National Center for Geographic Information and Analysis

SELECTIONS FROM A PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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by

The University of California at Santa Barbara
The State University of New York at Buffalo
The University of Maine at Orono

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Simonett Center for Spatial Analysis
University of California
35 10 Phelps Hall
Santa Barbara CA 93106-4060
Office (805) 893-8224
Fax (805) 893-8617
ncgia@ncgia.ucsb.edu

State University of New York
301 Wilkeson Quad, Box 610023
Buffalo NY 14261-0001
Office (716) 645-2545
Fax (716) 645-5957
ncgia@ubvms.cc.buffalo.edu

University of Maine
348 Boardman Hall
Orono ME 04469-5711
Office (207) 581-2149
Fax (207) 581-2206
ncgia@spatial.maine.edu

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PROJECT SUMMARY

The objectives of this project are to remove significant impediments to the widespread adoption of improved techniques of geographic information and analysis employing geographic information systems (GIA/GIS).

Three major classes of impediments that inhibit the development and applicability of GIA/GIS are (1) inadequate data handling capabilities for very large datasets, (2) inadequate analytical and modeling capabilities, and (3) inadequate analysis of applicability and user acceptance. The research proposed to addresses these and related impediments takes the form of a series of research initiatives, involving interaction not only between individual researchers, but also between academic, industrial and government research and user communities. The initiatives involve specialist meetings to define precise research objectives, working groups addressing problems for one to two years, and national and international conferences at which substantive findings of the research are presented. Subsequent research may also occur as a natural outgrowth of each initiative.

The severe shortage of well-trained professionals in the area of GIA/GIS is addressed by a series of educational initiatives involving development of new courses, the training of faculty from other universities in the use of the course materials, and development of and presentation of workshops at meetings of professional societies and other locations.

Finally, the results of the research and education program will be widely disseminated through a quarterly newsletter and publication of technical reports in various formats.

I
RATIONALE FOR A NATIONAL CENTER FOR GEOGRAPHIC INFORMATION AND ANALYSIS

1. The Need for a National Center

1.1. Introduction

There is a clear and pressing need for the establishment of a National Center for Geographic Information and Analysis (NCGIA). The need arises because available geographic information systems and the personnel who operate them are incapable of meeting the rapidly growing demands of science and society. These demands are especially apparent in the many large-scale problems now confronting science and society, problems whose solutions require processing large quantities of spatially addressed data. Hence there is urgency to examine a large class of difficult questions concerning both geographic information and analysis (GIA) and geographic information systems (GIS), to augment the inadequate supply of personnel trained to work with GIA/GIS, and to satisfy the increasing demand for information concerning GIA/GIS.

The vision that drives the University of California at Santa Barbara (UCSB), the State University of New York at Buffalo (UB), and the University of Maine (UM) to join in forming a national consortium for research, education, sad knowledge dissemination concerning GIA/GIS arises from two convictions:

- GIA/GIS will provide tools of fundamental significance for the basic and applied sciences. The application of such tools will result in major benefits to society.
- The next decade will provide critical opportunities for a National Center to play a leading role in developing applicable GIA/GIS technology, training a cadre of individuals able to apply and develop such technology, and disseminating knowledge concerning GIA/GIS.

GIA/GIS technology offers a great and largely untapped potential for increasing our understanding of the world and for applying such knowledge in ways that are valuable to society. A suitably focused GIA/GIS technology will provide a firm basis for efforts in the social, natural and engineering sciences that are directed at solving common problems and providing vital decision-making aids for the public and private sectors. As we move deeper into the information age, GIA/GIS will provide standard tools both for enhancing the competitiveness of U.S. industry in an increasingly competitive world and for solving social and environmental problems at scales ranging from local to global.

In order for the technology to realize its potential for providing a deeper understanding of our world, however, it must significantly increase its capacity to handle very large, spatially indexed databases, and must incorporate more powerful capabilities for modeling and analysis. The technology will attain its greatest value only if there exist both a sufficient number of individuals educated in its use and development and a sufficient body of knowledge concerning its availability and applicability.

Our main concerns, therefore, he not with the need for a National Center (which we take to be self-evident) but rather, in its mission, organization, and location. Although we provide a general rationale for establishing an NCGIA, we emphasize providing a rationale for its specific mission, organization, approach to management, and geographic location. This emphasis is based on our firm conviction that the scientific and social benefits accruing from a Center will largely depend on the clear definition and relevance of its mission and the degree to which its organization, management and location are supportive of that mission.

In the remainder of the Rationale, we first provide a general justification for an NCGIA. We then discuss the mission of the proposed Center: its roles in research, education, and knowledge dissemination and its importance to the basic and applied sciences and to the public and private sectors. Finally, we describe the nature of the proposed Center, including the organization and management of the consortium and the manner in which it will carry out its program for GIA/GIS research, education, and knowledge dissemination.

1.2. A General Rationale for an NCGIA

The solicitation for an NCGIA is part of a broad NSF initiative for center-based research. Many of the arguments for an NCGIA apply to all such centers. For example, major research endeavors increasingly require a critical maw of individuals and resources, multiyear funding, and multimode interactions, such as between universities and the private sector.

In the case of GIA/GIS, very strong arguments for center-based activities justify the establishment of a National Center; among these, three are particularly salient:

- There is, and will continue to be, a very substantial scientific and societal demand for systems that can handle very large spatial databases and can analyze and model complex spatial phenomena. Such systems currently are unavailable. Hence there is a wide gap between the benefits potentially available to society from a well-founded, systematic production and use of geographic information, and the relatively meager benefits available today.
- Significant advances in the nature and applicability of such systems require multidisciplinary research and development on a large scale.
- Successful development and use of such systems requires a coordinated effort involving not only research, but also education and the dissemination of knowledge concerning their availability and applicability.

We believe that these arguments alone provide a sufficient rationale for establishing an NCGIA. We therefore propose that an interdisciplinary consortium consisting of three universities form a National Center in order to address the preceding issues.

The *first* argument concerns the remarkable growth of interest in GIS as a modeling and decision-making tool in the academic, public, and private sectors. As noted above, based only on current computational technology, GISs cannot handle very large spatial databases or model a wide range of complex spatial phenomena. Given the demand for such tools and the major impacts they would have for decision making in many domains, their social and scientific benefits would be very substantial. To date, however, these potential benefits have barely been realized, since the primary applications of GIS technology have been largely confined to storing, updating and retrieving spatially indexed data from relatively small datasets and answering conceptually simple queries. Systems that handle very large spatial datasets or that integrate techniques for the modeling and analysis of geographic data are virtually unavailable.

The illustration on the following page shows the status of current systems and the research needed to increase applications and suitability. As it stands now, few systems indeed encompass reasoning while most present systems barely approach an adequate digitizing and display capability.

It follows that a serious need exists to critically investigate the field of GIA/GIS in order to discover, explore and disseminate sound concepts and techniques capable of satisfying society's demand for improved spatial knowledge. In particular, the investigation should lead to scientifically important research and to valid and reliable applications, expediting many of our everyday tasks and ultimately enhancing the quality of life. Central to the goal of satisfying the demand is the integration of spatial analysis techniques with GIS technology and the investigation of the applicability of the integrated technology.

The *second* argument relates to the need for multidisciplinary and large-scale research. The development and application of GIA/GIS require knowledge drawn from a variety of disciplines in the social, natural, engineering and management sciences, as well as input from the user community. Development of such systems requires, for example, a knowledge of computational, statistical, and modeling techniques. Application of such systems often requires not only a knowledge of the domains of application, but also a knowledge of techniques for assessing the value of such applications. The discipline-based structure of traditional academic institutions, together with the standard single-investigator approach to research, are therefore poorly suited to a field such as GIA/GIS, which is interdisciplinary in nature, and must address a great diversity of user needs at the local, national, and global levels. It is also clear that systems capable of handling very large spatial databases and analyzing and modeling complex spatial phenomena must themselves be large and complex. This fact imposes the requirement that research in the area of GIA/GIS be both large-scale and multidisciplinary.

The *third* argument concerns the need for a coordinated program of research, education and knowledge dissemination. A successful program for developing systems capable of handling very large databases and of analyzing and modeling the complex spatial phenomena that arise in real applications requires more than research on how to build such systems: it also requires an adequate infrastructure for educating individuals who will be capable of both applying and developing such systems. There is a significant shortfall in the current supply of individuals with the requisite educational background to support the demand for improved GIA/GIS. A successful program further requires that information concerning the availability and applicability of the technology be efficiently and adequately disseminated. Above all, it is essential that a large body of users find the technology to be accessible and acceptable.

The educational and knowledge dissemination functions of in NCGIA are of critical importance because the production, analysis, management, presentation, and use of geographic information involves a complicated interplay between theory, technology, and practice. In GIA, more than in many other fields, the gaps between theory and technology, between technology and application, and between application and theory are disconcertingly wide. These facts support the establishment of an NCGIA that will work diligently towards integrating education and knowledge dissemination with research.

In summary, we view the *rationale* for an NCGIA in terms of society's rapidly growing demands for the production and availability of geographic information. Such information must be of the highest quality and of the greatest relevance if its potential benefits to science and society are to be realized. We view the mission of an NCGIA in terms of the need for a nationally coordinated program that integrates research, education, and knowledge dissemination and that narrows the gaps between theory, technology, and application in the area of GIA/GIS.

The shared conviction of the three institutions forming the consortium is simple:

- We are convinced of the fundamental importance of GIA/GIS for a broad set of needs and applications, not only in the social and natural sciences, but also in the areas of planning, management, and engineering. We believe that the establishment of a National Center is the correct approach for developing the area of GIA/GIS and for integrating the requirements relating to research, education and knowledge dissemination.

The establishment of a National Center is an ambitious undertaking and will undoubtedly require resources well beyond those currently allocated by the National Science Foundation if it is to have the impact that the importance of GIA/GIS warrants. We are committed to marshaling resources for NCGIA development significantly in excess of those presently allocated by the National Science Foundation.

2. The Mission of the Proposed NCGIA

The basic mission of an NCGIA in the view of our consortium, is to provide a national focal point for addressing the issues that impede the progress of research, education, and knowledge dissemination in geographic information analysis. In the following sections, we describe this mission in relation to the major issues to addressed by the Center and the beneficiaries of the Center's activities.

2.1. The Need for Basic Research

Geographical analysis involves both theoretical and empirical investigations of spatially distributed phenomena that are typically very complex. In particular, geographical analysis frequently investigates the interactions between large numbers of time-varying and spatially distributed subsystems. While quantitative research in geography has involved both analytical and statistical methods, many spatially distributed systems have thus far proven extremely difficult to model, predict, or understand. The use of computational technology has permitted significant increases in the sophistication of model building and exploration, and has allowed the analysis of increasingly large datasets.

It is apparent, however, that although the application of computers and the increasing availability of large, spatially indexed datasets have led to advances in our understanding of many phenomena, their use has given rise to a large number of impediments. Because many of these impediments hinder the development and application of systems that combine traditional methods of spatial analysis with GIS technology, current GISs have realized only a small portion of their potential for geographical analysis, and are deficient in many respects. Whether these impediments are technical or conceptual in nature, their magnitude and diversity imply the need for large-scale research efforts. *Strategies* *for identifying and either reducing or eliminating impediments to the development and applicability of GIA/GIS lie at the core of this proposal and form the basis for our research agenda.*

Three major classes of impediments that inhibit the development and applicability of GLA/GIS are:

- *Inadequate data-handling capabilities:* Spatial datasets, such as those provided by remote sensing techniques, have attained sizes that far exceed the data-handling capabilities of current GISs. Hence such datasets cannot be analyzed adequately. In addition, the lack of compatibility among disparate data sources (such as census data, topographic data, and remotely sensed data) having different formats, spatial and temporal coverages, and levels of spatial resolution, has prevented adequate analysis and modeling of many important phenomena. It has also resulted in large expenditures of time, money, and resources. Problems relating to the resolution, precision, and accuracy of spatio-temporal data have led to many problems in the use of such data.
- *Inadequate analytical and modeling capabilities:* GIS development has dealt primarily with the entry, storage, updating, and retrieval of data and with a few simple queries relating to such data; the potential of GISs for spatial analysis, modeling, and forecasting has been largely ignored. The primitive nature of the spatial analytical techniques employed in GISs to date have rarely justified the large expenditures of resources made in collecting and encoding the data. More sophisticated techniques of modeling and analysis need to be developed, tested, and diffused throughout the GIS user community. The lack of formal methods for modeling error propagation in CIA/GIS operations has resulted in products that, all too often, have been of limited reliability as tools for decision making.
- *Inadequate analysis of applicability and user acceptance*: Little effort has been expended on such questions as the information value of the data employed, the trade-off between information value and cost, the loss of information with the increasing age of data, redundancy of information among different data layers, and variations in information value over space. As a consequence, much time, money, and effort have been wasted in the collection, encoding, and analysis of data of questionable utility. There has been a similar dearth of research concerning the factors that make GIA/GIS acceptable as research and decision making tools for users.

All three classes of impediments are central to our plans for research at the NCGIA and are discussed in detail in the Research Plan. Because of their intrinsic importance, however, we briefly discuss several important issues relating to handling very large, heterogeneous, and imprecise datasets and to incorporating techniques for analysis and modeling into GIA/GIS. This discussion is intended to exemplify several important issues, rather than to be exhaustive.

Concerning the inadequacy of the data handling capabilities of current GISs, key issues relate to very large databases and to data quality. First, the problem of very large databases of spatially indexed data provides technical and conceptual challenges to both researchers and users of GISs. The establishment of the International Council of Scientific Unions/IGU Commission on Geographic Data Handling and Analysis for large databases (for the Decade of Global Change) is one signal of the enormity of the challenge. The commitment of the USGS to an investigation of both local and upwardly compatible GISs for Survey use is another. NASA's proposed Earth Observing System (Eos) program and the current Geostationary Platform Committee study are both concerned with large, global databases. Work on such databases requires a high level of conceptual and cross-disciplinary thinking, as well as computational techniques that are highly efficient for retrieval, analysis, analytical modeling, and forecasting.

Second, issues relating to data quality and errors pervade many aspects of spatial data handling. The lack of theoretical understanding of error measures and of the propagation of errors through various GIS procedures hampers the use of GISs. It affects GISs in two ways: on the one hand, we cannot fully assess the quality of results derived in a GIS; on the other hand, we cannot assert in advance of data collection what level of precision is necessary to reach a determined level of quality. The development of comprehensive models of error is an essential part of any research agenda for the NCGIA and will be addressed from both a theoretical and an empirical perspective.

Concerning the set of impediments associated with *inadequate analytical and modeling capabilities*, four key issues require discussion. These issues involve modeling, data types, spatial concepts and multiple representations. First, in relation to *GIS and models of reality*, we note that substantial advances in many sciences have arisen from the construction and use of formal models of their research domains. Geographers, urban and regional planners, researchers in various social and natural sciences, and professionals using geographic data have benefited less from such constructs. Computer systems are an enabling technology for such modeling efforts, but success depends on conceptual as well as technical tools.

Second, *the concept of data types* is linked to questions concerning analysis and modeling. The absence of comprehensive rules for the combination and transformation of spatial data is currently a handicap in the use of GISs. Users without extensive training cannot combine data as needed, and often end up with meaningless or misleading data. Analytical work with a GIS often requires conversion from one scale of measurement (nominal, ordinal, interval, ratio) to another, and some changes are dictated more by technical issues of implementation than by conceptual abstractions of the phenomena themselves. Inferences may be derived from numerical or symbolic computations using values on nominal or ordinal scales. It has been observed that decision makers prefer values on nominal, ordinal, or even binary scales, whereas many analytical techniques assume ratio scales.

Third, an adequate set of *spatial concepts* is required for analysis and modeling. The models used to represent spatial data and the operations applicable to the data are closely tied. The data in a GIS are related to geographic location, and the analyses to be performed frequently involve spatial properties. Because current systems do not use comprehensive methods for spatial representation, they can support only small and specialized sets of spatial operations. This limits the ability of GISs to use data for multiple purposes and to maximize the utility of the data collected. Concepts must be found which permit easy translation from one model to another, as well as integrated analysis of mixed spatial representations.

Finally, since geographic analysis deals with spatial phenomena extending over a range of scales from single land parcels to global ecosystems, GIS must be prepared to employ *multiple representations of spatial objects*. Such representations must be able to analyze phenomena at different scales of resolution and at different levels of aggregation. Many questions arise in relation to the use of multiple representations. For example, employing several representations of the same phenomenon may increase the quantity of data that must be stored, but may reduce the amount of processing required for certain operations. This is particularly true for hierarchical representations. On the other hand, employing high-level representations of phenomena may reduce both the amount of data to be stored and the amount of processing, yet lead to inaccurate results. There is a critical need to understand the connections between multiple representations of the same spatial object and to learn how to use multiple representations for efficient processing.

The preceding discussion indicates some of the needs for basic research at the NCGIA. The development and application of GIA/GIS is, however, much more than a challenge to our theoretical understanding, since we must also recognize that systems are useful only if they can be built with today's computer technology and if they find acceptance among users. The inability to perform certain operations quickly currently impedes the use of GISs in many applications, especially when real-time reactions and decisions are necessary. Hence computational considerations take on major significance. While theoretical work often establishes that an operation is possible, it may be far from easy to find an efficient computational implementation. Many forms of spatial analysis seem amenable to parallel processing; we should anticipate and exploit these and other developments in machine architecture. Finally, much research is required to ascertain and overcome the considerable impediments to the acceptance of GIA/GIS technology by users.

It is clear from this discussion of a few issues relating to a few impediments that a great deal of basic research is required to satisfy growing user needs. It is our contention that research of this diversity and magnitude can only be carried out at an NCGIA that is involved in all aspects of GIA/GIS.

2.2. Relating Research Needs to our NCGIA Research Plan

The research strategy of the Center will revolve around the complementary concepts of *impediments* to the development and application of GIA/GIS and *Research Initiatives*-structured programs of research intended to overcome the given impediments. Research Initiatives may be viewed for the most part as multiperson/multidisciplinary research projects with a typical lifespan of six months to two years. There will be coordination among the several initiatives in progress at any given time. Each initiative will involve several members from the different sites of the NCGIA as well as individuals from a variety of other institutions, agencies, and corporations.

The choice of impediments for investigation and the associated research initiatives will be based on the five areas of research outlined in the solicitation for the Center. Most research initiatives will involve impediments from the three major classes identified above.

We briefly review the five research areas identified in the solicitation in relation to a set of typical impediments. A more detailed exposition may be found in the Research Plan for the Center.

- The area of *spatial analysis and spatial statistics* is well developed but needs to be integrated with the technology of data handling. For example, basic discrepancies at the interface between theory and computer implementation can often be traced to the incompatibilities between the continuous mathematics of most spatial models and their discrete computational counterparts. The problem is more severe for spatial models than for other types where only the temporal continuum needs to be discretized. Also, although space is an intrinsically "parallel" domain, very little use has been made to date of the potential of parallel computation for spatial data manipulation or spatial modeling.
- The area of *spatial relationships and database structures* addresses the need to investigate formal and computational representations of space. Current data structures have been designed largely to satisfy the requirements of cartographic data, but have difficulty in representing many important concepts such as fuzziness, spatial interaction, and time dependence. New conceptualizations are needed that are more compatible both with the ways in which humans think about spatial problems, and the ways in which current machines are best able to store, represent, and manipulate information.
- Since decision making in a spatial context is an inherently complex procedure, a detailed investigation is required of the role of *artificial intelligence (AI) and expert systems (ESs)* in bridging the gap between user and machine. AI and ES offer a means of dealing with the complexity of spatial decision making at the theory-applications interface, the complexity of data handling at the theory-technology interface, and the demands of human-machine interaction at the user-technology interface.
- Effective human-machine interaction demands more research into *visualization and issues of data representation and display*. Interfaces must mirror the way in which users represent spatial concepts mentally in order to facilitate effective human machine interactions. Thus the challenge of visualization is not merely to represent spatial information graphically but to develop forms of representation that facilitate comprehension and problem-solving.
- The widespread adoption and acceptance of GIS technology by private and public sector users requires that *social, economic, and institutional issues* relating to data ownership, legal liability and responsibility, and social and economic impacts of the technology be addressed. Inevitably, the social relevance of spatial theories and the enabling technology will need to be assessed as GIS applications increase.

Examination of such issues is necessary to establish guidelines for GIS research, education, and information dissemination commensurate with a national commitment to the advancement of science and technology for society's needs.

2.3. The Need for Education

The growing interest in GIS has created a pressing demand for trained professionals. We anticipate that this demand will increase rapidly for at least several years, as, for example, thousands of administrative agencies adopt GISs. On the supply side, only a limited number of colleges and universities offer one or more courses in GIA/GIS, and very few possess the strong technical base required for adequate teaching in these areas or incorporate current research into their curricula. Lack of trained faculty, equipment, and teaching materials exclude many institutions from introducing programs in GIA/GIS. Hence the demand for trained professionals with expertise in GIA/GIS far exceeds the supply of such individuals from colleges and universities.

The short supply of training programs is exacerbated by a number of factors:

- There is a shortage of standardized teaching methods such as course outlines and teaching materials.
- There are neither accepted prerequisites for GIS degrees nor general standards concerning areas of competence for GIS degrees.
- Approaches and methods of instruction are spread thinly over many academic fields.
- The literature on GIA/GIS is widely dispersed over many different fields.

There is also a serious shortage of both research-oriented and education-oriented conferences, seminars, and practical workshops devoted to GIS, although general conference activity in the area is increasing at a remarkable rate. In large part, however, such activities are organized by GIS vendors and organizations. These conferences have tended to emphasize applications-oriented research. There is a need for the education of users, educators, and researchers on many of the fundamental issues that we will be tackling in our research agenda.

It is clear that there is a pressing need for education in order to:

- increase significantly the quantity and quality of graduate and undergraduate degrees awarded in GIS;
- upgrade the qualifications of personnel already employed in GIS-related positions at both academic and nonacademic institutions;
- provide a stimulating environment for doctoral candidates qualified to fill academic positions;
- develop and disseminate educational materials including curricula and case studies, and otherwise assist institutions in developing their own GIA/GIS programs.

The role of the NCGIA in promoting research, described in the preceding section, applies equally to a role in promoting education. An NCGIA will play a key role in helping to meet these four educational needs, not only through direct training of students and professionals, but also through its involvement in research and knowledge dissemination.

2.4. The Need for Knowledge Dissemination

There is a lack of a coherent national plan for managing issues of data compatibility, communications protocols, formatting procedures and distributed processing. Although interagency groups at the federal level are beginning to examine a number of data issues, it is still imperative that the Center provide a locus where practitioners, educators, and researchers can work together and provide for the timely dissemination of results. Increased levels of data collection demand an integrated approach to networking at a national scale, while issues of distributed processing and data transfer between sites must be addressed so that practitioners may gain access to relevant and timely data.

As an applied technology dispersed over a large and heterogeneous group of practitioners, GIA/GIS suffers from the lack of a central agency from which information on a broad range of issues is obtainable. This is unlike the situation in remote sensing, in which NASA, NOAA, and USGS continue to play crucial roles, although even remote sensing data is occasionally hard to access. The NCGIA will act as information distributor and source of expert opinion, advice, and knowledge. However, except for distributing its own educational databases, the Center will not act as a data distributor, archivist, or clearinghouse.

Private and public agencies have provided much of the impetus for GIS development and growth. Links to such agencies must be firmly established in order to ensure that:

- the research agenda of a National Center is relevant and useful to practitioners;
- practitioners make full use of research advances arising at the Center and at other institutions.

A national agenda that includes technology transfer and dissemination of innovations is needed to ensure that findings of the research community are put to practical use and that basic research priorities reflect user needs. We will establish regular channels of communication with the user community in order to ensure the relevance of our research agenda.

2.5. The Importance of the NCGIA for Major Scientific Research and Teaching

Because many academic disciplines need to analyze large spatial datasets or model complex spatial phenomena, a successful NCGIA will have profound impacts on research and teaching in a large number of academic disciplines including many of the social, natural, engineering, and management sciences. Researchers will be able to deal with previously intractable problems; educators will be able to use more realistic examples in their teaching, such as examples involving very large spatial datasets or examples requiring sophisticated spatial analysis and modeling tools. Many of the impacts will result from:

- the increased ability to handle large spatial datasets and to model complex spatial phenomena that will follow from a successful research program at the NCGIA;
- the increased ability of academicians in many fields to use the techniques and technology of GIA/GIS as a result of successful educational initiatives at the NCGIA;

- the increased knowledge that many researchers and educators will possess-concerning both the availability of large spatial datasets and the availability of GIA/GIS technology as a result of a successful program of knowledge dissemination at the NCGIA.

We now describe specifically some of the impacts that a successful NCGIA should elicit in several different areas of academic endeavor.

2.5.1. The Importance of the NCGIA, for Geography

By definition, geography is a discipline that deals with a large variety of problems involving spatial phenomena. Many of the problems investigated by geographers have been intractable either because of the complexity of the spatial phenomena under study and the lack of techniques for modeling such phenomena or because of the lack of techniques for handling very large spatial datasets. Geographical analysis techniques and GIS technology have to date not proven adequate for investigating many problems that, in principle, are solvable. This is due in part to the complexity of the phenomena and to the large amount of research required to develop and apply such techniques and technology. But we believe that it is also due, to a significant degree, to the independent evolution of the area of spatial analysis and the area of GIS.

We propose to enrich GIS by integrating spatial analysis into its research agenda and its educational curriculum. Similarly, we propose to make spatial analysis more significant by linking its theory and model-building functions to the extensive databases of GISs. Underlying this effort is the ambitious goal of moving toward a more effective synthesis in the discipline of geography. The integration of the theoretical depth of spatial analysis with the data-handling power of GIS can provide a basis for dealing with many of the dynamic, multivariate geographic systems that have yet to be successfully investigated. Such an achievement would move us towards the establishment of a more cohesive discipline and would reverse the recent trend towards overspecialization in areas that are more properly regarded as subfields of other disciplines.

2.5.2. The Importance of the NCGIA for the Social Sciences

Most of the social sciences maintain as their general goal the identification and explanation of patterns in human behavior at both the individual and aggregate levels. Historically the unit of analysis has varied, from the emphasis of political science upon individuals, to the concentration of anthropology and sociology on small groups, to the investigation of large aggregates of individuals in economics. Increasingly, all the social science disciplines are developing methodologies requiring sophisticated, complex, and precise aggregate databases for at least two agendas central to their research missions, namely:

- the location of physical and human demands and the resources appropriate for meeting them;
- the explanation of relationships existing between discipline-specific aggregate patterns of data and various types of geographic information.

Since most relevant databases (such as income levels, public and private expenditures, capital resources, and health patterns) are neither consistently defined nor constructed for concurrent use, researchers have been frustrated in their ability to identify and weigh the relative importance of such factors. The well-defined GIA/GIS should facilitate new quantitative investigations of both basic theoretical questions and applications across the social sciences.

For the sake of concreteness, we provide a few specific examples of possible applications in the social sciences. A central theme of sociology is the study of human needs, such as epidemiological, welfare, and safety needs. Currently, medical sociologists are analyzing the environmental correlates of disease, and a comprehensive CIA/GIS would expand the data sources that could be spatially matched to health data. Similarly, analysis of crime statistics would be greatly enhanced by the availability of geographic data collected for the same spatial units. For anthropology and archaeology, the coregistration of numerous environmental data layers is now being expanded for possible simulation and modeling. A promising frontier in economics is the use of GIA/GIS for spatial econometric modeling of both aggregate and disaggregate phenomena. For political science, analysis of the policy process and its consequences for power distribution among politically relevant groups is central. Cognitive psychologists studying spatial cognition may benefit from the spatial datahandling capabilities offered by GIS.

A GIA/GIS that is both powerful and commonly accepted by practitioners and analysts would facilitate higher quality research concerning the processes, options, and outcomes in the public policy issues addressed by many social sciences. For the social science disciplines, GIA/GIS offers the promise of more consistent data and the hardly tapped potential of extending these and other types of research to several time periods. It may well provide the first significant impetus to analysis that is temporal as well as spatial, and thus constitute a major methodological advance for such investigations.

2.5.3. The Importance of the NCGIA for the Natural Sciences

Many natural scientists are beginning to realize the need for adequate geographic information analysis. For example, as mathematical ecologists develop highly sophisticated landscape ecology models, the application of such models to large areas will require powerful spatial data-handling methods. The lack of adequate systems for such problems implies the need to develop and support appropriate spatial data-handling procedures. Furthermore, there is a remarkable impetus to combine GIS and remote sensing in the context 'of environmental modeling. Several faculty and students in the consortium have conducted studies modeling the within- and between-class distribution of various phenomena, such as tree species, forest types, bird populations, and water masses, using a combination of remote sensing and GIA/GIS techniques. Data on the time-space behavior of organisms, usually obtained through telemetry, can be combined with an environmental GIS to estimate microhabitat preferences and resource needs for birds and mammals.

In the earth sciences, GIS technology has obvious applications in geology, geophysics, geomorphology, and other earth sciences. For example, in hydrologic science distributed-component modeling of hydrologic runoff poem difficult data-handling problems, while hydrologic modeling has implications ranging from flood prediction to land management to theoretical models of landscape evolution. In the marine sciences, very large database of time series are now being employed in spatially distributed modeling, and ever larger databases will become available during the Eos era.

With the much larger funding base available for the natural sciences than for the social sciences, the employment of GIA/GIS technology will no doubt proceed at a more rapid pace in the former. Nevertheless, effective modeling in the natural sciences also requires that many issues of spatial analysis, such an error propagation, indeterminacy, and spatial sampling, must be examined to ensure that the modeling is effective and that the potential scientific multipliers are realized.

2.5.4. The Importance of the NCGIA. for the Applied and Engineering Science

GIA/GIS will benefit all applied and engineering disciplines, particularly those that deal with planning and construction (e.g., geotechnical engineering, urban and regional planning, civil and surveying engineering, and engineering disciplines involved with public utilities and telecommunication). Many of these disciplines require cartographic presentations and analytical tools, and GIA/GIS will enable disciplines to interact and to integrate graphics and analysis. We expect that many GIA methods, such as spatial theory and visualization, will prove valuable in the CAD/CAM field in general.

To illustrate the applicability and value of GIA/GIS in engineering and applied science areas, we note that the technical infrastructure of America's cities has been severely neglected. Major repairs or extensions of such components as fresh water supply systems, sewer and drainage systems, and road systems will be necessary over the next few decades. Construction work in a city typically requires large spatial databases, incorporating information such as legal ownership and the locations of public utility lines. To collect and maintain such datasets is hardly possible without computer systems. On the one hand, most current systems are used primarily to produce and update maps. Analytical models of the behavior of features such as storm drains and road systems cannot be obtained from such databases, resulting in large amounts of data collection and inadequate modeling. On the other hand, the data-handling capabilities of GIA/GIS would contribute to this task since they permit rapid, cost-effective analyses of existing land uses, which can then be used as a basis for planning. The modeling capabilities of GIA/GIS may be used to integrate data describing the current infrastructure, to analyze its shortcomings, and to prioritize work.

2.6. The Importance of the NCGIA for Government Agencies and the Private Sector

The importance of GIA/GIS extends well beyond the research mandate of the National Science Foundation and into the domains of federal, state, and local agencies, as well as into the private sector. To interact with such groups in productive and mutually beneficial ways, the National Center must have mechanisms to ensure that:

- *practical* implications of the theoretical research carried out at NCGIA are well documented and transmitted to interested parties;
- the *results of research* funded directly by a given agency are transmitted to a wider audience if appropriate;
- government agencies, professional societies, nonprofit organization, and private corporations participate in the *detailed formulation of research plans*, participate at the beginning of NSF-funded Research Initiatives, and are actively encouraged to contribute personnel and resources to longer-term research efforts;
- the NCGIA *principals meet individually and at general meetings with such groups* for direct discussions relating to their interests and concerns.

In the mandated line responsibilities of government and private institutions, issues such as efficiency, timeliness, cost-effectiveness, social costs and benefits, privacy, access, legal liability, confidentiality, and technology assessment must all be examined.

Among the many concerns of these agencies which theoretical and applied GIA/GIS research will address are:

- development of efficient data structures and retrieval procedures for very large databases;
- development and dissemination of methods for handling very large and expensive databases too extensive to be converted to a single consistent form;
- creation of efficient structures for handling both raster and vector data;
- incorporation of remotely sensed and specialized ancillary data into a GIS for natural resource modeling and prediction;
- demonstration modeling of direct value in scientific, budgeting, and management decisions;
- provision of examples of cost savings via demonstration project research in an explicit cost/benefit mode.

2.7. The Importance of the NCGIA for International Competitiveness

U.S. companies have dominated world markets for commercial geographic information Systems for the last decade. However, firms based in Switzerland, Canada, Japan, and other countries are now investing heavily in GIA/GIS development and intend to capture a significant share of both world and U.S. markets in the very near future. The establishment of the NCGIA will enhance the international competiveness of the United States in a number of ways. Research at the NCGIA will have both direct and indirect effects, and the educational programs of the Center will also have significant impacts.

- **The involvement of personnel from U.S. companies involved in GIA/GIS will enhance the competitiveness of those companies in international markets.**

We are committed to a research program which, whenever possible, will involve research and other personnel from U.S. industry in the Specialist Meetings that begin our Research Initiatives. We also expect some of those individuals to spend more extended periods of time it the Center, to be involved in research Working Groups. When they return to industry, they should be well placed to improve the quality of the GIA/GIS products and services offered by their employers. In addition, the NCGIA will acquire state-of-the-art foreign GIA/GIS systems, permitting research and development staff from U.S. industry to gain first-hand experience with the products of their chief international competitors.

- **U.S. leadership in a basic research topic, established through effective presentation of results at international meetings and in scholarly journals, is one of the most effective ways to enhance the competitiveness of U.S. industry.**

Key members of the research and applications communities of countries throughout the world can be expected to attend scholarly meetings before making recommendations regarding GIA/GIS software acquisition to their employers. If U.S.-based academics show clear leadership in scientific achievements and progress, a favorable response to the products of U.S. industry will result.

- **U.S. training of young GIA/GIS scholars and practitioners from around the world will enhance U.S. competitiveness.**

This statement may seem counterintuitive at first, since such training might be expected to improve the competitive positions of the home countries of such foreign students at the expense of the United States. However, we expect that such training will increase the global demand for GIA/GIS and will predispose the next generation of world decision makers toward U.S.-produced GIA/GIS products.

- **The remarkably high level of microcomputer literacy among U.S. high school students in a tremendous resource base for all computational fields.**

If, through appropriate educational initiatives at the high school level, we can capture but a small fraction of this population for GIA/GIS, the critical lack of personnel in this area will vanish. The microcomputer is becoming the primary technical skill of high school students, a skill that is not gender-restricted. This resource base would ensure that the United States remains internationally competitive well into the next century.

3. The Nature of the Proposed Center

We propose that a consortium of three institutions constitute the National Center for Geographic Information and Analysis in order to address research, education, and knowledge dissemination issues in relation to GIA/GIS. As previously stated, the members of the consortium are:

- the University of California at Santa Barbara (UCSB),
- the State University of New York at Buffalo (UB),
- the University of Maine (UM). I

From its inception in June 1987, the consortium has proven to be a vigorous and successful partnership, despite the geographical distance between partners. The consortium has functioned as an effective and cooperative unit with strong commitments from all individuals and institutions concerned. Five meetings have brought together key personnel from the three institutions, and communication via computer networks has permitted a great volume of easy and valuable interaction. The interactions that have occurred during the development of this proposal have in fact led to the formation of a strong and cohesive foundation for a National Center.

In making the case that this consortium form the NCGIA, we first summarize the strengths that each institution brings to the project and then examine the benefits that will accrue to a National Center from the union of the three institutions. Lastly we examine the actual and apparent disadvantages of the consortium and describe how these will be handled through appropriate management.

3.1. The Strengths of Each Institution

3.1.1. University of California at Santa Barbara

The vision underlying the entry of UCSB into the fields of quantitative modeling and remote sensing was , and still is, much wider than a technological view of the future. Researchers at UCSB have viewed both modeling and remote sensing as key elements in addressing large scientific questions concerning the spatial and temporal dependencies of natural processes. In particular, remote sensing has played a central role in investigations concerning land, ocean, and atmospheric interactions, marine biological productivity, and hydrologic and vegetative modeling. The Center is a direct and natural extension of this vision, since, from the inception of the Department of Geography in 1975, the faculty have regarded GIA/GIS as able to integrate the theoretical and technological approaches that help unify the physical and human sides of the discipline.

Since 1975, the geography department at UCSB has grown to fifteen faculty, and is authorized to add four new positions over the next several years. Two of these positions are in the area of GIA/GIS, augmenting the four positions already in the area. The department has a very strong commitment to quantitative and analytical research in human and physical geography and to geographical skills, primarily in remote sensing, GIS, and computer cartography.

Operating as a collective enterprise with shared goals, the department has a coherent philosophy based on analytical and modeling skills and their application to substantive. geographical problems. Faculty have been added in order to increase the depth of the department's specializations rather than to broaden its coverage of specializations.

The faculty have developed strong research and teaching relationships with colleagues in several other disciplines at UCSB. For example, they have coauthored papers with colleagues in computer science, psychology, cognitive science, geological sciences, biological sciences, economics, education, and environmental studies.

Faculty members have a strong record of obtaining extramural research funding, which currently exceeds two million dollars per year. The faculty are very active as authors of books, book chapters, and refereed journal articles and conference proceedings; editors of major journals; members of editorial boards; and reviewers of manuscripts for professional journals. As a result, they have received numerous distinguished national awards, they serve on numerous national and international committees, are consultants with federal, state, and private agencies, and have been active in outreach teaching at the national and international level. Key faculty members have strong records as proven managers of large enterprises. Further details may be found in the appendices.

Although the department was established too recently to have been considered in the most recent NAS/NRC evaluation of graduate programs (it was not authorized to offer the Ph.D. degree until 1980), it now has one of the larger graduate programs in geography in the United States. With over 70 graduate students, it has become a leading producer of doctoral and master's graduates and has a substantial, established base of undergraduate majors. Of the geography Ph.D.-granting institutions in the nation, UCSB ranks approximately third in undergraduate enrollments (146), fifteenth in master's enrollments (30), and second or third in Ph.D. students (41).

The tables on the following two pages show the position of UCSB and SUNY-Buffalo in relation to other Departments of Geography with respect to Ph.D. and Masters enrollments.

Senior faculty provide initial guidance to both junior faculty and graduate students in the preparation of proposals, and act as coinvestigators with them. We require graduate students to prepare research proposals in conjunction with faculty early in their career, and subsequently to initiate their own research proposals. Of the fifty graduate students who enrolled before Fall 1987 (twenty additional students have enrolled since that time), thirty have either initiated or significantly participated with faculty in obtaining research funding.

MAJOR PH.D. GRANTING GEOGRAPHY DEPARTMENTS IN THE U.S.

Sorted numerically by number of PhD students using Schwendeman's figures.

		UNDERGRAD		MASTERS		PhD	
	INSTITUTION	*Schw*	*AAG*	*Schw*	*AAG*	*Schw*	*AAG*
	Clark University	80	59			56	45
	Univ of Colorado	300	260	40	36	40	34
	Columbia University	8		5		37	
	UC Berkeley	120	120	32	25	36	23
	Univ of Iowa	69	63	7	9	36	28
	Univ of Minnesota	115	135	46	29	36	25
	Univ of Hawaii	57	50	56	57	32	28
	U of Wisc, Milwaukee	36		24	29	30	22
	Univ of Kansas	51		38	24	27	22
10	U of Wisc, Madison	107	114	56	40	26	28
	UC Santa Barbara *	250	120	40	34	25	20
	Ohio State Univ	60	59	23	24	25	16
	Univ of Maryland	75	154	46	22	24	8
	Johns Hopkins	7			11	22	48
	Kent State Univ	43	32	20	10	22	15
	Louisiana St U.	21	31	21	33	22	25
	UC Los Angeles	169	178	41	31	22	18
	Univ of Chicago	25	10	11	10	22	14
	Indiana University	26	28	12	12	21	18
20	Univ of Cincinnati	24	22	15	5	21	13
	SUNY-Buffalo *	82	73	55	38	18	13
	Syracuse University	24	33	20	13	17	16
	Arizona State	126	95	16	18	16	12
	Rutgers University	61	55	30	22	15	13
	U of Texas, Austin	73	66	22	21	15	8
	U of Illinois-Urbana	36	37	25	21	14	16
	U of Nebraska, Lincoln	30	95	18	9	14	7
	Univ of Kentucky	40	60	18	12	14	12
	Univ of Oklahoma	36	32	11	12	14	13
30	Indiana State Univ	21	56	30	28	13	8
	Michigan State	30	28	20	20	13	16
	Oregon St Univ.	85	90	48	49	13	12
	U of Tenn, Knoxville	45	77	16	14	13	10
	UC Riverside	14	14	17	19	13	13
	Univ of Utah	152	173	21	18	13	11
	U of Arizona, Tucson	57	64	16	43	12	11
	Univ of Georgia	60	84	42	28	12	13
	Penn State Univ	145	109	34	34	11	11
	Texas A&M Univ	70	70	18	17	11	8
40	U of Florida	91	81	20	15	10	5
	U of NC, Chapel Hill	28	51	14	23	10	9
	U of S. Carolina	55	48	40	31	9	6
	Univ of Oregon	75	68	14	11	9	17
	Univ of Delaware	50		15	7	8	8
	UC Davis	40		10	8	4	7
	Univ of Denver	15	16	10	5	4	2
	U of N. Colorado	30		5		3	
	Northwestern Univ	12	10	2		2	2
	Boston University		20		10		15
50	U of Wash. Seattle		147		34		25
	** 1987/88 figures from departmental records:*						
	UC Santa Barbara	*146*		*30*		*41*	
	SUNY-Buffalo	*91*		*68*		*18*	
	U. Maine	*60*		*20*		*5*	
	Total	*297*		*118*		*64*	

Schw = Schwendeman's Directory of College Geography (figures from various dates between 1984 and 1986)

AAG = Guide to Graduate Departments of Geography, 1986 - 1987; published by the Association of American Geographers.

MAJOR PH.D. GRANTING GEOGRAPHY DEPARTMENTS IN THE U.S.

Sorted numerically by number of Masters students using Schwendeman's figures.

		UNDERGRAD		MASTERS		PhD	
	INSTITUTION	Schw	AAG	Schw	AAG	Schw	AAG
	U of Wisc, Madison	107	114	56	40	26	28
	Univ of Hawaii	57	50	56	57	32	28
	SUNY-Buffalo *	82	73	55	38	18	13
	Oregon St Univ	85	90	48	49	13	12
	Univ of Maryland	75	154	46	22	24	8
	Univ of Minnesota	115	135	46	29	36	25
	Univ of Georgia	60	84	42	28	12	13
	UC Los Angeles	169	178	41	31	22	18
	UC Santa Barbara *	250	120	40	34	25	20
10	U of S. Carolina	55	48	40	31	9	6
	Univ of Colorado	300	260	40	36	40	34
	Univ of Kansas	51		38	24	27	22
	Penn State Univ	145	109	34	34	11	11
	UC Berkeley	120	120	32	25	36	23
	Indiana State Univ	21	56	30	28	13	8
	Rutgers University	61	55	30	22	15	13
	U of Illinois-Urbana	36	37	25	21	14	16
	U of Wisc, Milwaukee	36		24	29	30	22
	Ohio State Univ	60	59	23	24	25	16
20	U of Texas, Austin	73	66	22	21	15	8
	Louisiana St U.	21	31	21	33	22	25
	Univ of Utah	152	173	21	18	13	11
	Kent State Univ	43	32	20	10	22	15
	Michigan State	30	28	20	20	13	16
	Syracuse University	24	33	20	13	17	16
	U of Florida	91	81	20	15	10	5
	Texas A&M Univ	70	70	18	17	11	8
	U of Nebraska, Lincoln	30	95	18	9	14	7
	Univ of Kentucky	40	60	18	12	14	12
30	UC Riverside	14	14	17	19	13	13
	Arizona State	126	95	16	18	16	12
	U of Arizona, Tucson	57	64	16	43	12	11
	U of Tenn, Knoxville	45	77	16	14	13	10
	Univ of Cincinnati	24	22	15	5	21	13
	Univ of Delaware	50		15	7	8	8
	U of NC, Chapel Hill	28	51	14	23	10	9
	Univ of Oregon	75	68	14	11	9	17
	Indiana University	26	28	12	12	21	18
	Univ of Chicago	25	10	11	10	22	14
40	Univ of Oklahoma	36	32	11	12	14	13
	UC Davis	40		10	8	4	7
	Univ of Denver	15	16	10	5	4	2
	Univ of Iowa	69	63	7	9	36	28
	Columbia University	8		5		37	
	U of N. Colorado	30		5		3	
	Northwestern Univ	12	10	2		2	2
	Boston University		20		10		15
	Clark University	80	59			56	45
	Johns Hopkins	7			11	22	48
50	U of Wash, Seattle		147		34		25
	** 1987/88 figures from departmental records:*						
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	SUNY-Buffalo	*91*		*68*		*18*	
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	Total	*297*		*118*		*61*	

Schw = Schwendeman's Directory of College Geography (figures from various dates between 1984 and 1986)

AAG = Guide to Graduate Departments of Geography, 1986 - 1987; published by the Association of American Geographers.

3.1.2. State University of New York at Buffalo

The Department of Geography of University at Buffalo is housed in a university committed to excellence in research and graduate studies. Faculty appointments to the department have reflected a firm policy of building on areas of strength and promoting excellence in those areas, which include GIS, cartography, urban and regional analysis, international trade, and physical geography. The department is consistently ranked among the top ten graduate geography programs in the United States in terms of a variety of measures, including publications and the completion of graduate degrees. Of the geography Ph.D.-granting institutions in the nation, UB now ranks approximately tenth in undergraduate enrollments (91), first in master's enrollments (68), and eighteenth in Ph.D. enrollments (18).

The Ph.D. program in geography at UB was established in 1971, with its initial strengths reflecting those of the department as a whole. The list of graduate geography degrees from Buffalo, attached as an appendix to this document, attests to the strength of Buffalo's graduate program. Graduates of our Ph.D. program currently hold tenured or tenure-track positions at Boston University (2), Pennsylvania State University, University of Nebraska, SUNY at Buffalo, Universite de Montreal, Duquesne University, University of Toronto, University of Hawaii, and Virginia Polytechnical Institute and State University. Most of these universities have doctoral programs in geography.

The University at Buffalo has an established Research Center for Geographic Information and Analysis with a research staff including 14 faculty from 6 academic departments, as well as long-established graduate and undergraduate programs in GIS, spatial analysis, cartography, and related fields. Of 18 Ph.D. and master's degrees already awarded in GIS, 13 were completed under the direction of current faculty (9 with Calkins, 4 with Mark). Eleven Ph.D. and 57 master's degrees have been awarded in spatial analysis, and two Ph.D's and 9 master's degrees in cartography. Several Buffalo Ph.D. and master's graduates hold prominent positions with firms in the GIS industry.

The faculty at UB include former editors of *Geographical Analysis, Annals of the Association of American Geographers*, *The Professional Geographer*, and of several books and conference proceedings.

3.1.3. The University of Maine

The University of Maine, at Orono, Maine, brings an engineering background and orientation to the consortium with its Surveying Engineering Program, established in 1970 as a four-year, rigorous engineering program. It was felt that a high-level surveying engineering education, based on the European model, was necessary in the United States and would lead to the production of professionals with skills having value in a variety of situations. The faculty in the program share the common conviction that *better decisions regarding land must be based on better information regarding land*; the program has therefore placed importance on the collection, management, representation, and presentation of spatial information. Courses in advanced software engineering, computer database management, computer cartography and spatial database design, as well as economic, institutional, and legal topics are considered of equal importance to traditional engineering courses, such as mathematics and physics, and surveying engineering, including geodesy, adjustment computation, and photogrammetry.

The program has been extremely successful and is one of ten programs of national prominence selected by the University of Maine administration for increased support. The program is accredited by the Accreditation Board of Engineering and Technology programs as in engineering program, and has been strongly supported by the surveying profession since its inception. Although the Surveying Engineering Program currently operates as part of the civil engineering department, with its own budget, it may become a separate department in 1988; this would then be the first surveying engineering department in an American university.

The number of faculty positions in the program has increased from four in 1986 to seven in 1987. At a time when hiring GIS specialists is difficult, the team has been able to fill the new positions with excellent young faculty from other universities or with excellent new graduates from Maine. The faculty of the Surveying Engineering Program is an interdisciplinary team, integrating scientists, engineers, lawyers, and a landscape architect. The faculty has been successful in obtaining outside funding for research from a variety of sources, including NSF, federal and state agencies, and the private sector, averaging $40,000 per faculty member per year over the last three year. The faculty in the program publish regularly in scientific and professional journals, participate in professional meetings, report on research, or organize workshops to disseminate new techniques. They are, or have been, editors of American Congress on Surveying and Mapping publications, and have served on several National Academy of Science panels.

The faculty in the program have always stressed the need to integrate education with research. Program graduates are in high demand, commanding high starting salaries with excellent career prospects. The graduate program was started in 1984. Formal approval of the M.Sc. in Surveying Engineering was given in 1987 and approval for the Ph.D. is expected in 1988. The number of undergraduate and graduate students is rapidly increasing. Maine currently brings some 60 undergraduate students in surveying engineering and forestry, 20 master's students, and five Ph.D. students to the consortium. Six M.Sc. degrees and one Ph.D. degree have already been granted; the doctoral graduate now teaches at the 'University of Laval, Quebec, Canada.

3.2. The General Advantages of this Consortium

Among the several general advantages this consortium brings to an NCGIA, we discuss:

- the strengths of the departments and individuals forming the consortium;
- the strong interdisciplinary composition of the consortium;
- the geographically distributed nature of the organization;
- the leadership and institutional commitments at the three institutions;
- the multiplier effects the consortium will induce in its research, educational, and knowledge dissemination functions.

We have already described the strengths of the three departments involved in the consortium. The *combined* strengths of these departments and their associates is worthy of further comment, however, since we believe that no single academic institution currently has the requisite resources or background to establish an effective program of research, education, and knowledge dissemination in the area of GIA/GIS.

GIA/GIS is an emerging field: different points of view are crucial to its inherently interdisciplinary development. The involvement of three different institutions explicitly recognizes the importance of diverse perspectives on research and education in GIA/GIS. Since the National Center is to be an interdisciplinary, large-scale enterprise, it is essential that it be directed by established researchers of wide, cross-disciplinary competence. The University of California at Santa Barbara and the State University of New York at Buffalo are two departments of geography that are remarkably strong in terms of their cross-disciplinary competence and interactions. The surveying engineering group at the University of Maine is composed of researchers with backgrounds in surveying, photogrammetry, remote sensing, geodesy, computer science, landscape architecture, and law. The three institutions reinforce each other's strengths while providing the multidisciplinary competence necessary for a comprehensive coverage of all five research areas identified by the NSF solicitation and accepted by us as fundamental to an NCGIA. Furthermore, at each institution faculty and students from such cognate disciplines as computer science, engineering, linguistics, and psychology, as well as from the social and natural sciences, will augment the research team.

The geographically distributed nature of the consortium is a strength, and provides easy access to Center activities for researchers, educators, and practitioners from three major regions of the country. This broad coverage of the nation will facilitate closer contacts with more educators, practitioners, and equipment and software firms than would be the case with a single-location Center. Furthermore, the distribution will facilitate the recognition of the diversity of the physical and cultural environments and land survey systems which exist in the United States and which influence GIA/GIS requirements. Geographical distribution has relatively little effect on communication within the consortium since the main methods of communication, namely computer networks, are now comparatively distance-independent. Thus we anticipate that communication between Buffalo, Orono, and Santa Barbara will continue to be as frequent and convenient as between, say, Santa Barbara and Los Angeles.

In addition to the strong team of resident researchers at the three universities, there are major institutional commitments to build on these strengths. Each one of the three departments is regarded by its university administration as being an academically strong program, and the administrations have made major investments in these programs. In large measure, those in leadership positions in the consortium created the positive and open academic environments that have allowed these individual departments to thrive. Such positive and open attitudes coupled with strong institutional support and active researchers and educators in both the core and cognate fields of study make the prospects of success for this consortium excellent. In practical terms, this approach of openness is of great importance to a National Center. If our consortium is identified as the NCGIA, we would commit ourselves to involving a large cadre of users, practitioners, researchers, and educators from across the nation in the activities of the Center.

In contrast to a single institution working in isolation, the consortium will be able to achieve significant multiplier effects in research, education, and data and information dissemination, through the interactions of the diverse members of the group. The consortium combines the distinct approaches of the social and natural sciences on one hand and the engineering and applied sciences on the other.

3.3. Particular Advantages of This Consortium for Basic Research

There are many particular advantages associated with the consortium in relation to basic research, including the abilities to:

- commit a large group of skilled researchers with established reputations to various aspects of GIA/GIS research;
- draw on a substantial, existing base of research by faculty and senior graduate students, as indicated by the fact that Santa Barbara, Maine, and Buffalo ranked first, second, and third among all institutions in number of papers presented at the recent International Geographic Information Systems (IGIS) Symposium: *The Research Agenda*;
- draw on the skills of other researchers from a wide disciplinary base in the social, physical and engineering sciences;
- strengthen the research and professional ties between members of these three institutions, who already frequently exchange ideas, papers and communications;
- provide a research center congruent with the NAS/NRC panel report on Engineering Science Centers, one whose wide geographic distribution and varied disciplinary base will ensure that a range of outside groups will be properly served;
- use research needs at the three locations to drive the improvement of communications involving large spatial datasets-a critical need of many federal and international organizations.

The consortium will involve major figures from the international GIA/GIS community in our research activities. Through appropriate commissions of the International Geographical Union and the International Cartographic Association, and through contacts at the individual level, we will provide a focal point for major international exchanges of ideas. We have already involved eminent international authorities in the field in preparing this proposal (including David Rhind, University of London, U.K., an ICA vice-president; Michael Jackson, Cambridge, U.K.; John O'Callaghan, CSIRO, Australia; and Kurt Brassel, University of Zurich, Switzerland).

3.4. Particular Advantages of This Consortium for Education

The particular advantages of this consortium in relation to education include the commitment to:

- build on an existing robust teaching base of graduate and undergraduate students (more than 180 graduate students and nearly 300 undergraduate majors in geography and surveying engineering at the, three sites, sufficient to markedly impact the total number of professionals with expertise in GIA/GIS);
- integrate the existing programs and courses in GIA and related fields offered by the three institutions, thereby enabling each institution to focus on areas of particular strength and facilitate the opportunity for students to specialize in particular areas;
- facilitate the interchange of graduate students and faculty to provide for the exchange of ideas, viewpoints, and knowledge and to allow graduate students to mature as post-doctoral researchers at other NCGIA branches before entering into academic or other employment;

  provide in additional incentive for attracting research-oriented graduate students, enabling them to develop their research skills in an environment that will foster the interchange of ideas from a broadly based interdisciplinary faculty.

3.5. Particular Advantages of This Consortium for Linkages Outside Academia

The particular advantages of the consortium for forming linkages to institutions outside academia include, first, the ability to facilitate contacts in different areas and within a sizable population base. The combined populations of California, New York, and Maine are approximately twenty percent of the total U.S. population. In addition, many of the high-technology firms that manufacture or use GIS are located in the densely populated coastal areas of the United States. The location of the three institutions relative to these firms will greatly enhance the opportunity to develop symbiotic relationships with industry.

Additionally, the consortium will be able to:

- diversify industrial contacts by making use of the existing support and contact base at each institution, and work actively to achieve industrial cooperation akin to NASA's multi-locational industry-university programs;
- utilize the previous experience of organizations abroad, such as the Remote Sensing Centers in the United Kingdom and Portugal, which deliberately chose several distributed sites;
- force each individual institution to look outward, thereby facilitating the development and documentation of standards to improve communication and the interchange of ideas.

3.6. Actual and Apparent Disadvantages of the Proposed Center and Their Management

Although there are some disadvantages relating to the proposed consortium, these are very much outweighed by the advantages listed above. There are potential management inefficiencies in a distributed system, but the quality of judgment and ultimately of management is, we feel, improved by the presentation of different viewpoints and the consequent necessity to examine all concerns very thoroughly before making decisions. It is, however, important to understand any real disadvantages in order to minimize their effect and to manage around them. The disadvantages may be perceived to include:

- *An increased administrative cost, due to the need to have an Associate Director at each of the three sites*. This disadvantage is more apparent than real, however, since the group is of manageable size at each site and commensurate with the management experience of the three Associate Directors. In addition, any apparent costs will be offset by institutional funding to match costs at the three sites. There is a clear multi-institutional commitment to invest institutionally in GIA/GIS and to maintain the center beyond the term of NSF funding.
- *The divergence of research foci at the three sites owing to local internal referencing*. This potential problem will be managed by having:

    - regular meetings of the Executive Committee (four times a year), the scientific policy committee (twice a year), and the Board of Directors (twice a year).
    - at least a monthly reporting of the Associate Directors to the Co-Directors
    - annual reviews at each of the three sites, attended by the Co-Directors and the Chief Scientist
    - internal documentation in the form of brief status reports
    - specific research goals at each site, with regular reporting requirements

- *The duplication of effort.* In some cases, including routine tasks, this will be unavoidable. Excessive duplication of effort will be avoided, however, with a research strategy reflecting the special skills at each institution.
- *The difficulty of communication and cooperation.* This will be managed by the use of regular meetings at each location, as well as teleconferencing and electronic mail communications as required. Many of these difficulties have in fact already been faced and solutions have been found in the course of developing this proposal.

3.7. The NCGIA After the NSF Funding Period

The National Center will continue to function after the end of the NSF funding period. We anticipate that many changes in the environment in which the Center operates will occur during the first eight years. In this section we discuss those changes and the effects that they are likely to have on the nature of the Center during the period extending from eight to fifteen years after its inception.

Although the majority of funding will come from NSF in the early years, the proportion of Center funds from this source will decline as support is obtained from other agencies and industry. We anticipate substantial donations of hardware and software, and see this continuing for as long as the Center remains prominent in the field. Funding will also come from industry in the form of joint research projects, and from local, state, and federal agencies. We see such external funding as growing in magnitude up to year eight, by which time the Center will be fully self-supporting. There is little likelihood of substantial decline in external funding after year eight, provided the Center remains effective as a consortium.

The arguments that have led to the formation of the consortium will remain valid following the termination of the eight years of NSF funding. If it is as successful as we anticipate, the Center will have corrected much of the imbalance currently existing between supply of and demand for personnel, and will have addressed many of the impediments identified in the Research Plan to the adoption of GIA/GIS technology. On the other hand, the need for dissemination of research results and information on software and databases will likely be as strong then as now, and new areas of research will have been suggested by new developments in the field. Thus we foresee that the research and dissemination objectives of the Center will continue to be important. Some aspects of the educational program may also continue to be important.

The transition from NSF to external funding will bring inevitable pressure to adopt a more applied approach to research. We believe the Center should continue to devote a large share of its efforts to basic research, even after year eight, sufficient, flexible funding to support the Center can be obtained from industry and agencies without compromising this principle. The central functions of the NCGIA at Santa Barbara will be supported after the end of NSF funding in part by the University of California and in part by other members of the consortium. The basis of this cost sharing will be determined by the Executive Committee, based on advice from the Board of Directors.

The balance between the three consortium institutions will inevitably change over time through faculty movements and additions. The Board of Directors will have the role of monitoring the relative contributions of the three institutions and determining appropriate changes in the Center's structure. This will be particularly important when NSF funding is terminated. We are very aware of the need for management policies that maintain an appropriate balance between the three institutions; such a balance must be maintained to ensure the success of our vision for the NCGIA, which we place above the needs of the individual researchers-and, indeed, above those of the individual institutions.

It is possible that events, particularly faculty movements, will render the UCSB/UB/UM solution less than optimal at some point after year eight. We consider this very unlikely, because of the impacts of long-term NSF and other funding on the strengths and interactions of the three institutions. We therefore believe that the consortium will continue to be active in basic GIA/GIS research after year eight. However, it is important that the Board of Directors remain open to the possibility of changes in the membership of the consortium after that time.

4. Concluding Statement

In summary, the team we have assembled to form an NCGIA and to carry out the necessary research, education, outreach, dissemination, and fund solicitation activities:

- Has the strong support of our respective administrations
- Is firmly committed to the goals and targets given in this proposal
- Contains a very strong group of able and entrepreneurial researchers
- Already has in place substantial research funding of direct relevance to NCGIA
- Has an existing large base of undergraduate, master's, and Ph.D. students on which to build an influential educational program
- Has the requisite experience to successfully manage a large, distributed enterprise
- Has the wide range of contacts and expertise to leverage the National Science Foundation funding

- Has members who have delivered on promises to build strong programs within their respective institutions, and has every confidence in its ability to do the same for the National Center for Geographic Information and Analysis

II
RESEARCH PLAN

1. Introduction

Research at the National Center will be organized around a series of Research Initiatives, drawn from the five major areas of research identified in the solicitation and designed to overcome impediments to the development and application of GIA/GIS. The five designated areas are:

- *spatial analysis and spatial statistics;*
- *spatial relationships and database structures;*
- *artificial intelligence and expert systems;*
- *visualization;*
- *social, economic, and institutional issues.*

The research plan comprises two segments. In the first, we discuss the five designated areas of research and identify impediments to the development and application of GIA/GIS in each. The second segment presents detailed research plans for twelve research initiatives to be undertaken during the Center's first three years.

2. The Five Major Areas of Research and Associated Impediments

The discussion of the five designated research areas and of the associated impediments to GIA/GIS development and application defines our view of current needs in GIA/GIS research, and provides a comprehensive basis for selecting, prioritizing, and investigating specific research topics. The Management Plan describes the mechanism by which this Research Plan will be updated and modified as new research needs become apparent.

Each of the five research area discussions begins with an overview of the research in relation to the advancement of theory and techniques relating to the development and application of GIA/GIS. Factors impeding advances are identified and specific strategies are presented for overcoming these impediments. We have consciously avoided references to the literature in the interest of brevity, but a bibliography keyed by research area is given in Appendix E.

3. Spatial Statistics and Spatial Analysis

Early GISs 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. The future success of GIS technology will depend to a considerable extent on the development of more sophisticated analytic and modeling capabilities, on a better understanding of the nature of the data being analyzed and on the ability of systems to handle increasingly large databases with reasonable speed.

Many of the mathematical findings that could provide the basis for advanced analytic capabilities exist already in the literatures 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 19605 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 geographic resolution and appropriate data structures, GIS technology can support the development of much more effective methods. Comprehensive statistical packages such as SAS have made statistical analyses easy to carry out on large nonspatial databases. There is no equivalent to such packages for spatial analysis, although there is a great need for GISs incorporating a comprehensive set of sophisticated spatial analysis techniques. At the same time, extensive application will have a beneficial effect on spatial analysis by forcing a reevaluation of models that fail to perform well and by identifying gaps in our current set of techniques.

Many forms of applied geographic analysis and modeling would be more powerful and useful if they were available within a GIS and if the data structures used in that GIS were more appropriate. These include such problems as optimally locating health care, retail, or emergency facilities in a region; determining optimal land use allocation and management strategies in agriculture and forestry; accurately predicting runoff in hydrological modeling; assessing the susceptibility of a region to earthquake damage; delineating school district boundaries to meet prescribed goals; routing vehicles for delivery of goods and services; and planning emergency evacuations. For all these problems, GIS capabilities are currently limited to simplistic analyses, and in many cases cannot represent the necessary topological relationships. Yet these systems potentially can couple sophisticated modeling with comprehensive data storage and display to create powerful decision support systems. This section focuses on impediments relating to the nature and analysis of spatial data. The related issues of data structures and display are discussed in sections 4 and 6, respectively. Finally, we note that for many areas of spatial analysis and spatial statistics, the methods of artificial intelligence (AI) may be of value, particularly in the construction of expert systems (ESs) that automate the application of certain procedures. For the sake of simplicity, we defer such a discussion until the section on AI/ES.

3.1. Spatial Statistics

Despite the importance of spatial data, our understanding of statistical processes in space is still relatively limited. Research in spatial statistics will be concentrated in two areas important to the successful development, adoption, and utilization of GIS technology.

3.1.1. Problems of spatial dependence and heterogeneity

Many of the most popular techniques of inferential statistics assume the absence of spatial effects in the data. When a technique such as simple regression is applied to spatial data, the distortions produced by spatial autocorrelation (which is almost always present) and by spatial non-stationarity may lead to erroneous conclusions.

- **The lack of readily accessible packages capable of conducting inferential tests in the presence of spatial effects is a severe impediment to our understanding of spatially distributed phenomena.**

It would be difficult to build a spatial series module into the common statistical packages because of their inadequate data models, which cannot represent complex spatial entities. These models must be adapted and extended for incorporation into GISs accessible to applied analysts. GISs would also offer the ability to manipulate and display data in its spatial context, and to combine different forms of spatial analysis within one package.

3.1.2. Statistical models of spatial data

The precision of digital analysis is usually determined by the machine and frequently exceeds the precision of the input data. One of the consequences of GIS development has therefore been a new concern for the accuracy of spatial data, and for associated error models and indices of uncertainty.

- **The lack of statistical models of complex spatial entities impedes the development of effective methods of determining accuracy in spatial databases and uncertainty in GIS products.**

Our current lack of appropriate models and indices is a major impediment to GIS adoption, since it is impossible to provide measures equivalent to the confidence limits normally available for the products of statistical analysis. For example, the forest manager has no defense if GIS estimates of forest yield are shown to be in error.

Statistical models of spatial data also may be useful in developing more efficient GIS procedures and algorithms. Many of the design choices in GIS construction discussed in the next section depend on assumptions about the nature of the data to be stored and manipulated.

The uncertainty in the location of a point can be treated as a simple bivariate extension of the conventional model of measurement error. But uncertainty in a line or polygon requires models that represent not only the topology of the object and its relationships with other objects, but also the complex statistical dependencies present. In addition, many spatial objects are abstract representations for which no true, undistorted version exists.

Research in this area will be directed first at developing appropriate statistical models of complex spatial objects and the errors present in them. Methods will be devised for estimating the parameters of these models and for designing numerical means of accuracy and proportioning error among the contributing sources. Finally, each of the common GIS functions, such as area measurement and polygon overlay, will be analyzed to develop appropriate confidence limits based on the underlying models.

3.2. Spatial Analysis

We view the development of GIA/GIS as a stimulus to spatial analysis, with the potential to make existing techniques more accessible, stimulate the development of new techniques and applications, and give structure to what often appears to be an uncoordinated body of material. The NCGIA must play a major role in realizing this potential, by bringing together a critical maw of individuals with expertise in the two areas. The lack of mutual awareness is at present a major impediment to the dissemination and adoption of GIA/GIS and spatial analysis technology in critical application areas time. The examples in the following three sections were chosen because they lie at the border between spatial analysis and GIS, and because in each case expertise in one area can be brought to bear on problems in the other. They represent a small part of the potential in the fertile intersection between the two fields.

3.2.1. Resolution, consistency, and spatial aggregation

Because agencies that collect social data are constrained by confidentiality and cost and by conventional methods of data dissemination, the information they report is usually aggregated in space and frequently aggregated in time. The reporting zones used for spatial aggregation are rarely designed for research purposes, and thus introduce uncontrolled and largely unpredictable bias; moreover, they are often subject to change. Information concerning the physical environment and collected by remote sensing systems or by direct observation at various levels of spatial resolution is subject to variable standards of accuracy. Problems arise, therefore, in comparing data collected at different times, for different units, and often for different types of spatial objects. The capabilities of GIS for spatial analysis have enormous potential for assisting research by allowing overlay of incompatible units across different geographical scales, by supporting spatial and temporal interpolation, and by responding rapidly to new data. We propose the following goals as foci for NCGIA research initiatives.

- *Overcome the difficulties imposed on social databases by variable reporting zones.* We will develop estimation and interpolation procedures to overcome traditional impediments to using social databases to be applied in demographic forecasting. This research has implications for public policy since there is increasing demand for data aggregated to units such as ZIP codes, which are far less permanent, well-defined, and homogeneous than more traditional reporting zones.
- *Reconcile social data collected for differing time intervals.* For example, migration flow data collected for a one-year period are incompatible with data collected for a five-year period. More sophisticated methods of translating data from one temporal unit to another need to be developed and implemented using GIS technology.
- *Determine optimal or desirable levels of spatial aggregation in social data.* There is a trade-off in many models between the cost of collecting a large volume of data for model calibration and the accuracy of the model's predictions. Techniques will be developed for evaluating this tradeoff by taking advantage of the capability of GISs to move freely between different levels of spatial aggregation.
- *Investigate the relationships between micro and macro socioeconomic phenomena using microsimulation and other techniques.* GIS provides the ability to study processes at varying levels of aggregation and will facilitate this type of research and its application to such fields as labor markets, airline schedules, and consumer spatial behavior.
- *Use data on the physical environment effectively.* Global environmental problems are increasingly prominent, owing to programs such as the International Geosphere Biosphere Program (IGBP) of ICSU. Data for this program comes from a variety of sources with different levels of completeness and spatial resolution and different standards of accuracy. Global data from remote sensing instruments must be combined with the results of direct observation, often at irregularly distributed stations. The success of IGBP and similar program depends on the development of effective methods for handling these problems, on technologies for storing and accessing the enormous volumes of data required, and on models that address the full range of scales of spatial resolution from local to global.

3.2.2. Continuous monitoring

Traditional spatial analysis methods in human geography, demography, and related disciplines have been geared to periodic data collection, led by the decennial census but now augmented by annual and monthly surveys of various kinds. GIA/GIS analysis is by comparison immediate, and can effectively use continuously updated data bases. This situation already exists in health statistics in the form of individual mortality records, in data on emergencies and criminal activities, and in many areas of physical science including electrical storms and earth-quakes, forest fires, and weather records.

Largely because of traditional data constraints, we lack adequate methods hypothesis-testing methods for continuously acquired social data, as well as appropriate models and methods of storage and display. A GIS dedicated to the continuous monitoring of national cancer records, for example, would need to test hypotheses continuously to identify spatial hot spots as they develop, and respond to user queries on trends and forecasts. *We propose to develop appropriate methods for hypothesis testing in such an environment and supporting GIS data structures and display methods.* A radically different approach to spatial analytic modeling will be required to deal with continuously varying parameters and associated methods of calibration. In the physical sciences, analytic techniques for continuous monitoring are comparatively well developed; the NCGIA will facilitate the transfer of ideas from experts in the spatial analysis of geoscience data.

3.2.3. Spatial decision support systems

Spatial search algorithms ;are used to determine optimal locations for facilities based on defined criteria; potential applications include retailing, delivery systems, social services, and health care. Although they have been applied extensively, impediments exist to the effective transfer of this technology to the sectors which can benefit most.

- **The simple data structures currently used in spatial search algorithms are inadequate, and subjective or intangible criteria cannot readily be incorporated into the decision-making.**

A decision support system for spatial search based on GIA/GIS would have several advantages that would lead in the long run to more extensive adoption of this methodology. It would combine tabular with graphic user interaction and would incorporate data from many sources at many different scales. It would also support the elicitation of preferences from which to construct objective multiple utility functions, and would operate in a continuous dialogue fashion to incorporate changes in criteria and constraints. It could operate on uniform national data, bases, allowing the user to explore for suitable locations at any scale over any selected area from a single graphics terminal, and using any available criterion.

NCGIA would consolidate current research on this problem and combine expertise in spatial search and GIS to design appropriate data structures for this area of application, along with appropriate user interfaces. Although this is treated here as an example of spatial analysis, progress can only be made by combining expertise in spatial search methods with research on the structuring of spatial data and on techniques of visualization, detailed in subsequent parts of this research plan. In addition, the development of sophisticated Spatial Decision Support Systems (SDSSs) will allow us to compare the effectiveness of various approaches for spatial analysis, such as exploration versus model-driven, parametric versus nonparametric, quantitative versus qualitative, and explanation versus policy-oriented.

3.2.4. Conclusion

The three preceding sections illustrate the benefits of merging spatial analysis with the capabilities of GIS technology. We envision the National Center pursuing these and many other similar topics where there is potential for mutual benefit. In addition, GIS provides the incentive and framework for organizing the body of spatial analytic technique into a more logical scheme. A coherent taxonomy of GIS and spatial analytic functions would serve several purposes: it would lead in to better organized GIS-user interfaces, and thus be germane to the questions of human/machine interaction discussed in section 6; it would provide the means for describing GIS workload, which is an essential component of the benchmarking research discussed in section 4; and it would help to set the research agenda for spatial analysis by identifying gaps and inadequacies in the current literature.

4. Spatial Relations and Database Structures

Many of the shortcomings of current GISs can be attributed to problems of modeling spatial relationships or to their implementation in current systems. The summary of the NASA-sponsored conference on GIS held at Palm Springs in 1983 stated:

> The [present] lack of a coherent theory of spatial relations hinders the use of automated geographic information systems at nearly every point. It is difficult to design efficient databases, difficult to phrase queries of such databases in an effective way, difficult to interconnect the various subsystems in ways which enhance overall system function, and difficult to design data processing algorithms which are effective and efficient. As we begin [to] work with very large or global spatial databases the inabilities and inefficiencies which result from this lack of theory are likely to grow geometrically.
> While we can continue to make some improvement in the use of automated geographic information systems without such a coherent theory on which to base our progress, it will mean that the development will rest on an inevitably shaky base and progress is likely to be much slower than it might be if we had a theory to direct our steps. It may be that some advances will simply be impossible in the absence of a guiding theory.

The long-term research goal in spatial relations and database structures is threefold: *1) to determine the spatial concepts human beings use; 2) to develop a coherent spatial theory or comprehensive geometry; 3) to use this theory to design a comprehensive basis for computer algorithms in GIA/GIS.* First, we discuss the cognitive and conceptual problems and describe theoretical methods to approach solutions. Then we assess the limitations of current implementations and strategies for building working systems with available computer technology. The approach proposed separates the abstract concepts of space, spatial relationships, and spatial reasoning from the specifics of spatial objects of determined types or specific spatial processes. Such abstract spatial concepts can then be applied and restructured to explain specific spatial phenomena; their effectiveness is judged by the degree to which they simplify such explanations.

4.1. Cognitive Impediments

Individuals, groups, disciplines, and cultures have established different frames of reference or schemas for perceiving and communicating spatial concepts and relations.

- **The principles by which humans code, store, recall, and use spatial information are not well understood.**

Although people within such groups can generally translate among systems, we lack a formal understanding of the methods involved; this impedes the construction of effective human interfaces for GISs. Cross-culture translation is even more difficult. When an operator interacts with a system, the spatial concepts used by the system may clash with the natural cognitive structure of the human being. Examples occur in which the operator is surprised by a system action, or cannot see how to express a query in terms of the spatial relations offered by the query language. The lack of understanding of human spatial cognition also hinders the building of navigation aids. Such systems must present spatial information in a quickly assimilable form, often under conditions of moderate stress. Advances in our understanding of the concepts humans use to describe spatial situations will also help to improve graphic displays.

Research to understand the conceptual structures humans use to represent and reason about spatial relationships must be interdisciplinary. One can foresee immediate contributions from collaboration with cognitive and linguistic scientists. Cognitive science applies psychological and artificial intelligence methods to detect and describe human conceptual structures, and is being extended to large-scale spatial situations. Another promising area of investigation involves the constructions available in natural languages to express spatial relationships. Both single-language and cross-linguistic studies of spatial reference in language must be pursued through interdisciplinary research.

There are many research questions to be addressed. What reference frames and schemas are used in describing spatial relations, and are they relative to the observer, or absolute in some sense? What roles do context and scale play in the reference problem? What spatial relationships are used? How do people deal with hierarchical systems (spatial reasoning in the large as compared with spatial reasoning in the immediate neighborhood)? How is spatio-temporal reasoning used to describe and understand spatial processes?

4.2. Conceptual Impediments

- **The design and coding of GIS software is currently limited by a lack of theoretical understanding of spatial relationships.**

The many ad hoc solutions that have been used in lieu of a comprehensive formal model have made building GIS software slow and expensive. The query languages available for selective retrieval of data do not include a full complement of spatial relations. Due to the lack of a theoretical base, systems from different vendors are very different. Exchange of data between GISs often requires expensive manual intervention.

- **There is a need for systems that can represent uncertain, imprecise, or time-dependent spatial data.**

Much current GIS methodology requires precise, expensive collection of primary data, discouraging application. Moreover, many applications require systems that can deal with spatial change as it occurs over time, which current systems cannot readily do.

The overall research goals are to formally represent spatial situations and to derive associated rules for reasoning about the locations and extensions of spatial objects and the relationships between them. A formal approach is necessary, first, to ensure that results can be translated into computer programs and, second, to establish a firm base for translation between different systems. As a unifying method, multisorted algebras allow systems to capture the meaning of complex relations between things in a formal way, and are closely related to methods used in software engineering to write formal specifications. Algebraic specifications can be used for formal proofs of properties of the defined systems. From these formal representations one can derive associated algorithms, data structures, and programs for implementation in spatial data handling systems.

4.2.1. Representation of spatial objects

- **Any GIS must represent the positions and extensions of spatial objects in a manner suitable for symbolic geometric reasoning.**

The use of analytic geometry to compute geometric operations is hindered by the finite number schemes used in computers, which cannot represent continuous space precisely. Spatial properties of objects can be represented in symbolic format using results from combinatorial topology, especially simplicial complexes. Representations that can be expressed in (first-order) predicate calculus are highly desirable, enabling the extension to include changes in time using modal and temporal logic and non-monotonic reasoning. A representation based on predicate calculus also simplifies the construction of expert systems, since inference algorithms (unification and Robinson resolution) are known and readily available (e.g., in the PROLOG programming language).

4.2.2. Multiple representations

Geography studies objects of very different sizes, from land parcels to nations, and from small watersheds to continents. A GIS database must be able to represent objects at different resolution levels and to support modification across resolution levels. This point also applies to object visualization, and is discussed from that perspective below.

- **A major impediment to full utilization of the GIS concept is the lack of methods to maintain multiple representations of the same objects.**

Starting from object descriptions at each resolution level, we must describe formally the connections between them such that changes applied to one cam propagate to the others, allowing other resolution levels to be deduced automatically. We can differentiate between methods that aggregate properties linked to geometric objects and operations that generalize geometric aspects of the objects. This problem, often called cartographic generalization, not only is useful for graphical display, but also assists spatial reasoning.

4.2.3. Object-oriented versus spatial addressing

Spatial data can be organized in raster or vector format. The first organizes the space itself, recording data values for each grid point or as an average for each raster cell; the second concentrates on objects, which have uniform values for selected properties, and records their locations as coordinates or their limits as vectors.

- **Current GISs are either raster- or vector-based, and have limited abilities to combine the two.**

These methods have fundamentally different theoretical models and different operations (raster processing versus analytic geometry). Human beings seem to use both concepts, depending on the problem. While current systems are built using one model or the other, an ideal GIS would offer both and allow full interaction between them. *The National Center will study the operations typical for each system (e.g., line intersection and point in polygon tests for vector; dilation, erosion, and convolution for raster) using algebraic methods.*

4.2.4. Spatial relationships

Basic relationships and rules must be defined, and other relationships deduced from them. The spatial relationships humans use should be explained in terms of the basic relationships so they can be used in human interfaces to GIS.

- **In a GIS, we are interested not only in the positions, extensions, and properties of the objects recorded, but also in their spatial relationships.**

Euclidean geometry defines distance and direction as basic relations between points; humans generalize these terms to describe the relations between extended objects ("Canada is north of Maine"). Formal definitions of such relations will be required for natural language query systems and to support spatial reasoning. The inclusion relation ("Penobscot County is in Maine") forms a partial ordering of spatial subdivisions; humans often see such relationships as hierarchies. We will explore these orderings and use them to simplify reasoning, employing concepts from the cognitive and linguistic sciences.

4.2.5. Uncertainty and ambiguity

Current systems require exact determination and cannot cope with multiple and differing descriptions even in situations that human beings can deal with unambiguously.

- **The geometric descriptions of objects in a GIS include errors of different types, and data from different sources may contradict each other.**

Formal systems to deal with inexact and vague data must be explored and applied to geometrical problems. An approach involving belief revision in a semantic network has been implemented within the Semantic Network Processing System (SNePS) developed by Shapiro and colleagues in the Computer Science department at Buffalo. Other methods, such as probability factors, fuzzy logic, and category/prototype theory, will also be examined.

4.2.6. Temporal problems

- **Change is of primary interest in many applications, and in some applications the combination of data gathered during different time periods could aid interpretation.**

Formal methods to handle situations that change over time are poorly developed in application areas. A small number of temporal logic systems exist; they must be assessed to determine which, if any, represent the conception of time used by humans in conjunction with geographic objects.

4.3. Implementation

The ideal GIS would include large collections or spatial data together with values for a varying set of properties. It would accommodate multiple layers and types of data, as well as time dependency. Once the concepts for handling such data are clear, the major impediment is the size and variety of data. Current GISs can process limited amounts of data; users often must divide data into map sheets. Only a few map sheets can be handled at a time, precluding comprehensive queries over large areas.

- **Because of their limited capabilities, current GISs are not true database systems, but are more accurately described as specialized file systems.**

Current GISs do not protect data from abuse and erroneous entries or allow multiple users to access and change data simultaneously. This is a major impediment to GIS use in environments such as local government administrations. The use of standard database management systems does not solve the problem since some of the requirements for data storage in an administrative environment are different from those of a GIS, or more generally from those of the scientific and technical domain. Data structures for nonstandard or engineering databases are more complex; data access paths are different and are used in a different pattern. Consistency constraints are also more complex, and special data structures are sometimes necessary. It is assumed that engineering databases can be built from a common kernel but must include some special-purpose adaptations and optimization depending on the application area. Starting with standard database management system functionality, we will determine which kernel functions and GIS-specific adaptations are necessary.

Another major research problem is to understand the interactions among different GIS processes and the selection of optimal solutions for each. Building large systems, even if the separate problems have known solutions, is a major intellectual achievement. Understanding how components interact and in what order they must be combined is valuable, providing theoretical knowledge of eminent practical significance.

4.3.1. Conceptual data models

- **The data structures necessary to represent geometry in an object-oriented system are very complex.**

Most current database systems cannot adequately model the geometry of spatial data. One can either extend the database structure or resort to special purpose code (preferably over a common core of storage functions). The advantages and disadvantages of these methods for GIS have not been assessed, and prototyping is needed.

The set of operations based on the relational data, structure does not seem well suited for low-level GIS operations. It will be necessary to work with database researchers on a comprehensive new concept that includes basic results from artificial intelligence (knowledge representation) and software engineering (abstraction mechanisms).

4.3.2. Transaction management

- **The special programs that manage GIS data today do not include transaction management and therefore cannot deal with concurrent users, nor do they provide methods to enforce consistency constraints.**

Transaction management in GIS databases differs from that in commercial database systems, since change operations are very complex, take considerable time to specify, and affect large sets of data. A promising method might be to separate change operations into short and long transactions. For short transactions, the standard DBMS transaction concept would be used; long transactions would be decomposed for processing. The operations permitted as short transactions must then fulfill a number of conditions (such as restartability and undo), requiring careful design.

Data are valuable and must be protected from corruption by either technical problems or user actions. This becomes exceptionally important when multiple agencies or user organizations share data. Responsibilities must be clearly defined, and the DME must provide technical means to enforce these policies. Current GISs do not provide this feature and thus are not suitable in a multi-agency situation where data are shared but responsibilities for the data must be clearly defined.

4.3.3. Query languages and user interfaces

- **Current query languages are not designed for spatial selection and graphical output.**

If GISs are to be used to answer questions and support decision making, users will require the means to express their information needs in the form of query languages. Future GISs must include user interfaces that are easy to learn, appear natural to the user, and do not depend on the internal structure of the system.

4.3.4. Parallel and distributed computation

- **Most current GISs are designed for computing environments with a single central processing unit.**

As new hardware architectures with multiple processing units become more widely available, the degree to which basic GIS algorithms can take advantage of parallel processing must be examined. New data structures and algorithms that perform better on parallel hardware must be developed. In the future, we expect GIA/GIS to move increasingly toward distributed workstations and central database servers. Overall architecture must be adapted to the distribution of tasks between central servers and workstations.

4.3.5. Physical storage

- **Because GIS data collections are often very large, data structures must be found which are effective when data are stored on relatively slow mass storage devices.**

Most database-oriented processing in dominated by the time taken to access data from disk (and not by processing in main memory). Operations in a GIS are dependent on spatial proximity, as consecutive accesses to data usually occur within a limited area. The data structure, and possibly the buffer strategies, must respect this. A number of strategies are already known and will be compared and evaluated.

Work in this area will be of particular importance to agencies that collect and manage very large spatial databases. Data management is an increasingly important aspect of remote sensing systems, as data volumes rise with instrument precision and as analysis and use of remotely sensed data become more sophisticated. The problems of very large spatial databases are also apparent in topographic mapping and in utility systems.

4.3.6. Benchmarking

- **Most acquiring agencies lack the resources to make informed decisions about the performance of proposed GIS configurations.**

As noted elsewhere in the proposal, we intend that NCGIA perform a significant function in developing and disseminating tools for system evaluation. Assessment must not be based solely on technical grounds but must take into account the full range of user requirements in a modern GIS. Evaluations today are hindered by the lack of a set of standardized test cases which can be used with a variety of systems, and by the lack of an accepted methodology for defining GIS workload and evaluating systems against it. This is particularly true for interactive systems requiring user/machine dialogue and immediate response, alphanumeric and graphical output, and multiple concurrent users.

5. Artificial Intelligence and Expert Systems

Artificial intelligence (AI) and expert systems (ESs) offer a set of techniques to overcome impediments arising in the context of computer-based GIA/GIS. AI may be defined in two distinct yet complementary ways. From an engineering perspective it is a set of computational techniques that may be employed to find acceptable answers to problems that humans can solve, but for which exact solutions either are not defined or are computationally intractable; from the perspective of cognitive science, AI uses the computer to reveal principles of intelligence in general and of human thought in particular. AI involves the study and application of special data structures, procedures, control structures, and computer architectures, together with heuristic domain-specific knowledge, that allow problems to be solved by computational means. Expert systems form a subfield of AI concerned mainly with building computational systems that incorporate expert human knowledge.

As a body of techniques and methods for problem solving, AI/ES cuts across the topically based organization of the other components in this proposal, contributing in substantial ways to all of the other designated research areas.

- **Many impediments involving both computational and cognitive aspects of geographic problem-solving may be overcome using AI/ES approaches.**

Many problems in geographic 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.

Building a large ES from scratch is both time-consuming and costly. There has, however, been great interest in constructing ES shells-very high-level programming languages that greatly reduce the cost of constructing ESs. It is important to determine whether ES shells with special applicability to spatial analysis exist and, if not, whether they can or should be constructed. If such shells become available, the cost of building relatively complex geographic information and analysis systems might be significantly lowered. Special-purpose ESs can be constructed that partly automate some aspects of:

- the statistical analysis of spatial data, including the selection of the statistical tests to be employed and warnings in the case of inappropriate use;
- the modeling of certain spatial phenomena;
- image interpretation, such as change-detection and feature extraction;
- the procedures used by human experts for making decisions concerning location/ allocation;
- cartographic design, including label placement and color selection;
- cartographic generalization.

6. Visualization for Display and Analysis of Spatial Data

The recent report of the NSF panel on Graphics, Image Processing, and Workstations (issued July 1987) 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.

Visual displays can thus be used to analyze 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 (e.g., spatial coincidence, proximity, contiguity) are difficult to interpret in the purely numeric 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 multivariate 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 last quarter 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 geographic flows, and of uncertainty or fuzziness in geographic information all present substantial research challenges.

6.1. Impediments to Visualization

Three types of impediments to visualization research in geography are evident.

- **We are impeded by the sheer volume of available data and by the lack of appropriate representational models.**

New approaches must be developed to enable scientists to comprehend the masses of data that can now be collected and stored. Researchers tend to think of a dataset as a snapshot of reality and to view data structures as static; this is a subtle trap that constrains the variety of research questions and the way they are posed. It is difficult to encapsulate the visual complexity of real-world objects in data matrices, and yet the commands contained in most computer graphics libraries are constrained to matrix manipulation (rotation, translation, pan, and zoom). As discussed in section 4, researchers also must determine formal expressions for the kinds of data structures and spatial objects we manipulate and analyze.

- **Current technology and hardware limit visualization research.**

Within two decades, topographic and other geographic data for the entire world will be available at high spatial and temporal resolutions, presenting major analysis and visualization challenges. Getting the graphics hardware and software tools into the hands of the scientists who study phenomena represented in such large databases is a primary goal, whose accomplishment will require ongoing collaboration between industry and research centers.

- **Researchers have incomplete knowledge of how the brain works and how optical signals are processed and transformed.**

Neurological, physiological, and to a lesser extent behavioral models clearly fall beyond the scope of most geographical research. But formal expression of graphical design principles remains a prerequisite to automating the construction of effective visual displays. Of particular relevance to visualization problems is the discipline of computational vision, which focuses on machine vision and on modeling human vision. Overcoming impediments regarding both types of vision operations requires research collaboration between geographers, psychologists, computer scientists, and others.

6.2. Impedimenta Involving Data and Data Models

- **The lack of realistic models which would allow multiple scales of graphic depiction to be constructed from a single digital database impedes the generation of maps by integrated software systems.**

Operations affected by this impediment include map overlay and map comparison; consistency of feature simplification operations may also be compromised. Digitizing and archiving data repeatedly is time-consuming and expensive. Models for digital representation of features must incorporate the possibility for scale-dependent geometry, in order to preserve recognizability while maximizing storage efficiency. A means to label features within a digital file as scale-free, self-similar, or scale-dependent would provide automatic flags for applying a particular model (e.g., fractal) for feature representation, and also provide markers to guide automatic modification of tolerance values during map generalization.

- **Use of GIS data is limited by inadequate methods for visually depicting data errors and related measures (reliability, uncertainty, fuzziness).**

Standard reliability diagrams as seen on topographic sheets cannot reflect the complexities of error propagation nor the associated probabilities on an overlay surface. Most depictions do not distinguish between positional and attribute error and do not indicate errors of omission or of logical consistency, confounding reliability problems for the map viewer.

6.3. Limits of Technology

- **In the past, the load-dependent speed of mainframes and the limited processing speed of microprocessers have impeded real-time processing and display for interactive visualization.**

Although a new generation of computers-including graphics workstations-may have largely removed this technological impediment, software development has lagged behind. New technology is expected to supplant to some degree the use of printed maps and images for support of navigation and for archival storage of spatial data. Hardware developments including screen size and resolution, video refresh rates, and dedicated graphics memory provide means for increased accuracy, precision, and complexity of visual display. Useful improvements that would expand digital holograms (for direct visual exploration of three-dimensional objects) and faster mass storage access.

Software developments including polygon fill, hidden line removal, and ray tracing have enabled more realistic visual presentations of spatial data and relationships. Standardized graphic storage formats (e.g., Postscript) will improve the portability of constructed images between applications. A means to transmit imagery efficiently over long distances is now needed: recent developments in transmission of high quality text by electronic mail systems should be complemented by similar techniques for high quality graphics.

6.4. Human Vision Considerations

- **Increasing reliance on special-purpose electronic "disposable" graphic displays has displaced much of the demand for general purpose printed maps and charts.**

Map design guidelines must be formalized as defaults for mapping and GIS software, to allow researchers to focus on the substance of their data rather than the mechanics of constructing data displays. Recent technological improvements have facilitated cartographic research on the use of color in thematic map design; these results must now be incorporated into new cartographic software. Tektronix has recently developed a directly viewable three-dimensional display device based on stereovision. The impact of this and related technology on map use and image analysis remains to be explored.

- **Nontraditional visual displays will provide a means to expand the types of research questions we ask.**

Map animation, for example, allows one to explore patterns that vary simultaneously over space and time, representing real time with temporal symbology patterns of traffic volume within a city, of recency of regional seismic activity, and of changing land use and ownership may be easily interpreted in animated form. Real-time animation plays an important role in electronic navigation systems.

- **Visual tools are of clear utility in cybernetic interfaces, an demonstrated by common use of screen menus, mice, and picking operations in design of integrated graphics software.**

Visualization helps researchers interpret the results of statistical testing and conduct sensitivity analyses. Graphic display of changes and interaction between variables may facilitate real-time guidance of computations. Just as one does order-of-magnitude calculations in one's head to validate arithmetical work, graphical depictions may help to avoid spatial nonsense and errors. Human factors research to determine the impact of visual interfaces on initial learning curves, user fatigue, and performance in spatial analysis is of obvious importance in the development of user shells and on-line documentation for large GIS packages, especially in educational applications.

6.5. Machine Vision Considerations

- **Principles of computational vision, implemented on machines, could overcome many factors impeding automated GIS data acquisition.**

Abstraction forms the core of the research process; in the context of visualization, this points to the importance of pattern recognition as an analytic tool. Pattern recognition is also required to restore topology to scanned data and raster displays, and must be applied to implement automatic feature labeling operations within a digital database. Finally, the application of machine vision to decision making, as shown by advances in robotics and ballistic strategy, demonstrates the need for continued interaction between industry and research centers.

7. Social, Economic, and Institutional Issues

An information system is an assembly of human and technical resources which captures, analyzes, represents, and delivers data and information. GISs 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 resources in appropriate form and at the appropriate time. The desire to reduce uncertainty in these decisions creates demand for improved information products.

Adoption and implementation of geographic and land information systems is a dynamic process characterized by mutual adaptation 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 GIS design and development.

The incorporation of GIS advances 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 impedimenta to 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.

7.1. The GIA/ GIS Technology Adoption Process

- **A central research problem is to understand the process by which users adopt and accept GIA/GIS technology.**

Research topics include the identification of direct and indirect users of land and geographic information, the manner in which users arrive at an understanding of GIA/GIS technology, the demand for geographic information, and the means by which attributes of useful products are determined. Mechanisms for acquisition of products from GIA/GIS technology also are critical.

In order to study the use and value of geographic information, models of the adoption process, including barriers and feedbacks, will be needed, along with a methodology to identify and measure the benefits of geographic information use. Elements of the process include: adaptation of economic theories of information to geographic information; characterization of geographic information as a public good; distinguishing between tangible and intangible benefits; understanding the legal regime regarding rights to information; and modeling of the benefits and costs.

7.2. Use and Value of Geographic Information

- **The benefits of GIS technology are difficult to assess absent a theory of value for geographic information.**

The theory of the use and value of geographic information is poorly developed. However, economic, psychological, sociological, and other existing social scientific methods will be applied to this problem. The role of information in decision-making, the mechanisms and processes by which information is defined and utilized, and the economic theory of information must all be addressed. Economic value is a demand-initiated concept. The desire to reduce uncertainty creates demand for information, yet its value is difficult to assess because of distribution of benefits, variation in the value of information by culture, location, and decision, and changing community standards.

7.3. Institutional Structure

- **There is a need for research on the institutional effects of adopting GIS technology.**

Changes in the activities of people, agencies, and professions brought about by specific changes in GIS technology must be identified and formal arrangements developed appropriate to these altered activities, including changes in rules, laws, and standards for individual, agency, and professional activity. It is also important to identify the impacts of institutions on GIS technology.

7.4. Liability

- **Uncertainty over legal liability impedes wider adoption of GIS technology.**

Geographic information products-traditionally map-often contain errors, are sometimes used in unintended ways, may be inappropriately combined, and may be misused. Furthermore, including data in a GIS almost certainly increases the chances of misuse. Such situations can result in conflict and, ultimately, in litigation when an injured party blames those who produced and relied upon the product. Map-based information is used as scientific or technical evidence and is particularly subject to litigation involving people's rights and value in real property.

Research at NCGIA will identify, analyze, and characterize the legal regime and professional standards for the use of geographic and land information, especially as scientific and technical evidence within courts and agencies, and apply the legal regime to the development of criteria for designing GIS technology and products. Recommendations and professional standards will result from such research.

7.5 Access to and Availability of Geographic and Land Information

- **Current rules of access to geographic information products are unclear and inconsistent.**

Reasonable access to geographic information is a technical, legal, social, and economic concern. Freedom of information laws, federal and state, elicit a bias in favor of full disclosure of publicly held data and information in a manner convenient for the citizen. Automated recording makes it possible to ask questions that previously could not be asked, but control of information is a political issues, especially in cases where citizen access without professional assistance is limited by technological complexity. Availability and access are limited when system development is inhibited because costs cannot be recovered due to pricing law and policy. Finally, equity and fairness are questioned when systems provide large amounts of accurate data and information about some areas and not about others.

The status of freedom of information and records laws in relation to GIS must be assessed, especially at the state and local levels. The attitudes of citizens and politicians toward GIA/GIS adoption must be determined, especially in regard to control of information, pricing policy, and equity and fairness of data distribution.

7.6. Privacy and Confidentiality

- **The confidentiality of GIS information is a concern in some cases.**

Privacy and protection from misuse of information in public files is a litigious issue in part because of the ability to collect, process, and integrate such information automatically. Physical security and protection against accidental or unauthorized access is a concern. The pace and extent of GIA/GIS adoption will depend on public perceptions, as well as on the outcome of litigation. Key research problems include the influence of litigation, public perceptions, and concern about government record systems on GIA/GIS development, protection of hardware and software from unauthorized access, and the role of governments and professions in privacy protection.

7.7. Technology Assessment

- **We know little about the factors affecting the transfer and adoption of GIs technology.**

Knowledge of the process whereby new technologies replace older ones is limited, though theories of technology transfer have evolved in several areas. Past studies of technology transfer have been limited by the need to apply a retrospective methodology. At its current stage, GIA/GIS and the transfer process can be analyzed in a real-time mode. Use of a case study approach in a real-time setting would generate valuable insights into the technology transfer process. Such insights can serve to guide the process by which GIA/GIS becomes available to and useful for the ultimate user.

8. Research Initiatives at the NCGIA

We now describe a specific research plan for the first three years of the Center's operation. This research agenda 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 three 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 closely modeled on the very successful pattern developed by the NSF-funded Institute of Theoretical Physics at the University of California, Santa Barbara. They 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 outside. Seminars may be organized to clarify in interdisciplinary effort, to identify future 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 in 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.

9. Proposed Research Initiatives

Twelve Research Initiatives are already planned to begin during the first three years of the Center's operation: five will start during the first twelve months as shown in the time-line diagram on the following page. This section describes this first set of initiatives, listing the titles, research areas, project leaders, center participants, duration, and objectives. Center participants listed are expected to participate in the Specialist Meeting which will begin the initiative; those whose names are followed by an asterisk will have a substantial role in the Working Groups as well. Expected participants from industry, government, and academic institutions outside the Center are not listed, in order to avoid possible conflicts of interest.

Initiative 1: Accuracy of Spatial Databases

Research Area: Spatial analysis and spatial statistics
Leader: Michael F. Goodchild*
Center Participants: Anselin*, Amrhein*, Davis, Estes, Mackinnon, Rogerson*, Simonett, Star, Tobler
Duration: September 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

Within spatial analysis, the Center will give first priority to an initiative on the accuracy of spatial databases. This topic is of central concern to data-collecting and product-generating agencies (such as the Bureau of the Census, the Defense Mapping Agency, the Environmental Protection Agency, the U.S. Geological Survey, and NASA), and is of key concern for spatial analysts using aggregated data. The Specialist Meeting in September 1988 will bring together researchers with expertise in spatial statistics (including Anselin), established GIS researchers with interests in data quality and error (including Amrhein, Davis, Estes, Goodchild, Star, and Tobler), and individuals with knowledge and expertise in the effects of accuracy on application and in problems of spatial aggregation from outside the Center. Research will be carried out by individuals and teams working in close cooperation during the succeeding twelve months, and will be presented at a National Conference, possibly in conjunction with North American meetings of the Regional Science Association.

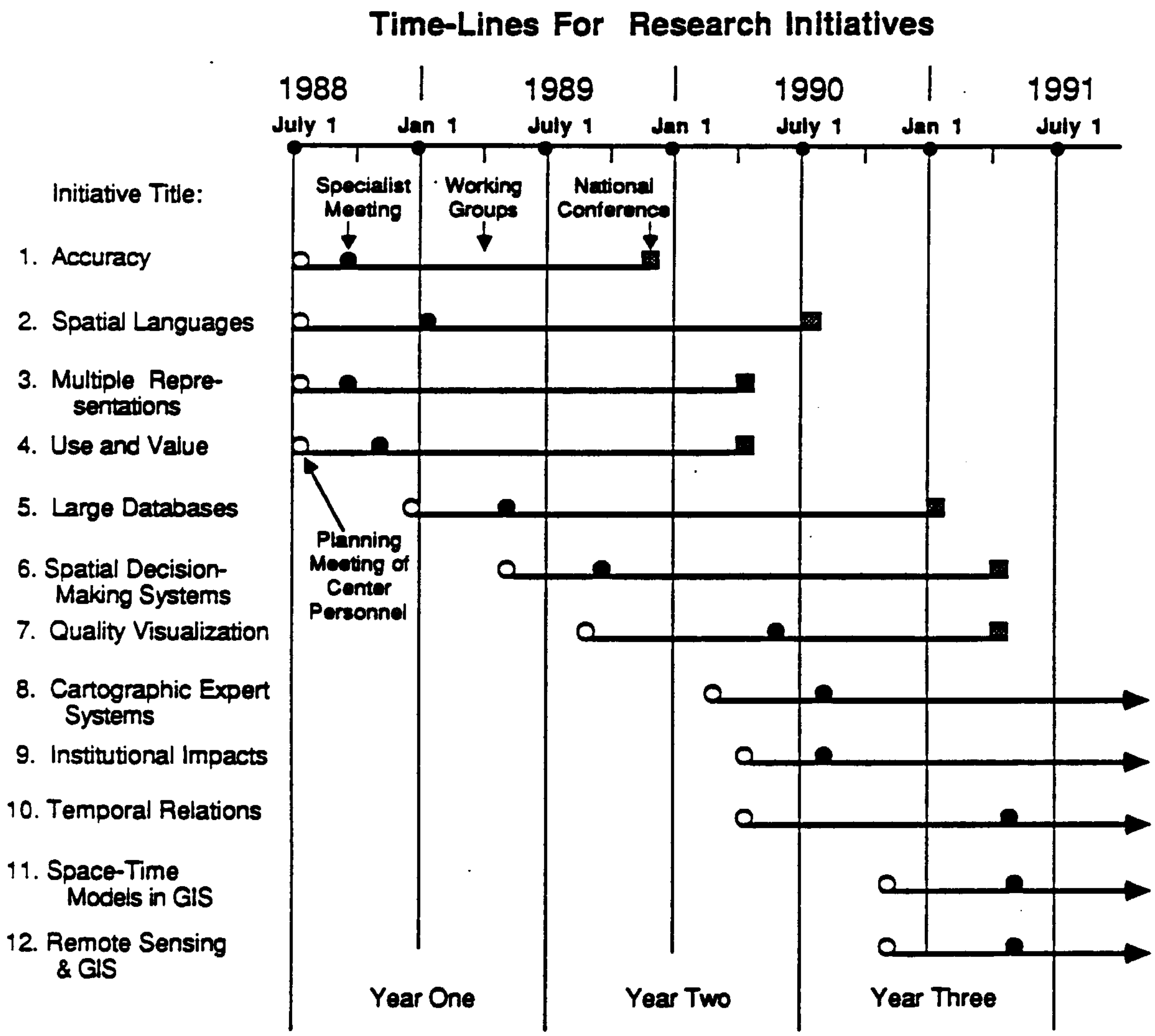
Several research modes are envisioned. Theoretical work is needed on stochastic process models of error and distortion and on methods of interpolation and estimation. There is also a need for applied work to empirically examine appropriate data to develop, test, and verify models and methods for effective evaluation of these output products. Calibration methods and descriptive indices will also be needed to implement models. The results of this project Will strongly influence Initiative 7 (Visualization of the Quality of Spatial Information), and will likely lead to the definition of one or more new initiatives to begin in Year 3.

Initiative 2: Languages of Spatial Relations

Research Area: General theory of spatial relations
Leaders: Andrew U. Frank* and David M. Mark*
Center Participants: Couclelis*, Ehlers*, Golledge, Rapaport*, Smith*, Zubin*
Duration: July 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



A general theory of spatial relations is essential to the design of many GIS components, including spatial data structures, query languages, and reasoning systems, as wen as influence standards for the exchange of geographic data. Such a theory should also contribute to our understanding of the communication of spatial relations and of human spatial behavior. There are two distinct and complementary approaches to such a general theory: a mathematical view, and a cognitive and linguistic view. In order to possess generality, a theory of spatial relations must include both views within a consistent framework.

Research on this topic at the NCGIA will begin with a planning meeting in Buffalo during July 1988, primarily involving Center faculty. Over the subsequent six months, research teams at each of the three sites will assemble background material and prepare position papers for a Specialist Meeting, to be held in Santa Barbara in January 1989. This meeting will bring together the aforementioned researchers, additional Center personnel, leading authorities from geography, surveying, and the cognitive and linguistic sciences, and graduate students.

The Specialist Meeting will identify linkages and differences between the mathematical and cognitive approaches, and develop specific subtopics and goals for parallel Working Groups to convene in Buffalo (Spatial Relations in Natural Language and Thought) and Maine (Mathematical Definitions of Spatial Relations) during the first half of 1989. Frequent electronic mail exchanges of seminar notes between the two sites will ensure consistency of approaches and continued evolution of topics. The results of these working groups will be assessed in a second Specialist Meeting to be held during the summer of 1989 in Maine. This meeting will report results and further integrate the two approaches and will identify topics and modes for further research by Working Groups during 1989-90 and subsequently. Preliminary results will be reported at a National Conference in late 1989. This initiative is expected to lead to research in several other areas, including spatial query languages; spatial reasoning; spatial behavior; vehicle navigation aid systems; and spatial aspects of the deictic center in understanding narrative text. Several of these topics will be of interest to private-sector firms (GIS vendors, vehicle navigation aid developers, etc.) and subsequently to all GIS users; one or more of these topics will be proposed as initiatives to begin in 1990 or later.

Initiative 3: Multiple Representations

Research Area: Visualization; spatial relations and database structures
Leader: Barbara P. Buttenfield*
Center Participants: Barrera*, Beard*, Ehlers*, Frank*, Mark, Smith*, Tobler*, Walters
Duration: September 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 wale-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

A single digital version of geographic features for representing phenomena at different levels of spatial resolution or focusing on different attentions limits the efficiency of GIA/GIS operations and reduces the quality of cartographic output. This initiative will explore efficient data structures that allow increasing resolution (such as trees and strip trees) and determine how dissimilar representations of the same geographic features can be related. General rules for aggregation can be used in spatial inference and hierarchical structures may lead to efficient heuristics for GIA expert systems. Error propagation will be studied in cooperation with Initiative 1. Research priorities include developing digital models to accommodate scale-dependent phenomena and calibrating such models for feature identification and abstraction.

Research will begin with a September 1988 Specialist Meeting in Buffalo. Attendees will bring expertise in analytical cartography, spatial inference and database query language, and data structuring and generalization. Participants will include GIA/GIS researchers with interests in spatial data structures, computational vision researchers from computer science, psychology, and other disciplines, geographers with interests in image processing, digital cartographers and geodesists, vendors with interests in computer graphics, and representatives of government agencies involved in map generalization such as the Defense Mapping Agency and the National Geodetic Survey.

Research will proceed through the winter months, culminating in a first National Conference to be held concurrently with the ACSM meetings in Baltimore (March 1989). This meeting provides an opportunity to meet with representatives from government agencies and large mapping houses. At the conference, the Working Group will report formally on their research. Additionally, a panel of external researchers and practitioners with expertise in image processing, computer vision, database design, and geometric issues will be invited to respond formally to initiative efforts and to present alternative methods and research results. A second National Conference will convene in Toronto at the AAG meetings (April 1990).

Initiative 4: Use and Value of Geographic Information in Decision Making

Research Area: Social, economic, and institutional issues
Leader: Earl Epstein*
Center Participants: Beard, Calkins*, Estes, Ducheneau*, Goodchild*, Onsrud*, Star, Zubrow
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 GIA/GIS

The first year will focus on the use and value of information. Some twenty leaders in the field from academia, industry, and government, will begin the initiative with a Specialist Meeting to discuss and explore different perspectives on the topic. Concepts of use and value of information are common to all information-producing activities and must be judged within a broad definition of social, economic, and legal impacts of those activities. This topic is of concern to all governmental agencies, but is particularly central to the Bureau of Land Management, the Department of Agriculture, and the Environmental Protection Agency. The initiative will examine the following topics and subtopics:

- Uncertainty and risk associated with decision making (the economic concept of utility applied to information; the role of information in uncertainty reduction; uncertainty reduction and absorption; limits to the search for information)
- Decision models (the decision-making process; the role of information; information as a product; the distinctions between data, information, and knowledge)
- Demand for information (value as a demand-initiated concept; identification of primary and subsequent users of information; the contrast between supply/push and demand/pull in the development of information systems; public good aspects)
- Benefits (direct and indirect benefits; uncertainty reduction; uncertainty absorption; expanded opportunity; avoided cost models)

The initiative will result in guidelines for GIS design, especially regarding which data to include and what benefits cam be expected. It also will form a starting point for investigations regarding data quality and how it affects the quality of decisions. It will provide some design criteria for Initiative 7 ("Visualization of the Quality of Spatial Information") by identifying those aspects of data quality most important to decision makers. Presents of this research will be discussed at a conference in conjunction with a suitable professional meeting.

Initiative 5: Architecture of Very Large GIS Databases

Research Area: Spatial theory and databases
Leader: Terence R. Smith*
Center Participants: Band, Barrera*, Estes, Ehlers*, Frank*, Gersho*, Star*
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

The design, construction, testing, and use of databases containing very large amounts of spatially indexed data is a major problem whose importance will only increase. This is particularly true as we move into the "Eos era" of the 1990s and the Global Change Initiatives (IGBP, etc.). We propose to address that problem by investigating the architecture of databases suitable for dealing with large amounts of geographic data. The Specialist Meeting, to be held in May 1989 in Santa Barbara, will bring together several researchers with expertise in database management for remotely sensed data in order to determine the requirements of users who must deal with very large GIS databases. The meeting will establish a set of requirements indicating the amount of data to be dealt with and the performance necessary. During the meeting, the architecture and performance of two or more key systems will be compared. In particular, architectures designed by several of the Center investigators (KBGIS-III and PANDA) will be discussed and the lessons learned from these systems examined. The meeting will also discuss the Center's agenda in this area and assign responsibilities to two Working Groups, which will conduct research in Santa Barbara and Maine during 1989-

1991. Research will be carried out by individuals and teams, working in close cooperation during the following two years, and will be presented at a National Conference.

The Santa Barbara team will concentrate on the data compression issues, especially how they integrate into the database environment and how intelligent methods of representation can be used to achieve high levels of compaction (e.g., the use of "delta" techniques and other forms of encoding). The Maine team will look at storage methods for large image datasets and their performance. In particular, they will investigate the suitability of current file systems and optical storage devices. They will also see how multiple representations can be used for indexing and spatial reasoning and consider the integration of these components. Cooperation with NASA in this area will be important. Expected results of the research include: 1) improved compression methods, particularly band on intelligent techniques; 2) the integration of indexing and storage methods in a single architecture; 3) a better understanding of the tradeoffs in performance of large image databases; and 4) an initial understanding of the opportunities to be derived from the use of parallel systems.

Initiative 6: Spatial Decision Support Systems

Research Area: Spatial analysis
Leader: Michael F. Goodchild*
Center Participants: Batta, Church*, Onsrud, Simonett, Smith
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

The second initiative in spatial analysis begins in September 1989 with a Specialist Meeting on SDSS, to be held in Santa Barbara. Current GIS capabilities for sophisticated forms of spatial search and decision making are limited; this initiative will develop and implement a research program aimed at incorporating advanced modeling techniques in a GIA/GIS environment. Suitable application areas for SDSSs include vehicle navigation and routing systems, retail site selection, facilities location, and emergency management. The initiative will consider appropriate data structures, algorithms for spatial search, the application of decision theory, and the design of suitable user interfaces. Representatives from the various application areas, including private sector consulting firms, GIS vendors, and appropriate government agencies, will play an important role in the Specialist Meeting.

Intensive interaction with potential users of SDSSs will be an essential component of this research. Prototypes developed by the working groups will be continually field-tested in spatial decision-making environments, and feedback used to improve designs. The National Conference to be held in conjunction with the 1991 AAG meetings will critically assess progress to date, and will result in a monograph on general principles of SDSSs.

Initiative 7: Visualization of the Quality of Spatial Information

Research Areas: Visualization, spatial statistics, applications
Leaders: Kate Beard* and Barbara Buttenfield*
Center Participants: Calkins, Couclelis, Goodchild*, Bialis, Amrhein,
Rogerson, Ehlers*, Frank, Mark*, Tobler*
Duration: May 1990 - 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

Elementary questions about the nature of our comprehension of data quality have not been considered in a visual context; this restricts wider use of GLA/GIS because of concerns about data reliability, and how it is perceived by users. Can data quality and content be displayed in a single diagram using, say, color for information on the pattern of some phenomenon and texture to represent quality? Does a windowed map display with spatial information on one side and data quality on the other afford an unreasonable amount of visual complexity in an interactive computing environment? Must a visual display of error be constrained in equivalent map form (choroplethic renditions of error on choroplethic maps) or can alternative visual formats be substituted? What other approaches can be used to communicate data quality to data users? Can visual displays be constructed to monitor data reliability dynamically, during database update, attribute analysis, and map overlay? Research concerning appropriate data structures for storing and monitoring data quality will also be conducted.

The research team will first determine the ways in which data quality are reduced (e.g., positional or attribute error, data omission, logical inconsistency). Work will then proceed to developing a wide spectrum of methods for visual display of these components. Evaluation procedures will also be developed, and implemented by empirical and statistical testing methods using human subjects. The results of Initiative 1, Accuracy of Spatial Databases, will be an important input to this effort, as will be user concerns identified in Initiative 4, Use and Value of Geographic Information in Decision Making.

Initiative 8: Expert System for Cartographic Design

Research Area: Visualization; expert systems
Leaders: Andrew U. Frank* and David M. Mark*
Center Participants: Barrera*, Beard*, Buttenfield*, Smith*, Tobler*
Duration: Spring 1990 - 1992

Objective:
To develop an expert system to design cartographic displays of various types.

Cartographic design represents an interesting problem for the application of an expert systems approach. A full cartographic expert system would be capable of producing maps of all types, ranging from graphics for rapid on-line GIS display to high quality hard-copy maps, for a variety of data sets and mapping purposes. These maps would in principle be as effective in visual communication as maps now produced by professional cartographers, and base map features would be integrated from a single, scale-independent data base. The system would be flexible in offering a variety of user-specified map scales, projections, symbology, and levels of generalization, but would make good decisions about any of these elements in default. Clearly, the design and implementation of such a system is a long term project. This initiative will concentrate on the design of the map types as a first step before attempting* the production of maps.

First, a small meeting of research personnel will be held in Maine during the first half of 1990; the objective of this meeting will be to develop a clear system design. The design must be highly modular, to incorporate new design elements independently as they are tested. This will be followed during the summer of 1990 by a Specialist Meeting in Buffalo which will include cartographers with research interests in map designs, researchers interested in human factors in visual displays, and specialists in knowledge engineering and expert systems design. Participating cartographers will be drawn from USGS, NOAA, and other federal and state agencies involved in map-making; from academia, major private-sector mapping houses and from organizations such as the National Geographic Society.

The Specialist Meeting will identify components of the system, use knowledge engineering methods to codify cartographic expertise, and decide which modules will be implemented by Working Groups during the first research year of the project, 1990-91. Results will be reported at National Conferences as appropriate. The initiative is expected to lead to other initiatives addressing other aspects of expert cartographic systems.

Initiative 9: Institutions Sharing Spatial Information

Research Area: Social, economic, and institutional issues
Leaders: Earl Epstein* and Hugh Calkins *
Center Participants: Ducheneau*, Estes, Frank, Onsrud*
Duration: Summer 1990 - 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.

This initiative deals with one of the central tenets of GIS work, namely, the sharing of information among organizations. It will determine conditions which favor such data sharing, and identify policy implications. It will deal with questions such as responsibility, liability, and cost, all of which are important when data are shared.

The initiative will begin with a Specialist Meeting during summer 1990, with participants drawn from academia and government agencies, including participants from other nations with experience in this area. This meeting will assemble various perspectives on the topic, and identify specific cases of interest which can be used for in-depth case studies. The results of the initiative should be useful in two distinct ways: (1) to guide the development of technical systems by indicating functional requirements; and (2) to design GISs for federal, state, and local governments which encourage data-sharing (largely through cost reductions) while at the same time allaying concerns regarding responsibility, liability, and control.

Initiative 10: Temporal Relations in GIS

Research Area: Spatial and spatio-temporal analysis
Leader: Andrew U. Frank*
Center Participants: Barrera*, Couclelis*, Mark, Michaelsen, Rapaport, Smith*, Tobler*, Zubrow
Duration: May 1990 - 1992

Objectives:
1) Understand the modeling of time (continuous time, discrete time, and events);
2) Assess inference methods in temporal logic and deduction strategies in non-monotonic systems;
3) Compare modeling of states to methods of modeling incremental changes 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]");
4) Extend the methods for dealing with multiple and alternative representations to include temporal aspects.

In many instances GIA/GIS users are more interested in temporal changes or in differences between two time periods than in static descriptions of the world. As a practical example, remotely sensed images may be easier to interpret and require less storage space if the changes between two images (or possibly rates of change) are stored instead of storing both full images. Other areas of application include the interpretation of archeological information where the spatio-temporal succession is of primary concern and legal cases where the chain of ownership or a parcel of land must be traced through all changes in ownership and subdivision. Temporal relations must be added to GIA/GIS in order to understand spatial processes. This has been proven to be more difficult than expected.

The primary focus of this initiative will be on the logical foundations for the representation of data with respect to time and the logical inference methods used for symbolic reasoning. We will bring together specialists from different backgrounds (logic, automaton theory, computer languages) to compare different methods for the formal description of time-dependent facts. A review of the temporal logic literature with respect to specific GIS requirements will be necessary and will at the same time help to clarify these requirements. We will also use results from the spatial domain (especially from Initiatives 2 and 3).

The set of practical rules for dealing with temporal data which have been developed in the legal system will be compared to the theoretical results. We will work on guidelines to determine the exact extent to which temporal or spatio-temporal reasoning is necessary for a given application and identify the exact nature of the problem that prevents a solution. We assume that a balanced approach, analyzing requirements and identifying theoretical problems, can lead to practical solutions, which, while not fully general, can be applied immediately. Implementation issues, especially compact data structures for large databases, are very important to the GIS field and will be given considerable attention.

To be successful, this initiative will require substantial preparation in order to have the background material in temporal modeling and temporal logic available. It will then have at least two Specialist Meetings, one primarily dealing with the application requirements, and the other concentrating on the theoretical issues. We anticipate substantial benefits will be gained from interaction with the group working on Initiative 11.

Additional Initiatives

Initiatives 11 and 12 address several GIA/GIS issues related to the acquisition, storage, distribution and use of socio-economic, environmental and remotely sensed data by large public agencies such as the Bureau of Census, NASA and NOAA. Successful implementation of these initiatives will require very substantial additional funding from the public agencies. Initiatives 11 and 12 both build heavily on earlier initiatives and should run concurrently with certain of these during the third and fourth year. At present, these initiatives are expository of the problems, but are not yet in specific experimental and research formats. Extensive discussions with federal agencies, followed by proposal submissions, must precede the final delineation of these initiatives. Such discussions will be an early order of business following establishment of the National Center.

Initiative 11: Space-Time Statistical Models in GIS

Research Area: Spatial and spatio-temporal analysis
Leaders: David S. Simonett* and Joel Michaelsen*
Center Participant: Abrahams*, Botkin*, Dozier, Estes, Frank, Mark, Melack*, R. Smith, Zubrow*s
Duration: October 1990 - 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.

Issues of resolution, error distribution, and consistency apply equally to information gathered through time as well as over space, and most spatial statistics have analogues in the time domain. For processes that vary both in space and time, an understanding of their basic variance structure in terms of scale-dependence, organization (e.g. hierarchical vs. non-hierarchical) and space-time interactions is a prerequisite to effective data collection and management, as well as to data analysis and utilization.

Many of the basic geographic data for the social and natural sciences are collected repeatedly through time, for example census data, remote sensing data and climate data. The scale-dependencies and dynamics of social and natural systems are reasonably well known, however a general and consistent set of space-time models for acquisition and storage of these data in GIA/GIS systems is currently lacking. Development of such models must focus on two primary issues: predominant space-time scales and implications for optimal sampling strategies; and statistical models of underlying structure which would facilitate storage, retrieval, and analysis.

This initiative will examine the above issues, especially with respect to the concerns most pressing to federal agencies such as NOAA, USGS, NASA, USDA, and the Census. Data collection and data management by these agencies should be reviewed with respect to system behavior, scale-dependence and space-time interactions as they impact on agency GIA/GIS systems and the ability to include the data in other GISs. It is anticipated that substantial funding from such agencies will be needed to augment resources obtained from NSF. This initiative will be developed and implemented in close cooperation with the group working on Initiative 10.

Initiative 12: Remote Sensing and GIS

Research Area: Spatial analysis and spatial statistics
Leaders: Jack Estes* and Frank Davis*
Center Participants: Dozier, Leick*, Simonett, R. Smith, Star*
Duration: October 1990 - 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.

Aircraft and satellite-borne sensors provide much of the primary data for geographic analyses. At the same time, other geographic data are used routinely to, improve and extend classification and analysis of remotely sensed digital data. Despite the inherent close coupling of remote sensing and geographic information systems, little attention has been paid to theoretical and practical issues in fully utilizing and integrating remotely sensed data in GIS applications. The potential exists for strong synergism in the development of GIS/GIA and remote sensing systems, particularly in the areas of data acquisition, data storage and retrieval and scene classification.

For example, opportunities for integrating GIS capabilities in acquisition and preprocessing of remotely sensed data include incorporating existing information to allow for selective acquisition (e.g. areas of change, areas with specified attributes), selective resolution (e.g. depending on the intrinsic grain of different environments), and for scene rectification and registration. Choice of data structures for efficient storage of raster sensor data could be guided by ancillary information on the nature of the environment under investigation. In addition to improving scene classification, a GIS can aid in sampling to calibrate sensor data or assessing map accuracy through regional stratification or interpolation. A further extension for scene classification is the application of expert or knowledge-based classifiers in a GIS-based approach. On the other hand, the power and usefulness of GISs would be greatly enhanced by better methods of incorporating remotely sensed data for updating information, testing the accuracy (both locational and thematic) of other data, and assessing the validity of output from spatial models.

The overriding objective of this initiative is to identify principles and procedures that will ensure the fullest possible integration of remotely sensed information into GIS/GIA systems. At present, only a small fraction of remotely sensed data are utilized for mapping and monitoring, in part because of the technical challenge and cost of image processing and classification, and also due to the difficulty of merging the product with other geographic data. At the earliest opportunity, the National Center should enter into discussions with agencies such as NASA and NOAA to identify user needs and capabilities and to prioritize research activities promoting development of integrated remote sensing and GIS/GIA systems.

III
EDUCATIONAL PLAN

1. Introduction

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 governmental 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 will be to alleviate this shortage by expanding the nation's supply of experts in GIS. The Center's education program will attack the problem along three different fronts:

- 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 will include 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
- Workshops and short courses for existing faculty who will teach GIA/GIS at other institutions
- Short courses and workshops for the practical and applied GIA community, including industry and government

Thus the goals of the educational program are to produce a greater number and better quality of trained graduates at all levels for both industry and government positions, and to expand university programs in GIA/GIS.

The following table summarizes the educational services to be provided by NCGIA and shows where the primary X and secondary (*) responsibilities for each activity lie:

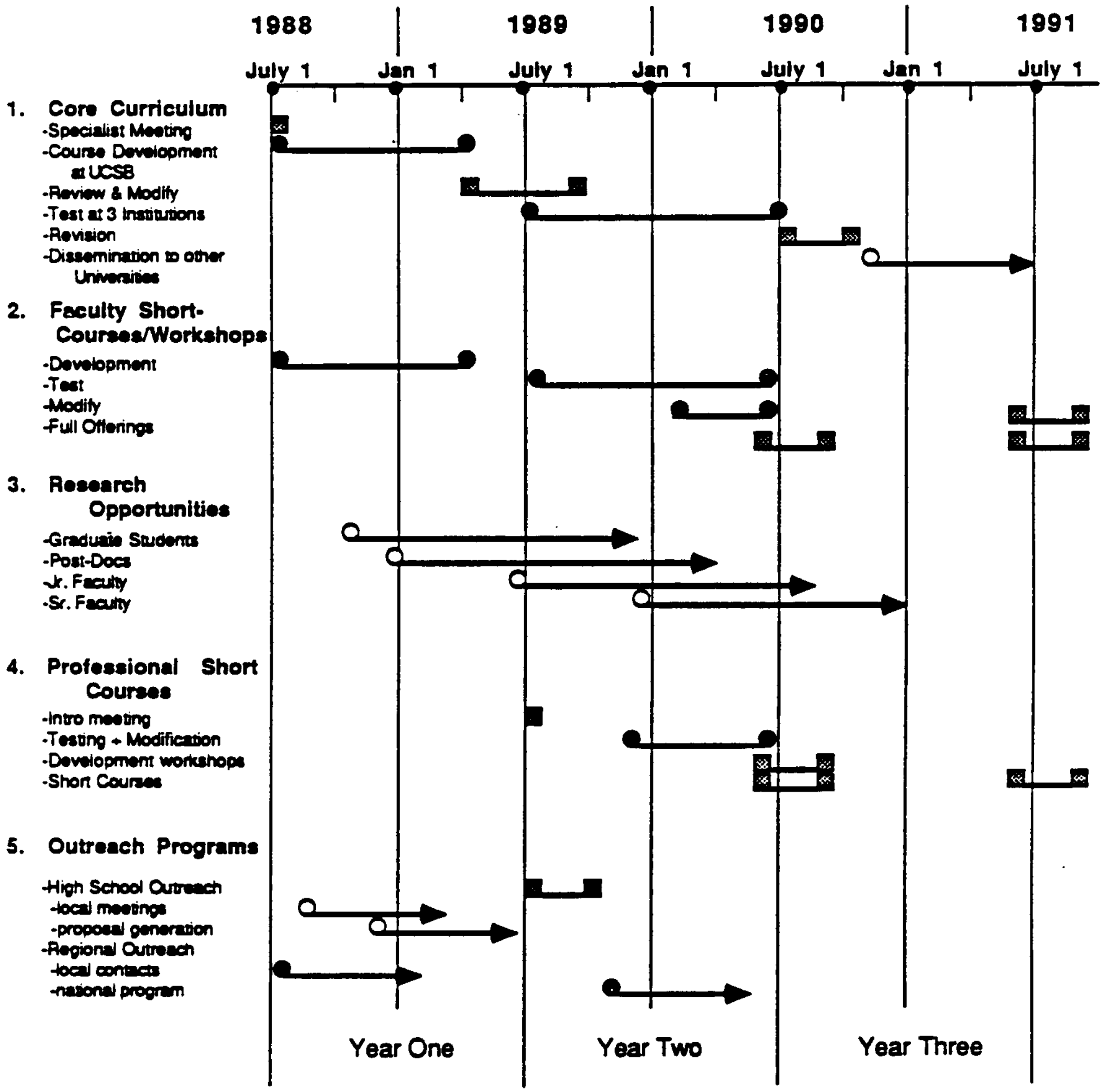
Table 3.1 Educational Programs of NCGIA

Educational Service	NCGIA	UCSB	Buffalo	Maine
GIA Curriculum Development:				
Undergraduate Course Sequence Development and Testing		X	X	X
Teaching Material Development		X	X	X
Program Dissemination	X			
Undergraduate Sequence Instructional Workshops	X	X	*	*
Outreach to High Schools		X	X	X
GIA Professional Training:				
Summer Seminars and Workshops		*	X	X
Off-Campus Seminars and Workshops	X			

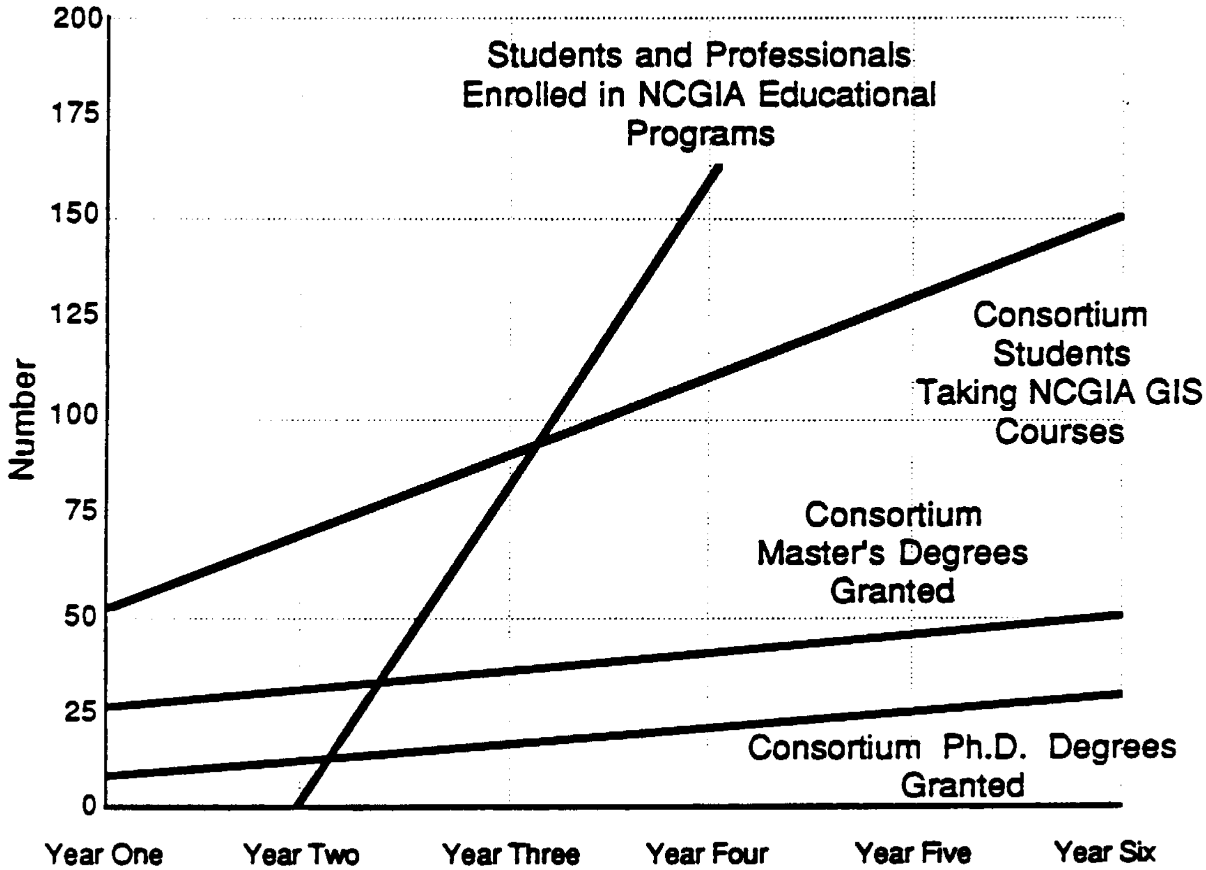
The time-line diagram on the following page shows the schedule for initiating and following-through on the activities listed above.

Key to the long-term successful use of GIA/GIS are the university-level training programs. Currently, the lead departments in the universities at this consortium (Geography at the University of California at Santa Barbara, Geography at the State University of New York at Buffalo, and the Surveying Engineering Group and Forestry Department at the University of Maine) have a combined total of about 280 undergraduate majors (declared majors in their junior and senior years). About one half of these will complete course sequences qualifying them for GIS positions. Graduate enrollments in the three institutions run about 180 students, some 60 at the Ph.D. level and 120 at the master's level, yielding roughly 45 to 50 masters per year and 12 to 15 Ph.D. graduates; of these, one half (22 to 25 and 6 to 8 respectively) will lie in the GIA/GIS area. The increased graduate enrollment associated with the NCGIA should in time double these latter figures in GIA/GIS to 45 to 50 Masters and 25 Ph.D.'s per year, probably within five years after the center is established. The graph on the following page shows the estimated multiplier effect that the NCGIA will have on the number of trained personnel above the present levels at the consortium institutions.

Time-Lines for Educational Initiatives



Annual Multiplier Effects of NCGIA Educational Programs Above the In-Place Programs at the Three Consortium Institutions



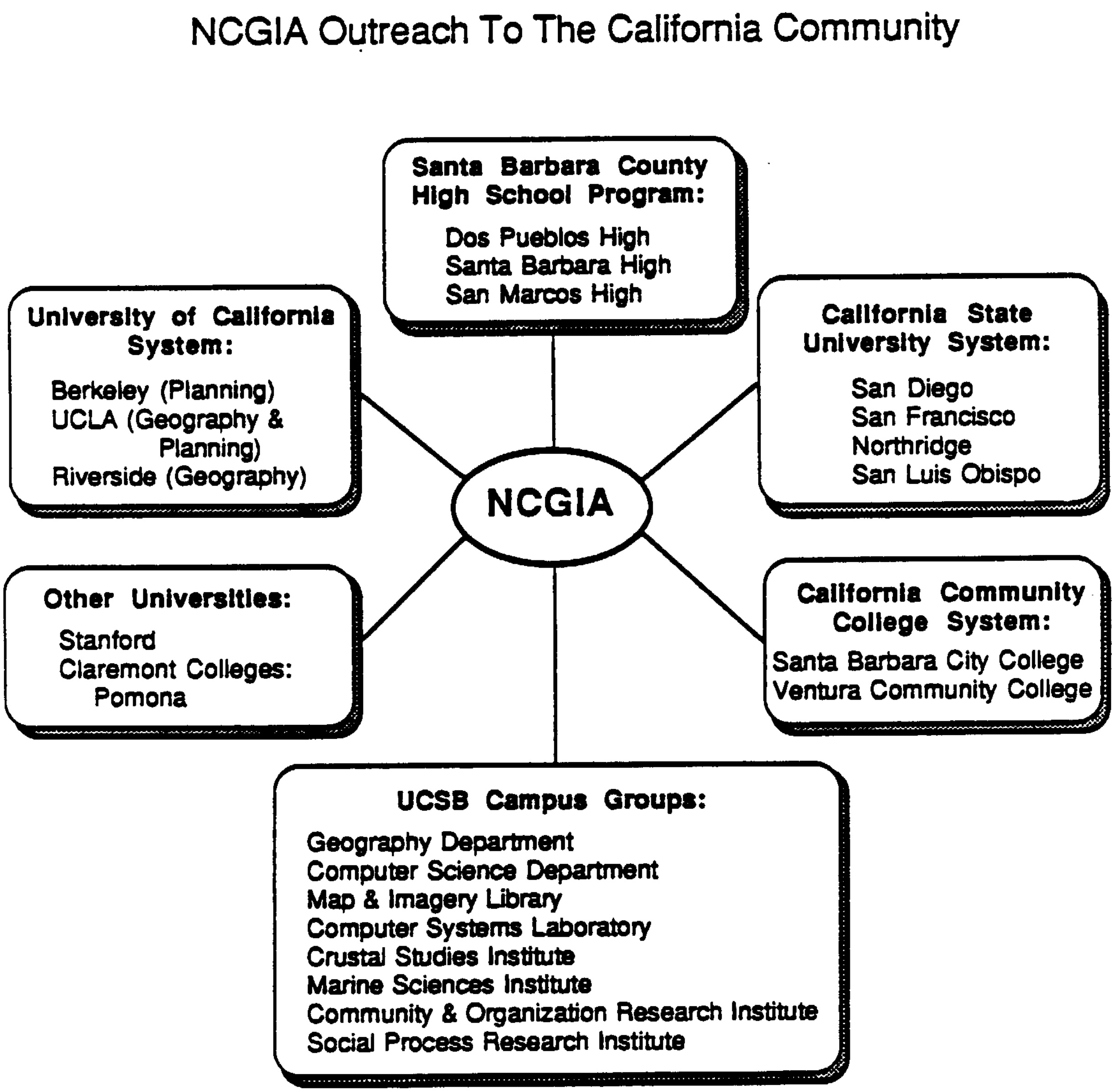
The national needs for undergraduate and graduate degrees in the area of spatial analysis and GIS are difficult to determine numerically, but certainly are higher than the current supply. Suggested targets for 1995 are:

- 400 undergraduate degrees awarded per year;
- 150 graduate degrees awarded per year.

Although the three universities in this consortium can contribute significantly to these targets, in order to achieve them the NCGIA will need to cooperate actively with all universities offering formal programs in GIA/GIS.

The National Center's educational program, specified below, uses many standard vehicles for undergraduate and graduate training, professional education, faculty skill enhancement, and information dissemination. Achievement of the broad goals stated above will be more a function of program management than of the particular instructional methods used. The educational program focuses on a common body of knowledge in GIS, which will be presented to different audiences in differing formats. This core will form the introductory sequence for undergraduate and graduate programs; a short course/workshop for practicing professionals; and the first of a series of summer training courses for university faculty.

The educational program will be managed by a small team, similar to the research team but composed of individuals at each of the three institutions responsible for program development. One individual will be selected as coordinator for the Center as a whole. It will be the responsibility of this team to define substantive content of the core and other important areas, to schedule short course/workshops and select instructors each year, and to oversee the dissemination of educational materials. Additionally, and possibly most importantly, this team will aggressively pursue an outreach program to introduce GIS/spatial analysis programs from each institution into other fields and into other universities. The vehicles for such activities will include national conferences, the educational program of professional associations, and other groups where a need for trained GIS professionals can be expressed. Each institution will also establish in its own region an outreach program to universities in its own university system and universities within an acceptable distance for cooperation. The form of these multiple outreach efforts is illustrated in the figure below, which shows for UCSB the general pattern to be followed at each site. At the end of the educational plan are tables listing the undergraduate, master's, and Ph.D. enrollments in geography of institutions with which we would seek to develop strong outreach programs.



2. Curriculum Development for Graduate and Undergraduate Students

2.1. Objectives and Strategy

Until recently, undergraduate training in GIA/GIS has been minimal at most institutions. One of the Center's primary educational roles will be to develop a strong undergraduate program in GIS. This program will include a broad-based introduction to GIS and an outreach effort to introduce undergraduates in other disciplines to GIS. To reach out to other disciplines that also use spatial analysis and modeling, such as forestry, geology, planning, environmental studies, and engineering, a strong foundation course in GIA/GIS will be required. This course could be viewed much like statistics, where students are introduced to the tools of statistical analysis and can then apply them to their area of interest. We hope that such a course will have the further advantage of involving interested students more permanently in the GIS curriculum.

The range of topics that must be addressed in a comprehensive educational program on spatial analysis and GIS at the undergraduate and graduate levels includes the conceptual and theoretical basis for the techniques as well as knowledge of how spatial analysis can be properly applied. University-level education should emphasize the theory, concepts, and application-oriented perspectives of the topic necessary to support a person through an entire career. However, the nature of GIS training requires that substantial skill development also be provided. Technical skills make many students immediately employable, whereas theoretical knowledge will provide them with an understanding of the need to maintain fluency in a rapidly evolving area, and permit them to remain current with developments in the field. A strong emphasis on the principles of GIS and spatial analysis (spatial thinking, spatial problem solving, and spatial decision making) at the theoretical and conceptual levels will promote that professional goal as well as prepare the next generation of GIA/GIS academics.

The current supply and demand factors in the field of GIS are considered to be a key problem. Those universities with formal GIS programs are not producing a sufficient supply of Ph.D's to allow for growth in the university system. More often than not, recent Ph.D.'s take industry jobs over university positions due to the substantial pay differentials and the relatively poor quality of equipment in university laboratories. In a sense, the GIS field is similar to computer science in that GIS too is "consuming its own seed corn," and we can foresee a situation where most persons with advanced training in GIS are employed in industry. This might satisfy industry needs in the short run, but in the longer run this will surely adversely affect all sectors.

The National Center we envision will be able to accomplish in the educational area what individual universities now find impossible. The longer-term benefits will be greatly enhanced when, through the National Center, a structure is put in place to ensure a continuing flow of well-trained personnel.

NCGIA, with input from the GIS community, will develop a core curriculum for the introduction of GIA at the undergraduate level while simultaneously implementing more specialized courses for advanced students. The core curriculum will be taught at each of the three locations. It will also be made readily available for transfer to other schools, together with appropriate course materials including course outlines, handouts, computer program, and datasets; this will enable other academic departments to add GIS specializations to their curricula. Preliminary contacts with other universities have indicated interest in this concept, and a number in California have already agreed to introduce the year-long introductory programs at their institutions. A one-year introductory GIS course sequence with the prerequisites will give all students the basic knowledge to understand the use and applications of GIS. The advanced courses will be particular to each campus and will reflect their current NCGIA-sponsored research.

2.2. Development of a GIA Curriculum for Dissemination

In order to impact the greatest number of students, NCGIA will develop a one year undergraduate course sequence introducing students to the field of geographic information and analysis. This sequence will be implemented first at the three NCGIA institutions, then modified and improved, and finally disseminated to the academic community. Curriculum development will initially focus on:

- The refinement of a one-year sequence in basic GIS concepts and applications, designed for senior undergraduates and/or first-year graduate student

- The preparation of support materials and software for teaching this sequence:

- lecture outlines and notes
- lecture graphics (overhead transparencies and slides)
- exercises and assignments
- reading lists and other bibliographies
- sample examinations
- catalogs of hardware and software suitable for teaching GIS
- instructional datasets
- recommendations on software

The geography department at Buffalo already has a suitable course sequence in place and can be used as a basis for developing and refining the proposed sequence. The surveying program at the University of Maine also offers a series of undergraduate courses that include theoretical aspects of spatial data-handling and system design, as well as hands-on technical training. UCSB has one undergraduate course now in place which also could form the basis for part of the one-year sequence. In addition, UCSB has a wide range of courses involving spatial analysis and relevant techniques.

The plan for development of this sequence is as follows:

1. Spring 1988: UB revises and adds to its existing courses and transmits to UCSB. UM provides copies of their course materials to UCSB.
2. Spring 1988: Consortium members attend the Ohio State Conference on GIS education and incorporate approaches from that conference.
3. Summer 1988: Follow-up workshop on education is arranged, if needed, to agree on course contents and approaches.
4. Summer 1988 and academic year 19SM9: UCSB, with matching funds from its administration (Office of Instructional Development), develops course and course materials and gives first trial run of these courses.
5. Summer 1989: The three institutions review and evaluate course materials, and modify for use in academic year 1989-90 at all three institutions and selected cooperating institutions. UCSB continues modifications and development of additional course materials under OID funding.
6. Summer 1990: Two-week education workshop convenes for training in the use of these course materials; materials are distributed to universities and technology application centers (such as that of the University of New Mexico) for further dissemination.

In subsequent years, additional funding will be sought from appropriate federal agencies, foundations, and corporations for modification of this instructional package and updating in response to changes in the field of GIS, changing computer technology, and feedback from universities who use the package. Additionally, submodules and extensions to the basic package relating to specific application and technical areas will be developed for additional undergraduate and graduate courses at the three institutions. These components will permit universities to integrate the teaching of spatial analysis and GIS with whatever applications disciplines are represented at their respective institutions.

The basic sequence in geographic information systems will be a year-long single course sequence; typically, this would involve one course per quarter for three quarters or one per semester for two semesters. This sequence will be defined by the National Center and made available to all universities desiring to offer a GIS program as noted in the next section. A preliminary outline is presented below.

One-Year Basic Program in Geographic Information Systems

Prerequisites:

Introductory course in physical geography
Introductory course in human geography
Introductory cartography
Introductory statistics
One computer programming course - (any high-level language)

(Or equivalent requirements from an engineering curriculum)

A. THEORY AND TECHNIQUES

1. History and Development of Geographic Information Systems and Spatial Analysis

2. Concepts of Geographic Information and Analysis

   2.1 GIA Fundamentals
      2.1.1 Geodesy and Surveying
      2.1.2 Models and Spatial Statistics
      2.1.3 Spatial Cognition

   2.2 Applications of GIA and Related Systems
      2.2.1 Cadastral Systems
      2.2.2 Local Government Systems
      2.2.3 Land and Resource Systems
      2.2.4 Automated Mapping / Facilities Management
      2.2.5 Socio-Economic Systems (i.e., census)

3. Functions and Operations of GIS

   3.1 Physical Components of a GIS (data, hardware, software, etc.)

   3.2 Functions of a GIS (input procedures, data management, analysis and modeling, output)

   3.3 Data Issues for GIA/GIS

      3.3.1 Spatial Data (entities, relationships, attributes)

- 3.3.2 Representation of Spatial Data on Maps
- 3.3.3 Reliability of Data
- 3.3.4 Data Sources
  - 3.3.4.1 Surveys
  - 3.3.4.2 Digital Cartographic Data
  - 3.3.4.3 Censuses and Economic Statistics
  - 3.3.4.4 Remotely Sensed Data
  - 3.3.4.5 Administrative Records

4. Related Systems and Techniques

- 4.1 CAD/CAM
- 4.2 Image Processing
- 4.3 Digital Cartography
- 4.4 Artificial Intelligence

5. Major Geographic Information Systems

- 5.1 Commercial Systems (ARC/INFO, SYSTEM9, SYNERCOM, INTERGRAPH, GFIS, etc.)
- 5.2 Large Government Systems (CGIS, TIGER, etc.)

6. Selected Applications (case studies)

- 6.1 U. S. Forest Service
- 6.2 Major Urban Examples
- 6.3 Commercial Applications (e.g., utility companies)
- 6.4 Soil Loss and Hydrological Modeling
- 6.5 Hazardous Waste Management
- 6.6 Environmental Change
- 6.7 Others as Appropriate

7. Laboratory Exercises

- 7.1 Representation of Spatial Data
- 7.2 Major GIS Functions
- 7.3 Simple Spatial Analysis Problems Using GIS

B. TECHNICAL ISSUES AND FUNCTIONS IN GIA

1. Data Input Issues
   - 1.1 Digitizing/scanning
     - 1.1.1 Accuracy/reliability
     - 1.1.2 Data Volumes
   - 1.2 Remote Sensing
   - 1.3 Photogrammetry
   - 1.4 Global Partitioning System Technology
   - 1.5 Basic Data Input Algorithms

2. Database Structure and Management Issues
   - 2.1 Object-oriented Data Organization
   - 2.2 Space-occupying Data Organization
   - 2.3 Raster vs. Vector

- 2.4 Quadtree Organization
- 2.5 Efficiency Issues
  - 2.5.1 Data Compaction
  - 2.5.2 Data Retrieval
- 2.6 Error Analysis
- 2.7 Basic Algorithms for Data Management
- 2.8 Database Design Techniques
- 2.9 Principles of Database Management Systems

3. Modeling and Analytical Issues
   - 3.1 Basic Spatial Data Handling Techniques (Algorithmic Issues)
   - 3.2 Spatial Statistics
   - 3.3 Functionality (urban, transport, resource management, location/allocation, network, optimization, terrain)

4. Output Issues
   - 4.1 Visualization
   - 4.2 Computer Graphics
   - 4.3 Computer Cartography
   - 4.4 Image Enhancement

5. Laboratory Exercises
   - 5.1 Database Design Exercises
   - 5.2 Spatial Data Handling Programming Project
   - 5.3 Development of Analysis Models
   - 5.4 Data Analysis Exercises
   - 5.5 Graphics Exercises

C. APPLICATIONS IN GIA AND GIS DEVELOPMENT

1. Use of GIA and GIS
   - 1.1 Simple Query and Display
   - 1.2 Analysis and Modeling
   - 1.3 Decision Support and Monitoring

2. Introduction to System Planning, Design and Implementation Consideration
   - 2.1 Applicable Software Engineering Concepts
   - 2.2 System Life Cycle Concepts
   - 2.3 Requirements Analysis
   - 2.4 System Design Models
   - 2.5 Implementation Plans (staff, schedules, etc.)

3. Evaluation Issues
   - 3.1 Benefit Assessment
   - 3.2 System Costs
   - 3.3 System Evaluation and Monitoring (QA/QC)

4. Introduction to Organizational Issues
   - 4.1 Database Management
   - 4.2 Networking / Distributed Processing
   - 4.3 Personnel

5. Legal, Social, and Economic Issues

5.1 Privacy/Access
5.2 Accuracy/Liability
5.3 Economic Cost/Benefit

6. Laboratory Exercises
   6.1 System Design Project
   6.2 System Evaluation Study

The National Center will develop and make available all supporting materials (reading lists, hardware and software catalogs, instructional datasets, etc.) needed to offer these courses.

2.3. GIA-Related Courses at the Three Centers

The following table presents the courses actually in place at the three institutions and courses that are being and will be developed in the context of NCGIA goals. The X's indicate an existing course while the O's represent a planned course. This list is not meant to be all-inclusive or exclusive: rather, it exemplifies the types of courses we will offer on a regular basis to the students at the three institutions.

Undergraduate and Graduate Courses and Locations Offered

Course Title	UCSB	UB	UM
Introductory GIS Course Sequence:			
Introduction to GIS	X	X	O
Technical Issues of GIS (Algorithms and Data Structures)	O	X	X
Applied Issues in GIS	O	X	O
Intermediate and Advanced GIS Courses:			
GIS Design and Development	O	X	O
Cognitive Science and AI Approaches to GIS	O	O	O
Analytical Modeling and Decision Theory in a GIS Context	O	O	
Visualization Issues in GIS Development	O	O	
Seminar in GIS	X	X	
Interactive Query Languages			X
Geometry and Computer Graphics for GIS			X
Spatial Analysis Courses:			
Spatial Analysis	X		
Advanced Quantitative Methods	X	X	X
Advanced Spatial Statistics	X	X	
Urban Geography	X	X	
Landuse Analysis		X	
Uncertainty and Spatial Decision Making	X		O
Regional Analysis	X	X	
Consumer Spatial Behavior	X		
Optimization Models	X		
Nonlinear Systems and Geographic Analysis	X		

Multidimensional Analysis of Spatial Problems	X		
Technique Courses:			
Computer Cartography	X	X	X
Analytical Cartography	X	X	X
Introductory Remote Sensing	X	X	X
Digital Elevation Models		X	O
Intermediate Digital Remote Sensing	X		
Advanced Digital Remote Sensing	X		
Remote Sensing Software	X		
Seminar in Remote Sensing	X		
Satellite Survey Techniques			X
Software Engineering for GIS			X
Geodesy			X
Cadastral Systems			X
Analytical Photogrammetry			X
Engineering Databases and Info. Systems			X
Remote Sensing Hardware	X		
Cartographic Transformations	X	O	
Seminar in Cartography		X	
Applied Courses:			
Survey Engineering			X
Environmental Law and Resource Regulation			X
Land Development and Design			X
Transport Systems Analysis	X	X	
Spatial Decision Making	X	O	
Geography in Planning and Policy Making	X	O	
Water Resource Planning & Management	X		
Locational and Environmental Issues in Planning	X		

2.4. Educational Program at Santa Barbara

Course offerings at UCSB are given in the appendix, and course titles are listed in the preceding table. These courses are all at the junior, senior, or graduate levels. UCSB is on the quarter system: an academic year is composed of three ten-week instructional sessions.

GIS courses: Inspection of this table shows that in addition to moving to a one-year introductory sequence in GIS, it will be necessary to add both intermediate and advanced GIS courses over the next three years to build a strong undergraduate and graduate teaching sequence. The recent appointment of Michael Goodchild, the return of Terence Smith to fifty percent time in geography, the decision by Jack Estes to teach at least one course in the introductory sequence, and the new appointments to be made in 1988 and subsequently will bring significant depth to the GIS offerings.

Spatial analysis: A significant range of spatial analysis courses is already in place. Most are offered in alternate years, except for advanced courses in quantitative methods, which are offered annually.

Techniques courses: These deal mainly with digital and analytical cartography, plus five courses in aspects of remote sensing digital image analysis. Many are offered annually, some in alternate years.

Applied courses: There are five applied courses, with a strong spatial analysis content, usually offered in alternate years. UCSB has a sizable group of master's and Ph.D. students in place, already working on GIA/GIS topics. The students and their topics are listed in Appendix D, as are the titles of completed master's theses and Ph.D. dissertations.

2.5. Educational Program at Buffalo

The State University of New York at Buffalo teaches on a semester system in which the academic year consists of two semesters, each of 15 weeks' duration. The Department of Geography offers both undergraduate and graduate degrees with a specialization in geographic information systems and computer cartography. One of the four major program areas, the GIS / computer cartography program was begun in 1973 with the establishment of the first fully equipped geographic information systems laboratory in a geography department in the United States. Buffalo has graduated a large number of undergraduates and graduates (M.A. and Ph.D) in geographic information systems and computer cartography. Students have found employment with industry, government, and academic institutions.

The program of studies for both undergraduate and graduate students has recently been substantially revised. Basic core materials for both GIS and computer cartography are presented in a two-course sequence (30 weeks) required of all students. This sequence leads to an undergraduate Certificate in Cartography of 24 semester hours; or a Certificate in Cartography/GIS with two courses each in computer science, mathematics, and statistics also required. The core of the certificate includes introductory courses in map and air photo use, cartography, computer mapping, and GIS. Students then follow their own particular interests by selecting from a set of six intermediate-level courses. Advanced courses, offered as special topics seminars, provide greater depth for Ph.D. students and for M.A. students who choose to spend extra time in the program. Master's students must complete a research project (thesis-like paper) and Ph.D. students prepare traditional dissertations. Appendix D lists M.A. research papers and Ph.D. dissertations completed and in progress at SUNY-Buffalo.

Senior undergraduate courses are cross-listed with beginning graduate courses. The core curriculum presented in section 2.2 is taught in two parallel fall semester courses: Introduction to Computer Mapping and Introduction to GIS. These are followed by two second-semester courses in GIS (Algorithms and Data Structures, Applications) and two others in cartography. The GIS and cartography sequences are now undergoing revision and these changed courses will be an input to the development and implementation of the year-long sequence at UCSB, 1988-89.

2.6. Educational Program at Maine

The Surveying Engineering Program at the University of Maine offers an introductory semester course at the sophomore level for students both inside and outside the program. This course promotes interest in and provides the foundation for higher-level courses covering both the theoretical and applied aspects of spatial information systems. The introductory course is designed to acquaint students with basic geographical principles, reasoning about spatial information, and the institutional contexts in which spatial information is collected, managed, and used. The higher level course sequence builds on the introductory material and allows two different foci: theory and applications. The program is designed to produce graduates with a sound training in GIS who they can readily fill entry-level positions in the public or private sectors or continue on with graduate studies. Such a program will also serve as a model for the NCGIA core sequence. The program's introductory course will then use the material from the NCGIA core curriculum, but the presentation will be shorter, more applied, and less in-depth. In the theory stream the program offers a course on geographic information systems and spatial databases and a second course dealing with geometry and computer graphics. A set of class notes for these two courses is in preparation and will be published in 1988. These class notes will be employed in helping to design and implement the year-long sequence at UCSB in 1988-89.

3. Faculty Short Courses

The primary purpose of faculty short courses will be to train existing faculty to teach the introductory GIS sequence, selected advanced GIS topics, and applications in several disciplines. In the summers of 1990 and subsequent years, we will present two-week summer courses (one each year) covering the teaching of the basic GIS sequence (not unlike the High School Geography Workshops sponsored by the National Geographic Society). The audience for these two courses will likely be those faculty who now teach selected aspects of GIS in the context of other courses, e.g., cartography. One criterion for the selection of participants will be a commitment from the participant's university to offer the full year sequence in GIS and to make the required investments in hardware and software.

Participants of these short courses would form the core of an academic education interest group in the teaching of GIA/GIS. This group would be formally organized to facilitate distribution of new and additional materials and to foster the exchange of ideas and experiences as each GIS program grows. After the first year, the educators interest group could, if desirable, hold separate meetings on the subject of GIS education, possibly in conjunction with other professional association specialty groups.

4. Research Opportunities for Graduate Students

NCGIA graduate programs will be both thesis and non-thesis track; the non-thesis track will be strongly oriented towards coursework and hands-on training with GIA/GIS hardware and software with the goal of rapidly augmenting the number of professionally trained people available to fill the needs of the public and private sectors. The thesis track program will include core courses and an independent research project. Each NCGIA institution will offer specialized graduate courses as listed in the above table.

Graduate fellowships will be made available to both thesis and non-thesis track graduate students in the form of fellowships, research assistantships, tuition waivers, and stipends. These will be funded by NCGIA and the individual institutions. In addition, NCGIA will facilitate the award of graduate fellowships sponsored by industry and professional organizations to students doing applied research. This program would include summer internships, cooperative programs, and the possibility of employment after graduation.

Advanced students will be able to work within the individual research initiatives carried out under NCGIA sponsorship. This research experience will give the candidates specialized backgrounds enabling them to develop as top-level professionals or academics. Financial assistance for these advanced students would be available from NCGIA, their respective institutions, and outside organizations. These students will work closely with senior NCGIA researchers and will participate in generating extramural funding to increase the amount of research funds available to NCGIA.

The advanced program for Ph.D. candidates will require a richer and wider training not only in GIA but in cognate areas in mathematics, statistics, economics, management, cognitive science, computer science, and remote sensing. The Ph.D. program will concentrate additional coursework beyond the Master's degree in the third year and involve further research in the second to third subsequent years, aiming at a five-to six-year combined master's and Ph.D. program. Upon graduation, the student may enter the applied field, continue research as a postdoctoral scholar, or move directly to a faculty appointment at another institution. In this manner, the research at NCGIA will be disseminated into the academic community.

5. Support for Junior Faculty and Postdoctoral Scholars

Scholars considered for NCGIA appointments in this category would include Ph.D.'s with strong training in geography, urban and regional planning, natural resource planning, urban economics, geodetic sciences, geology, civil engineering, computer sciences, management, artificial intelligence, statistics, remote sensing, or analytical modeling. Not all fields have a tradition of postdoctoral study, so NCGIA will actively seek junior faculty with appointments at other institutions. These will include young scholars who will be able to disseminate NCGIA knowledge to the widest audience in the shortest amount of time as a result of their training. Those with a strong background could complete training in a year, but most would need two years. Visiting scholars would be expected to take courses as well as participate in specialized research teams where they would work directly with NCGIA faculty and advanced graduate students.

Upcoming research themes will be publicized nationally on an annual basis so that junior faculty at other institutions would have sufficient advance notice to arrange spending their sabbatical leave at NCGIA.

Funding for junior faculty members could be shared equally by NCGIA and the member's sponsoring institution. The first half of the training period would be paid for by the institution and the second half by NCGIA, thus ensuring a concrete commitment to the program by the other institution. Sabbatical leave and other support would be expected from the home institution. Funding for unaffiliated postdoctoral fellows would be covered by NCGIA and supplemental extramural sources.

6. Senior Visiting Research Faculty and Training and Retraining of Less Experienced Senior Faculty

In addition to participating in special research teams investigating specific topics, experienced senior visiting faculty may also participate in the educational program by attending NCGIA advanced courses, or in some instances by offering specialized courses of their own. Faculty members who have advanced to a tenured professorial position typically are eligible for an academic year sabbatical (9 months), usually at one-half to two-thirds salary. As funding allows, NCGIA would increase this to full salary for a one-year residence. If the sponsoring institution increases this to full salary, NCGIA would, as finances allow, fund an entire second year. Faculty would engage in coursework, research, and publication.

7. Professional Short Courses

The training objective for industry and government personnel as well as academics will be aimed at disseminating information on research results, existing GISs, applications, datasets, development procedures, and other topics. Senior faculty, staff, and advanced Ph.D. students from NCGIA will offer summer workshops for industry, government, and academic personnel at convenient locations in major cities such as Washington, D.C., Boston, New York, Denver, Chicago, St. Louis, Houston, Atlanta, Los Angeles and San Francisco. Workshop formats will vary as needed in duration, level of difficulty, and emphasis. After the initial set of workshops, consortium members will focus their retraining efforts on academic personnel capable and interested in conducting their own retraining programs for others. In this manner, we will achieve a multiplier effect by assisting others to conduct short courses, especially introductory ones.

7.1. On-Campus Activities

NCGIA's short courses, seminars, and workshops will be designed to impact every level of the GIA community, from entry level to advanced. NCGIA will offer a full range of programs at the member institutions. These courses will be taught by NCGIA faculty and staff using the local facilities. Fees will vary according to content and audience (i.e. academic, private sector, federal agency, etc.).

Initial courses will be offered in conjunction with the faculty retraining program and various parts of the core GIS sequence. Sample topics would include:

- Systems analysis and planning for a GIS
- GIS database design
- GIS as a decision support system
- GIS and specific applications
- Purchasing and implementing a GIS
- Institutional change and GIS

Workshops held at the three member institutions will be able to utilize the full range of NCGIA hardware and software. However, the aim of NCGIA will be not to train technicians on the use of a specific system (a task better left to vendors), but rather to educate users at all levels on the basics of GIA theory and applications.

7.2. Off-Campus Activities

In addition to on-campus educational activities, NCGIA will offer external courses to the GIA community, again involving all levels of expertise and the widest possible audience. These workshops will be designed to be hardware-independent and will range in length from one day to a week. The courses will be taught by NCGIA staff and will incorporate the latest results from relevant NCGIA Research Initiatives.

This program will be run on a profit-making basis with fees in the range of a few hundred dollars per day and will allow for discounts to bonafide academics and students. Courses will be offered in major metropolitan areas and in other places where we see a demand, such as sites of large industries or federal agencies, and could be held at hotel meeting rooms or universities if appropriate. We plan to cooperate in this activity with university extension service organizers of such technical workshops in each institution. In this way, NCGIA training can be dispersed to the widest possible audience.

8. Outreach to High Schools

Each institution in the consortium will work with its campus Graduate School or Faculties of Education and with local county and city superintendents of education to establish simplified GIA/GIS courses in the local high schools. Such courses could use county and state statistical digital databases, and would compare to those developed recently for the Domesday project in the United Kingdom. Jointly, the NCGIA, local CGIAs, the Graduate Schools and Faculties of Education, and local education districts will solicit funding from appropriate agencies to develop, install, and test such programs in local high schools. This effort may be fruitfully combined with the High School Geography Workshops sponsored by the National Geographic Society, and eventually expand into a nationwide program.

9. Workshops at Professional Meetings

NCGIA will initiate workshops at meetings of professional societies on the teaching of GIA/GIS. Initially, these workshops will be held at the societies most directly related to the NCGIA initiative (NCGE, AAG, ASPRS, ACSM, URISA, AM/FM. As experience is gained and additional founding is received, such workshops will be offered with appropriate models at other society meetings in the social, natural, and applied and engineering sciences. Indeed, consortium members are already participating in activities such as the symposium on the use of GIS in biology and ecology to take place at the joint AIBS/ASE meetings in the summer of 1988.

10. Outreach to Regional Universities

It is intended that the consortium universities will make a special effort to outreach to regional universities and colleges within a reasonable distance for cooperation. In the earlier diagram in the introduction to the Educational Plan, we showed this for California as an example. In the tables on the following three pages, we extend this to show the larger institutions in terms of undergraduate and Masters enrollments within the range of the consortium sites.

MAJOR PH.D. GRANTING GEOGRAPHY DEPARTMENTS IN THE U.S.

Sorted numerically by number of undergraduate students using Schwendeman's figures, *and grouped into Institutions lying within an acceptable co-operation distance of UCSB and SUNY-Buffalo.*

ST	INSTITUTION	UNDERGRAD Schw	UNDERGRAD AAG	MASTERS Schw	MASTERS AAG	PhD Schw	PhD AAG
	University of California at Santa Barbara						
CO	Univ of Colorado	300	260	40	36	40	34
CA	UC Santa Barbara *	250	120	40	34	25	20
CA	UC Los Angeles	169	178	41	31	22	18
UT	Univ of Utah	152	173	21	18	13	11
AZ	Arizona State	126	95	16	18	16	12
CA	UC Berkeley	120	120	32	25	36	23
OR	Oregon St Univ	85	90	48	49	13	12
OR	Univ of Oregon	75	68	14	11	9	17
AZ	U of Arizona, Tucson	57	64	16	43	12	11
HI	Univ of Hawaii	57	50	56	57	32	28
CA	UC Davis	40	10	8	4	7	
CA	UC Riverside	14	14	17	19	13	13
	State University of New York at Buffalo						
PA	Penn State Univ	145	109	34	34	11	11
MN	Univ of Minnesota	115	135	46	29	36	25
WI	U of Wisc, Madison	107	114	56	40	26	28
NY	SUNY-Buffalo *	82	73	55	38	18	13
MA	Clark University	80	59				56
MD	Univ of Maryland	75	154	46	22	24	8
NJ	Rutgers University	61	55	30	22	15	13
OH	Ohio State Univ	60	59	23	24	25	16
DE	Univ of Delaware	50		15	7	8	8
OH	Kent State Univ	43	32	20	10	22	15
NY	Syracuse University	24	33	20	13	17	16
OH	Univ of Cincinnati	24	22	15	5	21	13
NY	Columbia University	8		5		37	
MD	Johns Hopkins	7			11	22	48
MA	Boston University		20		10		15
	Southeast						
FL	U of Florida	91	81	20	15	10	5
GA	Univ of Georgia	60	84	42	28	12	13
SC	U of S. Carolina	55	48	40	31	9	6
TN	U of Tenn, Knoxville	45	77	16	14	13	10
KY	Univ of Kentucky	40	60	18	12	14	12
NC	U of NC, Chapel Hill	28	51	14	23	10	9
LA	Louisiana St U.	21	31	21	33	22	25
	Upper midwest						
IA	Univ of Iowa	69	63	7	9	36	28
IL	U of Illinois-Urbana	36	37	25	21	14	16
WI	U of Wisc, Milwaukee	36	24	29	30	22	
MI	Michigan State	30	28	20	20	13	16
NE	U of Nebraska, Lincoln	30	95	18	9	14	7
IN	Indiana University	26	28	12	12	21	18
IL	Univ of Chicago	25	10	11	10	22	14
IN	Indiana State Univ	21	56	30	28	13	8
IL	Northwestern Univ	12	10	2		2	2
	Lower midwest						
TX	U of Texas, Austin	73	66	22	21	15	8
TX	Texas A&M Univ	70	70	18	17	11	8
KS	Univ of Kansas	51		38	24	27	22
OK	Univ of Oklahoma	36	32	11	12	14	13
	Western institutions						
CO	U of N. Colorado	30		5			3
CO	Univ of Denver	15	16	10	5	4	2
WA	U of Wash. Seattle		147		34		25
	** 1987/88 figures from departmental records:*						
	UC Santa Barbara	*146*		*30*		*41*	
	SUNY-Buffalo	*91*		*68*		*18*	
	U. Maine	*60*		*20*		*5*	
	Total	*297*		*118*		*61*	

Schw = Schwendeman's Directory of College Geography (figures from various dates between 1984 and 1986)

AAG = Guide to Graduate Departments of Geography, 1986 - 1987; published by the Association of American Geographers.

MAJOR PH.D. GRANTING GEOGRAPHY DEPARTMENTS IN THE U.S.

Sorted numerically by number of Masters students, *and grouped into Institutions lying within an acceptable co-operation distance of one of the three Consortium Institutions.*

ST	INSTITUTION	UNDERGRAD Schw	UNDERGRAD AAG	MASTERS Schw	MASTERS AAG	PhD Schw	PhD AAG
	University of California at Santa Barbara						
HI	Univ of Hawaii	57	50	56	57	32	28
OR	Oregon St Univ	85	90	48	49	13	12
CA	UC Los Angeles	169	178	41	31	22	18
CA	UC Santa Barbara *	250	120	40	34	25	20
CO	Univ of Colorado	300	260	40	36	40	34
CA	UC Berkeley	120	120	32	25	36	23
UT	Univ of Utah	152	173	21	18	13	11
CA	UC Riverside	14	14	17	19	13	13
AZ	Arizona State	126	95	16	18	16	12
AZ	U of Arizona, Tucson	57	64	16	43	12	11
OR	Univ of Oregon	75	68	14	11	9	17
CA	UC Davis	40		10	8	4	7
	State University of New York at Buffalo						
WI	U of Wisc, Madison	107	114	56	40	26	28
NY	SUNY-Buffalo *	82	73	55	38	18	13
MD	Univ of Maryland	75	154	46	22	24	8
MN	Univ of Minnesota	115	135	46	29	36	25
PA	Penn State Univ	145	109	34	34	11	11
NJ	Rutgers University	61	55	30	22	15	13
OH	Ohio State Univ	60	59	23	24	25	16
OH	Kent State Univ	43	32	20	10	22	15
NY	Syracuse University	24	33	20	13	17	16
OH	Univ of Cincinnati	24	22	15	5	21	13
DE	Univ of Delaware	50		15	7	8	8
NY	Columbia University	8		5		37	
MA	Boston University		20		10		15
MA	Clark University	80	59			56	45
MD	Johns Hopkins	7			11	22	48
	Southeast						
GA	Univ of Georgia	60	84	42	28	12	13
SC	U of S. Carolina	55	48	40	31	9	6
LA	Louisiana St U.	21	31	21	33	22	25
FL	U of Florida	91	81	20	15	10	5
KY	Univ of Kentucky	40	60	18	12	14	12
TN	U of Tenn, Knoxville	45	77	16	14	13	10
NC	U of NC, Chapel Hill	28	51	14	23	10	9
	Upper midwest						
IN	Indiana State Univ	21	56	30	28	13	8
IL	U of Illinois-Urbana	36	37	25	21	14	16
WI	U of Wisc, Milwaukee	36		24	29	30	22
MI	Michigan State	30	28	20	20	13	16
NE	U of Nebraska, Lincoln	30	95	18	9	14	7
IN	Indiana University	26	28	12	12	21	18
IL	Univ of Chicago	25	10	11	10	22	14
IA	Univ of Iowa	69	.63	7	9	36	28
IL	Northwestern Univ	12	10	2		2	2
	Lower midwest						
KS	Univ of Kansas	51		38	24	27	22
TX	U of Texas, Austin	73	66	22	21	15	8
TX	Texas A&M Univ	70	70	18	17	11	8
OK	Univ of Oklahoma	36	32	11	12	14	13
	Western institutions						
CO	Univ of Denver	15	16	10	5	4	2
CO	U of N. Colorado	30		5		3	
WA	U of Wash, Seattle		147		34		25
	** 1987/88 figures from departmental records:*						
	UC Santa Barbara	*146*		*80*		*41*	
	SUNY-Buffalo	*91*		*68*		*18*	
	U. Maine	*60*		*20*		*5*	
	Total	*297*		*118*		*61*	

Schw = Schwendeman's Directory of College Geography (figures from various dates between 1984 and 1986)

AAG = Guide to Graduate Departments of Geography, 1986 - 1987; published by the Association of American Geographers.

MAJOR UNDERGRADUATE (NON-PHD GRANTING) GEOGRAPHY DEPARTMENTS IN THE U.S.

Sorted numerically by number of undergraduate students using Schwendeman's figures, *and grouped into Institutions lying within an acceptable co-operation distance of one of the three Consortium Institutions.*

ST	INSTITUTION	UNDERGRAD Schw	UNDERGRAD AAG	MASTERS Schw	MASTERS AAG
	University of California at Santa Barbara				
TX	Southwest Texas St Univ	341	341	42	28
UT	Brigham Young Univ	277	271	25	18
CA	San Diego State	152	173	60	38
CA	Cal State, Chico	114	90	14	10
CA	Cal State, Northridge	108	107	34	35
CA	San Francisco State	90	95	25	30
CA	Cal State, Sacramento	85	60		
AZ	N. Arizona Univ	73	85	16	18
CA	Cal State, Fresno	67	78	12	14
CA	Humboldt State University	60	78		
CA	Cal State, Fullerton		102		18
NM	New Mexico State		100		25
	State University of New York at Buffalo				
MI	Central Michigan Univ	198	121		
MI	Western Michigan Univ	163	151	17	10
MI	Northern Michigan Univ	140	115		
NY	US Military Academy	121	198		
MD	Frostburg State College	117	115		
PA	Shippensburg Univ	110	108	15	10
MD	Towson State Univ	80	26	60	3
MD	Salisbury State College	60			
PA	Indiana Univ of PA	57	55	18	15
NY	State U College, Geneseo	55	60		
VA	Virginia Polytech Inst	55	65	15	
	The University of Maine				
MA	Salem State College	237	270	2	
NH	Plymouth State College	70			
NH	Dartmouth College	60	63		
MA	Univ of Massachusetts	49	32	16	19
	Southeast				
FL	U of South Florida	123	125	11	20
NC	U of NC at Charlotte	107	103	20	17
NC	East Carolina Univ	103	96	13	9
KY	Western Kentucky Univ	80	85	10	22
VA	Mary Washington College	66	63		
VA	James Madison Univ	58			
NC	Appalachian St. Univ	55	54	16	7
MS	U of S. Mississippi	55	55	19	18
	Upper midwest				
IL	Northeastern IL Univ	122	90	65	63
IL	Northern IL Univ	110	128	23	11
ND	U of North Dakota	86	125	22	23
SD	South Dakota State Univ	75	75	29	16
WI	U of Wisc, Eau Claire	65	62		
MN	Bemidji State Univ	60	41	3	
IL	Illinois State Univ	56	61		
OH	Ohio University	52	55	17	16
WI	U of Wisc, Oshkosh	52	57		
WI	U of Wisc, La Crosse	50	55		
	Lower midwest				
NE	U of Nebraska, Omaha	92	120	22	19
MO	Southwest Missouri St	85	154	25	16
OK	Oklahoma State Univ	50	59	14	19
	Western institutions				
OR	Portland State Univ	72	83	19	14
WA	Western Washington Univ	60	60	11	5
	** 1987/88 figures from departmental records:*				
	UC Santa Barbara	*146*		*30*	*41*
	SUNY-Buffalo	*91*		*68*	*18*
	U. Maine	*60*		*20*	*5*
	Total	*297*		*118*	*61*

Schw = Schwendeman's Directory of College Geography (figures from various dates between 1984 and 1986)

AAG = Guide to Graduate Departments of Geography, 1986 - 1987; published by the Association of American Geographers.

IV
COGNATE RESEARCH UNITS AND FACILITIES FOR THE CENTER

Since the proposed NCGIA will maintain operations on three different campuses, each campus will be discussed separately with regard to their respective cognate research units and facilities and equipment resources. Each of the three Universities has promised to allocate a sizable amount of space for center activities. Together, facilities at the three locations will make up a substantial operation from the outset. Over the next several years the Center will acquire roughly 10,000 assignable square feet of new space dedicated to the National Center, with expansion to 15,000 square feet by year three.

1. Cognate Research Units at the Three Universities

1.1. University of California, Santa Barbara

1.1.1. Remote Sensing Research Unit (RSRU)

The Remote Sensing Research Unit is an autonomous research entity within the Geography Department. Recognized by the National Aeronautics and Space Administration as a Center of Excellence in Remote Sensing Information Sciences, RSRU emphasizes investigations directed at spatial data processing in an information systems context. Established in the mid-1970's, RSRU currently has an annual budget of approximately $750,000, and a staff of 18, including graduate student research assistants. Most research projects in the last five years have involved both theoretical developments in and applications of geographic information systems.

Much of the research program in RSRU is based on the natural interplay between the technology of remote sensing, and the tools and models of geographic information systems. In a very real sense, the maximum utility of remotely sensed data can only be realized when this data is combined with other data forms (including multi-temporal observations, site specific biogeographical and biochemical knowledge, topographic and physiographic: information, and so on) in a geographic information system. At the same time, since the value of a GIS is fundamentally tied to the completeness and currency of the underlying data, remote sensing technology is a vital component of a modern spatial data processing environment. This viewpoint guides our research.

RSRU has a substantial history of involvement with geographic information systems. Several current projects are of particular relevance to the goals of the NCGIA. A project currently funded by the Regione del Veneto, an administrative unit in northern Italy, has the goal of developing algorithms for crop yield modeling, based on site-specific observations in conjunction with multi-temporal remotely sensed datasets, and then developing a geographic information system for the Regione which will permit these models to be implemented in an operational environment.

Another effort, funded by the U.S. Geological Survey, NASA, and Digital Equipment Corp. and undertaken jointly with T. R. Smith, is the development of KBGIS, a new GIS based on modern principles of data structures and artificial intelligence. A new project funded by NASA is to examine the kind of user interface required between users of spatial data and remote digital repositories of these data.

1.1.2. Computer Systems Laboratory: Center for Remote Sensing and Environmental Optics

The CSL Center for Remote Sensing and Environmental Optics is a center of excellence for the quantitative use of satellite imagery and associated image processing in all areas of earth science. It emphasizes research in remote sensing and optical properties of water, snow, vegetation, and the atmosphere, which depends on computers and photoecology, optical variability and bioluminescence in the sea, electromagnetic and chemical properties of snow, and hydrologic and surface climate modeling. The laboratory also develops software systems for machine processing of remotely sensed data from satellites and aircraft.

Research in the Center has as its rationale the recent advances in satellite technology which have provided fundamental new understanding and given new directions to earth science. For example, three satellites for ocean science and corresponding international global scientific programs are planned for the next decade. The satellites include: NROSS scatterometter, to determine wind stress, which is the major driving force for ocean currents; TOPEX altimeter, to determine ocean currents; and Ocean Color Images, to determine global distributions of phytoplankton biomass.

For snow and ice, the CSL Center for Remote Sensing and Environmental Optics, through the combination of its expertise in remote sensing and optical properties of snow and ice, is uniquely placed to make substantive contributions in these areas. By the 1990's there will be an increase of several orders-of-magnitude in the volume of remote sensing data relevant to the snow and ice community. This will come about through the DMSP and NOAA operational satellite collecting higher resolution passive microwave data, through ESA's ERS-1 satellite which will carry a SAR system and s radar altimeter, and through the complement of instruments on the Earth Observing System (EOS) to be launched in the mid-1990's. These systems will collect very high resolution data on snow cover and its characteristics, land and sea ice, glacier characteristics, and on ice sheet elevation.

1.1.3. UCSB University Library: Map and Imagery Laboratory

The Map and Imagery Laboratory was housed in the University Library to promote the interdisciplinary use of cartographic and remote sensing materials. The 11,000 square foot facility was custom-designed to facilitate the use of analog and digital imagery and maps in conjunction with specialized laboratory equipment. The 100,000,000 collection contains more than 3,100,000 images, 320,000 maps and 4,000 atlases and gazetteers, making it the largest of its kind in any United States academic library.

Since its opening in 1979, the Laboratory, a unique public research facility, has become the focus of regional and national academic seminars, research, and symposia on topics ranging from anthropology to marine science, geology to plant ecology. The Laboratory is a keystone of agricultural, ecological, geographical, geological, oceanographic and historical research and plays an important role in studies related to the management and assessment of earth resources.

The Map and Imagery Laboratory is the California State Affiliate for the U.S. Geological Survey's National Cartographic Information Center. It serves the academic and research needs of faculty and State College systems, local and national business and industry, federal and state government agencies, as well as other domestic and foreign educational institutions, agencies, and researchers.

The Imagery Collection contains photographic formats ranging from standard black and white prints to color infrared and radar transparencies. Coverage in these formats concentrates on California. Several of the special collections are:

- *Multispectral Landsat I and II original transparencies* covering most of the earth's surface from 1972-1978.
- *Johnson Space Center's AgRISTARS and LACIE* original research and presentation materials;
- *Mark Hurd Aerial Survey's Santa Barbara Sales Library* of large scale photographs of California's central coast counties.

Enhancing the imagery collection are the micro-browse file copies of one band, worldwide Landsat I-V, hard copy and microfiche catalogs of satellite imagery available from foreign Landsat receiving stations, 16 mm copies of NASA photography of the United States, microindexes and database listing of imagery produced by major federal agencies, and direct online access to EOSAT's and EROS Data Center's imagery databases.

The *Map Collection* provides cartographic materials covering the world's land and ocean areas at any scale. The subject emphases of this collection are the physical and biological sciences, topography, oceanography, land use, environmental conditions, urban planning, and resource development.

In the *Remote Sensing/Cartographic Laboratory*, researchers are provided with state-of-the-art equipment needed to maximize the utility of the remote sensing and cartographic collections. On the whole, the Map and Imagery Laboratory maintains a variety of specialized facilities, the most important of which are described below in the corresponding section on equipment.

1.1.4. Institute For Crustal Studies (ICS)

The Institute for Crustal Studies was recently formed at UCSB to study the earth's crust and lithosphere. Several universities (University of Southern California, California Institute of Technology, University of California at Berkeley, San Diego State University, and California State University at Los Angeles), the U. S. Geological Survey, and private industry are associated with ICS through CALCRUST, a group doing deep seismic profiling in the Southwest.

UCSB earthquake researchers are currently using spatial analysis to analyze the pattern of microseisms along a segment of the San Andreas Fault, create a geological map of the Tehachapi Mountains using ultrasound, correlate seismic reflection data with deep crust sediment samples, and assess type of surface. On another front, a Santa Barbara hydrologist is studying how toxic water travels through the crust into the water table, in order to discover how to control the flow of hazardous chemicals into the water supply. ICS projects are interdisciplinary, bringing together researchers in remote sensing, seismology, materials science, plate tectonics, scientific drilling, toxic waste disposal, and computing, as well as the various areas of geology, geography, physics, materials, mechanical engineering, biological sciences, and mathematics.

The expanded GIA/GIS capability at UCSB under the auspices of the NSF Center will be of value to ICS researchers. The Director has engaged in one study recently using GIS capability in geologic analysis, and anticipates that ICS studies will use GIS equipment in the Center or in the Geology Department, when the latter is added to the campus ethernet and a suitable workstation is available.

1.1.5. Marine Science Institute (MSI)

Research projects in the Marine Science Institute involve faculty, graduate students, and professional researchers from twelve disciplines. Although much of the research lies along the California coast, projects are also underway in many of the world's oceans, in cooperation with off-campus researchers.

Spatial analysis is important for present studies on hydrothermal vent communities along the deep-sea rifts; on the Pacific Rim geopolitical dynamics of fishery resources, ocean mining, the disposal of radioactive nuclear wastes; and on the development of models to predict size and composition of coral populations. Researchers have also studied storm effects on geographically distributed subtidal reef communities; the behavior and modeling of trace element in high temperature hydrothermal systems and hydrothermal effluent plumes at oceanic spreading centers; spatial and temporal distributions and interactions between chemistry and biology in hydrothermal systems; and element transport in the ocean. Satellite imagery and aerial photographs are being used to measure and analyze spatial and temporal variability and mixing patterns of nutrient ions in the Amazon Basin. One project is evaluating the ability of shuttle radar imagery for floodplain assessment. Another is developing and applying a computer generated bio-optical profiling system to MSI research programs such as the study of seasonal ocean convection and restratification.

1.1.6. Community and Organization Research Institute (CORI)

The Community and Organization Research Institute conducts interdisciplinary basic and policy research on many topics. Among the projects of particular interest for the NCGIA are studies in artificial intelligence (geography/psychology), expert systems and knowledge based information systems (geography), geographic information (geography), navigation without sight (education/ environmental studies/ psychology), water resource use (education/ geography), human behavior and robotics systems (psychology), and especially spatial behavior and knowledge (education/ geography/ psychology). The Institute's Center for the Study of Spatial Psychology and Geography have co-sponsored lectures by Santa Barbara faculty and guests on spatial research in these disciplines. Current research projects include the development of computerized spatial ability tests, computer-based studies of spatial orientation, spatial-visual reasoning, motor response, orientation, and verbal command complexity. Other researchers have looked at the problems of spatial knowledge representation, spatial reasoning procedures, knowledge acquisition and transfer, and navigation without sight.

These are all clearly areas in which research in CORI would benefit from the presence at UCSB of the NSF Center on Geographic Information and Analysis.

1.1.7. Social Process Research Institute (SPRI)

Faculty members, professional researchers, graduate students, and undergraduates in nine departments participate in projects in SPRI. Studies in progress include quantitative and qualitative research projects in criminal justice, immigration, social research methodology, gender, and anthropology, which to some degree would benefit from and participate in using GIA/GIS approaches and equipment in the National Center. Current activities include research in the applicability of Rasch measurement models to survey data; the factors involved in evaluating the impact of the petroleum industry on the social economic, and political development of metropolitan Los Angeles; social policy research on methodologies and statistical analyses for programs of police departments and small county prosecutors. The

International Anthropological/Archaeological Group has been mapping ancient Mayan settlements in Belize, correlating settlement patterns with soil and topography, and applying the results to interpretations of Mayan economy.

1.1.8. Research Libraries Group: Spatial Data Task Force

Those needing access to spatial research data are confronted with several problems. The bibliographic control methods used for traditional library materials have inadequate area descriptors. There is no current library system that will allow the user to receive materials by specific geographic coordinates or named location. Another element that complicates both cataloging and retrieval is the wide variety of non-standardized material formats and spatial reference terminology. As a result, catalog records are not sharable nor can existing databases easily communicate. Other problems associated with good spatial data control are a lack of a broadly shared geographic communication network that can connect widely scattered collections of data. All the above characteristics compound the problems of finding geoinformation in a timely fashion. It was the recognition of these obstacles that prompted the UCSB Library to enlist the Research Libraries Group (RLG), a consortium of 40 major research institutions and an organization with a proven ability to create and maintain large bibliographic databases, to attack this information handling problem. Under funding from the W. M. Keck foundation, the external design of a spatial information control system is being studied. Main objectives of this effort are: 1) to identify the key problems faced by researchers in finding spatially referenced material, 2) to develop an external system design, user friendly graphic search interface and cataloging standards, and 3) to determine the practicality of linking existing databases.

Currently the task force is completing the systems external design consisting of documents outlining the detailed scope of the project and the relationships of both the data and command components. Modules included are the graphic geographic searching interface, the online browsable gazetteers and thesaurus, and the data input work station. This should be completed by July 1988. The next step is the writing of the system code, prototyping and field testing of the completed system, loading a diverse sample of database records, and completing the necessary network link. Two persons from UCSB (L. Carver, the Director of the Map and Image Laboratory, and J. Star, of RSRU) are members of the RLG Spatial Data Task Force.

1.2. State University of New York at Buffalo

As part of an overall policy to make its outstanding facilities and resources available to industry, government, and other universities, UB has established nine other Centers. Three of them have strong potential relations to NCGIA.

1.2.1. Research Center for Earthquake Engineering and Systems Dynamics

In September 1986, a $50 million National Center for Earthquake Engineering Research was established at the University at Buffalo. This is the first such National Center sponsored by the National Science Foundation. NCEER's research activities represent a coordinated and integrated approach to the study of earthquake engineering. The efforts are focused on the systems aspects of structures and lifelines, with an initial emphasis on earthquake hazard mitigation in the eastern United States. The center proposed eight research programs: ground motions, soil and soil structure interaction, system response and unserviceability, reliability and risk assessment, laboratory and field experiments, innovative computing and expert systems, codified-design related issues, and societal and educational issues.

1.2.2. Center for Hazardous Waste Management

The New York State Center for Hazardous Waste Management was established to promote and encourage within the university community a coordinated, comprehensive program of research, development, information transfer, and service in hazardous waste management. The Center solicits and evaluates proposals and enters into contracts to fund hazardous waste management research and development projects. The research program focuses on the development of effective technologies and methods for: recovery, recycling, neutralizing or destroying hazardous waste; minimizing the quantity of hazardous wastes generated; and remediation at inactive hazardous waste sites.

1.2.3. Great Lakes Center

The Great Lakes Center has been established to facilitate policy- oriented research on important issues concerning the use and governance of the Great Lakes. It serves as an information clearing house to assist business, government officials and citizens' groups on both the U.S. and Canadian sides of the border. The program. has assisted U.S. and Canadian government officials and major commercial users to discover the current and potential problems regarding the Great Lakes. The program has been submitting proposals for special projects which study the above problems and provide remedies or formulate public policy. The program is focused on preventive measures as well as finding solutions to problems.

Related Graduate Research Groups

In addition to the three Centers mentioned above, the following facilities will have close relations with NCGIA.

1.2.4. Graduate Studies and Research Initiative in Cognitive and Linguistic Sciences

Cognitive Science is the scientific study of the mind: how it receives, encodes, stores, represents, and uses information. The research results are useful in the fields of linguistics, psychology, computer science, especially the development of artificial intelligence, and the design of information systems. Cognitive science incorporates both a formal component of modeling cognitive processes, and an empirical component of identifying and measuring cognitive processes as they occur in living organisms. The nature of research is highly interdisciplinary. The departments involved in the Initiative include Anthropology, Biophysics, Computer Science, Communication, Geography, Linguistics, Mathematics, Neurology, Physiology and Psychology.

1.2.5. Vision Group

The Vision Group is another interdisciplinary graduate group studying various aspects of vision. It is led by faculty members from the Departments of Anatomy, Biochemistry, Biophysical Sciences, Computer Science, Geography, Industrial Engineering, Physiology Lad Psychology. It provides an organized and integrated approach to scientific issues in vision. These issues include studies of biomedical aspects of visual pathways in the nervous system, psychological aspects of human vision, the development of artificial intelligence paradigms and computer modeling of vision, and the pursuit of applications related to the understanding of visual performance.

1.2.6. Graduate Group in International Trade and Development

The Graduate Group in International Trade and Development is an interdisciplinary research group involving faculty members from Social Sciences, the School of Management, and graduate students. One of the primary objectives of the group is to create a permanent formally organized resource base at SUNY Buffalo that is committed to an interdisciplinary approach, to the research issues associated with international trade and investment, and concerned with changes in industrial, national, and regional growth and development. In terms of its regional responsibility, the group is expected to utilize the results of their research activities to assist the economic growth and revitalization of the Western New York area.

1.3. University of Maine

1.3.1. Land and Water Resource Center

The Land and Water Resource Center of the University of Maine was established in 1965. The Center was formed partly in response to the emerging environmental movement of the 1960s and partly as a result of federal legislation that established a nationwide system of state water resource centers.

Funding for the Center, for the most part, has been shared by the University of Maine and the U.S. Department of the Interior, U.S. Geological Survey. Through the years, additional funds have come to the Center from other federal agencies, state government, and private foundations.

The Center performs the following functions and activities: it sponsors research projects on water resource problems; it coordinates large-scale, multi-disciplinary programs involving other departments of the University, state organizations, and in one case, universities and institutions in other parts of the country; it supports the training of students, particularly graduate students, through research projects and other activities; and it disseminates information on natural resources issues to decision-makers and to a wide range of groups and citizens in the state.

The Center has supported research projects carried out by faculty and students in Civil Engineering, Geology, Physics, Entomology, Plant and Soil Sciences, and other departments of the University. In addition to technical reports from these projects, the Center publishes special reports and bulletins. It also assists in the organization of seminars, workshops, and conferences. The research projects and other activities of the Center have dealt with a wide range of critical natural resource issues.

The Center has developed a strong 'information transfer' program in recent years. The activities have included workshops, audiovisual materials, exhibits and an information digest series. The information digests provide a synthesis of technical information in a form suitable for different user groups. The Center normally publishes three to five such digests each year. The Land and Water Resource Center supports the Maine Center for Geographic Information and Analysis through pre-established inter-disciplinary coordination among groups on campus, and maintains contact with federal and state agencies and other environmental groups.

1.3.2. University of Maine Technology Center

The University of Maine Technology Center is intended to provide technical services for Maine industry, business and government. The Center provides a wide variety of expertise in such areas as environmental law, computer control of power systems, robotics and automation, telecommunications, local area networks, process simulation and modeling, and many more scientific disciplines.

The Technology Center provides a variety of services to members and non-members. Members have certain laboratories and shops available to assist them. The Center publishes information in areas judged to be of particular interest to Maine firms - new findings, technical innovations, pertinent seminars, etc. The Center sponsors seminars, handles individual questions when possible or directs members to other sources, organizes short courses, and is involved in satellite teleconferences and other technical education programs distributed by satellite.

1.3.3. Canadian-American Center

The Canadian-American Center of the University of Maine supports the most comprehensive Canadian Studies program of any university in the United States. It has been designated by the United States Department of Education as a national resource center for the study of Canada. The center coordinates undergraduate and graduate education, research in the humanities, social sciences and natural sciences and directs outreach programs to regional and national audiences.

Canadian- related research activities are being pursued by more than 100 University of Maine faculty and professionals. Much of this research involves cross-border collaboration with scientists in Canadian universities and government agencies. Projects range from Canadian labor history and Maritime archaeology to acid rain studies and North Atlantic fisheries investigations. Many of the studies include spatial aspects and use geographic information and analysis tools.

The Center hosts several conferences during each academic year on topics of interest to both countries. These conferences bring together government, business, academic and cultural leaders from both sides of the border to exchange information, develop solutions to common problems, and suggest resolution of conflicting positions.

The Canadian-American Center provides the formal mechanisms for an international link. Since the early development of GIS, Canada has been at the forefront of development of GIS.

The Canadian-American Center has the contacts and facilities to assist and organize seminars on GIS issues and concerns common to both countries such as development of standards.

1.3.4. Department of Industrial Cooperation

The Department of Industrial Cooperation is responsible for coordinating the University's resources which are useful to private industry, individuals, and government agencies. Their primary responsibility is to make the University's accumulated expertise, equipment, and research capabilities available to private industry. The Department also maintains contacts with other agencies such as the Maine Department of Transportation, Land Use Regulation commission, etc, in an effort to keep the University involved in appropriate areas. The Department maintains contracts and information on all the major industries in Maine. It also has a file of over 1,000 clients and can assist in technology transfer of GIS research development to interested clients in both the public and private sectors.

2. Facilities and Equipment, University of California., Santa Barbara

2.1. Space

The proposed National Headquarters for NCGIA will be appropriately housed in one of several alternative sites on the UCSB campus or in space in the Engineering Research Center on Hollister Avenue. Space under consideration on the campus for the early years of the Center is about 4,000 square feet of useful space, with the possibility of later allocations to accommodate growth. Space in the Engineering Research Center will be of comparable size. If it is necessary for the Center to be housed off-campus it will be necessary to submit a revised budget. The Center at UCSB will initially involve primarily the Department of Geography in the College of Letters and Sciences, the Computer Science Department in the College of Engineering, the Computer System Laboratory's Center for Remote Sensing and Environmental Optics, the Geography Department's Remote Sensing Research Unit, and the Map and Imagery Laboratory of the Campus Library. The current function and existing infrastructure at these units will be outlined in the following pages. All are located in relatively close proximity on the UCSB campus. Other units in the Social Sciences will be involved as the research expands into issues of importance to social scientists. Specific issues regarding space are discussed in the remainder of this section.

2.1.1. Classroom and Conference Space at UCSB

UCSB maintains a large inventory of classroom and laboratory space that will be available for Center activities. The Geography Department directly supervises three main classrooms and several special instructional and research laboratory areas. This space can be made available for Center short courses and seminars outside regularly scheduled class use, and with essentially unrestricted access during summer months for short courses and workshops. With some exceptions, much of the classroom space and associated facilities on campus will be available at no cost for center activities. Further, The University Center maintains a number of nicely appointed conference rooms available at modest cost for campus use. In short, suitable space exists for summer short courses, specialized seminars and specialist meetings throughout the year. An added asset is the unusually attractive geographic location of UCSB, which draws visitors all year around. Several other units on campus which depend heavily on visiting scholars, such as the international Institute for Theoretical Physics, have very successfully capitalized on this locational advantage.

2.1.2. Space in the Department of Geography

The Department of Geography currently occupies portions of the first, third and fifth floors of Ellison Hall. Departmental space includes the main office, research accounting office, faculty offices, graduate student offices, laboratories, classrooms and seminar rooms. Additional space is in use by department faculty, staff, and students elsewhere on campus. At the present time, there are thirteen faculty, seven administrative staff, three technical support staff, six research staff, 74 graduate students, and 146 undergraduate students in the department. There are four rooms for computer equipment, 11 laboratory spaces, 7 administrative offices, 17 academic offices, 14 student offices, 3 staff offices, and 3 classrooms dedicated to the department. Total space allocated to the Geography Department is approximately 15,600 assignable square feet.

2.1.3. Potential for Sharing Space within the Department of Geography

Activities directly related to the Department of Geography will be accommodated within Departmental space to the extent possible. It is quite likely that many visiting scholars at the Center will be involved in Departmental programs, including teaching courses, leading seminars, and working on joint research. We expect that some scholars will be provided use of an office in the department for these and other center-related activities, though the majority of visiting scholars will be housed in the NCGIA Research Center. The Department's research accounting office is prepared to handle all accounting and financial management activities associated with Center operations on the UCSB campus, and is prepared to work closely with UB and UM. This means that accounting and financial management functions will not require separate space allocation at the NCGIA center at UCSB.

2.2. Computer Hardware and Software

The Department of Geography, the Computer Science Department, the Center for Remote Sensing and Environmental Optics, the Geography Remote Sensing Unit and the Map and Imagery Library all operate specialized image processing and GIS systems. Further, the UCSB Microcomputer Laboratory houses a large number of personal computers, some of which have been configured to handle image processing software and will also be configured to handle GIS modules. The computer equipment in these facilities has been developed and maintained for both research and instructional needs. This equipment and software can generally be utilized for Center activities at little or no cost.

As an example, the equipment and software at the Map and Imagery Library is available for research and instructional use at no cost. This equipment includes a VAX computer, image display, digitizing tablet, and ERDAS software. This facility can be made directly available to Center personnel through an ethernet link. All related computer facilities, such as the Geography Department Computer Graphics Laboratory, are described below. Charges for equipment access are typically used to pay for maintenance fees, software update, and amortized equipment costs and tend to be very reasonable. Whenever possible, center activities will utilize these existing resources. This will allow the NCGIA to invest only in specialized equipment that is specifically required for the Research Initiatives, and relevant instructional projects.

2.2.1. Geography Department

The Geography Department has various minicomputer and microcomputer facilities, both centralized and distributed to faculty research offices and laboratories. All of the following may be made available for various center activities.

2.2.1.1. Hardware

The Geography Department supports equipment both for teaching and faculty research programs. Several staff members are involved in training and maintenance in these facilities, which are supported mainly by campus teaching funds, with some modest additional resources provided by faculty research projects.

- Two VAX 11/750 minicomputers support a broad range of users. One runs the 4.3BSD Unix operating system, the other VAX/VMS 4.6. The former is used extensively for department teaching. It supports over 120 users via a direct access user room, a computer cartography lab, the campus wide broadband network (remote terminal and dial-in access)," and direct modem dial-in and out. BITNet, DECNet, ARPA internet (thus NSFnet) and the UUCP linked USENET are accessed by UUCP through the respective nodes here on campus. The second VAX is used primarily to support geographic information systems in the department, including ARC/INFO and KBGIS. Access to the machine is through the direct access user room, and the campus wide broadband network. Two laser printers and a number of line printer terminals serve these computers.
- The Department's Computer Cartography Lab has three Tektronix color graphic terminals with an ink jet plotter, two large Calcomp digitizers, a full sized Calcomp plotter, and two IBM PC/AT systems. Either VAX may be accessed from the terminals or the PC's. The lab is used for teaching (e.g. ARC/INFO), class demonstrations, instructional software development work, and research.
- The Department maintains several additional cartographic facilities, for both instructional and research purposes. The Cartographic Services Laboratory is equipped with an Apple Macintosh graphics workstation, Kroy 80K keyboard lettering system, and 2 light tables with Vemco drafting machines. The Cartographic Services Photographic Darkroom has developing and printing facilities, including an Agfa PMT system, Beseler 45MXII enlarger with dichro 45S color head, Polaroid MP4 copy stand with Nikon F3 camera and Copy-master flash, and a LogE/Robertson ML410 vertical process camera.

There are also two dedicated teaching rooms. The Cartographic Laboratory classroom is equipped with 32 drafting desks, half with light tables, a Map-O-Graph Model 55 vertical projector, and a Blu/Ray model 121 diazo machine. In the Cartographic Laboratory Classroom Darkroom, there is a Goodkin large format horizontal process camera, a NuArc FT26V Platemaker and contact vacuum frame, and a Compugraphic IV photo typesetter.

2.2.1.2. Software

Software in the Geography Department includes locally developed capabilities in a number of areas, as well as both commercial and public domain software systems. Capabilities include statistical analysis (including the S software package), geographic information systems (including both ESRI's ARC/INFO and the UCSB KBGIS III system), image processing (including NASA's VAX/VICAR), our own Image Processing Workbench IPW tools, several programming languages, document preparation, and so forth.

2.2.2. Computer Systems Laboratory: Center for Remote Sensing and Environmental Optics

Hardware installed at this time includes a VAX 11/750, two Microvax II workstations, six Sun 3 workstations, a Sun 3 fileserver, in IIS image display system, and an Adage image display system. Total disk space at this facility is approximately 4.3 Gigabytes.

Software in use includes VMS and Unix operating systems, the University of Miami image processing system, the UCSB IPW image processing system, and the S statistical package.

2.2.3. Remote Sensing Research Unit

Hardware installed and on order at this time includes: an ERDAS image display workstation, a Microvax VAX station II with 700Mb disk storage, a Microvax VAXstation 3500 with 270Mb disk storage (due for delivery in April 1988), 1600/6250 BPI tape drives, three IBM PC/AT color workstations, three IBM PC/XT word processing stations, a digitizing tablet and laser Printer. Local ethernet components and connections to the UCSB Campus broadband network have recently been installed an well.

Software in regular use includes the VMS and DOS operating systems, RIM and ORACLE database management systems, the ERDAS image processing system, VAX/VICAR, and various compilers, editors, and graphics software.

2.2.4. Information Systems and Computing

The Information Systems and Computing facility at UCSB provides campus-wide access to mainframe computers (IBM 3090 and NASCO AS-6), and supports the campus broadband network. The network provides a campus-wide ethernet, a terminal switching facility, and dial-in modems.

2.2.5. Center for Computational Science and Engineering

The Center for Computational Science and Engineering, in the College of Engineering, provides access, via the campus ethernet, to long-haul networks such as ARPA internet, BITNET, CSnet, UUCP, and NSFnet. A connection to the NSF Supercomputer Center at UC San Diego is supported by a full time programmer.

The center also supports various instructional facilities, including a Sun Workstation Laboratory (24 workstations and two servers) and provides hardware installation and repair services. These facilities can be made available for NCGIA activities

2.2.6. Physics Department

Physics Computer Services maintains several VAX/VMS systems and provides VMS system programmer support to various departments, including Geography. Physics also maintains a connection between the UCSB ethernet and the BITNET, DECnet and SPAN.

2.2.7. Department of Computer Science

The Computer Science Department has a wide range of computing capabilities. We mention only a few, which could be used in research and teaching efforts coordinated with the NCGIA. The Graduate Software Imaging Laboratory is based on 12 Microvaxes, and the Undergraduate Software Instructional Laboratory is a network of 25 SUN 3/50 Workstations. These teaching laboratories can be made available to NCGIA activities of various kinds, particularly in the several areas where the interests of the Center are closely allied with faculty in the Computer Science Department. This department also has a VAX 11/780 with 1 Gigabyte of storage which is dedicated to instruction, and a Symbolics 3650 and LMI machines, available for AI research. Further, via the Computer Science Department, NCGIA researchers have free access to a Connection Machine at UCLA.

2.2.8. Microcomputer Laboratory

The Microcomputer Laboratory is in instructional facility on the UCSB campus, supporting 4500 students per quarter. The laboratory consists of 5 classrooms, with the following hardware:

- 65 Apple II computers
- 70 Apple Macintosh computers
- 37 IBM PC computers
- 25 IBM PC/AT computers

Many departments use this facility for teaching purposes. The Geography department uses it for several undergraduate courses. Classes of direct relevance to the National Center include introductory and intermediate level geographic information system courses, programming language courses, and remote sensing/ image processing courses.

2.2.9. Map and Imagery Laboratory

Facilities include a Microvax II-based image processing system, with a Gould FD5000 image display system, Eikonix image scanner, 200Mb disk space, and 9-track tape drive, running the ERDAS software. In addition to this computer equipment, analytic instruments available to the entire research community include two monocular and one stereo zoom transfer scopes, four types of zoom stereoscopes, an IIS additive color viewer, a Bausch and Lomb hi-intensity light table, Hasselblad and Polaroid copy camera systems, manual and electronic planimeters, several variable intensity light tables, and hard-copy computer terminals.

2.3. Support Infrastructure

The Department of Geography has seven office staff, four within the main office and three in the research office and three technical support staff: a cartographer, a senior development engineer, and one full time computer system staff member.

2.3.1. Housing for Visitors

Housing for short-term visitors to workshops and seminars during the academic year will be in the Hampton Inn Motel, near the campus, with which we have negotiated a preferential institutional rate. Long-term summer workshop attendees could be housed in campus dormitories or apartments beginning in the summer of 1990 at rates of $60.00 per person per day, including meals, for a single dormitory room, or a two-person two-bedroom apartment, with no meals, for $192 per person per week. The UCSB housing office will assist persons staying for longer periods during the academic year.

2.4. Networking

The Information Systems and Computing center manages a broadband backbone network for the UCSB campus. They provide ethernet connectivity across the campus, terminal switching, dial-in modem services, and a Bitnet node. The UCSB Center for Computational Science and Engineering, in the College of Engineering, provides access to ARPANet, CSnet, UUCP, and NSFNet. The Physics Department maintains connections with Bitnet, DECNet and SPAN. The Geography Department now uses these facilities through the campus-wide network. The NCGIA will have the same access, providing us with cost-effective communications with collaborators around the world.

2.5. Outstanding Needs for Computer Hardware and Software:

2.5.1. Geography Department

Burgeoning enrollment and additional faculty positions, as well as a general increase in the level of extramural research, has stressed the department’s computing facilities. The NCGIA will place additional demands on our facilities. These demands, which derive from the research and instructional initiatives for the early years of the center’s activities, drive the following objectives concerning equipment improvements.

The necessary upgrades consist of improvements to the underlying infrastructure, the development of an advanced research and teaching laboratory, and the installation of a device to support intensive computational tasks. We tentatively budget $120,000 on average for each of the first two years, including University of California funding at $90,000 per annum. Year one provides networking capabilities that are clearly necessary for the conduct of the work we propose, and a server and workstations for the research initiatives. Year two provides additional workstations, completion of the network infrastructure, and replacement of outdated equipment. We reserve $52,000 in the second year equipment budget for hardware replacement costs. A powerful computer server is proposed as the principal component for purchase in the third year. We will seek non-NSF extra-mural funding for this purpose to augment NSF funds, as well as funding for further replacement of older equipment with high maintenance cost.

The existing resources will be supplemented (and replaced where appropriate) in several phases. The general areas discussed below revolve around the existing minicomputers, a new laboratory for advanced development, networking needs, and future computational resources. These items are specifically chosen to provide the necessary capabilities needed for the research initiatives and a significantly enlarged instructional program.

2.5.1.1. Existing Minicomputers

The Department's existing two DEC VAX 11/750 minicomputers are seriously overloaded. One, running UNIX, supports a wide range of undergraduate and graduate level teaching. This machine will require in additional large disk drive. We plan to retire this machine in the third or fourth year of the center's activities. The second, running VMS, is dedicated to research activities (including the use of ESRI's ARC/INFO and NASA's VAX/VICAR, plus development activities in support of UCSB's KBGIS). Recognizing the high support costs of this computer, we plan to retire this machine in the second year of the center's activities, and replace it with a Microvax III or equivalent.

Thus, the funds required in the second year to purchase a replacement computer and one large disk drive are approximately $52,000 (compared to list price of $93,000)

2.5.1.1.1. Network Components

A network to interconnect the various computing resources in the department is a very high priority. We require an ethernet repeater for the broadband connection, unibus ethernet interfaces, and appropriate cable/transceivers. Several terminal servers and multiport transceivers will be required in Ellison Hall, to connect both terminals and computers throughout the Geography Department. There will be significant improvements in access to Department resources from this new network, by both improving throughput as wen as permitting more users simultaneous access to computers. The estimated discounted cost of these improvements is $34,000. We propose to place these components in service over two years, at a cost of $24,000 in year 1, and $10,000 in year 2.

2.5.1.2. Research and Advanced Teaching Laboratory

A high priority is the development of a research and advanced teaching laboratory specifically for NCGIA. This laboratory is specifically meant to provide support for those research initiatives in which UCSB faculty and staff will play an important role. Taking into account trends in the industry as well as the importance of equipment compatibility with our two sister institutions, we intend to select computers from Digital Equipment Corp. The first-year purchases will support directly class software development for NCGIA-related courses, plus three research initiatives which will be based largely at UCSB. This includes two workstations and a server. In the second year we will add three more workstations.

Workstations are based, tentatively, on the VAXstation II CPU, with ethernet, a 16 color 1024 x 864 pixel 19" color display, and a 71Mb local disk. A workstation, equipped with digitizing tablet and workstand, will cost the university $12,320 (compared to $21,969 at manufacturer's list prices). Thus, the first-year cost of two workstations would be $24,640 at UCSB discount, or $43,938 at list prices. The second-year cost of three workstations would be $36,960 at UCSB discount, or $65,907 at list prices.

The server for the laboratory will be a DEC Microvax II. An appropriate configuration, including 1000Mb of disk storage and a 1600/6250 BPI tape drive, will cost the center approximately $69,000 (compared to list prices of $126,000). Network hardware necessary to interconnect the workstations and the server will cost $3000. Required peripherals include a shared postscript laser printer ($5000), plotter ($8000), and video camera plus monitors and one VCR for classroom demonstrations ($2000).

2.5.1.3. Compute Server for the NCGIA

In order to minimize the impact of advanced research on existing facilities, as well as to provide an effective environment for new research undertakings, we will seek additional extramural funding for a powerful computing engine in the new center in the third year. Based on current information, a Sun 4 server is a cost effective means to provide this capability. We will re-evaluate the available equipment late in the second year; the Sun 4 provides budgetary guidance at this point in time. Based on the manufacturer's information, a reasonable configuration, including 9-track tape drive, will cost $70,000 (compared to $101,400 at manufacturer list prices).

2.5.1.4. Options for Future Growth:

The components above have been selected to meet several goals, including that of economy. Several additional long-range options for future growth of the NCGIA facilities include:

1. Research and Teaching Laboratory - expand to a total of 12 workstations.
2. Additional color graphics workstations for locally-produced and new UNIX software, principally for the research environment. The long-range goal would be a graphics workstation, networked to center resources, for each active member of the center.
3. Multiple workstations plus server to augment/replace the instructional VAX 11/750 (i.e., Microvax workstations, or Sun 3/50's plus central Sun 4 server).
4. Microvax III for the Cartography lab, for classroom use
5. Array processor add-on for departmental computing server, if computational needs require it.
6. 3-D display system for visualization research

2.5.2. Remote Sensing Research Unit

Existing and proposed RSRU research efforts leave relatively little excess computer capacity. In the first two years of the NCGIA the RSRU will be involved in the Large Database Research Initiative. We believe that an additional 400Mb of disk space for one of our systems (approximately $6000), a small WORM optics. I disk (approximately $7000), plus a graphics terminal ($2500) will provide sufficient resources. We propose that the funding for the center provide a 50% match against extramural funds ($7750) towards these equipment needs.

2.5.3. Map and Imagery Laboratory

To make the materials in this laboratory more available to researchers both in the NCGIA and elsewhere, several new capabilities are required. Particularly relevant to the center is an enhanced ability to manage extremely large collections of spatial data. Necessary augmentation includes an additional VAX workstation, plus several hundred megabytes of disk space and a film recorder. These items have great relevance to the NCGIA, in both research and instructional efforts, and will be shared by a wide range of researchers. Total costs for these items is approximately $48,000 to the University, with a manufacturer's list price of $63,000. We recommend that the NCGIA make a modest contribution towards this new facility in the third year (earlier if additional funding is obtained) on the order of $10,000, if the Library is able to obtain the balance of the funding required.

2.5.4. Computer Systems Laboratory: Center for Remote Sensing and Environmental Optics

The substantial facilities already in place in this research unit initially need only modest augmentation, primarily for a VAX workstation for research on the Temporal and Remote Sensing Research Initiatives (Initiatives 11 and 12), beginning in year three. The proposed equipment compatible with the other UCSB sites and costing $12,320, will be purchased early in year three and consist of a VAXstation II CPU, with ethernet, a 16-color 1024x864 pixel 19" color display, 71 Mb local disk, a digitizing tablet and a workstand.

3. Facilities and Equipment, State University of New York at Buffalo

3.1. Space

3.1.1. Classrooms

The University at Buffalo has two principal campuses: the Amherst (or North) campus, on which the Buffalo Center for Geographic Information and Analysis and the Geography Department are located, and the Main Street (or South) campus. The combined seating capacity of all classrooms on these two campuses is over twelve thousand. Under the current University policy, any organization which has a recognized status in the University, such as the GIA Organized Research Center, may use the classroom facilities mentioned above without charge.

3.1.2. Research Space and Offices

The Department of Geography currently occupies the fourth floor and part of the third floor of Fronczak Hall, Amherst Campus. Departmental space includes the main office, faculty offices, graduate student offices, laboratories, and seminar rooms. An additional GIS laboratory is located in the Department of Anthropology in the Ellicott Complex.

The Geography Graphics Laboratory, a shared resource for the Buffalo Center for Geographic Information and Analysis and the Department of Geography, occupies several rooms on the fourth floor of Fronczak Hall. This laboratory includes a cartography laboratory with full darkroom facilities and a computer graphics laboratory. The Buffalo CGIA also has a conference room and a secretarial office. The Department has an additional conference room, a secretarial office, and 15 faculty offices plus the Chair’s office. There also are 10 graduate student offices accommodating 32 Master’s and Ph.D. students. Finally, the Geography Department has a soils laboratory and several storage rooms.

3.1.3. Available if NCGIA. is Awarded

Should this proposal be approved, an additional 1000 square feet of suitable space would be identified in the same building now occupied by the Center and the Department. By 1990, the Geography Department and the Center will have moved to new space in a large office building overlooking Lake Lasalle. Plans are for these units to share this building with Computer Science and Mathematics and perhaps one other social science department. Geography and the CGIA currently occupy approximately 10,000 square feet of space in Fronczak Hall; space allocated to these units will increase substantially with the move to the new building. The University has made a commitment that the center will have adequate space allocated for its activities.

3.2. Computer Hardware and Software

3.2.1. Geography Graphics Laboratory

The Graphics Laboratory is used for faculty and graduate research and advanced undergraduate instruction.

At present, the microcomputer facilities in the Lab include:

- Macintosh workstations, in AppleTalk network and a dedicated file server. Numerous peripherals are available to the Appletalk network, including laser printer, flatbed color plotter, color thermal plotter, digitizing tablet, and 4 color dot matrix printers. An IBM PC/AT microcomputer is dedicated for file transfer
- Two IBM PC/XT’s and two IBM PC/AT’s, running under DOS
- a second digitizing system (Calcomp) is currently on order.

The Geography Department also has access to several other hardware components, including:

- several IBM PC's and PC/XT's primarily used for word processing
- one IBM PC/AT running under the Xenix operating system
- a Sun 3/50 workstation is currently on order.
- an additional digitizing system and Arc/INFO workstation, located in the Department of Anthropology.

Software in the Lab provides capabilities for graphics programming, statistical analysis, desktop publishing, and production of statistical graphics and cartographic displays, as well as access to and hardcopy from the University VAXcluster and ARC/INFO.

In January 1987, the Department of Geography and University Computing Services installed the ARC/INFO geographic information system on the university VAX cluster. The NETWORK and TIN modules for transportation and terrain analysis are part of the installation, as is the new version of ARC/INFO for the IBM PC/AT. A direct ethernet link has been installed between the Graphics Laboratory and the VAX cluster site to support both the PC/AT's and several high speed color and monochrome graphics terminals installed in the Laboratory. Other University Computing Services facilities are discussed below.

3.2.2. University Computing Services (UCS)

Unlike the computing configurations at Santa Barbara and Maine, that at Buffalo is based on a centralized University Computing Services Unit designed to serve all major University programs. The University expects the central facility to provide and maintain all major equipment systems and has made a budgetary commitment sufficient that departments look first to UCS for meeting their basic computing needs. Thus, although the Geographic Information Systems Laboratory was originally set up as an independent, fully equipped facility within the Geography Department, more recent equipment and software upgrades have been carried out cooperatively with UCS, and the Department has focused its own acquisitions on top-of-the-line microcomputers and graphics workstations, all of which are connected to mainframe computers through high-speed communications networks. UCS resources and services are central to the NCGIA research and educational missions. UCS provides a number of key facilities to the Center operations at Buffalo, including

(1) *Housing, upgrading, maintaining, and consulting* on all major hardware systems and software packages. UCS has thus cooperated in the installation and maintenance of ARC/INFO on the Buffalo campus, and has dedicated two physical disks to ARC/INFO. It maintains graphics facilities at each of its user site operations, and provides consulting on all systems and software to all student and faculty users on a seven day per week basis.

(2) *Operating and upgrading user satellites.* UCS operates attended user facilities at the main Computing Center and five satellite units adjacent to units participating in the NCGIA (Engineering, Computer Science, Anthropology, Psychology), and provides output services at several other terminal/microlab sites on campus. Consulting is available at all attended sites.

(3) *Providing and staffing instructional facilities and short courses*. UCS provides large rooms with terminals, PCs and display facilities in two buildings on campus. Both instructional rooms are available to the NCGIA, and UCS staff are available to offer workshop or short-course instruction in topics related to GIA.

(4) *Supporting Departmental and Center equipment*. The UCS Electronics Lab and its technicians provide maintenance support for all computer equipment on campus except highly specialized units. In addition, software specialists are assigned to each major program in use on campus. The University at Buffalo currently has a VAX cluster consisting of two VAX 8650 computers, one VAX 8700, and one VAX-11/785, a running the current version of the VMS operating system; the VAX-11/785 is dedicated to batch, print server, and networking functions. There are also convenient tape-reading utilities, and programs to facilitate transfer of files to microcomputers. UCS computing facilities also include a large IBM 3081-GX with attached Floating Point Systems FPS-154 array processor, and three Primes dedicated to CAD/CAM work. Additional computer upgrades are scheduled.

In addition, UCS has the following systems running under the UNIX operating system:

- one Sperry 7000/40 processor with 1.25 Gigabyte disk, 8 MB memory, FPA, and 72 Terminal ports;
- one VAX-11/785 processor with 960MB disk, 14MB memory, FPA, 64 Terminal ports;
- one Sun 3/160 serving six Sun 3/110's (4 color, 2 greyscale), 560MB disk, 8MB memory; and
- one Sun 3/180 serving six Sun 3/50's 475MB disk, 8MB memory (each 3/50 has a FP processor);

These machines are connected on a common ethernet.

3.2.3. Department of Computer Science (CS)

The Department of Computer Sciences is connected to the same ethernet as the UCS UNIX systems outlined above are two VAX-11/750 machines and one VAX-11/785, 0 running under UNIX. In addition, the Department of Computer Science also has:

- 3 Symbolics Lisp Machines
- 4 TI Explorers Lisp Machines
- 1 Hypercube machine
- 14 Sun workstations plus a file server
- one Encore parallel processing machine

Access to CS Department machines generally can be arranged on a project-by-project basis if sufficient excess computing power and space are available.

The Department of Electrical and Computer Engineering has seven MicroVAX's devoted to VLSI research. The Faculty of Engineering and Applied Sciences also has an AT&T 3B15 (running UNIX System V) for instructional and research use.

3.2.4. Other Specialized Labs Available for the NCGIA

In addition to the lab facilities available in Geography and through the University Computing Center, three other relevant computing labs on campus are available for use:

(1) *The Faculty of Social Sciences Microlab.* This lab, located in the central Social Sciences building, houses 25 PCs, all with graphics capabilities and all wired to the University Computing Network. It includes an overhead display capability for teaching, and services on-campus and on-line service to the Inter-University Consortium for Political and Social Research at Michigan.

(2) *The MAClab*. Housed in the School of Education, this lab includes 40 Apple Macintosh computers with graphics capabilities, laser printing, and user consulting seven days a week. Several machines are linked to the University Computing Network.

(3) *The Center for Learning Technology*. Located in the School of Education, this lab includes 10 Macintosh computers used mostly in developing software applications for instruction. Programmers and faculty consultants are available in this facility.

3.3. Support Infrastructure

3.3.1. Technical and Secretarial Support

The Department of Geography currently has two non-teaching professional staff members (technicians), one in cartography and the other in geographic information systems; the latter position was created in the context of the GIA Center. Greg D. Theisen (B. A., SUNY at Buffalo) is the cartographic technician (instructional support specialist); in addition to traditional cartographic production, Mr. Theisen has expertise in computer graphics, using Pascal, C, BASIC, and FORTRAN, under DOS, NOS, and UNIX. James Smith (B. A., Louisiana State; M. S., Alberta) is a senior programmer analyst (GIS technician); he is familiar with FORTRAN, VMS, DOS, and several other programming languages and operating systems, and has experience with ARC/INFO and Intergraph GIS systems. The Department also has several graduate students in the Master's and Doctoral programs in Geographic Information Systems and/or Computer Cartography who often act as graduate research assistants. The Department has three secretaries, and the Center for Geographic Information and Analysis currently has its own half-time secretary.

3.3.2. Library Facilities

The University of Buffalo Libraries include a number of collections, memberships, and services of direct relevance to the activities of the NCGIA. The basic collections are extensive: in 1987 they included 2.31 million volumes, plus over 6 million manuscripts, 2.88 million microforms, and over 458,000 government documents, as well as research and resource materials in other formats. In addition, both Lockwood Research Library and the Law Library are government repositories for U.S., Canadian, and European Community documents. The Map Library is the repository for all USGS and Canadian topographic maps.

In addition, the Libraries maintain memberships in several national groups dedicated to information sharing, including the Online Computer Library Center (OCLC) and the SUNY branch of that Center (SUNY-OCLC). The Buffalo Libraries serve as the regional back-up for the Western New York Library Resources Council. The Libraries at Buffalo, along with those at Santa Barbara, also belong to the Research Libraries Research Group (RLG), a consortium of research libraries dedicated to sharing research materials and technologies for their transfer.

According to the Association of Research Libraries' composite index of library systems, the Libraries at Buffalo currently rank fourth in New York state, behind Cornell, Columbia and New York University. The Libraries are committed to increasing holdings in areas related to CIA as well as other major areas of graduate education and research at SUNY Buffalo.

3.3.3. Housing for Visitors

The University currently has facilities to accommodate conferences of up to 1000 people. Food service is available for a wide range of needs on campus, and the area surrounding the University hosts a number of restaurants in all price categories. Housing is available from several hotels and motels with shuttle service to the University, and during the summer months the University can offer 3000 dormitory beds at reasonable prices. To facilitate conferences, the University's Office of Conferences and Special Events offers the services of its staff in organization, publicity, and logistical planning. Several of the area hotels have conference facilities, and the University's Center for Tomorrow provides a dedicated conference site on campus with facilities for 300 participants. Finally, the University has just completed an agreement with developers of the Embassy Suite Hotels for an on-campus hotel and conference facility, including rooms for large and small meetings, which will be ready for use in 1991.

3.3.4. Conferences

There are two programs at the University at Buffalo to facilitate the organizing of conferences. They are:

1) *Conversations in the Disciplines*: This is a program of financial support offered by the University for intercampus scholarly conferences. One of the tasks of the program is to bring together State University faculty members and visiting scholars to examine new trends, review promising research findings and become better acquainted with professional developments in their fields and on other campuses.

2) *Conferences in the Disciplines*: This is a program to provide financial support for conferences, symposia, lectures or workshops of interest to members of the University community, the Western New York scholarly community, as well as a national or international community of scholars.

3.4. Networking

Jnet software has been installed on the UCS VAX cluster, and facilitates electronic mail connections directly to BITNet, and through BITNet gateways to other electronic mail networks. TCP/IP connections over Internet are available from both the VAXcluster and from the UNIX systems, and allow remote login and file transfer over the networks.

The University at Buffalo is currently linked to thirteen other universities via NYSERnet (the New York State Educational and Research Network). NYSERNet is a high speed 'clear channel' 56kbit communications network spanning New York state and reaching the supercomputer installations at Cornell and Princeton, as well as the Northeast Parallel Architecture Center at Syracuse University, which has a Connection Machine 1 (32K processors) as well as Alliant and Multimax parallel computers. NYSERNet is connected to the NSFNet supercomputer network at Cornell, and that too is a 56kbit network which includes supercomputers at San Diego, Pittsburgh, and Illinois. NYSERNet will be upgraded to ‘T1’ (1.544Mbits) standards soon, and is exploring the development of T1 and DS3 (44.5Mbits) links to the supercomputers.

3.5. Outstanding Needs for Computer Hardware and Software

1988-1989: In the first year it is proposed to purchase the following equipment: one color workstation with very high resolution including eight bit per pixel scanner; a 2540 dpi POSTSCRIPT raster printer; and a 1024 x 768 x 256 color processor. In addition a SUN Microsystems 3/160 with System/9 GIS would be purchased. Total estimated cost would be $95,000.

This equipment would support visualization of terrain data handling providing both the graphical and computational capabilities for the Initiatives in Spatial Error and Multiple Representation. The Initiative on Error Analysis will use the existing ARC/INFO installation but will need System/9 for comparison work. For the Initiative on Multiple Representation, research in the first year will require a stand-alone color workstation with capabilities for high resolution imagery. This equipment will provide for digital scanning of features from aerial photography at a range of resolutions and the output device will provide high quality depiction of terrain analysis and feature identification studies.

1989-1990: During the second year, it is anticipated that an ERDAS image processing system including an array processor and two color workstations would be purchased as well as a map animation workstation including a digital precision editing VCR and a digital laser disk player. Total estimated cost will be $100,000. These equipment acquisitions would be used in the Decision Support Research Initiative. This will permit the inclusion of remotely sensed imagery with GIS layers for continuous monitoring of natural and human resources. A color map animation workstation will be used in the study of temporal dynamics as part of the Multiple Representations Initiative.

1990-1991: During the third year, we anticipate the purchase of a digital acquisition network including four color workstations, local networking hardware and software, random access slide projector, graphics tablets and touch pads, shared mass storage, and the construction of soundproof cubicles for perception experiments. Total estimated cost for 1990-1991 is $110,000. These equipment acquisitions will be needed to test map reader response to alternative map designs. The Map Design Initiative will draw, in part, on research from earlier Initiatives, specifically Spatial Language and Multiple Representations.

1991-1993: Equipment need for the fourth and fifth years will depend on the direction the Research Initiatives have taken during the early years as well as technological developments.

4. Facilities and Equipment, University of Maine

The University of Maine System is a state university system with seven campuses, with the one at Orono being the 'flagship' campus for major research and graduate education. It is a land grant and sea grant university and also the only engineering school in the State (the Engineering Departments also offer selected courses at the graduate level at the University of Southern Maine campus, to reach out to professionals in this more populated area of the state).

Very substantial increases in state funding are occurring in the University System. As a result, renovations on campus and new buildings are currently going on to improve the physical plant, and the Legislature will consider in the next session a very ambitious plan for a total of $60 million for new capital investment of which a major part will go to the Orono Campus.

4.1. Space

4.1.1. Classrooms

The campus has a large number of classrooms which are intensively used during the academic year but would be available for NCGIA-related summer courses. Classroom space for additional graduate and undergraduate students is available to meet the needs for the first few years of Center operations and the University is currently considering adding a new classroom building.

4.1.2. Research Space and Offices

The Surveying Engineering Group currently uses seven faculty offices in Boardman Hall, and has seven more offices for faculty or graduate students in the Machine Tool Shop. Boardman Hill also has three larger rooms used for laboratories (photogrammetry) or for graduate and undergraduate workspaces.

The Surveying Engineering Group has grown very rapidly in the last two years, moving from four to eight faculty. Managing this rapid growth has been difficult, but we have experienced sustained support from the University administration. Despite the fact that the University added 2000 square feet of space during the summer of 1987, the need for additional space is recognized and additional space should become available for fall, 1988.

4.1.2.1. Space for NCGIA

Given the research program and the expected funding, we estimate that about 6000 additional square feet for researcher offices, graduate students and laboratories will be necessary. The University administration has promised to provide this space.

It is desirable that the Maine CGIA and the Surveying Engineering Group be located in close proximity. There are currently a number of possible solutions under consideration. The most advantageous would be for the Maine CGIA and the Surveying Engineering program to be housed together in a large existing building which may become available in 1988. Other possibilities considered include vacating some space in Boardman Hall currently occupied by other groups, or the construction of a new Engineering and Science building, which would primarily house CGIA and Surveying. Some of these plans would require a provisional solution for one to two years.

4.2. Hardware and Software

4.2.1. Surveying Engineering Group

The Surveying Engineering group has been successful in acquiring and maintaining an up to date collection of equipment and software valued at above one half million dollars. The equipment is used both for education and research.

The equipment owned by the program can be divided into several groups serving special needs in several areas.

Hardware

There are 6 MicroVAX computers (with an additional one on order) used for research and graduate education, which will be detailed below. For photogrammetry, the program recently acquired an analytical stereoplotter which allows stereoscopic viewing and precise measurements from photographs, automated data collection and computer-aided mapping. The stereoplotter is driven by its own microcomputer. For research in geodesy, the program recently acquired a pair of GPS receivers, an asset few other universities can claim. These receivers are capable of measuring positions rapidly and with potentially centimeter accuracy. The program is also in the process of replacing traditional surveying equipment with new equipment needed for quality undergraduate training.

The Department has various personal computer facilities located in the secretaries office, research offices and in the laboratories. Each faculty member is also provided with a personal computer. These machines are networked to facilitate exchange of data and electronic mail. Students have unrestricted access to a cluster of personal computers installed by the College of Engineering. Several languages, word processing, drafting and spreadsheet software are provided on the cluster. Hardcopy output is provided by four printers.

The workstations listed below form a local-area VAX cluster, running VMS t5.0 field test version (pre-release of V5.0) on some workstations, and VMS V4.6 on others. The cluster consists of 3 microVAX II graphics workstations, 2 microVAX I graphics workstations, 1 microVAX II/GPX 8-plane color graphics workstation and 1 microVAX 2000 color graphics workstation (on order). Shared components include two LN03 laser printers, a LA50 line printer, a LA75 line printer, TK50 95 MB cartridge tape, 25 terminals (VT220, VT240, Visual 550), 4 graphics terminals, a Tektronix T4663 plotter, and a HP7476A 6 Pen Plotter.

The program maintains sufficient hardware for immediate needs. The Maine CGIA will add research personnel as well as graduate students and hence additional workstations will become necessary, as well as the replacement of technically obsolete systems (the VAXstations I will fall in this category soon).

Software

In order to increase productivity, the Surveying Group has concentrated its efforts on a few systems. All of the program's microcomputers run the VMS operating system (UNIX is available, but used for special packages only).

The commercial GIS package ODYSSEY has been installed, and ARC/INFO is on order. For image processing we will add the ERDAS system.

Research and teaching in the design of GIS software is based on a software engineering support system and the GIS database software which has been built over the last several years. This is a unique facility. All the source code is written in a uniform object-oriented modular form that students can readily understand. With this format we can modify and experiment with every part of the GIS, from the data base to the graphics output modules. The system includes a PROLOG-like inference engine which can be modified to deal with new deductive methods for GIS expert systems. This testbed shortens the time needed to build additions or to test new ideas in the user interface. Without such a workbench new concepts in data structuring - one of the important areas of research for NCGIA - could not be tried in a realistic environment (it is generally not possible to receive the source code from commercial GIS Systems, nor is it often possible to understand and modify it even if available). This software is currently used as a base for commercial GIS development.

Our research cooperation with Digital Equipment Corporation has lead to the installation of Spatial II (Digital's commercial GIS software) and we should be receiving Trellis/Owl, their experimental object-oriented programming language and database, as well as their relational database product.

Specific software currently in use includes several languages (VAXPascal, VAXFortran, CProlog, ADA, Hope), plus a number of large programs: LOBSTER - a persistent PROLOG interpreter developed by the Surveying Engineering Program at the University of Maine; PANDA - an object oriented database developed by the Surveying Engineering Program at the University of Maine; MOOSE - an experimental programming environment developed by the Surveying Engineering Program at the University of Maine; ODYSSEY - commercial GIS developed by Harvard Laboratory for Computer Graphics; ARC/INFO - commercial GIS developed by Environmental Systems Research Institute; and Spatial U V1.1 - developed by Digital Equipment Corporation

Funds to purchase an ERDAS image processing system are included in the startup funds of a new faculty member and we expect the order to be placed soon.

4.2.2. Associated Computer Facilities

We maintain good relations with a number of other groups on campus who have computer equipment which is available for specific tasks. Computer equipment of the University of Maine with direct connections to the surveying network include: *College of Engineering*: The College has two major computer systems available to engineering department and the Computer Science Department. The systems are: a VAX-11/780 running VMS V4.4 with a connection to BITNet and a Data General MV10000 running UNIX 4.2

University of Maine System: The CAPS Computer Center maintains a number of computers throughout the Maine University System. The largest mainframe is placed on the Orono Campus and is available for all teaching and research needs. The systems are: a IBM Mainframe (MM 3090) with vector processor with a pen plotter and Versatec plotter.

Computer Science Department: The Computer Science Department uses primarily the IBM mainframe and the VAX-11/750, but has also acquired workstation (4 SUN Microcomputers [3/50, 3/140]) systems. Cooperation with this group is excellent and we regularly exchange software and organize joint courses. The Department's systems are: 1 MicroVAX GPX II and 1 MicroVAX II

Personal Computer Laboratory of the College of Engineering: This facility is heavily used by Surveying Engineering undergraduate students. Systems include: 12 Apple Macintosh stations with a 40 MB disk drive; 4 Imagewriter printers; and 20 IBM pc's.

4.2.3. Instruments in Surveying Engineering *Photogrammetry Equipment*: The following list identifies equipment that supports field research of the Surveying Engineering Group:

- Kern DSR-II analytical stereoplotter with 5-20x optics and two I micron 240x240 mm comparator plates
- IBM PC/AT with 30 MB hard drive 5 1/4 inch high density floppy drive, 80287 math coprocessor and color monitor (primarily for data acquisition with the stereo plotter).
- Zenith PC/AT compatible with 40 MB hard drive, 5 1/4 inch high density floppy drive and 80287 math coprocessor and color monitor (primarily to support digitizing).
- Hitachi HDG-4836BL 48" x 36" digitizing table
- 1 IBM Proprinter II
- 1 DMP-42 pen plotter
- 1 Kern PC-Pro Super System Software
- Autocad Computer-Aided Design Software

Geodesy Equipment:

- 2 Trimable 4000SX GPS satellite receivers
- 2 Zenith 181 laptop microcomputers (for data acquisition and compilation in connection with the GPS receivers).
- Integrated Geodesy Program
- Maine Pac I GPS Orbital and Carrier Phase Program
- Maine Pac II Geiod Undulations from Gravity
- Maine pac III Kinematic GPS Software

4.3. Support Infrastructure

The Surveying Engineering Group has a full time secretary. We currently employ two graduate students for technical support (one for the VAX systems, the other for Apple Macintosh personal computers). The Civil Engineering Department has a technician who performs simple repairs.

The College of Engineering and Science is in the process of hiring a faculty level person to manage the college VAX 11/780 and the Data General MV 10,000. This person will be housed with the Surveying Engineering Group and cooperate with them.

It is recognized that the current level of support is low. With the Maine CGIA three additional positions for clerical and technical support will be created.

4.4. Networking

The VAX systems in the Surveying Engineering Group are linked by ethernet cables. We used DECnet to manage all the CPUs in a single VAXcluster. The VAXcluster is further linked to the other VAX computers on campus, using DECnet. Terminals are connected to the ethernet cable using DECservers, allowing connection from any terminal to any VAX.

The personal computers (mainly Apple Macintosh) are connected by Appletalk and use common file servers and laser printers. Both the VAX and the central IBM mainframe are nodes in the BITNET network, connecting most universities in the US, Canada, and Europe. BITNet is connected to most other research networks, and we can reach most researchers with electric mail connections.

It is planned to add for the Maine NCGIA a high speed (T1) link to connect to NSFnet, especially to allow quick exchange of large amounts of data between the three consortium members.

The campus has decided to use fiber optic cables to connect the various buildings. A working group (with a representative from Surveying Engineering) and an external consultant is planning a comprehensive communications network, but no decisions have yet been made.

4.5. Outstanding Equipment Needs

The Research Plan can be carried out with high resolution workstations (some with color capabilities) and disk servers with a sufficient number of large hard disks and printer servers and plotters. The basic equipment of this type is already in place but further acquisitions are needed to meet the needs of an increased number of researchers and to replace equipment as it becomes obsolete. The following is a year-by-year list of projected needs.

1998: Major items will be: six Macintosh personal computers with hard disks at $3,000 each; Three workstations (VAXstation 2000 or equivalent) with hard disks and software licenses for $18,000 each including networking hardware and software and printers. The total comes to $80,000 retail but a contribution from the hardware manufacturer of $30,000 is expected.

1989: For the second year we plan to add a VAX 3000 type system, primarily as a central server ($80,000) and two additional workstations (VAXstation 2000 or equivalent) with high resolution color screens ($18,000 each). We will also need some additional Macintosh personal computers for research assistants and networking hardware, printer, etc. The total will be approximately $130,000, with contributions from the manufacturers of $60,000.

1990: A second image processing system with special hardware for the research on visualization may become necessary ($50,000). Two additional workstations will become necessary to replace the current VAXstation 1 workstations. The total for this year will be $100,000, with manufacturers contribution expected to be about $40,000.

1991: A second general server (VAX 3000 type) will be required as research increases, as well as special hardware to explore parallel processing if appropriate. The total for this year will also be about $100,000 with a manufacturer contribution of $45,000.

1992: Depending on the research directions pursued by that time, hardware worth $110,000 may be purchased with a manufacturers' contribution of about half that amount.

V
KNOWLEDGE AND DATA DISSEMINATION

1. Introduction

Although the National Center for Geographic Information and Analysis will primarily engage in research, it will need to play a much more active role in information dissemination than other research institutions in more traditional areas. Knowledge and data dissemination in the area of GIA/GIS is necessary because it is still a relatively new area, because it is inherently interdisciplinary, and because the gap between research and practice in this area must be bridged. Thus, one of the major functions of the Center will be the dissemination of information of its operations and projects to the various components of the GIA community: universities, federal agencies, local and state government, and the private sector. The consortium will supplement channels and outlets that currently exist (scholarly journals, professional conferences, and user group meetings) by introducing:

- A Publication Series including interim research Technical Papers, Monographs on completed research, and Annual Reports on each research initiative
- Workshops, seminars, and conferences in conjunction with NCGIA research initiatives
- A schedule of specialized workshops and seminars for the GIA community that will highlight the educational aspects of NCGIA
- A quarterly Newsletter about activities and research sponsored by NCGIA and general news about the GIA community

The following table summarizes the planned knowledge and data dissemination programs of NCGIA and shows where the primary responsibilities (X) and secondary responsibilities (*) for the particular activities will be.

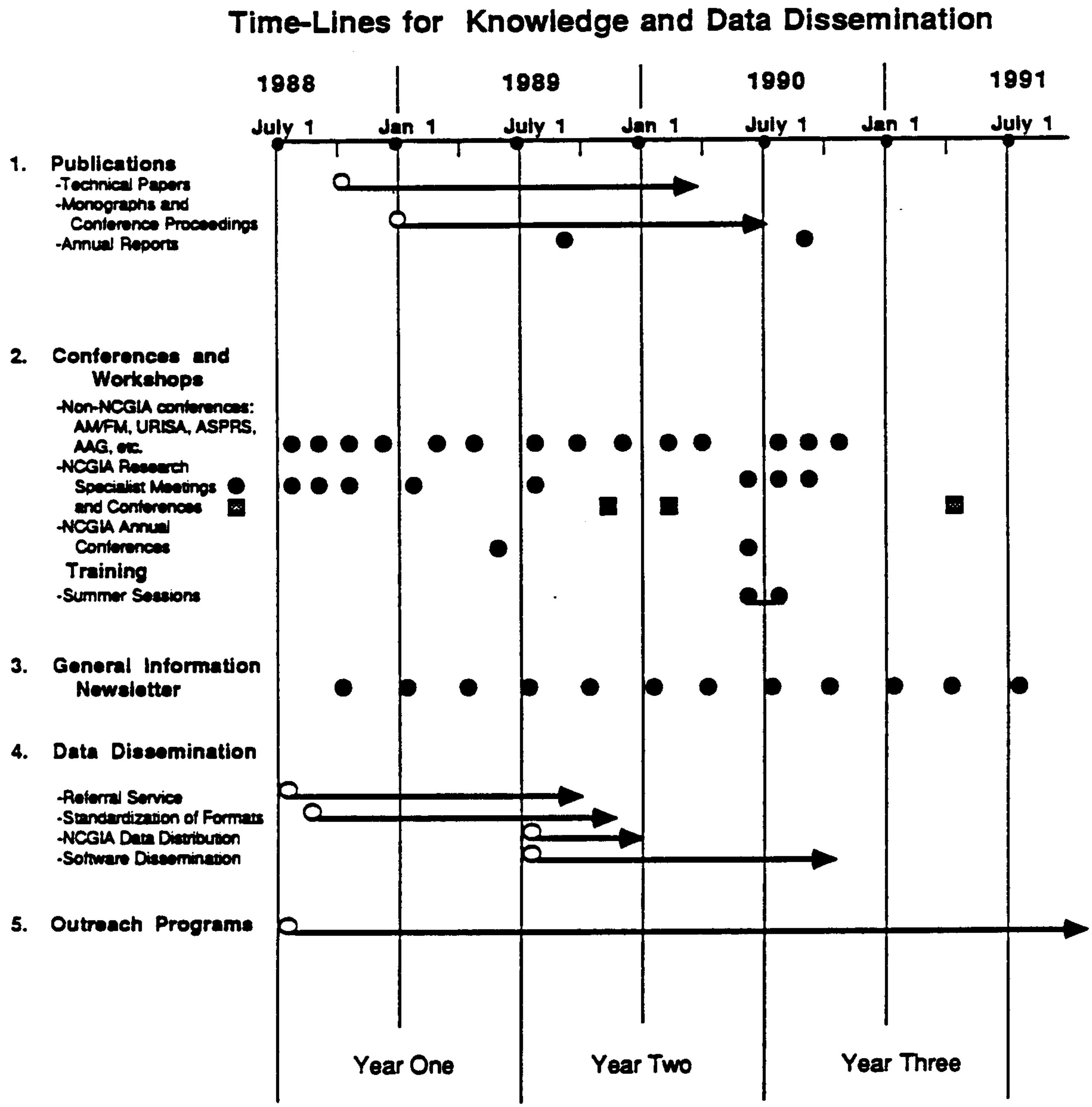
Table 5.1. Knowledge and Data Dissemination Products and Services

Products - Services	NCGIA	UCSB	Buffalo	Maine
Publications:				
Technical Papers		X	X	X
Monographs		X	X	X
Conference Proceedings	X	X	X	X
Annual Report	X	*	*	*
Newsletter	X			
Conferences - Workshops:				
GIA Community Meetings	X			
Research Initiative Meetings & Conferences		X	X	X
General NCGIA Conferences	X			
Educational Workshops & Seminars	X	*	*	*
Data Dissemination:				
Referral Service	X	X	*	*
Standardization of Formats	X			
NCGIA Database Distribution	X			
NCGIA Software Distribution	X			

The Center will assume responsibility for publicizing its own activities and for providing information about related projects in the field using its own Newsletter as well as existing professional journals. The data dissemination components of NCGIA will complement the educational facilities as both will transfer knowledge about GIA to the GIA community. The timeline diagram on the following page shows when each product or service will be initiated. Conferences and workshops sponsored by NCGIA and the GIA/GIS community are also shown as are NCGIA's dissemination roles. Every effort will be made to facilitate access not only to the end results of NCGIA research, but also to the research methods, including databases, algorithms, and information sources.

We plan to hire a dissemination specialist to carry out all the NCGIA dissemination activities and coordinate technically with the three sites. This should relieve researchers from the mechanics of knowledge dissemination and lead to a professional and effective organization.

We do not envision NCGIA as an information agency for general queries on GIS databases as this function is the charge of federal and other agencies; however, we will fulfill that role on an informal basis. Nor do we envision NCGIA as a database library that stores, catalogs, and evaluates externally generated databases, although again we will play that role on a limited basis. It is our view that a relatively limited share of the GIA/GIS Center's resources should be used for dissemination activities unless substantial additional funding for this explicit purpose can be generated. In any case, it is not clear that improved distribution of today's nonstandardized datasets would be of positive value to the community. Thus we will help to distribute descriptions of standardized formats for GIS data exchange.



2. Dissemination of New Knowledge

2.1. Publications

The goal of the publications program is to transfer information on GIA research in order to stimulate related research at other institutions and to make the research readily available to vendors and users at all levels. As a National Center, the consortium will assume responsibility for such knowledge and research dissemination and distribution and will facilitate it through three channels:

- Technical Papers series
- Specialized Monographs and Conference Proceedings

- Annual Reports

Research results will be regularly reported in professional journals or conference proceedings. Members of the NCGIA consortium will also present papers at professional meetings and publish the results of their research in refereed journals and in books. Consortium members have been extremely active in this regard. At the recent IGIS Research Agenda Conference held in Crystal City, Virginia, scholars associated with the consortium presented 18 papers and sat on three panels at plenary sessions; the three institutions rated 1, 2, and 3 respectively among academic institutions in the number of papers presented. At the GIS '87 conference in San Francisco, eight presentations were given by graduate students from UCSB alone. The new International Journal of Geographic Information Systems contained three articles by consortium members in its first two issues. This pace will increase with NSF sponsorship.

It should be noted that the research personnel involved in this consortium bring a significant and varied collection of experience to the important task of facilitating knowledge and data dissemination. In addition to their extensive publication records in major journals, faculty from consortium institutions have edited major journals (*Geographical Analysis, Papers of the Regional Science Association, Annals of the AAG, The Professional Geographer, Remote Sensing of Environment, Physical Geography, Urban Geography*), and have held numerous editorial board positions as well. They have also been unusually active in conference organization, having directed or served on the organizing committees for major International Geographic Union meetings, NSF workshops, and NATO Advanced Study Institutions.

This approach, at a low direct cost to NCGIA, will reach large audiences from multidisciplinary backgrounds, increase the visibility of NCGIA, and serve as a vehicle to generate interest in NCGIA projects. However, we also propose to augment this knowledge transfer by printing and distributing NCGIA research via the methods described below.

2.1.1. Technical Papers

The largest number of publication releases from the Center will be in the form of technical papers. Papers in this category are designed to disseminate information more quickly than scholarly journals or to distribute material not suitable for journal publication, such as tables, computer program, and bibliographies. They are specifically intended to elicit experimentation and feedback through a process more like a dialogue than a unilateral presentation of research results. Such reports may present either work in progress or work completed on a specific topic. All will be produced within the Center in a common format using the latest in desktop publishing technology. It is anticipated that each research team will produce several of these reports annually and will distribute them to all relevant constituents in their specific area as well as maintain them in a central technical report collection of the Center.

2.1.2. Monographs and Conference Proceedings

In addition to initialing in-house publication of technical reports, the Center will establish a series of monographs and conference proceedings in conjunction with a major national or international publisher. The monograph series will synthesize large research projects undertaken through NCGIA into coherent texts. It is envisioned that each of the Center's primary research initiatives will be the focus of a volume - either one edited to include distinct projects conducted by several researchers, or a monograph authored by a scholar or team working on that theme. In some instances, the authors may want to work with editors of major journals in the field to coordinate presentation of this type of volume in a special issue of the journal, again at virtually no cost to NCGIA.

Whereas the monograph series is intended to provide a master framework for specific projects under one of the primary research rubrics of NCGIA, the publication of conference proceedings will serve to assemble and synthesize work on the several rubrics of GIA. The Center will sponsor several such conferences each year in conjunction with individual research initiatives, and the principal research team members will assume responsibility for the editing and publication of their proceedings, while conforming to NCGIA protocols as they are established.

2.1.3. Annual Reports

The NCGIA will provide an Annual Report of its activities with a short version to be published in appropriate GIA/GIS journals. In some cases these reports will take the form of summaries of published research, with introductory text addressing the overall and specific missions of the Center. In others, where work in progress is not scheduled for immediate publication, NCGIA will provide an annual report on that research with at least a description of the State of the work. Non-research activities of the Center will also be summarized in the Annual Report. Each report will be deposited with NSF and made available to all members of the GIA community, until supplies are exhausted.

2.2. Conferences and Workshops

The second major facet of NCGIA knowledge dissemination will be a program of participation in national GIA and disciplinary meetings as well as sponsorship of a series of conferences on different themes. This program, like the publications component, will increase the visibility of NCGIA, stimulate related research at other institutions, broaden the scope of the GIA community, and attract scholars and students in the field.

2.2.1. Non-NCGIA Conferences

Because GIA is developing into a primary research subfield in a number of disciplines, one major aim of NCGIA is to promote dissemination of its information and research strategies through disciplinary and applied meetings. The Center will co-sponsor panels and dedicated workshops at the national and regional meetings of central professional associations in geography and regional science (AAG, ACSM, ASPRS, RSA, URISA, AM/FM) as well as those for potentially related disciplines (sociology, political science, economics, ecology, biology, geology, geomorphology, hydrology, computer science, planning and management), as financial and personal resources allow. In addition, Center personnel will attend selected user group conferences (ARC/INFO, Intergraph, Synercom, IBM GRASS, etc.) not only to publicize NCGIA activities but also to gain insight into the problems facing users in the applied fields. These meetings draw thousands of professionals who constitute the major portion of the GIA community.

2.2.2. NCGIA Research Initiative Specialist Meetings and Conferences

NCGIA, in conjunction with the research initiatives, will convene a specialist meeting early in each project and a conference at the conclusion. For the initial meeting, participation will be restricted to a relatively small number of invited specialists, drawn from different disciplines and institutions from academia, government, and industry, who will meet for one to two weeks to present position papers, critique each other's work, and chart future research projects. These meetings will thus be intensive working sessions for advanced-level scholars, and will be documented in technical papers.

At the conclusion of a research initiative, a conference will be held to present NCGIA work on the subject and also to bring in outside scholars to present their own research. One of the principal investigators from the consortium will direct each conference and prepare the resultant proceedings for distribution as a technical report or monograph.

2.2.3. NCGIA Annual Conferences

Conferences with a more general agenda will be held annually or biannually to provide a regular forum for research updates among members of the consortium and other scholars in the field. These conferences will have a tutorial as well as in information exchange function at a level not as advanced and specialized as that of the research initiative meetings. These sessions are designed to allow scholars to stay abreast of the broader field of GIA as they incorporate the perspectives of other research projects into their work on more specialized topics. The proceedings of these meetings will generally provide the basis for volumes in the more comprehensive monograph series.

2.2.4. Faculty Training Workshops

The NCGIA will host faculty training workshops, where faculty with interests in GIS topics can learn how we teach GIS courses, see how we use the course material, and get acquainted with the computer technology used. We will also advise them on potential equipment they could use. Such courses will be two to four weeks long. We will offer inexpensive housing and meal service in university facilities to keep participant costs low, and the NCGIA will cover the salaries and expenses of instructors; course fees will be minimal or nil. We will need two years to prepare the core GIS course material and test it before hosting the first such workshop. Thereafter, two workshops will be offered annually, one on the west coast and one on the east.

2.2.5. NCGIA Topical Workshops

The NCGIA faculty will offer short courses on various GIS topics at different levels. Such workshops will range from GIS overviews for industry and agency managers to introductory courses for professionals without specific

GIS background. Other workshops may treat specific topics for continuing education to GIS professionals, thus contributing to rapid dissemination of research results to practical application work. Such workshops will be of a few days' length and may be offered either in central locations (e.g., Washington, D.C.) or, when specific equipment is necessary, at the NCGIA sites. We will work with the respective university extension services which are experienced in offering professional workshops. Reduced participant fees will be charged for faculty and advanced graduate students.

2.3. NCGIA Newsletter

In order to facilitate communication between the Center and the GIA community, NCGIA will initiate a quarterly Newsletter to be distributed in both electronic and hard copy format. Each edition will include:

- Descriptions of GIA activities at each consortium institution, including research opportunities and curriculum developments
- Announcements of meetings sponsored by the Center
- Information about research projects in progress
- Listings of new publications completed under NCGIA auspices
- Reports from other centers in the U.S. and other countries
- Reviews of new GIA techniques, software, and databases

Each year one edition of the Newsletter will contain a compact version of the Annual Report. The Newsletter will also include a directory of electronic mail addresses for Center and affiliated personnel who can be contacted about specific topics. The Newsletter will be sent to all constituents in the GIA community as well as to other dissemination sources (professional journals and associations) in order to maximize distribution of its information.

In addition, a summary version of the Newsletter will be maintained as an electronic Bulletin Board, continuously updated by NCGIA staff and made accessible through all major networks (BITNet, NSFNet, ARPANet, UUCP, and possibly commercial nets). It will also be posted to appropriate Usenet news groups. This vehicle is seen as an important step in the process of developing a network capability for a major academic and professional institutions in this area. NCGIA, initially through its bulletin board newsletter, will maintain an online, updated set of information on NCGIA events and resources, bibliographies of NCGIA and related publications, and database access information. Remote users will then be able to browse through these listings as the source on current work sponsored by NCGIA.

3. Data Dissemination

3.1. Referral Service

Since faculty and staff of the NCGIA will be continuously involved in research, conferences on their work, and development of new technologies in GIA, the NCGIA will serve as in informal referral service with respect to specific inquiries from the GIA community. It is not anticipated that the Center will become an archival or clearinghouse facility, because the existence and development of literally thousands of databases would require a largely technical emphasis for the Center and a correspondingly large commitment of staff to that function alone. Rather, its commitment will be to function as a pointer service to other sources and centers whose primary roles involve archiving and distributing large datasets: the Census, USGS, and other federal, state, university, and commercial data dissemination organizations. In addition, Center personnel have close relationships with such organizations as The National Cartographic Information Center and Research Libraries Group, which are specifically mandated to serve as information sources. The Center will, as noted earlier, distribute its own educational databases.

3.2. Standardization of Data Formats

A major problem limiting the distribution and usability of GIS data sets is the lack of standardization of data formats. The Center will distribute descriptions of standardized formats to interested GIS workers and help them to select formats that facilitate data exchange. The Center will also participate in efforts to define standard GIS data exchange formats and will cooperate with others. Center personnel will work with federal agencies in their current effort for a GIS data exchange standard, and also with 1) the Inter-University Consortium for Political and Social Research at the University of Michigan, to establish a category within ICPSR's serial data collections for spatial social databases, and 2) the Research Libraries Group on standardization issues in accessing spatial research data.

3.3. Distribution of NCGIA Data

NCGIA will assume responsibility for distributing databases and documentation developed in Center projects primarily for teaching purposes. In these instances researchers and technical staff involved in specific projects will ensure that the data are complete and their documentation sufficiently clear to allow use by others. Direct distribution will be on a nominal fee basis, and the NCGIA will also deposit such data and documentation with the clearinghouses mentioned above.

The major thrust for datasets will be in the educational and testing areas. Datasets for benchmarking will be a high priority. Educational datasets will be developed to complement the educational aspects of NCGIA.

3.4. Software Distribution

NCGIA anticipates that a significant amount of both comprehensive and specialized software will be developed during the course of research undertaken in GIA. The primary concern of Center researchers is, of course, appropriate and accurate methodologies underlying their work. Thus the NCGIA Executive Committee and specific project researchers will decide when newly developed software should be refined for more general distribution. It is anticipated that agreements will be developed with commercial organizations to refine, edit for general use, and market such software. Such arrangements will maintain the focus of NCGIA on research while providing a channel for the development and distribution of quality software to a larger set of users.

4. NCGIA Outreach to the GIA/GIS Community

In order to promote the diffusion of analysis based on GIA/GIS throughout the applied and research community, NCGIA will undertake specific measures to impact the various constituencies. By combining the NCGIA educational programs with the knowledge dissemination program outlined above, NCGIA will be able to reach the majority of practitioners today. The following sections describe the outreach programs for each sector of the GIA/GIS community.

4.1. Federal Agencies

Federal agencies are at the forefront of GIA/GIS research and applications. NCGIA will participate to the fullest extent possible in research that can be applied to the needs of federal agencies. This includes:

- Efficient data structures and retrieval procedures for very large databases
- Structures for the efficient handling of both raster and vector data
- Explicit modeling incorporating both remote sensing and specialized ancillary data in a GIS environment
- Methods for handling very large, very expensive, existing databases too extensive to convert to a consistent topology
- Demonstration research in modeling of value in scientific, budgetary, and management decisions
- Demonstration project research in an explicit cost/benefit mode to provide examples of cost savings
- Real-time transfer of data to remote locations to facilitate distributed processing

Key NCGIA personnel, many of whom are already involved in federal agency research, will meet separately with appropriate agency administrators regarding research topics and requirements, financial support, personnel commitments, and the sharing of pertinent information. The process will be one of continuous contact between agency and Center administrators. It is only through this scenario that the Center can be appropriately responsive to the needs of federal agencies.

4.2. State Agencies

Due to the distributed aspect of the consortium, NCGIA will be in a position to positively impact a wide variety of state agencies in three separate states and regions. Essentially the same format will be followed as with federal agencies: individual discussions between NCGIA personnel and key personnel in state agencies. At present, UCSB has discussions underway with CALTRANS, the California Census Data Service, and the California Department of Water Resources, as well as funded research with the California Fish and Wildlife Service. Others will follow. The University of Maine is currently the focus of a statewide effort to use GIS in state agencies. Some state agencies currently use GIS software developed at the University and others are interested in cooperating with university researchers to attack the pressing problems of the state. SUNY at Buffalo has contacts with some six state agencies using or interested in GIS and with whom UB has, or could have, cooperative arrangements. The agencies are the state departments of Environmental Conservation, Transportation, Equalization and Assessment, and Parks and Recreation, the Committee on Reapportionment, and the Committee on the Siting of Low-Level Radioactive Waste Disposal Areas.

In addition, the NCGIA can reach a much larger audience by attending national conferences of state organizations such as the National Governors Conference, National Association of State Departments of Agriculture, and National Soil Conservation Societies. Key Center personnel can address these meetings and advise them on the current status and opportunities in GIA/GIS research.

4.3. Local Agencies

Many local agencies at the regional, county, and city levels have already purchased GIS software and have made substantial hardware and training investments. Such agencies are important attendees of the vendor annual conferences at which we will be represented by papers and informational booths. At these conferences we will, in conjunction with vendors, seek to keep abreast of local agency concerns, assess their research, education, and dissemination needs, and seek appropriate funding to address these concerns. Center faculty will make every effort to open contacts with local agencies in order to gauge the needs of the immediate GIS community in our service areas.

4.4. Private Sector

Outreach to the private sector will take a number of approaches. The NCGIA will:

- Develop programs to place students in the private sector on an internship basis
- Solicit private sector endowments to support a specific number of students in selected research projects
- Invite appropriate private sector personnel to fully participate in Specialist Meetings, Research Initiatives, and National Conferences
- Attend user meetings in order to ascertain user needs as well as publicize NCGIA research and opportunities to the applied community

The Center will work with individual companies to address specific requirements and solicit financial support for various aspects of NCGIA research, education, and dissemination functions, and hardware and software needs. At the time of submission of this proposal, contacts have been made with some twenty companies.

4.5. Educational Institutions

In addition to the activities discussed in the Education Plan, NCGIA will foster relations with such educational organizations as the National Council of Geographic Education (NCGE), the National Geographic Society, the Science Alliance, and the Geographical Education National Implementation Project (GENIP) to promote a renewed effort to prepare high school and undergraduate students for careers in GIA/GIS. This will include developing specialized course offerings for high schools (under appropriate additional funding), developing guidelines for prerequisites to the introductory GIS core sequence, acquainting faculty with applications and opportunities in GIA/GIS, and publicizing employment and career opportunities to students at all levels. This will stimulate high school and graduate interest in the field and will ultimately increase the number of trained professionals in years to come.

The Center will also set up an informal consulting service operated by the Director's office, which will advise smaller educational institutions on establishing and running GIA/GIS courses over and above the GIS core sequence. Modeled on the AAG Geography Department Consulting Service, this program will provide assistance to departments that do not have the resources to undertake such steps alone.

4.6. Professional Associations

The NCGIA will work closely with professional associations to coordinate GIA/GIS research. Specifically, the Center will:

- Use professional association newsletters to publicize NCGIA activities and opportunities
- Use the NCGIA newsletter to publicize professional association activities
- Organize special sessions and workshops at annual and regional meetings of professional societies such as NCGE, AAG, ASPRS, and URISA
- Have information booths at the commercial exhibit areas at annual meetings
- Encourage input from professional associations to the process and directions of research initiatives
- Work closely with appropriate specialty groups to promote the diffusion of research and opportunities

As a centralized, multidisciplinary organization, NCGIA will be able to consolidate the different viewpoints of a diverse set of practitioners. NCGIA will open and strengthen lines of communication between different disciplines. Each professional association has a certain agenda and clientele: AM/FM serves primarily utilities, vendors, and consultants; URISA is mainly concerned with land-based information systems; ASPRS is involved in the acquisition and capture of geographic data, ACSM in surveying and mapping; and so on, but all are concerned about and interested in GIS. URISA president Charles Kindleberger, writing in the October 1987 URISA newsletter, states the need for a liaison between professional associations having similar interests. The September GIS '87 conference in San Francisco and the November 1987 IGIS conference in Crystal City both demonstrated the need and possibility for such cooperation.

The NCGIA Office of Data Dissemination will undertake an active role not only in identifying the GIA/GIS aspects of professional organizations but also in emphasizing the common ground in research needs. NCGIA will make every effort to facilitate communication of specific issues between the various professional associations via participation in plenary sessions, steering committees, and specialty groups, and by input from membership. Due to its multidisciplinary nature, NCGIA occupies a unique position to effect such a process.

VI
MANAGEMENT PLAN

1. General Management for the NCGIA

The six primary goals of the NCGIA management plan are to:

- Make the center an outstanding national resource.
- Assure effective research and dissemination of results.
- Build strong programs in three institutions in the U.S. that can educate a significant share of the needed GIS personnel.
- Leverage the amount of funding available for Center research.
- Achieve a viable self-sustaining organization within 8 years.
- Assure an effective balanced use of resources, with timing appropriate to achieve rapid advances in all areas of GIA research, education, and dissemination.

Other important goals will be to:

- Strengthen graduate and undergraduate education at other colleges and universities
- Reach out to undergraduate education in the three state university and college systems and to local high schools within the three regions.
- Develop a wide range of links to the social and natural sciences and engineering faculty and to students interested in using GIA in their disciplines, especially in the three institutions, but also in other universities.

To be successful and have the desired impact, research in GIS needs to address *all* of the areas listed in the NSF solicitation. This requires cooperation between institutions, as no single university has the highly qualified research teams needed to work in all the areas listed in this solicitation. The three campuses of the NCGIA are committed to the goals expressed in the ‘rationale' section and the plans laid down in other sections of this proposal. The administration and faculty are convinced that only the cooperation of multiple groups, in the Social and Natural Sciences and in Engineering, brings the broad base necessary to investigate the intertwined research problems. The participants have strong mutual respect for each institution's contribution to the whole and understand the differences within the group. There are solid commitments from each institution to these principles. Each of the three institutions operates under slightly different policies and traditions. We believe these differences will broaden the viewpoints of the NCGIA; the management plan and administrative style described below will accommodate these differences.

Management will be crucial in the broad based approach to GIA research, where timing of individual activities has to respect distributed interdependencies and where multiple efforts compete for limited resources. It must lead to the most effective, balanced utilization of resources with appropriate timing, such that the interaction between the different research efforts leads to rapid advances in all areas of GIA research. Further, management must assure that resources are distributed effectively between research, education, and dissemination activities and balanced to achieve individual goals.

The central management concept revolves around *continuously updated plans for research, education, and dissemination.* The Research Plan, Educational Plan, and Knowledge and Data Dissemination Plan sections of this proposal are the starting point for the determination of the NCGIA's activities. They set out our initial concepts of long term goals and major priorities for timing and resource allocation. They are then developed in a more detailed plan that describes goals for the next three years and beyond in diminishing detail. Within these policies, goals can be revised and resources allocated accordingly. Periodic revision of plans allows for quick integration of new results from one area in the formation of new research directions in other areas.

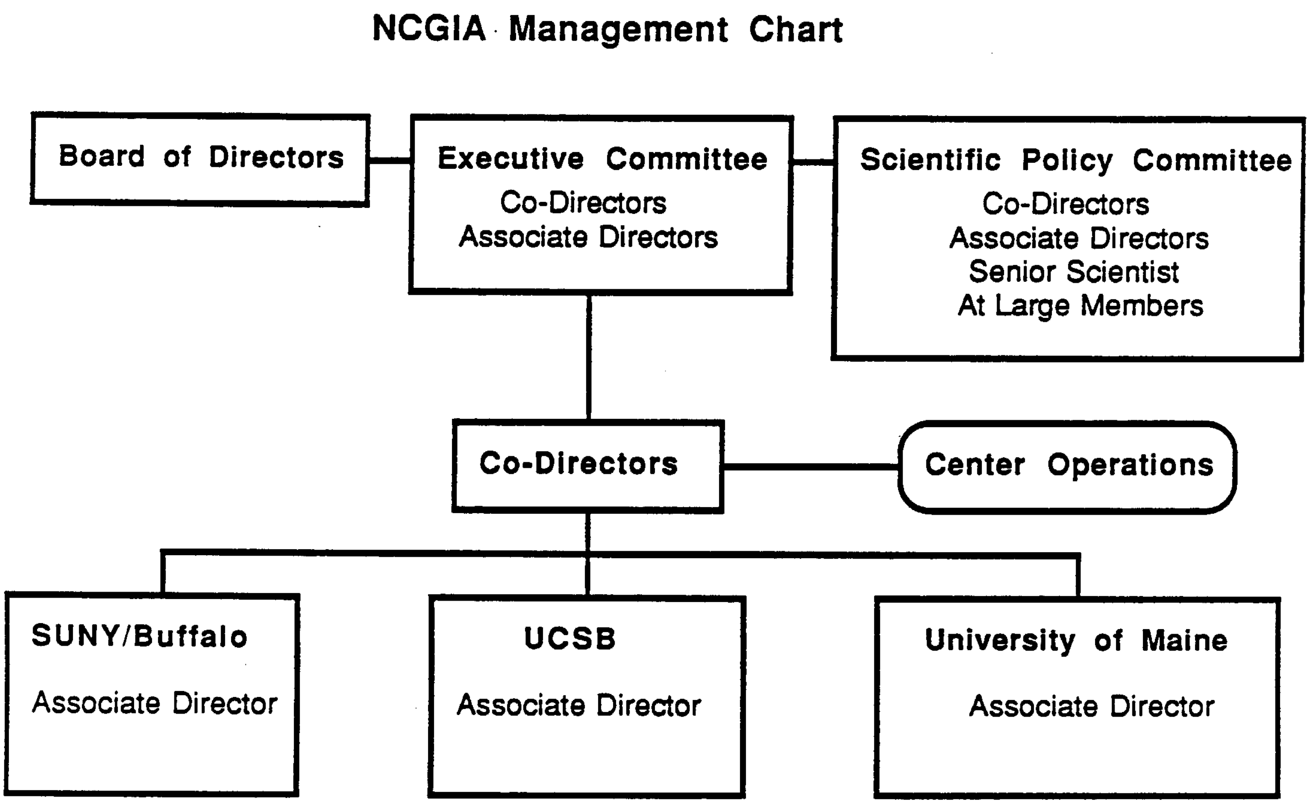
2. Management Organization

The management organization is divided into bodies that set policies and others that guide in their execution. A Board of Directors, composed of eminent external individuals, advises on and reviews Center operations. A Scientific

Policy Committee represents the Center faculty and formulates policy. The Executive Committee consists of the Center Director and the Associate Directors of the NCGIA.

2.1. The Director (Initially Co-Directors)

For the first three years of the Center, two Co-Directors, David Simonett and Michael Goodchild, will be appointed. Therefore, any references in this proposal to the 'Director' must be understood to apply to both Co-Directors during these first years.



The Director is the principal manager of the NCGIA and fills the role of the 'Project Director' identified in the NSF Solicitation. The Director makes all decisions necessary to carry out the policies set forth by the Scientific Policy Committee and the decisions made by the Executive Committee. The Director coordinates the activities of the individual campuses, integrates their efforts, and prepares the overall NCGIA budget. The Director prepares the annual report and other similar NCGIA-wide publications, and is generally responsible for distribution of information regarding the NCGIA. The Director also manages the central support activities of the NCGIA:

- The education program
- The management, coordination, and publicity of the educational activities (seminars, workshops, national announcements, etc.)
- The dissemination effort of the NCGIA
- The communication network between campuses
- The geographic data base information referral service
- Formal annual reviews of each campus operation, management, research, education, dissemination, and outreach activities.

The Director has the primary responsibility for securing additional funding for the NCGIA from outside sources and coordinates similar efforts by the Associate Directors and other faculty, as appropriate.

During the first two years of the NCGIA, Co-Director Simonett will take sabbatical leave each Fall Quarter and will devote 50 percent of that time in residence in Buffalo and Orono, assisting Buffalo and Maine in setting up training programs, establishing outreach programs with co-operating institutions, funds solicitation, and development of research proposals and proposals for private support. At Santa Barbara he will divide his time between comparable activities there and his research. During these Fall Quarters Co-Director Goodchild will manage all other aspects of the operation of the Center.

At other times during the first two years the division of responsibilities between Goodchild and Simonett when both are present at Santa Barbara will be broadly as follows, with each having an oversight role with respect to the other's responsibilities:

Goodchild:	Simonett
Fund Raising (shared)	Fund Raising (shared)
Annual Reviews (shared)	Annual Reviews (shared)
Budget (shared)	Budget (shared)
Annual Reports	Education
Publications	Dissemination
Networking	Data Base Referral Service

If the position of Director, for any reason, should fall vacant, the new Director will be chosen by the Executive Committee, in consultation with the National Science Foundation.

2.2. Associate Directors (ADs)

Each Associate Director manages the local operation of that institution's locally established Center for Geographic Information and Analysis (CGIA) and is responsible for maintaining appropriate contact with both the NCGIA and the local campus administration. The Associate Director makes all day-to-day decisions regarding local operations within budgets and policies set forth by the Executive Committee and the Director. The AD assigns research assistants to research initiatives and decides (in consultation with the Director) on Senior Visiting Scientist appointments and assignments. Each AD prepares the local CGIA budget and manages all local resources. Each AD reports every month to the Director on all activities within the campus CGIA and meets regularly every month with local center faculty.

The Associate Director organizes and supervises research at the local CGIA; meets regularly with faculty team leaders and supervises their management; determines the needs and allocation of resources within the budgetary limits; and coordinates the NCGIA efforts with the degree-granting departments and organizes the educational offerings of the CGIA.

In respect to technical papers, initiative leaders have the first round of editing responsibility, but the AD performs final editing - or assigns such editing responsibilities to appropriate persons - and ensures that edited camera-ready copy is forwarded to the Director's office for reproduction and distribution. The ADs maintain relationships with industries, users, and agencies in their areas and actively seek opportunities for additional funding for the campus CGIA. Each CGIA has primary responsibility within its own region. The ADs' tasks are coordinated through the Director to avoid competition between the CGIAs and to respect previously established relationships.

As with the Director, the Associate Directors are nominated by the Executive Committee and the respective center faculty with the final appointment being approved by the appropriate senior administrative officer at the local university. Initially the Associate Directors are to be Andrew Frank (UM), Ross MacKinnon (UB), and Terence Smith (UCSB).

2.3. The NCGIA Senior Scientist

The Senior Scientist is an eminent researcher from one of the campuses who maintains contacts with the international scientific community. The Senior Scientist advises the Director and Associate Directors on research issues and individual researchers who may ask for advice as need arises, and is also a member of the scientific policy committee.

Initially, the NCGIA Senior Scientist is to be Waldo Tobler (UCSB). Selection of the Senior Scientist is by the Executive Committee, and is initially for a three-year term, subject to renewal.

2.4. The Executive Committee

The Executive Committee consists of the NCGIA Director (initially Co-Directors, with one vote collectively) and the three Associate Directors. The Executive Committee decides on all NCGIA matters which are not within the purview of the Director or one of the Associate Directors. Decisions are made following rules and regulations of NSF and the individual universities and accepted methods governing the management and conduct of research and higher education.

The NCGIA Senior Scientist will be invited to the meetings of the Executive Committee as a non-voting member.

The Executive Committee meets in conjunction with the Scientific Policy Committee for two meetings and also for two additional meetings, in Santa Barbara in spring and alternately in Maine or Buffalo in fall for a total of four meetings per year. The Executive Committee decides on allocation of resources to research and other initiatives as laid out in the respective plans. Additionally, the Executive Committee can reach decisions using conference calls or unanimously by individual polling by the Director. Any action coming to a vote would require at least three supporting votes. The Executive Committee is the final decision point for research initiatives, their phasing in time, and their effective employment of human and other resources. The research initiative team leaders must manage their research with consultation with the local Associate Director and with the Executive Committee. The Executive Committee is charged with critical overview and evaluation of the operation. At each of its four meetings, the Committee will consciously review all aspects of the NCGIA *in an oversight mode*. The Committee is also charged with gathering concerns at each site for examination, remediation, or new action, as needed.

Each meeting of the Executive Committee will formally review:

1 The status of research
2 The status of documentation
3 The status of publications and educational efforts
4 Budgetary concerns: Matching funds; Outside funding; NCGIA allocations
5 Special seminars/conferences
6 Decisions on research associates
7 Time-lines for reviews
8 Each site's facilities and progress
9 After each Executive Committee meeting personnel at each site will gather for a general informational meeting to keep everyone informed of the activity at other sites.

2.5. Scientific Policy Committee

The Scientific Policy Committee consists of representatives of the faculty from the member campuses, the Director, the Associate Directors, and the NCGIA Senior Scientist. There will be a total of nine members, with four representing UCSB, three from Buffalo, and two from Maine. Each campus will develop a procedure whereby its representatives on the Committee are selected for renewable terms of two years.

The Scientific Policy Committee will meet twice a year, just before and after the Board of Directors. The Committee decides on the policies guiding the research, education, and dissemination activities of the NCGIA, and annually updates the research plan, the education plan, the dissemination plan, plans for facility enhancements, and plans for obtaining external support from institutional, industrial, and governmental agencies for the Center. Prior to this meeting the Committee will prepare position papers for the Board of Directors to consider. The Committee will then respond to comments and advice from the Board. This meeting format, straddling the Board of Directors meeting, will allow maximum interaction between the two groups and speedy processing of proposals.

Proposals for changes to the plans for research, education, dissemination, facilities, and support can be made by the Board of Directors, research faculty of the Center, or faculty from other universities, as well as from other parties interested in GIA research. Proposals may be either in the form of position papers, asking for a discussion in the Scientific Policy Committee without proposing concrete action, or motions to amend the plan by adding, deleting, or changing parts of it. Such a process is necessary to ensure well-formulated updates of plans in limited time intervals. The Scientific Policy Committee endorses any changes in the short term and long term plans for research, education, dissemination, and other aspects of the Center's operation.

Initially, the Scientific Policy Committee will be composed of David Simonett (UCSB) and Michael Goodchild (UCSB), Co-Directors; Andrew Frank (UM), Ross MacKinnon (UB), and Terence Smith (UCSB), Associate Directors; Waldo Tobler (UCSB), NCGIA Senior Scientist; and Barbara Buttenfield (UB), Earl Epstein (UM), and David Mark (UB).

2.6. Board of Directors of the NCGIA.

The Board of Directors is drawn from representatives of all aspects of the GIA/GIS community and will assure the input of a broad spectrum of researchers, private and government agencies, user organizations, and professional associations. The Board of Directors discusses and forwards comments and proposals regarding Center activities, especially any suggested changes in Center research priorities, to the Scientific Policy Committee and Executive Committee.

The Board of Directors will advise the Scientific Policy Committee on long term goals and revisions of the plans for research, education, and dissemination. It will advise the Executive Committee on management issues and bring to their attention opportunities for center activities, funding opportunities, co-operative research, and appropriate new initiatives. It will review and comment on the annual report of the NCGIA before it is forwarded to NSF. It will appoint a subcommittee for an annual follow-up review of the Center's management efficiency, and research, education, dissemination, and fund solicitation enterprises.

The Board of Directors will meet twice annually, in winter in Santa Barbara and in summer alternately in Buffalo and Orono. The meetings of the Board will be organized and chaired by a non-voting senior faculty member or the consortium, initially John Estes of UCSB.

Members of the Board of Directors will represent highly visible GIA contributors with national and international reputations, e.g., federal officials at the Assistant Director level and scientists from the National Academy of Science. They will represent the broad GIA community as well as the major user groups. The fifteen members of the Board will be selected, in roughly equal numbers, from the following groups:

- Universities
- Federal agencies with strong interests in GIS research and development
- Private industry (e.g. hardware and software vendors; major corporations; consulting companies)
- State and local governments representing user groups
- Professional associations and non-profit organizations with interest in GIA/GIS research, education, and dissemination.

Members of the Board of Directors will be asked to serve for three year terms, although the initial terms will be staggered in 2, 3, and 4 year terms to create an even turn over thereafter of one-third annual replacement. The original Board members will be selected by the Executive Committee after extensive consultation with the National Academy of Sciences, Federal agencies, professional societies, and other appropriate parties. Replacements will be selected by the Executive Committee, with advice from the current Board of Directors and the Scientific Policy Committee. Nominees will be solicited annually by letter from the Director to interested organizations and professional groups.

2.7. Research Personnel

All other researchers associated with the NCGIA will be divided into the following categories:

Center Faculty: Tenure track faculty at one of the three institutions with strong interests in GIS/GIA and the research issues described in the research plan.

Senior Scholars in Residence: Senior faculty from other universities or scholars from private firms or public agencies. Senior Scholars will work for several months or more on one of the NCGIA topics described in the research plan.

Visiting Scholars: Junior faculty from other universities, postdoctoral researchers, and junior research personnel on leave from private or public institutions, working on one of the Center's research initiatives, or participating in one of the center's educational development programs.

Research Assistants: Graduate or advanced undergraduate students working on research topics within the interests of the NCGIA.

Distinguished Consulting Scholars: Outstanding researchers from other universities and from private firms and public agencies. They are invited on a short term basis to participate in research projects within the NCGIA on topics of mutual interest. There are no disciplinary or national restrictions that would limit such invitations.

Research Center Staff: Center Researchers, appointed to staff research positions at one of the Center institutions.

The organizational chart on the following page shows how their research teams will be organized.

The mechanisms for selection of the above groups are respectively as follows. *Center Faculty* are self-selected simply by involvement with or without salary with any center research or educational initiative. *Senior Scholars in Residence* and *Visiting Scholars* apply for selection for involvement in a research or educational initiative as advertised in a range of professional journals, up to two years in advance of the relevant initiatives. Selection is by the Executive Committee, acting at any one of its quarterly meetings with input by the local Associate Director. *Distinguished Consulting Scholars* are chosen by the Executive Committee and are invited by the Director to be a consultant to one or more research initiatives requiring their expertise. *Research Assistants and Center Research Staff* are employed on a research or educational initiative at one of the Center campuses.

3. Management of Research

The Research Plan identifies major topics for research. The major research topics are subdivided into *Research Initiatives* which require interdisciplinary work and participation by faculty from more than one campus, and often involve university, government agency and private sector participants from outside the consortium. Research Initiatives will usually extend from one to two years and either terminate as their goals are achieved or are reformed as findings dictate. We plan to have about four to six concurrent Research Initiatives underway in the first two years, with additional initiatives being added in subsequent years as additional resources become available. Resources are allocated to these Research Initiatives by the Executive Committee within the guidelines set by the Scientific Policy Committee.

Research Initiative topics will be widely publicized in advance in professional journals and at workshops, national conferences, and vendor interest groups, to attract the attention of interested researchers. Scholars in Residence and Visiting Scholars will be selected depending on their potential for contribution to one of the Research Initiatives currently active, or to one intended for initiation in the following year(s).

A Research Initiative typically consists or a number of research subtopics which closely interact and where work in one area should influence and advance work in others. A Research Initiative typically consists of Specialist Meetings, Working Groups undertaking intensive research, in-progress seminars (as needed), and a national or international Conference.

Specialist Meetings: The major goals or the Specialist Meetings are to clarify the topic and its relation to the overall NCGIA goals and to set the research agenda for working groups. These meetings will be one to two week workshops allowing for discussion among Center faculty, other NCGIA personnel, Distinguished Consulting Scientists, and specialists from academia, industry, and government agencies.

A Center faculty member will lead each Research Initiative. The leader is expected to coordinate activities, have a major interest in the topic, and personally contribute to it. The leader of the Research Initiative organizes the Specialist Meeting and coordinates preparation or position papers and presentation of results. The leader is responsible for the compilation of the workshop report which contains the papers presented and major results from the discussion. The reports are essential for communicating to others the emergence of new topics and goals for research.

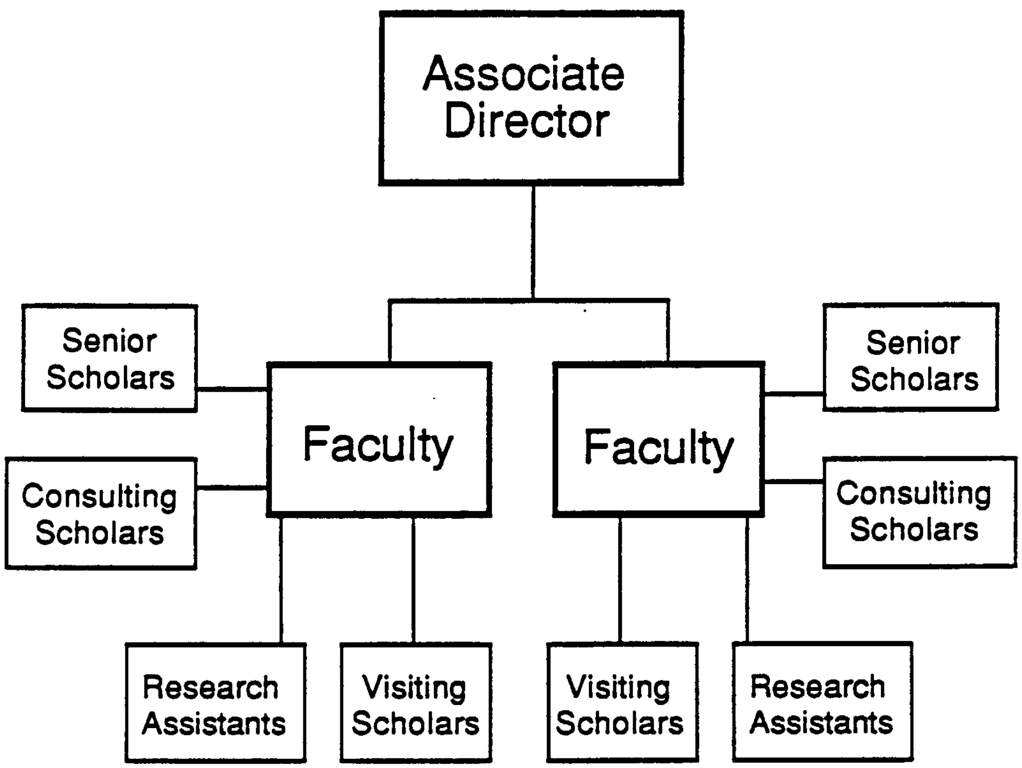
The preparation for each Specialist Meeting will be carried out by the Initiative leader and other Center personnel. Preparation will include inviting participants, soliciting position papers, collecting of relevant papers and developing bibliographies, and handling local arrangements.

Working Groups: The leader of a Research Initiative is assisted by a team of the Center Faculty and Senior Scholars in Residence who are expected to organize and work on individual topics within the Initiative. It will be common for participants to be members of more than one Initiative, further encouraging interaction and coordination between the Initiatives.

The team members organize the work on the individual topics typically by working with junior scholars and research assistants. Graduate student research will be coordinated with these research activities and should lead to Master's Theses, Ph.D. Dissertations, and publication in professional journals.

The leader prepares a research plan and budget, and requests resource allocation through the Associate Director of the campus. Team leaders are responsible for supervising their collaborators, for the management of the resources allocated to their Initiatives, and for the preparation of intermediate and final reports.

Research Team Makeup



In-Progress Seminars: Research Initiatives may expand into new areas as research progresses, through special In-Progress Seminars of two to four days duration. Such seminars would bring together a group of scientists with different views on a topic, both from within the NCGIA and from outside. Seminars may be organized to clarify an interdisciplinary effort, to identify future 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: Initiatives will typically culminate in a national or international conference or in special sessions at major professional meetings, in order to disseminate the results to a broader audience and discuss them with other researchers and users. Such conferences will ensure that the demands from the practical and application-oriented GIA community are recognized and influence further work.

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 directly relevant to the missions of 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 newly opened problems and thus will provide impact for changing the long term research plan of the Center. Management of New and Outgrowth research will involve coordination of grants and contracts obtained by single investigators with larger multi-person, multi-campus research.

Management Involvement: Effort will be made to expose personnel on all levels to management functions in order to train them for increased responsibility. This will require a participative style of management, clearly recommended for management of research with additional supervision and help from the senior personnel. We see this as benefiting graduate students in learning to write research proposals under the supervision of faculty members, younger faculty invited to direct large research initiatives under the auspices of the Director and CGIA, Associate Director, and for the training of research managers with the help of the Director and Senior Scientist.

4. Mechanisms for Defining Center Research, Education, and Dissemination Activities

The mechanisms for defining center research, education, and development activities have been mentioned earlier, but are so vital to NCGIA operations that they are reiterated here. They revolve around a general plan which is gradually refined into a detailed short term plan for each topic. The first general and short term plans form the respective sections of this proposal. The plans will be subject to review and may be revised at each meeting of the Scientific Policy Committee.

Proposals for discussion of trends and formulated proposals for amendments to the plans can be made by the Board of Directors, Center Faculty or other interested parties. The Board of Directors can and the Scientific Policy Committee must discuss all proposals received. After discussion with the Board of Directors, the Scientific Policy Committee decides on changes to the general plan, which should cover goals for a period of from five to ten years. The short term plan sets goals and activities for the next three years. The short term plan indicates the order in which topics will be treated and describes the research initiatives. The mechanisms for updating this short term plan are the same as for the general plan, with advice primarily from Center faculty.

The flow chart on the following page shows the annual NCGIA activities that define the research initiation, solicitation, reporting, and review procedures.

5. Other Management Issues

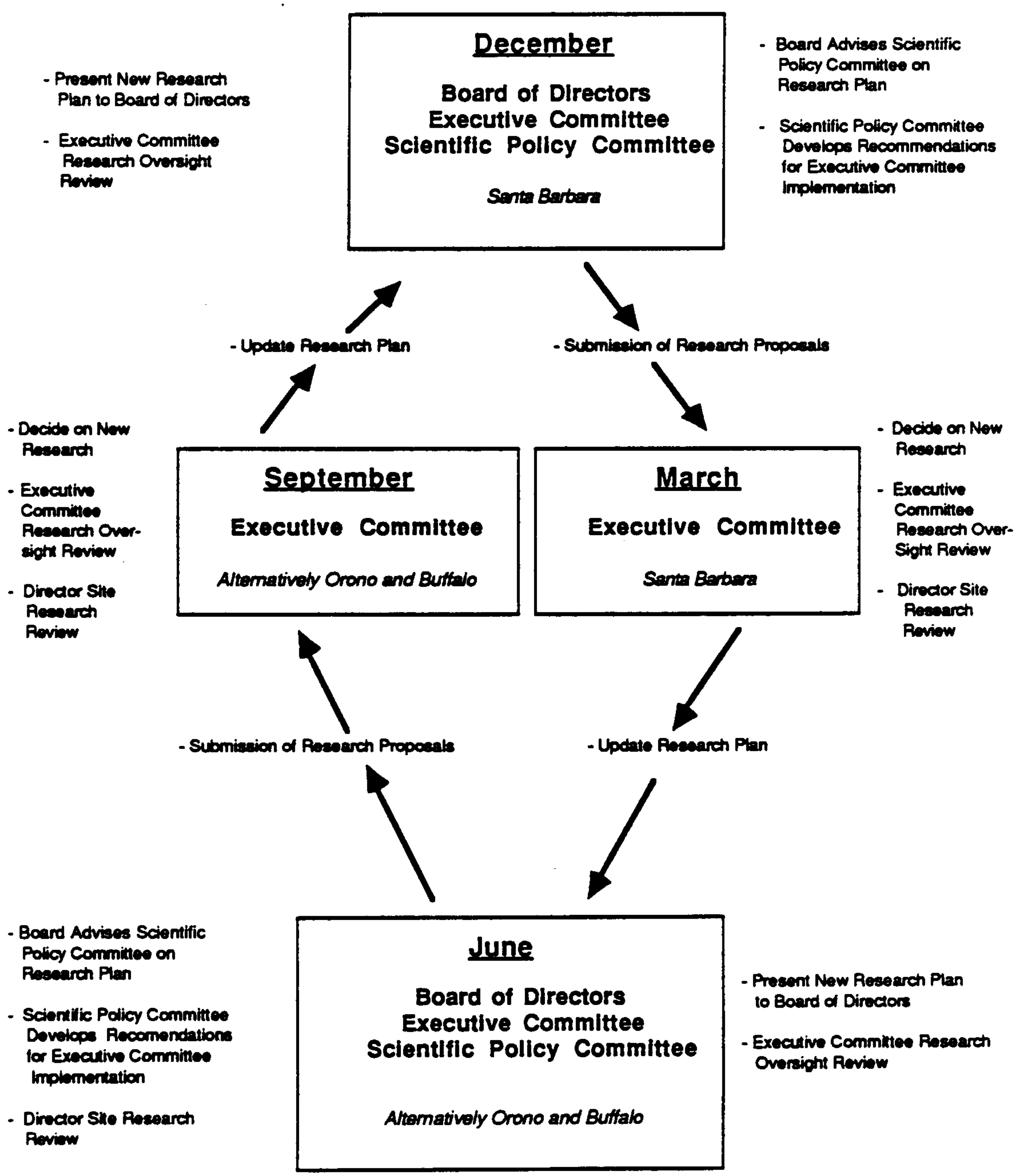
5.1. Managing External Relations:

5.1.1. Obtaining External Funds:

NSF funding will be only the beginning for NCGIA activities. We have already begun to solicit grants and support from private enterprise, the public sector, and foundations. We reiterate here that the consortium institutions already have significant in-place funding for both basic and applied GIS analysis; our intent is to build on this strong base. Each local CGIA will continue to organize and develop its own funding program with input and advice from the Director, the Senior Scientist, and the faculty member who is currently chair of the NCGIA Board of Directors. The Director will assist all components in providing models and background experience to each site in regard to funding, and where appropriate will coordinate joint funding and research initiatives involving two or more of the sites. No less importantly, the Director will also take the initiative in solicitation to benefit the Center as a whole.

Mechanisms For Defining Center Research Activities

Research Initiation, Solicitation, Reporting, and Review Schedule



5.1.2. Extending the Influence of the Center

In order to extend the influence of the Center to the social and natural sciences as well as the commercial and public sectors we will:

- Distribute information on NCGIA activities and opportunities to other universities, junior colleges, and high schools.
- Develop explicit plans for work with local high schools, junior colleges, and state and private universities within a reasonable distance for co-operation with each of the three institutions. Such plans are partially in place at this submission; more will be available at the time of a possible site visit.
- Develop training courses for the social and natural sciences, as a follow-on to the development of the one-year sequence, with theory, models, and applications appropriate to the disciplines in question.
- Initiate a minority and traditionally under-represented group outreach program, following the very successful Mentorship Model Program developed by Simonett and colleagues in the Graduate Division at UCSB.
- Organize and conduct workshops and/or panel discussions regarding GIA/GIS at professional meetings of leading learned societies in the social, behavioral, natural, and applied sciences.

5.2. Managing the NCGIA Educational Activities

The NCGIA Director will manage the educational role of the NCGIA, by coordinating the efforts of the local CGIAs and appointing individual faculty members or teams to work on the development of the course materials for the initial GIS year-long undergraduate sequence, and for subsequent educational course development and refinement initiatives. The Director will also work with faculty to organize workshops for the GIA profession on special topics. The NCGIA staff, under the supervision of the Director, will support the organization of the workshops.

The CGIA Associate Directors will supervise the local organization of all educational activities. They will cooperate with the Director to help the faculty prepare the GIS core course sequence material and teach GIS courses. They will also facilitate the local organization of the workshops. As with the research plan, the Board of Directors will advise on educational activities, the Scientific Policy Committee will set policy and priorities, and the Executive Committee will allocate resources.

5.3. Managing the Knowledge and Data Dissemination Activities

The NCGIA Director will manage the knowledge and data dissemination activities of the NCGIA. He or she will appoint and supervise a professional staff member to perform the necessary work. The Director coordinates the activities of the individual campuses.

The Associate Directors of each CGIA will cooperate with the NCGIA staff person, providing data and reports in a consistent and edited format appropriate for further dissemination. All documents and reports that are to be disseminated will be archived at the NCGIA lead center in Santa Barbara. The Associate Directors will also organize local dissemination activities. As with the research plan and educational activities, the Board of Directors will advise on data and knowledge dissemination activities, the Scientific Policy Committee will set policy priorities, and the Executive Committee will allocate resources.

5.4. Management of Communications between NCGIA Components

Effective communication is the key to effective management. To manage research effectively, a good balance between formal reporting and informal exchange of ideas must be found.

Guidelines for concise formal reporting will be established by the Director and be used to report progress in research at all levels: graduate students will discuss their progress weekly with the research leaders, and receive new assignments; research leaders will meet every two weeks with the Associate Directors, to review their research as a group; and Associate Directors will report monthly to the Director on progress and on research, and educational initiatives and management issues. Regular meetings and the practice of "management by exception" will reduce interventions by supervisors to special instances.

As good personal relationships are established between the parties, telecommunication means can be used very effectively to bridge the distance and to informally exchange ideas and documents. We have identified electronic mail as the most effective means of telecommunication and will continue to use it extensively for the exchange of documents and for informal discussions. A considerable number of the faculty involved in this proposal have collaborated closely with researchers at other sites and produced jointly authored articles and research proposals. Electronic mail and remote login will also be used for the exchange of data and programs between the centers. Obviously for certain discussions that need immediate exchange, the telephone will be utilized.

The Director will appoint a 'network specialist' to organize and coordinate the electronic communication in the NCGIA and help and advise the local CGIA on the best usage of these facilities. Each CGIA will have a local 'network specialist' who will coordinate with the NCGIA specialist and help researchers with all communication problems and maintain the local network.

5.5. Management of NCGIA Computer Systems

Research in the GIA area relies heavily on the use of computer systems. Such systems need careful attention in order to remain manageable, as a simple acquisition of hardware may have complex ramifications for both the operating systems and the programs used, and may thus invalidate existing expertise and make extensive relearning necessary. The cost of computer systems includes not only acquisition and maintenance, but also the cost of training people on the new system and keeping them current. Two of the Associate Directors (Smith and Frank) have extensive experience with the management of computer systems and the selection of appropriate systems for different tasks.

The principal guideline for the management of computer systems will be the minimizing of the number of different systems used, in order to keep the effort concentrated and avoid unproductive relearning. The NCGIA will primarily use the UNIX and Digital Equipment Corporation's VMS Operating Systems. Both systems will be operational at each location so that programs and data can be easily exchanged. In addition, researchers and students will be provided with ready access to personal computers (PC or Apple Macintosh) for appropriate tasks.

The primary systems will be accessed through personal workstations with considerable local computing power and high resolution color graphics, linked in local area networks sharing peripherals such as laser printers, plotters, large disk storage and connections to other universities. All three NCGIA universities already use such networks. In addition, the electronic mail available through these systems can be used very productively for scientific discussions and for management. Together with the long distance networks (NSFNet, BITNET, etc.), this new work environment reduces the physical distance between locations into only a minor factor in the cooperation between researchers.

Furthermore, we will organize the acquisition of commercial grade GIS and similar systems such that effective testing and benchmarking is feasible without undue maintenance efforts. At the current time, systems like ARC/INFO will be used in all locations for teaching and research except at the introductory undergraduate level where simple systems also have a role to play. More specialized systems such as Intergraph, Synercom, IBM's GFIS, and image processing systems will be available at one or more of the member institutions, depending on major research or educational needs.

The NCGIA is determined to create a very high quality, advanced technology environment for productive research, minimizing the researcher's effort in using computers. This involves not only the acquisition of powerful hardware and software, primarily in workstations, but also includes the technical support personnel necessary to maintain the systems at each location, thus improving effective access and usage.

In the current age of rapid technical development in computer science, regular hardware updates are essential. Each year, more powerful and less expensive hardware is usually on the market. Hardware that is bought before personnel are in place usually becomes outdated before it is used. Since resources that are expended too early are often thus essentially wasted, we will coordinate hardware purchases for research closely with the Research Initiatives.

Hardware and software will be used for both research and education to make the most effective use of expensive resources. Cooperation with hardware and software vendors will be sought to obtain significant discounts and early access to new systems. All three NCGIA institutions are beta test sites for a number of programs and enjoy favorable terms from the respective vendors.

6. Management Issues Specific to Santa Barbara

6.1. Organization of the Santa Barbara CGIA

The Santa Barbara CGIA will be formed as a Center within the College of Letters and Science, and will report directly to the Provost of Letters and Science. The University has made a commitment to hire additional faculty in GIA/GIS studies regardless of the outcome of the NCGIA proposal, and will provide basic funding for the administration of the Center for the first two years. The Deans of Engineering and the Instructional Development have pledged additional financial support during the first two years. Thereafter, extra-mural funding sources will be developed. The Center's primary strength will come from the existing group in Geography and Computer Science, but will also include faculty from social sciences, natural sciences, and engineering. (See Appendices A and B)

The primary mission of the Center for Geographic Information Analysis at Santa Barbara will be twofold: to carry out theoretical and applied research in GIA/GIS; and to strengthen the educational programs located in the Departments of Geography and Computer Science. Close contact will be maintained between the groups engaged in theoretical and applied research through regular meetings of all center faculty. The Center will provide a forum for the exchange of ideas between UCSB faculty and groups interested in GIS and for cooperation in education, research and outreach. The CGIA will also formalize contacts with CIA users in California, including state and local government agencies and private companies.

The organization of the unit will follow the format of the highly successful existing centers which report to the Dean of Engineering. The Center for Geographic Information and Analysis will use the in-place research office staff of the Department of Geography, but will maintain some autonomy in accounting, budgeting and reporting. The Director of the Santa Barbara CGIA will also be the Associate Director of the NCGIA. He or she will be responsible for overseeing UCSB site operations and coordinating UCSB activities with those of the other members of the consortium. The Director will be nominated by the Center faculty, approved by the NCGIA Executive Committee and appointed by the University administration. A local board composed of the other three UCSB members of the NCGIA Scientific Advisory Committee and representatives from associated fields will advise the Director.

Equipment acquisitions will be housed in space dedicated to the NCGIA, and in other sites, including the geography and computer science departments, the Map and Imagery Library, and other sites as specified in the section on facilities. New equipment will be networked with existing equipment and made available for teaching and training programs.

6.2. Evaluation Procedures for the Santa Barbara CGIA

The Provost of Letters and Sciences will appoint a faculty advisory committee which will produce an annual report on the operations of the local Center. The University has established review procedures for its Centers which will be used to review the CGIA regularly. These procedures follow accepted academic standards and consider the quality of research and publications that result, the education of graduate students, and the services rendered to groups outside the University.

6.3. Promotion and Tenure Practices at the Santa Barbara CGIA

Normal promotion and tenure practices of UCSB will be followed for all academic personnel engaged in research and teaching in conjunction with NCGIA. Some of the academic participants in the Center will engage in interdisciplinary work and hold joint appointments. These cases are reviewed separately by each department, with the joint submissions being considered by reviewing agencies (Dean, Ad Hoc Committee, Committee on Academic Personnel, Vice Chancellor, and Chancellor) for tenure, promotion, and merit review. The University is committed to fair treatment of all faculty and to due process, and encourages inter-disciplinary research.

7. Management Issues Specific to Buffalo

7.1. Organization of the Buffalo CGIA

The structure and operation of the Buffalo CGIA already exist, with substantial university support, as the Organized Research Center on Geographic Information and Analysis. The University at Buffalo established this ORC in the spring of 1987 with funding from three sources: Research Development Funds, the Office of the Provost, and the Dean of Social Sciences. The ORC is structured to facilitate both teaching and research programs in GIA. The Director of the ORC is currently the Dean of the Faculty of Social Sciences. In his role as Director, he reports to the Vice Provost for Graduate Education and Research. In its initial period of operation, the Center has expanded the facilities and activities originally housed in the Geography Department to include components basic to the proposed NCGIA site at Buffalo.

Current members of the Buffalo CGIA include five geographers, three computer scientists, a linguist, an anthropologist/archaeologist, two psychologists, and two engineers. Two new appointments in Geography will be filled this year by people who will be active members of the Buffalo CGIA. New faculty will have the opportunity for appointments as adjuncts with the Center, while research appointments will be made directly through the Center.

The ORC will coordinate a number of efforts supported totally or partially by NCGIA, including:

- curriculum (including degree program development and changes, visiting speakers, graduate student recruitment and advisement)
- research (including proposal development, coordination of teams, invitations to visitors)
- conferences and workshops (including developing and implementing events held at Buffalo)
- community/government liaison (including coordination of funded projects and presentations to relevant local and state agencies)

Special care will be taken to integrate new Center programs with instruction and research programs in participating departments:

The NCGIA Associate Director from Buffalo will be responsible for overseeing local operations and coordination local activities with those of the other members of the consortium. The other two Buffalo members of the NCGIA Scientific Advisory Committee will also be members of the Buffalo ORC advisory board, along with the chair of the department of geography and representatives from computer science, Engineering, and Anthropology.

New equipment will be housed in space dedicated to the NCGIA adjacent to the Geography Department. They will be networked with existing equipment and made available for teaching and training programs.

7.2. Evaluation Procedures for the Buffalo CGIA

The University has established specific procedures to be followed in evaluating the performance and continued status of Organized Research Centers. An annual review takes place, during which a report on research, conferences and symposia, guest scholars, curriculum development, publications, and grant activity is provided to a review committee. That committee is responsible for requesting additional data, meeting with Center personnel, and making recommendations for further University support.

At five-year intervals, each ORC will undergo a more rigorous and extensive review. At that point the ORC's performance in attracting significant external funding assumes an important role in determining whether the Center should continue on a research basis, shift its emphasis to internal University functions of teaching and interdisciplinary faculty coordination, or be downgraded to an informal grouping of interested university members.

All reviews are undertaken by committees which cross departments and Faculties and which include relevant administrative personnel from Academic Affairs and the Office of Sponsored Programs.

7.3. Promotion and Tenure Practices at the Buffalo CGIA

The University at Buffalo maintains its program of multidisciplinary centers within an academic structure based on disciplinary departments. All academic appointments will continue to be made primarily in one department or jointly between two departments. Research faculty, appointed on a term basis, may be appointed directly to the Center. The latter category will not mirror tenure-track appointments, but will provide short-term positions for research and training.

Faculty with interests in GIA will be appointed as adjunct faculty in the Center. In order to ensure that their Center activities are given appropriate credit in tenure and promotion decisions, the Director of the Center will maintain a file on all adjunct personnel documenting on an annual basis research grant activity, publications through the Center, teaching done under the auspices of the Center, university service emphasizing committee and development work. That information will be included in the faculty member's personnel file for consideration in tenure and promotion decisions.

8. Management Issues Specific to Maine

8.1. Organization of the Maine CGIA

The University of Maine is currently in the process of establishing an organized research unit called the 'Center for Geographic Information and Analysis.' It will have basic funding from the University for its administration, and will report directly to the Vice President of Research. The university has targeted GIS studies as a focal point for development on campus, so the center will be established independently of the outcome of the NCGIA proposal. The Maine CGIA will cooperate closely with the Surveying Engineering Group. The organized research unit will concentrate on GIS research and application, and possibly graduate education, while the Surveying Engineering Group continues its undergraduate program with a strong GIS emphasis and graduate programs in all aspects of surveying engineering as well as in GIS. Students may also pursue M. Sc. or Ph.D. degrees with a special concentration in GIA/GIS topics within the Department of Forestry. The research unit and the Surveying Engineering Program will share faculty and other resources and will be located in close proximity to each other. Departmental course development will also take into account the presence and goals of the CGIA and NCGIA.

The missions of the unit are research in theoretical areas of GIA and research to promote the application of GIA technology. This unit will group together various interests in GIS on campus and provide a forum for exchange of ideas and cooperation in education, research, and outreach service. The Center's primary strength will come from the existing group in Surveying Engineering, but will include interested faculty from Forestry, Economics, Computer Science, Mathematics and other departments and Centers.

The organization of the unit will be modeled on that of the University's highly successful 'Institute for Quaternary Studies,' an interdisciplinary group of geologists, anthropologists, biologists and oceanographers. Like this Institute, the Center will maintain some autonomy in accounting, budgeting and degree granting. It will cooperate with the 'Land and Water Resource Center' at the University, and will benefit from using their highly experienced personnel for accounting and technical communication. The Director is nominated by the Center faculty, confirmed by the NCGIA Executive Committee, and appointed by the University administration. The Director will be directly involved in specific Center research projects and also knowledgeable about the breadth of the research and applications carried out by the Center. He or she will also be appointed as one of the Associate Directors of the NCGIA. The Center faculty will also select the additional member of the Scientific Policy Committee of the NCGIA.

The Maine CGIA will develop liaisons with representatives of government, private industry and universities from the state of Maine and the New England area. They will advise the Maine CGIA on research opportunities in the New England area and on new applications, assist with technology transfer, and help to direct the dissemination and educational activities for the region's best advantage.

The CGIA will organize workshops and seminars to address GIS topics and disseminate research results to the university community and GIS user groups. The CGIA will also be a formal point of contact for GIA users in New England, such as state agencies, local authorities, and forest companies. For an annual fee, these users will receive information about ongoing research and will be invited to workshops at a reduced rate. Their responses will also be of use to the CGIA research program. Similar structures have been established for other research units at Maine, and interest on the part of these users has already been expressed.

8.2. Evaluation Procedures-for the Maine CGIA

The University is establishing review procedures for its Organized Research Units. These procedures will follow accepted academic standards, and consider the quality of research and publications, the education of graduate students, and the services rendered to groups outside the University; they will involve self-evaluation, and external peer-review.

8.3. Promotion and Tenure Practices at the University of Maine

A mechanism for the promotion and tenure process has already been devised, based on the proven ten-year-old system used by the Quaternary Institute. Decisions on tenure for faculty who are associated with the Center will be made by the departmental committee augmented by faculty representing the CGIA who are familiar with the person's work. The proportion will depend on the precise nature of the joint appointment. The department chairperson and the Center Director, the dean of the appropriate college, and the vice presidents for academic affairs and research will also have a voice. The Surveying Engineering Group at the University of Maine is composed of faculty with different professional backgrounds, and is already experienced at successfully dealing with promotion and tenure decisions among a heterogeneous group.

9. Review Procedures: Self Evaluation and External Evaluation

Effective operation of the National Center as a whole and of its component parts will require critical internal and external evaluation. A number of procedures involved in such evaluations have already been mentioned. However, we pull these and other procedures together here to show that we are very conscious of:

- The need for external and internal evaluations
- The roles such evaluations play in ensuring that the Center delivers a quality product, on time, and within-budget
- The procedures which are required to ensure that the reviews are penetrating, critical, and helpful in respect to quality, expenditures, and management of the research, education, dissemination, outreach, and fund solicitation enterprises as well as to the management itself.

In this respect we emphasize the experience of Deans Simonett and MacKinnon in program reviews. Simonett was one of two principals in redesigning all of the seven year departmental undergraduate and graduate program reviews for UCSB so that both internal and external reviews are of high quality and of a high critical, informational, and managerial content; he has been a key administrator in 25 such reviews; in addition, as principal investigator of a number of Department of Education Grants for minority graduate education (FIPSE, and Patricia Roberts Harris Fellowships), totaling over $800,000, he has been involved in program evaluation; he has also been a consultant to seven universities or national or international agencies on research and teaching program evaluations. MacKinnon has performed department evaluations for three other universities; he is also involved in every graduate review of the eleven departments in the Faculty of Social Sciences at SUNY Buffalo which take place every seven years. Both are involved in the evaluation of new graduate programs under review for initiation. Simonett has been involved in seven such reviews, MacKinnon for two. Several faculty in both education and psychology at both UCSB and Buffalo are expert in the formal procedures of program evaluation methodologies and will be sought as advisors in the construction and introduction of our evaluation procedures.

As stated in the solicitation, NSF will review the Center operation annually by reviewers and panels chosen by NSF, with major reviews performed every third year. We do not propose to wait for these reviews, but will be very proactive; simply put, annual reviews are inadequate for either a large or distributed enterprise, and this Center will be both. Hence we will put the following evaluation elements in place:

- Development of a formal Program Review Document (PRD) comparable to the in-place university procedures at UCSB but tailored to the program elements of the NCGIA. This document will spell out in detail the items to be reviewed by the agencies listed below, and the procedures to be followed.
- A Board of Directors sub-committee will review the program in detail each year, *six months in advance of the NSF review*, using the protocols of the PRD. The sub-committee report will form the basis of recommendations to the Scientific Policy Committee and the Executive Committee by the Board of Directors for improvement of overall operations and for helping to remove deficiencies.
- The Executive Committee will consciously evaluate performance in research, education, dissemination, outreach, and additional fund solicitation at each *quarterly* meeting, with especial attention to the early warning signs of problems; good management is anticipatory, but some warnings are also deliberately to be sought out in an oversight mode, following the PRD procedures.
- The Director and Senior Scientist will *at least once a year* formally review each of the three

sites immediately following or preceding the meeting of the Executive Committee. PRD procedures will be followed.

- The Scientific Policy Committee will include a review component in its twice-a-year meetings. Again, specific items for the attention of the Scientific Review Committee will be spelled out in the PRD.
- The Director is specifically charged with the appropriate implementation of review recommendations from all agencies which relate to the overall operations of the Center. The Director also is charged with oversight responsibility for the Associate Director's implementation of single-campus review recommendations.
- The Associate Director at each site is specifically charged with the appropriate implementation of review recommendations from all agencies which relate to that campus.
- The Center will also employ one academic and management consultant annually as both critic and counsel. A person of high calibre in judgement, experience, research attainment, and program management will be sought. Dr. John O'Callaghan of CSIRO, Australia, will be the initial external program review consultant.

The flow chart on the following page shows the annual NCGIA management review activities.

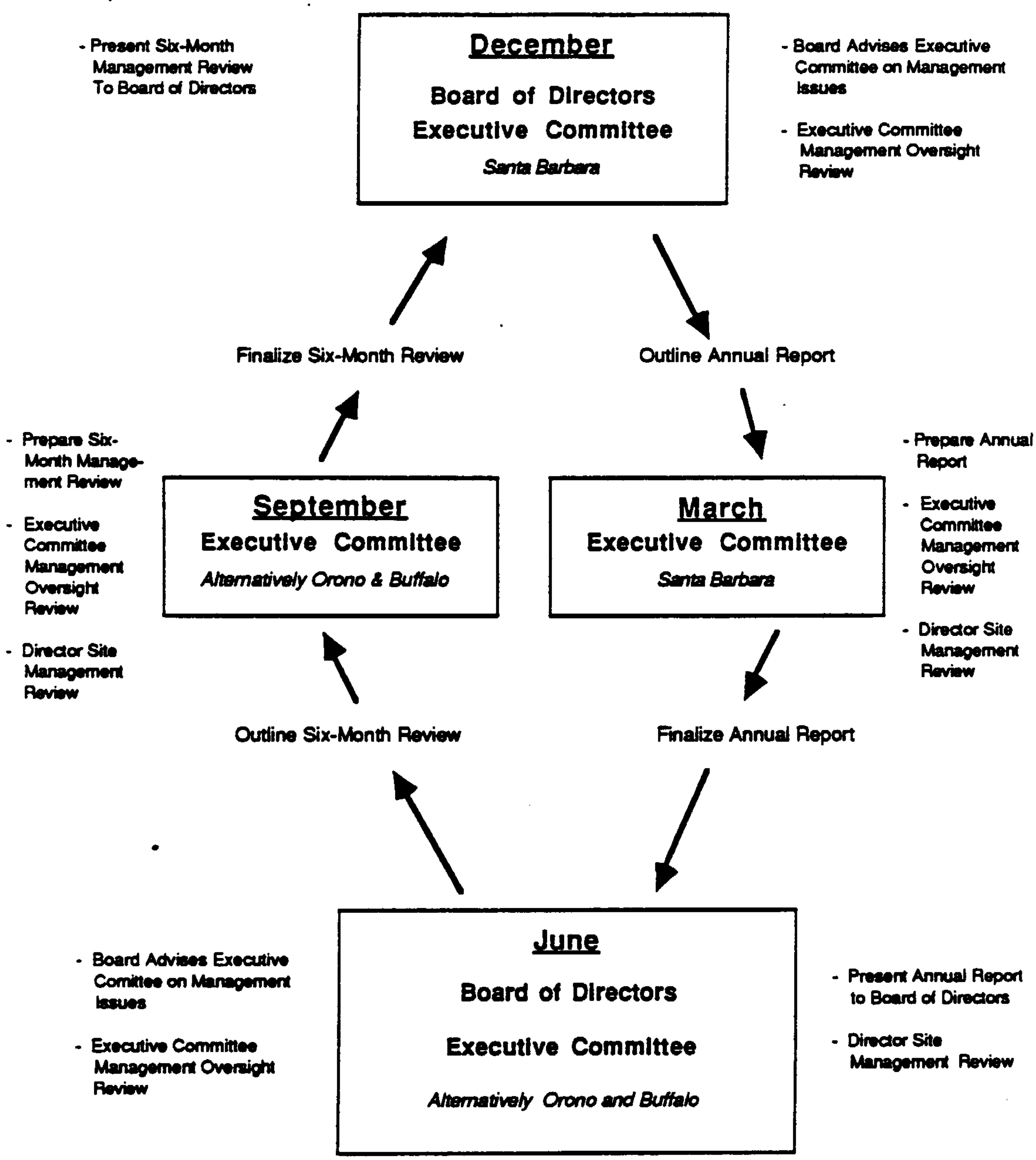
10. Managing the NCGIA After Year Eight

The Center will require careful management so as to flourish at the conclusion of NSF funding. In the Rationale we discussed our goals for the Center in the period from 8 to 15 years after formation and our vision of the nature of the Center in the long term.

A key objective of the NCGIA management will be the maintenance of a balance between the three institutions: it is essential that all three play the strongest possible role in the Center, and contribute to their full potential, particularly towards the end of the NSF funding period, and that all three be active in soliciting alternative funding.

The proposed management structure will continue after the NSF period if deemed necessary. Major changes, including additions or deletions of institutions, will be determined by the Board of Directors. The costs of central NCGIA management at the termination of NSF funding will be borne by the three institutions under a formula to be approved by the Board on recommendation of the Executive Committee.

Management Review Schedule



VII
INSTITUTIONAL, INDUSTRIAL AND GOVERNMENT SUPPORT

1. Institutional, Industrial and Government Support

The audiences and interests in GIA and the analytical capabilities of GIA/GIS extend beyond the research mandate of the National Science Foundation into the teaching, research, and public service responsibilities of the three academic institutions comprising the consortium, the mandated responsibilities of line Federal, state and local agencies, and the profit driven private sector. The National Center must evolve appropriate mechanisms for interacting responsively with such groups in productive and mutually beneficial ways. These mechanisms include participation in advisory capacities such as the Board of Directors, participation in conferences, workshops and submission of joint proposals among others. The funding available at this time from NSF clearly needs to be augmented to increase its impact, and it is incumbent on the consortium to garner the additional resources needed by being responsive to agency and industry concerns in research, applications, and dissemination. In the first five years, as the budget summary in the table below displays, the three institutions are committing $4,039,000 in cash, and $2,467,000 in kind, totaling $6,506,000. In addition we expect to obtain an additional $6,228,000 of federal, state and private support, to an overall total of $12,734,000, slightly more than double the NSF funds over the same period. We expect to be responsive to agency and private concerns, and have shown, by the present significant level of in-place support from such sources, our ability to be responsive and to garner research support. An early commitment will be to hold workshops of such agency and company representatives to examine their priority concerns and define methods to address these concerns in a timely fashion. This has been done already to a very limited degree as this proposal is submitted. If our consortium is selected as the NCGIA, we will promptly hold a workshop for this purpose in the summer/fall of 1988, for federal agencies, with subsequent workshops for other groups.

Consortium Institutional Support
Cash, and In-Kind plus Anticipated Non-NSF Extra-Mural Funds

	Institutional Commitments ($1000)			*Extra-Mural Funds*	
Years	*In-kind*	*Cash*	*Total*	*Other*	*NCGIA: NSF*
1	435	992	1427	309	1249
2	478	1051	1529	711	1249
3	508	784	1292	1247	1249
4	519	576	1095	1761	1249
5	527	636	1163	2200	1248
Five-year Totals	**2467**	**4039**	**6506**	**6228**	**6244**
Grand Total			**12734**		**6244**

1.1. Federal Agencies

Ten years from now, we believe, with the appropriate level of national investments in research, education and administration there will be GIS facilities used for geographical information and analysis in virtually all federal agencies, so pervasive is and will be the need for such facilities and analysis, to enable these agencies to enhance their mandate for the generation and the delivery of spatial information and services to the public. Members of this consortium currently have GIS research funded by the U. S. Geological Survey, the Department of Defense, and NASA, and we have some sense of their needs in this area. We will meet separately with appropriate administrators in these agencies regarding further support, not only for augmentation of our research initiatives and subsequent initiatives but also for specific related research keyed *directly* to their concerns. The following additional agencies are appropriate for a three day workshop/review in Washington DC in the late summer early fall of 1988:

- *Department of Agriculture*: Statistical Research Service, Forest Service, Soil Conservation Service, Office of Information Resources Management, Small Community and Rural Development Administration, Agricultural Research Service, Cooperative State Research Service, and the USDA Extension Service.
- *Department of Commerce*: Census Bureau, Federal Emergency Management Administration, National Oceanographic and Atmospheric Administration, National Telecommunications and Information Administration, Travel and Tourism Administration, Bureau of

Economic Analysis, National Technical Information Service, National Bureau of Standards, and the Economic Development Administration.
- *Department of Defense*: Defense Mapping Agency, Marine Corps, Corps of Engineers, Engineering Topographic Laboratory, NORDA, Command, Control, Communications, and Intelligence Office, Defense Communications Agency, Defense Intelligence Agency, and the Naval Facilities Engineering Command.
- *Department of Education*: Office of Educational Research and Improvement, including the Divisions of Policy and Planning, Operations, Information Services, Libraries, and Research.
- *Department of Energy* and DOE supported National Laboratories (Brookhaven, Argonne, Oak Ridge, Los Alamos, Lawrence Livermore, Lawrence Berkeley and Hanford).
- *Department of Health and Human Services*: Center for Disease Control, Food and Drug Administration, and the Social Security Administration.
- *Department of the Interior*: Bureau of Land Management, National Park Service, Bureau of Indian Affairs, Bureau of Mines, Geological Survey, Bureau of Reclamation, Fish and Wildlife Service, Land and Minerals Management Service, Office of Surface Mining, Reclamation, and Enforcement, and the Board of Geographic Names.
- *Department of Transportation*: Federal Aviation Administration, Federal Highway Administration, Federal Railroad Administration, National Highway Traffic Safety Administration, Research and Special Program Administration, and the Maritime Administration.
- *Environmental Protection Agency*: Environmental Monitoring Systems Laboratory, Environmental Research Laboratory, Environmental Engineering and Technology Division, the Science Advisory Board, and the National Data Processing Division.
- *National Aeronautical and Space Administration*: Office of Space Science and Applications, Office of Aeronautics and Space Technology.
- *Other Independent Agencies*: Agency for International Development, National Commission on Libraries and Information Sciences, and the Interstate Commerce Commission.

We plan to expand this list as we identify other agencies with GIS needs. We anticipate that among the many concerns of these agencies the following will be of common interest:

- Efficient data structures and retrieval procedures for very large data bases;
- Structures for the efficient handling of both raster and vector data;
- Explicit modeling incorporating both remote sensing and specialized ancillary data in a GIS environment;
- Methods for handling very large, very expensive, existing data bases which are too extensive to convert to a consistent topology.
- Demonstration project research in an explicit cost/benefit mode to provide examples of cost savings.
- Demonstration research in modeling of value in scientific and budgetary decisions and management.

Subsequent to these meetings, Co-Directors Simonett and Goodchild along with John Estes, augmented by Associate Directors and faculty as appropriate, will meet separately with each agency to further explore their concerns and to continue the dialogue, and if suitable, the exploration of future research and development projects. The process thereafter will be one of continuous contact with each visit to Washington. Coordination of subsequent visits will be by the Director's office to ensure that UCSB, UB, and UM address responsibilities and agencies appropriately. Some of the above agencies already support research of faculty involved in this proposed NCGIA. We expect that this type of support will increase and that this will help us in establishing a strong relationship with these agencies.

1.2. State Agencies:

In each of the three states of the consortium, the parallel state agencies will have particular issues and concerns which do not correspond exactly to their federal equivalents. We have meetings underway with such agencies at the time of submission of this proposal. Essentially the same format will be followed as with the Federal agencies. Some of the state agencies involved are discussed in sections devoted to each of the universities involved in this consortium, given below.

1.3. Local Agencies:

Many local agencies at the regional, county, and city level have already purchased GIS software and have made substantial hardware and training investments. Such agencies are important attendees of the vendor annual conferences at which we will have representation in the form of papers and an informational booth. We will, at these conferences, in conjunction with the vendors, continually seek to keep abreast of concerns, assess research, education, and dissemination needs, and seek appropriate funding to address concerns. Center faculty will make every effort to open contacts with local agencies in order to gauge the needs of the immediate GIS community. In addition co-operative arrangements for research will be sought. A number of such contracts have been made to date.

1.4. Private Sector:

To the private sector we will turn for the following information and support:

- Existing experience with GIS
- Improved requirements for GIS
- Financial support for various aspects of Center research, educational and dissemination functions, and hardware/software needs, as specified in the letter of solicitation included in Appendix F.
- Parallel beneficial research
- Participation of personnel in workshops and initiatives.

At the time of submission of this proposal, contacts have been made with some 20 companies. Discussions underway will be detailed at the time of the site visit if we are on the short list.

2. Institutional Support, UCSB

2.1. Institutional Support

The University of California at Santa Barbara has given substantial support through the development of the Department of Geography (1975), the inception of the Ph.D. program, (1980), and continued support in strengthening all areas of the department. This support has lead to the development of a strong faculty, large graduate and undergraduate programs and a large research support base. As part of the campuswide planning effort in December, 1986, the Geography Department proposed to add a major emphasis in GIS by the addition of new faculty in this area to augment those already in place. The University response to this plan was an immediate commitment of 2 FTE and a pending commitment of a third FTE to the department related to GIA/GIS. Further, the Department has received support for the recent purchase of ARC/Info and two special GIS workstations (color graphics terminals and digitizers). This ongoing support demonstrates an institutional commitment that has made an impact and will continue to make an impact in the next decade.

The UCSB administration has shown a solid-balanced approach in supporting new initiatives such as the NCGIA that has been recognized by the selection of UCSB to house a number of specialized programs including the world renowned NSF-funded Institute of Theoretical Physics and The Robotics Institute.

The proposed NCGIA has received support from all areas of the University: the Faculty Senate, Chancellor, The Academic Vice Chancellor, Associate Vice Chancellor for Research and Development, Provost of the College of Letters and Sciences, and the Deans of the College of Engineering, Graduate School of Education, and Instructional Development. With this broad base of support, UCSB has pledged in-kind cost sharing and cash support (calculated with benefits and overhead) at $2,626,986 for the first five years of operation. This is a very substantial commitment. When combined with the institutional support packages from UB and UM the three campuses provide a solid institutional support base for the NCGIA. Along with the financial and programmatic support, the University will also make an appropriate space commitment to begin center operations. Facilities and support services are discussed in a separate section of this proposal.

2.2. Industrial Support

A number of UCSB faculty who are members of this proposed consortium have consulted with California industry on GIS or topics directly related to GIS. As the NCGIA develops, we expect that many of these corporations will support special GIS educational programs and special research projects. We view the involvement of industry as an important objective in ensuring the long term success of the center beyond the first five to eight years. We believe that strong industrial support will make a large difference in the overall success of the NCGIA. UCSB has initiated discussions with ERDAS, Criterion, Inc, Santa Barbara Research Corp (a major part of GM-Hughes), UNEP-GRID, and TRW. We have developed a target list of more than twenty corporations that we will contact within the first few months of center operation, in order to begin the process of industrial involvement. UCSB center personnel will also work closely with UB and UM in setting up special industrial ties with national firms.

2.3. California State and Local Agency Support

We expect that the NCGIA at UCSB will develop a good working relationship with a number of state agencies over the next decade. Geography faculty at UCSB have already received funding for research project from a number of state agencies. We expect that with the focus of the center at UCSB, this involvement will substantially increase. State agencies that will be particularly appropriate in California include:

- California Transport Commission, the State Lands Commission, the Public Utilities Commission, and the Office of Emergency Services.
- *Department of Business, Transport, and Housing:* Highway Patrol, Dept. of Real Estate, Department of Motor Vehicles, Department of Transportation (CALTRANS), and Department of Commerce.
- *Department of Resources*: California Coastal Commission, California Conservation Corps, Department of Parks and Recreation, Department of Water Resources, California Energy Commission, and the Department of Fish and Game.
- *Department of Environmental Affairs:* Air Resources Board, State Water Resources Control Board, and the California Waste Management Board.
- *Department of Finance*: State Census Data Center

At this time we have explicit research discussions underway with CALTRANS, the California Census Data Service, the California Department of Water Resources, and the California Department or Fish and Game. Others will follow.

2.4. Federal Agency Support at UCSB

Geography faculty at UCSB have significant federal agency funding. Currently, $800,000 annum of this is directly related to information systems including GIS. Agency support presently comes from NASA, USGS, ONR, and NSF. This funding supports a considerable number of graduate students with already-declared interests in GIA/GIS, some of whom will be able to move across to NCGIA, after completion of master's degrees. This level of base funding and graduate students in-place assures an immediate response to the new NSF funding without a significant lag time.

3. Institutional Support, State University of New York at Buffalo

3.1. General University Multidisciplinary Commitment

The State University of New York at Buffalo has had a long standing tradition of support for multi-disciplinary research and teaching programs. Since 1985, this tradition has been significantly strengthened by the implementation of two University-wide initiatives.

First, the University at Buffalo sponsored a campus-wide competition in 1985 in which groups of faculty from different departments proposed to establish cross- disciplinary Organized Research Centers that had the potential to achieve national prominence in their fields of study. As a result of that competition, eight Centers were established and awarded substantial University support for their first three years of operation. One of the Centers, the Center for Earthquake Engineering Research, received a major grant from the NSF after its first year. Subsequently, three additional University Centers were established including the Research Center in Geographic Information and Analysis, bringing the total number of Presidentially approved Centers to eleven.

Second, the State University, primarily the four university centers, proposed and received funding from the State through the Graduate Research Initiative that is adding substantial resources to selected multidisciplinary research program within those institutions. One specific goal of this initiative is "...to develop on its doctoral campuses multidisciplinary 'Centers of Excellence' capable of responding creatively to the needs of the State and its major regions…". The University at Buffalo is the recipient of the largest proportion of the first year funding under that Initiative, and further funding increases are anticipated over a five-year development period through 1992. In addition to the focus on multidisciplinary themes, selected departments will receive additional resources designed to upgrade their graduate and research programs. Buffalo's Geography and Computer Science programs are among those targeted for growth under this Initiative.

3.2. Specific University Commitments to GIA: The Center on Geographic Information and Analysis

3.2.1. The Buffalo Organized Research Center

The structure and operation of what would be the Buffalo Site of the NCGIA are already in place at UB, in the form of its Center on Geographic Information and Analysis, which currently receives substantial University support. The University at Buffalo established this Center in the spring of 1987 with funding from three sources: Research Development Funds, the Office of the Provost, and the Dean of Social Sciences. The Center is structured to facilitate both teaching and research programs in GIA/GIS. In its initial period of operation, the Center has expanded the facilities and activities originally housed in the Geography Department. The support provided to date has allowed for:

- *Upgraded GIS and Cartography Lab Facilities.:* The University provided funds for additional hardware, communications systems, and technical support personnel for the GIS and Cartography Labs as well as a satellite Lab in Anthropology. An agreement was reached with ESRI for the purchase of extensive GIS software and training of UB personnel on ARC/INFO and related systems. A technician was added to the one currently employed in Geography to support software development and equipment maintenance. In addition, a half-time secretary was hired to support the Center activities.
- *Additional Graduate Student Lines*. The number of graduate students to be recruited and admitted in the area of GIA was doubled to accommodate increased interest in this area of study.
- *Visiting Professors*. The Geography Department is hosting two international scholars as Visiting Professors during the 1987-88 year: R. Weibull from the University of Zurich and F. Csillag from the Hungarian Research Institute for Soil Sciences. They will teach courses in the GIA area and work with both students and faculty on coordinated projects.
- *Travel*. Travel funds to enable Center members to attend GIA conferences and consortium meetings.

3.2.2. Contingent Operating Budget Commitments

In addition to the resources committed to the Buffalo Organized Research Center, the University has made a major commitment to a Buffalo site of the NCGIA. As detailed in the budget statement, the University contribution to the Site will total over one million dollars over the first three years of the NCGIA operation. That figure is distributed across all categories of support, and in almost every instance involves real-dollar rather than in-kind commitments.

3.2.3. Space for the Buffalo Center for Geographic Information and Analysis

The current space for the Buffalo Center is shared with the Department of Geography. Should this proposal be approved, an additional 1000 square feet of suitable space would be identified in the same building now occupied by the center and the Department. By 1990, the Geography Department and the Center will have moved to new space in a large office building overlooking lake Lasalle. Plans are for these units to share this building with Computer Science and Mathematics. Geography and the Center currently occupy approximately 10,000 square feet of space in Fronczak Hall; space allocated to these units will increase substantially with the move to the new building. The University has made a commitment that the Center will have adequate space allocated for its activities.

3.2.4. Future Tenure Track Appointments

The University has made long-term commitments to maintain and upgrade the academic standing of the Geography Department as one of the leading units on the Buffalo Campus. Searches are currently underway for *three tenure track* appointments in the Department. At least two of these will be central contributors to the GIA effort. We anticipate that two additional appointments will be made by 1990, bringing the Department size to 18. If this NCGIA bid is successful, it is anticipated other departments would make at least three tenure track appointments of scholars who could play a major role in the research undertaken under the auspices of the NCGIA. Likely departments to participate would be computer science, political science, economics and sociology.

3.2.5. Office of Sponsored Program

The Department and the Center in Geographic Information and Analysis work closely with the University Office of Sponsored Programs to facilitate: (1) preparation of research proposals to both major funding agencies and to related centers in the private sector; and (2) cooperative research and training programs with area industry and with state and local government agencies. The publications division of the University will support the Center and NCGIA Site research reports, in order to provide an efficient distribution of Center Newsletters and Research Reports to the GIA community.

3.3. Local and State Support at UB

Faculty at UB have identified a number of state and local agencies that have interests in GIA. Among these, several agencies have already been contacted for interaction with and support of center activities. We recognize that each local center can have a significant impact on local agencies and that this can form a source of test data sets, intern progresses for students, research and support funding, and serve as a "test bed." Among the agencies that we have identified, we believe the following could be interested from the outset in cooperative arrangements. They include:

State

New York State Science and Technology Foundation
New York State Department of Environmental Conservation
New York State Department of Transportation
New York State Department of Equalization and Assessment
New York State Office of Parks, Recreation, and Historic Preservation
New York State Committee on Reapportionment
New York State Committee on the Siting of Low Level Radioactive Waster
Disposal Areas

Regional

Western New York Technology Development Center
Adirondack Park Agency
Tug Hill Commission (regional planning for the Fort Drum Military Reservation Area)
Erie-Niagara Counties Regional Planning Board

Local

City of Buffalo
City of Niagara Falls
Town of Amherst

4. Institutional Support, University of Maine

4.1. Institutional Support

The University of Maine has already supported the concept of Geographic Information Systems in several programs. Both the Forestry Department and the Surveying Engineering Program have worked on various aspects of GIS and have benefited from substantial, University support. The Surveying Engineering Program is one of a few programs of national prominence on the UM campus and has in consequence received substantial increases in funding and has been allowed to expand the number of faculty members in the last year from 4 to 7.

The University of Maine system has also supported the Surveying Engineering Program: a request for a M. Sc. in Surveying Engineering was granted in 1987, and in the same year, an 'intent to plan' for a Ph.D. Program in Surveying Engineering (to be initiated in 1988) was accepted as well.

The University administration has without hesitation and on all levels encouraged the NCGIA proposal and is committed to contribute substantially to the Maine CGIA. The faculty in Surveying Engineering and the Dean of Engineering and Science have agreed to release five faculty from teaching one course per year and devote their time fully to NCGIA research (a total of 1.6 full time faculty equivalent, with fringe benefits and overhead, a value of $120,000 per year). The President of the University together with the Vice President for research are committed to contributing to the CGIA unrestricted funds for graduate student stipends, equipment and other operating expenses. This commitment for the next five years is, with overhead:

1988	1989	1990	1991	1992
251	314	315	184	195

The University has expressed its willingness to continue funding the cost of the administration of the Maine CGIA beyond five years, which is a first step towards assuring the continued existence of the NCGIA beyond the end of NSF funding.

Dr. Dale Lick, the President of the University, has promised to provide the Maine CGIA with about 6,000 square feet of space. A number of attractive alternatives are possible. A building is currently under construction and others are in the planning stage and the possibility exists of moving other departments out of Boardman Hall and consolidating the CGIA into that space along with Surveying Engineering. Detailed assignments for the CGIS cannot be fixed at the present time.

4.2. Industrial Support:

Three sizable mapping and GIS consulting firms (Kork Systems Inc., James W. Sewall Co., and DeLorme Mapping) have their headquarters in Maine. They all have ties with the University and specifically with the Surveying Engineering Department. They have expressed a strong interest and support for the Maine CGIA.

A number of surveying engineering companies in the Boston area, the largest being Boston Surveying Consultants, have regularly supported the Surveying Engineering Program with contributions through the regional New England chapter of the American Congress on Surveying and Mapping.

One of Maine's largest industries, the Paper Industry, has already invested in GIS for forest and timber management. Great Northern Paper Company, Champion International, and Boise Cascade have attended GIS meetings and expressed support for the University role in the National Center.

Digital Equipment Corp. has a plant in Augusta, Maine and its headquarters in the Boston area. The Surveying Engineering Group has good contacts with the Augusta plant and a long history of cooperation with the engineering systems group in Marlboro. The Surveying Engineering group also has had regular contacts with the Computer Corporation of America, a computer specializing in the development of non-standard databases, and also with Intergraph Corporation. Common research interests have been explored.

We regularly receive equipment grants from Digital Equipment Corp. in addition to research contracts with them. We are currently working on one contract and are exploring new topics with them. Our abilities to receive grants in the past were limited by the small number of faculty (4) and graduate students. This should rapidly change and we will pursue research for the GIS industry very actively.

4.3. Government Support

The Surveying Engineering Group has contracts with a number of federal government agencies that are interested in GIS. Over recent years, we have worked with the National Geodetic Survey (part of NOAA), with the EROS Data Center in Sioux Falls (part of USGS) and the Bureau of the Census. Opportunities for continuing work with these agencies and with other federal agencies are clear.

The State of Maine is currently facing several issues which have raised the need for, and interest in, GIS. The tremendous growth and the corresponding pressure on the environment in the southern and coastal part of the State is causing widespread concern. Most of Maine's industries are based on its natural resource base and the agencies responsible for the management of these resources are looking to GIS as in essential tool to provide them with the information they need to make effective decisions. The State already has some GIS capability, but is anxious to expand and improve on this capability. The Governor's Office, State Planning, the State Department of Conservation, the Department of Environmental Protection, the Department of Transportation, the Department of Human Services, the Department of Inland Fisheries, and Wildlife are interested in GIS. They all support the University and its effort to advance GIS functionality.

The Surveying Engineering Group has had grants from the State Geological Survey. We recognize that there is more potential for cooperation with the State agencies and one of the recently hired faculty members has started an active dialogue with them. Two meetings have already been held with agencies interested in GIS. The University of Maine has recently concluded a general agreement with the Maine Department of Transportation, covering all types or research and development work to be carried out through the University. GIS work by the Surveying Engineering Group will be facilitated by this contract.

Local government agencies, as well have expressed an interest in GIS. The Greater Portland Council of Governments is in the process of implementing a GIS for the Portland Regional Area and is supportive of the University's affiliation in a National Center.

4.4. Additional Funding for the Maine CGIA

The small number of Surveying Engineering faculty have, despite heavy teaching loads, over the past year maintained an average of $40,000 of outside funding per year per faculty member. With the addition of four new faculty, three of them with previous experience in grantmanship, as well as with the increasing number of graduate students, this will rapidly increase.

It is anticipated that the 7 faculty who will form the central group of the Maine CGIA will produce $50,000 in outside funding each per year, independent of NSF funding, and thus reach the $350,000 planned in year 3 of the CGIA. We will then be capable of adding another faculty position, and increase the number of projects as well as their size to reach the funding goals set for years four and five.