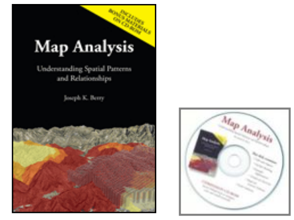
Beyond Mapping III

Topic 1 – Data Structure Implications



Map Analysis book/CD

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Grids and Lattices Build Visualizations

(GeoWorld, July 2002)

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For thousands of years, points, lines and polygons have been used to depict map features. With the stroke of a pen a cartographer could outline a continent, delineate a highway or identify a specific building's location. With the advent of the computer, manual drafting of these data has been replaced by the cold steel of the plotter.

In digital form these spatial data have been linked to attribute tables that describe characteristics and conditions of the map features. Desktop mapping exploits this linkage to provide tremendously useful database management procedures, such as address matching, geo-query and routing. *Vector-based* data forms the foundation of these techniques and directly builds on our historical perspective of maps and map analysis.

Grid-based data, on the other hand, is a relatively new way to describe geographic space and its relationships. Weather maps, identifying temperature and barometric pressure gradients, were an early application of this new data form. In the 1950s computers began analyzing weather station data to automatically draft maps of areas of specific temperature and pressure conditions. At the heart of this procedure is a new map feature that extends traditional points, lines and polygons (discrete objects) to continuous surfaces.

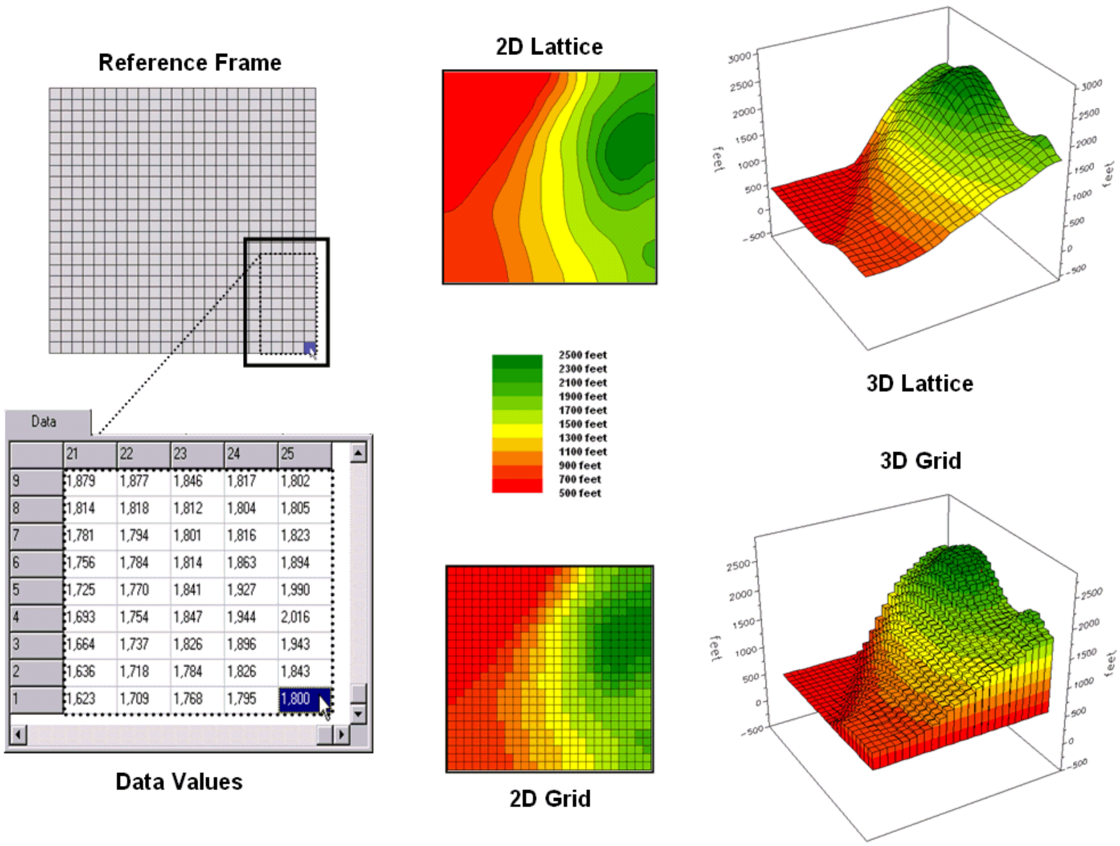

Figure 1. Grid-based data can be displayed in 2D/3D lattice or grid forms.

The rolling hills and valleys in our everyday world is a good example of a geographic surface. The elevation values constantly change as you move from one place to another forming a continuous spatial gradient. The left-side of figure 1 shows the grid data structure and a sub-set of values used to depict the terrain surface shown on the right-side.

Grid data are stored as an organized set of values in a matrix that is geo-registered over the terrain. Each grid cell identifies a specific location and contains a map value representing its average elevation. For example, the grid cell in the lower-right corner of the map is 1800 feet above sea level. The relative heights of surrounding elevation values characterize the undulating terrain of the area.

Two basic approaches can be used to display this information—lattice and grid. The ***lattice*** display form uses lines to convey surface configuration. The contour lines in the 2D version identify the breakpoints for equal intervals of increasing elevation. In the 3D version the intersections of the lines are "pushed-up" to the relative height of the elevation value stored for each location. The ***grid*** display form uses cells to convey surface configuration. The 2D version simply fills each cell with the contour interval color, while the 3D version pushes up each cell to its relative height.

The right-side of figure 2 shows a close-up of the data matrix of the project area. The elevation values are tied to specific X,Y coordinates (shown as yellow dots). Grid display techniques assume the elevation values are centered within each grid space defining the data matrix (solid back lines). A 2D grid display checks the elevation at each cell then assigns the color of the appropriate contour interval.

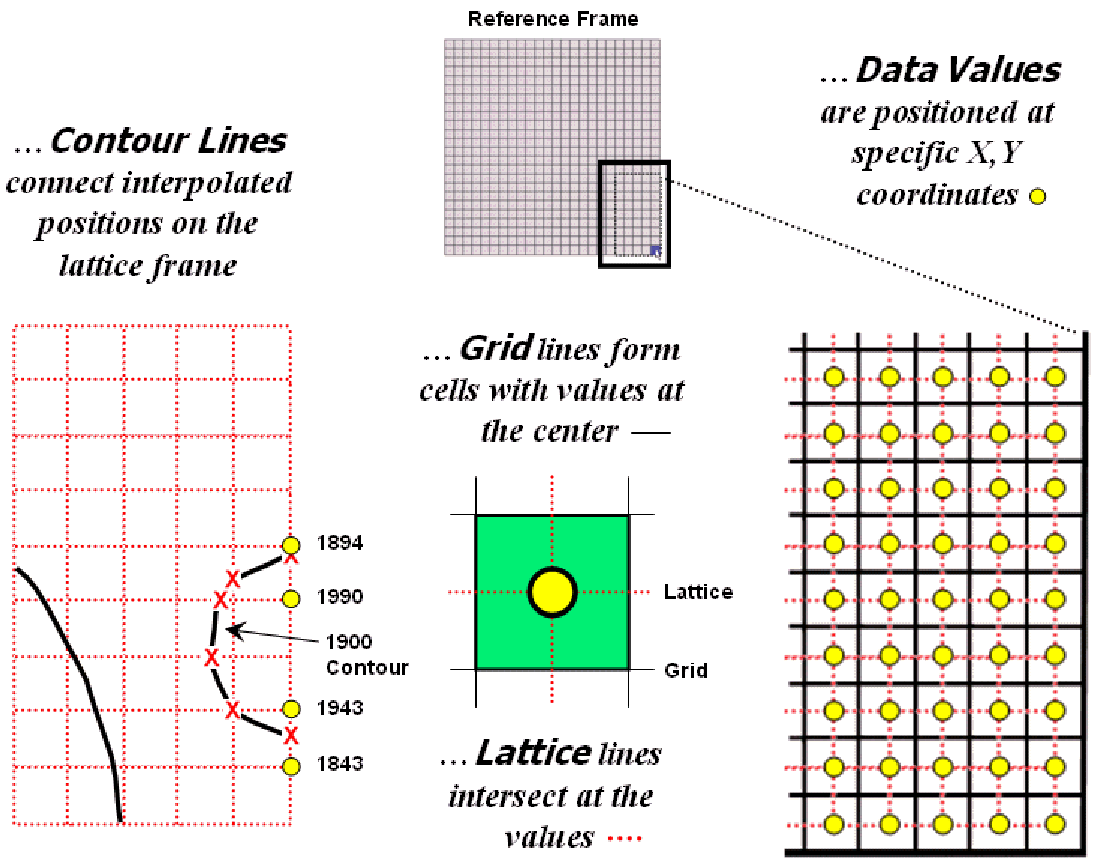

Figure 2. Contour lines are delineated by connecting interpolated points of constant elevation along the lattice frame.

Lattice display techniques, on the other hand, assume the values are positioned at the intersection of the lines defining the reference frame (dotted red lines). Note that the "extent" (outside edge of the entire area) of the two reference frames is off by a half-cell*. Contour lines are delineated by calculating where each line crosses the reference frame (red X's) then these points are connected by straight lines and smoothed. In the left-inset of the figure note that the intersection for the 1900 contour line is about half-way between the 1843 and 1943 values and nearly on top of the 1894 value.

Figure 3 shows how 3D plots are generated. Placing the viewpoint at different look-angles and distances creates different perspectives of the reference frame. For a 3D grid display entire cells are pushed to the relative height of their map values. The grid cells retain their projected shape forming blocky extruded columns.

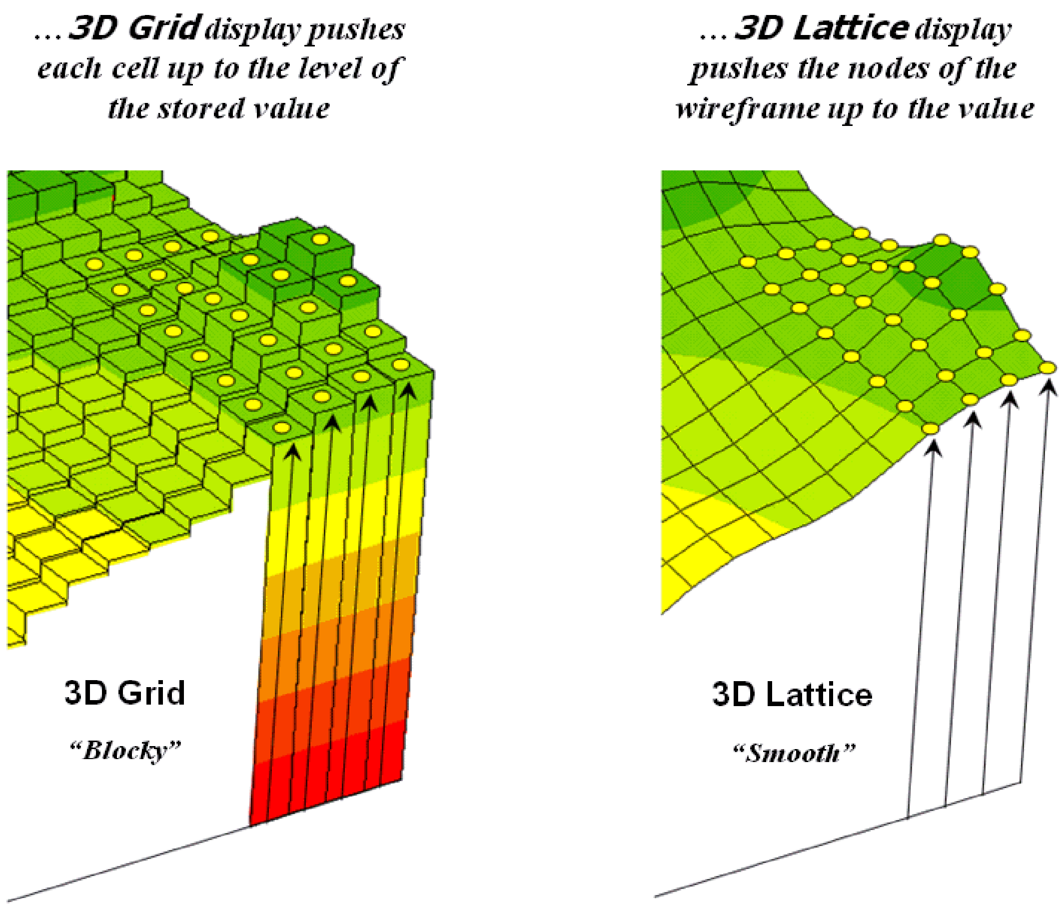

Figure 3. 3D display "pushes-up" the grid or lattice reference frame to the relative height of the stored map values.

3D lattice display pushes up each intersection node to its relative height. In doing so the four lines connected to it are stretched proportionally. The result is a smooth wireframe that expands and contracts with the rolling hills and valleys. Generally speaking, lattice displays create more pleasing maps and knock-your-socks-off graphics when you spin and twist the plots. However, grid displays provide a more honest picture of the underlying mapped data—a chunky matrix of stored values.

***Author's Note**: Be forewarned that the alignment difference between grid and lattice reference frames is a frequent source of registration error when one "blindly" imports a set of grid layers from a variety of sources.*

Maps Are Numbers First, Pictures Later

(GeoWorld, August 2002)

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The unconventional view that "*maps are numbers first, pictures later*" forms the backbone for taking maps beyond mapping. Historically maps involved "precise placement of physical features for navigation." More recently, however, map analysis has become an important ingredient in how we perceive spatial relationships and form decisions.

Understanding that a digital map is first and foremost an organized set of numbers is fundamental to analyzing mapped data. But exactly what are the characteristics defining a digital map? What do the numbers mean? Are there different types of numbers? Does their organization affect what you can do with them? If you have seen one digital map have you seen them all?

In an introductory GIS course, concepts of "vector" and "raster" seem to dominate discussion of what a digital map is, and isn't. Within this context, the location of map features are translated into computer form as organized sets of X,Y coordinates (vector) or grid cells (raster). Considerable attention is given data structure considerations and their relative advantages in storage efficiency and system performance.

However this geo-centric view rarely explains the full nature of digital maps. For example consider the numbers themselves that comprise the X,Y coordinates—how does number type and size effect precision? A general feel for the precision ingrained in a "single precision floating point" representation of Latitude/Longitude in decimal degrees is*…

1.31477E+08 ft = equatorial circumference of the earth
1.31477E+08 ft / 360 degrees = 365214 ft/degree length of one degree Longitude
Single precision number carries six decimal places, so—
  365214 ft/degree * 0.000001= .365214 ft *12 = **4.38257 inch** precision

Think if "double-precision" numbers (eleven decimal places) were used for storage—you likely could distinguish a dust particle on the left from one on the right.

In analyzing mapped data, however, the characteristics of the attribute values are even more critical. While textual descriptions can be stored with map features they can only be used in geo-query. For example if you attempted to add Longbrake Lane to Shortthrottle Way all you would get is an error, as text-based descriptors preclude any of the mathematical/statistical operations.

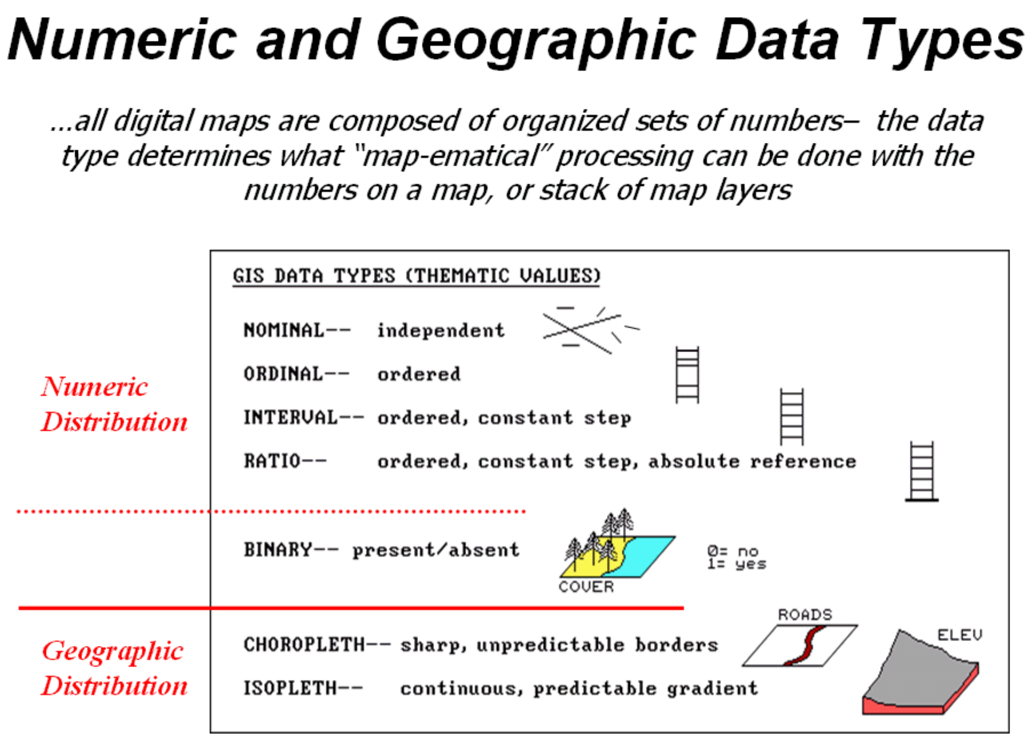

Figure 1. Map values are characterized from two broad perspectives—numeric and geographic—then further refined by specific data types.

So what are the numerical characteristics of mapped data? Figure 1 lists the data types by two important categories—numeric and geographic. You should have encountered the basic numeric data types in several classes since junior high school. Recall that ***nominal*** numbers do not imply ordering. A 3 isn't bigger, tastier or smellier than a 1, it's just not a 1. In the figure these data are schematically represented as scattered and independent pieces of wood.

Ordinal numbers, on the other hand, do imply a definite ordering and can be conceptualized as a ladder, however with varying spaces between rungs. The numbers form a progression, such as smallest to largest, but there isn't a consistent step. For example you might rank different five different soil types by their relative crop productivity (1= worst to 5= best) but it doesn't mean that soil 5 is exactly five times more productive than soil 1.

When a constant step is applied, ***interval*** numbers result. For example, a 60^{o} Fahrenheit spring day is consistently/incrementally warmer than a 30 ^oF winter day. In this case one "degree" forms a consistent reference step analogous to typical ladder with uniform spacing between rungs.

A ***ratio*** number introduces yet another condition—an absolute reference—that is analogous to a consistent footing or starting point for the ladder, analogous to zero degrees "Kelvin" defined as when all molecular movement ceases. A final type of numeric data is termed "***binary***." In this instance the value range is constrained to just two states, such as forested/non-forested or suitable/not-suitable.

So what does all of this have to do with analyzing digital maps? The type of number dictates the variety of analytical procedures that can be applied. Nominal data, for example, do not support direct mathematical or statistical analysis. Ordinal data support only a limited set of statistical procedures, such as maximum and minimum. Interval and ratio data, on the other hand, support a full set mathematics and statistics. Binary maps support special mathematical operators, such as .AND. and .OR.

Even more interesting (this interesting, right?) are the geographic characteristics of the numbers. From this perspective there are two types of numbers. "***Choropleth***" numbers form sharp and unpredictable boundaries in space such as the values on a road or cover type map. "***Isopleth***" numbers, on the other hand, form continuous and often predictable gradients in geographic space, such as the values on an elevation or temperature surface.

Figure 2 puts it all together. ***Discrete*** maps identify mapped data with independent numbers (nominal) forming sharp abrupt boundaries (choropleth), such as a covertype map. ***Continuous*** maps contain a range of values (ratio) that form spatial gradients (isopleth), such as an elevation surface. This clean dichotomy is muddled by cross-over data such as speed limits (ratio) assigned to the features on a road map (choropleth).

Discrete maps are best handled in 2D form—the 3D plot in the top-right inset is ridiculous and misleading because it implies numeric/geographic relationships among the stored values. What isn't as obvious is that a 2D form of continuous data (lower-right inset) is equally as absurd.

While a contour map might be as familiar and comfortable as a pair of old blue jeans, the generalized intervals treat the data as discrete (ordinal, choropleth). The artificially imposed sharp boundaries become the focus for visual analysis.

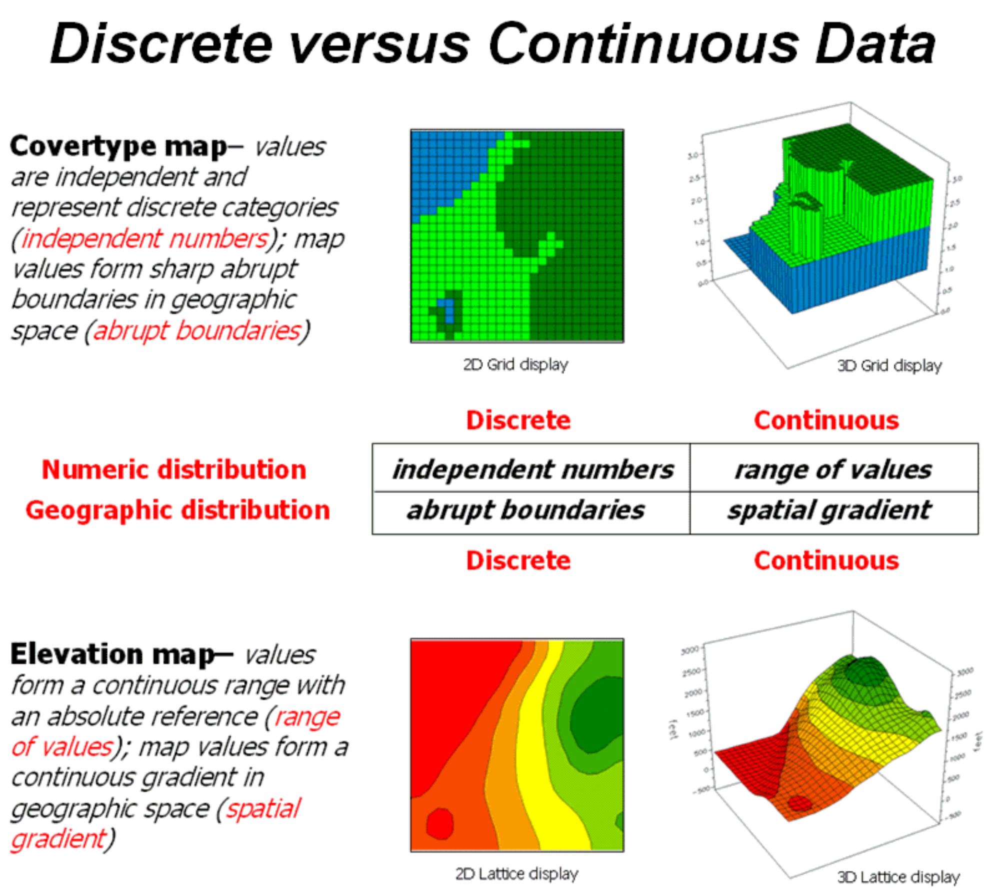

Figure 2. Discrete and Continuous map types combine the numeric and geographic characteristics of mapped data.

Map-*ematical* analysis of the actual data, on the other hand, incorporates all of the detail contained in the numeric/geographic patterns of the numbers ...where the rubber meets the spatial analysis road.

Normalizing Maps for Data Analysis

(GeoWorld, September 2002)

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The last couple of sections have dealt with the numerical nature of digital maps. Two fundamental considerations remain—data normalization and exchange. ***Normalization*** involves standardizing a data set, usually for comparison among different types of data. In a sense, normalization techniques allow you to "compare apples and oranges" using a standard "mixed fruit scale of numbers."

The most basic normalization procedure uses a "goal" to adjust map values. For example, a farmer might set a goal of 250 bushels per acre to be used in normalizing a yield map for corn. The equation, **Norm_GOAL = (mapValue / 250) * 100**, derives the percentage of the goal achieved by each location in a field. In evaluating the equation, the computer substitutes a map value for a field location, completes the calculation, stores the result, and then repeats the process for all of the other map locations.

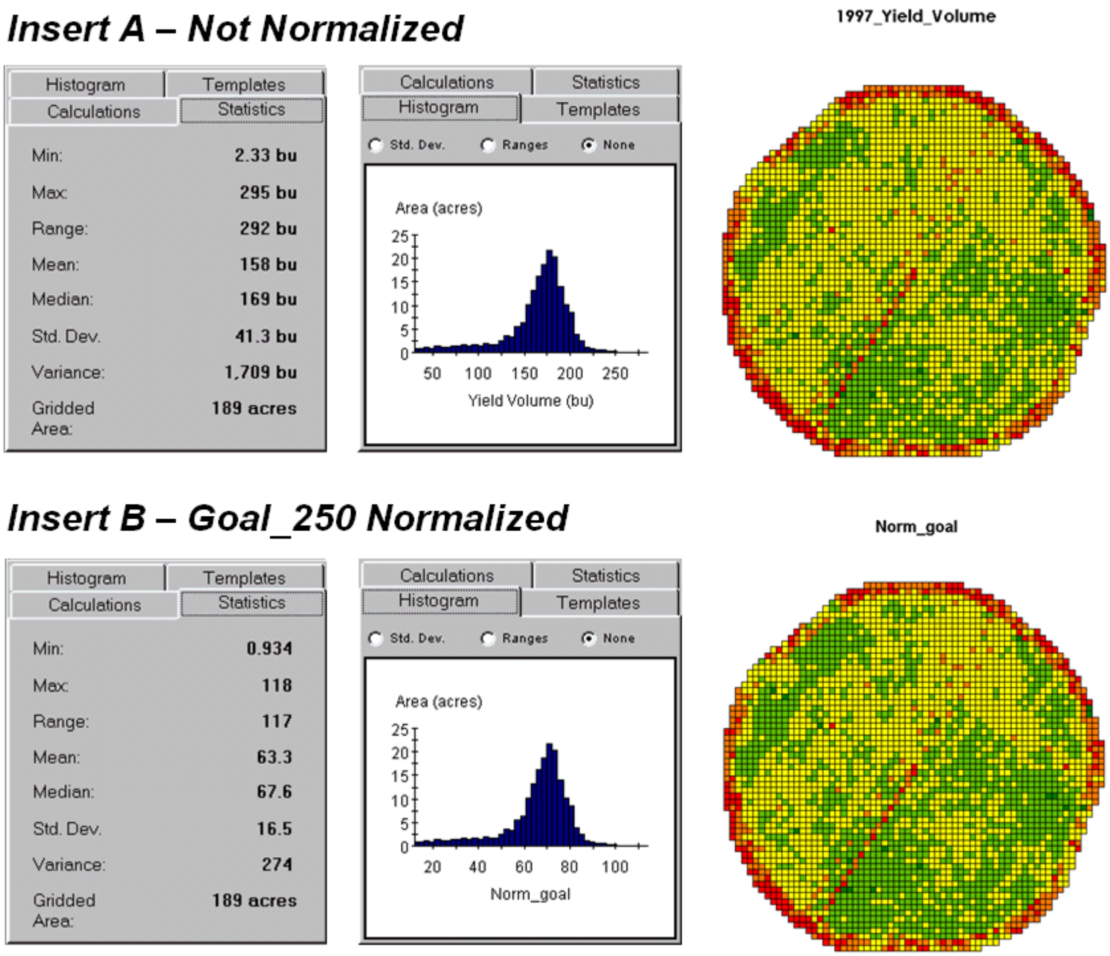

Figure 1. Comparison of original and goal normalized data.

Figure 1 shows the results of goal normalization. Note the differences in the descriptive statistics between the original (top) and normalized data (bottom)—a data range of 2.33 to 295 with an average of 158 bushels per acre for the original data versus .934 to 118 with an average of 63.3 percent for the normalized data.

However, the histogram and map patterns are identical (slight differences in the maps are an artifact of rounding the discrete display intervals). While the descriptive statistics are different, the relationships (patterns) in the normalized histogram and map are the same as the original data.

That's an important point— both the numeric and spatial relationships in the data are preserved during normalization. In effect, normalization simply "rescales" the values like changing from one set of units to another (e.g., switching from feet to meters doesn't change your height). The significance of the goal normalization is that the new scale allows comparison among different fields and even crop types based on their individual goals— the "mixed fruit" expression of apples and oranges. Same holds for normalizing environmental, business, health or any other kind of mapped data.

An alternative "0-100" normalization forces a consistent range of values by spatially evaluating the equation **Norm_0-100 = (((mapValue – min) * 100) / (max – min)) + 0**. The result is a rescaling of the data to a range of 0 to 100 while retaining the same relative numeric and spatial patterns of the original data. While goal normalization benchmarks a standard value, the 0-100 procedure rescales the original data range to a fixed, standard range (see Author's note).

A third normalization procedure termed Standard Normal Variable (SNV), uses yet another approach. It rescales the data based on its central tendency by applying the normalizing equation **Norm_SNV = ((mapValue - mean) / stdev) * 100**. The result is a rescaling of the data to the percent variation from the average. Mapped data expressed in this form enables you to easily identify "statistically unusual" areas— +100% locates areas that are one standard deviation above the typical value; -100% locates areas that are one standard deviation below.

Map normalization is often a forgotten step in the rush to make a map, but is critical to a host of subsequent analyses from visual map comparison to advanced data analysis. The ability to easily export the data in a universal format is just as critical. Instead of a "do-it-all" GIS system, ***data exchange*** exports the mapped data in a format that is easily consumed and utilized by other software packages.

Figure 2 shows the process for grid-based data. Recall that a consistent analysis frame is used to organize the data into map layers. The map values at each cell location for selected layers are reformatted into a single record and stored in a standard export table that, in turn, can be imported into other data analysis software.

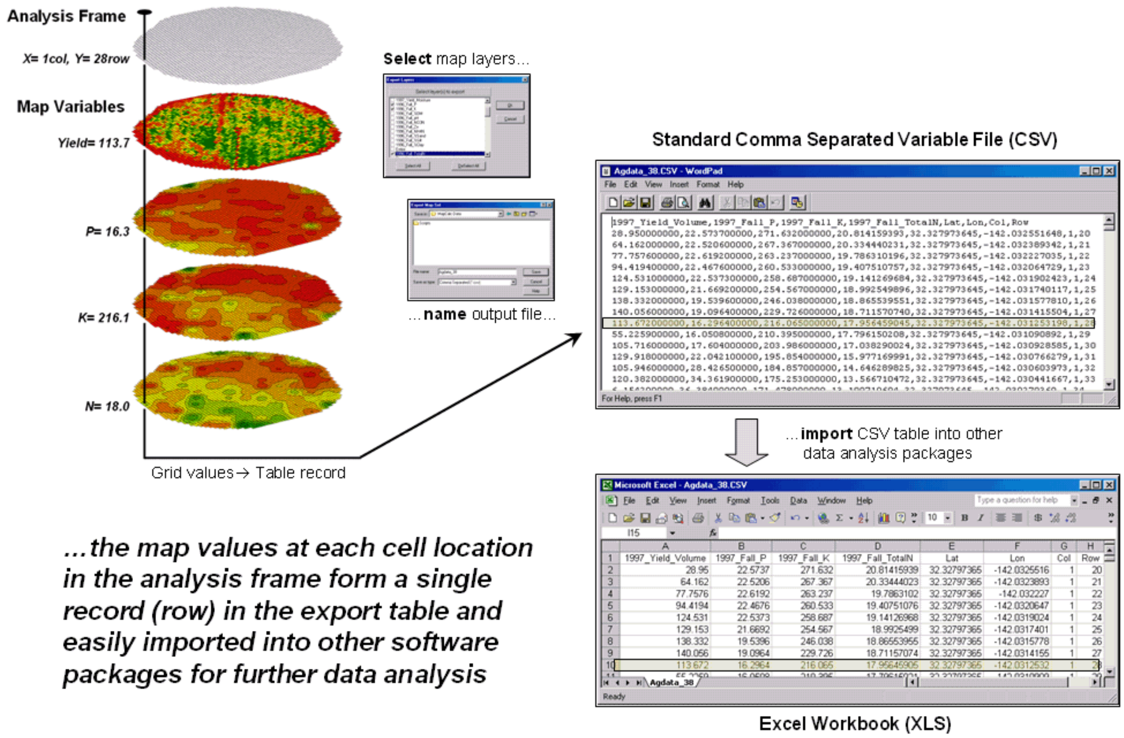

Figure 2. The map values at each grid location form a single record in the exported table.

Figure 3 shows the agricultural data imported into the JMP statistical package (by SAS). Area (1) shows the histograms and descriptive statistics for the P, K and N map layers shown in figure 2. Area (2) is a “spinning 3D plot” of the data that you can rotate to graphically visualize relationships among the data patterns defining the three map layers.

Area (3) shows the results of applying a multiple linear regression model to predict crop yield from the soil nutrient maps. These are but a few of the tools beyond mapping that are available through data exchange between GIS and traditional spreadsheet, database and statistical packages—a perspective that integrates maps with other technologies.

Modern statistical packages like JMP “aren’t your father’s” stat experience and are fully interactive with point-n-click graphical interfaces and wizards to guide appropriate analyses. The analytical tools, tables and displays provide a whole new map-ematical view of traditional mapped data.

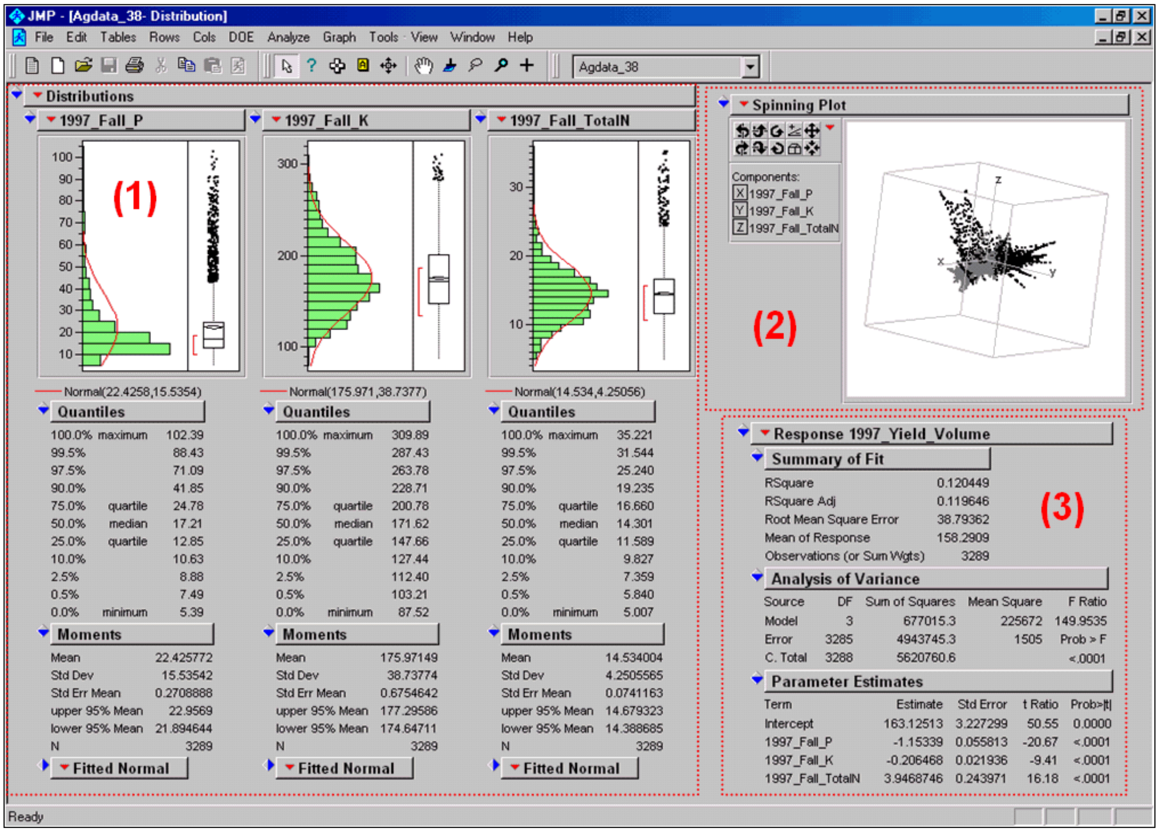

Figure 3. Mapped data can be imported into standard statistical packages for further analysis.

While a map picture might be worth a thousand words, a gigabyte or so of digital map data is a whole revelation and foothold for site-specific decisions.

Author's Note: *the generalized rescaling equation to* normalize a data set to a fixed range of Rmin to Rmax is…

Normalize R*min* to R*max*= (((X-D*min*) * (R*max* – R*min*)) / (D*max* – D*min*)) + R*min*

…where Rmin and Rmax is the minimum and maximum values for the rescaled range, Dmin and Dmax is the minimum and maximum values for the input data and X is any value in the data set to be rescaled.

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

Multiple Methods Help Organize Raster Data — *discusses different approaches to storing raster data (April 2003)*
Use Mapping "Art" to Visualize Values — *describes procedures for generating contour maps (June 2003)*

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