Epilog

A Brief History, Driving Forces and Future Directions in Map Analysis

Historical Overview

Much of land management and decision-making are inherently spatial. The data are particularly complex as they require two descriptors, namely the precise location of what is being described, and a clear description of its physical characteristics. For hundreds of years the link between the two descriptors has been the traditional, manually drafted map involving pens, rub-on shading, rulers, planimeters, dot grids, and acetate sheets.

More recently, analysis of mapped data has become an important part of resource planning. This new perspective marks a turning point in the use of maps—from one emphasizing physical descriptions of geographic space, to one of interpreting mapped data, and finally, to spatially communicating decision factors. This movement from "***description*** to ***prescription***" has set the stage for entirely new concepts in resource planning and management.

Since the 1960's, the decision-making process has become increasingly quantitative, and mathematical models have become commonplace. Prior to the computerized map, most spatial analyses were severely limited by their manual processing procedures. The computer has provided the means for both efficient handling of voluminous data and effective spatial analysis capabilities. From this perspective, all geographic information systems are rooted in the digital nature of the computerized map.

Computer Mapping

The early 1970's saw ***computer mapping*** automate map drafting. The points, lines and areas defining geographic features on a map are represented as an organized set of X,Y coordinates. These data drive pen plotters and graphic displays that can rapidly redraw the connections at a variety of colors, scales, and projections. The map image, itself, is the focus of this processing.

The pioneering work during this period established many of the underlying concepts and procedures of modern GIS technology. An obvious advantage with computer mapping is the ability to change a portion of a map and quickly redraft the entire area. Updates to resource maps, such as a wildfire burn, that could take weeks of manual drafting now can be done in a few hours. The less obvious advantage is the radical change in the format of mapped data—from analog inked lines on paper, to digital values stored on disk.

Spatial Data Management (Descriptive)

During the early 1980's, the change in data format and computer environment was exploited. ***Spatial database management systems*** were developed that linked computer mapping capabilities with traditional database management procedures. In these systems, identification numbers are assigned to each geographic feature, such as a timber harvest block or wildlife management parcel. For example, a user is able to point to any location on a map and instantly retrieve information about that location. Alternatively, a user can specify a set of conditions, such as a specific forest and soil combination, and direct the result of the geographic search to be displayed as a map.

During the early development of GIS, two alternative data structures for encoding maps were debated. The ***vector data model*** closely mimics the manual drafting process by representing map features as a set of discrete points, lines or areas that, in turn, are stored as a series of organized X,Y coordinates. An alternative structure, termed the ***raster data model***, establishes an imaginary grid over a project area, and then stores resource information for each cell in the grid. The early debate attempted to determine the universally best structure. The relative advantages and disadvantages of both were viewed in a competitive manner that failed to recognize the overall strengths of a GIS approach encompassing both formats.

By the mid-1980's, the general consensus within the GIS community was that the nature of the data and the processing desired determines the appropriate data structure. This realization of the duality of mapped data structure had significant impact on geographic information systems. From one perspective, resource maps form sharp boundaries that are best represented as lines. Property ownership, timber sale boundaries, and haul road networks are examples where lines are real and the data are certain. Other maps, such as soils, site index, habitat areas and slope are interpretations of terrain conditions. The placement of lines identifying these conditions is subject to judgment, statistical analysis of field data, and broad classification of continuous spatial distributions. From this perspective, the sharp boundary implied by a line is artificial and the data itself is based on probability.

Increasing demands for mapped data focused attention on data availability, accuracy and standards, as well as data structure issues. Hardware vendors continued to improve digitizing equipment, with manual digitizing tablets giving way to automated scanners at many GIS facilities. A new industry for map encoding and database design emerged, as well as a marketplace for the sales of digital map products. Regional, national and international organizations began addressing the necessary standards for digital maps to insure compatibility among systems. This era saw GIS database development move from project costing to equity investment justification in the development of corporate databases.

Map Analysis (Prescriptive)

As GIS continued its evolution, the emphasis turned from descriptive query to prescriptive analysis of maps. For the greater part, early systems concentrated on automating traditional mapping practices. If a forester had to repeatedly overlay several maps on a light-table, an analogous procedure was developed within the GIS. Similarly, if repeated distance and bearing calculations were needed, the system was programmed with a mathematical solution. The result of this effort was GIS functionality that mimicked the manual procedures in a forester's daily activities. The value of these systems was primarily the savings gained by automating tedious and repetitive operations.

By the mid-1980's, the bulk of descriptive query operations became available in most GIS systems. In parallel a comprehensive theory of spatial analysis began to emerge. The dominant feature of this theory is that spatial information is represented numerically, rather than in analog fashion as inked lines. These digital maps are frequently conceptualized as a set of "floating maps" with a common registration, allowing the computer to "look" down and across the stack of map layers. The spatial relationships of the data can be summarized (database queries) or mathematically manipulated (analytic processing). Because of the analog nature of traditional map sheets, manual analytic techniques are limited in their quantitative processing. Digital representation, on the other hand, makes a wealth of quantitative (as well as traditional qualitative) processing possible. The application of this new theory to natural resources is revolutionary. Its application takes two forms—spatial statistics and spatial analysis.

Geophysicists have used ***spatial statistics*** for many years to characterizing the geographic distribution, or pattern of mapped data. The statistics describe the spatial variation in the data, rather than assuming a typical (average) response is everywhere. For example, field measurements of snow depth can be made at several plots within a watershed. Traditionally, these data are analyzed for a single value (the average depth) to characterize the entire watershed. Spatial statistics, on the other hand, uses both the location and the measurements taken at the sample points to generate a map of relative snow depth throughout the entire watershed.

The impact of this map-ematical treatment of maps is yet to be fully exploited. The application of such concepts as spatial correlation, statistical filters, map uncertainty and error propagation await their translation into natural resources contexts.

Spatial analysis, on the other hand, has a rapidly growing number of contemporary resource applications. For example, forest managers can characterize timber supply by considering the relative skidding and log-hauling accessibility of harvesting parcels. Wildlife managers can consider such factors as proximity to roads and relative housing density to map human activity and incorporate this information into habitat delineation. Forest planners can assess the visual exposure of alternative sites for a facility to sensitive viewing locations, such as roads and scenic overlooks.

Spatial mathematics has evolved similar to spatial statistics by extending conventional concepts. This "map algebra" uses sequential processing of spatial operators to perform complex map analyses. It is similar to traditional algebra in which primitive operations (e.g., add, subtract, exponentiate) are logically sequenced on variables to form equations. However in map algebra, entire maps composed of thousands or millions of numbers represent the variables of the spatial equation.

Most of the traditional mathematical capabilities, plus an extensive set of advanced map processing operations, are available in modern GIS packages. You can add, subtract, multiply, divide, exponentiate, root, log, cosine, differentiate and even integrate maps. After all, maps in a GIS are just an organized set of numbers. However, with map-ematics, the spatial coincidence and relatively positioning of values among and within maps create new operations, such as effective distance, optimal path routing, visual exposure density and landscape diversity, shape and pattern. These new tools and modeling approach to natural resource information combine to extend record-keeping systems and decision-making models into effective decision support systems.

Spatial Reasoning (Communicating Perceptions)

The 1990's will build on the cognitive basis, as well as the databases, of current geographic information systems. GIS is at a threshold that is pushing beyond mapping, management, and modeling, to ***spatial reasoning and dialogue***. In the past, analysis models have focused on management options that are technically optimal—the scientific solution. Yet in reality, there is another set of perspectives that must be considered—the social solution. It is this final sieve of management alternatives that most often confounds resource decision-making. It uses elusive measures, such as human values, attitudes, beliefs, judgment, trust and understanding. These are not the usual quantitative measures amenable to computer algorithms and traditional decision-making models.

The step from technically feasible to socially acceptable options is not so much increased scientific and econometric modeling, as it is communication. Basic to effective communication is involvement of interested parties throughout the decision-making process. This new participatory environment has two main elements—consensus building and conflict resolution. ***Consensus building*** involves technically driven communication and occurs during the alternative formulation phase. It involves the resource specialist's translation of the various considerations raised by a decision team into a spatial model. Once completed, the model is calibrated and weighted and then executed under a wide variety of conditions. The differences in outcome are noted, discussed and form the basis of enlightened decisions.

From this perspective, a single map of a natural resources plan is not the objective. It is how maps change as the different scenarios are tried that becomes information. "What if avoidance of visual exposure is more important than avoidance of steep slopes in siting a new backcountry road? Where does the proposed route change, if at all?" Answers to these analytic queries focus attention on the effects of differing perspectives. Often, seemingly divergent philosophical views result in only slightly different map views. This realization, coupled with active involvement in the decision-making process, often leads to group consensus.

If consensus is not obtained, ***conflict resolution*** is necessary. This socially-driven communication occurs during the decision formulation phase. It involves the creation of a "conflicts map" which compares the outcomes from two or more competing uses. Each management parcel is assigned a numeric code describing the actual conflict over the location. A parcel might be identified as ideal for a wildlife preserve, a campground and a timber harvest. As these alternatives are mutually exclusive, a single use must be assigned. The assignment, however, involves a holistic perspective that simultaneously considers the assignments of all other locations in a project area.

Traditional scientific approaches are rarely effective in addressing the holistic problem of conflict resolution. Most are linear models, requiring a succession, or cascade, of individual parcel assignments. The final result is strongly biased by the ordering of parcel consideration. Even if a scientific solution is reached, it is viewed with suspicion by the layperson. Modern resource information systems provide an alternative approach involving human rationalization and tradeoffs. This process involves statements like, "If you let me harvest this parcel, I will let you set aside that one for wildlife habitat." The statement is followed by a persuasive argument and group discussion. The dialogue is far from a mathematical optimization, but often closer to an effective decision. It uses the information system to focus discussion away from broad philosophical positions, to a specific project area and its unique distribution of conditions and potential uses.

Conclusion

Planning and management have always required information as their cornerstone. Early information systems relied on physical storage of data and manual processing. With the advent of the computer, most of these data and procedures have been automated during the past two decades. As a result, resource information processing has increasingly become more quantitative. Systems analysis techniques developed links between descriptive data of the landscape to the mix of management actions that maximizes a set of objectives.

This mathematical approach to resource management has been both stimulated and facilitated by modern information systems technology. The digital nature of mapped data in these systems provides a wealth of new analysis operations and a comprehensive ability to spatially model complex resource issues. The full impact of the new data form and analytical capabilities is yet to be determined. Land management professionals are challenged to understand this new environment and formulate new applications. It is clear that map analysis has, and will continue, to revolutionize planning and management in a wide array of land-based disciplines.