The Unique Qualities of a Geographic Information System: A Commentary

*H. Dennison Parker**
Cooperative GIS Technology Laboratory, College of Forestry and Natural Resources, Colorado State University, Fort Collins, CO 80523

THE TERM "geographic information system" (GIS) is a misnomer in many respects, for a GIS is more than just a special kind of information system. It is a *technology*. A technology is "the whole body of methods and materials used to achieve . . . objectives" (Soukhanov, 1984). When GIS is viewed as a technology for spatial data handling, not simply a computer system, its real significance becomes apparent. This paper will attempt to organize and present the characteristics of a GIS that make it a technology.

Many terms are used as synonyms for GIS. Clarke (1986) lists "geo-base information system," "natural resource information system," "geo-data system," and "spatial information system." To these I would add "geographic data system" (White, 1984) and "land information system," Burroughs (1986) refers to "geographical information systems."

Another term frequently used as a synonym for GIS is "multipurpose cadastre." Although some authors have drawn a distinction between a multi-purpose cadastre and a GIS (Kevany, 1986), others have coined the term Geographic Base Information System (GBIS) as a synonym for multipurpose cadastre (Rhyason and Salmer, 1985). According to Clapp *et al.* (1985), a cadastre is ". . . a record of interest in land, encompassing both the nature and extent of those interests." They suggest the term, Multipurpose Land Information System (MLIS), to include the cadastre as well as all other information about the land.

GIS technology is often confused with other sciences and technologies that deal with spatial data handling. These include remote sensing, cartography, surveying, geodesy, photogrammetry, and, of course, the "father" science to GIS, geography. The difficulty of attempting to draw distinctions between these from an educational perspective prompted Dahlberg and Jensen (1986) to lump them all together into a new conceptual model they refer to as an Integrated Spatial Information System ISIS).

So, just what is a GIS? Once again, there is a wide diversity of definitions. Marble *et al.* (1983) simply refers to a GIS as a spatial data handling system. Cowen (personal communication, 1986) says GIS is an ". . . information system that handles geographically or spatially referenced data." Burrough (1986) defines GIS as ". . . a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world. . . ." Berry (1986) provides a different view, pointing out that a GIS is an ". . . internally referenced, automated, spatial information system. . . ." Some authors do not even concede that a GIS is necessarily computer based (Calkins and Tomlinson, 1984). Finally, Devine and Field (1986) wrote that GIS is " . . . simply a device to expand the use of maps."

My own view is that a GIS is best defined as an information *technology* which stores, analyzes, and displays both spatial and non-spatial data. This definition does not imply that some functions (e.g., storage and display) cannot be performed by separate software, a fact which once again points out that GIS is actually a technology, and is not necessarily limited to the confines of a single, well-defined software system.

*The author is an employee of the Bureau of Land Management.

GIS CHARACTERISTICS

On careful scrutiny, I believe that most GIS definitions turn out to be much the same, or nearly so, and the differences are merely fodder for debate. The common thread through all definitions is the notion of *spatial* data processing, in addition to the more familiar textual or numeric data processing. Spatial data are data which represent objects that have physical dimensions — they take up space. *Geographic* spatial data occur on, in, or above the planet Earth. In the context of GIS technology, spatial data are landscape features which can be represented on a map. I am not speaking of a simple description of location, such as a street address. As we shall see, the street address is a *descriptor* of a land parcel, one of many potential attributes of a parcel. The parcel itself is the spatial entity.

Spatial data occur in three forms: points, lines, and polygons or areas. In two-dimensional space, there exist no other alternatives. A soil type or forest stand appears on the land as a polygon. Rivers and roads are lines (or very narrow polygons), and wells, stream intersections, or eagle nests are points. All features of the landscape can be reduced to one of these three spatial data categories. This is an important concept because GIS technology is a computer technology, and computers know nothing of eagle nests or timber stands. However, they can be taught to "know" something about points and polygons. To use computers for handling spatial data, we must reduce our data to the computer's level of comprehension, so to speak. We must specify three things for the computer. (1) *Where* each feature is in geographic space, (2) *What* each feature is, and (3) What is each feature's spatial *relationship* to other features on the map.

Geographic location might be specified by simply taking coordinates off a standard USGS 7-1/2 minute quadrangle map. But, more and more agencies and firms are attempting to insert *cadastral* data into GIS databases, most of which use latitude/longitude as their basic reference system. Cadastral data usually references ownership boundaries on the ground without specific reference to geographic coordinates (National Research Council, 1982).

Today, we can use Earth-orbiting satellites to determine the position of anything on the globe within a few centimeters. But we cannot always relate this information directly to land ownership boundaries, the most basic of all land and resource management themes.

The second thing we must tell the computer is *what* various spatial features are. The labels we attach are called *attributes*, and landscape features can have an unlimited variety. For example, a lake may be described by its name, depth, water quality, fish populations, chemical composition, color, bottom contour, algal levels, salinity, taste, biological productivity, ownership, etc. As new information is acquired, it must be added to the GIS database. Furthermore, as we use the GIS we may transform data already in the database to produce new information internally. For example, fish population sizes, productivity levels, access, and other factors might be combined in a model to set catch limits by fish species, which in turn become new attributes describing the lake.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 54, No. 11, November 1988, pp. 1547-1549.

0099-1112/88/5411–1547$02.25/0

Finally, we must know how individual landscape features relate topologically to other features. For example, we might want to know about access to our lake. What roads, trails, or barriers border the lake and affect its use for recreation? Questions like this require knowledge of the spatial relationships *between* landscape features.

Wildlife biologists are taught the concept of juxtaposition of landscape features that constitute wildlife habitat. The mere existence of a food source, for example, does not alone equal habitat. There must also exist cover and, in some form, water, and these must all be located in relationship to and interspersed with one another to meet life requirements of a particular wildlife species in question. These spatial relationships are described as the *juxtaposition* of habitat components.

When such landscape features are portrayed on maps, the concept of juxtaposition can be translated into map topology, the spatial relationships between *map* features. Are these features side by side, close together, distant? How would one travel from one feature to another? The treatment of topology, or lack of it, constitutes a fundamental difference between modern GISs and older ones, and between GISs and most other types of computer graphics systems.

There are, of course, a wide variety of other types of computer graphics systems today, including ones intended for computer aided design or drafting (CAD), engineering (CAE), manufacturing (CAM), surveying, road design, and, of course, Hollywood's Star Wars variety. While these are generally good for specific jobs, they do not possess all the functions of a GIS, as noted earlier. For example, a GIS can create new information, a major difference between GIS and computer-assisted cartography (Burrough, 1986).

Before the day of computers, the map was *the* spatial database. In order to produce new information from maps, humans had to read and study them with a great deal of effort. After all, how many maps can one hold in human memory at once? How many overlays can one mentally register at a time? Perhaps two or three. Certainly not dozens as are often required in resource management. But a GIS can hold as many maps as the computer hardware will allow. Not only that, but it can combine them, add them, subtract them, multiply and divide them, and perform many other such operations. With GIS we can answer extremely complex questions, such as "What are all possible pipeline corridors between El Paso and Los Angeles that do not rise above 8300 ft in elevation; are at least 50 percent on public land; do not pass within less than 1 mile of known endangered wildlife populations; cross no streams at angles less than 80 degrees; include no grades over 7 percent; etc."

GIS analytical operations can be broken into two classes, *primary* and *compound*. Primary operations include basic GIS functions like area and distance measurement, buffer generation, reclassification, and various Boolean operations. These have been referred to as a spatial data handling "primitives" (Berry, 1986) or GIS "tools" (Dangermond, 1986). They are the building blocks out of which compound procedures are developed. Advanced compound procedures, using macro commands or expert system techniques, are still largely experimental in resource management GIS applications. This is partly because of system limitations, but more importantly it is because natural resource management is itself not a well-defined process, and managers have not yet learned how best to use GIS.

GIS IN NATURAL RESOURCE MANAGEMENT

The major GIS application in natural resource management to date is planning. All natural resource management agencies are obligated by law to produce management plans which take into account a wide variety of potential land uses, environmental protection measures, and public opinions. Either through modeling, or expert opinion, land and resource use alternatives are formulated, and the GIS is used to evaluate each in terms of environmental impacts, economic implications, land areas involved, and potential use conflicts. Fifty or more different thematic maps may be digitized and used in various stages of the planning process (Zulick, 1986). It is important to remember that, although digitizing can be expensive, it is permanent. The Bureau of Land Management (BLM), for example, makes continuing, wide-ranging use of the data which were originally digitized for resource management plans.

Other natural resource GIS applications reported over the past few years include modeling of forest pest impacts (White, 1986), water quality monitoring (Welch, 1986), modeling narcotic crop sites (Waltz and Holm, 1986), waste disposal site assessment (Buckley and Hendrix, 1986), and analyzing effects of carbon dioxide development on elk (*Cervus canadensis*) (Brekke, 1986). There are many more.

One of the most powerful applications of GIS in future land and resource management will surely be simulation modeling. The resource manager will use GIS technology to simulate and evaluate competing land uses, potential coal leases, scenic area designations, timber sales, new fence construction, utility corridors, and virtually all other field resource management activities. Both the economic and political payoffs will be substantial. Mistakes made in computer simulation are much less painful and expensive than mistakes made on the ground.

THE REMOTE SENSING CONNECTION

When you hear the term GIS today, some reference to remote sensing is often not far behind. As a result, there is often a good deal of confusion over where the line is between the two technologies. It is tempting to define remote sensing as a data source technology, and GIS as a data processing technology. On the surface, this distinction is adequate. But, we've already stated that GIS can create new information itself, internally. I believe a better distinction would be that remote sensing constitutes an *external* information source for *input* to a GIS. Its also well to keep in mind that, although remote sensing data can be an important data source for a GIS, it is usually not the *primary* source.

Those familiar with remote sensing will immediately point out that digital image processing systems now include most, perhaps all, of the functions of a GIS. Remote sensing analysis systems which include spatial data handling functions provide powerful means for increasing the utility of remote sensing data. A recent example is given by Cibula and Nyquist (1987), who used topographic and climatological data in a GIS to increase from 9 to 21 the number of land-cover classes distinguished by Landsat data. This concept is now new. Over a decade ago, georeferenced, topographic, soils, and other types of data were being merged with Landsat data to improve classification. These were often called "ancillary" data—they were, then, ancillary to the Landsat data. Today, it is probably more accurate to describe the *remote sensor* data as "ancillary," because a GIS can contain a great many data layers, only one or a few of which are derived from remote sensing.

CONCLUSIONS

I believe we are on the verge of major advances in the use of modern computer technologies in natural resource management, and environmental assessment and monitoring. These advances will come about as a result of the fortuitous convergence of several key factors in GIS technology over the past decade or so.

First are the dramatic advances in computer hardware technology, brought on by the advent of microprocessors and incredible new storage technologies. Second, as a result of these advances, spatial data processing software has advanced to the point where it is beginning to match the applications challenges presented by natural resource management, even on a global scale. Finally, we've seen a political climate evolve recently in which public agencies at all levels are seeking new, more efficient approaches to resource management, and to other tasks requiring intensive spatial data handling. It would appear that the "time" of GIS has indeed come.

REFERENCES

Berry, J. K., 1986. Learning computer-assisted map analysis. *Journal of Forestry*. Oct:39–43.

Brekke, E. B., 1986. Use of GIS to analyze impacts of CO2 gas development on elk calving areas. *Proc. Third National MOSS Users Workshop*. Bureau of Land Management, Denver, Colorado 236 p.

Buckley, D. J. A., and W. G. Hendrix, 1986. Use of geographic information systems in assessment of site suitability for land application of waste. *Proc. Geographic Information Systems in Government*. U.S. Army Engineer Topographic Laboratory, Ft. Belvoir, Virginia. 968 p.

Burrough, P. A., 1986. *Principles of Geographical Information Systems for Land Resources Assessment*. Oxford University Press, N.Y. 193 p.

Calkins, H. W., and R. F. Tomlinson, 1984. *Basic Readings in Geographic Information Systems*. SPAD Systems, Ltd. Williamsville, N.Y. 363 p.

Cibula, W. G., and M. O. Nyquist, 1987. Use of topographical models in a geographical data base to improve landsat MSS classification for Olympic National Park. *Photogrammetric Engineering and Remote Sensing*, 53(1):67–75.

Clapp, J. L., J. D. MacLaughlin, J. G. Sullivan, and A. P. Vonderhoe, 1985. Toward a method for evaluation of multipurpose land information systems. *Proc. Annual Conference of the Urban and Regional Information Systems Assoc.* 359 p.

Clarke, K. C., 1986. Recent trends in geographic information system research. *Geo-Processing* 3:1–15.

Dahlberg, R. E., and J. R. Jensen, 1986. Education for cartography and remote sensing in the service of an information society: the U.S. case. *The American Cartographer* 13(1):51–71.

Dangermond, J., 1986. The software toolbox approach to meeting the user's needs for GIS analysis. *Proc. Geographic Information Systems Workshop*. American Society for Photogrammetry and Remote Sensing, Atlanta, Georgia. 425 p.

Devine, H. A., and R. C. Field, 1986. The gist of GIS. *Journal of Forestry*. Aug. 17–22.

Kevany, M. J., 1986. The importance of geodetic control in the development of a geographic information system. *Proc. Geographic Information Systems in Government*. U.S. Army Engineer Topographic Laboratory, Ft. Belvoir, Virginia. 968 p.

Marble, D. F., and D. J. Peuquet, 1983. Geographic information systems and remote sensing. *Manual of Remote Sensing*. 2nd ed. American Society for Photogrammetry and Remote Sensing, Falls Church, Virginia.

National Research Council, Committee on Integrated Land Data Mapping, 1982. *Modernization of the Public Land Survey System*. National Academy Press, Washington, D.C. 74 p.

Rhyason, D. B., and T. Salmer, 1985. An evaluation of the city of Edmonton's Geographic Base Information System (GBIS) after 7 years. *Proc. Annual Conf. of the Urban and Regional Information Systems Assoc.* 359 p.

Soukhanov, A. H. (ed.), 1984. *Webster's II New Riverside University Dictionary*. Houghton Mifflin, Boston. 1536 p.

Waltz, F. A., and E. A. Holm, 1986. Modeling narcotic crop-growing sites with MOSS. *Proc. Third National MOSS Users Workshop*. Bureau of Land Management, Denver, Colorado. 236 p.

Welch, R., M. M. Remillard, and S. S. Fung, 1986. Monitoring aquatic vegetation and water quality with a geographic information system. *Proc. Geographic Information Systems Workshop*. American Society for Photogrammetry and Remote Sensing, Atlanta, Georgia. 425 p.

White, M. S., 1984. Modeling forest pest impacts – aided by a GIS in a decision support system framework. *Proc. Third National MOSS Users Workshop*. Bureau of Land Management, Denver, Colorado. 236 p.

Zulick, C. A., 1986. Application of a geographic information system to the Bureau of Land Management planning process. *Proc. Geographic Information Systems in Government*. U.S. Army Engineer Topographic Laboratory, Ft. Belvoir, Virginia. 968 p.

New Sustaining Member

Geophysical Services Inc.
PO Box 655621, MS 3977, Dallas, TX 75265
Telephone 214-995-7773, fax 214-995-7676, telex 73301 GEESYE

Geophysical Services Inc. is a worldwide provider of surveys, geophysical explorations, and geophysical measurements. GSIs pioneer physicists fielded the world's first seismograph field party in 1930. From that year until the present, GSI has operated from a strong technological base, setting the pace for industry leadership in seismic reflection technology, instrument advances, and data processing techniques. With the advent of the electronic revolution, GSI reorganized in December 1951 and became a wholly owned subsidiary of Texas Instruments. Halliburton, a large oil field services holding company, acquired a sixty percent interest in GSI in March 1988. GSI, a Halliburton company, currently employs approximately 2600 personnel worldwide.

GSI Global Positioning Services is pleased to offer its experienced personnel and technologically advanced resources to meet the needs of the geodesist, surveyor, photogrammetrist, or civil engineers and planners on any specific control survey requiring utilization of GPS data collection and processing techniques. GSI is in the unique position of being one of the largest companies in the world offering GPS services to both the public and private sectors of the business community.

GSI is a leader in the advancement of GPS development and has funded a large amount of research which has benefitted both manufacturers, developers, and governmental agencies as well as our own interests. GSI is committed to further development of GPS as a means to accurately determine positions, both inshore, offshore and in real-time. GSI sees its GPS service as an important first step in meeting the future goals of its clients, whether it be an Automated Mapping/Geographic Information System, pipeline construction, aerial photography, watershed or flood control analysis, forestry management, national or local control network densification, subsidence studies, glacial drift prediction, plate tectonic relationships, or well location mapping.