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CHAPTER 2

Geographic Information Systems and Geographic Research

Michael F. Goodchild

Many disciplines have contributed to the development of geographical information systems (GIS), and in turn GIS has been used in many disciplines as a research tool, but there is no doubt that GIS and geography have a special relationship. This chapter explores some of the dimensions of that relationship, with particular emphasis on geographic research.

Good debate is entertaining. Because I am the author in this book most clearly identified with GIS, many readers, I suspect, are hoping to be entertained by my clever defense of GIS, and perhaps even by my rousing counterattack to what they may interpret in recent literature as critique. Phrases like "GIS über alles" (Smith, 1992) have appeared in the pages of geography's more respected journals, and a colleague has written that its "basic goals . . . are precisely to foster the technics and ideology of normalization" (Pickles, 1991, p. 83). From the other side, Openshaw's (1991) editorial in *Environment and Planning A* was certainly a spirited defense of GIS, as was his later response (Openshaw, 1992) to Taylor and Overton (1991).

But Smith (1992) is perfectly correct in pointing out that the GIS literature places far more emphasis on civilian applications and tends to ignore—or to be ignorant of—the military ones, and Pickles is correct too when he points out that GIS can be used in support of civilian surveillance. As academics, it is our responsibility to reflect on all aspects of GIS, from its basic design and functionality to the more profound aspects of its meaning to society. While it is hard to see power in the possession of a soil map, or politics in the measurement of atmospheric temperature, there are real ethical issues arising from many applications of GIS: a technology that can be used to promote democracy can also be used to deny it. The gerrymandered 1992 electoral map of North Carolina (see Figure 2.1) was designed by a GIS to empower minorities, but previous generations would have seen creation of such an engineered district as an extreme abuse of the electoral process. Another GIS product (see Figure 2.2), prepared by Lauretta Burke, compares the locations of industries emitting toxic chemicals into the atmosphere of Los Angeles with the locations of census tracts occupied primarily by minority populations. It makes a powerful statement of spatial association, and played a minor role in the 1992 election campaign.

The role played by GIS in society is clearly an important dimension of the relationship between GIS and geographic research, and possibly the most important in many contexts, but it is only one dimension. Every student of GIS should be aware of the technology's possible uses,

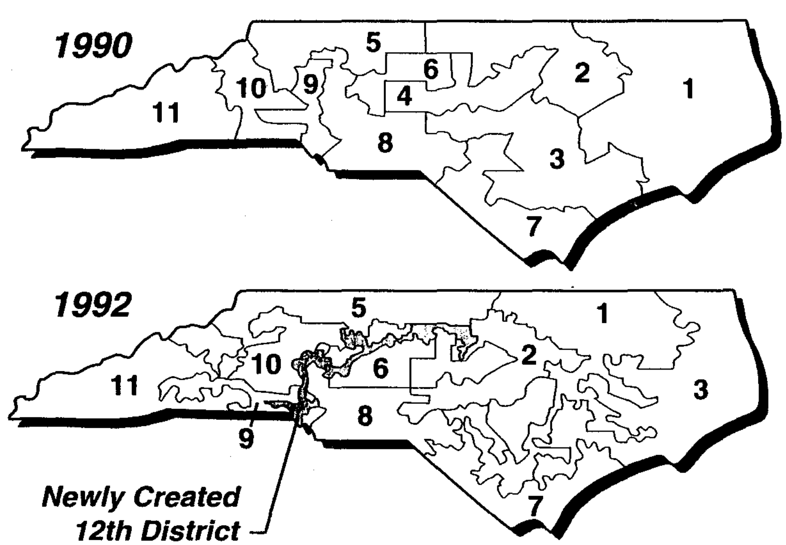

FIGURE 2.1. Congressional districts formed by the 1992 reapportionment of North Carolina, with 1990 districts for comparison.

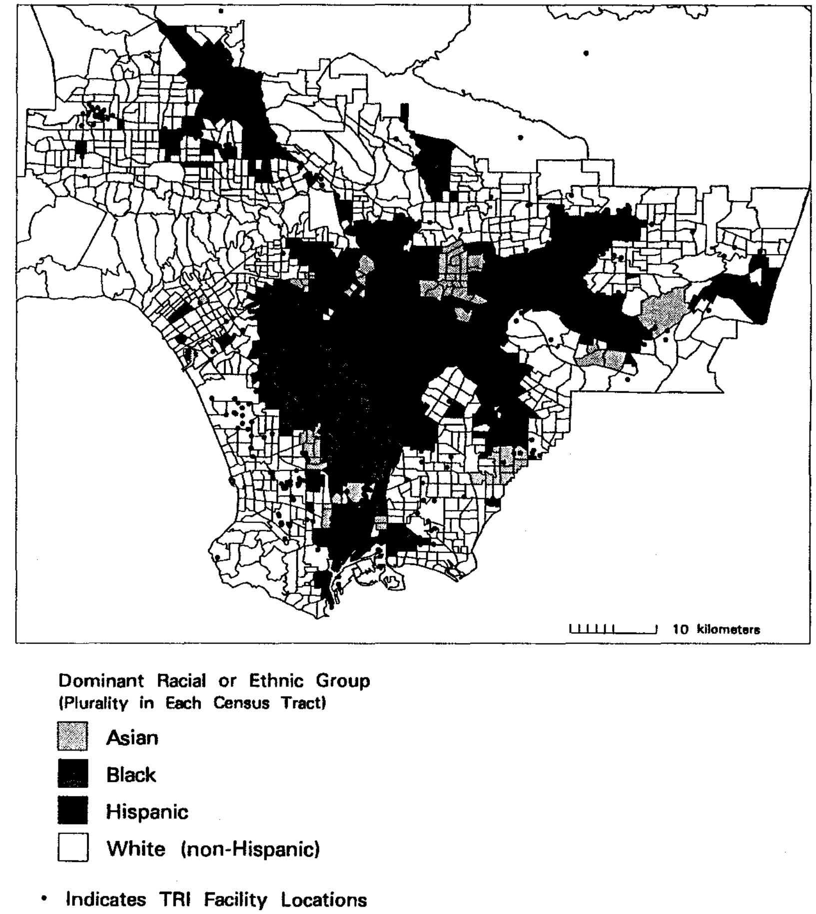

FIGURE 2.2. Locations of industries emitting toxic chemicals (data source: 1989 U.S. Environmental Protection Agency, Toxic Release Inventory database), and dominant ethnic group by census tract (source: U.S. Bureau of the Census, 1990 census), for Los Angeles County (Burke, 1993).

for both good and evil, and of the difficulties we all frequently face in making such clear distinctions, even with the benefit of hindsight. But writers often take extreme positions in debate, perhaps to be more exciting, or because they feel driven to present their position forcefully in order to counter what they see as incorrect tradition. It seems absurd to me to suggest that all users or developers of GIS should see their relationship to the Persian Gulf War (Smith, 1992) as somehow similar to Robert Oppenheimer's moral dilemma over the atomic bomb, or to argue that GIS is a "surveillance technology" (Pickles, 1991), or conversely to argue that the white knight of GIS will put geography's pieces together again (Openshaw, 1991). While this kind of debate may be fun for a while, there are nevertheless serious and interesting issues to be resolved, and scientific questions to be pursued in GIS, and it would be a shame if they were lost in a cacophony of position taking. I hope the reader will be convinced, by the end of this chapter, that both GIS and geography are relatively small specializations, and each needs the other badly if both are to survive.

In the following sections I will attempt to review the relationship between GIS and geographic research, in all of its dimensions. The chapter begins with an overview of GIS technology, and then moves to a discussion of research *on* GIS, and the nature of the GIS research community. The following section discusses research *with* GIS, and the role that can be played by geographers in that multidisciplinary activity. The final section looks briefly at the ethics of GIS and its significance to society, and ends with a call for extensive research on the topic by geographers.

Before I begin, it seems appropriate to provide a context for this chapter. If GIS must be examined in its societal context, then so too must writing about GIS, so perhaps a little self-deconstruction is in order. My undergraduate degree was in physics and my Ph.D. in physical geography, and I still find myself able to write words like *scientific, objective,* and *truth* without placing them in quotation marks, and to associate the name "Foucault" with a pendulum. While I would agree that social science often says as much about the observer as about the observed, I have seen little in the way of alternatives to positivism among the more fundamental physical sciences. Though much of GIS literature can be rightly criticized for ignoring military applications, it seems to me that much writing in geography about the decline of positivism similarly ignores the physical side of the discipline. Of course, part of the attraction of GIS is its ability to surmount the human/physical divide. So unlike Heywood (1990), Taylor (1990), and others who see in GIS a resurgence of positivism, I see the GIS literature as containing elements of the entire spectrum, from the positivist end to the other end. Cartographers writing on GIS sometimes object strongly to words like *truth,* whereas computer scientists seem equally impatient with *debate.*

But however strong the case against positivism in the social sciences may be, I also believe that quantification, analysis, numerical models, and related concepts provide us with valuable points of reference. Objectivity is always embedded in the subjectivity of human experience, and the success of disciplines like physics lies in their ability to extend objectivity over such a large, connected set of phenomena. In the social sciences, the extent of objectivity is much more limited, and the subjective context is encountered more immediately. But however small, islands of objectivity—the spatial interaction model, central place theory, microeconomics—provide us with the well-defined points of reference that make debate and intellectual progress possible.

THE NATURE OF GIS

Though many definitions of GIS exist, most identify a database in which every object has a precise geographical location, together with software to perform functions of input, management, analysis, and output. Besides geographical locations, the database will also contain numerous attributes that serve to distinguish one object from another, and information on the relationships between objects. There are several excellent introductions to GIS, including Burrough (1986), Star and Estes (1990), and Thompson and Laurini (1992). Maguire, Goodchild, and Rhind (1991) provide a comprehensive overview of GIS.

This section provides three different perspectives on the current nature of GIS: as a technology, as a research field, and as a community. All three are legitimate interpretations of what is meant by the acronym, and yet together they contain an enormous variety of activities, personalities, and capabilities. In some ways the success of GIS is related to the power of labels in society—as an acronym, it is initially free of associations, and can act as a rallying point in ways that traditional terms overburdened with meaning, like *geography,* cannot.

GIS: The Technology

Although computer hardware and specialized peripheral equipment are essential for GIS, the key component of this particular technology is its software. Over the past decade, interest in GIS has provided a significant incentive to developers, and the range of products that call themselves GIS has grown wider and wider. A 1991 directory (GIS

World, Inc., 1991) listed 371 available software products, representing an enormous diversity of capabilities and approaches. The borders of GIS are very fuzzy, particularly with remote sensing, computer assisted design (CAD), and computer cartography, all of which are recognized areas of software that to some degree meet the definition of GIS given above. Various tests have been suggested or applied in an effort to refine the definition, including the following:

- The ability to store and analyze spatial relationships between objects, such as *crosses, intersects, is adjacent to,* or *is connected to,* or to compute them as required (often called *topology* in the loose terminology of the GIS community)
- The ability to store and analyze an unlimited number of attributes of each object
- An emphasis on analysis, rather than simple data management and retrieval
- The ability to integrate data from different sources, perhaps at different scales and using more than one mode of representation

The most effective principle for organizing the range of GIS software is based on each product's underlying *data model.* In computer science, a data model is the set of rules used to create a representation of information, in the form of discrete entities and the relationships between them. Thus geographical data modeling (Goodchild, 1992a; Peuquet, 1984) is the set of rules used to create a representation of geography in the discrete, digital world of a computer database. The human mind uses a myriad of poorly understood methods for structuring geographical knowledge; it is GIS's supreme conceit that one can structure a useful representation of geographical knowledge in the absurdly primitive domain of the digital computer, just as it is cartography's conceit that one can accomplish the same objective with pen and paper. Yet clearly there are areas of human activity—finding underground pipes, tracing the ownership of land, navigating through unfamiliar cities, managing forests—where it can be done with satisfaction. As Taylor (1990) has pointed out, it is much easier to do so when the information being modeled consists of geographical facts (bridges, streets, buildings) than when it consists of geographical interpretations of complex phenomena, like soil, terrain, or urban landscapes, or of geographical knowledge and understanding. Hence the danger arises that a geography that accepts GIS too readily will become a discipline dominated by facts rather than by understanding.

Two classes of data models have dominated GIS over the past decade, although one arrived much later than the other. The roots of GIS lie in the 1960s, and it is generally acknowledged that the first GIS was the Canada Geographic Information System (Tomlinson, 1988), developed by and for the Government of Canada to support the mapping and assessment of Canada's land base. Land was inventoried in the form of a number of distinct variables—capability for agriculture, capability for recreation, land use, and so on—and assembled into maps, initially at a scale of 1:50,000. Since each variable was determined uniquely at every point, the maps could be conceptualized as a series of *layers,* or *fields* in mathematical terms, and the database as a layer cake. Thus the distinct feature of the field class of data models is a database that contains a finite number of variables, each mapped over the area covered by the database, and each having a unique value at every point in the area.

The second significant root of GIS lay in the U.S. Bureau of the Census and its management of the 1970 census. Here again, fields provided an acceptable conceptual framework for data modeling, since every point in the United States is in exactly one state, one county, one census tract, or the like. When these two threads came together in the work of the Laboratory for Computer Graphics at Harvard in the 1970s (Chrisman, 1988) the layer-cake view of the world was set to dominate GIS. The ARC/INFO GIS, developed and marketed by Environmental Systems Research Institute (ESRI) and one of today's most successful GIS, is the direct intellectual descendant of that work at Harvard, as are several other current products.

There are many ways of representing a field as a collection of discrete objects, and GIS currently makes extensive use of six of them. One can sample the field at randomly located points (e.g., weather stations), or at a grid of regularly spaced points. One can divide the space into rectangular cells, and record the average, total, or dominant value in each cell (e.g., remote sensing). One can divide the space into areas that are more or less homogeneous and record the average, total, or dominant value in each area (e.g., census data, or soil maps). One can record the locations of lines where the field has certain fixed values (e.g., contour or isopleth maps). And finally, one can divide the space into irregularly shaped triangles, and assume that the field varies linearly in each (the TIN, or triangulated irregular network model, used commonly to model surfaces, e.g., topography).

All of these alternative field models are approximations, made in the interests of capturing a reasonably accurate representation of a complex phenomenon. The quality of the approximation is clearly of concern, and there are difficult choices to be made in ensuring that the representation is as accurate and useful as possible. Such choices are best made by people who understand the phenomenon and the processes that caused its particular geographic distribution. Ideally, a digital representation of a complex geographic field should capture elements of our knowledge and understanding of the phenomenon, through choices about what to measure, where to measure it, and how to represent the results in digital form. Just as a soil map captures the training, knowledge, and understanding of the soil scientist that made it, so too should a GIS representation, but without some of the constraints imposed by cartographic technology (Goodchild, 1988). All too often, however, the same choices are constrained by software limitations, or by lack of understanding on the part of the GIS user.

No current GIS gives its users full access to all six field data models. So-called *raster* GISs support only grids of regularly spaced points and rectangular arrays of cells, and do not distinguish between them. Each layer in the database of such systems must have identical size, spacing, and orientation, so that cells on one layer match perfectly with cells on all other layers. Well-known raster GISs include IDRISI, an excellent PC-based system developed at Clark University; GRASS (Geographic Resources Analysis Support System), a Unix workstation-based system developed by the U.S. Army Corps of Engineers and widely adopted in federal agencies for environmental and resource management; and MAP-II (Map Analysis Package), developed for the Macintosh II by Micha Pazner, now of the University of Western Ontario, and distributed by Wiley.

So-called *vector* GISs, on the other hand, support representation of fields through irregularly spaced points, irregular areas, irregular triangles, or contour lines. Each is regarded as a collection of objects—points, lines, and areas, respectively—with associated attributes. The geometric forms of areas and lines are normally represented as points (pairs of coordinates) connected by straight lines. Thus areas are often called *polygons* in GIS terminology, and lines are often called *polylines* by extension.

The second class of data models takes a very different approach. Since 1980, the most rapidly developing and largest area of GIS application has been in local government and utility companies. Far from seeing the world as a layer cake of fields, these applications are dominated by a view of the world as an empty space populated by various

kinds of discrete objects. A telephone company must manage a vast and complex network of facilities, including poles, connection boxes, cables, and so on, each of which can be regarded as a discrete and well-defined object. The space in between the objects is empty, and there is no value in using space in the computer by creating representations of it, such as empty cells. For this reason, and also because such systems typically need high spatial resolution, they are exclusively handled by vector GIS. The term *layer* may be used, but it has a much looser meaning than for field data models, and is merely employed to group together collections of objects for management purposes. In an object model, any place may be empty or occupied by one or more objects, in one or more layers, whereas in a field model every place has exactly one value on every layer. The terms *coverage* and *theme* are broadly synonymous with *layer*.

The objects used to represent a field—points, lines, or areas—must satisfy certain constraints: Contours cannot cross, and areas representing a field cannot overlap. Thus although field models and object models are both represented internally as collections of points, lines, and areas, their behaviors and meanings are very different. In a *layer-based* vector GIS, such as ARC/INFO, polygons in one coverage must follow the rules of a field, that is, they must exhaust the space and not overlap. In an *object-based* vector GIS, such as System/9 (Computervision), on the other hand, objects follow the rules of an object model: The space between them is empty and they may overlap. Recently, systems like GDS (Geographic Data System; marketed in the United States by EDS Inc.) have begun to apply the field/object distinction locally and selectively within layers of the database. Within a local government database, for example, land parcels exhaust the limits of a city block and do not overlap, but are surrounded by empty space, and may be crossed by other objects of different classes, such as creeks.

These options, which stem ultimately from different ways of viewing the occupation of geographic space, create a wide and confusing range of options for the GIS user. The absence of strong organizing principles or a rigorous terminology has meant that it is easier to be trained in the operation of one system than to be educated in the concepts of the field of GIS as a whole. It has meant that a database constructed using ARC/INFO may be of very little value to a user of System/9, or of Intergraph's TIGRIS, because of fundamental data model differences. In time these problems should resolve themselves, as the field develops a better conceptual framework and more consistent terminology, but that process will be slow.

Field models are difficult to update because of the integrity that must extend over each layer of the database. It is difficult, for example, to update or modify a contour model because of the need to preserve spatial relationships between adjacent contours. Layer-based GISs are poorly adapted for selective update or editing of layers, and consequently do not support time-dependent data well. In a remote sensing system, each old image is replaced by a complete new image, leading to redundancy wherever the image has not changed. Object-based GISs are inherently better adapted to temporal dependence, but in general GIS today remains a technology for static data, a major impediment to its use in modeling social and economic systems.

Another, and perhaps more serious, impediment to the use of GIS in social science lies in the current emphasis in its data models on the absolute positions of objects, and the inability to represent information about interaction. Couclelis (1991) has noted that this short coming has affected GIS's applications in planning, and has led to an inevitable emphasis on the physical rather than the social or the economic aspects of human activity. GIS includes much functionality for computing, storing, and analyzing the spatial relationships between objects, but has not yet addressed the need to qualify those relationships with their own attributes, such as flow, distance, or volume of trade, and to provide functions to support the display and analysis of this information, although elements have appeared in recent versions of ARC/INFO.

The final area of debate in current data models concerns the existence of hierarchical concepts in many geographical data. A map shows information in terms of one uniform scale, but a GIS database may include information drawn from many different maps, and may even present different representations of the same information. Change of scale can reveal more objects, and more detail in existing objects, and can even cause a change in the nature of an object, as when a single-line river becomes a double-line river. From a software point of view, there is often a tension in database design between the need to accommodate the hierarchical relationships between objects and the spatial relationships that exist at a single scale. Products such as ARC/INFO have resolved this tension in favor of the spatial relationships rather than the hierarchical ones, and in general current GIS technology is not good at allowing the user to represent the cross-scale structures

that exist in geographical data. Only a few vector systems, such as System/9 and GDS, have implemented hierarchical concepts in their data models. On the raster side, the quadtree structure (Samet, 1990) does allow a limited form of hierarchical linkage.

If one were looking for a quick, general summary of the successes and failures of current GIS, it might look something like this:

- Two-dimensional, with some excursions into three
- Static, with some limited support for time dependence, particularly in remotely sensed imagery
- Good at capturing the physical positions of objects, their attributes, and their spatial relationships, but with very limited capabilities for representing other forms of interaction between objects
- A diverse and confusing set of data models, or general rules of spatial representation
- Still dominated by the map metaphor, or the view of a spatial database as a collection of digital maps, particularly in the first three characteristics listed above

It is perhaps remarkable given these limitations that GIS has attracted such interest, and has been adopted by so many agencies, governments, companies, and scientific researchers, who are able to find beneficial uses for the current technology despite its comparative crudity. As an industry, GIS is currently valued at some $1 billion annually, although estimates vary widely, and it has been estimated by ESRI that the U.S. annual expenditure on input of spatial data is now $4.5 billion. Clearly there is room here for much fascinating and exciting research, particularly by geographers interested in the ways people conceptualize, construct, analyze, and reason about geographical spaces.

GIS: The Research Agenda

I hope I have managed to convey in the previous section some of the difficulties that arise when one tries to make sense out of the current range of GIS products, and to suggest that challenging and fundamental research issues abound. Many of them are old issues; indeed, part of the fascination of GIS lies in the way it has remotivated interest in issues of spatial representation and cartography that have existed for centuries. Cartographers have long struggled with the difficulties of portraying interaction and change in map form; with GIS they have an opportunity to take advantage of a wealth of new technical capabilities, including animation. Monmonier (1992) has begun to explore the cartographic possibilities of what he calls "map scripts," using sequences of map and other information to convey types of messages to the user that have not been possible with traditional maps. We can now combine maps with sound and images, change scales at will, create maps from seamless databases, and generate orthographic views of three-dimensional surfaces. All of these possibilities, and more, have helped to revitalize cartography and to give an old and honored discipline new meaning.

GIS raises important issues for many disciplines, and has done much to remove the traditional isolation between photogrammetry, remote sensing, geodesy, cartography, surveying, and geography (one could add to this list computer science, operations research, spatial statistics, cognitive science, behavioral psychology, and any other discipline with interests in the generic issues of spatial data). In an earlier paper (Goodchild, 1992b) I argued that these are the disciplines of geographic information *science,* and that it made more sense for the research community to decode the GIS acronym in this way, focusing on the fundamental issues of spatial data, rather than on the limited solutions offered by today's geographic information *system* products.

There have been several published attempts to identify the set of fundamental research issues raised by GIS, and to lay them out as research agendas. These are agendas for research *on* GIS, not research *with* GIS, although clearly the first advances the second goal. There have been debates over whether such an agenda is possible, in the sense that it assumes the existence of a set of generic issues, while in reality all issues of spatial data may be specific. For example, it may be true that there are no general principles for reasoning with spatial data, and that reasoning therefore always depends on context. It may be true that uncertainty in spatial data is similarly specific to context. But GIS itself rests on the assumption that different kinds of spatial data have common structures, and are processed in similar ways, and that there is consequently value in creating common spatial data handling and processing systems. And ultimately this is one argument for the existence of geography itself as a discipline.

Maguire (1990) describes a GIS research agenda for the 1990s aimed both at advancing the technology itself and promoting our un-

derstanding of its impact on the organizations that make use of it. Better methods for assessing GIS costs and benefits are needed, as is a better understanding of its role in organizations and the factors that influence its adoption. That same theme is stressed by Craig (1989), writing on behalf of URISA (Urban and Regional Information Systems Association), whose membership includes many professional GIS users. Perhaps the most extensive discussion of GIS research topics is the agenda developed in 1987–1988 by a consortium of the University of California, Santa Barbara, the State University of New York at Buffalo, and the University of Maine, as part of a proposal to the U.S. National Science Foundation (NSF) for the National Center for Geographic Information and Analysis (NCGIA), which subsequently published the agenda in 1989. It argued that fundamental research was needed in certain specific areas to remove impediments to further development, better use, and more widespread adoption of GIS, particularly for scientific work.

Since the proposal was accepted in 1988, NCGIA research has focused on all of the five major areas originally identified by NSF:

1. Spatial analysis and spatial statistics
2. Spatial relationships and database structures
3. Artificial intelligence and expert systems
4. Visualization
5. Social, economic, and institutional impacts of GIS

Within these broad areas, research has been organized as a series of initiatives, each focused on a topic of basic scientific interest, and each lasting roughly two years:

1. Accuracy of Spatial Databases (December 1988–November 1990)
2. Languages of Spatial Relations (January 1989–July 1990)
3. Multiple Representations (February 1989–August 1990)
4. Use and Value of Geographic Information (May 1989–May 1992)
5. Design and Implementation of Very Large Spatial Databases (July 1989–June 1993)
6. Spatial Decision Support Systems (March 1990–April 1993)
7. Visualizing the Quality of Spatial Information (started June 1991)
8. Formalizing Cartographic Knowledge (started October 1993)

9. Institutions Sharing Spatial Information (started February 1992)
10. Temporal and Spatial Reasoning in GIS (started May 1993)
11. Remote Sensing and GIS (December 1990–April 1993)
12. User Interface Design (June 1991–March 1994)
13. Spatial Analysis and GIS (started April 1992)
14. Multiple Roles for GIS in Global Change Research (to start in 1994)
15. Legal Issues (to start in 1994)

Several countries have developed GIS research strategies, and there are organizations analogous to NCGIA in the Netherlands, France, Australia, and the United Kingdom.

I do not wish to imply by this focus on NCGIA that it somehow monopolizes GIS research. Rather, the center's research agenda provides a useful way of giving an overview and selection of significant research topics. A much more complete overview of international GIS research is provided by Maguire et al. (1991), or by the pages of the major journals of the field.

The issues raised by the development and use of GIS attract researchers from a number of disciplines. Although geographers continue to play a prominent role in research on GIS, borders between disciplines are comparatively unimportant, and progress on these issues will clearly require many different perspectives. In summary, GIS as a field of research is very different from the limited view offered by GIS as a technology. It is not isolated or well defined, since progress on many of these issues benefits not only GIS, but a host of related fields such as image processing, remote sensing, map production, and cognitive science. Instead, GIS as a technology is providing an essential motivation for a wide range of interesting and fundamental research questions.

GIS: The Community

Many aspects of the behavior of disciplines are best understood from a sociological perspective: In many ways disciplines are like tribes, with traditions, loyalties, totems, icons, and symbols of membership. For debating purposes, GIS as the abstract area of interest may take human form in a caricature of the typical GIS specialist, a person obsessed with technology; tainted by association with Big Science, the military, and the security agencies; unethical; entrepreneurial; and politically conservative. Taylor (1990) refers to the "GISer," a term I believe I have never heard used by people in the GIS community to refer to each other—in fact I wonder whether any such term exists, and that in itself may be indicative of the loose cohesion of the field. From inside, an academic community provides stimulus and support, but from outside, it is easy to see a group as "other," especially when suspicions are fostered by an inability to understand the group's language. In return, the GIS community finds it easy to label more traditional fields as irrelevant and lacking in the impetus that derives from ties to activities outside the walls of academe.

In reality, the GIS community today is a loose consortium of interests, held together by a somewhat intangible enthusiasm for a poorly defined technology. It includes academics with solid research records, and others who one suspects could not survive without the protection of the group. It includes people with a deep understanding of the technology, and others who know it only as a black box. Like any other human group, it captures the rich diversity of the human condition.

Within U.S. geography, perhaps the most accessible way of identifying the GIS community is through the membership of the AAG (Association of American Geographers) GIS Specialty Group, now the largest in the association. Like specialty groups in general, it has a higher proportion of students than the association, and, despite its size, finds it difficult to foster a strong sense of belonging and a strong program of group activities. Perhaps this problem reflects the multidisciplinary nature of GIS—that loyalty to GIS and to geography is stronger than loyalty to a group of specialist geographers interested in GIS. I have seen the same pattern in other disciplines, where there is much interest in learning about GIS and in using it in the discipline, but a reluctance to develop a specialized group that may be in danger of becoming peripheral to the discipline as a whole.

GIS AS A TOOL FOR RESEARCH

Having offered three different views of GIS—the software, the set of research issues, and the stereotype GISer—I will now examine the role of GIS as a tool for research. The notion that one could automate the handling and analysis of spatial information—Dobson's "automated geography" (Dobson, 1983)—has intrigued geographers and others for many years. Physicists routinely use pattern recognition techniques to process the vast numbers of photographs produced by nuclear reaction experiments, and remote sensing specialists automate the interpretation of images, so why not extend these concepts to the more sophisticated and complex analysis and interpretation of geography and related disciplines?

GIS is now being used routinely by researchers in many disciplines. Although some of these disciplines, such as archaeology, geology, or transportation science, have traditionally employed a spatial perspective, in others GIS has generated a new interest in space and spatial thinking. Some of the more interesting applications of GIS in social science are emerging in history, sociology, criminology, and economics, all disciplines in which spatial thinking has played a very minor role in the past.

In practice, the part played by GIS in all these activities varies markedly, and only the software remains constant. At the most elementary level, space acts as little more than a convenient index, a means of arranging information in manageable form. Thus the archaeologist may map artifacts at a site simply because that is a convenient way to organize them. In this role, GIS acts as little more than a mapping system, allowing the user to manage data in an organized fashion, and to present them in convenient and readily understood ways.

At a somewhat more sophisticated level, GIS is used as a tool for preprocessing data prior to modeling or analysis. An environmental modeler will likely write his or her model in source code, typically FORTRAN or C, but may well maintain a GIS, linked to the modeling system, to preprocess data, and to analyze and present the model's results. This type of GIS use probably characterizes the majority of efforts in environmental simulation modeling at this time in disciplines like forestry, atmospheric science, or ecology; its state of development is extensively reviewed in Goodchild, Parks, and Steyaert (1993).

Interest in GIS in the emerging discipline of landscape ecology (Turner & Gardner, 1991) takes a rather different form. Recent research in biodiversity, gap analysis, and related areas has led to concern for simple geometric properties of ecological landscape, such as shape, and their role in determining habitat quality. GIS, with its emphasis on simple geometric analysis and spatial relationships, is an obvious toolbox for supporting such research.

In landscape architecture and related areas of resource management, the analysis functions of GIS perform a direct role in problem

solving, modeling, and decision making. Here GIS is equivalent to a programming language, and the commands of GIS are in simple correspondence to the primitive operations needed by the scientist or manager. GIS has perhaps reached its highest level of analytic sophistication in these disciplines, where efforts have been made to codify the appropriate set of commands into simple spatial languages. Tomlin (1990) gives an excellent treatment of this field.

For many other scientists, GIS is a toolbox with useful commands, but some form of coupling must exist with other types of software in order to create a complete research environment. GIS typically do not contain statistical functions, or optimization routines, so it is common to find GIS coupled with the statistical packages: SAS, SPSS, S, and the like. Other specialized research may require the development of special modules, written in source languages like C, and coupled with the GIS. In these cases GIS performs the role of a general-purpose manager of spatial data.

This extensive adoption of GIS as a useful research tool has gone on with little regard for disciplinary boundaries, and despite the limited state of development of the technology. One now finds software like ARC/INFO installed widely on major research campuses—at Santa Barbara, we now have well over 100 licenses distributed across half a dozen departments. Geography has often been the initiator, but GIS is as likely to be found in biology, geology, anthropology, or any other discipline in which a spatial perspective is useful and insightful. However, GIS is most likely to be taught in one of the disciplines that contribute to geographic information science, particularly geography but also civil engineering, surveying, and geodesy.

Of all these disciplines, geography is clearly the one most able to close a critical gap in the use of GIS, the ability to combine an understanding of real geographic phenomena with the issues of their representation in a spatial database. Spatial representation is a strong part of a geographic education, and so too is a broadly based understanding of processes that affect the geographical landscape. Thus if the key issues of GIS are those of spatial representation in digital form, as I argued earlier in this chapter, then geography is the discipline most equipped to address them. It is the geomorphologist who is best able to choose the data model for representation of terrain in a GIS, not the computer scientist or the statistician, and it is the urban geographer who is best able to advise on how to represent the many facets of the urban environment in a GIS designed for urban planning. Outside geography, there seems to be widespread acceptance of this position, and a genuine willingness to hire geographers to provide the conceptual and intellectual framework for GIS.

GIS AND ETHICS

Many aspects of the GIS phenomenon continue to puzzle me. Why does the GIS community—defined, say, as the group of 3,000 or so people who attend one of the annual GIS/LIS (Land Information Systems) conferences—attract such a wide range of people, from computer hackers to map collectors? Maps are attractive because they are visual and they stimulate the imagination, and perhaps also because they present the world as simpler, more orderly, and less dynamic than it really is. Computers are attractive because they give power to their users, convey prestige and status, and behave in orderly ways. Is GIS attractive because these two sets of factors are somehow complementary? Or is it attractive because it allows people without training in cartography to make maps, people with little training in geography to analyze geographical distributions, and people without mathematical skills to model spatial phenomena?

Whatever the reasons, the strength of the GIS phenomenon is indisputable, and nowhere more so than in agencies of the federal government. In the past few years, the U.S. Environmental Protection Agency, the U.S. Forest Service, the Bureau of Land Management, the U.S. Geological Survey, and the Department of the Navy, among others, have all undertaken or initiated major procurements of GIS. In September 1992, the Department of the Navy announced the award of a contract valued at over $400 million to Intergraph Corporation for the supply of several thousand GIS workstations, with associated services, and a similar-sized procurement by the U.S. Forest Service was under way. Why would an agency like the Forest Service, charged with management of the nation's National Forests, undertake such a procurement and at the same time reduce staffing of backcountry stations, expenditures on fire protection, and other more traditional forms of resource management? Does society really want a Forest Service of GIS users at computer terminals rather than one of rangers on horseback?

It is easy to speculate on explanations, but it would be better to do so within the frameworks provided by the literature and major theories of social processes. GIS is now too widely adopted to be ignored;

perhaps it is the most significant event in spatial data handling since the invention of the map. We need to understand GIS's success, and the statements that it makes about the nature of society and its organizations. Is the Forest Service procurement part of an inevitable process in our litigious society toward management practices that are standardized and procedural, and therefore more open, and more defensible in court? Does it reflect a desire by management to control the actions and decisions of the organization, and an unwillingness to trust individuals to make decisions? Is a GIS user empowered by the technology, or demeaned by it? In many ways the GIS phenomenon surely mirrors patterns already evident in the adoption of other technologies in large organizations, but seldom have these been of such magnitude, and made at such cost. Although these issues clearly have little relevance to scientific users of GIS, they are important parts of the GIS research agenda for less technically minded geographers. Perhaps the recent literature on ethics and GIS cited earlier, and the other chapters of this book, will be the beginnings of a productive literature on GIS by geography's social theorists.

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CHAPTER 3

Geographic Information Systems and Geography

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The portrayal of how geography has developed must always be a reconstruction. (Olavi Grano, 1981, p. 17)

GIS AS AN OUTGROWTH OF THE "QUANTITATIVE REVOLUTION"

The recent phenomenal growth of interest in geographical information systems (GIS) within geography is not an autonomous process. Rather, it is part of the discipline's ongoing development and as such can be interpreted using the concepts devised in historiographic studies of geography. In fact, the rise of GIS fits very neatly into the contextual approach to the history of geography, which focuses on balancing the influence of "external" and "internal" factors on disciplinary change (Stoddart, 1981). Obviously GIS represents the interface between geography and an external technology, because developments in computers have been the key enabling factor that has made GIS possible. In this chapter we concentrate on the other half of the story, the much more contested question of how GIS emerged out of intellectual trends within geography.

The "quantitative revolution" provides a benchmark for considering contemporary geography (Taylor, 1991), and this is particularly the case for GIS. In the 1950s and 1960s a powerful intellectual move-