in the background forms Mt St. Helen's three-dimensional terrain surface by storing elevation values in a matrix of 30 meter grid cells of 466 rows by 327 columns (152, 382 values). In this form, the computer can "see" the terrain and perform its map-ematical magic.

Figure 2 depicts a bit of computational gymnastics involving three-dimensional geography. Assume you are standing at the viewer location and looking to the southeast in the direction of the point of interest. Your elevation is 3,219 feet with the mountain's western rim towering above you at 6,312 feet and blocking your view of anything beyond it. In a sense, the computer "sees" the same thing—except in mathematical terms. Using similar triangles, it can calculate the minimum point-of-interest height needed to be visibly connected as (see author's notes for a link to discussion of the more robust "splash algorithm" for establishing visual connectivity)…

Tangent = Rise / Run

$= (6312 \text{ ft} – 3219 \text{ ft}) / (\text{SQRT}[(134 – 33)^2 + (454 – 325)^2] * 98.4251 \text{ ft})$

$= 3093 \text{ ft} / (163.835 * 98.4251 \text{ ft}) = 3893 \text{ ft} / 16125 \text{ ft} =$ **0.1918**

Height = (Tangent * Run) + Viewer Height

$= (0.1918 * (\text{SQRT}[(300 – 33)^2 + (454 – 114)^2] * 98.4251 \text{ ft})) + 3219 \text{ ft}$

$= (0.1918 * 432.307 * 98.4251 \text{ ft}) + 3219 =$ **11,380 Feet**

Since the computer knows that the elevation on the grid surface at that location is only 3,267 feet it knows you can't see the location. But if a plane was flying 11,380 feet over the point it would be visible and the computer would know it.

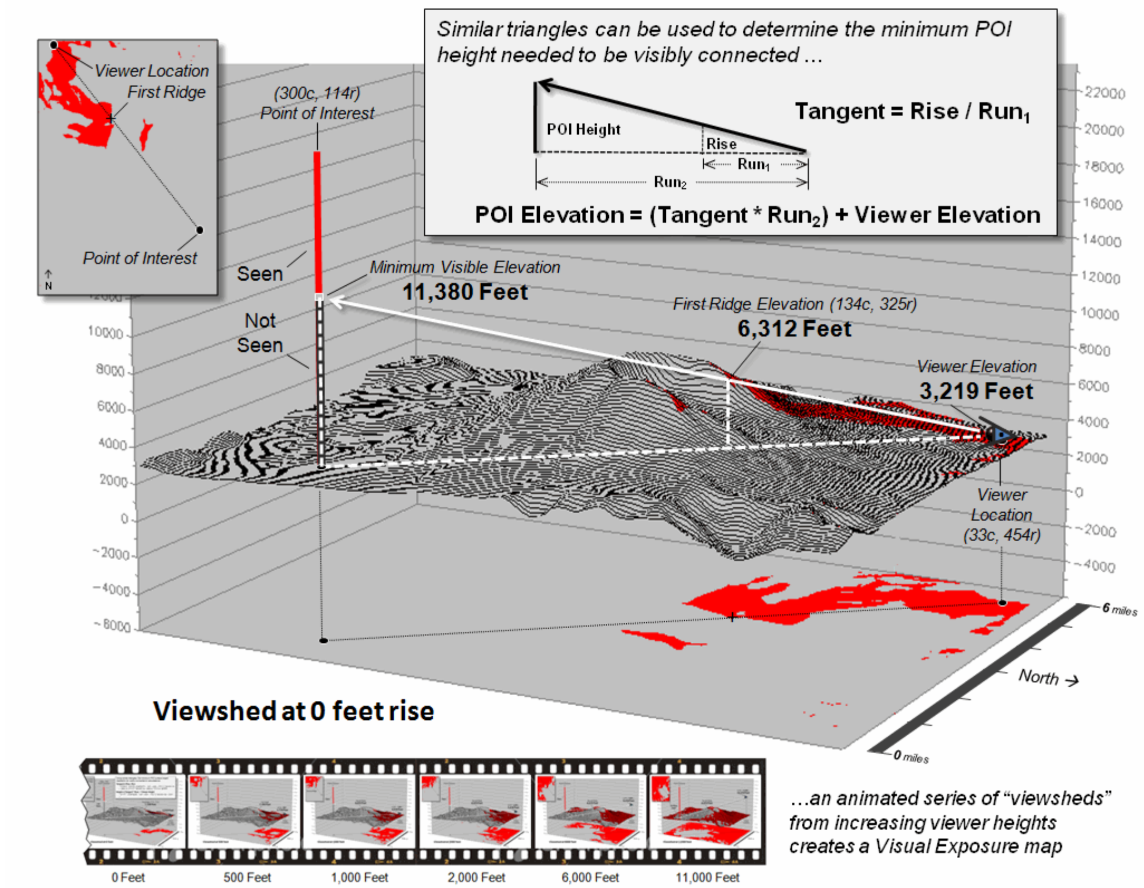


Figure 2. Basic geometric relationships determine the minimum visible height considering intervening ridges.

Conversely, if you "helicoptered-up" 11,000 feet (to 14,219 feet elevation) you could see over both of the caldron's ridges and be visually connected to the surface at the point of interest (figure 3). Or in a military context, an enemy combatant at that location would have line-of-sight detection.

As your vertical rise increases from the terrain surface, more and more terrain comes into view (see author's notes for a link to an animated slide set). The visual exposure surface draped on the terrain and projected on the floor of the plot keeps track of the number of visual connections at every grid surface location in 1000 foot rise increments. The result is a traditional two-dimensional map of visual exposure at each surface location with warmer tones representing considerable visual exposure during your helicopter's rise.

However, the vertical bar in figure 3 depicts the radical change that is taking us beyond mapping.

In this case the two-dimensional grid "cell" (termed a pixel) is replace by a three-dimensional grid "cube" (termed a voxel)—an extension from the concept of an area on a surface to a glob in a volume. The warmer colors in the column identify volumetric locations with considerable visual exposure.

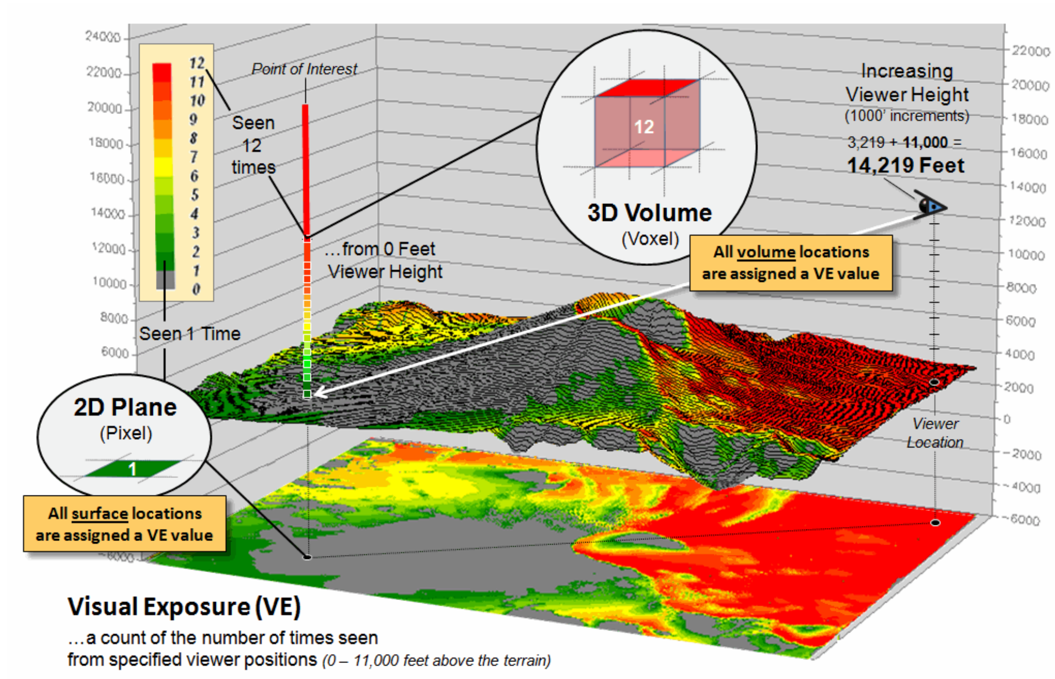


Figure 3. 3-D Grid Data Structure is a direct expansion of the 2D structure with X, Y and Z coordinates defining the position in a 3-dimensional data matrix plus a value representing the characteristic or condition (attribute) associated with that location.

Now imagine a continuous set of columns rising above and below the terrain that forms a three-dimensional project extent—a block instead of an area. How is the block defined and stored; what new analytical tools are available in a volumetric GIS; what new information is generated; how might you use it? …that's fodder for the next section. For me, it's a blast from the past that is defining the future of geotechnology.

Author's Notes: *for a more detailed discussion of visual connectivity see the online book Beyond Mapping III, Topic 15, "Deriving and Using Visual Exposure Maps" at* www.innovativegis.com/basis/MapAnalysis/Topic15/Topic15.htm. *An annotated slide set demonstrating visual connectivity from increasing viewer heights is posted at* www.innovativegis.com/basis/MapAnalysis/Topic27/AnimatedVE.ppt.

Thinking Outside the Box

(GeoWorld, November 2009)

([return to top of Topic](#))

Last section used a progressive series of line-of-sight connectivity examples to demonstrate thinking beyond a 2-D map world to a three-dimensional world. Since the introduction of the digital map, mapping geographic space has moved well beyond its traditional planimetric pancake perspective that flattens a curved earth onto a sheet of paper.

A contemporary Google Earth display provides an interactive 3-D image of the globe that you can fly through, zoom-up and down, tilt and turn much like Luke Skywalker's bombing run on the Death Star. However both the traditional 2-D map and virtual reality's 3-D visualization view the earth as a surface—flattened to a pancake or curved and wrinkled a bit to reflect the topography.

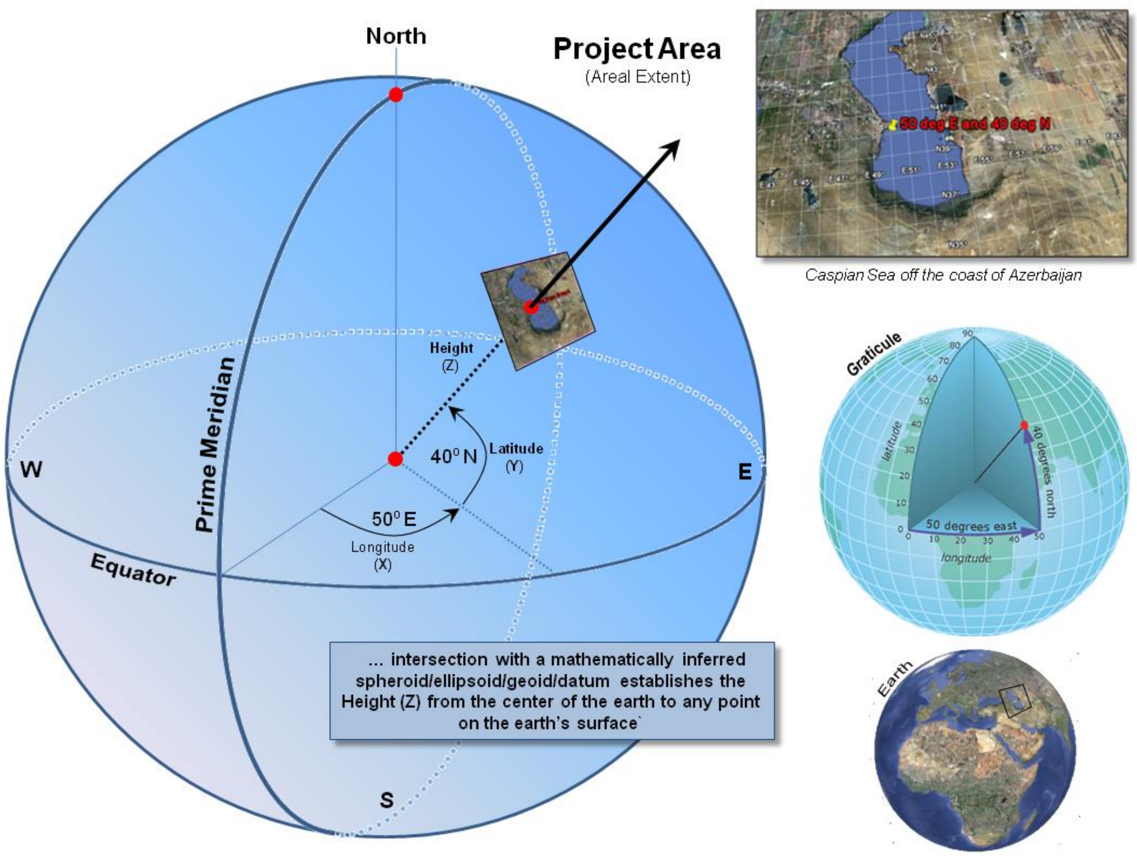


Figure 1. A 3-dimensional coordinate system uses angular measurements (X,Y) and length (Z) to locate points on the earth's surface.

Figure 1 summarizes the key elements in locating yourself on the earth's surface …sort of a pop-quiz from those foggy days of Geography 101. The Prime Meridian and Equator serve as base references for establishing the angular movements expressed in degrees of Longitude (X) and Latitude (Y) of an imaginary vector from the center of the earth passing through any location. The Height (Z) of the vector positions the point on the earth's surface.

It's the determination of height that causes most of us to trip over our geodesic mental block. First, the globe is not a perfect sphere but is a squished ellipsoid that is scrunched at the poles and pushed out along the equator like love-handles. Another way to conceptualize the physical shape of the surface is to imagine blowing up a giant balloon such that it "best fits" the actual shape of the earth (termed the geoid) most often aligning with mean sea level. The result is a smooth geometric equation characterizing the general shape of the earth's surface.

But the earth's mountains bump-up and valleys bump-down from the ellipsoid so a datum is designed to fit the earth's surface that accounts for the actual wrinkling of the globe as recorded by orbiting satellites. The most common datum for the world is WGS 84 (World Geodetic System 1984) used by all GPS equipment and tends to have and accuracy of +/- 30 meters or less from the actual local elevation anywhere on the surface.

The final step in traditional mapping is to flatten the curved and wrinkled surface to a planimetric projection and plot it on a piece of paper or display on a computer's screen. It is at this stage all but the most fervent would-be geographers drop the course, or at least drop their attention span.

However, a true 3-D GIS simply places the surface in volumetric grid elements along with others above and below the surface. The right side of figure 2 shows a Project Block containing a million grid elements (termed "voxels") positioned by their geographic coordinates—X (easting), Y (northing) and Z (height). The left side depicts stripping off one row of the elevation values defining the terrain surface and illustrating a small portion of them in the matrix by shading the top's of the grids containing the surface.

At first the representation in a true 3-D data structure seems trivial and inefficient (silly?) but its implications are huge. While topographic relief is stable (unless there is another Mount St. Helens blow that redefines local elevation) there are numerous map variables that can move about in the project block. For example, consider the weather "map" on the evening news that starts out in space and then dives down under the rain clouds. Or the National Geographic show that shows the Roman Coliseum from above then crashes through the walls to view the staircases and then proceeds through the arena's floor to the gladiators' hypogeum with its subterranean network of tunnels and cages.

Some "real cartographers" might argue that those aren't maps but just flashy graphics and architectural drawings …that there has been a train wreck among mapping, computer-aided drawing, animation and computer games. On the other hand, there are those who advocate that these disciplines are converging on a single view of space—both imaginary and geographic. If the X, Y and Z coordinates represent geographic space, nothing says that Super Mario couldn't hop around your neighborhood or that a car is stolen from your garage in Grand Theft Auto and race around the streets in your hometown.

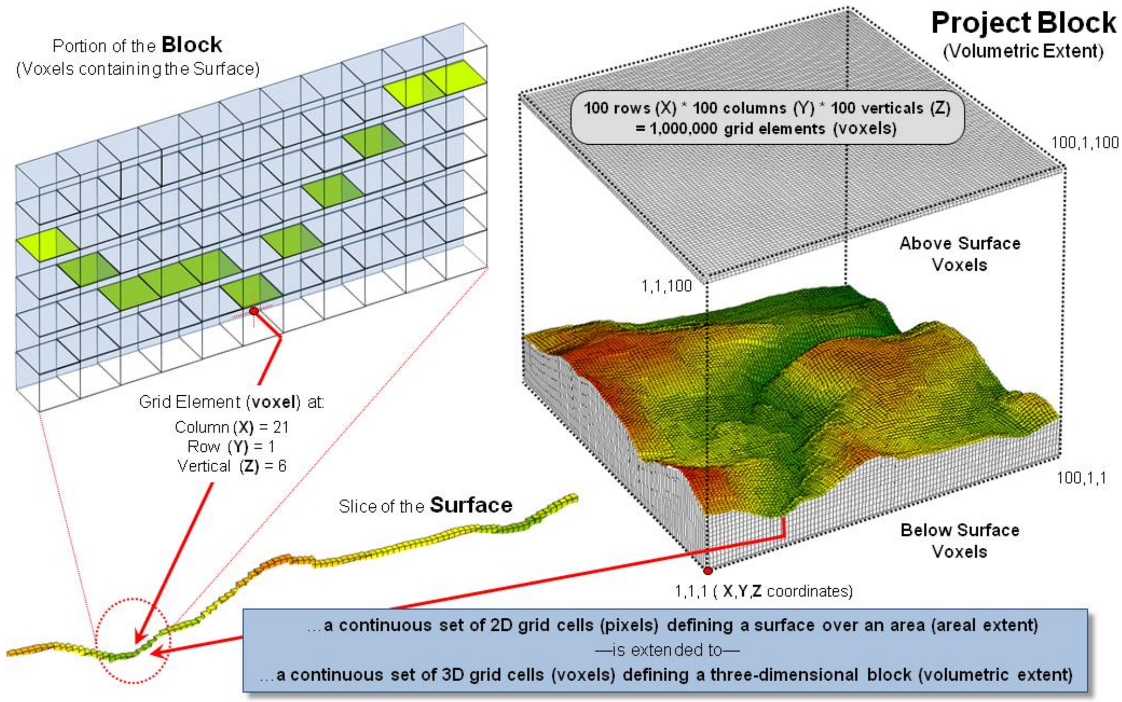


Figure 2. An implied 3-D matrix defines a volumetric Project Block, a concept analogous to areal extent in traditional mapping.

The unifying concept is a "Project Block" composed of millions of spatially-referenced voxels. Line-of-sight connectivity determines what is seen as you peek around a corner or hover-up in a helicopter over a mountain. While the mathematics aren't for the faint-hearted or tinker-toy computers of the past, the concept of a "volumetric map" as an extension of the traditional planimetric map is easy to grasp—a bunch of three-dimensional cubic grid elements extending up and down from our current raster set of squares (bottom of figure 3).

However, akin to the seemingly byzantine details in planimetric mapping, things aren't that simple. Like the big bang of the universe, geographic space expands from the center of the earth and a simple stacking of fixed cubes like wooden blocks won't align without significant gaps. In addition, the geometry of a cube does not have a consistent distance to all of its surrounding grid elements and of its twenty six neighbors only six share a complete side with the remaining neighbors sharing just a line or a single point. This inconsistent geometry makes a cube a poor grid element for 3-D data storage.

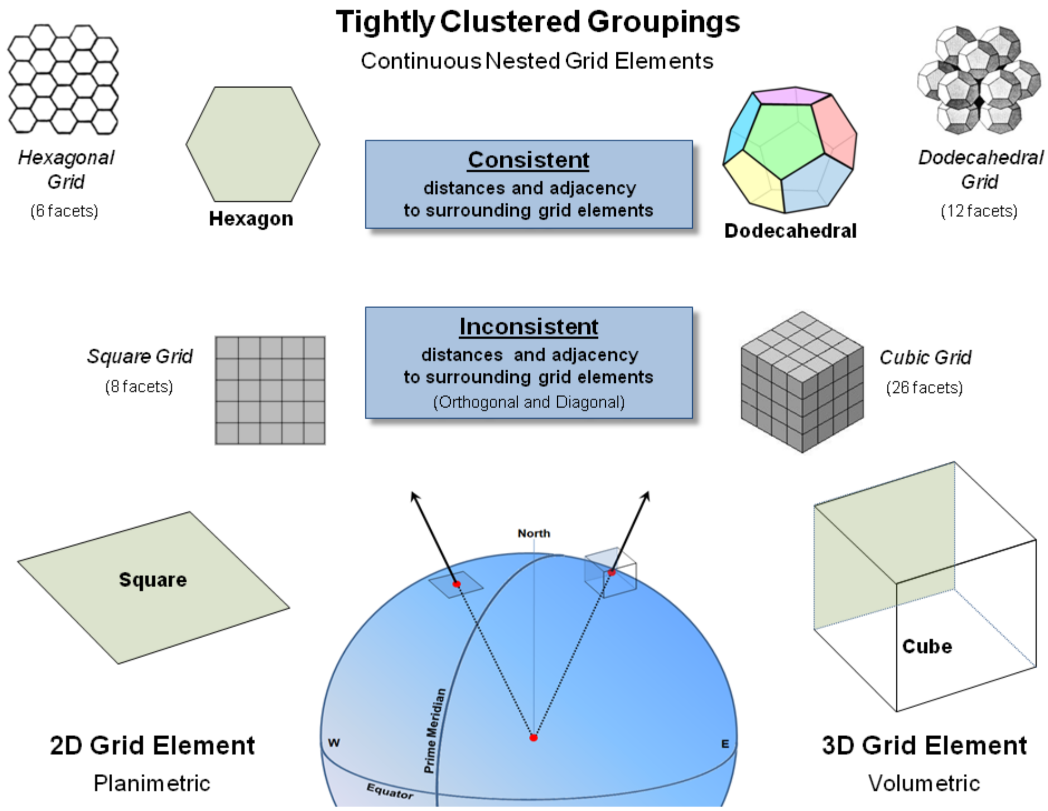


Figure 3. The hexagon and dodecahedral are alternative grid elements with consistent nesting geometry.

Similarly, it suggests that the traditional "square" of the Cartesian grid is a bit limited—only four complete sides (orthogonal elements) and four point adjacencies (diagonal). Also, the distances to surrounding elements are different (a ratio of 1:1.414). However, a 2D hexagon shape (beehive honey comb) abuts completely without gaps in planimetric space (termed "fully nested"); as does a combination of pentagon and hexagon shapes nests to form the surface of a spheroid (soccer ball).

To help envision an alternative 3-D grid element shape (top-right of figure 3) it is helpful to recall Buckminster Fuller's book *Synergetics* and his classic treatise of various "close-packing" arrangements for a group of spheres. Except in this instance, the sphere-shaped grid elements are replaced by "pentagonal dodecahedrons"— a set of uniform solid shapes with 12 pentagonal faces (termed geometric "facets") that when packed abut completely without gaps (termed fully "nested").

All of the facets are identical, as are the distances between the centroids of the adjoining clustered elements defining a very "natural" building block (see Author's Note). But as always, “the Devil is in the details” and that discussion is reserved for another time.

Author’s Note: *In 2003, a team of cosmologists and mathematicians used NASA’s WMAP cosmic background radiation data to develop a model for the shape of the universe. The study analyzed a variety of different shapes for the universe, including finite versus infinite, flat, negatively- curved (saddle-shaped), positively- curved (spherical) space and a torus (cylindrical). The study revealed that the math adds up if the universe is finite and shaped like a pentagonal dodecahedron (http://physicsworld.com/cws/article/news/18368). And if one connects all the points in one of the pentagon facets, a 5-pointed star is formed. The ratios of the lengths of the resulting line segments of the star are all based on phi, Φ, or 1.618… which is the "Golden Number" mentioned in the Da Vinci Code as the universal constant of design and appears in the proportions of many things in nature from DNA to the human body and the solar system—isn't mathematics wonderful!*

Further Online Reading*: (Chronological listing posted at* ***www.innovativegis.com/basis/BeyondMappingSeries/****)*

From a Map Pancake to a Soufflé *— continues the discussion of concepts and configuration of a 3D GIS (December 2009)*

(return to top of Topic)

(Back to the Table of Contents)