By Michael F. Goodchild

The National Center For Geographic Information and Analysis

1 YEAR

November 15 marked the end of the first year of funding for the National Science Foundation's National Center for Geographic Information and Analysis (NCGIA). Our anniversary provides an opportunity to step back and assess the center's development thus far. This article describes how NCGIA was established, the progress made on its research and education agendas, and current trends in the field and their potential impact on the center.

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Y E A R

BACKGROUND

On August 19, 1988, the National Science Foundation (NSF) awarded the NCGIA to a consortium of the University of California, Santa Barbara, the State University of New York at Buffalo, and the University of Maine, with funding of $1.1 million a year for five years. Ron Abler, who was director of the Geography and Regional Science Program at NSF until his return to Pennsylvania State University in July 1988, has described the decision to establish the center and the process that led to selection of the winning consortium in an article published in the *International Journal of Geographical Information Systems* (1987, vol. 1, pp. 303-326).

NSF's solicitation for the center (published in 1987) identified "basic research on geographic analysis utilizing GIS" as the center's primary mission and suggested five areas as possible research topics: improved methods of spatial analysis and advances in spatial statistics; a general theory of spatial relationships and data base structures; artificial intelligence and expert systems relevant to the development of geographic information systems; visualization research pertaining to the display and use of spatial data; and social, economic, and institutional issues arising from the use of GIS technology.

In addition to research, the center was to take steps to "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 for disseminating information regarding research, teaching, and applications."

The solicitation, which appeared in mid-1987, attracted intense interest. GIS, though emerging as a significant industry, was not identified clearly with any academic discipline and did not have the usual symbols of academic respectability—journals, societies, textbooks, etc. NSF's willingness to commit major funding for basic GIS research seemed to give the field a new level of respectability, not only as a tool for management and mapping, but as a powerful technology for scientific analysis and research.

Moreover, the funding was to be channeled through NSF's Geography and Regional Science Program and Division of Social and Economic Science, unlike previous centers established in science and engineering. This reinforces belief in GIS as an "enabling technology" for a wide range of sciences dealing with spatially distributed phenomena.

ESTABLISHMENT

The center is housed in two geography departments (Santa Barbara and Buffalo) and in a surveying engineering department (Maine). Michael Goodchild and David Simonett, Santa Barbara, are the co-directors; the three associate directors manage the site operations: Terence Smith in Santa Barbara, Ross Mackinnon in Buffalo, and Andrew Frank in Maine.

A board of directors, which meets in June and December, reviews all aspects of the center's operation. The 18 members, who are drawn from universities, industry, government agencies, and professional societies, include three members of the National Academy of Sciences. John E. Estes, University of California, Santa Barbara, is chairman of the board.

The Santa Barbara operation moved into its permanent quarters last September. The Buffalo site will be moving with the geography department into renovated space early next year and at the Maine site there are plans for a new building to house the center and the surveying engineering department.

RESEARCH

The consortium proposed a research plan built around the concept of "impediments": that GIS technology had enormous potential, but that numerous roadblocks needed to be overcome. Some obstacles were technical, such as the unfriendliness of many user interfaces; some were institutional, such as the lack of

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1 YEAR

standards for digital geographical data; and others were social and economic, including the difficulty of assessing costs and benefits of GIS, and lack of understanding of the impacts of GIS technology on organizations.

Research at the center is organized around the systematic removal of these impediments, within the five areas suggested in the solicitation document. The full text of the research plan has been published in the *International Journal of Geographical Information Systems* (1987, vol. 1, pp. 303-326).

The research program is structured as a series of initiatives, each one focusing on a single topic for a period of one to two years. An initiative begins with a specialist meeting, which brings together outside experts to plan the initiative's agenda. Typical meetings held in the first year have involved from 25 to 50 people from universities, government agencies, and industry.

During the first year the center began research initiatives in five areas:

1. **Accuracy of Spatial Data Bases.** Many GIS users are aware of the problems that result from inaccuracies or errors in spatial data, and the way these propagate through GIS operations. More than 50 participants attended the specialist meeting for Initiative 1 in Santa Barbara in December 1988 and developed a research agenda that called for a bibliography and taxonomy of spatial data errors; improved models of error for the contents of spatial data bases; better methods of error description and ways of incorporating these into data bases; analysis of error propagation, particularly in the sophisticated models now being built on spatial data bases; better understanding of the relationship of accuracy and choice of data models, particularly for topographic data; and the role of geography in the accuracy of social and economic data.

Research on these topics began shortly after the specialist meeting and is continuing. Results are available for some areas and have been published in the center's technical papers.

2. **Language of Spatial Relations.** There are considerable differences in the ways spatial data are structured and processed in GIS, and in the ways people learn and reason about spatial information. These gaps will have to be closed if user interfaces are to be improved substantially.

Initiative 2, which held its specialist meeting in Santa Barbara last January, is led by Andrew Frank and David Mark (Buffalo). Research is well under way on the following topics: wayfinding, driving directions, and spatial knowledge acquisition; analysis of their structure, cross-cultural and cross-linguistic variation, with potential application to vehicle navigation aid systems; cross-linguistic analysis of locative expressions, 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, research on formal definitions, the algebra of spatial relations, and formal reasoning.

3. **Multiple Representations.** Although the ability to change the scale of a display is one of the more immediately attractive features of a GIS, scale and spatial resolution are established clearly by such parameters as raster cell size or the scale of the input document. Complex rules of generalization are needed to convert the representation of a simple feature like a coastline to a smaller scale, and it is extremely difficult to convert to a larger scale in an appropriate way. As a result, many data bases must include multiple representations of the same geographical feature.

Initiative 3, led by Barbara Buttenfield in Buffalo, had its specialist meeting last February. This research focuses on hierarchical data structures, which store information about an object or spatially distributed phenomenon at a range of scales; rules to automate the generalization process; systems for describing change of geometry with scale; and data structures that formalize the relationships of multiple representations.

In cooperation with a number of federal agencies, the center is developing a multi-agency, multiscale data base to be distributed as a standard for research work in this area. Next April the center will co-sponsor a symposium, Towards a Rule Base for Map Generalization, at Syracuse University, organized by Barbara Buttenfield and Robert McMaster.

4. **The Use and Value of Geographic Information.** Initiative 4, led by Harlan Onsrud (Maine) and Hugh Calkins (Buffalo), is the first to address social, economic, and institutional issues raised by the adoption of GIS technology. At the specialist meeting held last May three research themes emerged that are being refined by the research team:

The taxonomy of geographic information and its uses. What types of geographic information exist, and how do they relate to the variety of data models of spatial data bases? Are certain types of geographic information more or less suitable for handling in spatial data bases? What role does geographic information play in human activity, who uses it, and for what purposes?

The value of geographic information. It is essential that we be able to measure the benefits of geographic information in decision making if we are to come to grips with the most problematic half of the GIS cost-benefit ratio.

The diffusion of innovations. What factors control the rate at which knowledge about GIS diffuses and the rate at which this new technology is adopted in organizations? If these factors are potential impediments to adoption, how can they be controlled or removed?

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Y E A R

5. **Design and Implementation of Large Spatial Data Bases.** Last July two meetings were held on this research topic in Santa Barbara: a formal symposium that attracted more than 150 participants, and a smaller, more intensive, workshop to develop the initiative's research agenda.

Initiative 5, led by Terence Smith and Andrew Frank, will examine the technical problems that arise in handling the large spatial data bases now being constructed, such as the U.S. Geological Survey's digital cartographic data base.

Next March the center will hold the specialist meeting for Initiative 6, Spatial Decision Support Systems (SDSS), in Santa Barbara. Issues to be discussed include the relationship of SDSS and GIS, data structure and software requirements, the design of user interfaces, and the value of the SDSS approach in complex spatial decision making.

EDUCATION

The rapid development of the GIS field in the last few years has led to an acute shortage of adequately trained staff at all levels, particularly in those areas that require a moderate level of technical skills combined with an understanding of GIS applications.

The center's major effort in education in the past year has been the Core Curriculum Project, which was designed to increase the availability of teaching materials in GIS quickly so that courses could be introduced in new institutions and disciplines.

The curriculum offers a one-year sequence, which may be taken in three quarter courses or two semester courses, with a total of 75 one-hour lectures. The courses include lectures that introduce GIS, and cover technical and application issues, and include lab exercises.

During the 1989-90 academic year, 74 institutions have agreed to evaluate and test the materials by incorporating them into their courses. A large proportion are geography departments, but the test sites also include marine science, geology, anthropology, and engineering and other disciplines. Based on instructor and student feedback, a second, final version of the curriculum will be developed for distribution next summer.

Other education projects the center would like to pursue in the future include short courses for core curriculum instructors; short courses in specialized topics—two such one-day workshops were developed in our first year and presented at several conferences; a case-study course modeled on those offered in many business schools; and training courses for users of specific systems, emphasizing analytic and modeling capabilities.

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1 YEAR

TRENDS IN GIS

One trend with significant implications for GIS and the center is the growing concern about global-scale issues, particularly global environmental change and its human dimensions. Geographic information systems have an enormous role to play in supporting the sciences that will tackle these problems, but at the same time a series of impediments may prevent that role from being played. These include volumes of data far beyond the limits of current GIS; visualization problems in dealing with data distributed over a curved surface; modeling problems in analyzing error propagation through large, non-linear systems; lack of suitable hierarchical structures to handle multi-scale data; and incompatibilities between current image processing systems and GIS, since remote sensing will be a major source of global environmental data.

A second issue facing the center is the balance between GIS applications in the natural, health, and social sciences. Digital spatial data has a more established role in natural science, supporting studies of the environment and its resources, than in the social or health sciences. Yet there is ample reason to suppose that GIS technology has as much potential in supporting research in such areas as locational factors in marketing, retailing, and provision of public services; spatial variation in health, social well-being, crime, justice, employment, etc.; migration and changing demography; epidemiology and spatial variations in the incidence of disease; and planning, transportation, and the impact of the environment on the quality of life.

Many existing examples of spatial decision support systems, the topic of upcoming Initiative 6, are in the areas of resource management. But some of society's most pressing problems are in an area bordering natural and social science. For example, a spatial data base might be built by coding city blocks according to building type, using Topologically Integrated Geographic Encoding and Referencing System (TIGER) files as the base, and estimating each block's susceptibility to earthquakes. An SDSS might then model the locations of structural damage and human injury, utilization of evacuation routes, locations of evacuation centers, order of evacuation of each neighborhood, etc.

To date, one of the most common applications of GIS technology in social science has been in archaeology, where it is helping to inventory and understand such problems as the detailed spatial juxtaposition of artifacts at excavated sites and early patterns of human settlement.

To explore the issues involved in encouraging greater use of GIS technology in the social sciences, the center is planning a conference in 1990 entitled GIS and Social Science Research: Potentials, Problems and Present Status.

A third issue confronting the center is the nature of the GIS field itself. At present, GIS is a loose collection of interests without strong identification with any one discipline. On the academic side it has elements of surveying, cartography, geography, environmental studies, forestry, and anthropology. It includes applications in resource management, facilities management, land information, urban government, and mapping. As the field matures we can expect to see increasing specialization, as the community comes to recognize natural divisions within what we now identify as GIS.

Already there are signs that one particular dimension effectively differentiates the community, although it is far from a clear division at this point. At one end of the continuum are systems designed to support complex decision making, as occurs in forestry management, where a GIS must

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provide the information needed to determine cutting schedules, road maintenance, replanting, etc. This type of application has led to the definition of GIS as a spatial decision support technology, and as an enabling technology for scientific research. Such systems are characterized by a data base that may contain many different types and scales of data, and software with a high level of functionality.

At the other end of the continuum are systems that began with the addition of simple geographical access to large, existing administrative data bases. For example, a city government may wish to "add geography" to an existing data base of land parcel records. Systems for this class of application are characterized by fast access, the ability to interface with a variety of data base management systems, and a relatively low level of functionality.

Which way is the field going? Is the second type of application larger in terms of potential market, and will the GIS vendor community be drawn in this direction, or will two types of vendors emerge? Or are the needs of both ends similar enough to prevent a split in the field? From the center's perspective, do both ends share common problems and impediments that can be addressed with a single research agenda and single education strategy, or should the center focus on one direction at the expense of the other? At this time the former strategy is clearly the more appropriate of the two, but the picture may be entirely different in a few years.

This issue is of key importance for GIS as a technology for scientific research. There are several possible analogies for the potential role of GIS as a software package supporting a wide range of scientific disciplines. Word processing, for example, developed to a large extent in response to the office automation market, but found a compatible market in academic writing and publishing. Packages to support statistical analysis, such as SAS and SPSS, were developed largely to satisfy a scientific market. But like word processing, GIS has been driven by the applied marketplace, and scientific applications have emerged only recently. The danger is that the applied market will continue to develop more strongly and will begin to move in a different direction from the scientific market.

A community with the energy and growth exhibited by GIS in the last few years needs a strong presence at the national level if it is to assist effectively in formulating national policy and coordinating orderly development of the field. Ideally, it must have simple organizational and institutional structures and a federal agency with clear responsibility in the area. But GIS is comparatively new, and includes a wide variety of interests and approaches, so any radical reorganization seems unlikely in the near future.

Clearly, NCGIA's role lies in doing basic research, promulgating the results to the community as a whole, and working to improve the quality and availability of GIS education. To do so it needs strong ties with similar organizations in the United States (such as ACSM and the Urban and Regional Information Systems Association) and in other countries.

If you consider the current and potential scale of the industry (several estimates project a $200 to $300 million range) and the level of interest in GIS indicated by attendance at conferences, NCGIA's annual budget represents a low level of investment in research and development. The center has developed strong ties with other GIS research universities and national laboratories, in an effort to coordinate activities and increase the total resources of funding and expertise that we can collectively bring to bear on the research agenda.

The center publishes a biannual newsletter and a technical paper series, as well as other occasional publications such as initiative reports. For information about the center or its publications, write to NCGIA, University of California, Santa Barbara, CA 93106. Phone: 805/961-8224. Fax: 805/961-8016. Email: ncgia@sbitp.bitnet or ncgia@topdog.ucsb.edu. You may also contact the Maine or Buffalo sites or the initiative leaders identified in this article. ■

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