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INTERNATIONAL FEDERATION OF SURVEYORS
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Land Information Systems
Systèmes d'Information du Territoire
Landinformationssysteme

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COMMISSION

FIG XIX INTERNATIONAL CONGRESS
HELSINKI, FINLAND, 1990

The National Center for Geographic Information and Analysis in the United States of America[1]

Le centre national pour l'information et l'analyse géographique dans les Etats Unis d'Amérique

Das Nationale Zentrum fuer Geographische Information und Analyse in den Vereinigen Staaten von Amerika

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SUMMARY

The National Center for Geographic Information and Analysis (NCGIA) was founded in Fall 1988 by the National Science Foundation (NSF) as a distributed center with headquarters at the University of California in Santa Barbara, and participation from the State University of New York at Buffalo and the University of Maine. This paper outlines some of the salient points about the process of creating such a center. It then describes the goals set forward by the NSF for the NCGIA and explains how the team will address them. Researchers from other groups are invited to participate in the center's activities. The center will also cooperate with research organizations in other countries. The paper concludes with an invitation to other countries to form similar centers to further GIS research and applications.

RÉSUMÉ

En automne 1988 la fondation nationale pour la recherche scientifique (NSF) a fondé le centre national pour l'information et l'analyse géographique. Le centre est distribué sur trois universitées avec un office central a l'Université de Californie a Santa Barbara. L'Université de l'Etat de New York a Buffalo et l'Universite du Maine sont les deux autres participants. L'article décrit premierement les évennements les plus importants qui ont mené a la création de ce centre. Il decrit ensuite les buts qui ont été etablis par NSF et comment les chercheurs du centre pensent les implémenter. Le centre encourage la colaboration internationale avec chercheurs et groupes de recherche et invite d'autres pays d'établir des centres similaires.

ZUSAMMENFASSUNG

Das Nationale Zentrum fuer Geographische Information und Analyse wurde ende 1988 von der Natinal Science Foundation (NSF) ins Leben gerufen. Es hat sein Hauptquartier an der Universitaet von Kalifornien in Santa Barbara; die State University of New York in Buffalo und die Universitaet von Maine sind die andern Mitglieder. Dieser Artikel erwaehnt zuerst die wichtigsten Etappen, die zur Gruendung des Zentrums gefuehrt haben. Er beschreibt dann die Ziele, welche NSF dem Zentrum setzt und wie das Forscherteam diese zu erreichen gedenkt. Forscher von andern Gruppen sind eingeladen, bei den Forschungsinitiativen mitzumachen. Das Zentrum ist auch an formellen Abkommen zur Zusammenarbeit interessiert und ermutigt andere Laender, aehnliche Zentren zu gruenden.

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1. Introduction

In August 1988 the National Science Foundation announced the funding of a National Center for Geographic Information and Analysis (NCGIA). The new center must conduct basic research on geographic information and analysis. Specifically, research efforts are to address the following five areas :

- new modes and methods of spatial analysis
- a general theory of spatial relationships
- artificial intelligence and expert systems in GIS
- visualization and
- social, economic and institutional issues.

The award was made to a consortium of three universities: the University of California at Santa Barbara, the State University of New York at Buffalo and the University of Maine. Each of these universities has considerable experience in GIS research. The Department of Geography at the University of California at Santa Barbara has one of the world's leading groups in remote sensing research. The Geography Department at the State University of New York at Buffalo has integrated GIS work with geography and has an outstanding reputation for advanced GIS education. The Surveying Engineering Department at the University of Maine has concentrated on the information management and processing aspects of GIS and contributes an engineering perspective to the Center.

The Center is lead by the co-directors Dr. David Simonett and Dr. Michael Goodchild, both at the University of California at Santa Barbara. The individual teams are lead by the associate directors Dr. Terence Smith, University of California at Santa Barbara, Dr. Ross MacKinnon, State University of New York at Buffalo and Dr. Andrew Frank, University of Maine.

The NCGIA will carry out its research by selecting and concentrating on a few topics - called 'research initiatives' - at a time. Current topics include:

- Initiative 1: Accuracy of Spatial Databases -*Leader*: Michael Goodchild
- Initiative 2: Languages of Spatial Relations - *Leaders:* Andrew Frank and David Mark
- Initiative 3: Multiple Representations - *Leader*: Barbara Buttenfield
- Initiative 4: The Use and Value of Geographic Information in Decision Making *Leaders*: Harlan Onsrud and Hugh Calkins
- Initiative 5: Architecture of Very Large GIS Databases - *Leaders*: Terence Smith and Andrew Frank

2. The Creation of the Center

The concept of a National Center for Geographic Information and Analysis evolved over a period of about 4 years. There was a preparatory phase where the idea took shape, eventually resulting in the request for proposals. Then competitive research groups worked on proposals for different realizations of the Center. The sequence of events concluded with the selection of the University of California at Santa Barbara/State University of New York at Buffalo/University of

Maine team and the actual start of the Center. In this section I will briefly outline the preparation and the request for proposals as issued by NSF; readers interested in more details and a view from the inside are recommended to read the excellent account by Dr. Ron Abler, the NSF Program Director responsible for the NCGIA [Abler 1987]. In section 3 I will describe the proposal made by our team.

2.1 The Need for a GIS Research Center

A number of influential leaders in the geography and GIS/LIS area realized the need for more theoretical research to address the basic problems of GIS. One could observe a large number of applications of GIS technology being used for an ever increasing set of problems. These implementations were often beset with problems which were then overcome by some pragmatic shortcuts. The construction of a GIS was, and still is, an art and requires the application of some 'magic' to make it work.

At the same time, geographers were discussing the changes possible in their discipline due to the new capabilities of computerized tools. Obviously GIS can provide geographers with much better data and analytical tools to perform their research [Dobson 1983]. But research in GIS can also address some of the most fundamental problems in geography. In the 1960's, an influential group of geographers made enormous efforts to move geography from descriptive and qualitative arguments to a more quantitative base. However, due to a lack of data and today's powerful analytical tools, this 'quantitative revolution' could not fully succeed [Chrisman 1987]. A subsection of the American Association of Geographers (AAG) founded a special interest group in GIS , stressing the intellectual character of the research work to be carried out. This special interest group grew extremely fast and is now one of the largest in the AAG .

From these two well reasoned but fundamentally different intellectual positions, two different approaches for a Center emerged:

1) a '**geographic data and tools**' Center that would collect and manage geographic data, and make the data available to researchers. It would also maintain an array of tools for processing and analyzing these data, (e.g the commercial GIS systems), and staff experienced with using these tools. The Center would operate as a service organization supporting researchers in geography that require these tools for geographic research. It would also help to train researchers in the use of GIS tools and provide access to its facilities using electronic communication [Dobson 1984, 1985]

2) a '**geographic information and analysis research**' Center that would explore the theoretical issues associated with the use of spatial information. It would study the base issues of collecting, managing and understanding spatial information.

There is considerable experience in the U.S. with centers of the first kind, for example, the Oak Ridge National Laboratory or the National Center for Atmospheric Research (NCAR). They are often funded by and act as the major research units for particular Federal Departments and Agencies. There are also a number of research centers, mostly at universities, with basic research missions.

The National Science Foundation, the major funding agency for basic and fundamental research in science and engineering, (including social sciences, but excluding medicine and humanities) is traditionally organized around research projects with a very specific topic, lasting for two to three years, and headed by a single principal investigator (a number of other countries have national research agencies which work essentially along the same principles and administrative methods). Since 1984 the National Science Foundation has increasingly funded interdisciplinary research centers, first in engineering research, then in science and technology. The NCGIA is following these directives but is the only research center under the directorate of social and behavioral sciences. The budget is considerably less than the typical funding for engineering research centers. It is a total of $8.8 million for a period of 8 years ($1.1 million per year). The center is supposed to continue and to be self sufficient after this period.

A number of meetings were held at different locations during 1985 and 1986. The work of the British 'committee of enquiry' headed by Lord Chorley [Dept. of the Environment 1986] contributed significantly. Some researchers raised the concern that the field of GIS research would not be large enough to support an additional center and that the creation of the Center would 'bleed' the currently fledgeling research groups. According to Ron Abler, this is a normal incidence in the phase of the creation of a center [Abler 1987]. From these fears and the general agreement that the field lacked a sufficient number of researchers, NSF was asked to stress education and formation of future GIS researchers.

For me, the key meeting was one where Dr. Duane Marble, then at the State University of New York at Buffalo, invited active researchers in GIS to discuss the possible Center from their perspective. At this meeting, a large number of potential principals for a Center were united. The participants started to explore the feasibility of a consortium combining the forces of more than one university. In the year following this meeting, many of the potential competitor groups explored whether other researchers could be persuaded to join them at their universities, and indeed a few important researchers changed employers.

2.2 The National Science Foundation Solicitation for a National Center

On June 24, 1987 the National Science Foundation issued the final solicitation for proposals for a Center. The solicitation stressed the fundamental research that would address impediments that limit the current use of GIS technology. However, it mentioned all three areas (research, education and information dissemination).

The solicitation concentrated on the following research areas:

- new modes and methods of spatial analysis
- a general theory of spatial relationships
- artificial intelligence and expert systems in GIS
- visualization and
- social, economic and institutional issues [Abler 1987]

and asked that proposals address some or all of them. Proposals were due at NSF by January 20, 1988.

The planned selection process involved a review of the written proposals by a small group of experts - there were some questions as to how enough knowledgeable researchers could be found to do this since most were involved in the proposals - and then site visits for the top ranked contenders. It was hoped that the reviews could be finished in spring and the site visits done in early summer with an announcement in mid-summer.

3. The Proposal by the University of California at Santa Barbara/State University of New York at Buffalo/University of Maine Team

3.1 The Team

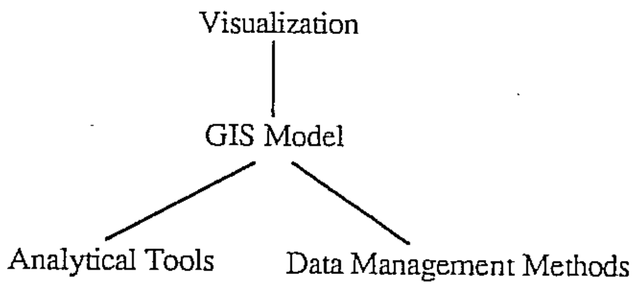
After intense and lengthy contact between possible participants for a team, a decision to form a consortium under the leadership of David Simonett and Michael Goodchild was reached. One of the apparent problems was the difficulty in identifying capable and widely recognized leaders. Many of the best researchers in GIS are very young and do not have a proven track record to warrant trusting them with the task of successfully managing a large, interdisciplinary multi-year research center. This is not only true for geographers with GIS experience, but is likewise the case for surveying and mapping leaders. From experience gained since the formation of the NCGIA, I can see similar struggles taking place the world over for the few capable leaders to fill the vacancies. Shortage of leadership is a global problem (at least for the English-speaking world) in GIS, surveying and cartography!

The team which was formed brought together two geography departments with considerably different backgrounds and experiences, and a surveying engineering department. It includes a number of widely recognized experts and leaders (David Simonett, Waldo Tobler, John Estes, Michael Goodchild, Ross MacKinnon etc). Cooperation between researchers in these departments was enhanced as it became clear immediately that the strengths of each group were complimentary and not much overlap existed.

Forming a team, especially a consortium as geographically dispersed as this one, had to be weighed against a single university center. The team approach brought us breadth - it was clear from the special expertise of the researchers involved, that we could address all the research topics. This was a major advantage in forming the team. On the other hand, forming a consortium involves some costs: transportation to common meetings, cost of communication etc. Ultimately, we felt that with modern electronic communication means the additional costs would be minimal and not significant for a center of the size envisioned. Indeed, experience has shown that there are not more problems managing a dispersed center than would be found with a single-campus center.

Two concepts for an approach were developed: 1) the center should identify and work towards the removal of impediments to the adoption and application of geographical information system technology [NCGIA 1989]; 2) we identified a number of common problems, appearing in more than one research topic, and for which we thought a multi-disciplinary approach useful.

Some of us found a diagram useful to illustrate the important aspects of the research to be conducted, in spite of the limitations of any such diagram:



3.2. GIS as a Model of (certain aspects) of Reality

A GIS is a model of reality, exactly those parts of reality that geographers, researchers in various social and natural sciences, regional planners, surveyors and similar professionals deal with. Historically, the use of formal models of their subjects has been an effective way for other sciences to advance (especially physics), but geography has only partially benefitted from such a concept. Computer systems are the enabling technology for such an effort, but they are based on the use of conceptual tools.

The lack of a unifying view of GIS as a model of reality, hinders the application of different tools as they are designed to deal with specific aspects. The central concern is what methods are used to represent the available knowledge about reality (the available data). This is the common problem of knowledge representation in artificial intelligence which needs to be addressed for the specific situation of geography. The knowledge representation must be designed so that it supports the analytical and visualization methods and can be implemented on a current (or future) computer system.

3.3. Types of Data in a GIS

The data in a GIS describe the quality of some attribute at a specific location. Some attributes appear to be continuous, and others 'naturally' discrete. Data for some phenomena may be collected for some sampling points, while in other cases uniform values are delineated. Analytical work with a GIS most often implies conversions from the 'natural' scale of the phenomena to the one the tool at hand uses. The questions users ask are often not related to the properties for which values were collected, but are for other properties, for which values must be deduced from those collected.

3.4. Errors and Other Imprecisions

Neither the observation and recording of values for attributes nor the determination of locations can be carried out without error. Determining a value with more precision is generally more expensive and cumbersome. Depending on the purpose, attribute values are often collected not on their natural scale (e.g. ratio) but on a simpler one (e.g. ordinal).

The lack of a theoretical understanding of error measurement and propagation of errors through the derivation of data based on collected values, is a major limiting factor in the use of GIS. It affects GIS in two ways: 1) we cannot assert what level of precision is necessary in the data originally collected (and thus not determine the economical effort); and 2) we cannot assess the quality of results derived in a GIS (and thus not prevent the distribution and use of meaningless or misleading information). The fear of liability for problems associated with the information produced will hinder its availability.

3.5. Multiple Representation (or generalization hierarchy)

Geography deals with spatial phenomena existing on a broad range of scales. For instance, scales may vary from single house/tree/small stream on a topographic map sheet, to a world scale of large cities, ecosystems and major rivers. Typically we deal with representations for the same phenomena on different scales (or better, different levels of aggregation) inside a GIS or during an exchange of data between GIS.

Moving from a detailed representation to a more general one has two advantages (to humans as well as to computers): (1) it reduces the amount of data to be stored; and (2) processing becomes faster. Understanding the connections between multiple levels or resolution of detail for the same phenomena (including the errors associated with it) will allow the use of heuristics to solve problems for which no straightforward (brute-force) approaches are known.

3.6. Spatial Theory

The data in a GIS are related to space. In many instances the analysis to be performed on them includes spatial properties. Current systems do not incorporate comprehensive methods, but instead have a specialized subset of spatial operations. There are very close links between the models used to represent spatial data and the operations applicable. Today's systems include each of several different models available and are restricted to a subset of spatial relations and operations.

4. Assessment of the Five Research Areas

This section summarizes the principal impediments to GIS applications and the corresponding research needs as identified in the team's proposal. For a more detailed description, please refer to *The Research Plan of the National Center for Geographic Information and Analysis* [NCGIA 1989].

4.1 Spatial Statistics and Spatial Analysis:

Early GIS emphasized simple queries reflecting the needs of urban planners and resource managers for basic record keeping and land inventory. They incorporated techniques - such as overlay mapping - that are simplistic, subject to indeterminate errors and easily abused.

Many of the mathematical findings that could provide the basis for advanced analytical capabilities exist already in the literature of spatial statistics, spatial analysis and spatial econometrics, but have yet to be applied. Several prominent spatial analysts have recently drawn attention to this persistent gap between theory and practice. For example, though retailing is a major application of spatial interaction models, no comprehensive calibration package is available for retail applications to apply the advances made since the 1960's in spatial interaction modeling. These problems of technology transfer are due, at least in part, to the extremely simplified (and hence unrealistic) spatial representations that underlie many models: the uniform plain, the isolated city, the square grid or matrix, or even the real line or circle. By providing ready access to realistic databases with detailed geographical resolution and appropriate data structures, GIS technology can support the development of much more effective methods. Comprehensive statistical packages for spatial analysis, although there is a great need for GIS incorporating a comprehensive set of sophisticated techniques of spatial analysis. At the same time, extensive application will have a beneficial effect on spatial analysis by forcing a re-evaluation of models that fail to perform well and by identifying gaps in our current set of techniques.

4.2 Spatial Relations and Database Structures

Many of the shortcomings of current GIS can be attributed to problems of modeling spatial relationships or to their implementation in current systems. The long-term research goal in spatial relations and database structures is threefold:

1) to determine the spatial concepts humans use
2) to develop a coherent spatial theory or comprehensive geometry, and
3) to use this theory to design a comprehensive basis for computer algorithms in geographical information analysis (GIA) and GIS.

4.3 Artificial Intelligence and Expert Systems

Artificial intelligence (AI) and expert systems (ES) offer a set of techniques to overcome impediments arising in the context of computer-based analysis of geographical information.

As a body of techniques and methods for problem solving, AI/ES cuts across the topically-based organization of the other components in this research agenda, contributing in substantial ways to all of the other major research areas. Many impediments involving both computational and cognitive aspects of geographical problem-solving may be overcome using AI/ES approaches. Many problems in geographical analysis can be solved using relatively well-known analytical approaches. For other problems, however, no currently available theories, techniques, or even research procedures provide adequate solutions. For some such problems, AI/ES techniques may prove valuable. In particular, these techniques may be usefully applied to overcome some of the more difficult impediments that arise in the areas of spatial analysis, spatial relationships and data structures, and visualization.

4.4 Visualization for Display and Analysis of Spatial Data

The report of the NSF panel on graphics, image processing and workstations defines visualization as

> a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations ... Visualization embraces both image understanding and image synthesis. That is, visualization is a tool both for interpreting image data fed into a computer, and for generating images from complex multi-dimensional data sets. It studies those mechanisms in humans and computers which allow them in concert to perceive, use, and communicate visual information [NSF 1987, p.3].

Visual displays can thus be used to analyse as well as to illustrate information and to generate hypotheses as well as to interpret the results of scientific research. Methods for visualizing spatial data form a major component of the long-established discipline of cartography. Visual displays in the form of graphic and cartographic products are one of the most important research tools in spatial analysis, and it is appropriate that many geography curricula require students to study cartographic principles. Fundamental geographical variables (eg. spatial coincidence, proximity, contiguity) are difficult to interpret in the purely numerical context of conventional computing environments, yet their patterns become obvious in appropriate graphic depiction. Visualization provides capabilities to explore spatial patterns that are not directly accessible, for example in statistical landscapes where topography is determined by population density, travel accessibility or volumes of fiscal transfer. We may also visualize in order to simplify the interpretation of patterns that exist in more than three dimensions, such as mulivariate distributions changing simultaneously in space and time. Visualization in spatial analysis can be accomplished more efficiently with the aid of computer technology, but requires a clear understanding of human and machine cognition.

Much of the effort in computer-assisted cartography over the past quarter of a century has been concerned with automating traditional cartographic representations and techniques; there has been too little concern for cartographic methods that go beyond what was possible on the static printed map. Graphic portrayal of three-dimensional data, of time-varying spatial data, of geographical flows and of uncertainty or fuzziness in geographical information all present substantial research challenges.

4.5 Social, Economic and Institutional Issues

An information system is an assembly of human and technical resources which captures, analyses, represents and delivers data and information. GIS are potentially extremely useful to a wide variety of users in the private and public sectors who assemble land-related data and draw conclusions based on information derived from them. This varied group includes planners, developers and investors, as well as scientists and engineers who study spatial patterns and processes. Decisions resulting in rational use of physical and human resources are most likely to occur when users have information about land, water and other resources in appropriate form and at the appropriate time. The desire to reduce uncertainty in these decisions creates a demand for improved information products.

Adoption and implementation of geographical and land information systems is a dynamic process characterized by mutual adoption between products and services and user needs. Adaptation is not an automatic or instantaneous process, but can be promoted by various intervention strategies. Social, legal, economic and institutional factors -both real and perceived - all affect the pace and extent of adoption. Research on these factors will not only provide greater knowledge of the adaptation process, but also yield feedback relevant to the design and development of GIS.

The incorporation of advances in GIS into the operations of government and private industry will create numerous problems, some of which are unpredictable. Of those which are currently evident, some are considered critical impediments to the adoption of GIS technologies, and will be among the first problems addressed by the National Center. The primary research effort will be directed at developing methodologies and bodies of knowledge which government, private industry and other institutions will find valuable as they cope with the societal ramifications of GIS technologies.

5.0 Research Initiatives

Research on these topics is carried out following a model that has worked for the Institute of Theoretical Physics at the University of California at Santa Barbara, namely concentrating the efforts of many researchers in a collaborative and interdisciplinary fashion to bear on a common problem. 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.

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

Working Groups conduct research for periods of six months to two years following the Specialist Meeting. We assume that the largest commitments are 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 use a variety of modes of inquiry, including seminars, computer modeling and prototyping, and empirical investigation.

National/International Conferences are held at which substantive findings are presented to a larger audience.

Research Initiatives:

Initiative 1: Accuracy of Spatial Databases
Leader: Michael Goodchild (Santa Barbara)
Duration: October 1988-November 1989
Objectives:
1) Assess statistical models of spatial data
2) Construct and evaluate techniques for interpolation and estimation to overcome problems of variable reporting zones and missing values
3) Develop indices of data uncertainty and confidence for GIS products
4) Conduct studies of the effects of aggregation on spatial modeling.

Initiative 2: Languages of Spatial Relations
Leader: Andrew Frank (Maine) and David Mark (Buffalo)
Duration: October 1988-July 1990
Objectives:
1) Identify formal cognitive/semantic models of spatial concepts and relations in natural languages
2) Develop reliable methods for determining reference frames for spatial language
3) Construct formal mathematical/logical models of spatial concepts and relations based on topology and geometry
4) Integrate the two kinds of formal models into a general theory of spatial relations.

Initiative 3: Multiple Representations
Leader: Barbara Buttenfield (Buffalo)
Duration: October 1988 - 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
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
Leaders: Harlan Onsrud (Maine), Hugh Calkins (Buffalo)
Duration: October 1988 - 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 GIS/GIS

Initiative 5: Architecture of Very Large GIS Databases
Leader: Terence Smith (Santa Barbara)
Duration: May 1989 - 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
Leader: Michael Goodchild (Santa Barbara)
Duration: September 1989 - 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

Future initiatives: six more initiatives are planned for the following years. They will include:

Initiative 7: Visualization of the Quality of Spatial Information
Initiative 8: Expert System for Cartographic Design
Initiative 9 Institutions Sharing Spatial Information
Initiative 10: Temporal Relations in GIS
Initiative 11: Space-Time Statistical Models in GIS
Initiative 12: Remote Sensing and GIS

6. Education

The shortage of individuals trained in geographic data management and analysis is a matter of considerable concern. The limited supply of trained people to fill positions at all levels of government, the private sector, and academia is noted in the National Research Council report *Need for a Multipurpose Cadastre*. The report also documents the lack of qualified personnel to perform the functions inherent in a comprehensive geographic information system and the need to support and encourage development activities and programs. Many federal, state, and local government agencies are finding the lack of such personnel to be in fact the major limiting factor in developing their own systems. One of the NCGIA's primary objectives is to alleviate this shortage by expanding the nation's supply of experts in GIS. The Center's education program addresses these problems in three different ways:

- Education of undergraduate, graduate, and postgraduate students at the three NCGIA institutions and introduction of GIA/GIS-related courses in local high schools
- Education of undergraduate and graduate students enrolled at other institutions
- Extensive workshops, summer seminars, conferences, educational publications, and related outreach activities for the GIA/GIS community.

In order to implement the above program, NCGIA includes the following features:

- Curriculum development in support of undergraduate and graduate instruction in geography, surveying engineering, and other GIA-related fields at the three member institutions
- Development and dissemination of a standardized curriculum for teaching the basics of GIA to undergraduate and graduate students elsewhere and for preparing local high school students to enter the field.
- Research opportunities for graduate students
- Shared support for junior faculty and full support for postdoctoral scholars in conjunction with NCGIA activities.

As a major first achievement, the model curriculum has been developed and was used during the 1989/90 academic year at a number of locations. The center has collected reports from these users and will use them for a major revision of the contents before a wider dissemination of the material. We expect that the course material will be generally available in Fall 1990.

11. Dissemination

The results from Center research will be primarily published in recognized refereed journals. We have also several projects for edited volumes of papers from different authors, which will be printed by commercial publishers and distributed through bookstores.

In order to keep fellow researchers up to date on our efforts, we will participate in national conferences and present or discuss our intermediate results there. In addition, we are preparing a series of technical reports which are available from the NCGIA office at the University of California at Santa Barbara[2].

12. International Connections

The Center is aware that its efforts are part of the international research effort in GIS. Collaboration with researchers and research teams in other countries is very important, to make the best use of limited resources, and to avoid duplication of efforts. In several countries, efforts to establish similar research centers concentrating on geographic information and analysis are underway . Cooperation with groups in the UK is well underway. In Britain there has already been established a Centre for Geographic Information. Ties to groups in some european countries are working well and we also have contacts with researchers in Latin America. The center welcomes such cooperation and is interested in formalizing cooperative efforts.

13. Conclusions - Invitation

The NCGIA has - as of the time of this writing - just concluded its first year of operation. Research on a number of important topics is well underway. An impressive list of publications makes the results of Center research available to other researchers. The Center has also presented results at numerous national and international conferences. Interestingly, and this seems to be very important, the presence of the Center seems to have a stimulating effect on research groups at other universities and research organizations. Last but not least, the Center has established ties with U.S. industry for cooperative research and so has enhanced the transfer of results from the university laboratory to the practical world.

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