GIS and Basic Research: The National Center for Geographic Information and Analysis

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The National Center for Geographic Information and Analysis (NCGIA) was established by the National Science Foundation in late 1988 to conduct basic GIS research. Its Research Plan is based on the contention that numerous impediments to the use of GIS technology exist, which must be removed if the technology's potential is to be realized fully. The article reviews the current state of GIS, arguing that it is a loose consortium of interests held together by common hardware and software solutions. The NCGIA is particularly concerned with the role of GIS within the broad scientific community. Research is organized as a series of initiatives, of which six are currently under way, focused on specific sets of impediments. Issues facing the Center and affecting its future research directions include the balance between basic and applied research, education and training, social and physical sciences, and scientific and infrastructural applications of GIS. The future of GIS will depend on the extent to which it can develop an intellectual core.

The establishment of the National Center for Geographic Information and Analysis (NCGIA) was announced by the National Science Foundation (NSF) on August 19, 1988. It consists of a consortium of three institutions: the University of California, Santa Barbara as the lead institution, together with the State University of New York at Buffalo, and the University of Maine. David S. Simonett and Michael F. Goodchild are the Center's co-Directors, located at Santa Barbara; Terence R. Smith, Ross D. MacKinnon and Andrew U. Frank are the Associate Directors at Santa Barbara, Buffalo and Maine respectively. General

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oversight is provided by a 17-member Board of Directors chaired by John E. Estes. Abler has described the process of creating the Center, which began with a proposal to NSF from Jerome Dobson of Oak Ridge National Laboratory in 1984.[1] Funding for the Center from NSF is initially at a level of $1.1 million per year for 5 years.

The primary purpose of the Center was laid down in the solicitation document issued by NSF in late 1987: to conduct "basic research on geographic analysis utilizing geographic information systems." This puts the emphasis clearly on applications, and particularly scientific and policy-oriented applications, rather than on technical development. On the one hand, the statement of purpose implies that the technology offers significant potential for a wide range of geographically based analyses. On the other, it suggests that although GIS has been widely adopted as a technology in numerous fields, its applications to date have often been relatively unsophisticated. Openshaw has described GIS as "20th century technology being used for 19th century purposes."[2] implying dissatisfaction with the somewhat rudimentary nature of many applications.

The purposes of this article are as follows:

- Provide an overview of the Center's detailed research plan, which has already been published in the International Journal of Geographical Information Systems[3];
- Describe some of the thinking which lay behind the formulation of the research plan, and a perspective on the present state of the GIS field;
- Summarize the progress made in the first year following the official start date of November 15, 1988; and,
- Discuss some of the issues now confronting the Center.

OVERVIEW OF GIS

The very rapid rates of growth which have occurred in the GIS industry in the past five years create the impression that this is a new phenomenon. In fact, the roots of GIS go back to the mid-1960s, when the term was coined independently and virtually simultaneously in two different fields. Marble and others at Northwestern University used "Geographic Information System" to describe a computer-based system for management and modeling of transportation networks, in connection with the large-scale transportation studies then in vogue. Almost at the same time Tomlinson and others in the Canadian federal government were developing the "Canada Geographic Information System (CGIS)" as a practical solution to the problems of managing and analyzing the data being collected by the Canada Land Inventory.

Although the same term was used in both cases, there is no evidence that the designers of CGIS believed that their system could be used to model traffic flows, or that a system for modeling traffic would be useful for resource management. Even today, GIS is not so much a homogeneous community as a collection of largely independent application fields loosely held together by a common set of software and hardware solutions. The development of a sense of commonality is one of the more significant elements in the evolution of GIS over the past two decades. Nevertheless, GIS still lacks a clear intellectual core, and although a consensus is developing, there are still major differences of approach between the various groups which make up the GIS community. In essence, this is a "bottom-up" field, defined by its component parts rather than by acknowledged commonalities. It lacks almost all of the usual trappings of an intellectual core—textbooks, disciplines, academic departments, journals, and learned societies—although this situation is changing rapidly.

Definitions of GIS

It is perhaps not surprising that there is no single, widely accepted definition of a GIS. "Geographic" implies only that the database is georeferenced, or that it includes some means of accessing data by geographic location. To be called an "Information System", a software product must integrate a variety of functions, and must allow the user to access a database without detailed knowledge of its format. A GIS can be defined by its functionality ("a system for input, storage, analysis, and output of geographically referenced information"), its contents ("a system containing geographically referenced information"), or by its purpose ("a system for support of spatial decision making"). However, all three are broad enough to include a vast array of software products.

The next sections provide a brief overview of the application fields of GIS. From a sociological perspective, these are some of the more significant subcultures which make up the GIS consortium. The fields are not exclusive or exhaustive. This attempt at a taxonomy is merely intended to underscore the diversity of GIS at this stage of its development.[4]

Resource Management

Maps are very efficient stores of information, but it is surprisingly difficult to obtain certain types of numeric information from them. One traditional method of measuring area, for example, requires the counting of dots on a transparent overlay, an extremely tedious and labor-intensive operation. Nevertheless, such measurements are an essential part of many aspects of resource management, for example in computing timber yields in forestry. Three operations are particularly significant in explaining the early interest in GIS applications in resource management: measurement of area, superimposition and analysis maps of different themes, and the generation of buffer zones of specified width around map features.

Infrastructure Management

Organizations which maintain complex infrastructure need the ability to track and manage installations geographically. For example, it is important to a utility company to know the locations of requests for service in order to schedule its service vehicles efficiently. "One-call" services which provide information on underground infrastructure rely almost entirely on geographical access to records, in order to identify any existing facilities within range of a proposed construction project. Major customers for infrastructure management using GIS include utilities, departments of transportation, railroad companies, and city and county engineering departments. The acronym AM/FM (automated mapping/facilities management) is often used for infrastructure applications of GIS.

Land Information Systems

Land information systems (LIS) maintain data on individual ownership parcels and associated attributes relevant to assessment and taxation. The term "multipurpose cadaster" (MPC) refers to a parcel-level database used to support activities in a number of areas besides taxation, such as infrastructure management. Since an LIS is often constructed from raw survey information, there is a strong linkage between this field and the discipline of surveying, just as resource management applications are often strongly linked with remote sensing.

Vehicle Routing and Scheduling

In resources and infrastructure applications, it is widely acknowledged that the establishment of the necessary database can often absorb the majority of the system's budget. Other applications of GIS have grown around existing digital databases, in part because the costs of data input can be largely avoided. The existence of the Bureau of the Census's TIGER and DIME files has led to a number of GIS applications, particularly in the routing and scheduling of vehicles. Vehicle navigation aids, for example, offer the capability to display to the driver a continuously updated route map. Vehicle routing systems generate instructions for following an optimum path through a street network.[5]

Marketing and Retailing

Location is of paramount importance in determining the success or failure of retail establishments, so it is not surprising that geographical factors play a significant role in retail analysis. Marketing and retailing are comparatively recent application areas for GIS. Key GIS functions in this field include: geocoding, the ability to generate coordinate locations from street addresses; point in polygon operations to identify the reporting zone (e.g., ZIP code and census tract) containing a customer's location; and polygon overlay to transfer estimates of population counts between two sets of incompatible reporting zones.[6]

Related Disciplines

An alternative view of GIS is that it is an intersection (or perhaps union) of disciplines. As a technology, it combines aspects of cartography, remote sensing, photogrammetry, surveying, geodesy, computer science and computer engineering—in computer science, particularly computer graphics, computational geometry and databases. The applications of GIS and its role in public policy formation intersect the interests of forestry, environmental science, urban planning, civil engineering, transportation, and landscape architecture. Geography has a very strong interest in GIS because of its emphasis on spatial analysis, spatial processes and the role of space as an organizing framework. Finally, GIS technology has a technical role to play in supporting a wide variety of disciplines concerned with spatial data, including the earth sciences, history, anthropology, demography, political science, sociology, economics, etc.

Growth of GIS

Although the roots of GIS go back to the 1960s, the current period of dramatic growth of interest began only in 1980, when the field as a whole moved into the central portion of the logistic growth curve. Several factors account for the very long lead time, and the emergence of GIS as a prominent technology in the past decade.[7] First, 1980 marked a key stage in the development of hardware and the continual reduction in computer costs. The "super-minis" which emerged from companies such as Digital, Prime and Data General around that time were the first to provide sufficient computing power and storage for GIS applications in a low-maintenance, dedicated machine. The 386-based machines of 1987/1988 were similarly critical in opening GIS applications within the desktop environment.

Second, a GIS is a complex software product, and it is estimated that on the order of 10 person-years are required to develop a minimal system capable of competing in the marketplace. By 1980, interest in GIS had risen to the point where these levels of investment could be justified against likely returns. The 1960s and 1970s were also a vitally necessary period of research and development, and produced many key advances in the areas of data structures and algorithms.

Finally, and perhaps most importantly, GIS applications do not generally replace existing activities, unlike word processing for example. The products which a GIS is capable of generating have typically not played a large role in traditional decision-making, because of the difficulty and expense of generating them by hand. The case for GIS must often be based on the benefits of new products, and these must be weighed against the fact that GIS applications typically add new costs and do little to reduce existing ones.

The GIS Industry

Recent surveys[8] have placed the size of the GIS software industry between $150 and $300 million annually, growing at perhaps 35% per year. Total GIS-related activities, including data collection, management, hardware sales etc. clearly run to many billions. What are the characteristics of the current industry, and how can this be expected to change in the future as the industry matures?

First, current software products show an enormous diversity of functionality, limitations, operating systems, hardware platforms, data structures, etc. There are few if any widely accepted standards in the industry. In part, this is a consequence of rapid growth, particularly in newer application areas where requirements are not yet well-defined. Because much current GIS software originated in research environments, standards of software engineering are sometimes low in comparison with other, more mature software industries such as CAD. Systems have often been criticized for their lack of clear conceptual designs, poor approaches to data security and transaction management, and crude user interfaces.

Second, the GIS industry is characterized by substantial development times and slow market acceptance for new products. As a result, there is often a gap of as much as 10 years between initial design and final acceptance. Many of the products now on the market reflect hardware and software approaches of 10 years ago, and many find it difficult to retro-fit more recent advances in hardware, operating systems or graphics interfaces.

As the industry matures, we can expect to see increasing dependence on standards, particularly in data formats and structures and in user interfaces. Products will slowly converge as competition forces vendors to offer a common set of functions and capabilities. Vendors who can substantially reduce the product lead time, and offer systems which exploit the latest advances in hardware and software will enjoy a competitive edge, provided they can at the same time offer upward compatibility to users with large investments in existing systems.

On the other hand, substantial differences between various classes of GIS applications may lead to a bifurcation in the industry, as vendors choose to specialize in specific submarkets. There are indications that this is already happening in the case of infrastructure applications and perhaps LIS. High functionality, high volumes, and fast access are to a large extent incompatible in today's hardware environment, but the complex functionality needed to support resource management and marketing applications is largely unnecessary in infrastructure applications—instead, these tend to require fast response to a few simple classes of queries from databases which may be extremely large.

Education and Training

One of the most important factors currently limiting growth in GIS is the extreme shortage of adequately trained staff. GIS is a comparatively new field at the edge of several disciplines, and not well served by people trained in the traditional curricula of any one discipline alone. Although many positions in GIS technical support can be staffed by people trained in computer science, it is currently almost impossible to find people with the ability to relate GIS technology to potential applications, that is, people with an understanding both of the application context and of the technological solution. The lack of people with doctorates in GIS able to fill the range of university positions currently being advertized means that this situation is unlikely to improve substantially in the short term.

OBJECTIVES OF THE CENTER

The previous sections have outlined the setting within which NSF chose to establish the Center, and aspects of the Center's underlying rationale. To quote from the solicitation document, the goals of the Center are to:

- Advance the theory, methods and techniques of geographic analysis based on GIS in the many disciplines involved in GIS research;
- Augment the nation's supply of experts in GIS and geographic analysis in participating disciplines;
- Promote the diffusion of analysis based on GIS throughout the scientific community; and
- Provide a central clearinghouse and conduit for disseminating information regarding research, teaching and applications.

The first and third goals both give the Center a role in promoting GIS specifically as an enabling technology for science. The GIS community is currently dominated by applications in management, inventory and policy formation, and the potential scientific applications of GIS have attracted comparatively little interest to date from the scientific community. Scientific applications stress the power of GIS to place information in a spatial context, to suggest relationships based on spatial proximity, and to explore the role of distance as a causal factor. For example, GIS can assist in superimposing spatially organized data (maps) from different sources, and one can envision an "exploratory spatial analysis" tool analogous to the Exploratory Data Analysis (EDA) tools now common in statistics.[9] GIS technology greatly increases our ability to view data from different perspectives and under different forms of manipulation and summary. In fact, it seems that the power of spatial organization to suggest causes, explanations and relationships is significantly superior to other forms of data organization, such as the table or even the graph. Recently ESA tools have begun to offer the capability to view data through multiple windows—tabular, graphical and cartographic—with simultaneous updating, so that movement of a cursor within the cartographic window results in continuous (and appropriate) updating of the tabular window, for example.

Applications of GIS in the social sciences have lagged behind those in the earth and natural sciences for many reasons. Funding for technical tools is less readily available; there is a general suspicion of technical approaches in many areas of social science; data may be less reliable and harder to come by; and spatial analysis has only recently become common in disciplines such as history and anthropology. The Center's role as a promoter of scientific applications of GIS applies especially to the social sciences.

Besides ESA, scientific applications require comparatively sophisticated capabilities for modeling and analysis, which are lacking in many GIS activities. The Center therefore stresses not only the incorporation of spatial modeling and analysis techniques with GIS, but also the formal, theoretical basis for GIS and the development of an intellectual and conceptual core to the field.

A useful analogy is between GIS as a scientific tool and other widely distributed software tools for science such as the statistical packages (e.g., SAS, SPSS, and BMD). These have emerged in a similar time frame to GIS, but almost entirely as products for the scientific market, whereas the scientific applications of GIS have had relatively little role in driving and directing its development. Although there is some overlap, one can argue that GIS is a supporting tool for spatial analysis in the same way that SAS, for example, is a supporting tool for statistical analysis. Given the usefulness of spatial organization and the spatial context for data, one might contend that the long-term potential for GIS in this context is as large as it is for SAS.

Based on these goals, the Center's programs fall into three general areas: research, education and outreach. Specific approaches taken to the research objectives are discussed in the next section.[10]

RESEARCH AGENDA

Research Plan

The Center's research agenda is based on the proposition that GIS technology has enormous potential in a variety of applications, particularly science, but that numerous impediments currently exist which constrain the full realization of that potential. The Research Plan[11] described these impediments in detail under five general headings (in large part these match the five suggested areas of research contained in the NSF solicitation) so they will be merely summarized here:

- Spatial analysis and spatial statistics. Impediments exist in the lack of implementation of spatial analytic methods within GIS, and also in the lack of explicit treatment of data quality (accuracy and uncertainty) in current systems;
- Spatial relationships and database structures. The power of a GIS is constrained by the methods used to represent spatial data within its database. Current systems use a limited range of data models and structures, often derived from cartographic representations, and are based on inadequate understanding of the nature of spatial relationships;
- Artificial intelligence (AI) and expert systems. Many analysis and modeling requirements of GIS are poorly structured and could benefit from AI technologies, as could the complex processes of data input and output;
- Visualization of spatial data. The electronic display offers enormous potential for improved methods of visualization, but current GIS technology largely fails to exploit the capabilities of the new medium; and
- Social, economic, and institutional issues. GIS technology raises numerous issues of a managerial, organizational or legal nature, and its adoption is currently impeded by the difficulties of accurately assessing its costs and benefits, and by adequate understanding of its impact on organizations.

In formulating a specific agenda of research, the Center looked for a mechanism which would allow it to operate as a three-institution, multidisciplinary, multi-investigator consortium but at the same time focus attention on well-defined topics within the broader research plan. The Center also realized that the plan defined a range of research topics which would be far too large for it to handle, and that the mechanism would therefore have to allow it to encourage and stimulate as much research outside the Center as possible, and provide effective two-way communication.

Research Initiatives

The research plan is implemented through a series of Research Initiatives, based on a model which has worked well at UCSB's Institute for Theoretical Physics. An initiative lasts for between one and two years, with four or five running at any one time. It begins with a Specialist Meeting, which brings together from 25 to 50 people from three constituencies: organizations with experience of the problem and its effects, researchers with interests in solving the problem, and representatives from the vendor community who can implement the solutions. The purpose of the specialist meeting is to lay out the specific research agenda, including tasks which can be accomplished by the Center or affiliated groups and individuals in the timeframe of the initiative, but recognizing that the meeting will have a role in stimulating research by other groups and individuals as well. The subsequent research at the Center is undertaken by faculty, research assistants, and visiting researchers, and the results are reported at a suitable occasion such as a national or international conference. In several cases it has proven useful to establish a mailing network associated with an initiative, to distribute current information about research activities during the research period.

The current program of initiatives is as follows, with the names of initiative leaders and dates of specialist meetings:

1. Accuracy of Spatial Databases (Michael F. Goodchild, Santa Barbara; December, 1988). GIS are high precision systems which process data as if they were perfectly accurate: in reality, spatial data are often subject to surprisingly high levels of uncertainty and inaccuracy, which current GIS designs largely ignore. Over 50 people attended the specialist meeting for the first research initiative, and a book is being published from the proceedings. Research has been under way for almost a year, and results are starting to appear in different forms. Specific research activities include a bibliography and taxonomy of spatial data errors, to raise user awareness of the problem; fundamental work on the formulation of models of error; methods for incorporating error information within spatial databases; analysis of the propagation of error through GIS processes; and development of finite resolution data structures.
2. Languages of Spatial Relations (David M. Mark, Buffalo; Andrew U. Frank, Maine; January, 1988). GIS can be seen broadly as a technology for helping people work with spatial data, and more specifically as a tool for learning and reasoning about space and spatial relationships. As such, the technology will be most useful when its data representations and operations emulate the learning and reasoning processes of users, yet current data models and structures fall far short of this ideal. Initiative 2 is conducting research which will ultimately help to improve the way spatial data is represented digitally, and the design of GIS user interfaces. The research agenda includes the following topics: wayfinding, driving directions and processes of spatial knowledge acquisition; analysis of the structure, cross-cultural and cross-linguistic variations of driving directions, with potential applications to vehicle navigation aid systems; cross-linguistic analysis of locative expressions, and studies of linguistic variation in natural language terms for spatial relations; user interface design, including research on multi-media interfaces, metaphors for conveying and perceiving spatial information, and the visualization of spatial relations; and formalization of spatial relationships, the algebra of spatial relations, and formal reasoning.
3. Multiple Representations (Barbara P. Buttenfield, Buffalo; February 1989). The representation of a geographical feature on a map depends on the map's scale, and the same feature will likely be represented in markedly different ways at various scales. Within a spatial database it is attractive to imagine that a feature might be given a single representation, which would be generalized or simplified for display at different scales. Because this has proven difficult to do, it is common for databases to contain several representations of the same features. Moreover, GIS databases currently provide no explicit and fully satisfactory means of logically relating the various representations of a feature. Hierarchical data structures offer potential and are one of the research topics of this initiative. Other topics include definition of the rules required to automate the generalization process; systems for describing the ways features change with scale; and data structures which formalize the logical relationships of multiple representations. The Center is developing a multi-agency, multi-scale database to be distributed as a standard for research work in this area.
4. Use and Value of Geographic Information (Harlan Onsrud, Maine; Hugh Calkins, Buffalo; May 1989). This is the first initiative to address the social, economic, and institu-

tional issues raised by the adoption of GIS technology. Three research themes emerged at the specialist meeting: the need for a taxonomy of geographic information and its uses; development of objective methods for measuring the value of geographic information; and empirical studies of the diffusion of GIS technology. The taxonomy must address questions such as: what types of geographic information exist, and how do they relate to the variety of data models of spatial databases; are certain types of geographic information more or less suitable for handling in spatial databases; what role does geographic information play in human activity, who uses it, and for what purposes? Objective measurement of the value of geographic information is an essential component of any serious attempt to evaluate GIS benefits. Finally, research on the diffusion of GIS technology will determine the factors which control the rate of diffusion, and how they can be modified.

5. Design and Implementation of Large Spatial Databases (Terence R. Smith, Santa Barbara; Andrew U. Frank, Maine; July 1989). Two meetings were held on this topic in July 1989: a symposium with formal position papers, and a smaller workshop discussion to lay out the initiative's research agenda. The initiative will examine the technical problems which arise in handling the large spatial databases now being constructed, such as the U.S. Geological Survey's digital cartographic database.

6. Spatial Decision Support Systems (Paul J. Densham, Buffalo; Michael F. Goodchild, Santa Barbara; March 1990). The specialist meeting for this initiative was held in March 1990, and looked at the issues surrounding the development of decision support systems based on GIS technology.[12]

Future Initiatives

Future plans call for further initiatives which will extend the range of research foci, but at the same time build on the results of previous work. Initiatives 7 through 12 have been identified:

7. Visualization of the quality of spatial information;
8. Expert systems for cartographic design;
9. Institutions sharing spatial information;
10. Temporal relations in GIS;
11. Space-time statistical models in GIS; and
12. Remote sensing and GIS.

This list of initiatives represents a grouping and prioritization of the much larger set of impediments identified in the research plan. It is likely that the order will change, and that the list will be extended, in response to future changes in priorities.

Several specific issues are likely to affect future planning for research initiatives. First, although the methodology and subject matter for much of Initiatives 2, 4 and 9 belong in the social sciences, as well as many of the applications of Initiative 1, no initiative is directed explicitly at developing social science applications of GIS. To rectify this, the Center is planning a conference specifically on that topic in late 1990. Second, GIS technology has enormous potential in modeling the global environment and the interaction between human and physical systems at global scales. Yet no initiative is explicitly concerned with global scale GIS, although there is relevant research in Initiatives 1 and 5. Data input and conversion are a topic of great significance to the GIS community but not explicitly treated in the current agenda. It may be necessary to find ways of increasing the number of initiatives which can be supported, at any one time, perhaps by a mechanism which would allow initiatives to be led at sites outside the Center.

ISSUES AND CONCERNS

This section identifies some broader issues of concern to the Center at this time and related to the general development of GIS.

Science vs. Infrastructure

Earlier sections touched on the fundamental differences between two extreme forms of GIS application: the analysis and modeling workstation suited primarily for scientific and public policy application; and applications which emphasize fast, repetitive access to large administrative databases. The dichotomy is illustrated by a pair of vendors currently operating in the GIS market and owned by the same parent company. One markets "Geographic Information" systems, largely to municipal and utility customers, while the other sells "Spatial Analysis" systems to a variety of customers, including government agencies and universities. If this suggestion of dichotomy strengthens within the industry, the effect may be a reduction in the resources available for development and marketing of spatial analysis tools for scientific and public policy applications.

What can be done to ensure continued development of spatial analysis tools? First, vendors must perceive the analytic market as large enough to warrant attention, and the university market as essential to their long-term interests because of its role in educating GIS professionals. Second, it is essential to develop the activities and institutions necessary for survival of any scientific field—courses, programs, texts, journals, conferences, and learned societies. In the long run, one might envision a specific science of spatial information, occupying the common ground between GIS, cartography, remote sensing, spatial analysis, spatial statistics, surveying, and photogrammetry. The intellectual core of the discipline might be formed by a formal theory of spatial information and spatial relationships.

Basic vs. Applied Research

It is interesting to compare the context and objectives of the NCGIA with those of the comparable organization in the United Kingdom, the Economic and Social Research Council's Regional Research Laboratories.[13] The total funding available to the two programs is similar, and there are similarities also in the overall objectives. Although the NCGIA is spread over three sites, it is nevertheless funded as a single, national consortium for basic research. In the UK, on the other hand, there are currently 8 RRLs involving a total of 17 institutions, located in a deliberate attempt to provide research and development potential in every major region of the country. There is a much heavier emphasis on tangible products—software and applied research—and on proselytizing within the local community. Finally, the funding for the RRLs is for a more limited period of 3 years, after which the centers are expected to be entirely self-supporting.

NCGIA has taken the position that its primary concern is with basic research, built around the concept of impediments. Although much basic research requires the development of software prototypes, our strategy has been to develop linkages with industry which can be used to transfer prototypes as rapidly as possible. GIS software and expertise are already widely available in the United States in universities and corporations, and there would be little point in a national center competing with established university groups and companies in applying GIS technology to local problems.

The Future of GIS

The high growth rate experienced recently in the GIS industry is exciting, but it inevitably lead to concern for the future: how long can the GIS phenomenon last, and has GIS been oversold? To some extent, growth has been sustained because new application fields have appeared, or new disciplines have become interested in GIS tools, but this cannot continue forever.

GIS is a loose collection of interests held together by common hardware and software solutions, whose long-term survival depends on the emergence of an intellectual core and the symbols and institutions normally associated with a discipline. It is difficult to think of precedents in the form of disciplines which have been founded on tools, although one might argue that computer science emerged when computing found an intellectual foundation, and developed a program of basic, fundamental research. The 20-year horizon seems to offer two alternative scenarios for GIS: a technology which failed to deliver on its promises, or a technology which blossomed into a spatial information science.

FURTHER INFORMATION

The Center publishes a Newsletter in June and December each year, and a Technical Papers series. Information on these and other publications, and on any aspect of the Center's activities in research, education, or outreach can be obtained from any of the three sites:

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NOTES AND REFERENCES

1. R.F. Abler, "The National Science Foundation National Center for Geographic Information and Analysis," *International Journal of Geographical Information Systems,* 1 (1987): 303–326.
2. S. Openshaw, "Quest Editorial: An Automated Geographical Analysis System," *Environment and Planning A,* 19 (1987): 431–436.
3. NCGIA, "The Research Plan of the National Center for Geographic Information and Analysis," *International Journal of Geographical Information Systems,* 3 (1989): 117–136.
4. For general texts on GIS see J. Star and J.E. Estes, *Geographic Information Systems: An Introduction* (Englewood Cliffs, NJ: Prentice Hall, 1990); S. Aronoff, *Geographic Information Systems: A Management Perspective* (Ottawa: WDL Publications, 1989); P.A. Burrough, *Geographical Information Systems for Land Resources Assessment* (Oxford: Clarendon, 1986).
5. For a discussion of vehicle navigation aids see M. McGranaghan, D.M. Mark, and M.D. Gould, "Automated Provision of Navigation Assistance to Drivers," *The American Cartographer,* 14 (1987): 121–138.
6. For a more extensive discussion of GIS applications in this area see M.F. Goodchild, "Geographic Information Systems and Market Research," *Papers and Proceedings of Applied Geography Conferences,* 12 (1989): 1–8.
7. R.F. Tomlinson, "Current and Potential Uses of GIS: The North American Experience," *International Journal of Geographical Information Systems,* 1 (1987): 203–218.
8. Gene Bylinsky, "Managing with Electronic Maps," *Fortune* (April 1989).
9. See J.W. Tukey, *Exploratory Data Analysis* (Reading, MA: Addison-Wesley, 1977).
10. Readers interested in the education agenda can find a recent summary in M.F. Goodchild, "The National Center for Geographic Information and Analysis: Year One," *ACSM Bulletin,* 123 (December 1989): 35–40.
11. NCGIA, op. cit. (see note 3)
12. P.J. Densham and M.F. Goodchild, "Spatial Decision Support Systems: A Research Agenda," *Proceedings, GIS/LIS '89* (Bethesda, MD: ASPRS/ACSM/AAG/URISA, 1989), pp. 707–716.
13. J.W. Shepherd, I. Masser, M. Blakemore, and D.W. Rhind, "The ESRC's Regional Research Laboratories: An Alternative Approach to the NCGIA," *Proceedings, AutoCarto,* 9 (Bethesda, MD: ASPRS/ACSM, 1989): 764–774.