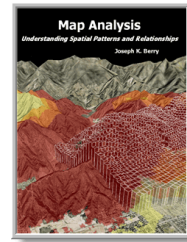


Beyond Mapping III

Epilog: Technical and Cultural Shifts in the GIS Paradigm



[Map Analysis](#) book with companion CD-ROM for hands-on exercises and further reading

[Lumpers and Splitters Propel GIS](#) — describes the two camps of GIS (GeoExploration and GeoScience)

[The Softer Side of GIS](#) — describes a Manual GIS (circa 1950) and the relationship between social science conceptual frameworks for understanding/judgment in GIS modeling

[Melding the Minds of the “-ists” and “-ologists”](#) — elaborates on the two basic mindsets driving the geotechnology community

[Is GIS Technology Ahead of Science?](#) — discusses several issues surrounding the differences in the treatment of non-spatial and spatial data

[The Good, the Bad and the Ugly Sides of GIS](#) — discusses the potential of geotechnology to hinder (or even thwart) societal progress

[Where Do We Go from Here?](#) — Swan Song after 25 years of Beyond Mapping columns

Note: The processing and figures discussed in this topic were derived using MapCalc™ software. See www.innovativegis.com to download a free MapCalc Learner version with tutorial materials for classroom and self-learning map analysis concepts and procedures.

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Lumpers and Splitters Propel GIS

(GeoWorld, December, 2007)

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Earlier discussions have focused on the numerical nature of GIS data (GeoWorld Sep-Nov, 2007; *Topic 7* in the online *Beyond Mapping III* compilation at <http://www.innovativegis.com/basis/MapAnalysis>). The discussions challenged the traditional assumption that all data are “normally” distributed suggesting that most spatial data are skewed and that the *Median* and *Quartile Range* often are better descriptive statistics than the *Mean* and *Standard Deviation*.

Such heresy was followed by an assertion that any central tendency statistic tends to overly generalize and often conceal inherent spatial patterns and relationships within nearly all field collected data. In most applications, *Surface Modeling* techniques, such

as density analysis and spatial interpolation, can be applied to derive the spatial distribution of a set of point-sampled data.

Figure 1 outlines the major points of the earlier discussion. The left side of the figure depicts *Desktop Mapping's* approach that reduces a set of field data to a single representative value that is assumed to be everywhere the same within each polygon (Discrete Spatial Object). Each parcel is “painted” with an appropriate color indicating the typical value—with darker green indicating a slightly lower average value derived from numerous samples falling within the polygon.

Map Analysis's approach, on the other hand, establishes a spatial gradient based on the relative positions and values of the point-sampled data (Continuous Spatial Distribution). A color ramp is used to display the continuum of estimated values throughout each parcel—light green (low) to red (high). Note that the continuous representation identifies a cluster of extremely high values in the upper center portion of the combined parcels that is concealed by the discrete thematic mapping of the averages.

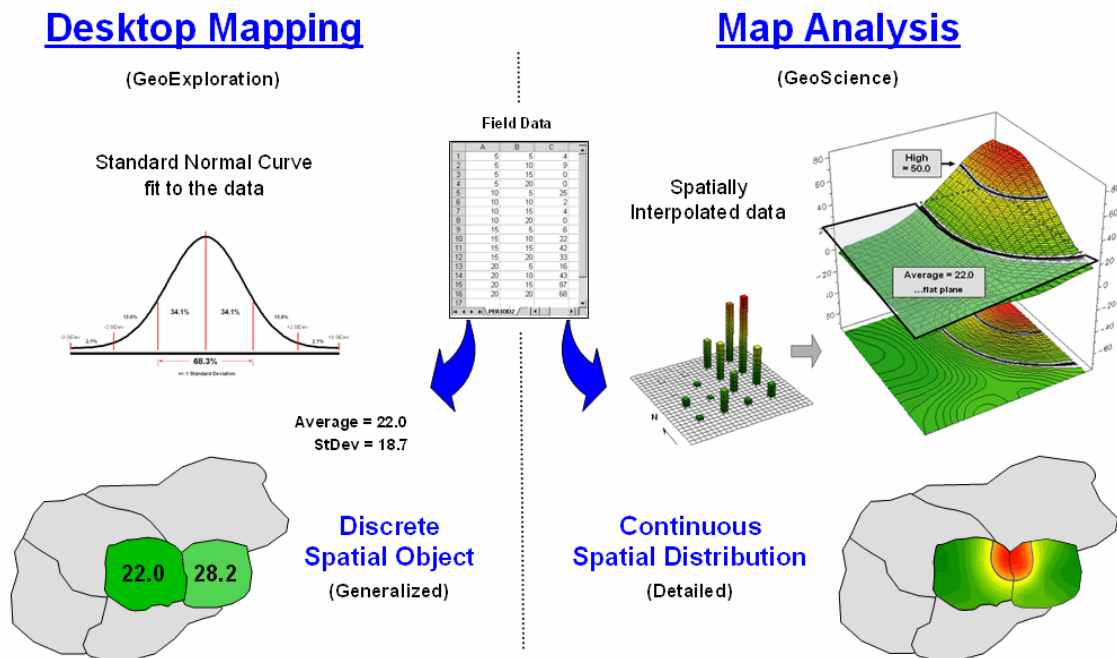


Figure 1. A data set can be characterized both discretely and continuously to derive different perspectives of spatial patterns and relationships.

OK, so much for review ...what about the big picture? The discussion points to today's convergent trajectory of two GIS camps— *GeoExploration* and *GeoScience*. Traditional computer companies like Google, Microsoft and Yahoo are entering the waters of geotechnology at the GeoExploration shallow end. Conversely, GIS vendors with deep keels in GeoScience are capitalizing on computer science advances for improved performance, interoperability and visualization.

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An important lesson learned by the GeoScience camp is that data has to be integrated with a solution and not left as an afterthought for users to cobble together. Another lesson has been that user interfaces need to be intuitive, uncluttered and consistent across the industry. Additionally, the abstract 2D pastel map is giving way to 3D visualization and virtual reality renderings—a bit of influence from our CAD cousins and the video game industry.

But what are the take-aways for traditional computer science vendors? First and foremost is an active awareness of the breadth of geotechnology, both in terms of its technical requirements and its business potential. Under the current yardstick of “eyeball contacts,” GeoExploration tools have been wildly successful.

But at the core, have recent technological advancements really changed mapping? ...or has the wave of GeoExploration tools just changed mapping’s expression and access? ...has the GIS evolution topped (or bottomed) out? ...what about the future?

Current revolutionary steps in analytics and concepts are underway like the energized paddling beneath a seemingly serene swan. As a broad-brush framework for discussion of where we are heading, recall from your academic days the Philosopher’s Progression of Understanding shown in figure 2. It suggests that are differences between the spatial *Data/Information* describing geographic phenomena and the *Knowledge/Wisdom* needed for prescribing management action that solve complex spatial problems.

Philosopher’s Progression of Understanding —

✓ **Data** (all facts)

✓ **Information** (facts within a context)

...**GeoExploration** emphasizes tools for data access
and visualization (general user)

Mapping focus

.....
Data/Structure and Analysis focus

✓ **Knowledge** (interrelationships among relevant facts)

✓ **Wisdom** (actionable knowledge)

...**GeoScience** emphasizes tools for spatial reasoning
and understanding of spatial patterns and relationships
(application specialist)

Figure 2. The two broad camps of geotechnology occupy different portions of the philosopher’s progression of understanding.

Most GeoExploration applications simply assemble spatial data into graphic form. While it might be a knock-your-socks-off graphic, the distillation of the data to information is left to visceral viewing and human interpretation and judgment (emphasizing Data and Information).

For example, a mash-up of a set of virtual pins representing crimes in a city can be poked into a Google Earth display. Interpretation and assessment of the general pattern, however, is left for the brain to construe. But there is a multitude of analytics that can be brought into play that translates the spatial data into information, knowledge and wisdom needed for decision-making. Geo-query can segment by the type of crime; density analysis can isolate unusually high and low pockets of crime; coincident statistics can search for correlation with other data layers; effective distance can determine proximity to key features; spatial data mining can derive prediction models.

While the leap from mapping to map analysis might be well known to those in GeoScience, it represents a bold new frontier to the GeoExploration camp. It suggests future development of solutions that stimulate spatial reasoning through “thinking with maps” (Information and Knowledge) rather than just visualizing data— a significant movement beyond mapping.

In part, the differences between the GeoExploration and GeoScience camps parallel society’s age-old dichotomy of problem perception—lumpers and splitters. A "lumper" takes a broad view assuming that details of a problem are not as important as overall trends ...a picture is worth a thousand words (holistic). A "splitter" takes a detailed view of the interplay among problem elements ...a model links thousands of pieces (atomistic).

So how does all this play out in geotechnology’s future? The two camps are symbiotic and can’t survive without each other; sort of like Ralph and Alice Kramden in *The Honeymooners*. GeoExploration fuels the fire of mass acceptance, and in large part finances technology development through billions of mapping clicks (General User; access and visualization). GeoScience lubricates the wheels of advancement by developing new data structures, analytical tools and applications (Application Specialist; spatial reasoning and understanding).

It’s important to note that neither camp is stationary and that they are continually evolving as we move beyond traditional mapping. A large portion of the mystique and influence of application specialists just a few years ago are now commonplace on the desks (and handheld devices) of the general public. Similarly, the flat, pastel colored maps of just a few years ago have given way to interactive 3D displays. While there will always be the lumpers and splitters differences in perspective, their contributions to the stone soup of geotechnology are equally valuable—actually invaluable.

The Softer Side of GIS

(GeoWorld, January, 2008)

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While computer-based procedures supporting Desktop Mapping seem revolutionary, the idea of linking descriptive information (What) with maps (Where) has been around for quite awhile. For example, consider the manual GIS that my father used in the 1950s outlined in figure 1.

The heart of the system was a specially designed index card that had a series of numbered holes around its edge with a comment area in the middle. In a way it was like a 3x5 inch recipe card, just a little larger and more room for entering information. For my father, a consulting forester, that meant recording timber stand information, such as area, dominant tree type, height, density, soil type and the like, for the forest parcels he examined in the field (What). Aerial photos were used to delineate the forest parcels on a corresponding map tacked to a nearby wall (Where).

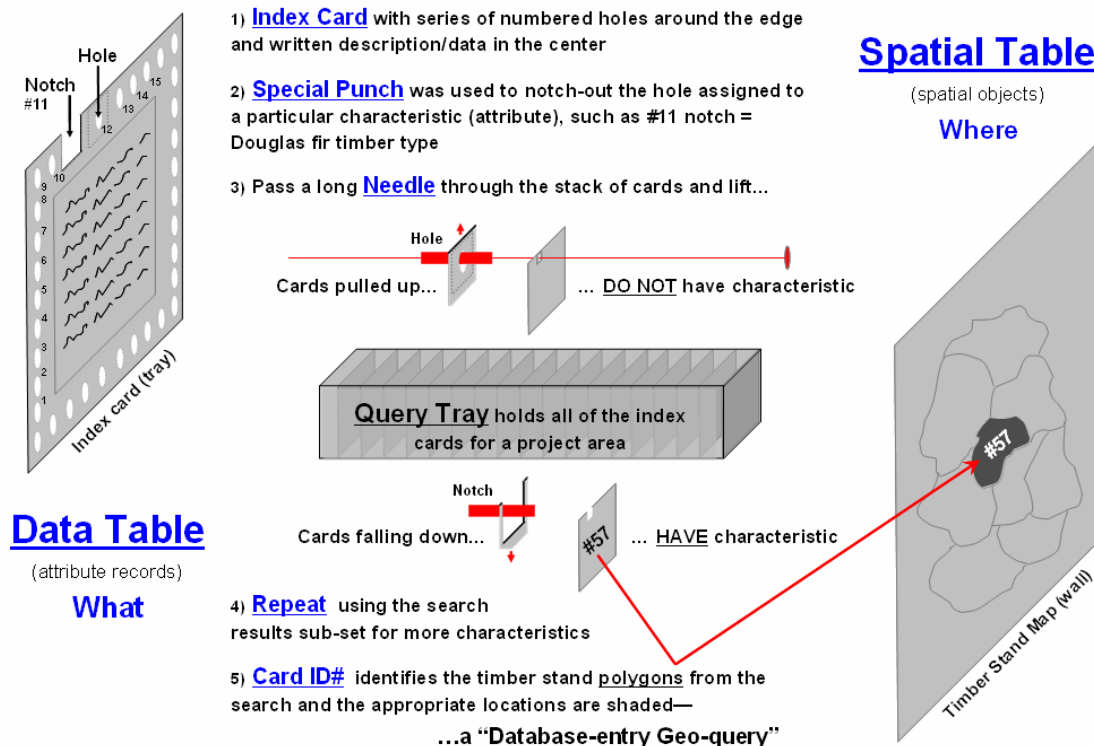


Figure 1. Outline of the processing flow of a manual GIS, circa 1950.

What went on between the index card and the map was revolutionary for the time. The information in the center was coded and transferred to the edge by punching out (notching) the appropriate numbered holes. For example, hole #11 would be notched to identify a Douglas fir timber stand. Another card would be notched at hole #12 to indicate a different parcel containing ponderosa pine. The trick was to establish a mutually exclusive classification scheme that corresponded to the numbered holes for all of the possible inventory descriptors and then notch each card to reflect the information for a particular parcel.

Cards for hundreds of timber stands were indiscriminately placed in a tray. Passing a long needle through an appropriate hole and then lifting and shaking the stack caused all of the parcels with a particular characteristic to fallout— an analogous result to a simple SQL query to a digital database. Realigning the subset of cards and passing the needle through another hole then shaking would execute a sequenced query—such as Douglas fir (#11) AND Cohasset soil (#28).

The resultant card set identified the parcels satisfying a specific query (What). The parcel ID# on each card corresponded to a map parcel on the wall. A thin paper sheet was placed over the base map and the boundaries for the parcels traced and color-filled (Where)—a “database-entry geo-query.” A “map-entry geo-query,” such as identifying all parcels abutting a stream was achieved by viewing the map, is achieved by noting the parcel ID#'s on the map and searching with the needle to subset the abutting parcels to get their characteristics.

The old days wore out a lot of shoe leather running between the index card tray and the map tacked to the wall. Today, it’s just electrons scurrying about in a computer at gigahertz speed. However, the bottom line is that the geo-query/mapping approach hasn’t changed substantially—linking “What is Where” for a set of pre-defined parcels and their stored descriptors. But the future of GIS holds entirely new spatial analysis capabilities way outside our paper map legacy.

	Human Dimensions' Framework		Technology's Expression	
	<i>Philosopher's Levels of Understanding</i>	<i>Cognitive Levels of Judgment</i>	Map Types	Spatial Processing
Description	Data – all facts	Facts – Earth circumference is 24,900 mi – Britney Spears was born 12/2/1981 – Britney Spears is 26 years old – the temperature is 32° F :	Base – measured features, conditions and characteristics (fact)	Collect – direct acquisition of primary information (e.g. elevation)
	Information – facts within a context	Relevant Facts – the temperature is 32° F	Derived – inferred conditions and characteristics (implied fact)	Calculate – uses algorithms to derive secondary information (e.g., slope)
Prescription	Knowledge – interrelationships among relevant facts	Perception – it sure is cold (Floridian) – it's not cold (Alaskan)	Interpreted – adjusted to reflect expertise and presumption (judgment)	Calibrate/Weight – translates information into relative scales (preference & importance)
	Wisdom – actionable knowledge	Opinions/Values – I hate this weather (Floridian) – I love this weather (Alaskan)	Modeled – potential solution within model logic and expression (conjoined judgment)	Simulate – “what if” investigation of alternative scenarios (multiple perspectives)

Figure 2. Conceptual framework for moving maps from Description to Prescription application.

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Figure 2 graphically relates the softer (human dimensions) and harder (technology) sides of GIS. The matrix is the result of musing over some things lodged in my psyche years ago when I was a grad student (see Author's Note 1). Last month's column (December 2007) described the Philosopher's Levels of **Understanding** (first column) that moves thinking from descriptive *Data*, to relevant *Information*, to *Knowledge* of interrelationships and finally to prescriptive *Wisdom* that forms the basis for effective decision-making. The dotted horizontal line in the progression identifies the leap from visualization and visceral interpretation in GeoExploration of Data and Information to the map analysis ingrained in GeoScience for gaining Knowledge and Wisdom for problem solving.

The second column extends the gradient of Understanding to the stark reality of **Judgment** that complicates most decision-making applications of GIS. The basic descriptive level for *Facts* is analogous to that of Data and includes things that we know, such as the circumference of the earth, Britney Spears' birth date, her age and today's temperature. *Relevant Facts* correspond to Information encompassing only those facts that pertain to a particular concern, such as today's temperature of 32°F.

It is at the next two levels that the Understanding and Judgment frameworks diverge and translate into radically different GIS modeling environments. Knowledge implies certainty of relationships and forms the basis of science—discovery of scientific truths. The concept of *Perception*, however, is a bit mushier as it involves beliefs and preferences based on experience, socialization and culture—development of perspective. For example, a Floridian might feel that 32° is really cold, while an Alaskan feels it certainly is not cold, in fact rather mild. Neither of the interpretations is wrong and both diametrically opposing perceptions are valid.

The highest level of *Opinion/Values* implies actionable beliefs that reflect preferences, not universal truths. For example, the Floridian might hate the 32° weather, whereas the Alaskan loves it. This stark dichotomy of beliefs presents a real problem for many GIS technologists as the bulk of their education and experience was on the techy side of campus, where mapping is defined as precise placement of physical features (description of facts). But the other side of campus is used to dealing with opposing “truths” in judgment and sees maps as more fluid, cognitive drawings (prescription of relationships).

The columns on the right attempt to relate the dimensions of Understanding and Judgment to **Map Types** and **Spatial Processing** used in prescriptive mapping. The descriptive levels are well known to GIS'ers—*Base* maps from field *collected* data (e.g., elevation) and *Derived* maps *calculated* by analytical tools (e.g., slope from elevation).

Interpreted maps, on the other hand, *calibrate* Base/Derived map layers in terms of their perceived impact on a spatial solution. For example, gentle slopes might be preferred for powerline routing (assigned a value of 1) with increasing steepness less preferred (assign values 2 through 9) and very steep slopes prohibitive (assign 0). A similar preference scale might be calibrated for a preference to avoid locations of high Visual Exposure, in

or near Sensitive Areas, far from Roads or having high Housing Density. In turn, the model criteria are *weighted* in terms of their relative importance to the overall solution, such as a homeowner's perception that Housing Density and Visual Exposure preference ratings are ten times more important than Sensitive Areas and Road Proximity ratings (see Author's Note 2).

Interpreted maps provide a foothold for tracking divergent assumptions and interpretations surrounding a spatially dependent decision. *Modeled* maps put it all together by *simulating* an array of opinions and values held by different stakeholder groups involved with a particular issue, such as homeowners, power companies and environmentalists concerns about routing a new powerline.

The *Understanding* progression assumes common truths/agreement at each step (more a natural science paradigm), whereas the *Judgment* progression allows differences in opinion/beliefs (more a social science paradigm). GIS modeling needs to recognize and embrace both perspectives for effective spatial solutions tuned to different applications. From the softer side perspective, GIS isn't so much a map, as it is the change in a series of maps reflecting valid but differing sets of perceptions, opinions and values. Where these maps agree and disagree becomes the fodder for enlightened discussion, and eventually an effective decision. Judgment-based GIS modeling tends to fly in the face of traditional mapping— maps that change with opinion sound outrageous and are radically different from our paper map legacy and the manual GIS of old. It suggests a fundamental change in our paradigm of maps, their use and conjoined impact—are you ready?

Author's Notes: 1) Ross Whaley, Professor Emeritus at SUNY-Syracuse and member of my doctoral committee, in a plenary presentation at the New York State GIS Conference outlined the cognitive levels of judgment, described how they impact natural resource decision-making and commented on spatial information's role in the mix. His remarks rekindled a flurry of thoughts from social science courses and late night discussions that continue to haunt my overly technical emersion in GIS technology. Figure 2 ties together some of these "softer science" musings on the critical challenges face GIS as it crosses the chasm from descriptive to prescriptive applications—thank you to Jim Smith, Perry Brown, Al Dyer, Evan Vlachos and the cauldron of thinking at Colorado State University in the 1970s. 2) Related discussion on the softer side of GIS is in Topics 7 and 8 in the *Map Analysis* book (Berry, 2007; GeoTec Media, www.geoplance.com/books/MapAnalysis) and Topics 19 and 23 in the online *Beyond Mapping III* compilation (www.innovativegis.com/basis/MapAnalysis).

Melding the Minds of the “-ists” and “-ologists”

(GeoWorld, July 2009)

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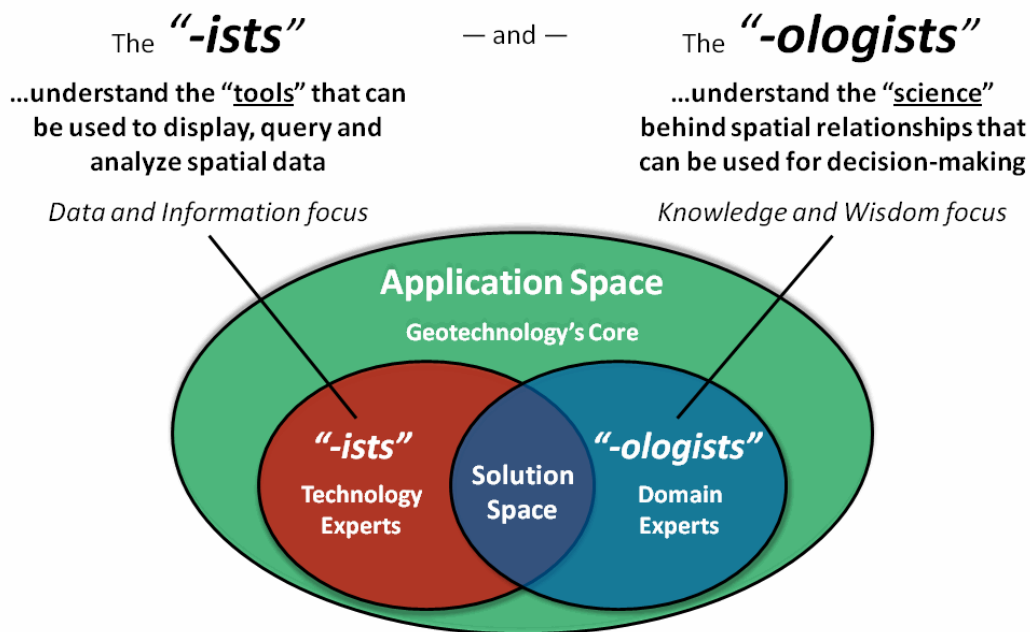
I recently attended the GIS in Higher Education Summit for Colorado Universities that wrestled with challenges and opportunities facing academic programs in light of the rapid growth of the geographic information industry and its plethora of commercial and government agency expressions. Geotechnology's “mega-technology status” alongside

the giants of Nanotechnology and Biotechnology seems to be both a blessing and a curse. The Summit’s take-away for me was that, while the field is poised for exponential growth, our current narrow footing is a bit unstable for such a giant leap.

Duane Marble in a thoughtful article (*Defining the Components of the Geospatial Workforce—Who Are We?*; ArcNews, Winter 2005/2006) suggests that—

“Presently, far too many academic programs concentrate on imparting only basic skills in the manipulation of existing GIS software to the near exclusion of problem identification and solving; mastery of analytic geospatial tools; and critical topics in the fields of computer science, mathematics and statistics, and information technology.”

This dichotomy of “tools” versus “science” is reminiscent of the “-ists and -ologists” Wars of the 1990’s. While not on the same level as the Peloponnesian War that reshaped Ancient Greece, the two conflicts have some parallels. The pragmatic and dogged Spartans (an oligarchy) soundly trounced the intellectual and aristocratic Athenians (a democracy). However in the process, the economic toll was staggering, poverty widespread, cultures devastated and civil war became a common occurrence throughout the Greek world that never recovered its grandeur.



Together the “-ists” and the “-ologists” frame and develop the Solution for an application.

Figure 1. A civilized and gracious tension exists between the of-the-tool and of-the-application groups.

Figure 1 portrays a similar, yet more civilized and gracious tension noted during the Education Summit. The “-ists” in the group pragmatically focused on programs emphasizing a GIS specialist’s command of the tools needed to display, query and

process spatial data (Data and Information focus). The “-ologists,” on the other hand, had a broader vision of engaging users (e.g., ecologists, sociologists, hydrologists, epidemiologists, etc.) who understand the science behind the spatial relationships that support decision-making (Knowledge and Wisdom focus).

My first encounter with the “-ists” and “-ologists” conflict involved the U.S. Forest Service’s Project 615 in the early 1990’s (615 looked like GIS on the line-printers of the day). The nearly billion dollar procurement for geographic information technology was (and likely still is) the largest sole-source acquisitions of computer technology outside of the military. The technical specifications were as detailed as they were extensive and identified a comprehensive set of analytical capabilities involving innovative and participatory decision-making practices. The goal was a new way of doing business in support of their “New Forestry” philosophy using ecological processes of natural forests as a model to guide the design of managed forests—an “-ologists” perspective justifying the huge investment and need for an entirely new approach to maps and mapping.

However, the initial implementation of the system was primarily under the control of forest mensurationists—an “-ists” perspective emphasizing data collection, inventory, query and display. The result was sort of like a Ferrari idling to and from a super market of map products.

Geotechnology’s critical and unifying component is the application space where the rubber meets the road that demands a melding of the minds of technology and domain experts for viable solutions. While mapped data is the foundation of a solution, it is rarely sufficient unto itself. Yet our paper-map legacy suggests that “map products” are the focus and spatial databases are king—“build it and they (applications) will come.”

Making the leap demanded by mega-technology status suggests more than a narrow stance of efficient warehousing of accurate data and easy access to information. It suggests “spatial reasoning” that combines an understanding of both the tool and the relevant science within the context of an application.

Like a Russian nesting doll, spatial applications involve a series of interacting levels of people, policies and paradigms (figure 2). *Decision-makers* utilize a spatial solution derived by the “-ists and -ologists” within the guidance of *Stakeholders* (imparting value judgments), *Policy Makers* (codifying consensus) and the *General Public* (recipients of actions). An educated society needs to understand spatial technology commensurate with the level of their interaction—to not do so puts Geotechnology in “black box” status and severely undermines its potential utility and effectiveness.

An academic analogy that comes to mind is statistics. While its inception is rooted in 15th century mathematics, it wasn’t until early in the 20th century that the discipline broadened its scope and societal impact. Today it is difficult to find disciplines on campus that do not develop a basic literacy in statistics. This level of intellectual diffusion was not accomplished by funneling most of the student body through a series of one-size-fits-all courses in the Statistics Department. Rather it is accomplished through a

dandelion seeding approach where statistics is enveloped into existing disciplinary classes and/or specially tailored courses (e.g., Introduction to Statistics for Foresters, Engineers, Agriculturists, Business, Basket Weaving, etc.).

Decision Makers utilize the **Solution** under **Stakeholder, Policy & Public** auspices.

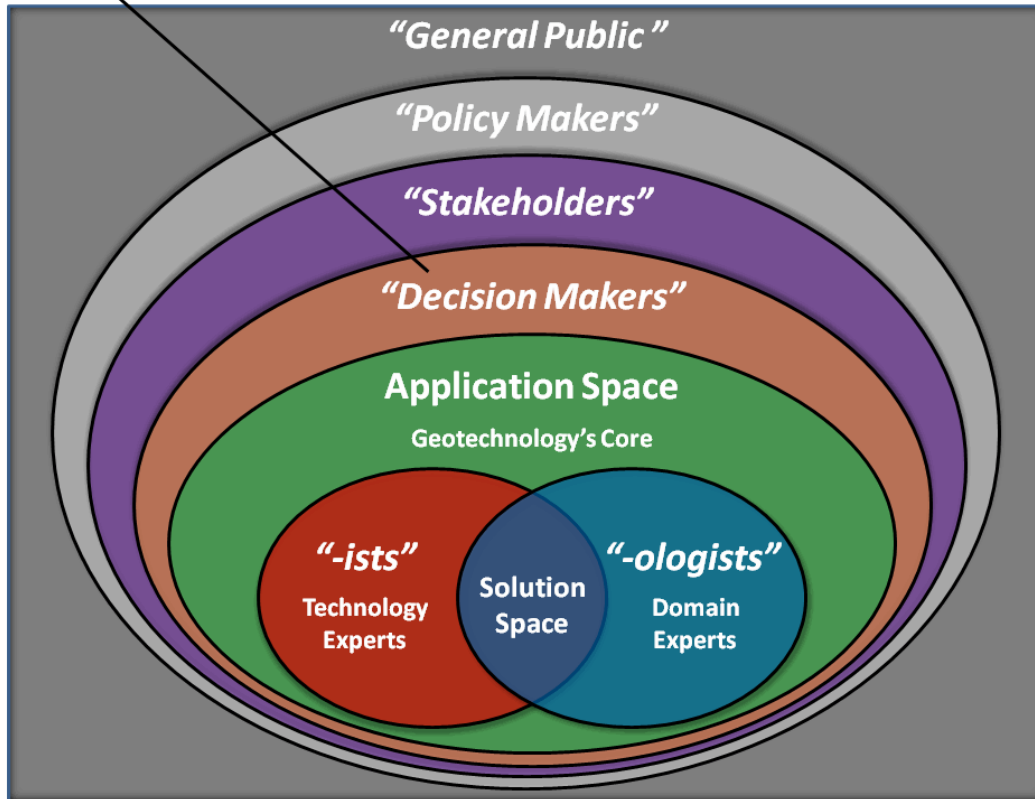


Figure 2. Geotechnology applications involve series of interacting levels of people, policies and paradigms.

This doesn't mean that deep-keeled Geotechnology curricula are pushed aside. On the contrary, like a Statistics Department, there is a need for in-depth courses that produce the theorists, innovators and specialists who grow the technology's capabilities and databases. However it does suggest a less didactic approach in which all who touch GIS must "start at the beginning and when you get to the end...stop" (The Cheshire Cat).

It suggests breadth over depth for many of tomorrow's GIS "-ologists" who might be more "of the application" than the traditional "of the tool" persuasion— sort of like an outrigger canoe with Geotechnology as the lateral support float. Also it suggests a heretic thought that a "disciplinary silos" approach which directly speaks to a discipline's applications might be the best way to broadly disseminate the underlying concepts of spatial reasoning.

While academic silos are generally inappropriate for database design and development (the "-ists" world), they might be the best mechanism for introducing and fully engaging potential users (the "-ologists" world). In large part it can be argued that the outreach to

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other disciplines is our foremost academic challenge in repositioning Geotechnology for the 21st Century.

Is GIS Technology Ahead of Science?

(GeoWorld, February 1999, pg. 28-29)

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The movement from mapping to map analysis marks a turning point in the collection and processing of geographic data. It changes our perspective from “spatially-aggregated” descriptions and images of an area to “site-specific” evaluation of the relationships among mapped variables. The extension of the basic map elements from points, lines and areas to map surfaces and the quantitative treatment of these data has fueled the transition. However, this new perspective challenges the conceptual differences between spatial and non-spatial data, their analysis and scientific foundation.

For many it appears to propagate as many questions as it seems to answer. I recently had the opportunity to reflect on the changes in spatial technology and its impact on science for a presentation* before a group of scientists. Five foundation-shaking questions emerged.

Is the “scientific method” relevant in the data-rich age of knowledge engineering?

The first step in the scientific method is the statement of a hypothesis. It reflects a “possible” relationship or new understanding of a phenomenon. Once a hypothesis is established, a methodology for testing it is developed. The data needed for evaluation is collected and analyzed and, as a result, the hypothesis is accepted or rejected. Each completion of the process contributes to the body of science, stimulates new hypotheses, and furthers knowledge.

The scientific method has served science well. Above all else, it is efficient in a data-constrained environment. However, technology has radically changed the nature of that environment. A spatial database is composed of thousands upon thousands of spatially registered locations relating a diverse set of variables.

In this data-rich environment, the focus of the scientific method shifts from efficiency in data collection and analysis to the derivation of alternative hypotheses. Hypothesis building results from “mining” the data under various spatial, temporal and thematic partitions. The radical change is that the data collection and initial analysis steps precede the hypothesis statement—in effect, turning the traditional scientific method on its head.

Is the “random thing” pertinent in deriving mapped data

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A cornerstone of traditional data analysis is randomness. In data collection it seeks to minimize the effects of spatial autocorrelation and dependence among variables. Historically, a scientist could measure only a few plots and randomness was needed to provide an unbiased sample for estimating the typical state of a variable (i.e., *average* and *standard deviation*).

For questions of central tendency, randomness is essential as it supports the basic assumptions about analyzing data in numeric space, devoid of “unexplained” spatial interactions. However, in geographic space, randomness rarely exists and spatial relationships are fundamental to site-specific management and research.

Adherence to the “random thing” runs counter to continuous spatial expression of variables. This is particularly true in sampling design. While efficiently establishing the central tendency, random sampling often fails to consistently exam the spatial pattern of variations. An underlying systematic sampling design, such as systematic unaligned (see GIS World, Beyond Mapping columns February-April, 1997), is better at insuring an even distribution of samples over an area of interest.

Are geographic distributions a natural extension of numerical distributions?

To characterize a variable in numeric space, density functions, such as the standard normal curve, are used. They translate the pattern of discrete measurements along a “number line” into a continuous numeric distribution. Statistics describing the functional form of the distribution determine the central tendency of the variable and ultimately its probability of occurrence. Consideration of additional variables results in an N-dimensional numerical distribution visualized as a series of scattergrams.

The geographic distribution of a variable can be derived from discrete sample points positioned in geographic space. Map generalization and spatial interpolation techniques can be used to form a continuous distribution, in a manner analogous to deriving a numeric distribution (see GIS World, Beyond Mapping columns May-August, 1998). In effect, the Gaussian, Poisson and binomial density functions used in non-spatial statistics are akin to the polynomial, inverse-distance-squared and Kriging density functions used in spatial statistics.

Although the conceptual approaches are closely aligned, the information contained in numeric and geographic distributions is different. Whereas numeric distributions provide insight into the central tendency of a variable, geographic distributions provide information about the geographic pattern of variations. Generally speaking, non-spatial characterization supports a “spatially-aggregated” perspective, while spatial characterization supports “site-specific” analysis. It can be argued that research using non-spatial techniques provides minimal guidance for site-specific management— in fact, it might be even dysfunctional.

Can spatial dependencies be modeled

Non-spatial modeling, such as linear regressions derived from a set of sample points, assumes spatially independent data and seeks to implement the “best overall” action everywhere. Site-specific management, on the other hand, assumes spatially dependent data and seeks to evaluate “IF <spatial condition> THEN <spatial action>” rules for the specific conditions throughout a management area. Although the underlying philosophies of the two approaches are at odds, the “mechanics” of their expression spring from the same roots.

Within a traditional mathematical context, each map represents a “variable,” each spatial unit represents a “case” and the value at that location represents a “measurement.” In a sense, the map locations can be conceptualized as a bunch of sample plots—it is just that sample plots are everywhere (vis. cells in a gridded map surface). The result is a data structure that tracks spatial autocorrelation and spatial dependency. The structure can be conceptualized as a stack of maps with a vertical pin spearing a sequence of values defining each variable for that location— sort of a data shishkebab. Regression, rule induction or a similar technique, can be applied to the data to derive a spatially dependent model of the relationship among the mapped variables.

Admittedly, imprecise, inaccurate or poorly modeled surfaces, can incorrectly track the spatial relationships. But, given good data, the “map-ematical” approach has the capability of modeling the spatial character inherent in the data. What is needed is a concerted effort by the scientific community to identify guidelines for spatial modeling and develop techniques for assessing the accuracy of mapped data and the results of its analysis.

How can “site-specific” analysis contribute to the scientific body of knowledge?

Traditionally research has focused on intensive investigations comprised of a limited number of samples. These studies are well designed and executed by researchers who are close to the data. As a result, the science performed is both rigorous and professional. However, it is extremely tedious and limited in both time and space. The findings might accurately reflect relationships for the experimental plots during the study period, but offer minimal information for a land manager 70 miles away under different conditions, such as biological agents, soil, terrain and climate.

Land managers, on the other hand, supervise large tracks of land for long periods of time, but are generally unaccustomed to administering scientific projects. As a result, general operations and scientific studies have been viewed as different beasts. Scientists and managers each do their own thing and a somewhat nebulous step of “technology transfer” hopefully links the two.

Within today’s data-rich environment, things appear to be changing. Managers now have access to databases and analysis capabilities far beyond those of scientists just a few years ago. Also, their data extends over a spectrum of conditions that can’t be matched by traditional experimental plots. But often overlooked is the reality that these operational data sets form the scientific fodder needed to build the spatial relationships demanded by site-specific management.

Spatial technology has changed forever land management operations— now it is destined to change research. A close alliance between researchers and managers is the key. Without it, constrained research (viz. esoteric) mismatches the needs of evolving technology, and heuristic (viz. unscientific) rules-of-thumb are substituted. Although mapping and “free association” geo-query clearly stimulates thinking, it rarely contains the rigor needed to materially advance scientific knowledge. Under these conditions a data-rich environment can be an information-poor substitute for good science.

So where do we go from here?

In the new world of spatial technology the land manager has the comprehensive database and the researcher has the methodology for its analysis— both are key factors in successfully unlocking the relationships needed for site-specific management. In a sense, technology is ahead of science, sort of the cart before the horse. A GIS can map spatial patterns and reactions to a meter (*technological cart*), but our historical science base has been calibrated by non-spatial analysis (*scientific horse*). The need for a partnership between managers and scientists has never been more acute; nor has it been so obtainable. For the first time managers and scientists share the same set of tools and an increasingly convergent perspective.



Author's Note: This column is based on a keynote address for the Site-Specific Management of Wheat Conference, Denver, Colorado, March 4-5, 1998; a copy of the full text is online at www.innovativegis.com/basis, select Presentations & Papers.

The Good, the Bad and the Ugly Sides of GIS

(GeoWorld, November 2013)

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Sometimes GIS-perts imagine geotechnology as a super hero (“GIS Techymon,” see figure 1) who can do anything— process data faster than a gigahertz processor, more powerful than a super computer, able to leap mounds of mapped data in a single bound and bend hundreds of polylines with a single click-and-drag—all for truth, justice and all that stuff. With the Spatial Triad for super powers (RS, GIS, GPS), the legacy of manual mapping has been all but vanquished and millions upon millions of new users (both

human and robotic) rely on GIS Techymon to fill their heads and circuit boards with valuable insight into “where is what, why, so what and what if” expressions of spatial patterns and relationships.

In just few decades, vast amounts of spatial data have been collected and corralled, enabling near instantaneous access to remote sensing images, GPS navigation, interactive maps, asset management records and geo-queries as a widely-used “technological” tool. To the Gen X generation, technology is a mainstay of their lives—geotechnology is simply another highly useful expression.

A similar but much quieter GIS revolution as an “analytical” tool (see Author’s Notes 1) has radically changed how foresters, farmers, and city planners manage their lands; how retail marketers, political forecasters and epidemiologists “see” spatial relationships in their data sets; how policemen, generals and political pundits develop tactics for engaging the opposition; plus thousands of other new paradigms and practices. This growing wealth of sophisticated spatial models and solutions did not exist a couple of decades ago, but now they have become indispensable and commonplace parts of contemporary culture. All is good ...or is it?

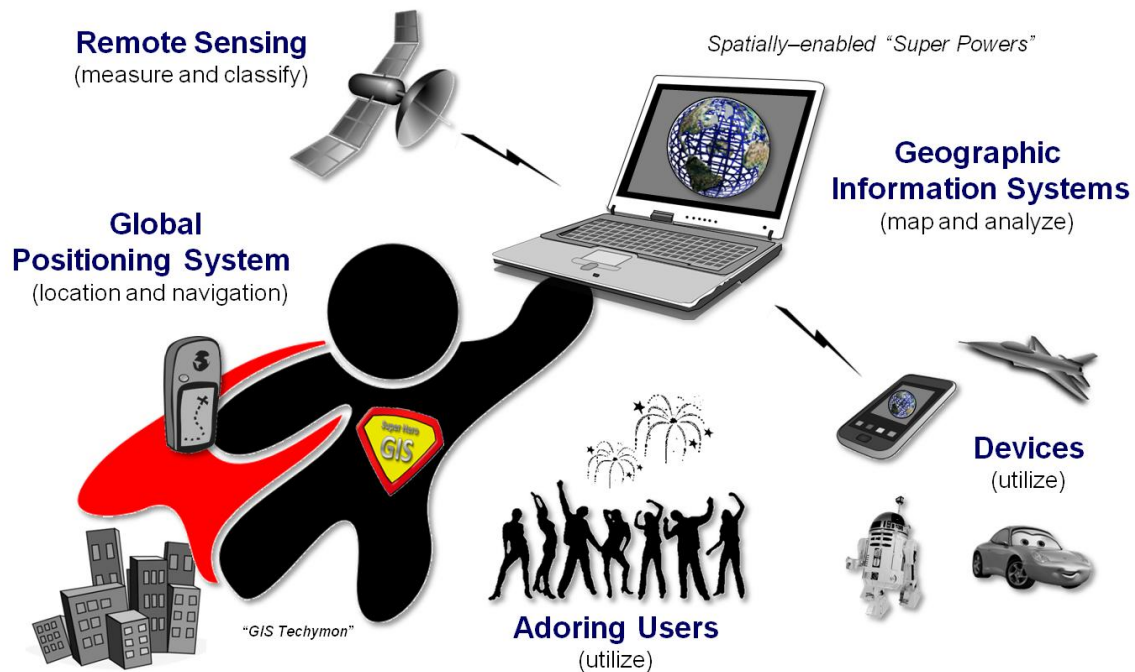


Figure 1. Look up in the data cloud, it's GIS Techymon to save the day...all is good (or is it?).

Some fail to see virtue in all things GIS and actually see the “law of unintended consequences” at play to expose a darker-side of geotechnology. Even the best of intentions and ideas can turn bad through unanticipated effects.

High resolution satellite imagery, for example, can be used to recognize patterns, map land cover classes and assess vegetation biomass/vigor throughout the globe—the greater

the spatial detail of the imagery the better the classifications. But in the early 2000s when the satellite resolution was detailed enough to discern rooftop sun bathers in London the Internet lit up. It seems zooming in on an Acacia tree is good but zooming in on people is bad—an appalling violation of privacy.

Fast forward to today with drone aircraft tracking people as readily as it tracks an advancing wildfire. Or consider the thousands of in-place and mobile cameras with sophisticated facial recognition software that shadow private citizens in addition to criminals and terrorists. Or the concern for data mining of your credit card swipes, demographic character and life style profile in both space and time to better market to your needs (good) but at what cost to your privacy (bad).

Or just last week in my hometown, a suspect parking database was discovered that has captured license plates “on-the-fly” for years and can be searched to identify the whereabouts of any vehicle. The system is good at catching habitual parking offenders and possibly a bad guy or two, but to many the technology is seen as a wholesale assault on the privacy of the ordinary good guy.

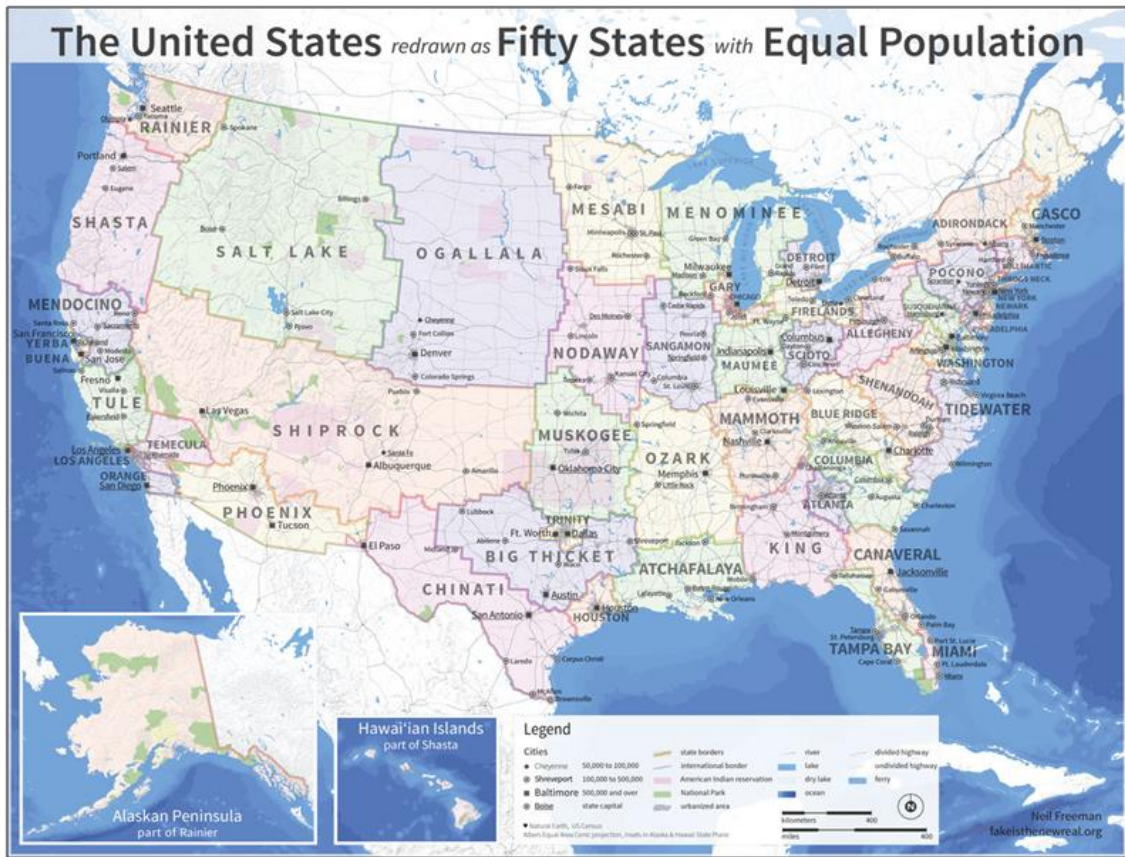
The Rorschach ink blot nature of most technology that flips between good and bad has been debated for decades. Several years ago I had the privilege of hosting a Denver University event exploring “Geoslavery or Cyber-Liberation: Freedom and Privacy in the Information Age” (see Author’s Note 2). While the panel of experts made excellent points and provided stimulating discussion, an acceptable balance that encourages geotechnology’s good side while constraining its bad side was not struck. The Jekyll and Hyde personality of geotechnology still persists, however it has been magnified many fold due to its ever-expanding tentacles reaching further and further into general society.

The collateral damage of unintended consequences seems to tarnish GIS Techymon’s image as a classic super hero. However the purposeful perverse application of geotechnology is really ugly. Mark Monmonier’s classic book “How to Lie with Maps” (1996, University Of Chicago Press) reveals how maps can be (and often must be) distorted to create a readable and understandable map. These cartographic white lies pale in comparison to the deliberate misrepresentation or misuse of mapped data to support biased propaganda or hidden agendas.

For example, the top inset in figure 2 depicts a hypothetical map that rearranges state borders to equally distribute the population of the United States so each of the imagined states has 1/50th of the total population or about 6 million people (see Author’s Note 3). This cartogram is far from an ugly distortion of fact as it effectively conveys population information in a diagrammatic form that stimulates thought.

The bottom inset addresses the spatial distribution of population as well. However, in this case it involves deliberate manipulation of polygon boundaries for partisan political advantage by combining census and party affiliation data to “gerrymander” congressional districts (see Author’s Note 4). The drafting of spindly tentacles and ameba-like pseudopods concentrate the voting power of one party into as many safe districts as

possible and dilute opposition votes as much as possible. In the opinion of many political pundits, the GIS-gerrymandered districts are the root-cause of much of the current bifurcated, dysfunctional and down-right hostile congressional environment we face.



Inset (a). Neil Freeman, fakeisthenewreal.org



Inset (b). Peter Wattson, www.senate.leg.state.mn.us/departments/scr/REDIST/red907.htm

Figure 2. Inset (a) shows a redrawing of the 50 states forcing equal populations; inset (b) shows examples of deliberate manipulation of political boundaries for electoral advantage.

Map analysis is very effective in addressing the gerrymandered spatial optimization problem, regardless of any adverse moral and political ramifications. It also is good at efficiently keeping less technologically endowed peoples at bay, tracking children and the elderly for their own safety, monitoring the movements of parolees and pedophiles, fueling information warfare and killing people, and hundreds of other uses that straddle the moral fence.

GIS is most certainly an agent of good ...most of the time. But it is imperative to remember that GIS isn't always good, or always bad, or always ugly. The technological and analytical capabilities themselves are ethically inert. It is how they are applied within a social conscience context that determines which side of GIS surfaces (see Author's Note 5).

Author's Notes: 1) See "Simultaneously Trivializing and Complicating GIS" in the *Beyond Mapping Compilation Series* at <http://www.innovativegis.com/basis/MapAnalysis/Topic30/Topic30.htm> 2) see <http://www.innovativegis.com/basis/Present/BridgesGeoslavery/> for panel discussion summary. 3) See "Electoral College Reform (fifty states with equal population)" at <http://fakeisthenewreal.org/reform/>. 4) See *Beyond Mapping* column on "Narrowing-in on Absurd Gerrymanders" in the *Beyond Mapping Compilation Series* at <http://www.innovativegis.com/basis/MapAnalysis/Topic25/Topic25.htm> . 5) See "Ethics and GIS: The Practitioner's Dilemma" at http://www.spatial.maine.edu/~onsrud/GSDIArchive/gis_ethics.pdf.

Where Do We Go from Here?

(GeoWorld, December 2013)

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I have been involved in GIS for over four decades and can attest that it has matured a lot over that evolutionary/revolutionary period. In the 25 years of the *Beyond Mapping* column, I have attempted to track a good deal of the conceptual, organizational, procedural, and sometimes disputable issues.

In the 1970s the foundations and fundamental principles for digital maps took the form of "automated cartography" designed to replace manual drafting with the cold steel of a pen plotter. In the 1980s we linked these newfangled digital maps to traditional data base systems to create "spatial database management systems" that enabled users to easily search for locations with specific conditions/characteristics, and then display the results in map form.

The 1990s saw an exponential rise in the use of geotechnology as Remote Sensing (RS) and the Global Positioning System (GPS) became fully integrated with GIS— so integrated that *GIS World* became *GeoWorld* to reflect the ever expanding community of users and uses. In addition, map analysis and modeling spawned a host of new applications, as well as sparking the promise of a dramatic shift in the historical perspective of "what a map is (and isn't)."

The 2000s saw the Internet move maps and mapping from a “down the hall and to the right” specialist’s domain, to everyone’s desktop, notebook and mobile device. In today’s high tech environment one can fly-through a virtual reality rendering of geographic space that was purely science fiction a few decades ago. Wow!

My ride through GIS’s evolution has been somewhat akin to Douglas Adams’ *Hitchhiker’s Guide to the Galaxy Series*. Writing a monthly column on geotechnology finds resonance in his description of flying— “There is an art, it says, or rather, a knack to flying. The knack lies in learning how to throw yourself at the ground and miss.” As GIS evolved, the twists and turns around each corner were far from obvious, as the emerging field was buffeted in the combined whirlwinds of technological advances and societal awakening.

In most cases, geotechnology’s evolution since its early decades has resulted from outside forces: 1) reflecting macro-changes in computer science, electrical engineering and general technological advances, and 2) translating workflows and processes into specialized applications. The results have been a readily accessible storehouse of digital maps and a wide array of extremely useful and wildly popular applications. Geotechnology’s “where is what” data-centric focus has most certainly moved the masses, but has it moved us closer to a “why, so what, and what if” focus that translates mapped data into spatial information and understanding?



Figure 1. The idea of map variables being map-atically evaluated has been around for decades but still not fully embraced. (I wonder what other nutty ideas are languishing in the backwaters of geotechnology that have yet to take form).

While the technological expression of GIS has skyrocketed, the analytical revolution that was promised still seems grounded. I have long awaited a Big Kahuna wave of map analysis and modeling (figure 1) to sweep us well beyond mapping toward an entirely new paradigm of maps, mapping and mapped data for understanding and directly infusing spatial patterns and relationships into science and problem-solving.

From the online book *Beyond Mapping III* by Joseph K. Berry posted at www.innovativegis.com/basis/MapAnalysis/
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In the 1970s and 80s my thoughts turned to a “map-ematical” framework for the quantitative analysis of mapped data (see Author’s Notes 1 and 2). The suggestion that these data exhibited a “spatial distribution” that was quantitatively analogous a “numerical distribution” was not well received. The further suggestion that traditional mathematical and statistical operations could be spatially evaluated was resoundingly debunked as “disgusting” by the mapping community and “heresy” by the math/stat community.

In the early years of GIS development, most people “knew” what a map was (an organized collection of point, line and polygon spatial objects) and its purpose (display, navigation, and geo-query). To suggest that grid-based maps formed continuous surfaces defining map variables that could be map-ematically processed was brash. Couple that perspective with the rapidly advancing “technological tool” expressions, and the “analytical tool” capabilities were relegated to the back of the bus.

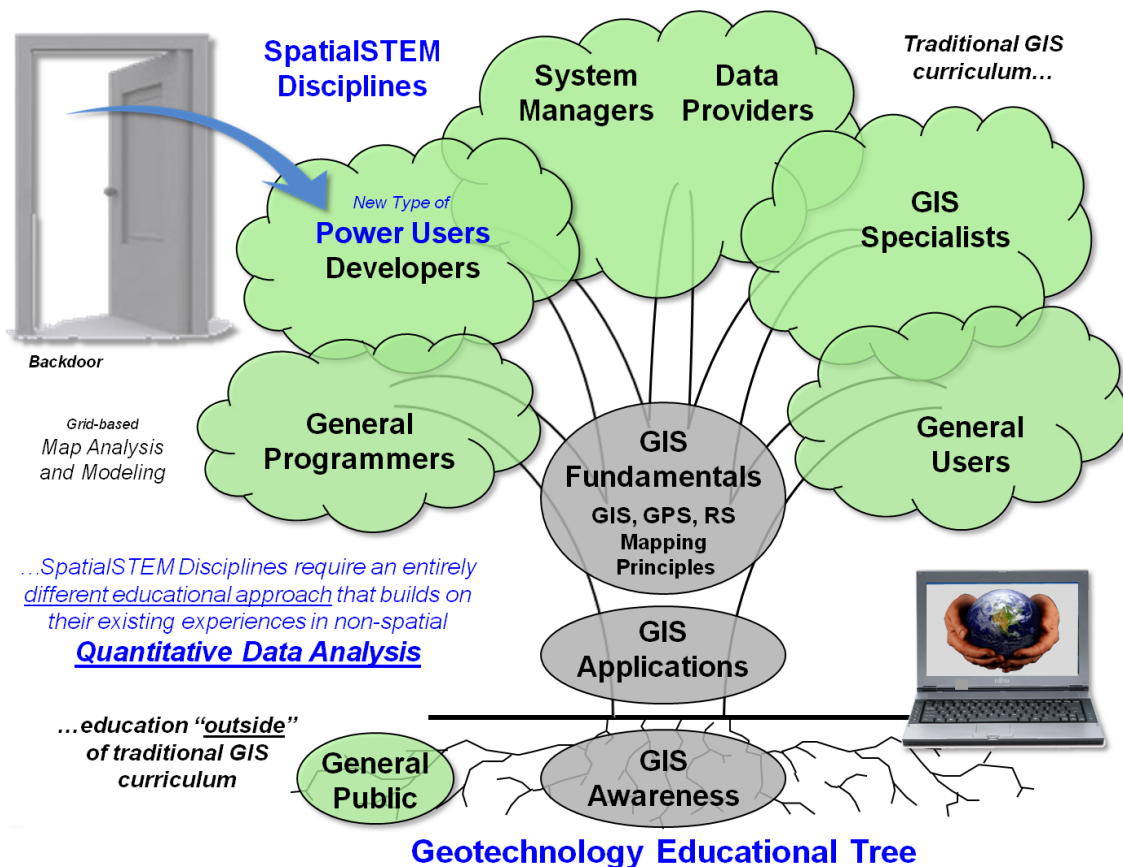


Figure 2. Traditional GIS education does not adequately address STEM disciplines’ focus on quantitative analysis of mapped data.

Fast-forward to today and sense the changes in the wind and sea of thought. Two central conditions are nudging the GIS oil tanker toward grid-based map analysis and modeling: 1) the user community is asking “is that all there is to GIS?” (like Peggy Lee’s classic

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song but about mapping, display and navigation), and 2) a building interest in spatialSTEM that is prodding the math/stat community to no longer ignore spatial patterns and relationships— increasing recognition that “spatial relationships exist and are quantifiable,” and that “quantitative analysis of maps is a reality.”

Education will be the catalyst for the next step in geotechnology’s evolution toward map analysis and modeling. However, traditional GIS curricula and programs of study (Educational Tree in figure 2) are ill-equipped for the task. Most STEM students are not interested in becoming GIS-perts; rather, they want to employ spatial analysis tools into their scientific explorations—a backdoor entry as a “Power User.” What we (GIS communities) need to do is engage the STEM disciplines on their turf—quantitative data analysis—instead of continually dwelling on the technical wonders of modern mapping, Internet access, real-time navigation, awesome displays and elegant underlying theory.

These wonders are tremendously important and commercially viable aspects of geotechnology, but do not go to the core of the STEM disciplines (see Author’s Note 3). Capturing the attention of these folks requires less emphasis on vector-based approaches involving collections of “discrete map features” for geoquery of existing map data, and more emphasis on grid-based approaches involving surface gradients of “continuous map variables” for investigating relationships and patterns within and among map layers. AKAW!! ... surfers cry when they spot a “hugangus” perfect wave.

However, after 25 years of shuffling along the GIS path, I have reached my last Beyond Mapping column in GeoWorld ...the flickering torch is ready to be passed to the next generation of GIS enthusiasts. For those looking for an instant replay of any of the nearly 300 columns, you can access any and all of them through the Chronological Listing posted at—

<http://www.innovativegis.com/basis/MapAnalysis/ChronList/>

Also, for the incredibly perseverant, I will be making a blog post from time to time discussing contemporary issues, approaches and procedures in light of where we have been (beginning in January 2014)—

<http://blog.innovativegis.com>

I hope some of you will join me on the continuing journey. Until then ...keep on GISing outside the traditional lines.

Author’s Notes: 1) See “An Academic Approach to Cartographic Modeling in Management of Natural Resources,” 1979 and 2) “A Mathematical Structure for Analyzing Maps,” 1986 ...both historical papers posted at www.innovativegis.com/basis/Papers/Online_Papers.htm. 3) See “Topic 30, A Math/Stat Framework for Map Analysis” in the Beyond Mapping Compilation Series posted at www.innovativegis.com/basis/MapAnalysis/.

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