

Academic MapCalc: Educational Materials for Instruction in Grid-Based Map Analysis

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Abstract

Desktop mapping has gained popularity in many disciplines across campus. The additional dimension of “where” has provided new approaches to data analysis and decision formulation. However, instruction in grid-based processing has been limited. Until recently, GIS software supporting surface modeling, geo-statistics and spatial analysis has been too expensive and too complex for all but advanced courses. The *MapCalc educational package* is a set of inexpensive, Windows-based materials for learning map analysis concepts, considerations and procedures. The educational materials are suitable for self-learning and introductory through advanced courses. The *MapCalc Learner* CD (US\$21.95 plus shipping) consists of tutorial versions of Surfer (for surface modeling) and MapCalc (for spatial statistics/analysis), a basic set of exercises and databases, the *Precision Farming Primer* and the *Map Analysis* online texts, and numerous application scenarios. The *MapCalc Academic* CDs (US\$495 plus shipping) contains all of the student materials plus a multi-seat license for a single computer lab, an extensive set of PowerPoint presentations for lectures, additional sets of exercises and exam questions/answers. This paper describes and demonstrates the materials for both self-instruction and classroom teaching.

Note: this presentation contains several real-time demonstrations that are encapsulated in several of the figures. A more complete description of these and other grid-based processing examples are online at www.innovativegis.com/basis. The reader is encouraged to review the examples then download a free evaluation copy of the MapCalc program from the website for hands-on experience and springboard to the Learner or Academic versions for more in depth understanding of map analysis.

Introduction

Courses in Geographic Information Systems (GIS) technology are proliferating on campus. What used to be the domain of geography departments 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. Yet it is apparent that 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 the student's manual mapping experiences and thought to involve advanced statistics and “map-ematical” modeling techniques. The result of this rationale is that exposure to grid-based analysis rarely occurs in most introductory courses.

This paper describes some of the instructional considerations surrounding grid-based map analysis. In addition it describes the inexpensive MapCalc Learner software and supporting materials for student and instructor alike.

The Grid-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*. The grid-based construct enables display and processing of geographic space as a continuum. Its base spatial unit is a cell defined by the column and row coordinates of an imaginary grid superimposed over an area. The base spatial unit is a grid cell and is used to identify...

- **Points**—single cell,
- **Lines**—connected set of cells,
- **Polygons**—all cells identifying the edge and interior of the parcel, and
- **Surface**—all 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).

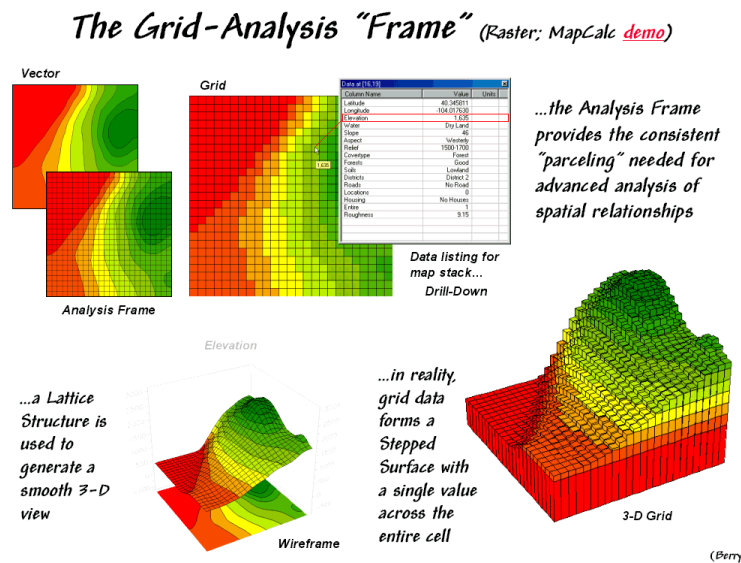


Figure 1. The grid-analysis frame is used to represent geographic space as a continuum.

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

The plots in the lower portion of the figure show two types of 3-D displays. Connecting the grid lines at the center of each grid space forms a *lattice* structure. The lengths of the lines are a function of the difference between the values stored at adjacent grid spaces. The result is a "wireframe" that forms the peaks and valleys of the spatial distribution of the data. The color zones identify contour intervals that are draped on the frame.

The larger plot in the lower-right portion of the figure shows a *grid* structure surface of the same data. The boundary lines for each grid space are drawn to a relative height as function of the stored value. The result is a “stepped surface” that depicts the actual data defining the terrain and available for map analysis.

Map Analysis Procedures

An important characteristic of grid-based data is that a map area is subdivided into a uniform set of parcels (grid cells) that is used to characterize all map layers. The analysis frame provides the geographic consistency needed for investigating spatial relationships within and among grid layers. However the consistency is obtained at a loss in positional accuracy unless the grid is very fine and approaches the X,Y reference grid used in a vector-based system.

The tradeoff between *positional accuracy* and *analysis utility* is key in determining appropriate applications for vector and grid-based systems. In general, vector systems are best suited for computer mapping and geo-query of discrete map features but have limited map analysis capabilities. Grid systems, on the other hand, are ill suited for mapping and query but contain a robust set of analytical operations.

For example, consider calculation of terrain slope. In a vector-based system the relative distance between contour lines graphically portrays steepness—closer the lines the steeper slopes. But the ability to calculate a slope map is practically impossible using this data structure.

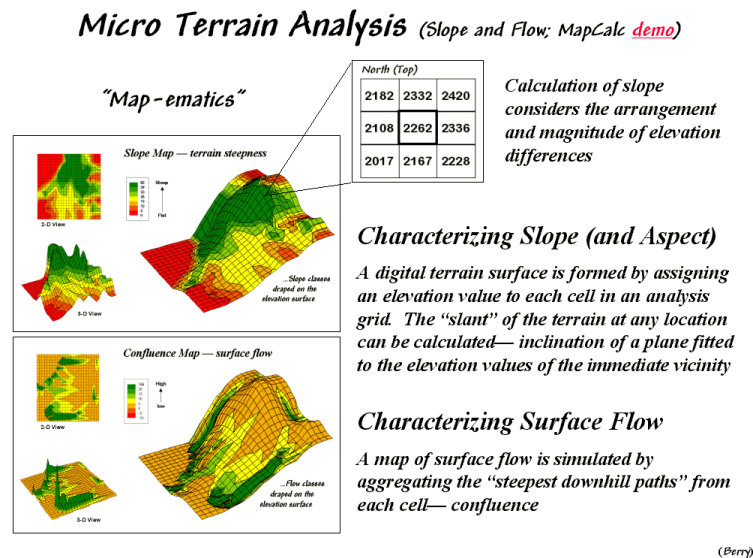


Figure 2. Calculation of terrain slope and surface flow maps.

The top portion of figure 2 shows 2-D and 3-D views of a *slope map* derived using the analysis frame. The larger 3-D display on the right shows the slope map draped over the elevation surface. Note that the steep areas (green) and flat areas (red) align with the appropriate surface inclinations providing visual conformation of the calculated slope values. As diagramed in the figure, the processing involves moving a 3x3 window over the entire elevation surface and calculating the slope of a plane that best fits the nine elevation values in the roving window.

The bottom portion of the figure shows a derived surface *flow map*. Note that the areas with higher flow values (green) align with the small ravines visible on the terrain surface. The process simulates a drop of rain falling at each grid cell, tracing its steepest downhill path while accumulating the number of paths that cross each cell. Higher numbers on the flow map indicate locations of water confluence.

Problem Solving

The result of an individual map analysis operation is the assignment of a computed value (*slope* and *flow* in the previous example) for every grid cell of a new map layer. Sequencing operations develop analysis procedures, such as erosion potential, as depicted in Figure 3.

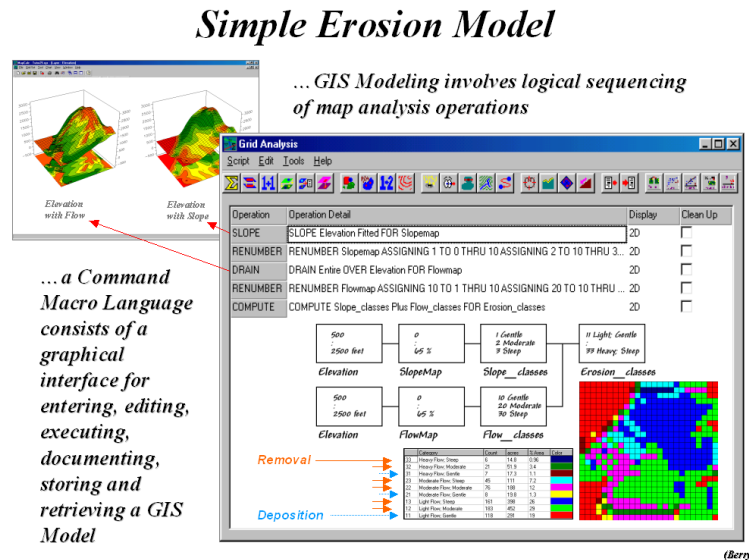


Figure 3. A command macro contains logically sequenced map analysis operations that solve a problem.

The two red arrows in the figure link the MapCalc commands with the 3-D displays of the slope and flow maps. Calibrating and combining the two maps construct a simple erosion potential model. Common sense suggests that areas with steep slopes and heavy flows tend to have higher erosion than flat areas with minimal flows.

The sequence of commands listed in the macro accomplishes three things—1) derives the slope and flow maps (using the SLOPE and DRAIN operations), 2) calibrates these layers for gentle-moderate-steep and light-moderate-heavy classes (RENUMBER), and 3) combines the two maps into a single erosion potential map (COMPUTE). The procedure used a simple mathematical trick where the slope classes are assigned the values 1, 2 and 3 while the flow classes are assigned the values 10, 20, and 30. Adding the two maps generates a two-digit code with the first number (tens digit) indicating the slope class and the second number (ones digit) indicating the flow class—e.g., 11 isn't an eleven but a “one-one” depicting a location with a gentle slope (1) and a light flow (1).

The map in the lower-right corner shows all of the combinations of slope and flow classes that occur in the project area. The color-coded arrows identify the combinations as to whether erosion (orange) or deposition (blue) is likely to occur. While this simple erosion model is far from complete it has general merit and aptly illustrates the construction of a command macro used to evaluate a GIS model.

Figure 4 diagrams an extension to the simple model that generates an effective proximity map to open water based on the intervening erosion potential. The RENUMBER operation is used to calibrate the map in figure 3 into a “friction” map characterizing the relative difficulty of erosion—1= high ... 10= minimal erosion potential. The SPREAD operation (dialog box in lower-left) is used to calculate effective distance from the streams and lakes on the water map. This process is like successive buffers in a vector-based system but the buffers reach farther in areas of high erosion potential—a “variable-width” buffer that is responsive to intervening conditions.

Micro Terrain Analysis (extending the erosion model)

SEDIMENT LOADING POTENTIAL

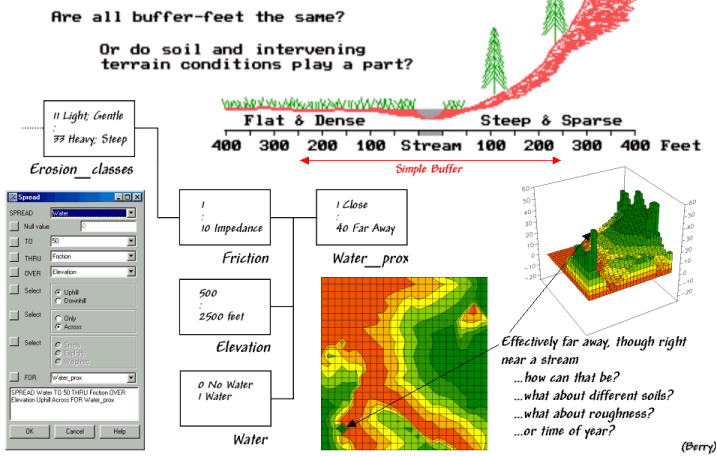


Figure 4. Extending the simple erosion model.

Consider the sketch in the top portion of the figure. A simple buffer of 250 feet on either side of the stream would allow soil-disturbing activities near the top of the steep inclination that would likely result in considerable sediment raining down on the stream. On the other side of the stream, activities would be prohibited although the terrain is perfectly flat and erosion potential minimal. A variable-width buffer, however, reaches much farther on the right side and much less on the left—not 250 feet regardless of conditions.

Measuring Distance & Connectivity (MapCalc demo)

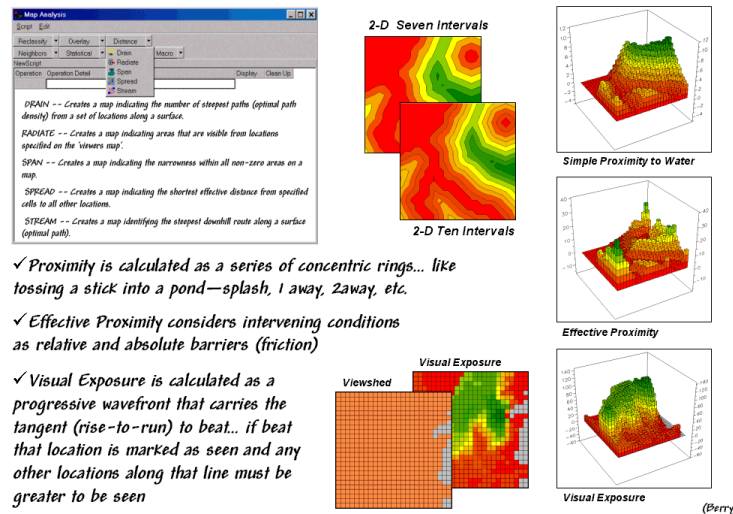


Figure 5. Additional examples of distance/connectivity operations (simple versus effective distance, optimal paths, and visual exposure).

Distance operations in MapCalc involve calculation of a series of concentric rings about a starting location (point feature) or set of locations (line or polygon feature). These rings are analogous to the ripples generated by tossing a rock into a pond—splash, one away, two away, etc. Every grid cell in the map area is assigned its “ripple number” with larger values indicating greater distances. When viewed as a 3-D plot, simple proximity forms a bowl-like *accumulation surface* about the feature (top-right plot in figure

5) with the starting locations of the water map forming the “valley” and increasing proximity forming the “mountains.”

Effective proximity considers the intervening conditions as the wave propagates. The result is a warped-bowl-shaped accumulation surface with varying slopes that correspond to changes in conditions. Steeper areas indicate locations that are effectively farther away than simple straight-line distance suggests.

Simple distance is defined as “the shortest, straight line between two points.” *Simple proximity* relaxes the limitation of just two points to “...among sets of locations,” such as all water cells to all other grid cells. *Effective proximity* further relaxes the assumption of straight-lines allowing distance measurement to simulate movement considering the effects of relative and absolute barriers. The ability to characterize realistic connectivity among map features and relax the oversimplifying assumptions of Euclidean geometry greatly extends simple buffer analysis in desktop mapping systems—“as-the-crow-flies.”

But if straight-line connectivity is not assumed, the question arises what is the “shortest, not necessarily straight route connecting two points?” This involves optimal path analysis that tracks the steepest downhill path over an proximity surface. In effect, this process retraces the route the wave front took from the starting location(s) around and through the intervening barriers to any other location on the surface. Like walking through a parking lot with a lot of mud puddles you could choose to go around some and slowly trek through others. In effect *accumulation surface analysis* evaluates all possible routes and assigns the shortest—the value indicates the distance away and the optimal path indicates the route.

The concept of connectivity can be expanded to include visual connectivity by considering straight-rays in three-dimensional space. If the ridge occurs between two points one cannot be seen from the other. If the ray is not interrupted, the two points are visually connected. Grid-based visibility analysis, however, does not use vector calculations in three-dimensional space. It uses the distance “ripples” to identify the distance from a viewer location and calculates the difference in elevation to derive a “rise to run” ratio (tangent) between two points. If the ratio is larger than any of the ratios of the previous rings along the cell is marked as seen and that ratio becomes the one to beat as the wave front continues. In effect, the algorithm goes “splash” at a viewer cell and the wave front propagates carrying the tangent to be beat that is evaluated at each location as it is crossed.

The result is a map that identifies a viewer location’s *viewshed*—all locations that can be seen. If multiple viewer locations are considered a *visual exposure surface* is derived—map values indicate the number of times seen. If the viewer cells have differential weights a *weighted visual exposure surface* is generated. If the weights are both positive (beautiful things) and negative (ugly things) a *net-weighted visual exposure surface* is generated. For example, a recreation planner might generate such a map to use in locating a hiking trail that has the best views of beautiful features while avoiding visual connections to ugly things.

MapCalc Educational Software and Materials

The discussion in the previous section illustrates just a few of the map analysis capabilities contained in MapCalc.

The twenty-six analytical operations are grouped into five classes—*reclassify*, *overlay*, *distance*, *neighbors* and *statistics*—as listed in figure 6. The previous discussions involved the analytical operations of SLOPE (neighborhood), RENUMBER (reclassify), COMPUTE (overlay), DRAIN, SPREAD, and RADIATE (distance). A cross-reference to comparable operations in other grid-based systems is included in the documentation. For example, the translation to GRID commands (a module of ARC/INFO GIS system by ESRI) is SLOPE= slope, DRAIN= flowaccumulation, RENUMBER= reclassify, SPREAD= costdistance, and RADIATE=visibility.

tutorial exercises keyed to these books and Dr. Berry's other books *Beyond Mapping* and *Spatial Reasoning* (Wiley & Sons publishers).

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- ✓ MapCalc applications/exercises
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- ✓ Surfer tutorial exercises
- ✓ Concepts in GIS slide set (gCON)
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- ✓ Precision Farming text
- ✓ Single seat educational license

...designed for computer lab use

- ✓ Multi-Seat educational license for all of the Student version materials, plus...
- ✓ Materials for one-day workshop on grid-based map analysis
- ✓ Materials for introductory course on GIS modeling
- ✓ PowerPoint lecture sets
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- ✓ Advanced Spatial Statistics and Map Analysis operations
- ✓ Interactive 2D & 3D display
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...stop by the Red Hen Systems booth for information and a demonstration of the MapCalc educational materials for students and instructors, or visit our website at www.redhensystems.com

...materials developed by Joseph K. Berry, author of *Beyond Mapping* & *Spatial Reasoning* with over 30 years of GIS teaching experience.

Figure 8. Listing of materials in the MapCalc Learner and Academic packages.

The *MapCalc* software by Red Hen Systems (www.redhensystems.com) has extensive capabilities in spatial analysis and statistics. The *Surfer* software by Golden Software (www.goldensoftware.com) provides extended capabilities in surface modeling and 3-D graphics. The *MapCalc* tutorial version is constrained to a 100x100 grid configuration (10,00 grid cells) and some of *Surfer*'s output features are constrained in the tutorial version. Both software systems have data exchange tools and accept data for creating your own databases.

The *MapCalc Learner* package is designed for student and self-learning and licensed for educational use on a single computer. It is distributed on a single CD for US\$21.95 plus shipping and handling. The *MapCalc Academic* package is designed for instructors and contains all of the *Learner* materials plus lecture PowerPoint's, additional exercises, one-day workshop and full introductory course materials supporting classroom instruction. The materials were developed by Dr. Berry (www.innovativegis.com/basis) who has over 30 years of GIS teaching experience and has presented hundreds of workshops and numerous college courses on map analysis. The *Academic* package includes multiple-seat license for educational use in a single computer lab and are distributed on two CDs for US\$495.00 plus shipping and handling.

Conclusion

The discussion in the "Problem Solving" section of this paper illustrates a small set of the analytical operations in grid-based map analysis. The live demonstrations and online annotated applications provide a wealth of experience in GIS modeling and spatial reasoning. The sequencing of analytical operations to form application macros enables users to truly "think with maps" within a problem-solving context.

In many respects GIS modeling 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 *MapCalc* educational materials enable students and instructors an opportunity to get hands-on experience in applying this powerful yet often overlooked side of GIS technology. For less than the cost

of a textbook, a student can have state-of-the-art map analysis software on his or her own computer. For less than most single seat licenses, an instructor can populate an entire computer lab, as well as getting a jump-start on integrating grid-based analysis within their courses through the extensive teaching support materials.

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