GIS State of the Art

by *Michael F. Goodchild*

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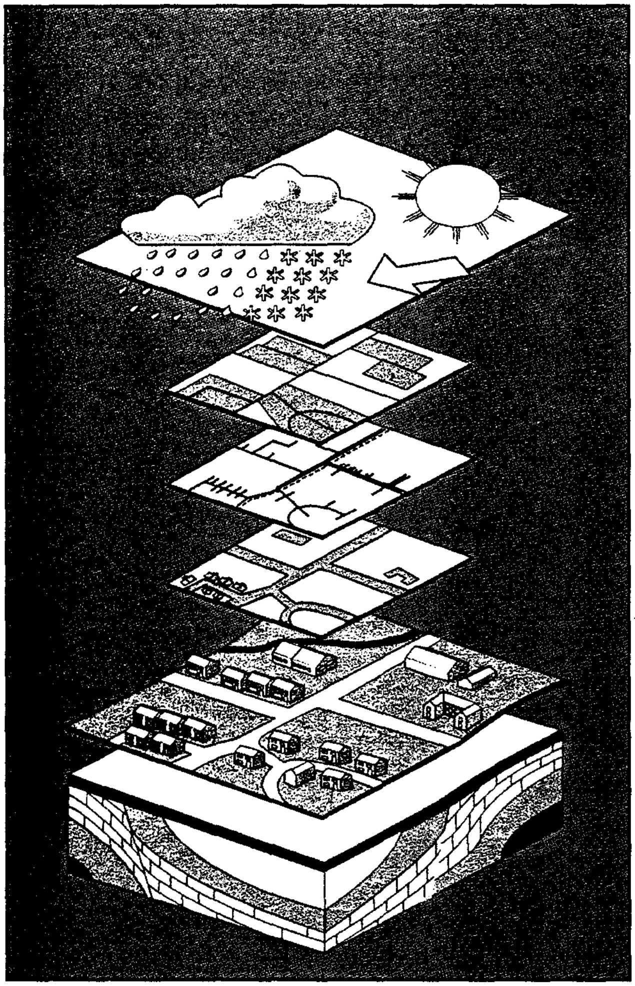
The field of Geographic Information Systems has grown enormously over the past three decades and now comprises many different viewpoints, perspectives, and software systems. In trying to provide a view of the GIS state of the art for educators, perhaps it is most important to stress the key concepts of GIS, how they have been implemented, and for what purpose. What follows, therefore, is one person's view of the key concepts of GIS today and of the issues that currently confront the field.

Perhaps the simplest concept of GIS is that it allows the contents of maps to be stored in computers. If interpreted broadly, maps include not only the conventional paper sheets, but also images of Earth from space, and, more generally, any information tied to specific points on the Earth's surface. Today's GIS can accommodate most types of geographic data, storing them and allowing the user to query and analyze them in a wide range of ways.

Why would one want to store the contents of maps in computers? Most obviously, one could overcome some of the traditional limitations of maps—the frustrations of dealing with places located at the edges of adjacent map sheets, the inability to change scales or "zoom" the problems of navigating with a paper map on which "up" is always North. In principle, a computer display can avoid all these problems. Less obvious, perhaps, is the speed with which one can make maps from data stored in computers, at scales that meet the exact needs of users. Computer data can be edited and updated much more easily than paper maps, and used to manage fast-moving events like the recent fires in Southern California or the Mississippi floods of 1993. We are already beginning to see the advantages of moving geographic data over the information superhighway, with its ability to search for and retrieve relevant information from a vast national and international resource.

A second fundamental concept of GIS is the notion that one can represent the geography of the Earth's surface as a series of layers, each describing the spatial variation of one variable of interest. A GIS database can be built of individual layers of land use, geology, roads, population distribution, or agricultural crops, to name a few of the vast range of possibilities. Each layer is the digital representation of one map, but in combination the layers give a complete geography of a project area—although of course no finite set of layers can ever capture all of an area's geographical variation.

By tying the layers together through common geographic location, GIS provides a unique way of linking data that would otherwise exist in relative isolation. It is often argued that the introduction of a GIS into an agency leads to a more or less complete reorganization, as links are established between departments and their respective databases through the simple concept of common geographic location.



A GIS image illustrating layers from the GISTutor 2 materials. Courtesy of Longman Geoinformation, Cambridge, England.

Related to this second concept is a third, the view of GIS as a new, geographical access path to more conventional types of data. Although this concept is perhaps more mundane than the others, it is nevertheless the major explanation for much of the interest in GIS among utility companies and local government. For example, a gas utility might use GIS to find customer billing records or maintenance data on underground pipes simply by pointing at a computer screen, using the GIS to find conventional database records that have been linked to the map base. The same basic concept is used to find and notify residents living within a certain prescribed distance of a planned land use change, using the simple GIS function of "buffer zone" generation.

Fourth, GIS provides the power to handle vast quantities of geographic information, and thus to avoid much of the need for approximation or generalization that is inherent in conventional map making. A GIS can show geographic distributions in much greater detail than a map or atlas and can also inform its users about the uncertainty present in its data, in ways that go far beyond the techniques available to the map maker.

Finally, and in many ways most importantly, GIS provides a practical means of analysis of geographic information. Maps are notoriously difficult to analyze by hand, and traditional map-measuring devices are crude and imprecise. With the development of GIS has come a renewal of interest in thinking about information in a geographic context and in seeking understanding of the processes that occur on the landscape through a spatial perspective. Analysis can range from simple display and juxtaposition of data, as when a map shows the relative proximities of minority populations and polluting industries, to complex applications of models of environmental processes. The layers of information in a GIS can be used as explanatory factors in studying the distributions of plants or animals. GIS can be used to provide the input data for models of atmospheric circulation and to display the results of simulation. The range of possibilities for spatial analysis is literally endless, and in recent years GIS software developers have added substantial new functionality in this area.

Although estimates vary, it seems that annual sales of GIS software now amount to some $1 billion per year, while the total of all activity related to the collection, dissemination, and use of digital geographic data in the U.S. is worth some $14 billion per year. GIS is clearly a significant sector of the electronic data processing industry, although it may be difficult to define its exact limits.

Despite this level of activity, GIS state of the art is still far short of its potential, in the sense that many important research and development issues remain in the application of computer technology to geographic information. Perhaps most obvious is the fact that GIS remains a technology of maps — and thus predominantly static and two-dimensional. Much research has gone into the problems of handling three-dimensional, time-dependent geographic data, including collection, storage, analysis, and display. But true 3-D stretches the processing capabilities of most of today's computers, and very few truly 3-D data are available.

Another major problem that must be resolved if GIS is to progress centers on data quality. The user of a GIS tends to regard its contents and products as correct, or at least accurate. Maps, on the other hand, are creations of cartographers, designed to give their readers impressions that may be significantly different from scientific truth. It is common, for example, to displace features on highly generalized maps if their symbolic representations would otherwise overlap and thus confuse the reader. Maps are sometimes deliberately distorted or falsified for security reasons.

At one level, GIS can give students a useful lesson in the tensions between scientific measurement and subjective description. More generally, GIS state of the art is rapidly coming to include methods for describing data quality, storing information in the database, visualizing its implications, and propagating it to measures of the reliability of GIS results. Here, and in many other ways, GIS is raising fundamental issues of measurement, information structuring, visualization, and problem solving.