Incorporating Grid-based Map Analysis into GIS Curricula

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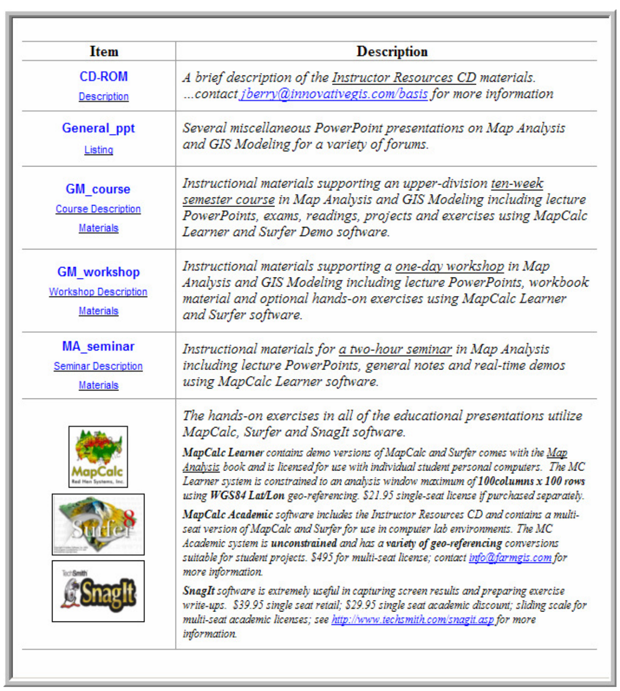
Abstract

Popularity of inexpensive and easy-to-use desktop mapping systems has fueled introductory GIS course offerings in a variety of disciplines on most campuses. Textbooks and supplemental teaching materials support basic concepts and procedures, such as data issues, thematic mapping, geo-query and display. However, the bulk of the teaching materials focus on vector data processing and applications, with none or minimal reference to grid-based map analysis. This paper describes a comprehensive set of materials for instructors and students providing hands-on exposure to the concepts, capabilities and considerations in grid-based map analysis and modeling.

Instructional Materials *(available June, 2007)*

The **Instructor CD** *for Grid-based Map Analysis* contains a comprehensive set of instructional materials supporting a variety of workshops and courses including syllabus, PowerPoint lectures, exercises, databases, and study/exam questions with answers. The topics covered include data structure, display types, vector-raster data exchange, analytical operations and GIS modeling. The instructional materials are available for US$45 plus shipping and handling charges (for more information or to order contact the author at **jberry@innovativegis.com**).



Item	Description
CD-ROM Description	*A brief description of the Instructor Resources CD materials. ...contact jberry@innovativegis.com/basis for more information*
General_ppt Listing	*Several miscellaneous PowerPoint presentations on Map Analysis and GIS Modeling for a variety of forums.*
GM_course Course Description Materials	*Instructional materials supporting an upper-division ten-week semester course in Map Analysis and GIS Modeling including lecture PowerPoints, exams, readings, projects and exercises using MapCalc Learner and Surfer Demo software.*
GM_workshop Workshop Description Materials	*Instructional materials supporting a one-day workshop in Map Analysis and GIS Modeling including lecture PowerPoints, workbook material and optional hands-on exercises using MapCalc Learner and Surfer software.*
MA_seminar Seminar Description Materials	*Instructional materials for a two-hour seminar in Map Analysis including lecture PowerPoints, general notes and real-time demos using MapCalc Learner software.*
MapCalc Red Hen Systems, Inc. Surfer 8 TechSmith SnagIt	*The hands-on exercises in all of the educational presentations utilize MapCalc, Surfer and SnagIt software.* ***MapCalc Learner*** *contains demo versions of MapCalc and Surfer comes with the Map Analysis book and is licensed for use with individual student personal computers. The MC Learner system is constrained to an analysis window maximum of* ***100columns x 100 rows*** *using* ***WGS84 Lat/Lon*** *geo-referencing. $21.95 single-seat license if purchased separately.* ***MapCalc Academic*** *software includes the Instructor Resources CD and contains a multi-seat version of MapCalc and Surfer for use in computer lab environments. The MC Academic system is* ***unconstrained*** *and has a* ***variety of geo-referencing*** *conversions suitable for student projects. $495 for multi-seat license; contact info@farmgis.com for more information.* ***SnagIt*** *software is extremely useful in capturing screen results and preparing exercise write-ups. $39.95 single seat retail; $29.95 single seat academic discount; sliding scale for multi-seat academic licenses; see http://www.techsmith.com/snagit.asp for more information.*

General_ppt — this item accesses several PowerPoint presentations on Map Analysis and GIS Modeling supporting variety of forums from overview keynote addresses to paper presentations describing specific analysis capabilities and applications.

GM_course — this item accesses instructional materials supporting an upper-division ten-week semester course in Map Analysis and GIS Modeling including lecture PowerPoints, exams, readings, projects and exercises using MapCalc Learner and Surfer Demo software.

GM_workshop — this item accesses instructional materials supporting a one-day workshop in Map Analysis and GIS Modeling including lecture PowerPoints, workbook material and optional hands-on exercises using MapCalc Learner and Surfer Demo software.

MA_seminar — this item accesses instructional materials for a two-hour seminar in Map Analysis including lecture PowerPoints, general notes and real-time demos using MapCalc Learner software.

Figure 1. Listing of Instructor CD contents (main entry/access page).

The materials extend the discussions in the Map Analysis book (Berry, 2007; GeoTec Media, $45.20 which includes S&H; see **www.geoplace.com/books/MapAnalysis**) and its MapCalc companion software (see **www.redhensystems.com**, select Products→ MapCalc; a GeoWorld Review of the MapCalc software is posted at **www.innovativegis.com/basis/present/GW01_MCreview/GW_JUN01_mapcalcReview.htm**).

The lecture sets and hands-on exercises focus on two broad groups of grid-based map analysis operations. The Spatial Analysis operations investigate the "contextual" relationships in mapped data and are divided into logical classes based on processing similarities—*Reclassifying Maps*, *Overlaying Maps*, *Measuring Distance and Connectivity*, and *Neighborhood Summary*. Numerous examples of GIS models are included and students are encouraged to encode local data and formulate their own models.

The Spatial Statistics experience focuses on the "numerical" relationships and is divided into two classes of operations—*Surface Modeling* involving spatial interpolation of point data into continuous geographic distributions and *Spatial Data Mining* investigating numerical relationships within and among mapped data to include predictive modeling.

Much of the material was developed and originally presented at the University of Denver and reflect the circumstances of their original presentations. You are free to use the materials for educational purposes and are encouraged to reorganize, edit, augment and integrate the materials with your own resources as appropriate for your class offerings and other presentations.

Background

Courses in Geographic Information Systems (GIS) technology are proliferating on campuses. While GIS used to be the domain of geography departments, it has diffused into application disciplines ranging from forestry to business, engineering, law enforcement, public health and a multitude of other departments. A major factor fueling the expansion is inexpensive and user-friendly desktop mapping software.

These vector-based systems are ideal for learning the fundamentals of mapping and spatial database management. The educational experience with desktop mapping provides an excellent entry into GIS and hands-on experience in applying the basic concepts. An increasing number of resources tailored to specific application areas are available. The datasets and structured exercises provide meaningful learning experiences for a wide range of students.

Basic thematic mapping and geo-query, however, only address a portion of GIS capabilities and grid-based map analysis hasn't received the same attention in most academic programs. This condition often is attributed to less familiar analysis techniques that are outside manual mapping experiences and, until recently, involved complex software running on expensive hardware platforms and requiring specialized programming knowledge. The result is that through exposure to grid-based analysis capabilities rarely occurs in introductory courses.

Grid-based maps represent a different paradigm of geographic space. Whereas traditional vector maps emphasize "precise placement of physical features," grid maps seek to "statistically characterize continuous space in both real and cognitive terms." The tools for mapping of database attributes are extended to analysis of spatial relationships. The remainder of this paper describes some of the basic concepts, considerations and procedures in grid-based data handling and analysis operations.

Grid-Based Analysis Frame

Vector-based systems identify three basic map features that comprise all maps—*points*, *lines* and *polygons*. These features are suitable for characterizing discrete spatial objects, such as light poles, streets and property boundaries. However, continuous gradients, such as an elevation surface or a proximity map are poorly represented as contour lines that generalize detailed data into a set of intervals used for display.

The introduction of a grid-analysis frame provides a framework for storage and processing of a fourth basic map feature—a *surface*—as well as supporting a host of new analysis operations by treating geographic space as a informally sampled continuum. Its base spatial unit is a "cell" defined by the column and row coordinates of an imaginary grid superimposed over an area. The grid cell and is used to statistically characterize:

- *points* as individual cells,
- *lines* as connected sets of cells,
- *polygons* as all cells identifying the edge and interior of discrete parcels, and
- *a surface* as all of the cells within a project area with a value assigned to each that indicates the presence by feature type (discrete object) or the relative variable response (continuous gradient).

The top-left portion of figure 2 shows an elevation surface displayed as a traditional contour map, a superimposed analysis frame and a 2-D grid map. The highlighted location depicts the elevation value (1,635 feet) stored at one of the grid locations. The pop-up table at the lower-right shows the values stored on other map layers for a selected location. As the cursor is moved, the "drill-down" of values for different locations are instantly updated.

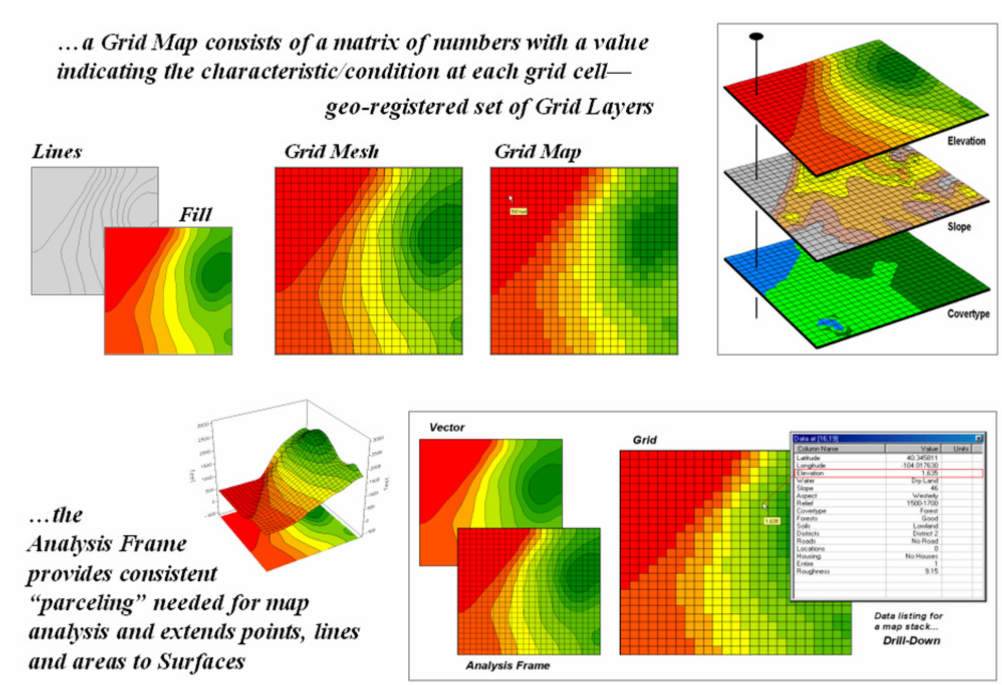


Figure 2. The grid-analysis frame is used to represent geographic space as a continuum.

Connecting the grid lines at the center of each grid space forms the 3-D plot in the lower-left portion of the figure. The lengths of the lines are a function of the elevation difference between the values stored at adjacent grid spaces. The result is a "wireframe" plot that forms the peaks and valleys of the spatial distribution of the mapped data forming the surface. The color zones identify contour intervals that are draped on the frame. In addition to providing a format for storing and displaying map surfaces, the analysis frame provides the consistent structuring needed for advanced grid-based analysis operations.

Spatial Statistics and Analysis

Grid-based map analysis is often used in natural resources management and land use planning. However, some of its most innovative applications have been in disciplines with minimal mapping legacy. The following discussions focus on geo-business applications to illustrate the Spatial Statistics and Spatial Analysis operations ingrained in grid-based map analysis.

The two fundamental Spatial Statistics capabilities of *Surface Modeling* and *Spatial Data Mining* are described.

Surface Modeling

Surface modeling involves the translation of discrete point data into a continuous surface that represents the geographic distribution of data. Traditional non-spatial statistics involves an analogous process when a numerical distribution (e.g., standard normal curve) is used to generalize the central tendency of a data set. The derived mean (average) and standard deviation reflects the typical response and provides a measure of how typical it is. This characterization seeks to explain data variation in terms of the numerical distribution of measurements without any reference to their spatial distribution.

In fact, an underlying assumption in most statistical analyses is that the data is randomly distributed in space. If the data exhibits spatial autocorrelation many of the analysis techniques are less valid.

Spatial statistics, on the other hand, utilizes geographic patterns in the data to further explain the variance. There are numerous techniques for characterizing the spatial distribution inherent in a data set but they can be characterized by three basic approaches:

- *Point Density* mapping that aggregates the number of points within a specified distance (number per acre),
- *Spatial Interpolation* that weight-averages measurements within a localized area (e.g., kriging), and
- *Map Generalization* that fits a functional form to the entire data set (e.g., polynomial surface fitting).

For example, consider Figure 3 showing a point density map derived from customer addresses. The project area is divided into an analysis frame of 250-foot grid cells (100c x 100r = 10,000 cells). The number of customers for each grid space is determined street addresses in a desktop mapping system ("spikes" in the 3D map on the left). A neighborhood summary operation is used to pass a "roving window" over the project area calculating the total customers within a half-mile of each map location. The result is a continuous map surface indicating the relative density of customers—peaks where there is a lot of customers and valleys where there aren't many.

In essence, the map surface quantifies what your eye sees in the spiked map—some areas with lots of customers and others with very few. Spatial interpolation also moves a roving window about point data but utilizes more sophisticated summary techniques, such as Inverse Distance, Kriging and Minimum Curvature. The result in either case, are map surfaces that respond to the spatial distribution in the data.

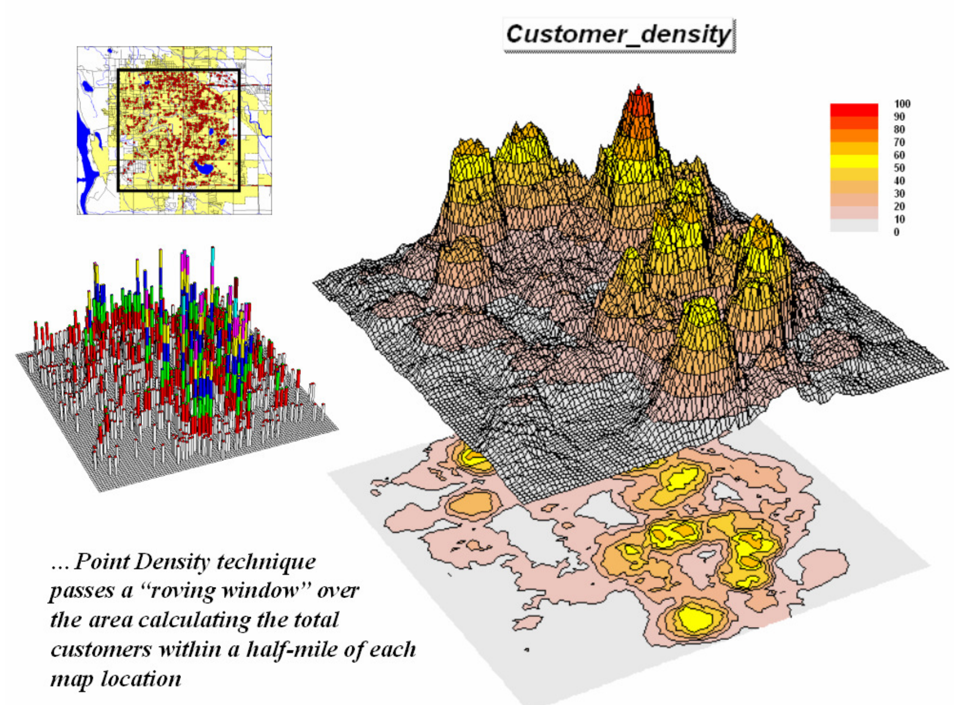


Figure 3. Point density map aggregating the number of customers within a quarter of a mile.

An underlying assumption of surface modeling is that that the variable under study forms a gradient in geographic space (termed "isopleth" data). The derived surface is an approximation of that gradient. A further assumption is that the data exhibits spatial autocorrelation—"nearby things are more alike than distant things." While some maps containing discrete objects do not have these qualities, many business decision variables, such as sales and demographics, express themselves as spatially auto-correlated gradients. In these instances, surface modeling is a viable approach to characterizing the geographic distribution of point-sampled data.

Spatial Data Mining

Spatial data mining seeks to describe relationships within and among mapped data utilizing techniques such as coincidence summary, proximal alignment, statistical tests, percent difference, surface configuration, level-slicing, map similarity, and clustering in comparing maps and assessing similarities in data patterns.

Another group of spatial data mining techniques focuses on developing predictive models. For example, the customer density map described in the previous section might be strongly related to mapped data of demographics. If that is the case, a mathematical (or "map-*ematical*") prediction equation can be derived. Simple linear regression, often used in research, can be applied to a stack of grid maps—they are just an organized set of numbers awaiting analysis. In essence, the technique goes to a grid location and notes the density of customers (dependent variable) and the demographic information, (independent variables) and quantifies the data pattern. As the process is repeated for thousands of cells a predictable pattern between the density values and the demographic values often emerges. If the relationship is strong, the regression equation can be used to predict a map of expected customer levels for another city slated for a new office.

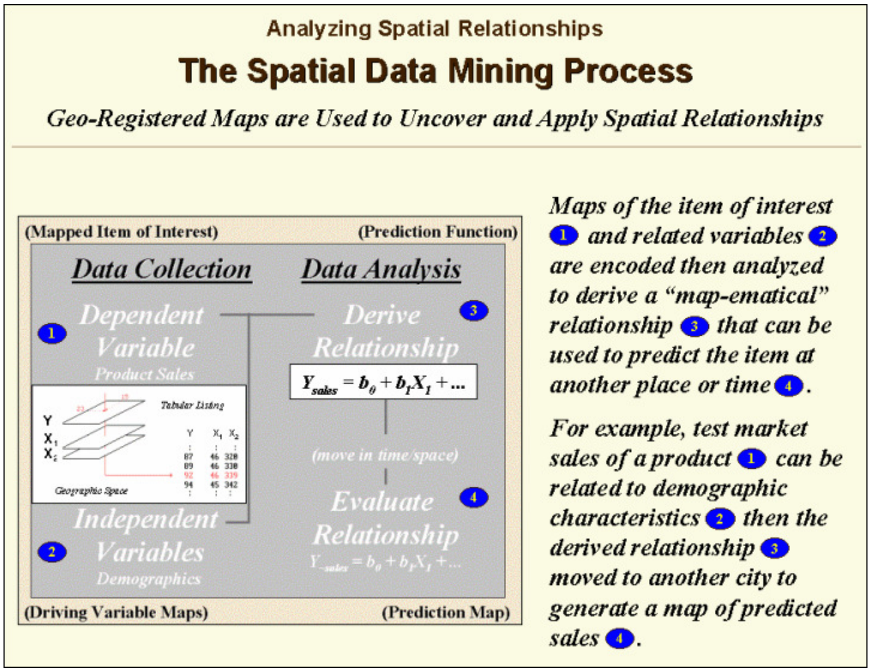


Figure 4. Spatial data mining can be used to derive predictive models of the relationships among mapped data.

For example, predictive modeling was used in the early 1990s to extend a test market project for a phone company (figure 4). The customer's address was used to geo-code sales of a new product that enabled two numbers with distinctly different rings to be assigned to a single home phone—one for the kids and one for the parents. Like pushpins on a map, the pattern of sales throughout the city emerged with some areas doing very well, while in other areas sales were few and far between.

The demographic data for the city was analyzed to calculate a prediction equation between product sales and census block data. The prediction equation derived from the test market sales in one city was applied to another city by evaluating exiting demographics to "solve the equation" for a predicted sales map. In turn the predicted map was combined with a wire-exchange map to identify switching facilities that required upgrading before release of the product in the new city.

A couple of considerations are important in predictive modeling. First, the mapped data needs to form spatially auto-correlated gradients as previously mentioned. Secondly, traditional multivariate techniques assume that the data values are not categorical or binary (such as male/female), as the regression technique needs a continuum of values (such as income levels) to work properly. However, there are other more advanced predictive techniques (such as CART technology) that can utilize nominal data types.

Spatial data mining approaches have been used for years in automated classification of remote sensing data. In these instances, spectral values are analyzed for a stack of grid layers. Geo-business spatial data mining applications simply relate grid layers that characterize other information. In addition, geo-business applications focus more on predictive statistics than descriptive classification.

Cutting-edge research in spatial data mining is pushing the envelope from descriptive and predictive statistics to "prescriptive" modeling that seeks to spatially optimize management action. An example is the generation of a prescription map in precision agriculture that changes a fertilization program throughout a field based on the current distribution of nutrients and yield prediction. Variable-rate technology actually alters the blend of nutrients "on-the-fly" as a GPS-equipped spray rig moves across the field. Future decision support systems for business will likely implement prescriptive modeling based on predictive/descriptive statistics derived from mapped data. These systems will generate spatially responsive guidance—"do this over here but that over there"—that fully incorporates the geographic distribution inherent in mapped data.

Spatial Analysis

Whereas surface modeling and spatial data mining respond to "numerical" relationships in mapped data, spatial analysis is used to investigates the "contextual" relationships. Tools such as slope/aspect, buffers, effective proximity, optimal path, visual exposure and shape analysis, fall into this class of spatial operators. Rather than statistical analysis of mapped data, these techniques examine geographic patterns, vicinity characteristics and connectivity among features.

An example of this group of operations builds on two specific map analysis capabilities—effective proximity and accumulation surface analysis. The following discussion focuses on the application of these tools to competition analysis between two stores.

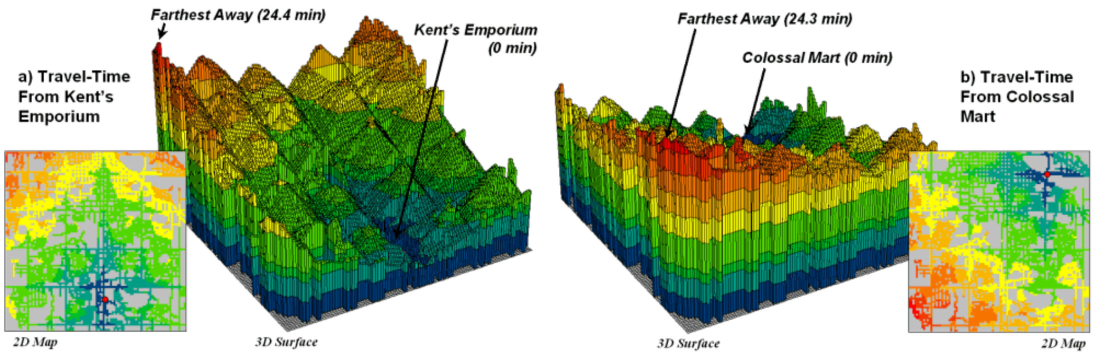


Figure 5. Travel-time surfaces show increasing distance from a store considering the relative speed along different road types.

The left side of figure 5 shows the travel-time surface from Kent's Emporium. It is calculated by starting at the store then moving out along the road network like waves propagating through a canal system. As the wave front moves, it adds the time to cross each successive road segment to the accumulated time up to that point.

The result is the estimated travel-time to every location in the city. The surface starts at 0 and extends to 24.4 minutes away. Note that it is shaped like a bowl with the bottom at the store's location. In the 2D display, travel-time appears as a series of rings—increasing distance zones. The critical points to conceptualize are 1) that the surface is analogous to a football stadium (continually increasing) and 2) that every road location is assigned a distance value (minutes away).

The right side of figure 5 shows the travel-time surface for another store, Colossal Mart, with its origin in the northeast portion of the city. The perspective in both 3D displays is consistent and Kent's surface appears to "grow" away from you while Colossal's surface seems to grow toward you.

Simply subtracting the two surfaces derives the relative travel-time advantage for the stores (figure 6). Keep in mind that the surfaces actually contain geo-registered values and a new value (difference) is computed for each map location. The inset on the left side of the figure shows a computed Colossal Mart advantage of 6.1 minutes (22.5 – 16.4= 6.1) for the location in the extreme northeast corner of the city.

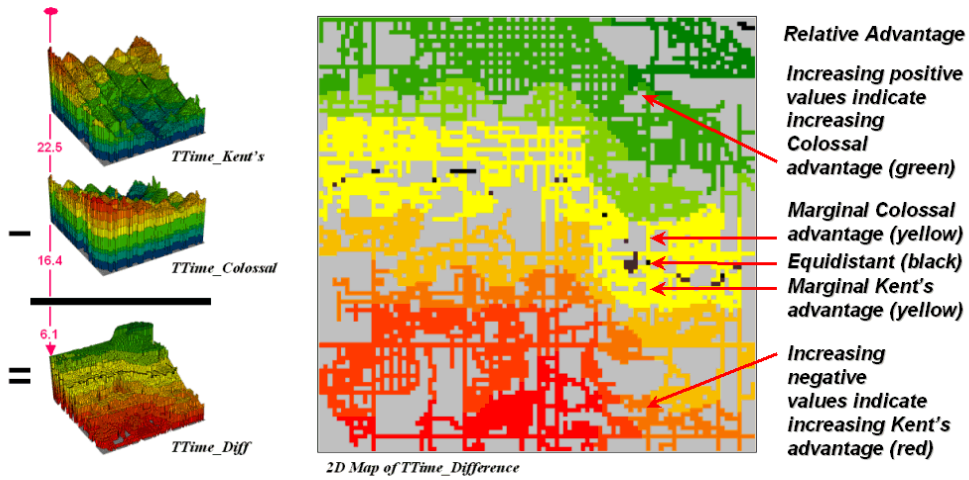


Figure 6. Two travel-time surfaces can be combined to identify the relative advantage of each store.

Locations that are the same travel distance from both stores result in zero difference and are displayed as black. The green tones on the difference map identify positive values where Kent's travel-time is larger than its competitor's—advantage to Colossal Mart. Negative values (red tones) indicate the opposite—advantage to Kent's Emporium. The yellow tone indicates the "combat zone" where potential customers are about the same distance from either store—advantage to no one.

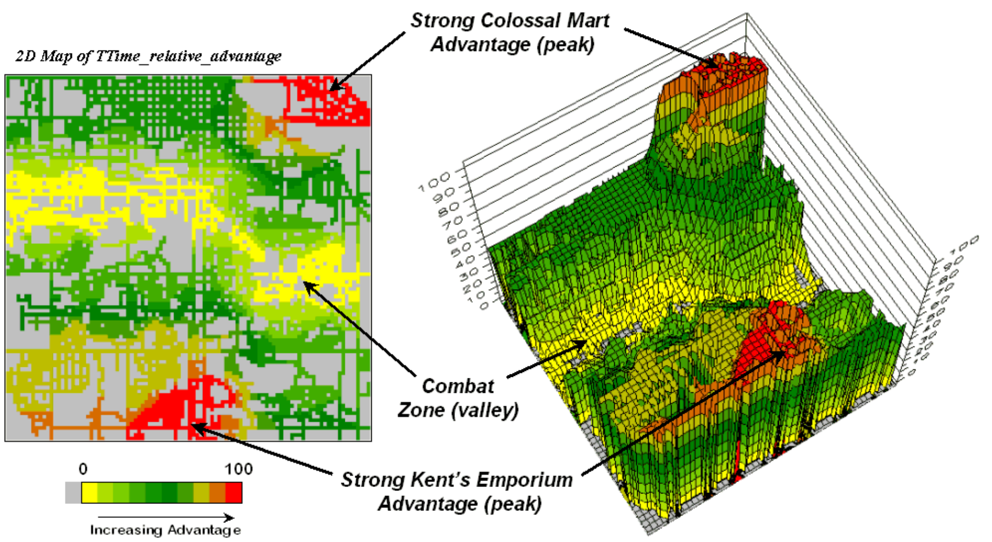


Figure 7. A transformed display of the difference map shows travel-time advantage as peaks (red) and locations with minimal advantage as an intervening valley (yellow).

Figure 7 displays the same information in a bit more intuitive fashion. The combat zone is shown as a yellow valley dividing the city into two marketing regions—peaks of strong travel-time advantage. Targeted marketing efforts, such as leaflets, advertising inserts and telemarketing might best be focused on the combat zone. The similarity of travel-time to either store in the combat zone suggests that residents might be more receptive to store incentives.

At a minimum the travel-time advantage map enables retailers to visualize the lay of the competitive landscape. However the information is in quantitative form and can be readily integrated with other customer data. Knowing the relative travel-time advantage (or disadvantage) of every street address in a city can be a valuable piece of the marketing puzzle. Like age, gender, education, and income, relative travel-time advantage is part of the soup that determines where one shops.

There are numerous other map analysis operations in the grid-based "toolbox"—too many to enumerate and fully discuss in this paper. The travel-time and competition analysis examples merely illustrate a couple of geo-business applications capitalizing on the new tools. Motivated readers are encouraged to use the online links in the References section to extend the discussion.

Conclusion

In many respects map analysis is as different as it is similar to desktop mapping. While a majority of the extended capabilities are conceptually intuitive and have been known for decades, their practical application has been shrouded in complex and expensive software that has kept map analysis out of most classrooms. The **Instructor's CD** *for Map Analysis* contains a comprehensive set of educational materials providing both lecture notes and hands-on exercises in applying this powerful yet often overlooked side of GIS technology.

References

- The hardcopy book and companion CD, Map Analysis: Understanding Spatial Patterns and Relationships, is designed to support the course and workshop materials in the Instructor CD for Grid-based Map Analysis. The CD contains single-seat license for MapCalc Learner and Surfer software.
  (Berry, 2007; GeoTec Media, $45.20 which includes S&H; see **www.geoplace.com/books/MapAnalysis**)

- The Beyond Mapping III online book is a compilation of popular "Beyond Mapping" columns containing twenty-seven chapters discussing various aspects of grid-based analysis.
  (posted at **www.innovativegis.com/basis/MapAnalysis/**)

- The MapCalc Learner-Academic software is designed for students and teachers who want "hands-on" experience with the concepts, procedures and considerations of grid-based analysis. The single-seat MapCalc Learner version for students is US$ 21.95; the multi-seat MapCalc Academic for instructors designed for computer lab use is US$ 495.
  (see **www.redhensystems.com**, select Products→ MapCalc)

  A review of MapCalc Learner-Academic software is posted at…
  (see **www.innovativegis.com/basis/present/GW01_MCreview/GW_JUN01_mapcalcReview.htm**)

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[1]Joseph K. Berry is a leading consultant and educator in the application of Geographic Information Systems (GIS) technology. He is the Principal of BASIS, consultants and software developers in GIS and the author of the "Beyond Mapping" column for GeoWorld magazine. He has written over two hundred papers on the theory and application of map analysis, and is the author of the popular books Beyond Mapping and Spatial Reasoning. Since 1976, he has presented college courses and professional workshops on GIS to thousands of individuals from a wide variety of disciplines. Dr. Berry conducted basic research and taught courses in GIS for twelve years at Yale University's Graduate School of Forestry and Environmental Studies, and is currently a Special Faculty member at Colorado State University and the W. M. Keck Visiting Scholar in Geography at the University of Denver. He holds a B.S. degree in forestry, an M.B.A. in business management and a Ph.D. emphasizing remote sensing and land use planning.