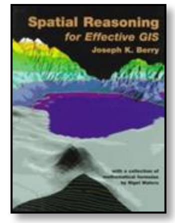
Beyond Mapping II

Topic 5 – A Framework for GIS Modeling



Spatial Reasoning ***book***

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(*Back to the Table of Contents*)

What's in a Model?

(GeoWorld, January 1995)

(*return to top of Topic*)

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

– *Do you know of any model types or characteristics missing from the outline? Are there any in the outline misrepresented?*
– *The following are other terms often used to describe models: physical, atomistic, holistic, constrained, fragmented, dispersed, data, 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 to GIS? If so, 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 or academic (gee, that might be redundant) exercise? Who might benefit from such an outline?*

1) **Modeling**: a model is a representation of reality in either *material* form (tangible representation) or *symbolic* form (abstract representation); GIS modeling involves symbolic

representation of *locational* (WHERE), as well as *thematic* (WHAT) and *temporal* (WHEN) attributes describing characteristics and conditions of space and time.

2) **<u>General Types of Models</u>**: Structural and Relational

a) **Structural**. Focuses on the composition and construction of things; *object* and *action*.

i) ***Object***. *Static entity-based*, forming a visual representation of an item, e.g., an architect's blue print of a building. Characteristics include scaled, two- or three-dimensional, symbolic representation.

ii) ***Action***. *Dynamic movement-based*, tracking space/time relationships of items, e.g, a model train along its track. Characteristics include time-slices, change detection, transition statistics and animation.

b) **Relational**. Focuses on the interdependence and relationships among factors; *functional* and *conceptual*.

i) ***Functional***. *Input/Output-based*, tracking relationships among variables, e.g., storm runoff prediction. Characteristics include cause/effect linkages, hard science and sensitivity analysis.

ii) ***Conceptual***. *Perception-based*, incorporating both fact interpretation and value weights, e.g., suitability for outdoor recreation. Characteristics include heuristics (expert rules), soft science and scenarios.

3) **<u>Types of GIS Models</u>**: Cartographic and Spatial

a) **Cartographic**. Automation of *manual techniques* that traditionally use drafting aids and transparent overlays, e.g., a map identifying locations of productive souls and gentle slopes using binary logic expressed as a geo-query.

b) **Spatial**. Expression of mathematical relationships among map variables, e.g., a map of surface heating based on ambient temperature and solar irradiance using multivalue logic expressed as variables, parameter and relationships.

4) **<u>GIS Model Characteristics</u>**: Scale, Extent, Purpose, Approach, Technique, Association and Aggregation

a) **Scale**. *Micro* and *Macro*

i) ***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 crop specified for each individual field revised each year.

ii) ***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 10 years.

b) **Extent**. *Complete* and *Partial*

i) ***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.

ii) ***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.

c) **Purpose**. *Descriptive* and *Prescriptive*

i) ***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.

ii) ***Prescriptive***. Characterization of the direct and indirect factors related to system response used in determining appropriate management actions (decide), e.g., a campground suitability map based on interpretation of landscape features.

d) **Approach**. *Empirical* and *Theoretical*

i) ***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.

ii) ***Theoretical***. Based on linkage (synthesis) of proven or postulated relationships among variables, e.g., a map of spotted owl habitat based on accepted theories on owl preferences.

e) **Technique**. *Deterministic* and *Stochastic*

i) ***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.

ii) ***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.

f) **Association**. *Lumped* and *Linked*

i) ***Lumped***. The state/condition of each individual location is *independent of other map locations* (point-by-point).

ii) ***Linked***. The state/condition of an individual location is *dependent of other map locations* (vicinity, neighborhood or regional).

g) **Aggregation**. *Cohort* and *Disaggregated*

i) ***Cohort***. Executed for *groups of objects* having the same characteristics, e.g., a timber growth map for each management parcel based on a look-up table for growth for each specific set of landscape conditions.

ii) ***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).

h) **Temporal**. *Static* and *Dynamic*

i) ***Static***. Treats time as a constant, and model variables *do not vary over time*, e.g., a map of timber value based in forest inventory and relative access to existing roads.

ii) ***Dynamic***. Treats time 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*: The next section translates the outline into a generalized Classification Guide for GIS Models. Sound like fun, or more pedagogical pomposity?*

Dodge the GIS Modeling Babble Ground

(GIS World, February 1995)

(return to top of Topic)

As you may recall from the previous section, there are many dimensions to GIs modeling. 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 different data for many diverse purposes. In the applied arena, GIS modeling mean different things to different people— hence the "babble-ground" lines are drawn in the sands of confusion.

If you strip away the details of specific of specific applications, however, common threads appear among the GIS models themselves and the modeling processes undertaken. The previous section attempted to capture some of the more important threads. The factors discussed are stripped of their verbiage and summarized in the classification guide shown in figure 1.

Model
(Representation)

Material …………… **Abstract**
(Tangible) (Symbolic)

General Model **TYPE**:

Structural: Object …….. Action

Relational: Functional ………..….. Conceptual

GIS Model **TYPE**: Cartographic ………..….. Spatial

Spatial GIS Model **CHARACTERISTICS**:

SCALE	Micro ………..….. Macro
EXTENT	Complete …….…….. Partial
PURPOSE	Descriptive …………..... Prescriptive
APPROACH	Empirical ………..….. Theoretical
TECHNIQUE	Deterministic ……..…….. Stochastic
ASSOCIATION	Linked ………..….. Lumped
AGGREGATION	Disaggregated …………..... Cohort
TEMPORAL	Dynamic ……..…….. Static

Figure 1. Guide identifying the types and characteristics of GIS Models.

One of the most frustrating aspects of any classification scheme is being forced to assign something to one of two choices (binary logic). It's like those dumb questions on the Scholastic Aptitude Test— not everything is black and white. In the classification guide the descriptors for each factor identify opposing extremes. The 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 Ph.D. in complex studies.

Let's tackle an easy example and force responses to the extremes. Consider Michelangelo's sculpture of Venus de Milo. Sure it's a model (abstraction), or she sure has us all fooled by sitting so still. Within the limits of the classification guide, falls into the following categories:

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

Granted, she's not a GIS model. If she was, however, she could be categorized as follows:

- *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 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 attached 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. Figure 2 indicates "refined" response positioning along each of the scales, whereas the following discussion identifies the extremes.

The first part is easy, as the fire model leans toward the following categories:

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

The more perplexing part the following GIS model type and characteristics:

- *Spatial* (a lot of math behind this one)

- *Micro* (considers only 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 next)
- *Disaggregated* (independently considers each burning location and its propagation options)
- *Dynamic* (diurnal and ongoing fire behavior change model variables)

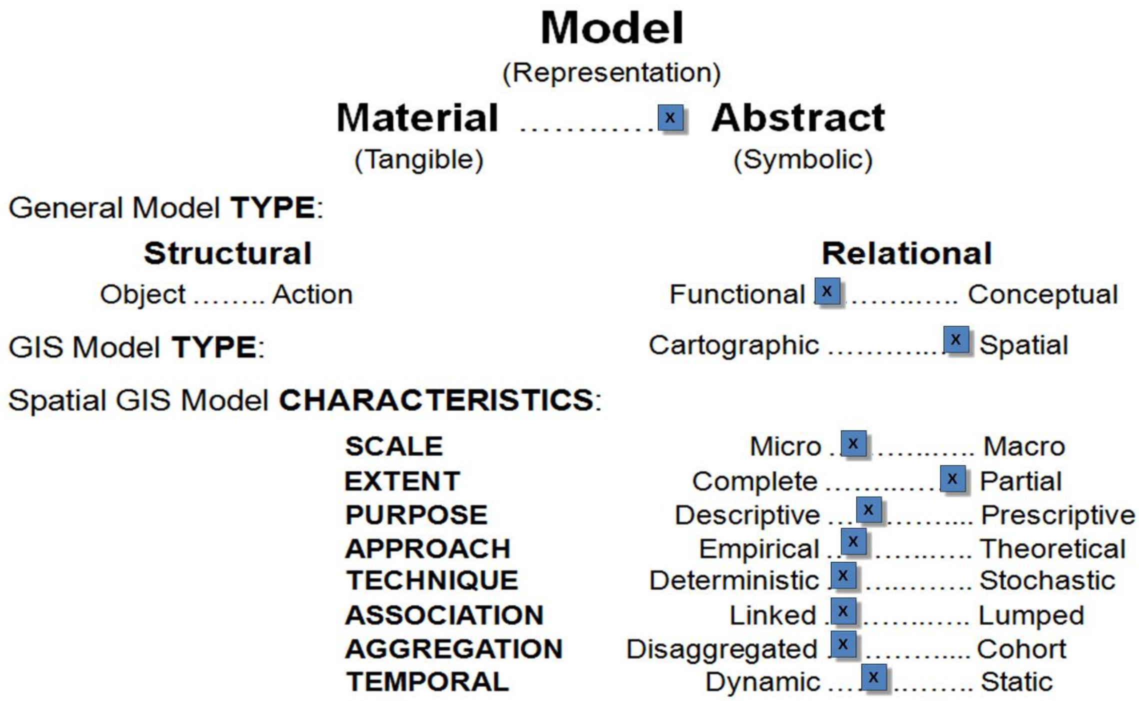

Figure 2. Categorization of a GIS model generating an animated set of maps predicting wildfire movement.

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 nation park
– An elk habitat model
– 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
- A set of maps of wildfire risk generated each morning
- A dynamic wildfire growth model responding to temperature fluctuations, complex wind vectors and fire abatement actions

Enjoy!

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.*

From Layers to Tapestry

(GeoWorld, February 1995 Supplement)

(return to top of Topic)

Most people 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, there are different views regarding the relative importance of the three elements. Some people have a *data-centric* perspective, as they prepare individual data layers and/or assemble the comprehensive databases GIS needs. Other people are *operations-centric*, because they lock in on refining and expanding the GIS toolbox of processing and display capabilities. Finally, the *applications-centric* folks see the portentous details of data and operations as mere 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 matured, the focus shifted to applications. As a result, more attention is directed toward the assumptions and linkages that are embedded in GIS models—map analysis solutions to pressing problems. In essence, we're weaving our data layers into complex, logical tapestries of map interrelationships. A crucial component of this evolution is an effective mechanism to communicate model logic, as well as processing flow.

Programmers and system analysts routinely use diagramming techniques for communicating data/processing flow. Various approaches include structure and flowcharts, as well as data flow, entity relation, control flow, and state transition diagrams. 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 (figure 1). The technique uses large circles to symbolize operations, with the lines connecting the operations identifying the data layers (input and output) used in each processing step. Its design draws one's attention to the processing steps over the data states, thereby best serving an operations-centric orientation.

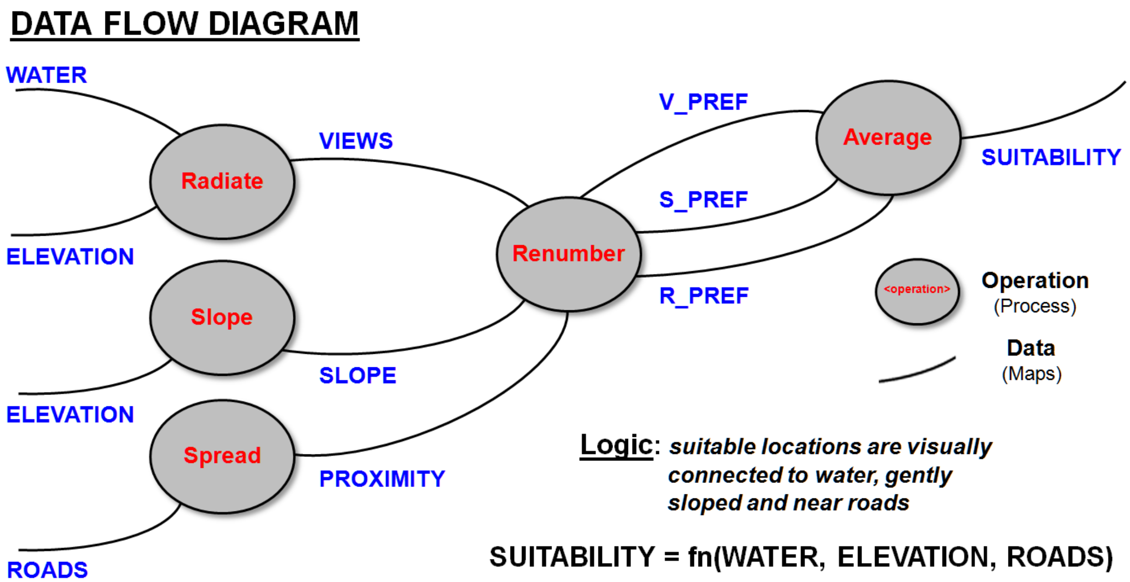

Figure 1. Example of a Data Flow Diagram emphasizing the processing steps used in converting one data set into another (Lines= processing; Ovals= maps).

Processing-oriented diagrams work well for nonspatial 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 greater than 13 percent AND unstable soils AND are devoid of vegetation?" use standard database management systems technology. In such instances, standard diagramming techniques are most appropriate.

However, spatial analysis techniques go beyond repackaging existing data. For example, it's a different story if you want to establish variable-width buffers around salmon spawning streams. You simultaneously need to 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 and relative elevations at a minimum. These, and myriad other spatial analysis procedures, have strong data dependency. They aren't just setting a few parameters for traditional, nonspatial processing techniques. Spatial analysis is a new kettle of fish as it is dependent on the unique geographic patterns of the data sets involved— definitely data-centric conditions.

As introduced in previously (Topic 1), a GIS model 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. Obviously, this focus is data-centric because it draws your attention to the mapped variables.

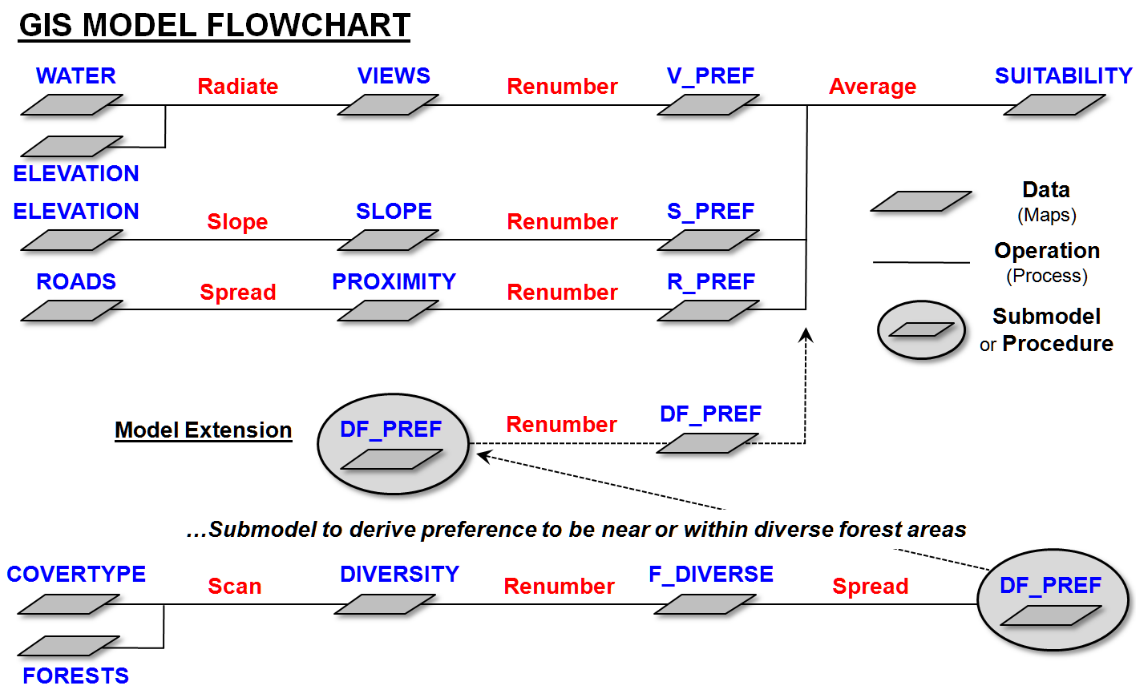

Figure 2. Example of a GIS Model Flowchart where maps (i.e., data sets) are depicted as "floating boxes" and operations (i.e., processing steps) are depicted as lines.

Arguably, it's also applications-centric. Most GIS users have experience with manual map analysis techniques. They've struggled laboriously with rulers, dot grids, and transparent overlays to 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 (FOREST). Areas of high diversity are isolated (renumber), and a proximity map from these areas (DF_PROX) is generated for the entire project area. Because several models might share this command set, it's stored as a generalized procedure and is attached using the *SubModel* or *Procedure* flowcharting "widget."

Figure 3 identifies an interactive construction of a processing modification to the model. In this example, a display of the SUITABILITY map with road vectors (ROAD.BLN) graphically overlaid is used as a backdrop for the user to manually draw a potential set of SUITABLE sites. Statistics on the sites (STATS.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 *Nonspatial Operation* widgets in a manner similar to constructing a schematic in AutoCAD.

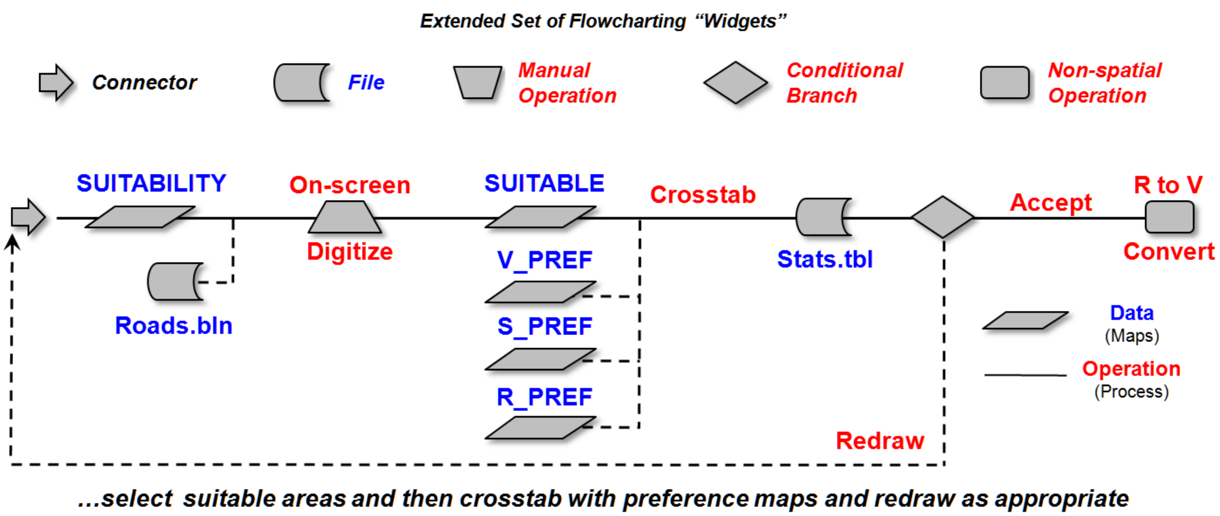

Figure 3. *Interactively modifying a "live" GIS flowchart using graphic widgets similar to constructing a schematic in AutoCAD.*

So what? All that discussion about *click-to-construct* a model's logic seems to be "much ado about nothing." It's just a bunch of globs, lines, and silly symbols.

Actually, it might be the best way for GIS to get out of the black box and into the light of creative applications. General users need a simple flowchart of model logic 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 that can be embellished with processing flow details.

Heck, in the not too distance future the GIS processing code (command macro) will be generated automatically— simply draw a GIS model's logic and the command file needed to execute it will be created on-the-fly. Clicking on a line will pop-up the command's dialog box enabling you to you edit it and run a different scenario. Awesome!!!

(return to top of Topic)

(Back to the Table of Contents)