THE U.S. NATIONAL CENTER FOR GEOGRAPHIC INFORMATION AND ANALYSIS: AN OVERVIEW OF THE AGENDAS FOR RESEARCH AND EDUCATION

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ABSTRACT

In August of 1988, the National Science Foundation announced the establishment of a National Center for Geographic Information and Analysis (NCGIA). The Center was awarded to a consortium led by the University of California at Santa Barbara, and including the State University of New York at Buffalo and the University of Maine. This paper describes the research and educational agendas of the NCGIA. Basic research at the NCGIA is organized into Research Initiatives, which provide focussed inter-disciplinary, inter-campus research projects of 12-24 months' duration. Research Initiatives begin with Specialist Meetings which bring together researchers from two or more NCGIA sites, from government, from the private sector, and from other academic institutions. The first initiative in the educational agenda of NCGIA is a project to develop and disseminate a model curriculum for GIS, consisting of a core of 75 basic lectures organized into modules and into three courses. Both the Research and Educational Agendas are discussed.

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INTRODUCTION

In June of 1987, the National Science Foundation (NSF) of the United States announced plans to establish a National Center for Geographic Information and Analysis (NCGIA), and called for proposals from U.S. Universities. Abler (1987) has discussed the history of the NCGIA concept and it evolution through to the stage of proposal submission. A total of eight proposals from consortia involving 17 institutions were received by the 29 January 1988 deadline, and on 19 August 1988, NSF announced that the NCGIA had been awarded to a consortium led by the University of California at Santa Barbara (UCSB), and including the State University of New York at Buffalo (UB) and the University of Maine (UM). The initial award is for a total of $US 5.5 million over five years. The primary mission of the NCGIA is basic research in geographical analysis using Geographic Information Systems; it also has major roles in education and in technology transfer.

This paper begins with a brief overview of the NCGIA's organization. This is followed by an outline of of the basic research agenda for the Center, including the sequence, organization, and objectives of the first twelve research initiatives. Lastly, the NCGIA's curriculum development initiative will be described in some detail.

CENTER OVERVIEW

The National Center for Geographic Information and Analysis is organized around four distinct units: the administrative and communications center located at the University of California at Santa Barbara, and the three research and education centers located at Santa Barbara, the State University of New York at Buffalo, and the University of Maine at Orono. David Simonett and Michael Goodchild, both from Santa Barbara, are the Co-Directors of the National Center, while Associate Directors Terence Smith of Santa Barbara, Ross MacKinnon from Buffalo and Andrew Frank from Maine head their respective research centers on their campuses. Waldo Tobler of Santa Barbara is the Senior Scientist and John Estes, also of Santa Barbara, is Chair of the Board of Directors.

Research at the NCGIA is undertaken by means of Research Initiatives, or projects designed to fully investigate impediments to the more widespread implementation of geographic information systems (GIS). A Research Initiative typically consists of a number of research subtopics which closely interact and where work in one area should influence and advance work in others. A Research Initiative consists of Specialist Meetings, Working Groups undertaking intensive research, in-progress seminars (as needed), and a national or international Conference to present results.

Educational activities include the development of a one-year (two-semester or three-quarter) model curriculum of basic GIS concepts, techniques, and applications, and will include professional short courses and workshops held both on-campus and off, and training for GIS educators.

Outreach to all segments of the GIS/GIA community, both private and public sector, is an important aspect of the Center's activities. In addition to the research and educational activities outlined above, the Center will act as a 'research clearinghouse' of GIS information and provide a multi-disciplinary link among the many disparate uses of the technology.

BASIC RESEARCH AGENDA FOR THE NCGIA

The research agenda of the NCGIA is based on long-term research priorities reflecting the needs and concerns of researchers in GIA/GIS. The Center will include researchers from a variety of disciplines at each of the three sites, and its effective operation will require coordination, prioritization, and scheduling of a broad spectrum of research activities. Topics chosen for the first two years reflect both sequencing constraints (whether the results of one initiative are needed before another can begin) and the individual strengths and interests of current research personnel.

Research Initiatives are designed to take advantage of the Center's potential for new modes of research. This approach is based on enhancing interaction, not only between individual researchers but also between the academic, industrial, and government communities. Initiatives consist of five components:

Specialist Meeting: Center research on a specific topic is initiated by a meeting of one to two weeks' duration, at which perspectives on the topic are presented by specialists drawn from Center personnel, researchers from outside the Center, and other representatives of government and industry. These meetings will promote cross-disciplinary exchanges, work out the agenda for the Research Initiative, and assign responsibilities to Working Groups. Some multiyear initiatives will have annual Specialist Meetings. Organization for the initial Specialist Meeting will occur during the initiative planning period.

Working Groups: Specific commitments of time and resources are made for Working Groups which will conduct research for periods of six months to two years following the Specialist Meeting. We assume that the largest commitments will be made by Center personnel (permanent faculty, visiting fellows, research assistants), but that in many cases research will be conducted jointly with other institutions, agencies, and firms. Working groups will use a variety of modes of inquiry including seminars, computer modeling and prototyping, and empirical investigation.

In-Progress Seminars: Progress on Research Initiatives may be expanded through seminars of two to five days' duration. Such seminars would bring together a group of scientists with differing views on a topic, both from within the NCGIA and from the outside. Seminars may be organized to clarify an interdisciplinary effort, to identify further research directions or to integrate and make available results from other areas of research with relevance to GIS research. The assimilation of methods and results from other areas is an important contribution to scientific advances, but the theoretical background and limitations of each must be understood. A direct discussion between the researchers involved can be an efficient method to achieve this interaction.

National/International Conferences: The fourth component of the Research Initiative model is a National or International Conference at which substantive findings are presented to a larger audience. We anticipate that many of these will be held in conjunction with other national and international meetings, and that these conferences will be a prominent feature of the NCGIA.

New and Outgrowth Research: Initiatives may lead naturally into long-term single-investigator projects of greater depth and specificity. The involvement of graduate students in Research Initiatives will have considerable educational impact; doctoral dissertation research will be a very important part of this outgrowth research. Many initiatives will also lead to applied research relevant to federal agencies, state and local governments, and the private sector. Funding for such outgrowth research will be sought from the agencies involved. Initiatives will usually conclude with descriptions of new problems which have been exposed, and thus influence the Center's long-term research plan.

Research Initiatives

Twelve Research Initiatives are planned to begin during the first three years of the Center's operation: three Specialist Meetings already (March 1989) have been conducted, and two others will be held during the next five months. This section lists the twelve initiatives included in the original proposal to NSF, giving the titles, research areas, project leaders, duration, and objectives.

Initiative 1: *Accuracy of Spatial Databases*. Research Area: Spatial Analysis and Spatial Statistics. Leader: Michael F. Goodchild (Santa Barbara). Specialist Meeting: December 13-16, 1988. Duration: December 1988-April 1990. Research has begun under this initiative aimed at developing improved models of error and uncertainty in spatial databases, methods of specifying uncertainty and tracking it through complex sequences of GIS operations, and reporting confidence limits on GIS products. The results of the research will include a taxonomy and bibliography of spatial database errors, studies of the relative efficiency and accuracy of alternative terrain representation methods, and case studies of the propagation of error within GIS processes. The papers of the specialist meeting will appear in a proceedings volume.

Initiative 2: *Languages of Spatial Relations*. Research Area: General theory of spatial relations. Leaders: Andrew U. Frank (Maine) and David M. Mark (Buffalo). Specialist Meeting: January 15-19, 1989. Duration: January 1989 to July 1990. Major objectives of this Initiative are to identify formal cognitive/semantic models of spatial concepts and relations in natural languages, to construct formal mathematical/logical models of spatial concepts and relations based on topology and geometry, and to integrate the two kinds of formal models into a general theory of spatial relations. The Specialist meeting brought together 26 participants, from geography, engineering, linguistics, computer science, and related

disciplines. A large list of "researchable questions" was developed during the meeting, and are being prioritized. Cross-linguistic analyses of spatial terms in geographic description and analysis is a high priority topic being addresses by a Working Group at Buffalo. Formalized spatial relations and their relations to data structures and query languages represent a focus of the working group at Maine.

Initiative 3: *Multiple Representations*. Research Area: Visualization; spatial relations and database structures. Leader: Barbara P. Buttenfield (Buffalo). Specialist Meeting: February 18-21, 1989. Duration: February 1989 to April 1990. Objectives: 1. Critically examine the relations of the geometry of geographic features to the scale of representation (self-similarity vs. scale dependence, etc.); 2. Develop models for digital description of cartographic features (object-oriented vs. spatially addressed models; hierarchical models; conversion between models); 3. Study problems associated with scale-changing, and propose solutions and algorithms based on pattern recognition and feature identification, inference across levels of resolution, and automation of feature simplification and selection; 4. Characterize the effects of multiple representation on error propagation (this has obvious links to Initiative 1); 5. Determine database organizations capable of dealing with multiple representations of the same objects.

Initiative 4: *Use and Value of Geographic Information in Decision Making*. Research Area: Social, economic, and institutional issues. Leader: Tom Ducheneau (Maine). Duration: May 1989 to April 1990. Objectives: 1. Identify problems of dealing with uncertainty and risk associated with decision making; 2. Develop and test models of the decision-making process regarding land use, focusing on the role of information; 3. Identify primary and subsequent users of spatial information, and determine the value of such information; 4. Evaluate the direct and indirect benefits of GIA/GIS.

Initiative 5: *Architecture of Very Large GIS Databases*. Research Area: Spatial theory and databases. Leader: Terence R. Smith (Santa Barbara). Duration: May 1989 to 1991. Objectives: 1. Assess the requirements for very large databases; 2. Determine characteristic data types for remotely sensed data; 3. Identify functional components for very large GIS databases and related GIS products; 4. Develop methods to group components to achieve high performance; 5. Build prototypes and test components;

Initiative 6: *Spatial Decision Support Systems*. Research Area: Spatial analysis. Leader: Michael F. Goodchild (Santa Barbara). Duration: September 1989 to April 1991. Objectives: 1. Design GIS data structures to support decision systems; 2. Develop methods for effectively structuring spatial search algorithms within a GIS framework; 3. Classify spatial search problems and identify gaps in current models; 4. Produce and test prototypical user interfaces.

Initiative 7: *Visualization of the Quality of Spatial Information*. Research Areas: Visualization, spatial statistics, applications. Leaders: Kate Beard (Maine) and Barbara Buttenfield (Buffalo). Duration: May 1990 to 1992. Objectives: 1. Develop and implement a large number of distinct methods for displaying the quality (reliability, accuracy, certainty, etc.) of spatial information; 2. Evaluate the efficacy of these methods using experimental subjects; 3. Test the most promising methods in real-world situations.

Initiative 8: *Expert System for Cartographic Design*. Research Area: Visualization; expert systems. Leaders: Andrew U. Frank (Maine) and David M. Mark (Buffalo). Duration: Spring 1990 to 1992. Objective: To develop an expert system to design cartographic displays of various types.

Initiative 9: *Institutions Sharing Spatial Information*. Research Area: Social, economic, and institutional issues. Leaders: Tom Ducheneau (Maine) and Hugh Calkins (Buffalo). Duration: Summer 1990 to 1992. Objectives: 1. Identify the social science aspects of people, agencies, and professionals dealing with geographic information; 2. Document policies regarding inter-agency and agency-citizen information exchange; 3. Investigate the sharing of information in the public-sector agencies (i.e., the non-technical aspects of building common databases); 4. Explore the liability aspects of sharing data, and the impacts of electronic data processing on responsibilities; 5. Develop models for political support for shared databases, including aspects of privacy and public access; 6. Analyze the impacts of GIS on the standards of professional practice by surveyors, planners, and lawyers.

Initiative 10: *Temporal Relations in GIS*. Research Area: Spatial and spatio-temporal analysis. Leader: Andrew U. Frank (Maine). Duration: May 1990 to 1992. Objectives: 1. Understand the modeling of time (continuous time, discrete time, and events); 2. Assess inference methods in temporal logic and abduction strategies in non-monotonic systems; 3. Compare modeling of states to methods of modeling incremental change with respect to different GIS applications; 4. Study the problems of building temporal

GIS databases and implications for queries (What was known as of [date 1] about the state of X as of [date 2]); 5. Extend the methods for dealing with multiple and alternative representations to include temporal aspects.

Initiative 11: *Space-Time Statistical Models in GIS*. Research Area: Spatial and spatio-temporal analysis. Leaders: David S. Simonett (Santa Barbara) and Joel Michaelsen (Santa Barbara). Duration: October 1990 to September 1992. Objectives: 1. Systematic documentation of characteristic scales of spatial and temporal variation for basic processes in the social, natural, and applied sciences; 2. Development of a taxonomy of space-time statistical models to help select appropriate database structures for representing the temporal variability of specific social and natural processes in GIS; 3. Development of algorithms for efficient data refreshing in systems with different characteristic frequencies and scales of temporal variation; 4. Development and application of methods of multiple representation in the time domain for computing efficiency.

Initiative 12: *Remote Sensing and GIS*. Research Area: Spatial analysis and spatial statistics. Leaders: Jack Estes (Santa Barbara) and Frank Davis (Santa Barbara). Duration: October 1990 to September 1991. Objectives: 1. Improve methods for data acquisition and processing; 2. Develop principles for identifying appropriate data structures for storage and integration of remotely sensed data in GIS systems; 3. Extend GIS applications in scene classification, contextual classifiers, and expert systems.

NCGIA GEOGRAPHIC INFORMATION SYSTEMS MODEL CORE CURRICULUM

Recognizing the pressing demand for professionals trained in GIS, the National Center for Geographic Information and Analysis is developing a model curriculum as a guide for institutions wishing to introduce an introductory instructional sequence in GIS. While some universities have already developed specialties in GIS, many departments have recognized the need for training in GIS but have been unable to devote their limited resources to addressing this task. Meetings on GIS education hosted at Ohio State University in June 1988 (and another planned for 1989), as well as papers presented at the GIS/LIS'88 symposium (cf. Barnes and Loon, 1988; Kuennecke, 1988; Sullivan and others, 1988; Tucker and Devine, 1988; and several others) recognize concern for educational and training issues related to GIS. It is hoped that this curriculum will assist with the integration of GIS concepts into programs taught by many Geography departments, as well as other disciplines concerned with spatial phenomena such as surveying, geology, landscape architecture, forestry and resource management.

Philosophy of the Model Curriculum Design

There are several distinct areas of need for GIS professionals. The proliferation of systems in planning and resource management offices has made the lack of trained GIS operators critical. This kind of training can be accomplished most directly by in depth exposure to specific hardware/ software systems. But beyond this functional level, there is a need for people with a broader exposure to GIS, with a general idea of where GIS fits into existing managerial and planning decision processes. At another level, people are needed who can carry out basic research so that GIS can reach beyond being simply an applications driven toolbox and become a fully functional system for guiding spatial analysis. A recognition of this range of needs has been a driving force in the curriculum design.

There is, however, a more philosophical objective to be achieved in this curriculum. GIS is distinguished from other spatial data handling activities by its emphasis on analysis. Although in its early stages the development of GIS has been driven largely by applications, it is important now to address its more fundamental and conceptual aspects. GIS can, in fact, be used to teach many fundamental concepts about spatial analysis. We see the challenge in the development of this curriculum to be a careful balancing between the needs of the job market and the recognition of GIS as a new opportunity for advancing spatial research and analysis. We do not wish to perpetuate the black box image of GIS by training uninformed operators. On the other hand, we do wish to provide our students with marketable skills. To this end, the basic driving philosophy in the development of this curriculum is to provide a general education on the basic principles and concepts of GIS, to examine the theory and tools of spatial information analysis and to provide a broad exposure to GIS applications so that objective decisions can be made about system acquisition and implementation. The approach is therefore more that of the generalist than the technical specialist.

Course Objectives

Specifically, the overall objectives of the curriculum are to provide an introduction to GIS. If GIS is seen as a powerful way to examine spatial relationships, the amount of material that can be covered in one year long course is very small. However, viewing GIS as a way to organize many diverse areas of study around a spatial analysis model provides a useful conceptual framework.

Seen as a whole, then, the courses will provide an introduction to the many related but complex subjects which come together in GIS. Different facets will be reviewed briefly so that students are given a taste of the exciting worlds beyond. The first course is an introduction to the hardware, software and operations of GIS, providing the essentials required by a beginning GIS technician. The advanced courses focus on two distinct aspects. One deals with technical aspects and explores areas related to the computer science and computer cartography roots of GIS. The other course deals with the applied aspects of spatial analysis, spatial decision making and management issues.

In the **Introductory Course**, students will review hardware and software components, explore several applications and will be introduced to data structures and basic functions. Several different GISs will be reviewed. Specifically, students completing this first course will learn to: identify and describe the hardware components of a GIS; state differences between database models; describe and evaluate methods of data capture and sources of data; discuss the nature and characteristics of spatial data and objects; list and define typical GIS operations; identify types of products from GIS; identify various applications of GIS; classify systems according to their characteristics; and recognize differences between raster and vector systems.

Laboratory exercises will be included to give students hands-on experience. Depending on the objectives of specific institutions, laboratory exercises can be used to provide in depth instruction on a single system or to give a broader exposure by using several different ones. Labs will provide instruction in: the operation of lab computers; the procedures involved in completing simple GIS operations; issues of data integration into systems; and the use of GIS to address a resource management problem.

The Technical Issues course deals with GIS algorithms, data structures, advanced computational topics and analysis of error. Labs will include technical programming exercises. Students will learn to: identify sources of error; compare and contrast different coordinate systems and projections; describe several methods of storage of spatial data objects and to evaluate these methods for various applications and data types; construct simple algorithms to conduct basic GIS operations such as overlay, intersection, area; recognize significant aspects of map accuracy and data quality; and conduct error tracking and estimation procedures.

The Applications in GIS course explores operational and management issues. Ways in which traditional planning and management theories and techniques can be implemented in GISs will be examined. Students will learn which issues need to be considered when proposing and implementing a new GIS and will have opportunities to evaluate how GIS can be used to answer specific planning problems. Topics covered will help students to: discuss the problems of data exchange standards and large databases; evaluate the use of spatial analysis techniques in the GIS context; describe applications of GIS in various fields; discuss social impacts of GIS, including legal aspects and effects on management decisions; describe relevant aspects of the implementation of GIS in an institutional setting, including incorporation into an agency, cost and benefit, benchmarking, request for proposals; and identify future directions in GIS. Practical work will include analytical exercises using spatial analysis techniques and GIS products in management/ planning contexts and reviews of actual implementations to evaluate their successes and failures.

Although the three courses described above constitute the core of the curriculum presently being developed, there are several additional areas which we feel would be fruitful for future development. These include: one or more modules on specific software systems to provide the in depth systems training some departments may wish to provide; applications modules which will allow students to work in teams to organize and conduct complete GIS analysis projects; and case studies, designed after the business school case study model, which would allow students to make significant management/ planning decisions based on actual data.

Curriculum Design and Development

The curriculum is designed as a series of 75 one hour lectures. The choice of lecture topics and emphasis given to each area included has undergone considerable discussion and review with input received both from within and outside the NCGIA consortium. It is recognized that, even at the lecture writing stage, priorities and topics are still likely to be rearranged.

To assist with our planning process, lectures have been grouped into the three courses described and are sequentially listed so that some progression in learning can be assumed. However, lecture modules within each course have been identified to ensure that considerable flexibility is designed into the curriculum. We recognize that different institutions have different priorities and may wish to rearrange the lectures to accommodate different academic calendars, and may wish to remove some lectures and insert others. As far as possible, this flexibility will be maintained.

Having identified the major topics that need to be included in the lectures, we have requested assistance from members of the GIS community to help us write the lecture materials. The response has been generous. Although considerable editing will need to be done to ensure consistency in the final product, our curriculum will recognize contributions from over 30 GIS professionals in the U.S., Canada, Great Britain and Australia. Lecture materials will include detailed lecture notes, professionally produced visual aids, student handouts, suggested readings and examination and discussion questions.

Laboratory materials, likewise, will be contributed by many individuals who have already developed and tested their own versions. It is planned that labs will be designed for implementation on several different hardware and software systems so that they can be used in both fully equipped GIS labs and in departments with very limited software budgets. Datasets for the labs are also being gathered. Laboratory manuals will be provided with fully worked examples for instructors.

In addition, several supplementary materials are being developed. These will include textbook and video reviews, evaluations of various hardware and software configurations and a guide for departments wishing to implement a GIS program (including budgets, arguments for establishing GIS programs and course descriptions).

The curriculum will be tested at several sites during the 89/90 school year. Instructors using the materials during this testing stage will be required to submit, at frequent intervals, detailed evaluations of all materials used. A workshop for these evaluators will be held at the end of that school year. Discussions at this workshop are expected to suggest significant revisions. These will be incorporated into the curriculum and materials will be ready for wide distribution for the fall of 1990.

Summary and Discussion

This paper has presented a brief overview of the National Center for Geographic Information and Analysis, with particular emphasis on the agendas for basic research and for education. We cannot emphasize too much that the NCGIA is open to involvement by researchers, educators, and practitioners from other academic institutions, from government agencies, and from the private sector. We particularly welcome interactions with Centers and laboratories in other countries. Post-doctoral fellowships and leave supplements will, in principle, be available at all three NCGIA sites. Persons interested in becoming involved in NCGIA activities should contact: initiative leaders with respect to involvement in the research agenda; site Associate Directors with respect to visiting positions; and either of the first two authors with respect to the educational agenda.

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