The National Center for Geographic Information and Analysis

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INTRODUCTION

THE IDEA OF A NATIONAL CENTER funded by the National Science Foundation (NSF) as a focus for GIS-related activities was first seriously proposed by Jerome Dobson, a geographer working at Oak Ridge National Laboratory, in the early 1980s (Abler, 1987). At that time GIS technology and related databases were still comparatively inaccessible. Hardware costs were still in the six figure range for a system of minimal configuration to support a GIS, and the lack of standards and affordable peripherals led Dobson to the conclusion that a national center could help to move the cause of GIS and related activities forward. The center would focus on the development and transfer of affordable technology, and on providing a central database and GIS service over the communication lines then available.

Between the early 1980s and the solicitation for the center issued by NSF in 1987 (NSF, 1987), the underlying parameters of GIS changed dramatically. The introduction of the personal computer and UNIX workstation made it possible to put more than the power of a 1980 minicomputer on a researcher's desk for one hundredth of the cost. Mature, powerful GIS software packages became readily available for a few thousand dollars, and large datasets could now be packaged on CD-ROM for tens of dollars per gigabyte. GIS teaching programs were established at the undergraduate and graduate levels in many U.S. universities in a range of disciplines from geography to surveying and civil engineering, and research labs made GIS available as a supporting technology for a wide variety of activities.

However, by 1987 it had become clear that, while the hardware, software, and data needs of GIS users were better satisfied, there was an increasingly serious shortage of intellectual capital: trained teaching staff; documentation of the core concepts and theories of GIS; and awareness of methods of analysis and decision-making suitable for GIS. To an agency like NSF charged with supporting U.S. scientific research, the dominance of the GIS vendor industry by non-scientific applications like facilities management in utilities and local government was increasingly worrisome. How could the power of GIS be made more available to U.S. scientific researchers?

The solicitation for a National Center for Geographic Information and Analysis issued by NSF in late 1987 requested proposals for a center to be funded at a little over $1 million per year for five years; the center would be expected to generate substantial additional funding from other institutions. Eight bids were received involving a total of 17 institutions, and the center was awarded in August 1988 to a consortium led by the University of California, Santa Barbara, and including the State University of New York at Buffalo, and the University of Maine. Funding began 1 December 1988. It is generally acknowledged that the competition for the center led to substantial exposure for GIS within the U.S. academic community, and many universities made significant investments in GIS at that time.

A consortium seemed to make good sense for several reasons. Academic GIS in 1988 was still a small and esoteric specialty, and it would have been counterproductive to have tried to bring enough expertise for a center together in one place. Three institutions would provide better regional outreach. And last but not least, each of the three sites brings a somewhat different set of skills, with Maine providing much of the center's strength in surveying and land information.

The solicitation document established "basic research on geographic analysis utilizing GIS" as the primary mission of the center. The four subsidiary goals are to "advance the theory, methods, and techniques of GIS," "augment the nation's supply of experts" in this field, "promote GIS throughout the scientific community" as an enabling technology for research, and "provide a central clearing house for information." The consortium argued in its successful proposal that the last function could be much more effective if it emphasized intellectual information, such as bibliographies, software, and the development of common research agendas, because several agencies already had responsibility for distributing digital geographic data.

NCGIA RESEARCH

Five research areas were identified by NSF as potential topics for the center:

- **spatial analysis and spatial statistics**, particularly the development of improved methods of analysis, and the use of statistical methods to deal with uncertainty in spatial data;
- **spatial relationships and database structures**, particularly based on comparisons between abstract digital representations of space, and the processes of human cognition and reasoning about geographic information;
- **artificial intelligence and expert systems**, and the application of these techniques to GIS;
- **visualization of spatial data**, and the exploitation of the potential of electronic display to help the user analyze and understand geographic phenomena; and,
- **social, economic, and institutional issues**, widely believed to be the most significant impediments to the effective use of GIS, but at the same time probably the most difficult to resolve.

The research plan included in the consortium's proposal (NCGIA, 1989) found significant research issues in each of these areas, and proposed to tackle them using a standard format, the Research Initiative. Four or five initiatives run at any one time, and focus the attention of center researchers on specific topics in a multidisciplinary, multi-investigator framework. Initiatives all follow the same basic structure, beginning with a Specialist Meeting which brings 30 or 40 people together from all parts of the GIS community to discuss and lay out an appropriate research agenda. The center uses a variety of strategies to coordinate its research with that going on in other groups and institutions, and the specialist meeting has been used as a way of building a community-wide consensus and research network in each area. After one to two years of research, the results of the initiative are presented at a major conference.

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Twelve initiatives were originally identified for the first three years of activity, and the list has since been modified and extended. Approved initiatives are listed below with the dates of their specialist meetings. Three initiatives have now been closed, although research continues, particularly in new initiatives with related subject matter. Indeed, some of the research initiatives have literally raised more questions than they have answered; in such cases they perform a useful function in raising interest and awareness in the GIS research community, paving the way for further research.

(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)
(5) Design and Implementation of Very Large Spatial Databases (July 1989)
(6) Spatial Decision Support Systems (March 1990)
(7) Visualizing the Quality of Spatial Information (June 1991)
(8) Formalizing Cartographic Knowledge (1992)
(9) Institutions Sharing Spatial Information (February 1992)
(10) Temporal and Spatial Reasoning in GIS (1993)
(11) Space-time Statistical Models in GIS (1992)
(12) Remote Sensing and GIS (December 1990)
(13) User Interface Design (June 1991)
(14) Spatial Analysis and GIS (April 1992)
(15) Multiple Roles for GIS in Global Change Research (1992)
(16) Legal Issues (1993)

Initiative 1 focused on the uncertainty and error present in much spatial data, and on their effects on GIS processing. Error models were developed and applied to help understand the propagation of uncertainty from GIS input to output. A book was published (Goodchild and Gopal, 1989) and many papers have appeared based on the research. Initiative 2 focused on the terms used by people to learn, understand, and reason with spatial data, and on how the languages used by GIS might be made more compatible with them: a book presenting many of the results of this initiative has been published (Mark and Frank, 1991), and many of the research themes of this initiative are being applied to the design of user interfaces in the new Initiative 13. Initiative 3 studied the problem of multiple representation – the need to present the same information differently at different scales, and the duplication and redundancy that causes for many GIS databases. A book including reports of much Initiative 3 research has been published (Buttenfield and McMaster, 1991) and the results of Initiative 3 have also appeared in many papers and conference presentations. Reports on many aspects of NCGIA research can also be found in the chapters of Maguire *et al.* (1991).

Among the newer research areas, Initiative 7, which began in June 1991, focuses on whether it is feasible to modify GIS displays to convey some notion of the uncertainty present in spatial data, and leads directly out of the research already completed in Initiative 1. Similarly, Initiative 13 leads on from Initiative 2 to address the practical design of user interfaces, and the exploitation of metaphor, graphic icons, and other techniques of modern interface design. In essence, it must reconcile two sharply contrasting bodies of opinion: that user interfaces should be simple and easy to use; and that simplicity and ease of use are fundamentally at odds with the complexity of spatial concepts and reasoning. Initiative 14, which began in April 1992, will explore the ability of GIS to support a wide range of forms of spatial analysis, from simple intuitive exploration to complex confirmatory tests of statistical hypotheses.

More information on all of these research activities is available in the NCGIA newsletter "Update," published twice a year; in the publications of the center's Technical Papers series; and in numerous articles and books. Annual reports listing all center publications are also available.

CONFERENCES

As part of an effort to explore the value of GIS to scientific research, the center has sponsored a number of conferences on various topics. "GIS and the Social Sciences," held in Santa Barbara in March 1991, brought about 25 social science researchers together to discuss the application of GIS in disciplines ranging from economics to anthropology. "The Sacred Geography of China, Japan, and the U.S." in July 1991 explored the use of GIS to display and interpret the religious meaning of a range of sacred landscapes, while "States and Space in the Pacific Rim" in March 1990 examined the value of GIS and spatial perspectives as tools for research into the economics and political science of the modern Pacific Rim. In September 1991 the center joined with a number of U.S. federal agencies in sponsoring the "First International Conference and Workshop on Integrating GIS and Environmental Modeling," in Boulder, Colorado, and in February 1992 it sponsored "The Anthropology of Human Behavior through Geographic Information and Analysis" in Santa Barbara.

EDUCATION

After much soul-searching, the consortium concluded in 1987 that the best way to "augment the nation's supply of experts in GIS technology" would be to provide a set of readily accessible, adaptable teaching materials. At that time there was a serious lack of textbooks in GIS, and an instructor faced a daunting task in mounting a GIS course from scratch. The materials would have to be augmented by local examples, but could provide a much-needed resource in a readily useable form. To be compatible with the objectives of the center, they should stress the concepts and theoretical underpinnings of GIS, the relationships between the database and the real phenomena represented, and the value of GIS as a tool for science, rather than the technicalities of particular software.

The Core Curriculum project, as it became known, developed into a set of teaching materials for three 25-unit courses (Goodchild and Kemp, 1990). Within the University of California, Santa Barbara, these are taught in a one-year sequence in geography, but could be adapted to fit the teaching timetables and needs of other institutions and disciplines. The materials include instructor course notes, exam and discussion questions, handouts, overheads, and slides. Individual units are designed to be as independent as possible, and are grouped into modules of related units. The materials are intended to be adaptable, and to be used selectively with other material.

The term "core" was chosen rather than "model" for several reasons. First, GIS is comparatively immature with a lack of strong consensus over its precise content, and in these circumstances it would be foolish to try to prescribe an ideal program. Second, "core" emphasizes the adaptability and flexibility of the materials. Finally, any instructor is faced with the problem of selecting intelligently from the enormous range of material that might legitimately be regarded as essential to GIS.

Discussion of an outline of three courses in "Introduction to GIS," "Technical Issues in GIS," and "Application Issues in GIS" began in late 1988. After many comments and modifications, contributions of material were invited from over 40 prominent people in the worldwide GIS community. The results were edited in the summer of 1989 and released as a test version. Over 100 sites received the test materials and used them to varying degrees in their own courses, and returned comments and completed student questionnaires. After much revision and editing, the final version of the curriculum was released in late July, 1990. Much of the credit for the project must go to Karen Kemp, Coordinator of NCGIA education programs.

By the end of 1991 over 750 copies of the curriculum had been distributed. Approximately 60 percent have gone to educational

institutions, and 37 percent of those to departments of geography. Over 50 countries have now received copies. An international program has been instituted whereby the center sponsors translation and distribution from a central site in each country. A number of user group meetings and workshops have been held at national and international meetings, and an electronic discussion list has been started.

The center has completed two further education projects. One deals with lab exercises, and with the need to provide practical, challenging hands-on experience to students to supplement the instructional material of the Core Curriculum. "Volume Four" (Dodson et al., 1991) consists of a directory of available lab materials, and we have also published two volumes of labs developed at the center for use in conjunction with the Core Curriculum (Dodson, 1991; Veregin, 1991). The directory includes references to materials made available by other institutions, and also materials developed for practical university education programs by GIS vendors. The second completed project is a set of six case studies of GIS teaching labs, including discussion of hardware, software, funding, maintenance and staffing (Palladino and Kemp, 1991).

WHAT REMAINS TO BE DONE?

The worldwide GIS research community has accumulated a vast amount of useful and significant results over the past two decades, and recent interest in GIS has been matched by an accelerated rate of activity, of which NCGIA represents only a small part. At the same time major issues remain, and GIS seems to create as many problems as it resolves. In fact, GIS may be its own worst enemy in revealing inadequacies in data, errors and uncertainties, and the lack of effective methods for decision-making. Two problems seem particularly worrisome.

Reference was made earlier to the seriousness of social, institutional, and managerial issues in impeding the success of GIS, and to the difficulty of tackling these impediments at the research level. Research to date has made it clear that there are no simple solutions to these problems, and that results are extraordinarily difficult to generalize. There may, for example, be as many ways of evaluating the benefits of GIS as there are GIS installations. There are no simple research strategies for addressing these issues, and research can often do little more than draw attention to them, in the hope that by doing so their impact will be lessened. There is a distinct need for policy-oriented research, aimed at affecting the entire context within which GIS operates, in addition to problem-oriented research aimed at the removal of specific impediments.

Second, GIS is a highly applied environment, in which basic research must somehow find a useful role to play in supporting a fast-moving software industry and a dynamic user community. The motivation for basic research must often come directly from application, and the results must be transferred through close university-industrial cooperation if they are to be effective. This is an environment in which center-based research can be much more effective than traditional, single-investigator research, because a center can support the infrastructure needed for effective communication. Centers can sponsor courses for industry, joint conferences, publications, and electronic networks, all of which can help move research results into the applications domain.

The infrastructure of science has changed tremendously in the past ten years, and centers are only one manifestation of other more deep-seated changes. Industry, investigators, and applications interact much more effectively than before, and this is particularly important for developing technologies like GIS. A very significant contribution to increased interaction is being played by electronic mail. Several years ago the Buffalo site of NCGIA sponsored GIS-L, an electronic mail discussion list for GIS. It now has about 600 readers and contributors, and a message traffic averaging around 20 per day. Discussion is lively, and not always particularly deep, but lists like GIS-L allow daily international communications between scientists, users, and developers that are largely independent of discipline, national boundaries, distance, and many of the traditional constraints on human interaction. Several instructors have recognized the value of GIS-L as a source of insight for their students into the concerns and opinions of the GIS community. Perhaps the most poignant failing of the new electronic medium is its inability to overcome barriers of language. But it certainly demonstrates the fast-moving, international character of the GIS community.

FURTHER INFORMATION

Further information on all center activities can be obtained by contacting the center at any of its three sites. The publications office is located at 3510 Phelps Hall, University of California, Santa Barbara, CA 93106, phone (805) 893-8224, FAX (805) 893-8617, email ncgia@ncgia.ucsb.edu. Many center publications are available over anonymous ftp.

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