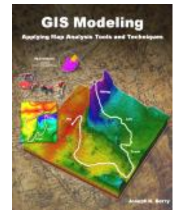
Beyond Mapping IV

Topic 5 – Structuring GIS Modeling Approaches



GIS Modeling book

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

(*Back to the Table of Contents*)

Mixing It up in GIS Modeling's Kitchen

(GeoWorld, May 2013)

(*return to top of Topic*)

The modern "geotechnology recipe" is one part data, one part analysis and a dash of colorful rendering. That's a far cry from the historical mapping recipe of basically all data with a generous ladling of cartography. Today's maps are less renderings of "precise placement of physical features for navigation and record-keeping" (meat and potatoes) than they are interactive "interpretations of spatial relationships for understanding and decision-making" (haute cuisine).

Figure 1 carries this cheesy cooking analogy a few steps further. The left portion relates our modern food chain to levels of mapped data organization from mouthfuls of map values to data warehouses. The center and right side of the figure ties these data (ingredients) to the GIS modeling process (preparation and cooking) and display (garnishing and presentation).

A map stack of geo-registered map layers is analogous to a pantry that contains the necessary ingredients (map layers) for preparing a meal (application). The meal can range from Pop-Tart à la mode to the classic French coq au vin or Spain's paella with their increasing complexity and varied ingredients, but a recipe all the same.

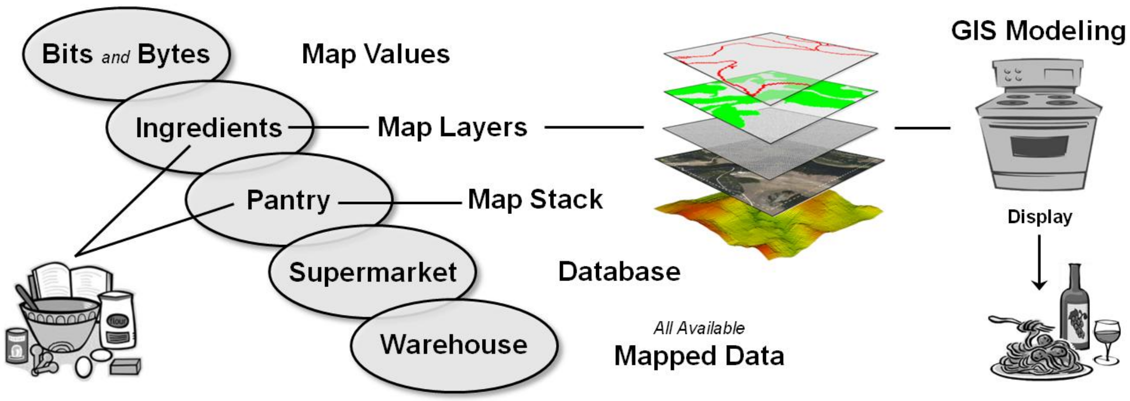


Figure 1. The levels of mapped data organization are analogous to our modern food chain.

GIS Modeling is sort of like that but serves as food for quantitative thought about the spatial relationships and patterns around us. To extend the cooking analogy, the rephrasing of an old saying seems appropriate— "Bits and bytes may break my bones, but inaccurate modeling will surely poison me." This suggests that while bad data can certainly be a problem, ham-fisted processing of perfect data can spoil an application just as easily.

For example, a protective "simple distance buffer" of a fixed distance is routinely applied around spawning streams ignoring relative erodibility of intervening terrain/soil/vegetation conditions. The result is an ineffective buffer that continues to rain-down dirt balls that choke the fish in highly erodible palaces and starve-out timber harvesting in places of low erodibility**.** In this case, the simple buffer is a meager "rice-cake-like" solution that propagates at megahertz speed across the mapping landscape helping neither the fish nor the logger. A more elaborate recipe involving a "variable-width buffer" is needed, but it is rarely employed.

GIS tends to focus a great deal on spatial data structure, formats, characteristics, query and visualization, but less on the analytical processing that "cooks" the data (meant in the most positive way). So what are the fundamental considerations in GIS models and modeling? How does it relate to traditional modeling?

At the highest conceptual level, GIS modeling has two important characteristics—processing structure and elemental approaches. The center portion of figure 2 depicts the underlying ***Processing Structure*** for all quantitative data analysis as a progression from fundamental *operations* to generalized *techniques* to key *sub-models* and finally to full application *models*.

This traditional mathematical structure uses sequential processing of basic math/stat operations to perform a wide variety of complex analyses. By controlling the order in which the operations are executed on variables, and using common storage of intermediate results, a robust and universal mathematical processing structure is developed.

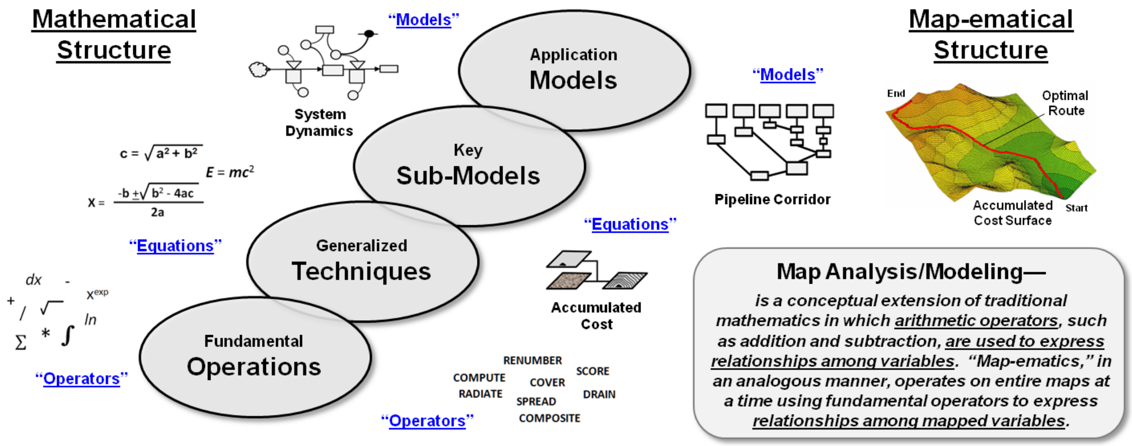


Figure 2. The "map-ematical structure" processes entire map layers at a time using fundamental operators to express relationships among mapped variables in a manner analogous to our traditional mathematical structure.

The "map-ematical" structure is similar to traditional algebra in which primitive operations, such as addition, subtraction, and exponentiation, are logically sequenced for specified variables to form equations and models. However in map algebra 1) the variables represent entire maps consisting of geo-registered sets of map values, and 2) the set of traditional math/stat operations are extended to simultaneously evaluate the spatial and numeric distributions of mapped data.

Each processing step is accomplished by requiring—

- retrieval of one or more map layers from the map stack,
- manipulation of that mapped data by an appropriate math/stat operation,
- creation of an intermediate map layer whose map values are derived as a result of that manipulation, and
- storage of that new map layer back into the map stack for subsequent processing.

The cyclical nature of the retrieval-manipulation-creation-storage processing structure is analogous to the evaluation of "nested parentheticals" in traditional algebra. The logical sequencing of map analysis operations on a set of map layers forms a spatial model of specified application. As with traditional algebra, fundamental techniques involving several primitive operations can be identified that are applicable to numerous situations.

The use of these primitive map analysis operations in a generalized modeling context accommodates a variety of analyses in a common, flexible and intuitive manner. Also it provides a framework for understanding the principles of map analysis that stimulates the development of new techniques, procedures and applications (see author's note 1).

The ***Elemental Approaches*** utilized in map analysis and GIS modeling also are rooted in traditional mathematics and take on two dimensions— *Atomistic/Analysis* versus *Holistic/Synthesis*.

The *Atomistic/Analysis* approach to GIS modeling can be thought of as "separating a whole into constituent elements" to investigate and discover spatial relationships within a system (figure 3). This "Reductionist's approach" is favored by western science which breaks down complex problems into simpler pieces which can then be analyzed individually.

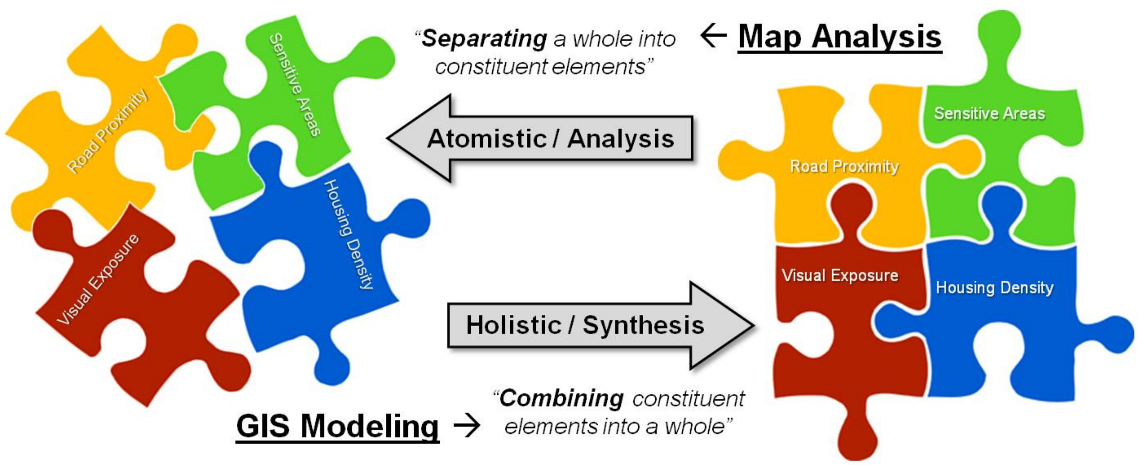


Figure 3. The two Elemental Approaches utilized in map analysis and GIS Modeling.

The *Holistic/Synthesis* approach, in contrast, can be thought of as "combining constituent elements into a whole" in a manner that emphasizes the organic or functional relationships between the parts and the whole. This "Interactionist's approach" is often associated with eastern philosophy of seeing the world as an integrated whole rather than a dissociated collection of parts.

So what does all this have to do with map analysis and GIS modeling? It is uniquely positioned to change how quantitative analysis is applied to complex real-world problems. First, it can be used account for the spatial distribution as well as the numerical distribution inherent in most data sets. Secondly, it can be used in the atomistic analysis of spatial systems to uncover relationships among perceived driving to variables of a system. Thirdly, it can be used in holistic synthesis to model changes in systems as the driving variables are altered or generate entirely new solutions.

In a sense, map analysis and modeling are like chemistry. A great deal of science is used to break down compounds into their elements and study the interactions—atomistic/analysis. Conversely, a great deal of innovation is used to assemble the elements into new compounds—holistic/synthesis. The combined results are repackaged into entirely new things from food additives to cancer cures.

Map analysis and GIS modeling operate in an analogous manner. They use many of the same map-ematical operations to first analyze and then to synthesize map variables into spatial solutions from navigating to a new restaurant to locating a pipeline corridor that considers a variety of stakeholder perspectives. While dictionaries define analysis and synthesis as opposites, it is important to note that in geotechnology, analysis without synthesis is almost worthless …and that the converse is just as true.

Author's Notes*: 1) see "SpatialSTEM – Seminar, Workshop and Teaching Materials for Understanding Grid-based Map Analysis" posted at www.innovativegis.com/Basis/Courses/SpatialSTEM/. 2) For more on GIS models and modeling, see the Beyond Mapping Compilation Series, book II, Topic 5, "A Framework for GIS Modeling" posted at www.innovativegis.com/basis/.*

How to Determine Exactly "Where Is What"

(GeoWorld, February 2008)

(return to top of Topic)

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 bulls eye 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.

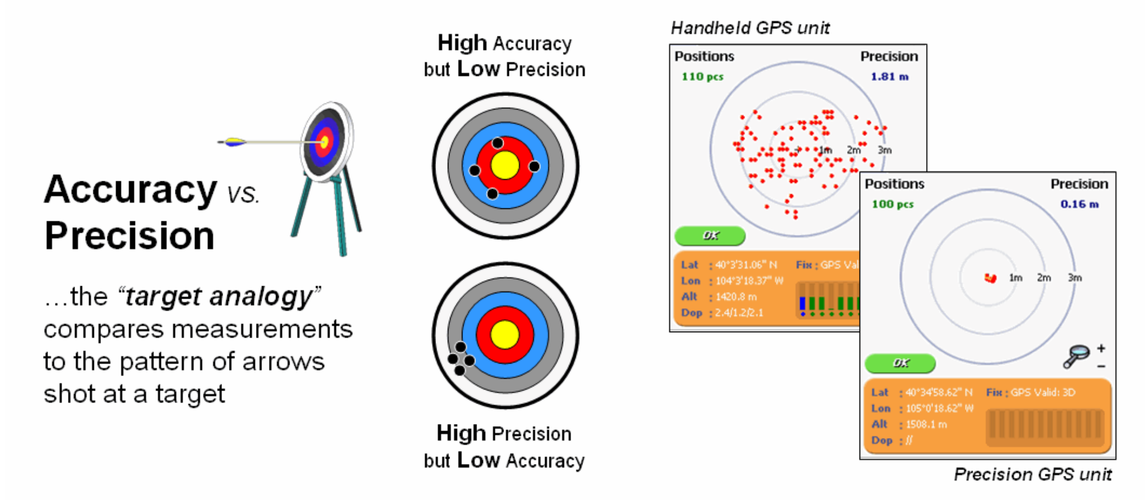


Figure 1. Accuracy refers to "exactness" and Precision refers to "repeatability" of data.

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.

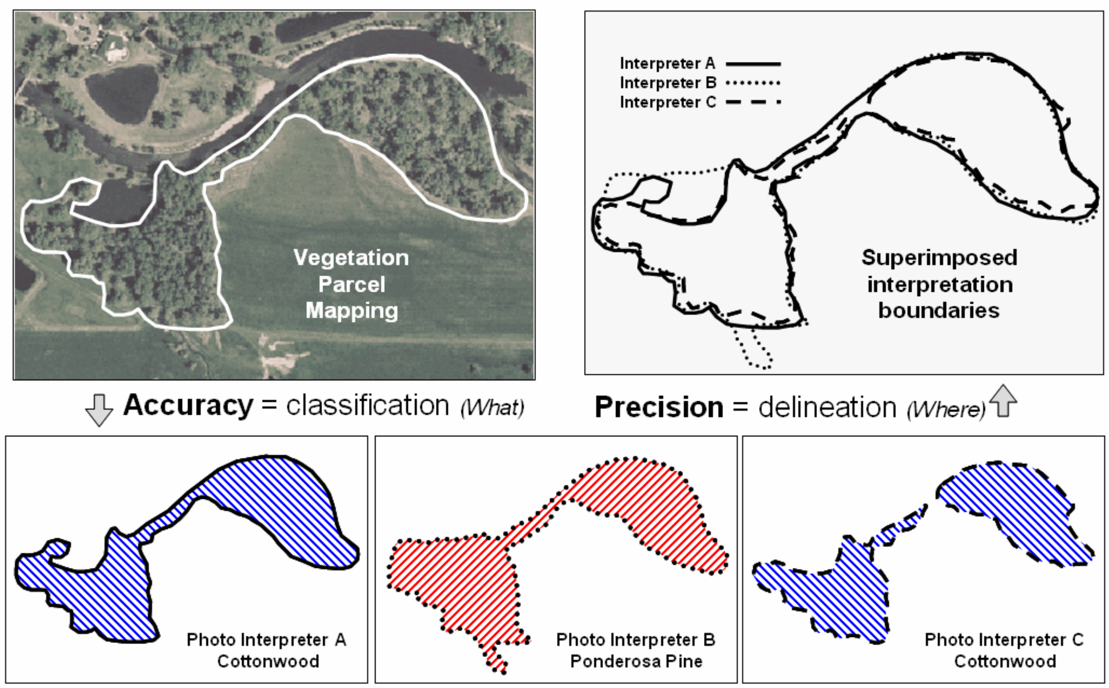


Figure 2. In mapped data, precision refers to placement whereas accuracy refers to classification.

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.

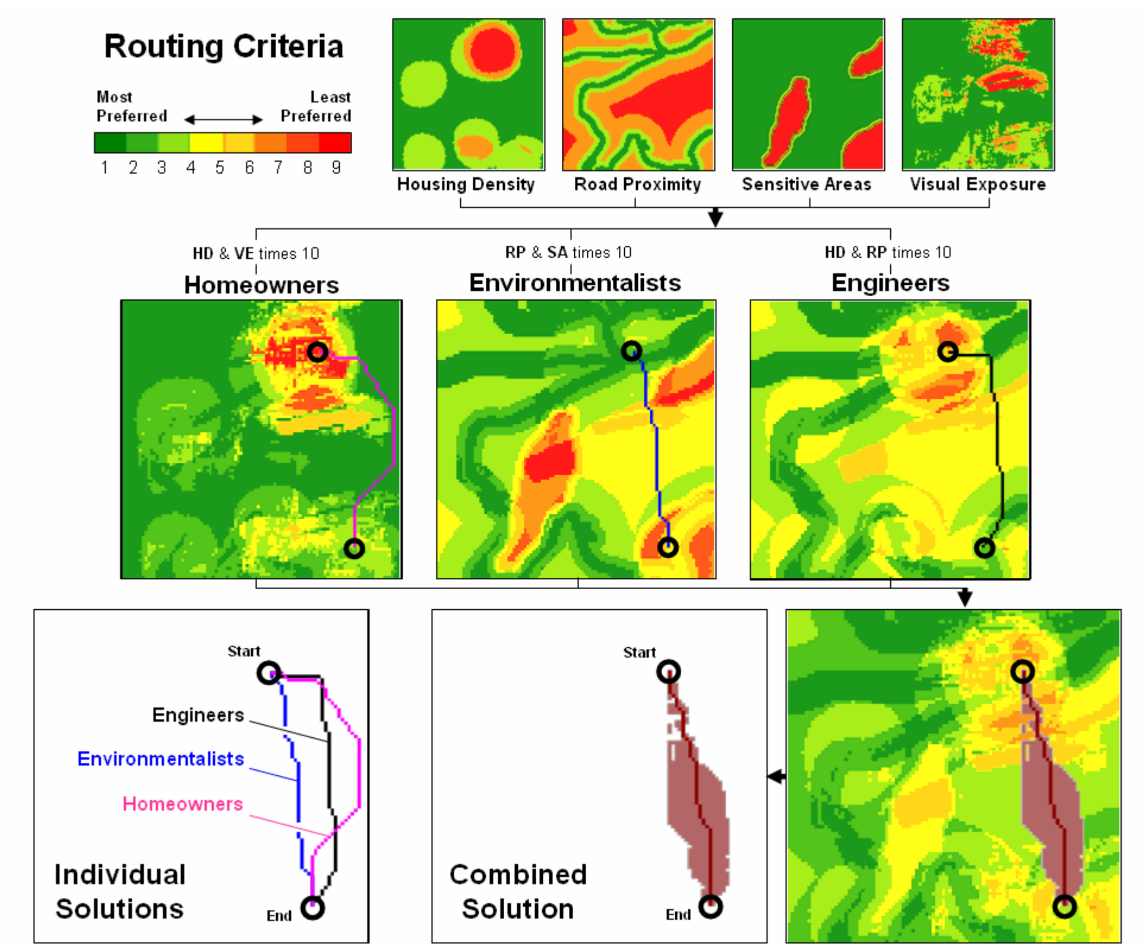


Figure 3. Maps derived by GIS modeling also involve accuracy of the interpretation, logic, understanding and judgment ingrained in the spatial reasoning.

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).

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****).*

Getting the Numbers Right

(GeoWorld, May 2007)

(return to top of Topic)

The concept that "*maps are numbers first, pictures later*" underlies all GIS processing. However in map analysis, the digital nature of maps takes on even more importance. How the map values are 1) retieved and 2) processed establishes a basic framework for classifying all of the analytical capabilities. In obtaining map values for processing there are three basic methods— Local, Focal and Zonal (see author's note).

While the Local/Focal/Zonal classification scheme is most frequently associated with grid-based modeling, it applies equally well to vector-based analysis— just substitute the concept of "polygon, line or point" for that of a grid "cell" as the smallest addressable unit of space providing the map values for processing.

Local processing retrieves a map value for a single map location independent of its surrounding values, then processes the value to derive and assign a new value to the location (figure 1). For example, an elevation value of 8250 associated with a grid cell location on an existing terrain surface is retrieved and then the contouring equation of *Interval = [Integer((MapValue - ContourBase) / ContourInterval)] = [int((8250 + 100) / 100)] = 83* is evaluated. The new map value of 83 is stored to indicate the 83rd 100-foot contour interval (8200-8300 feet) from a sea level contour base interval of 1 (0 to 100 feet). The processing is repeated for all map locations and the resultant map is filed with the other map layers in the stack.

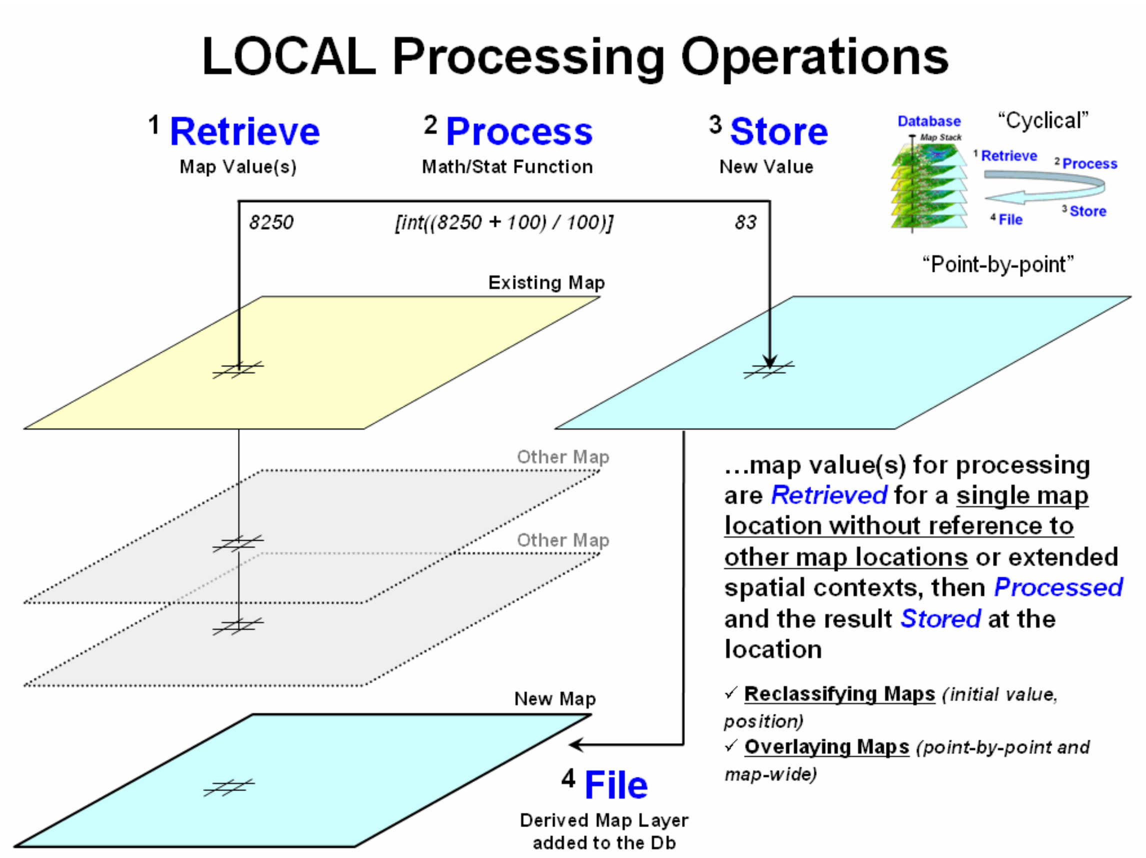


Figure 1. Local operations use point-by-point processing of map values that occur at each map location.

A similar operation might multiply the elevation value times 0.3048 *[ElevMeters = ElevFeet * 0.3048= 8250 * 0.3048= 2871]* to convert the elevation from feet to meters. In turn, a generalized atmospheric cooling relationship of 9.78 degC per 1000 meter rise can be applied *[(2871 / 1000 * 9.78]* to assign a value of 28.08 degC cooler than sea level air (termed Adiabatic Lapse Rate for those who are atmoshperic physics challenged).

The lower portion of figure 1 expands the Local processing concept from a single map layer to a stack of registered map layers. For example, a point-by-point overlay process might retrieve the elevation, slope, aspect, fuel loading, weather, and other information from a series of map layers as values used in calculating wildfire risk for a location. Note that the processing is still spatially-myopic as it addresses a single map location at a time (grid cell) but obtains a string of values for that location before performing a mathematical or statistical process to summarize the values.

While the examples might not directly address your application interests, the assertion that you can add, subtract, multiply, divide and otherwise "crunch the numbers" ought to alert you to the map-ematical nature of GIS. It suggests a map calculator with all of the buttons, rights and privileges of your old friendly handheld calculator— except a map calculator operates on entire map layers composed of thousands upon thousands of geo-registered map values.

The underlying "cyclical" structure of *Retrieve*→ *Process*→ *Store*→ *File* also plays upon our traditional math experience. You enter a number or series of numbers into a calculator, press a function button and then store the intermediate result (calculator memory or scrap of paper) to be used as input for subsequent processing. You repeat the cycle over and over to solve a complex expression or model in a "piece-by-piece" fashion—whether traditional scaler mathematics or spatial map-ematics.

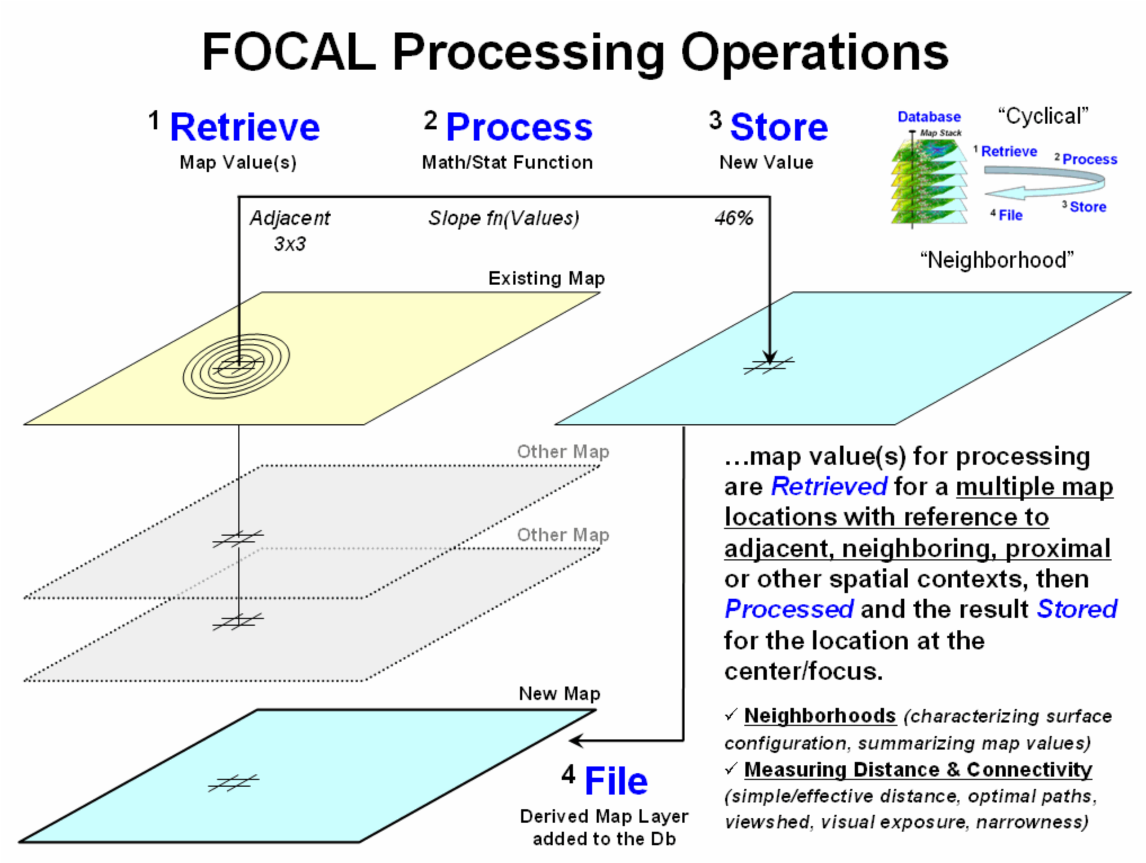


Figure 2. Focal operations use a vicinity-context to retrieve map values for summary.

Figure 2 outlines a different class of analytical operators based on how the values for processing are obtained. *Focal* processing retrieves a set of map values within a neighborhood/vicinity around a location. For example a 3x3 window could be used to identify the nine adjacent elevations at a location, and then apply a slope function to the data to calculate terrain steepness. The derived slope value is stored for the location and the process repeated over and over for all other locations in a project area.

The concept of a fixed window of neighboring map values can be extended to other spatial contexts, such as effective distance, optimal paths, viewsheds, visual exposure and narrowness for defining the influence or "reach" around a map location. For example, a travel-time map considering the surrounding street network could be used to identify the total number of customers within a 10-minute drive. Or the total number of houses that are visually connected to a location within a half-mile could be calculated.

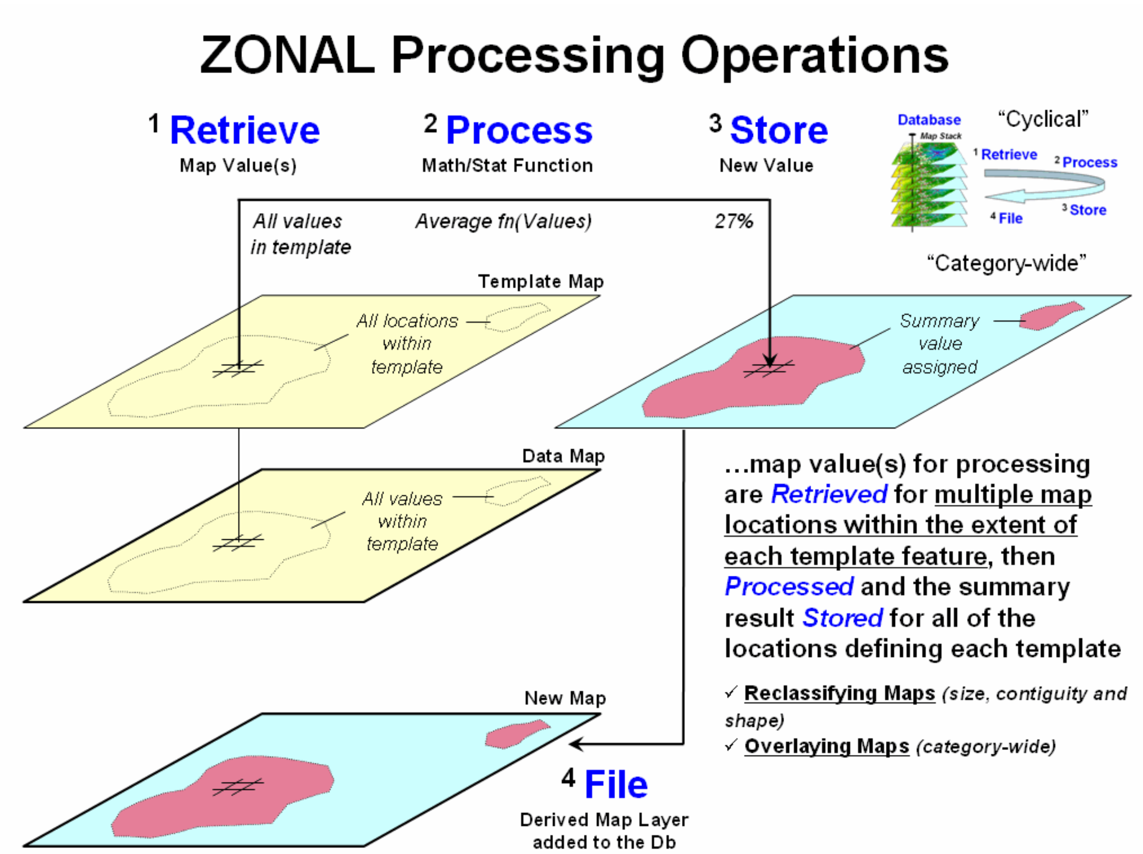


Figure 3. Zonal operations use a separate template map to retrieve map values for summary.

While Focal processing defines an "effective reach" to retrieve surrounding map values for processing, *Zonal* processing uses a predefine "template" to identify map values for summary (figure 3). For example, a wildlife habitat unit might serve as a template map to retrieve slope values from a data map of terrain steepness. The average of all of the coincident slope values is computed and then stored for all of the locations defining the template.

Similarly, a map of total sales (data map) can be calculated for a set of sales management districts (template map). The standard set of statistical summaries is extended to spatial operations such as contiguity and shape of individual map features.

The Local/Focal/Zonal organization scheme addresses how analytic operations work and is particularly appropriate for GIS developers and programmers. The Reclassify/Overlay/Distance/Neighbors scheme I have used throughout the Beyond Mapping series uses a different perspective—one based on the information derived and its utility (see, *Use a Map-ematical Framework for GIS Modeling*, GeoWorld, March 2004, pg 18-19).

However, both the "how it works" and "what it is" perspectives agree that all analytical operations require retrieving and processing numbers within a cyclical map-ematical environment. The bottom line being that maps are numbers and map analysis crunches the numbers in challenging ways well outside our paper-map legacy.

Author's Note: *Local, Focal and Zonal processing classes were first suggested by Dana Tomin in his doctoral dissertation "Geographic Information Systems and Cartographic Modeling" (Yale University, 1980) and partially used in organizing the Spatial Analyst/Grid modules in ESRI's ArcGIS software.*

Putting GIS Modeling Concepts in Their Place

(GeoWorld, October 2010)

(return to top of Topic)

The vast majority of GIS applications focus on spatial inventories that keep track of things, characteristics and conditions on the landscape— mapping and geo-query of *Where* is *What*. Map analysis and GIS modeling applications, on the other hand, focus on spatial relationships within and among map layers— *Why*, *So What* and *What If*.

Natural resource fields have a rich heritage in GIS modeling that tackles a wide range of management needs from habitat mapping to land use suitability to wildfire risk assessment to infrastructure routing to economic valuation to policy formulation. But before jumping into a discussion of GIS analysis and modeling in natural resources it seems prudent to establish basic concepts and terminology usually reserved for an introductory lecture in a basic GIS modeling course.

Several years ago I devoted a couple of Beyond Mapping columns to discussing the various types and characteristics of GIS models (see Author's note). Figure 1 outlines this typology with a bit of reorganization and a few new twists and extensions gained in the ensuing 15 years. The dotted connections in the figure indicate that the terms are not binary but form transitional gradients, with most GIS models involving a mixture of the concepts.

Simply stated any model is a representation of reality in either material form (*tangible representations*) or symbolic form (*abstract representations*). The two general types of models include structural and relational. *Structural models* focus on the composition and construction of tangible things and come in two basic forms— *action* involving dynamic movement-based models, such as a model train along its track and *object* involving static entity-based models forming a visual representation of an item, such as an architect's blueprint of a building. CAD and traditional GIS inventory-oriented applications fall under the "object" model type.

Relational models, on the other hand, focus on the interdependence and relationships among factors. They come in two types— *functional* models based on input/output that track relationships among variables, such as storm runoff prediction and *conceptual* models based on perceptions that incorporate fact interpretation and value weights, such as suitable wildlife habitat derived by interpreting a stack of maps describing a landscape.

Fundamentally there are two types of GIS models—cartographic and spatial. *Cartographic models* automate manual techniques that use traditional drafting aids and transparent overlays (i.e., McHarg overlay), such as identifying locations of productive soils and gentle slopes using binary logic expressed as a geo-query. *Spatial models* express mathematical and statistical relationships among mapped variables, such as deriving a surface heat map based on ambient temperature and solar irradiance involving traditional multivariate concepts of variables, parameters and relationships.

All GIS models fall under the general "symbolic --> relational" model types, and because digital maps are "numbers first, pictures later," map analysis and GIS modeling are usually classified as mathematical (or maybe that should be "map-ematical"). The somewhat subtle distinction between cartographic and spatial models reflects the robustness of the map values and the richness of the mathematical operations applied.

The general characteristics that GIS models share with non-spatial models include purpose, approach, technique and temporal considerations. *Purpose* identifies a model's intent/utility and often involves a *descriptive* characterization of the direct interactions of a system to gain insight into its processes, such as a wildlife population dynamics map generated by simulation of life/death processes. Or the purpose could be *prescriptive* to assess a system's response to management actions/interpretations, such as changes in a proposed power line route under different stakeholder’s calibrations and weights of input map layers.

A model’s *Approach* can be empirical or theoretical. An *empirical* model is based on the reduction (analysis) of field-collected measurements, such as a map of soil loss for each watershed for a region generated by spatially evaluating the empirically derived Universal Soil Loss equation. A *theoretical* model, on the other hand, is based on the linkage (synthesis) of proven or postulated relationships among variables, such as a map of spotted owl habitat based on accepted theories of owl preferences.

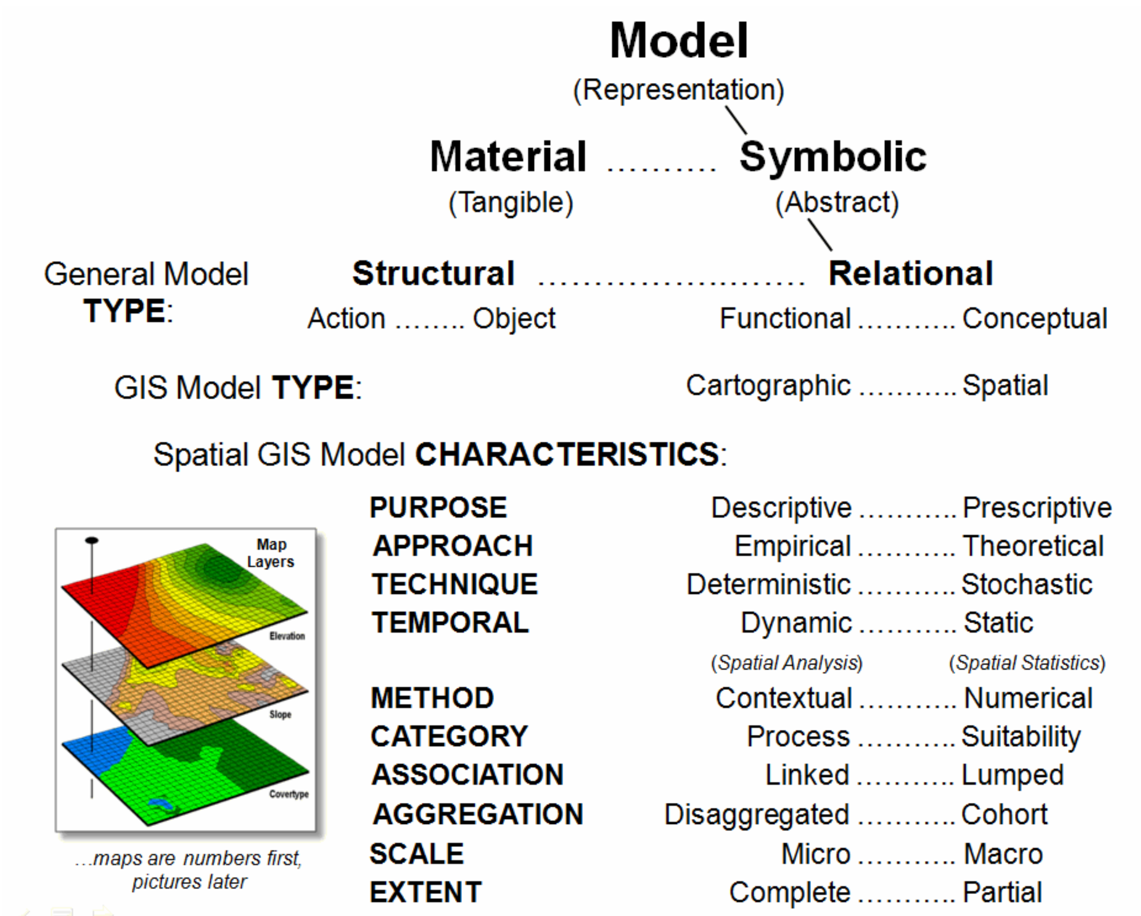


Figure 1. Types and characteristics of GIS models.

Modeling *Technique* can be deterministic or stochastic. A *deterministic* model uses defined relationships that always results in a single repeatable solution, such as a wildlife population map based on one model execution using a single “best” estimate to characterize each variable. A *stochastic* model uses repeated simulation of a probabilistic relationship resulting in a range of possible solutions, such as a wildlife population map based on the average of a series of model executions.

The *Temporal* characteristic refers to how time is treated in a model— dynamic or static. A *dynamic* model treats time as variable and model variables change as a function of time, such as a map of wildfire spread from an ignition point considering the effect of the time of day on weather conditions and fuel loading dryness. A *static* model treats time as a constant and model variables do not vary over time, such as a map of timber values based on the current forest inventory and relative access to roads.

The modeling *Method*, however, is what most distinguishes GIS models from non-spatial models by referring to the spatial character of the processing— contextual or numerical. *Contextual* methods use spatial analysis to characterize "contextual relationships" within and among mapped data layers, such as effective distance, optimal paths, visual connectivity and micro-terrain analysis. *Numerical* methods use spatial statistics to uncover "numerical relationships" within and among mapped data layers, such as generating a prediction map of wildfire ignition based regression analysis of historical fire occurrence and vegetation, terrain and human activity map layers.

Spatial Analysis (contextual spatial relationships) and *Spatial Statistics* (numerical spatial relationships) form the "toolboxes" that are uniquely GIS and are fueling the evolution from descriptive mapping and "geo-query" searches of existing databases to investigative and prescriptive map analysis/modeling that address a variety of complex spatial problems— a movement in user perspective from "recordkeeping" to "solutions."

The *Category* characteristic of GIS models is closely related to the concept of "Relational" in general modeling but speaks specifically to the type of spatial relationships and interdependences among map layers. A *process*-oriented model involves movement, flows and cycles in the landscape, such as timber harvesting access considering on- and off-road movement of hauling and harvesting equipment. A *suitability*-oriented model characterizes geographic locations in terms of their relative appropriateness for an intended use.

Model association, aggregation, scale and extent refer to the geographic nature of how map layers are defined and related. *Association* refers to how locations relate to each other and can be classified as *lumped* when the state/condition of each individual location is independent of other map locations (i.e., point-by-point processing). A *linked* association, on the other hand, occurs when the state/condition of each individual location is dependent on other map locations (i.e., vicinity, neighborhood or regional processing).

Aggregation describes the grouping of map locations for processing and is termed *disaggregated* when a model is executed for each individual spatial object (usually a grid cell), such as in deriving a map of predicted biomass based on spatially evaluating a regression equation in which each input map layer identifies an independent "variable," each location a "case," and each map value a “measurement” as defined in traditional statistics and mathematical modeling.

Alternatively, *cohort* aggregation utilizes groups of spatial objects having similar characteristics, such as deriving a timber growth map for each management parcel based on a look-up table of growth for each possible combination of map layers. The model is executed once for each combination and the solution is applied to all map locations having the same “cohort” combination.

GIS modeling characteristics of *Scale* and *Extent* retain their traditional meanings. A *micro* scale model contains high resolution (level of detail) of space, time and/or variable considerations governing system response, such as a 1:1,000 map of a farm with crops specified for each field and revised each year. A *macro* scale model contains low resolution inputs, such as a 1:1,000,000 map of land use with a single category for agriculture revised every 10 years.

A GIS model’s *Extent* is termed *complete* if it includes the entire set of space, time and/or variable considerations governing system response, such as a map set of an entire watershed or river basin. A *partial* extent includes subsets of input data that do not completely cover an area of interest, such as a standard topographic sheet with its artificial boundary capturing limited portions of several adjoining watersheds.

For those readers who are still awake, you have endured an introductory academic slap and now possess all of the rights, privileges and responsibilities of an introductory GIS modeling expert who is fully licensed to bore your peers and laypersons alike with such arcane babble. Next month’s discussion will apply and extend these concepts to model logic, degrees of abstraction, levels of analysis and processing levels using an example model for assessing campground suitability.

Author’s Note: *If you have old GW magazines lying about, see “What’s in a Model?” and “Dodge the GIS Modeling Babble Ground” in the January and February 1995 issues of GIS World (the earlier less inclusive magazine name for GeoWorld) or visit www.innovativegis.com, and select Beyond Mapping Compilation Series, Chronological Listing, and scroll down to the Beyond Mapping II online book of Beyond Mapping columns from October 1993 to August 1996.*

A Suitable Framework for GIS Modeling

(GeoWorld, November 2010)

(return to top of Topic)

Suitability Modeling is one of the simplest and most frequently used GIS modeling approaches. These models consider the relative “goodness” of each map location for a particular use based on a set of criteria.

For example, figure 1 outlines five *Criteria* considerations for locating a campground: favor gentle terrain, being near roads and water, with good views of water and oriented toward the west.

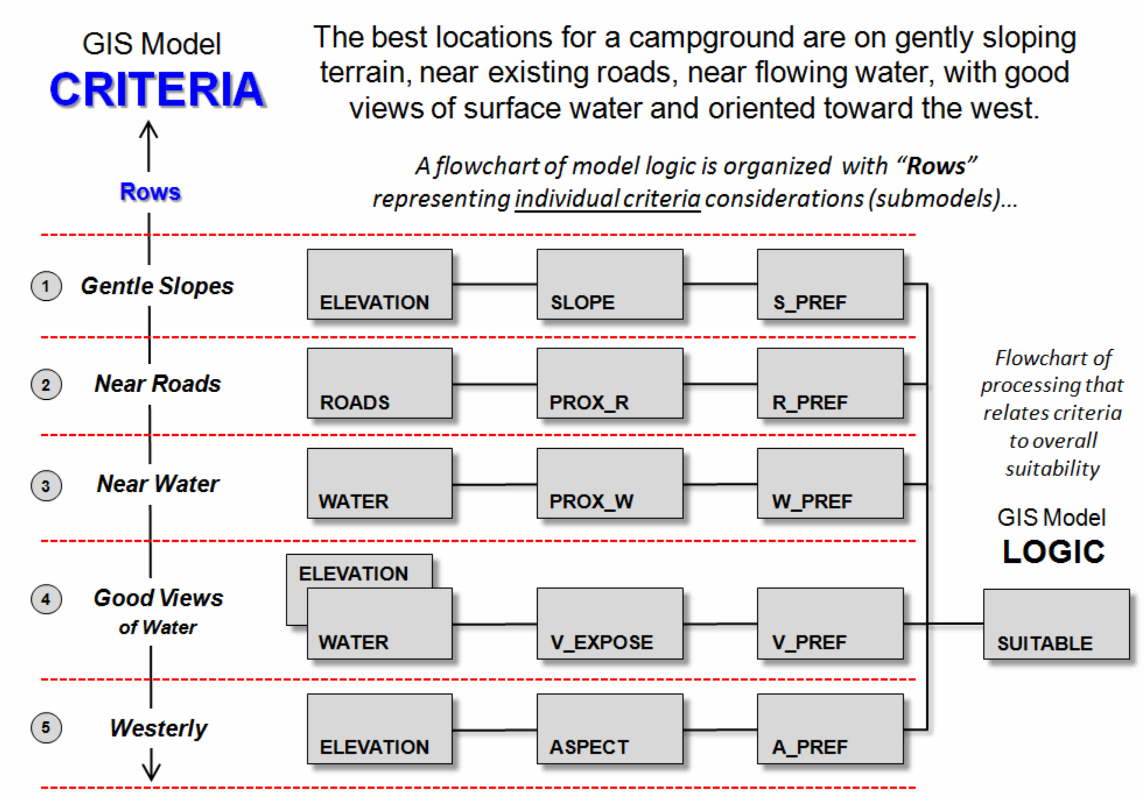


Figure 1. Campground Suitability model logic with rows indicating criteria.

In the flowchart of the model's logic, each consideration is identified as a separate "row." In essence every map location is graded in light of its characteristics or conditions in a manner that is analogous to a professor evaluating a set of exams during a semester. Each spatial consideration (viz. exam) is independently graded (viz. student answers) with respect to a consistent scale (viz. an A to an F grade).

Figure 2 identifies *Analysis Levels* as "columns" used to evaluate each of the criteria and then combines them into an overall assessment of campground suitability. *Base Maps* represent the physical characteristics used in the evaluations— maps of Elevation, Roads, and Water in this case. But these "facts" on the landscape are not in a form that can be used to evaluate campground suitability.

Derived Maps translate physical descriptions into suitability contexts. For example, it is not Elevation per se that affects campground suitability, but the rate and direction of the change in elevation expressed as Slope and Aspect that characterize terrain configuration. Similarly, it is not the presence of roads and water but the relative closeness to these features that affects the degree of suitability (Prox_R and Prox_W).

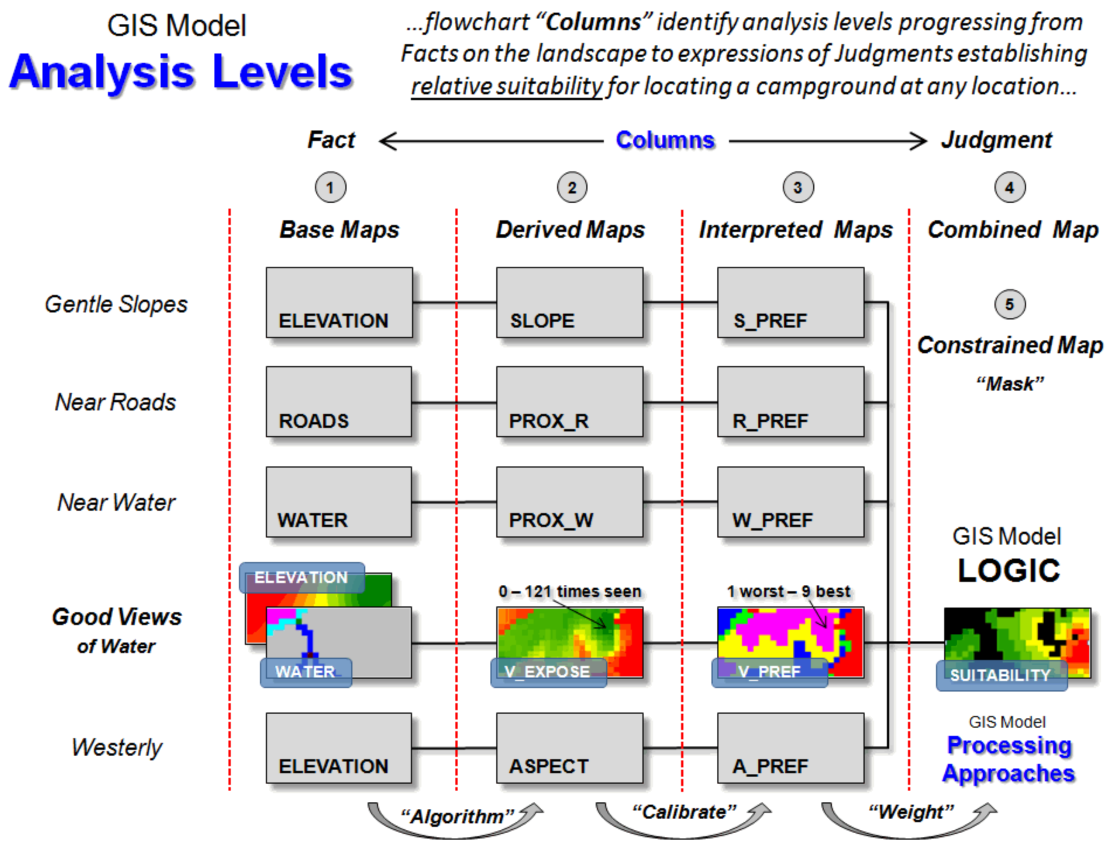


Figure 2. Flowchart columns represent analysis levels transforming facts into judgment.

Interpreted Maps identify increasing abstraction from Facts on the landscape to Judgments within the context of suitability. At this level, derived maps are interpreted/graded into a relative suitability score, usually on a scale from 1 (least suitable/worst) to 9 (most suitable/best). Using the exam grading analogy, a map location could be terrible in terms of terms of proximity to roads and water (viz. a couple of F's on two of the exams) while quite suitable in terms of terrain steepness and aspect (viz. A's on two other exams).

Like a student's semester grade, the overall suitability, or *Combined Map*, for a campground is a combination of the individual criteria scores. This is usually accomplished by calculating the simple or weighted-average of the individual scores. The result is a single value indicating the overall "relative goodness" for each map location that in aggregate forms a continuous spatial distribution of campground suitability for a given project area.

However, some of the locations might be constrained by legal or practical concerns that preclude building a campground, such as very close to water or on very steep terrain. A *Constraint Map* eliminates these locations by forcing their overall score to "0" (unsuitable).

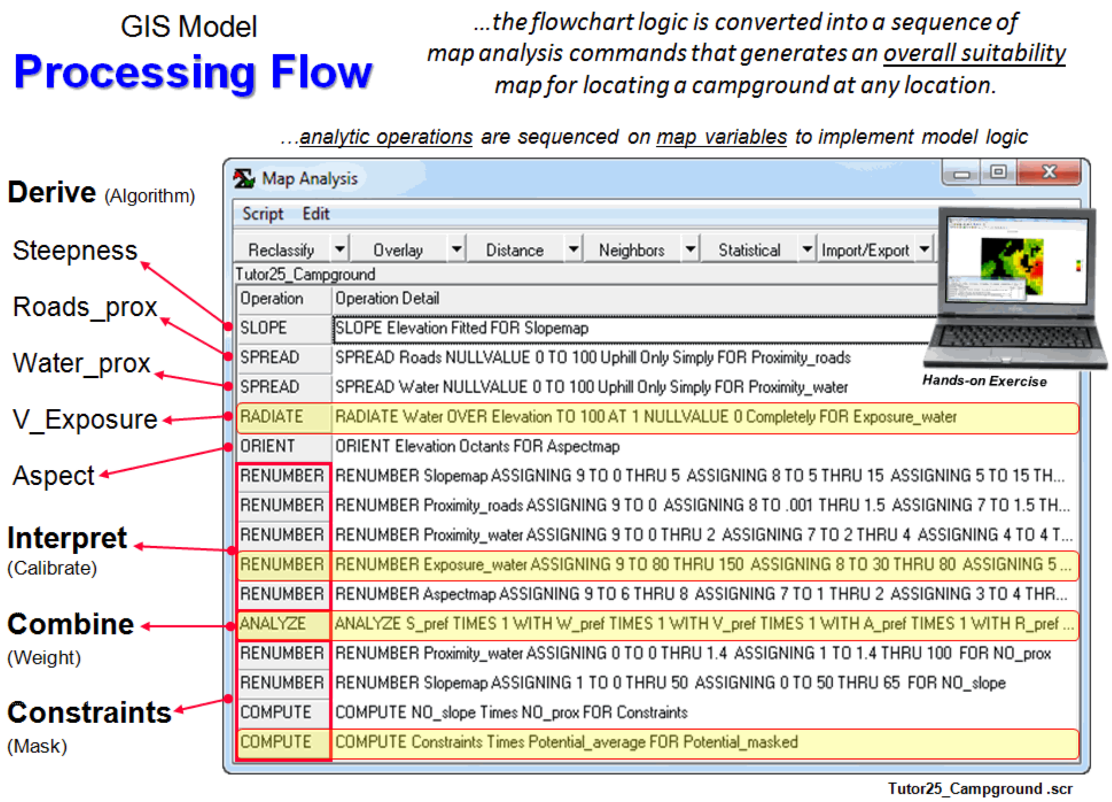


Figure 3. Processing flow that implements the Campground Suitability model.

Figure 3 depicts the *Processing Flow* as a series of map analysis operations/commands. You are encouraged to follow the flow by delving into more detail and even complete a hands-on exercise in suitability modeling (see author's note)— it ought to be a lot of fun, right?

The logical progression from physical Facts to suitability Judgments involves four basic *Processing Approaches*— Algorithm, Calibrate, Weight, and Mask. For example, consider the goal of "good views of water." The derived map of visual exposure to water (V_Expose) uses an *Algorithm* that counts the number of times each location is visually connected to water locations—

RADIATE **Water** OVER **Elevation** TO 100 AT 1 Completely FOR **V_Expose**

…that in this example, results in values from 0 to 121 times seen. In turn, the visual exposure map is *Calibrated* to a relative suitability scale of 1 (worst) to 9 (best)—

> RENUMBER **V_Expose** ASSIGNING 9 TO 80 THRU 121 ASSIGNING 8 TO 30 THRU 80 ASSIGNING 5 TO 10 THRU 30 ASSIGNING 3 TO 6 THRU 10 ASSIGNING 1 TO 0 THRU 6 FOR **V_Pref**

The interpreted visual exposure map and the other interpreted maps are *Weighted* by using a simple arithmetic average—

> ANALYZE S_PREF TIMES 1 WITH W_PREF TIMES 1 WITH **V_Pref** TIMES 1 WITH A_PREF TIMES 1 WITH R_PREF TIMES 1 Mean FOR **Suitable**

Finally, a binary constraint map (too steep and/or too close to water = 0; else= 1) is used to *Mask* unsuitable areas—

> COMPUTE **Suitable** Times **Constraints** FOR **Suitable_masked**

Author's Note: *An annotated step-by-step description of the Campground Suitability model and hands-on exercise materials are posed at www.innovativegis.com/basis/Senarios/Campground.htm. Additional discussion of types and approaches to suitability modeling is in Beyond Mapping Compilation Series book III, Topic 7, "Basic Spatial Modeling Approaches" posted at www.innovativegis.com.*

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

Explore the Softer Side of GIS — *describes a Manual GIS (circa 1950) and the relationship between social science conceptual (January 2008)*

Use Spatial Sensitivity Analysis to Assess Model Response — *develops an approach for assessing the sensitivity of GIS models (August 2009)*

(return to top of Topic)

(Back to the Table of Contents)