An Academic Approach to Cartographic Modeling in Management of Natural Resources

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PROBLEM

The size and complexity of today's large-scale land planning organizations have made the traditional managerial functions of planning, organizing, and controlling work in natural resources management increasingly difficult to execute. At the same time, successful application of these functions has become increasingly essential the orderly development and stability of our natural resources.

Computer-assisted Geographic Information Systems (GIS) show promise for providing capabilities clearly needed for effective land planning. However, the need for such capabilities has prematurely cast the developing science of spatial information analysis into operational contexts without adequate user education. The result has been a technology that often intimidates potential users and discourages what otherwise would be valuable input in identification, clarification, and development of new applications. In fact, this perspective may foster an adversary relationship between user and analyst that ultimately jeopardizes project results. Even if an adversary posture is avoided, the uninformed user can jeopardize the effective application of this technology. For example, unwarranted enthusiasm, fueled by miscommunication, might result in unrealistic expectations of the technology. Thus, in such an environment, practical failure is preordained.

Another factor that contributes to the lack of effective communication in the field of spatial information analysis is the absence of a comprehensive framework that organizes the wide range of analytic techniques available for processing of spatial data. Until this academic framework is established, geographic information systems will continue to be thought of as special-purpose "black boxes."

One academic approach frequently used in this area is the case study. In this context, a student is exposed to a variety of practical application experiences that demonstrate an array of analytic capabilities. Learning in this environment is by induction. When this form of instruction is properly organized and presented, it can be very effective. Critical to this approach, however, is the selection of sample applications that match student interest and experience. A mismatch of these aspects can result in confusion about the specifics of the example and the fundamental principles being demonstrated. Furthermore, the selection of cases must balance the inherent complexity of interesting applications with the simplicity necessary for clear portrayal of fundamental theory.

Another instructional approach relies on establishment of a fundamental theory of spatial analysis. This approach is analogous to the traditional presentation of basic mathematics, in which general principles and operations are introduced and then demonstrated through practical examples. The deductive nature of this approach is particularly appropriate for audiences with diverse backgrounds and interests.

However, the development of a deductive approach to spatial information analysis has two drawbacks. First, this developing science is continually redefining existing techniques and rapidly generating new ones. The dynamic environment makes identification of an enduring general framework difficult. Second, in order for this approach to be effective, supporting examples and exercises aimed at conversion of general theory into practical experience will still be required. In the case of basic mathematics, exercises are easily defined and executed. However, the hardware and software resources required for "hands-on" instruction in spatial information analysis are much more sophisticated and demanding.

This paper describes recent developments of a graduate-level course in geographic information analysis at the Yale School of Forestry and Environmental Studies. The course was developed in response to the need for more effective ways of presenting techniques of spatial analysis to students in forestry, landscape architecture, ecology, planning and other professionals who 1) must rely increasingly on cartographic information in digital form; 2) are likely to be exposed to several different software packages; 3) are not comfortable with abstract mathematics, computer programming or geographic theory; and 4) represent a wide diversity of specific application areas.

METHOD

Because of the diversity of students in the Yale program a deductive approach to instruction was chosen.[1] Thus, a generalized framework had to be established for presenting the various techniques related to encoding, storage, analysis, and display of cartographic data. Particular emphasis was placed on analytic techniques in general and on the techniques of modeling and data synthesis (as opposed to statistical analysis.

The framework aided in the development of attempts to identify fundamental map-processing operations that were common to a broad range of higher-level techniques of environmental analysis. Most of the operations identified are generally available as part of one or more spatial information systems currently in use. However, these operations often are embedded within application-specific programs. It is hoped that through the extraction and organization of primitive operations within a logical framework the basis for generalized cartographic modeling language or "map algebra" can be developed that can 1) accommodate a variety of traditional styles of environmental analysis in a common, flexible, and intuitive manner; 2) provide a framework for comparison with existing techniques; 3) suggest new techniques; and 4) anticipate strategies for efficient implementation of software.

In order to use primitive operations for performance of any sort of complex analysis, one must be able to control the sequence in which those operations are performed. One must also be able to store intermediate results in a form suitable for subsequent processing. If primitive operations are to be flexibly combined, each operation must accept input and generate output in the same format. In conventional algebra, the balance is achieved through cyclical processing of intermediate numerical results that are indicated by nested parentheticals. In map algebra, the same can be accomplished with use of sequential operations. Each operation performs three functions: 1) retrieval of one or more maps from the data file; 2) manipulation of data to create a new map; and 3) storage of the new map in the data file for subsequent processing. The cyclic nature of this processing structure is common to many mapping systems with modeling capabilities.

Within this structure, each primitive operation may be regarded as an independent tool limited only by the characteristics of the data to which it is applied, regardless of the application-specific nature of that data. Functions typical of these fundamental operations are as follows:

1. Assignment of a numerical weighting to the categories of a map
2. Redefinition of a map's thematic values according to the size or shape of the areas initially associated with those values
3. Combination or comparison of maps on an overlay basis
4. Measurement of Euclidean or other proximity
5. Computation of minimum-cost paths
6. Determination of viewsheds
7. Computation of topographic slope, aspect or relief form
8. Characterization of "roving window" neighborhoods

Additional operations necessary for operational cartographic modeling structure include those associated with data encoding, statistical analysis, display, and program control.

This organization of fundamental data-processing operations is one that is generally familiar to students and that provides a generalized approach to instruction of spatial information analysis. If the approach is to be effective, however, it must be presented as part of a curriculum that includes opportunities to apply these methods to real problems.

Appendix 1 outlines the syllabus for a one-semester graduate-level course in spatial information analysis. The first half of the semester is devoted to the introduction of fundamental map-processing operations. This introduction normally involves two hours of lecture and two hours of laboratory exercises each week. Each lecture deals with general theory and practice associated with a group of related functions. Coordinated laboratory sessions include discussion of the forthcoming exercise and student presentations of solutions to the previous week's assignment. Exercises are designed to give students and opportunity to apply the fundamental theory presented in the lectures. Several sample exercises and their solutions are presented in Appendix 2. These exercises are completed outside of class and normally require an average of two to four hours each week. Students are encouraged to work in pairs, an arrangement that is likely to be mutually constructive. Friendly competition between working groups also is encouraged. The reading material for this phase of instruction consists primarily of specially prepared course material.

Students are introduced to techniques of data acquisition, encoding, and display after the eighth week of the semester and a midterm examination. This policy is in keeping with the course emphasis on techniques of cartographic modeling as opposed to functions of data management. It also serves to instill greater appreciation for and patience with some of the more labor-intensive aspects of spatial information processing. At this point, students compare exercises that call for manual grid encoding, electronic cursor digitization, and pen-plotter display. Data acquisition is dealt with only briefly in this context but is covered in detail by concurrent courses in remote sensing and satellite-data processing.[2]

During the ninth week of the course, students are exposed to some of the broader complexities of cartographic modeling. In this respect, they are given several opportunities to design cartographic models and apply their knowledge of fundamental processing operations in a comprehensive manner. The remaining lectures are devoted to discussion of contemporary processing systems and applications. These topics are presented as much as possible within the general framework developed during the first half of the course. Reference material for this phase of instruction consists of selected theoretical papers, project reports, software manuals, and hardware descriptions.

Along with this overview of current practice, student team projects are initiated. These projects are intended to give students broader experience in the design, implementation, and presentation of actual cartographic analyses. In preparing these projects, students must 1) meet with outside "clients" in order to define a real problem in spatial terms; 2) prepare cartographic models of analyses required; 3) encode necessary data; 4) implement the analytical models developed; and 5) present results to the clients.

Team projects for the academic year 1978-79 addressed the issues of residential development and choosing sites for sanitary landfills in the Town of Guilford, Connecticut. The residential development study was partitioned into four subsections. The first involved the generation of a map defining the coastal zone of the town in terms of the specific directives of the federal Coastal Zone Management Act. The other three subsections were considerably more complex. Each examined the study area in order to determine which areas could accommodate residential development. One model investigated the physiographic attributes of the town, while the other two models dealt with the spatial ramifications of both existing zoning regulations and policies of a newly developed comprehensive plan.

RESOURCES

Software support for this course was provided through use of the Map Analysis Package (MAP). This package is a set of programs under development at Yale that provide for the encoding, storage, analysis, and display of cartographic information. Its development represents an attempt to accommodate many of the academic objectives outline above. Thus, use of the package is similar in many ways to the use of traditional techniques that involve conventional geographic maps. The data-processing capabilities of MAP are organized as a series of primitive operations that may be combined to perform a variety of complex map analyses. These operations are specified intuitively through a user-oriented command language of English-like phrases that does not require formal knowledge of computer programming.

The MAP software is written in FORTRAN IV and may be implemented for both interactive and batch processing. At present, the package employs a grid-cell data structure but has line segment-oriented input and output capabilities.

Each of the more than 60 independent operations is associated with one of the five major categories (storage, analysis, display, program control, and user-defined) according to its function and its relation to the flow of information between programs, data files, and input or output media. The analytic operations are further sub-grouped into categories associated with reclassification of map categories, overly of maps, measurement of cartographic distance and connectivity, and characterization of cartographic neighborhoods.

Hardware used in support of the course includes an IBM 370/158 computer, high-speed data link, Hewlett-Packard 2648A graphics terminal, Decwriter typewriter terminal, Summagraphics Bit-Pad tablet digitizer, Talos RP648a large bed digitizer, and CalComp 763 pen plotter. The most extensively used pieces of equipment were the two terminals remotely linked to the IBM computer.

The data base used for most of the exercises was developed professionally in 1977. It includes small grid maps of 1,575 cells each, with dimensions of 25 rows by 63 columns. This configuration has proved to be both extensive enough to provide adequate demonstration of processing operations and small enough to ensure efficient computation and display. The data base includes local maps at a cell size of 250 meters square and regional maps at a cell size of one mile square, covering the tristate area of Alabama, Tennessee, and Georgia. These maps are listed in Appendix 3.

The Guilford data base used for student projects included maps of 20,500 cells each, with dimensions of 205 rows by 100 columns. Each cell in this data base represents and area of 348 feet square. The Guilford maps are listed in Appendix 4.

All these maps were encoded by students. The elevation and land-use maps were grid-encoded manually, whereas all other maps were digitized as line segments and later converted to the grid-cell format. The base maps used in the encoding were at scales of 1:24,000 and 1:12,000. The entire effort was completed over a period of 10 days, with commitment of about 15 hours for each student.

RESULTS

The most dramatic result of this course was the enhanced ability of students to conceptualize spatial considerations in land planning. A few students had previous experience in nonspatial modeling, and several had working knowledge of procedures of statistical analysis. However, the idea of incorporating spatial aspects into decision-making was new to most students. By the end of the term, most students felt that they had developed a fundamental understanding of spatial information systems. This opinion was substantiated by the acceptable performance of all students on a comprehensive midterm examination. Furthermore, the general framework of primitive analytic operations enabled students to communicate effectively among themselves, as demonstrated by the team projects.

A few students also developed insight beyond elementary knowledge. For example, one student-initiated discussion involved the effect of computing the slope-of-a-slope map in order to indicate areas of topographic transition. This map would be the second derivative of an elevation map. Similarly, the slope of a “travel-time” map would be a map of the relative speed limits (first derivative); and the slope of the map of the map of relative speed limits would indicate acceleration (second derivative). From an economic perspective, it was decided that the slope of an accumulated cost surface originating at a landing for timber harvesting would generate a map of marginal costs that reflect the unque spatial relationships among factors affecting log skidding.

Team projects gave students experience in preparing significantly different types of reports. An oral presentation of project results was made to approximately 35 residents of Guilford, including the Board of Selectmen, Conservation Commission, Town Planner, Planning Commission, and several concerned citizens. These reports were prepared with a nontechnical audience in mind, and use of a simplified version of the flowchart for each model and display of significant intermediate maps proved to be effective.

During this presentation, considerable attention was given to the necessity of iterative input by users in order to effectively construct and calibrate a valid cartographic model. Since this principle of “continued dialogue” was not observed in preparation of the academic projects, the audience was cautioned to focus on the structure of the models rather than on the map products. This perspective allowed the audience to discuss the issues objectively using the framework for each model to suggest possible criteria for decision making. One hour was devoted to student presentations, and another hour was devoted to small-group discussions.

A written report also was prepared that described in detail the method and results of each cvartographic model. These reports were prepared with a more technical audience in mind. Each report contained a statement of the problem, a narrative discussion of its solution, comments on the limitations of the study, a flowchart of the cartographic model, and an appendix of resultant maps.

PROBLEMS ENCOUNTERED

One major problem encountered concerned encoding and registering of data in the team projects. The digitization system used was still in its developmental stages, with only limited supporting software. In order to prepare a line-segment data file for entry into the MAP system, that data had to be transferred from the digitizer to a microcomputer and then to the IBM mainframe computer where it was reformatted, edited, and converted as necessary. Each of these steps had to be executed sequentially with use of special-purpose programs that were not nearly as user-friendly as those described earlier. This abrupt immersion into the complexities of data-file manipulation was frustrating to students who had little or no experience in data processing. The problem was partially alleviated by assignment of two experienced students as “experts” to assist the others.

In addition, the encoding process proved to be more costly than expected. While the $150 per student budget was more than ample for the term’s computing at Yale’s rate of $6.00 per CPU minute, the $75 per student budget for data encoding proved inadequate. Costs in this area are expected to be significantly reduced as Yale’s system becomes operational, but encoding is still recognized as generally one of the most expensive aspects of digital cartography. We are presently exploring a new encoding procedure that uses the “autoplot” and “raster dump” capabilities of the Hewlett-Packard graphics terminal for production of a MAP system data file directly from the CRT screen.

Another problem involved scheduling of facilities and unnecessary computing by overeager students. The large-bed digitizer and minicomputer controller are supported by Yale’s central computing facility, which serves several general purpose users. Strict adherence to a reservation system alleviated this problem. The tendency of students to recomputed exercises in order to get clean copy was eliminated through generation of a data file of problem solutions that students could access for off-line printing.

USEFULNESS OF GRAPHICS

The most frequently used graphic displays were character-based “printer” representations of the maps produced in the exercises and projects. This form of output has the advantage of low cost and clarity in interpretation of results of analytic operations. Printer-generated maps were registered on a light table, where changes created by a series of primitive operations in individual cells were noted easily. More elaborate “line plots” were produced only for demonstration of this alternative form of computer graphics outputs.

Flowcharts of cartographic models were used to express ways in which primitive map-processing operations were combined. On such flowchart is presented in Figure 1. It traces the structure of one student’s landfill-siting model for Guilford. The approach consisted of two parts. First, a “primary Suitability” map was generated in order to eliminate areas that were completely unsuitable for use as a landfill site (e.g., flood-prone areas, steep slopes, shallow soils and aquifers, developed areas). The residual areas identified as having primary suitability then were screened for minimal area extent. A secondary suitability map was then developed in which the possible sites were rated according to relative desirability (e.g., existing land use, ownership, visibility from developed areas, travel time from town center, earmarked conservation reserves). A consultant for the town assisted in the definition of these criteria.

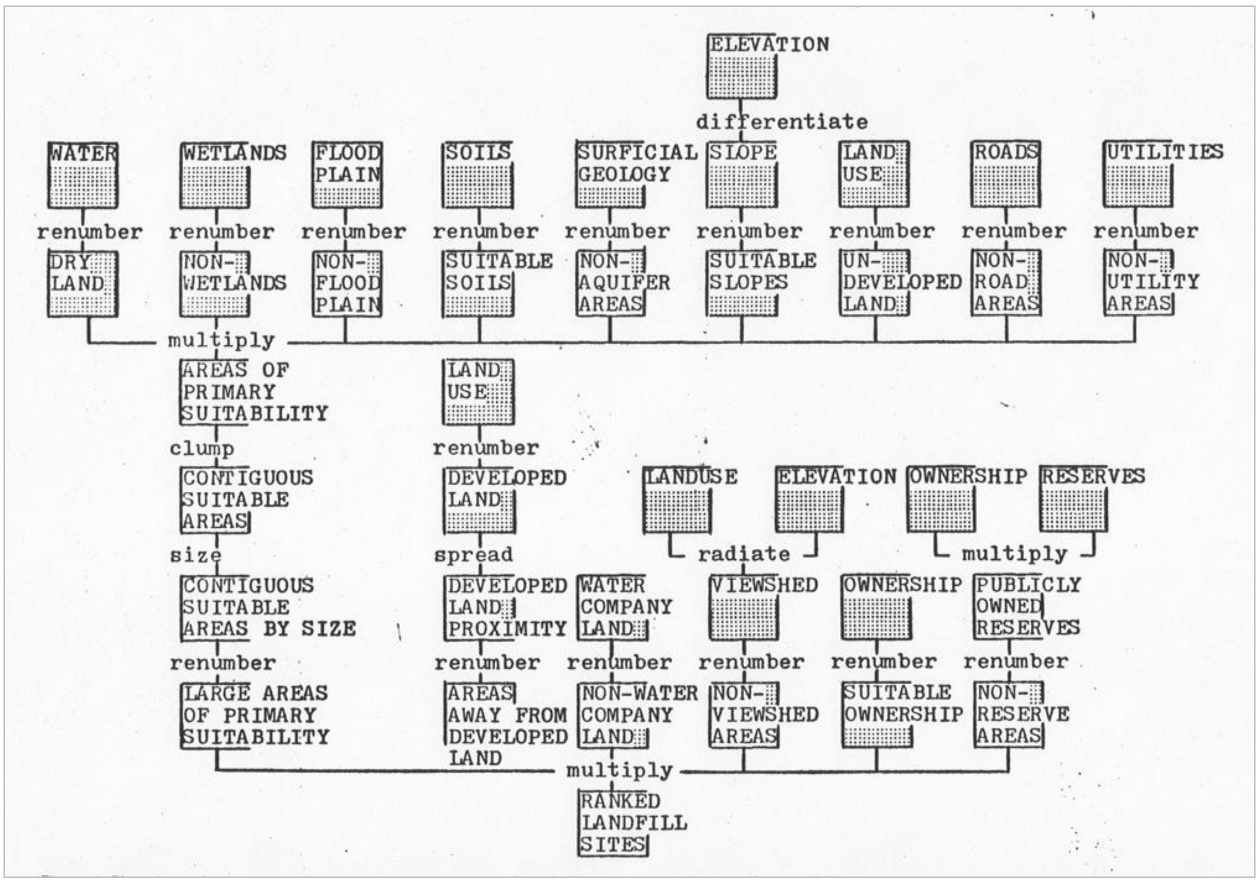

Figure 1. *Flowchart of a cartographic model showing combination of primitive map-processing operations. Cartographic modeling is analogous to conventional algebraic evaluation in which primitive mathematical operations are ordered sequentially in order to solve complex expressions. This flowchart portrays such a model with a series of map operations (lines) in order to derive intermediate maps (boxes) leading to a final map that ranks possible landfill sites*

Note that the tree shown in Figure 1 is rooted in the final “Ranked Landfill Sites” map, which was derived from a series of intermediate maps that ultimately result from several student encoded data maps. This structure can be regarded as analogous to that of an algebraic equation, such as $a = ((b + c) / d) - e$. However, the scalar variables such as “*a*,” “*b*,” and “*c*,” are replaced by various maps, such as “*Floodplain*,” “*Primary Suitability*,” and “*Viewshed*.” Algebraic operations such as “+,” “/,” and “-“ are replaced by cartographic operations, such as “*renumber*,” “*differentiate*,” and “*spread*.”

In order to develop a cartographic model and flowchart of this sort, it is suggested that one begin, not with the initial data, but with a mental construct of the final map. This approach is particularly effective for students who are unfamiliar with modeling techniques. By beginning at the end, initial units of measurement and judgment can be defined in relatively abstract terms. These units can then be expressed at increasingly lower levels of abstraction and may be related ultimately to concrete data. In this way, the analysis determines the data requirements and priorities, rather than vice versa; this point becomes particularly important in light of the high cost of geographic information collection and encoding.

In this context, the flowchart of a cartographic model has attributes of an algebraic equation. The deductive nature of its construction facilitates understanding of the interrelationships among mapped variables. It is succinct in it expression of spatial relationships yet requires minimal mathematical sophistication. The structure of the flowchart also serves as a universal language that is readily understood by both users and technicians.

STUDENT RESPONSE

The projects described above represented the culmination of efforts for the term. Even though these reports consumed a large portion of each student's limited time, enthusiasm remained high. Several student evaluations noted that the projects were particularly valuable because they provided the opportunity for experiencing the complexities of practical application. One student remarked that the course was "…challenging. The material is new and the opportunity to work with a new analytic process is fantastic."

Students believed that the command language and control structure of the MAP software were appropriate to the course. The free-format, English-like commands proved to be particularly user friendly. Since there are no differences apparent to the user between interactive and batch processing with MAP, the transition was made easily from interactive-based exercises to batch-oriented projects.

Team projects proved to be valuable learning experiences, from the standpoint of both decision making and the analysis of geographic information. This realization led one student to comment in a project report:

> *Not only has the exercise of dealing with land use problems in the town of Guilford been valuable in demonstrating the techniques of computer-assisted geographic analysis, but we can learn something of the characteristics of land use decisions and the public's response to professional presentations of the same.*
>
> *…We should have learned that land use decisions are difficult and delicate. The cold steel and warm transistors of a computer can only inventory our processes for us; and in that light they do an unparallel job. The decisions, however, must continually be made by people in a dynamic fashion. The rules must continually change to accommodate the chaning world. And the people must be informed: informed on where their present policies have brought them, where they are, and where they are likely to lead under their best projection of the future.*

This perspective identifies a knowledgeable individual who recognizes the need for joint input by both user and analyst in the analysis of geographic information. It also clarifies the role of these systems as a tool in the land-planning process rather than a substitute for the process.

The same theme was iterated by several of the Guilford residents who attended the oral presentations. In the comments, the role of the analyst was clearly established as that of definition of relationships to be calibrated by the user. On citizen on the Conservation Commission noted that, although she had previous exposure to digital map processing, she felt that she now understood the modeling approach for the first time and could actually comment on model construction.

TRANSFER POTENTIAL

Several of the 1978-79 students have expressed an interest in pursuing individual projects during the academic year. As a result of the class, two doctoral dissertations also utilize the skills acquired during the course. One deals with the relationships among site, land form, stand composition, and other geographic factors in management of the spruce budworm in the spruce-fir forests of Maine. The project is sponsored by the U.S. Forest Service and will be conducted at the Northeastern Forest Experiment Station at Orono, Maine. The other concerns development of an empiric air-quality model for heavy metal contamination surrounding a primary lead smelter in Idaho.

Two types of workshops also have been developed as an extension of the course. The first is a one-hour seminar designed to familiarize individuals with the fundamental 0principles and procedures of geographic information analysis. A supplemental three-hour workshop will give participants an opportunity to have experience in actual map processing through remote access to the Yale Computer Center. The second workshop is an intensive two-day workshop that will focus in more detail on the fundamental operations used in computer-aided map analysis. The curriculum has a lecture/exercise format similar to that of the academic course described above.

DOCUMENTATION OF THE APPROACH

A more detailed discussion of the general modeling approach and analytic operations used in this course is presented in a recent paper.[2] This approach is also the subject of a doctoral dissertation currently in preparation.[1]

Course materials are available in unpublished form. However, copies of the exercises and solutions can be obtained directly from the authors of this paper. Workbooks, which contain a large portion of the material presented in the class, also are available.[3, 4]

A complete discussion of the group projects is available in the report to the town of Guilford prepared by the class.[5] Particular attention is given in the formal report to the specific limitations and assumptions of the various models.

CONCLUDING REMARKS

This course attempted to develop an academic framework for a deductive modeling approach to the conceptualization of geographic information analysis. This structure is useful because it allows students to develop a fundamental knowledge of techniques of spatial analysis. This general framework also enables them to extend this knowledge to applications of their own design.

Essential to this approach is the ability to provide actual experience in processing spatial data. This opportunity gives prospective users a realistic view of the analyst's tasks. It also reinforces, in a practical context, the range of fundamental assumptions that must be made in any study. The MAP system proved to be ideally suited to this experience.

However, overdependence on this fundamental approach may be dangerous. Students also must develop breadth of exposure and an appreciation of existing systems. It is anticipated that next year's class will be given more time to review the wealth of literature on the subject. Less formal emphasis will be given to the aspects of individual techniques. This slight change in course emphasis recognizes the user-oriented character of the students participating in the course.

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Appendix 1*. Syllabus for Introductory Course in Geographic Information Analysis, Yale School of Forestry and Environmental Studies, 1978-79.*

Week

1. *INTRODUCTION:* course outline; overview of cartographic data analysis techniques and computer-oriented information systems; introduction to the Map Analysis Package (MAP) and Yale computing facilities; MAP operations EXPLAIN, LIST, DISPLAY, and STOP.
   Exercise: Introduction to the MAP System.
2. *CARTOGRAPHIC DATA AND RECLASSIFICATION FUNCTIONS:* thematic and locational attributes of cartographic information; qualitative vs. quantitative data; MAP data structure, processing structure, and command format; reclassifying mapped data as a function of thematic value, location, size or shape; MAP operations INFORM, MAP, DESCRIBE, PROTECT, EXPOSE, SCALE, LABEL, RENAME, ZAP, IDENTIFY, RENUMBER, SLICE, SIZE EULER, and SURVEY.
   Exercise: Reclassifying Map Categories.
3. *OVERLAY FUNCTIONS:* overlaying maps to generate arithmetic, logical, and statistical combinations of mapped data; MAP operations ADD, SUBTRACT, MULTIPLY, DIVIDE, EXPONENTIATE, MAXIMIZE, MINIMIZE, AVERAGE, CROSS, and SCORE.
   Exercise: Overlaying Maps.
4. *DISTANCE FUNCTIONS:* cartographic representation of movement; measuring true vs. weighted distance; generating travel-time and travel-cost maps; delineating watersheds, MAP operations SPREAD, NOTE, and PRINT.
   Exercise: Measuring Euclidean distance.
5. *DISTANCE FUNCTIONS:* generating viewsheds and shortest paths; MAP operations RADIATE and STREAM.
   Exercise: Measuring non-Euclidean distance.
6. *NEIGHBORHOOD FUNCTIONS:* characterizing points on a three-dimensional surface; topographic slope, aspect, and relief; MAP operations DIFFERENTIATE, ORIENT, and PROFILE.
   Exercise: Characterizing Points on a 3-D Surface.
7. *NEIGHBORHOOD FUNCTIONS:* narrowness; connectivity; "roving window" statistics; interpolation; contour smoothing; azimuth and distance weighting; map scale conversion; MAP operations CLUMP, SPAN, SCAN, and RESPACE.
   Exercise: Characterizing Cartographic Neighborhoods.
8. *DATA COLLECTION, ENCODING, AND DISPLAY:* information sources; digitizing methods; use of satellite imagery; computer graphics display devices; cartographics projection; MAP operations POINT, GRID, STRIP, TRACE, CONTOUR, HATCH, OUTLINE, SHADE, and COPY.
   Exercise: Geocoded Data Encoding and Display.
9. *MODELING TECHNIQUES:* flowcharting and logical structuring of models using primitive operations; error handling; interactive vs. batch processing; extending MAP capabilities; MAP operations FLOWCHART, ECHO, QUIET, REMEMBER, OVERLOOK, REMIT, READ, WRITE, INSERT; midterm exam; assignment of team projects.
   Exercise: Program Control Operations.
10. *SOFTWARE:* digital representation of information; alternative cartographic data structures, processing structures, and command languages; computational efficiency.
11. *CURRENT PRACTICE:* implementation and operating costs; available systems; recent projects.
12. *TEAM PROJECT REVIEW:* preliminary presentation and critical discussion.
13. *TEAM PROJECT REVIEW:* preliminary presentation and critical discussion.
14. *TEAM PROJECT PRESENTATION:* final presentation.

Appendix 2. *Sample Exercise and Solutions used in Introductory Course in Geographic Information Analysis*

1. *EXERCISE:* Whenever combining maps, it is important to know just how similar each is to the others. For example, it might be useful to compare the WOODLAND map with the WATER map to find out which water category is most often associated with forested areas. Use "score" to develop these statistics and generate a five-level (0–4 values) map of the "overlap."
   SOLUTION: SCORE WOODLAND BY WATER OVERLAP
   SLICE THATMAP INTO 5 FOR COINCIDENCE
   DISPLAY COINCIDENCE
2. *EXERCISE:* Air quality and airborne pollutants considerations have become increasingly important in plant location. Using the WINDS map (a barometric surface indicating pressure gradients and resulting wind patterns), generate a WINDSHED map (upwind locations) from the institutional areas depicted on the LANDUSE map (sensitive receptors).
   SOLUTION: RENUMBER LANDUSE FOR INSTITUTES A 0 to 1 TO 3 TO 4/
   A 1 to 2
   SPREAD INSTITUTES OVER WINDS TO 70 FOR WINDSHED
   DISPLAY WINDSHED
3. *EXERCISE:* Generate a map that locates the "down-wind" areas from the commercial portions of the study area (point sources).
   SOLUTION: RENUMBER LANDUSE FOR COMMERCIAL A 0 TO 2 THR 4
   SPREAD COMMERCIAL DOWNHILL OVER WINDS TO 70
   DISPLAY THATMAP
4. *EXERCISE:* Characterize the existing residential pattern by generating map that identifies the distance between dwelling units (HOUSING) and heavy duty roads (ROADS). For the entire study area, what is this average?
   SOLUTION: RENUMBER ROADS A 0 TO 1 THR 3 A 1 TO 4
   SPREAD THATMAP TO 20 FOR XROADS
   RENUMBER HOUSING FOR OPPOSITE A 1 TO 0/
   A 0 TO 1 THR 5
   COVER OPPOSITE WITH XROADS FOR PROXIMITY
5. *EXERCISE:* Generate a map called COSTS that reflects the fact that the cost of traversing a forested cell with a powerline right-of-way is $11 as compared to $1 for an unforested cell.
   SOLUTION: RENUMBER VEGETATION FOR COSTS A 1 TO 0 A 11 TO 1
6. *EXERCISE:* Using COSTS, generate a map called COSTZONES which indicates the cumulative dollar-cost "distance" between the northwest powerline and all "cells" within a radius of $51.
   SOLUTION: RENUMBER POWERLINE FOR NWLINE A 0 TO 2 TO 3
   RENUMBER COSTS FOR FRICTION A 0 TO 1 A 1000 TO 11
   SPREAD NWLINE THROUGH FRICTION FOR COSTZONES TO 51
7. *EXERCISE:* Use the STREAM operation and your COSTZONES map to generate a map called BESTPATH, which locates the lowest cost right-of-way alignment from the existing Central line to the existing Northwest line.
   SOLUTION: RENUMBER POWERLINE FOR CENTRAL A 0 TO 1 THR 3/
   A 1 TO 2
   STREAM CENTRAL OVER COSTZONES FOR BESTPATH

Appendix 3. *Primary Data Base for Exercise Shown in Appendix 2.*

- Regional Highways
- Regional Railroads
- Regional Water Bodies
- Regional Forest Cover
- Local Land Use
- Local Housing Density
- Local Forest Cover
- Local Elevation
- Local Roads
- Local Powerlines
- Local Water Bodies

Appendix 4. *Primary Data Base for Guilford Connecticut Project*

- Elevation
- Sensitive Soils
- Surficial Geology
- Water Bodies
- Flood-Prone Areas
- Wetlands
- Forest Cover
- Open Space
- Town Reserves
- Farm Resource Areas
- Public Lands
- Conservation Resource Areas
- Water Company Lands
- Water Company Watersheds
- Roads
- Utility Rights-of-Way
- Land Use
- Zoning
- Planned Residential Development Areas
- Principal Committed Residential Areas