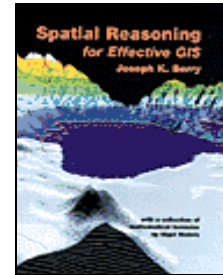


Beyond Mapping II

Topic 5: A Framework for GIS Modeling



[Spatial Reasoning](#) book

[What's in a Model?](#) — outlines the different types of models and describes their characteristics
[The GIS Modeling Babble-Ground](#) — describes a Classification Guide for GIS Modeling
[Layers to Tapestry](#) — describes a technique for determining the set of n^{th} best paths between two points

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What's in a Model?

(GeoWorld,)

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Each year I conduct a lot of courses and workshops on GIS. As you might imagine they frequently move beyond the fundamental concepts to futuristic musings. One topic consistently captures the imagination of participants and dominates informal discussion (you know, the elevated B.S. in the sunken lounge)— **what are the types and characteristics GIS models?** The accompanying outline is the current state of a "sourdough" handout used to provoke this impassioned discussion... what do you think?

Do you know of any model types or characteristics missing from the outline? Are any in the outline misrepresented?

The following are other terms often used to describe models: physical, atomistic, holistic, constrained, fragmented, dispersed, data, analytical, diffusion, scale, optimizing, simulation, analytical, process, synthetic, systems, flow, statistical, mathematical, hierarchical, binary... Can you explain what is meant by these terms? Are any relevant? Where might they fit into the outline?

Do you see any utility in developing a comprehensive classification scheme for GIS modeling?... or is this just another esoteric and academic (gee, that might be redundant) exercise? Who would benefit from such an outline?

TYPES AND CHARACTERISTICS OF GIS MODELS

I. **MODELING**: Material and Symbolic — Positional, Thematic and Temporal

A model is a “representation of reality” in either 1) *Material* form (tangible representation) or 2) *Symbolic* form (abstract representation).

GIS Modeling involves symbolic representation of *Positional* properties (WHERE), as well as *Thematic* (WHAT) and *Temporal* (WHEN) attributes describing characteristics and conditions of space and time.

II. GENERAL TYPES OF MODELS: *Structural and Relational*

- 1) **STRUCTURAL**: focuses on the composition and construction of things; *Object* and *Action*
 - **OBJECT MODEL** — *Static Entity-based* which forms a visual representation of an item; e.g., an architect's blueprint of a building. Characteristics include scaled, 2 or 3-dimensional, symbolic representation.
 - **ACTION MODEL** — *Dynamic Movement-based* which tracks the space/time relationships of items; e.g., a model train along its track. Characteristics include time-slices, change detection, transition statistics, and animation.
- 2) **RELATIONAL**: focuses on the interdependence and relationships among factors; *Functional* and *Conceptual*
 - **FUNCTIONAL** — *Input/Output-based* which tracks relationships among variables; e.g., storm runoff prediction. Characteristics include cause/effect linkages, hard science, and sensitivity analysis.
 - **CONCEPTUAL** — *Perception-based* which incorporates both fact interpretation and value weights; e.g., suitability for outdoor recreation. Characteristics include heuristics (expert rules), soft science, scenarios.

III. TYPES OF GIS MODELS: *Cartographic and Spatial*

1) **CARTOGRAPHIC MODEL** — automation of *manual techniques* which traditionally use drafting aids and transparent overlays; e.g., a map identifying locations of productive soils and gentle slopes using binary logic expressed as a geo-query.

2) **SPATIAL MODEL** — expression of mathematical relationships among mapped variables; e.g., a map of surface heating based on ambient temperature and solar irradiance using multi-value logic expressed as variables, parameters and relationships.

IV. GIS MODEL CHARACTERISTICS: *Scale, Extent, Purpose, Approach, Technique, Association and Aggregation*

- 1) **SCALE**: *Micro* and *Macro*
 - **MICRO** — contains high-resolution of space, time and/or variable considerations governing system response; e.g., a 1:1,000 map of a farm with the crop specified for each individual field revised each year.
 - **MACRO** — contains low-resolution of space, time and/or variable considerations governing system response; e.g., a 1:1,000,000 map of land use with a single category for agriculture revised every ten years.
- 2) **EXTENT**: *Complete* and *Partial*
 - **COMPLETE** — includes entire set of space, time and/or variable considerations governing system response; e.g., a map of an entire watershed or river basin.

- **PARTIAL** — includes subsets of space, time and/or variable considerations governing system response; e.g., a standard topographic sheet with its "artificial boundary" capturing limited portions of several adjoining watersheds.
- 3) **PURPOSE:** *Descriptive and Prescriptive*
- **DESCRIPTIVE** — characterization of the direct interactions of system components to gain insight into system processes (understand); e.g., a wildlife population dynamics map generated by simulation of life/death processes.
 - **PRESCRIPTIVE** — characterization of direct and indirect factors which are related to system response used in determining appropriate management action (decide); e.g., a campground suitability map based on interpretation landscape features.
- 4) **APPROACH:** *Empirical and Theoretical*
- **EMPIRICAL** — based on reduction (*analysis*) of field collected measurements; e.g., a map of soil loss for each watershed in a region generated by spatially evaluating the Universal Soil Loss Equation.
 - **THEORETICAL** — based on the linkage (*synthesis*) of proven or postulated relationships among variables; e.g., a map of spotted owl habitat based on accepted theories on owl preferences.
- 5) **TECHNIQUE:** *Deterministic and Stochastic*
- **DETERMINISTIC** — direct evaluation of a defined relationship (results in a single repeatable solution); e.g., a wildlife population map based on one model execution using a single "best" estimate to characterize each variable.
 - **STOCHASTIC** — simulation of a probabilistic relationship (results in a range of possible solutions); e.g., a wildlife population map based on the average of a series of model executions using probability functions to characterize each variable.
- 6) **ASSOCIATION:** *Lumped and Linked*
- **LUMPED** — the state/condition of each individual location is *independent of other map locations* (point-by-point).
 - **LINKED** — the state/condition of an individual location is *dependent on other map locations* (vicinity, neighborhood or region).
- 7) **AGGREGATION:** *Cohort and Disaggregated*
- **COHORT** — executed for *groups of objects* having similar characteristics; e.g., a timber growth map for each management parcel based on a look-up table of growth for each specific set of landscape conditions.
 - **DISAGGREGATED** — executed for each *individual object*; e.g., a map of predicted biomass based on spatially evaluating a regression equation in which each input map identifies an independent variable, each location a case, and each value a measurement (usually raster-based grid cells).
- 8) **TEMPORAL:** *Static and Dynamic*
- **STATIC** — treats time as constant and model variables *do not vary over time*; e.g., a map of timber value based on forest inventory and relative access to existing roads.
 - **DYNAMIC** — treats time as variable and model variables *change as a function of time*; e.g., a map of the spread of pollution from a point source.

Author's Note: next month we will translate the outline into a generalized "Classification Guide for GIS Models"... sound like fun, or more pedagogical pomposity?

The GIS Modeling Babble-Ground

(GeoWorld,)

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As you might recall from dozing off face down on last month's Beyond Mapping column there is a myriad of dimensions to GIS modeling. Hopefully you wrestled with the brief descriptions, dismissed some and added others. Modeling is as personal as the underwear you buy or the politics you support. GIS modeling perspectives are the result of the data you keep and the things you do. A county clerk, city engineer, forester, and market forecaster work with radically differing data for multitude of divergent purposes. In the applied arena, what constitutes GIS modeling to one is rarely the same as it is to another— hence the "babble-ground" lines are drawn in the sand of confusion.

However, if you strip away the details of specific applications, common threads appear among the GIS models themselves and the modeling processes undertaken. Last month's article attempted to capture some of the more important threads. The factors discussed have been stripped of their verbiage and summarized into the Classification Guide shown in the figure below.

CLASSIFICATION GUIDE FOR GIS MODELS			
MODEL (Representation)			
MATERIAL <input checked="" type="checkbox"/> ABSTRACT			
⟨Tangible⟩		⟨Symbolic⟩	
General Model TYPE:			
STRUCTURAL		RELATIONAL	
Object Action	Functional	<input checked="" type="checkbox"/>	Conceptual
GIS Model TYPE:			
		Cartographic <input checked="" type="checkbox"/> ..	Spatial
GIS Model CHARACTERISTICS:			
SCALE	Micro	<input checked="" type="checkbox"/>	Macro
EXTENT	Complete <input checked="" type="checkbox"/> ..	Partial
PURPOSE	Descriptive	<input checked="" type="checkbox"/>	Prescriptive
APPROACH	Empirical	<input checked="" type="checkbox"/>	Theoretical
TECHNIQUE	Deterministic	<input checked="" type="checkbox"/>	Stochastic
ASSOCIATION	Distributed <input checked="" type="checkbox"/> ..	Linked
AGGREGATION	Cohort <input checked="" type="checkbox"/> ..	Disaggregated
TEMPORAL	Static <input checked="" type="checkbox"/> ..	Dynamic

Figure 15-4. A completed Classification Guide evaluating an animated set of maps predicting wildfire growth for hourly time steps.

One of the most frustrating aspects of any classification scheme is being forced to assign something to just one of two choices (binary logic). It's like those dumb questions on the SAT exam— not everything is black and white. In fact, those who see good arguments for grey are more likely the creative individuals. In the Classification Guide the descriptors for each factor identify opposing extremes. The ten dots separating the extremes provide a range of possible responses— you simply place an "X" at the appropriate spot along the continuum. The dichotomies have been arranged so a clustering of marks toward the left

indicate models that are easier to comprehend without a PhD in Complex Studies.

Let's tackle an easy example and force our responses to the extremes. Consider Michelangelo's sculpture of Venus deMilo... sure its a model (abstraction), or she sure has us all fooled by sitting so still. Within the limits of the Classification Guide, she's

- *Material* (one big piece of marble; no abstract symbols here)
- *Structural* (the model characterizes her construction; don't know about her relationships)
- *Object* (visual rendering of just her; no movable parts)

Now she's not a GIS Model, but if she were she would be

- *Cartographic* (manual techniques; no wimpy mathematics)
- *Micro* (about a 1:1 scale; unless she's a scaled version of Goliath's mom)
- *Partial* (missing arms and legs; or maybe they were nicked in a Bekins move)
- *Descriptive* (wow, and how; doesn't tell you what to do... she's just a rock)
- *Empirical* (direct measurement; or Mickey-A had an active imagination)
- *Deterministic* (direct single solution; hips and shoulders have no chance of being attached elsewhere)
- *Linked* (the hip bone is connected to the thigh bone...; can't talk about her chin without noticing her eyes)
- *Disaggregated* (one-of-a-kind; though millions strive for a favorable comparison)
- *Static* (hasn't changed for centuries; the whole effect is dynamite, but not dynamic)

Now let's try a tougher one— an animated set of maps predicting wildfire growth for hourly time steps. The accompanying figure indicates "refined" response positioning along each of the scales, whereas the following discussion identifies the extremes. The first part is easy, with the fire model tending toward

- *Abstract* (or you had better get a hose)
- *Relational* (fire ignition is dependent on several mappable factors including terrain, vegetation type/condition, and weather)
- *Functional* (mostly uses fire science research tracking the relationships among variables)

Now for the more perplexing part involving GIS model type and characteristics.

- *Spatial* (lot of math behind this one)
- *Micro* (at each instant the model is only considering the fire front and its immediate surroundings)
- *Partial* (until the fire is extinguished)
- *Descriptive* (unabated fire propagation without fire management actions)
- *Empirical* (based on field calibrated equations)
- *Deterministic* (based on a defined set of input parameters)
- *Linked* (adjacent parcels are the next to burn)
- *Disaggregated* (independently considers each burning location and its propagation options)
- *Dynamic* (both diurnal and on-going fire behavior conditions change model variables)

Whew! Now try your hand at "classifying" the following representations of reality and/or your own favorite GIS models...

- *Mount Rushmore's faces of the presidents*
- *A landscape architect's cardboard model of a National Park*
- *An elk habitat map*
- *A set of seasonal maps of elk habitat*
- *An elk population dynamics model responding to landscape conditions and predator/prey*

interactions

- *A GIS implementation of the Universal Soil Loss Equation for a watershed*
- *A GIS implementation of the Horton Overland Flow Equations evaluating surface water runoff for a set of watersheds*
- *A crop yield prediction map*
- *Maps of wildfire risk generated each morning*
- *A dynamic wildfire growth model responding to temperature fluctuations, complex wind vectors and fire abatement actions*

Author's Note: A classic reference for modeling is *Mathematical Modeling with Computers*, by Jacoby and Kowalik, Prentice-Hall, 1980. Ample "poetic license" was used in extending the basic modeling framework to the unique conditions and approaches used in GIS modeling.

Layers to Tapestry

(GeoWorld,)

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Most of us will agree that there are three essential elements to GIS— data, operations and applications. To use the technology you need a bunch of digital maps, an analytic "engine" to process the maps, and interesting problems to solve. However, not all of us have the same view of the relative importance of the three elements. Some have a *data-centric* perspective, as they prepare individual data layers and/or assemble the comprehensive databases GIS needs. Others are *operations-centric* and are locked in on refining and expanding the GIS toolbox of processing and display capabilities. A third group is *applications-centric* and sees the portentous details of data and operations as merely impediments to problem solving. Such is the fractious fraternity of GIS.

In the early years, the data and operations orientations dominated the developing field. As GIS matures, the focus is shifted to applications. As a result, attention is increasingly directed toward the assumptions and linkages embedded in our GIS models— the map analysis solutions to pressing problems. In essence, we are weaving our data layers into complex, logical tapestries of map interrelationships. A crucial component to this evolution is an effective mechanism to communicate model logic, as well as processing flow.

Programmers and system analysts routinely use diagramming techniques for communication of data/processing flow. Structure and flow charts, as well as data flow, entity relation, control flow, and state transition diagrams, are but of few of the various approaches. Each technique invokes a subtly different perspective in communicating structure and logic. For example, a *Data Flow Diagram* emphasizes the processing steps used in converting one data set into another. The technique uses large circles to symbolize operations, with the lines connecting those representing data sets (Figure 1). Its design draws one's attention to the processing steps over the data states, thereby best serving an operations-centric orientation.

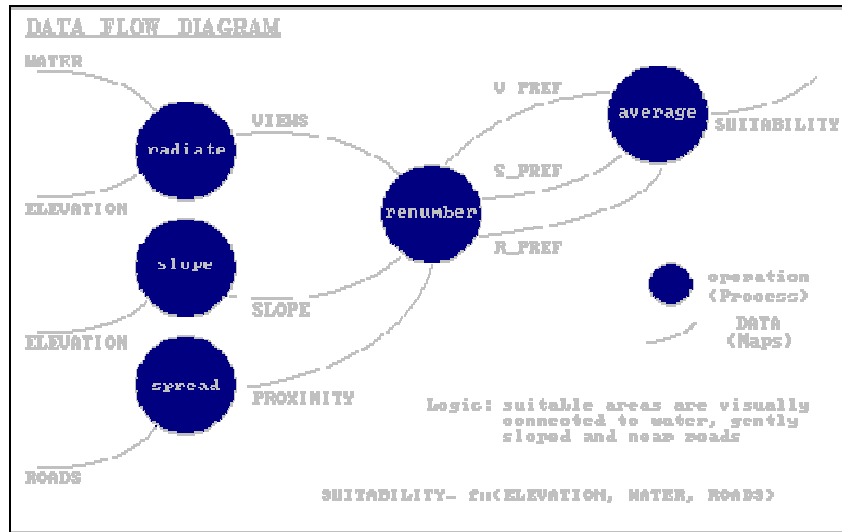


Figure 1. Data Flow Diagram.

Processing-oriented diagrams work well for non-spatial information processing. They relate data about entities through indexed files. In these instances, the specifications in a database query are paramount. Instances of geo-query, such as "where are all the locations that have slopes over 13% AND unstable soils AND are devoid of vegetation," use standard database management systems technology. Standard diagramming techniques, in such instances, is most appropriate.

However, spatial analysis techniques go beyond the repackaging of existing data. For example, if you want establish variable-width buffers around salmon spawning streams it's a different story. You need to simultaneously consider intervening slopes, ground cover, and soil stability as you "measure" distance. If you want to establish a map of visual exposure density to roads, you need to consider maps of the road network, relative elevations at a minimum.

These, and the myriad of other spatial analysis procedures, have strong data dependency. They are not just setting a few parameters for traditional, non-spatial processing techniques. Spatial analysis is an entirely new kettle of fish. It is dependent upon the unique geographic patterns of the data sets involved—definitely data-centric conditions.

A *GIS Modeling Flowchart*, or "map model," takes such a perspective. The top of Figure 2 uses a flowchart to track the same data/processing steps as shown in the Data Flow Diagram. Maps (i.e., data sets) are depicted as boxes and operations (i.e., processing steps) are depicted as arrows. This focus is obviously data-centric as it draws your attention to the mapped variables, but also it is arguably an applications-centric one as well. Most users of GIS have prior experience with manual map analysis techniques. They have struggled with rulers, dot grids, and transparent overlays to laboriously draft new maps that better address a question at hand. For example, you may have circled areas where the elevation contour lines are close together to create a map of steep slopes. In doing so, attention is focused on the elevation data and the resultant circles inscribed on the transparent overlay—the input and output maps.

The bottom portion of Figure 2 shows a "logic modification" incorporating a preference to be near or within diverse forested areas. A neighborhood operation (scan) assigns the number of different vegetation types (COVERTYPE) within the vicinity of each forested location (FORESTS). Areas of high diversity are isolated (renumber), and a proximity map from these areas (DF_PROX) is generated for the entire project area. Since several models might share this command set, it is stored as a generalized procedure

and is simply attached using the *SubModel or Procedure* flowcharting "widget."

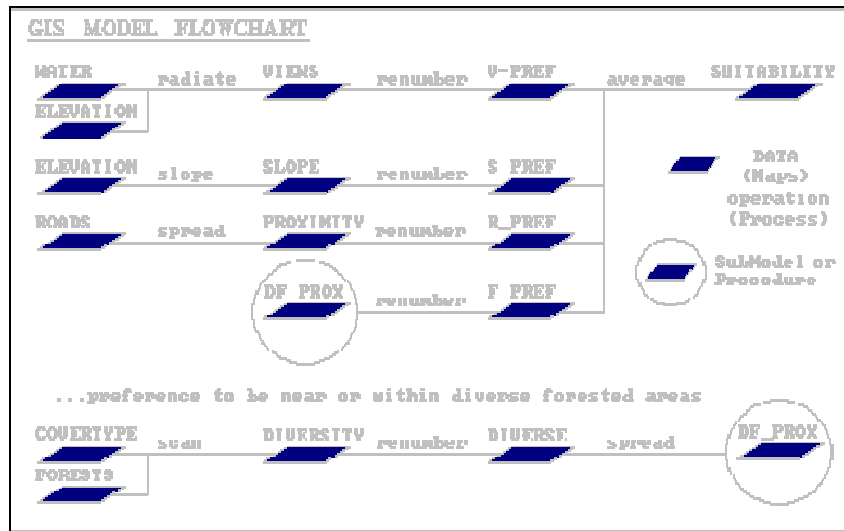


Figure 2. GIS Model Flowchart.

Figure 3 identifies a "processing modification" to the model. In this example, a display of the SUITABILITY map with roads vectors graphically overlaid (ROADS.BLN) is used as a backdrop for the user to manually draw a potential set of SUITABLE sites. Statistics on the sites (STAT.TBL) are presented and the user can either accept them or redraw another set of potential sites. When accepted, the raster map is converted to vectors and stored. The example uses an extended set of "Connector, File, Manual Operation, Conditional Branch and Non-Spatial Operation" widgets.

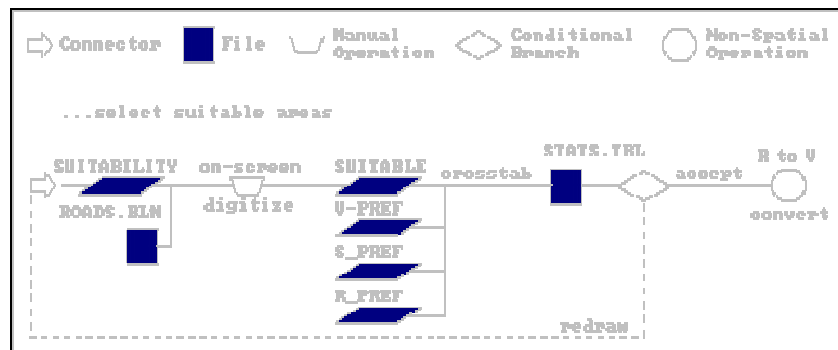


Figure 3. Additional Flowchart Widgets.

So what? All this seems to be "much ado about nothing"... just a bunch of globs, lines and silly symbols. Actually, it may be GIS's ticket out of the "black box" and into the light of creative applications. A simple flowchart of model logic is needed by general users to understand and appropriately apply a model. A more complex flowchart extending to processing flow is needed by the GIS specialist who wrestles with the actual code. What we all need is a single diagramming technique that can operate at both levels... a simple logical expression which can be embellished with processing flow details.