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*NATIONAL CENTER FOR GEOGRAPHIC INFORMATION
AND ANALYSIS*

ANNUAL REPORT

Year 2
(December 1, 1989 - November 30, 1990   )

University of California, Santa Barbara
State University of New York at Buffalo
University of Maine

January 19, 1991

NATIONAL CENTER FOR GEOGRAPHIC INFORMATION
AND ANALYSIS

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SUMMARY

The National Center for Geographic Information and Analysis was announced by the National Science Foundation on August 19, 1988, and awarded to a consortium of the University of California, Santa Barbara; the State University of New York at Buffalo; and the University of Maine, for an initial period of five years. Funding began December 1, 1988. The Center's mission reflects the desires of the NSF, as expressed in the solicitation document: to advance the theory, methods and techniques of geographic analysis based on geographic information systems (GIS) in the many disciplines involved in GIS-based research; to augment the nation's supply of experts in GIS and geographic analysis in participating disciplines; to promote the diffusion of analysis based on GIS throughout the scientific community, including the social sciences; and to provide a central clearing house and conduit for disseminating information regarding research, teaching and applications.

This document reports on the Center's second full year of operation. During this period, many of the activities begun in the first year have been completed, and the Center has initiated a number of new efforts. Three research initiatives have been completed, and two new ones have begun. The product of the first major education project, the Core Curriculum, has been released. These activities continue to be fully consistent with the proposal submitted to NSF. The Center has been successful in raising substantial additional support for its activities. Numerous outreach activities have drawn attention to the existence of the Center, and helped to promulgate its research findings and other contributions, and the level of awareness and acceptance of the Center's contributions in the external community has continued to grow. The Center continues to support a high level of external involvement in many of its activities. Finally, the Center has continued to function effectively as a distributed enterprise.

1. BACKGROUND

On August 19, 1988, the National Science Foundation (NSF) awarded the NCGIA to a consortium of the University of California, Santa Barbara; the State University of New York at Buffalo; and the University of Maine, with funding of $1.1 million per year for five years. The second year's operation began officially on December 1, 1989 (funding for Year 2 was reduced to $1.078 million due to deficit reduction programs). The decision to establish the Center and the selection process have been described by Abler (*International Journal of Geographical Information Systems* **1**: 303-326 (1987)).

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

In addition to research, the Center was to take steps to "augment the nation's supply of experts in GIS and geographic analysis in participating disciplines; promote the diffusion of analysis based on GIS throughout the scientific community; and provide a central clearinghouse for disseminating information regarding research, teaching and applications."

The GIS boom that began in the early 1980s has continued at full strength in the past year, and may even have accelerated. New vendors continue to enter the market with new and exciting products, education and training programs are proliferating, the GIS software industry is reporting growth rates in excess of 40%, new textbooks and magazines are appearing, and GIS technology continues to find new applications and new acceptance. Over 4,000 registrants were attracted to the national GIS/LIS conference in Anaheim in November, and regular regional meetings are now held in most parts of the US. *Geo Info Systems*, a new magazine with a free distribution of 30,000, appeared in 1990, and the more established *GIS World* reported over 5,000 paid subscriptions. *Geographical Systems*, a new learned journal, was launched in Europe.

All the same, the NCGIA Annual Report provides an appropriate opportunity to reflect on the changing nature of the GIS field, and the spatial analysis that it supports, and the First Annual Report included such an editorial section. The 1980s were years of unprecedented economic growth, both in Western economies generally and in GIS, and it is clear that the resources that were available to fund this growth in the 1980s will be much harder to find in the future. The 1980s also saw unprecedented changes in computing hardware with the development of personal computing and the workstation. The discussion that follows is intended to offer a limited perspective on some aspects of the state of GIS in late 1990; other perspectives will be presented in future Annual Reports.

GIS is a large and growing industry. Estimates vary, but expenditures world-wide on GIS hardware, software and services are certainly in the billion-dollar range. But despite its growth, GIS continues to encompass a remarkably diverse set of interests. Its applications range from resource management through urban infrastructure to emergency response, from political districting to forestry. GIS software runs on platforms from the PC to the large mainframe. It includes an enormous range of software architectures, from the simple, self-contained raster systems such as GRASS and IDRISI to the large database managers such as IBM's GFIS. Some vendors focus on a single platform, while others, notably ESRI, offer a single product over the full range of platforms and operating systems from DOS to VM. The GIS community includes an extraordinary range of disciplines, from archaeology and landscape ecology through forestry to civil engineering and computer science. And there is as much variety in the definitions of the field. GIS is variously described as a spatial decision support system; a system for input, storage, analysis and output of geographic data; or a geographically referenced information system (to cite only three of the competing definitions).

Looking at the development of the field, and its current condition, one might well be curious about the glue that holds it all together. One major part of that glue is clearly the technology itself, and a widespread fascination with processing geographical data. Maps and graphics are interesting in their own right, and a computer system that analyzes and displays them is doubly interesting. There has been a steady and accelerating improvement over the past three decades in the cost and availability of graphic computing, and this has had an undeniable impact on the growth of GIS. P.J. Taylor, in a recent editorial in *Political Geography Quarterly*, characterized GIS as "geography's own little bit of the 'high-tech' revolution" (*Political Geography Quarterly* **9(3)**: 211-212 (1990)).

In its original proposal, the consortium argued that as a recent and immature technology, GIS suffered from a variety of impediments to its full utilization. While some of these could be seen as technical deficiencies to be solved by further technological improvements, others were more fundamental to the nature of geographic information itself. The current range of GIS software and hardware products already incorporates an impressive range of technological breakthroughs. Concepts such as the TIN and quadtree are the direct result of GIS research, and are only two among the many innovative ideas to have emerged over the past three decades. Any technologically based field must be constantly supplied with new ideas if it is to thrive, and needs to be supported by an active

research and development community.

The Center's Research Plan (subsequently published as *International Journal of Geographical Information Systems* **3(2)**: 117-136 (1989)) proposed that the most important issues confronting the field were not necessarily technological. Whatever the application or EDP (electronic data processing) solution, every user of GIS faces the same set of problems in dealing effectively with digital geographic data. Some of the more prominent are:

- data capture - how to convert data from raw to digital form in an efficient, cost-effective manner;

- data modeling - how to represent the infinite complexity of the real world in a discrete, digital machine - whether to use raster or vector, layers or objects, how to model complex objects;

- accuracy - how to cope with the uncertainty present to varying degrees in all geographical data;

- volume - how to deal with demands for geographical data that often exceed available storage;

- access - how to design data structures, indexes and algorithms to provide rapid access to large volumes of geographic data;

- analysis - how to link GIS databases with advanced modeling capabilities;

- user interfaces - how to present the GIS database to the user in a friendly, comprehensible, readily used fashion;

- costs and benefits - how to measure the benefits of GIS information and compare them to the costs;

- impact on organizations - how to introduce GIS successfully into a complex organization.

All of these issues transcend the technology itself, and all of them in one way or another affect the technology's usefulness, whatever the application and whatever the platform.

The Center's original premise has been endorsed directly and indirectly in other GIS research agendas. Craig has compared it with the URISA agenda (Craig W J, "URISA's research agenda and the NCGIA" *Journal of the Urban and Regional Information Systems Association* **1(1)**: 7-16 (1989)) and two comparisons with the UK Regional Research Laboratories' agendas have appeared (Maguire D J, "A research plan for GIS in the 1990s" *The Association for Geographic Information Yearbook 1990* London, Taylor and Francis: 267-277 (1990); Masser I, "The Regional Research Laboratory initiative: an update" *The Association for Geographic Information Yearbook 1990* London, Taylor and Francis: 259-263 (1990)). Goodchild ("Keynote address: spatial information science" *Proceedings, Fourth International Symposium on Spatial Data Handling, Zurich* **1**: 3-14 (1990)) has argued that together these research issues constitute a science of geographic information, and that the future of the GIS community lies in recognizing a common interest in geographic information science rather than the technology of geographic information systems.

The case for GIS as a science of geographic information will likely be debated for many years to come, but the complementary argument that GIS is a technological tool for the support of science is much more widely accepted, and reflected in applications from archaeology to epidemiology. Geography provides a very powerful way of organizing and exploring data, but the map has lagged far behind the table and graph because early generations of scientific computing tools made it so difficult to handle. GIS has finally provided the breakthrough, although it remains far from perfect. If we were to draw an analogy between GIS and statistical software, which began to emerge in the 1960s, then the current state of GIS development is probably equivalent to the state of the statistical packages around 1970. But GIS and statistics are ultimately very complementary sets of tools, both capable of supporting an enormous range of scientific inquiry.

To date, the major success of GIS has been in capturing and inventorying the features of the earth's surface, particularly as represented on maps, and in supporting simple queries. There has been much less success in making effective use of GIS's capabilities for more sophisticated analysis and modeling. It is hard to find examples of insights gained through the use of GIS, or discoveries made about the real world. GIS has not yet found widespread application in the solution of major social problems - disaster management, environmental quality, global issues or health. In part this comment is unfair, because such insights would be next to impossible to document. In part the reason is commercial - the market for GIS as an information management tool is far larger

than that for spatial analysis, and vendors have invested relatively little in developing and promoting analytic and modeling capabilities. And although GIS is a major improvement, it is still difficult to collect, display and analyze data in geographical perspective. Finally, Couclelis ("Geographically informed planning: requirements for a planning-relevant GIS" *Papers, Regional Science Association* (to appear)) has made the point that the current generation of GIS concentrates on a static view of a space occupied by passive objects, and offers little in support of a more humanistic view of dynamic interactions.

Although there may be strong agreement on the research agenda, there are increasing signs of diversification in GIS software products, and this trend is likely to continue to strengthen in the next few years. GIS applications such as facilities management fall under the spatial information paradigm, whereas scientific and resource analysis applications fall under the spatial analysis paradigm. The former emphasizes the database and query aspects of GIS, whereas the latter tends to focus on modeling. The split is illustrated by the case of two Canadian companies - TYDAC and GeoVision - one marketing 'spatial analysis systems' with the very successful SPANS product, the other marketing 'geographic information systems'. Within the PC marketplace, there is increasing divergence between products aimed at GIS applications in resource management, facilities management, or market research (compare, for example, PAMAP, TYDAC's SPANS, Facility Mapping Systems' FMS/AC and Strategic Mapping's ATLAS*GIS).

This trend to diversification is appropriate and rational, as it matches software and platforms with different functions and applications. The complex modeling and analysis of resource management require a very different solution from intensive digitizing or the management of large facility inventories. In time, we can expect this trend to lead to more and more specialization within the GIS industry, as it becomes less and less possible to offer a single software solution for all platforms and all applications. One vendor may specialize in digitizing stations using PCs, another in database maintenance using large mainframes and terminals, another in spatial analysis using advanced personal workstations, and another in 3D applications.

But despite this sense of growing diversity in the GIS vendor community, there is evidence of convergence in the community as a whole. The past few years have seen the emergence of several series of conferences aimed at the full GIS community. In the US, the annual GIS/LIS series sponsored by a consortium of five societies (AAG, ASPRS, ACSM, AM/FM and URISA) has grown quickly to over 4,000 attendees. In Canada, the Ottawa meetings in early March have been similarly successful. The lone textbook of 1986 by Peter Burrough (*Principles of GIS for Land Resources Assessment*, Oxford) has now been joined by several others (eg Aronoff's *GIS: A Management Perspective*, WDL, Ottawa; Star's and Estes' *Introduction to GIS*, Prentice-Hall), and many more are on the way. New organizations have appeared, and the Association for Geographic Information (AGI) in the UK seems to be a particularly successful example, and GIS now has its own journals.

All of these would be recognized in the sociology of science as symbols of an emerging scientific community - in short, a discipline. But if GIS is a discipline, then it is clearly not 'owned' by any traditional one, and the Center must continue to stress its basic multidisciplinary character. Geography, cartography, surveying, photogrammetry and engineering have all been accused from time to time of trying to dominate GIS, but with little success, as GIS is fundamentally an interdisciplinary field. Whether it develops the institutional structures of a discipline in its own right, like statistics, or remains an interdisciplinary consortium of interests like remote sensing remains to be seen.

In many areas the future of GIS will continue to be determined by developments in hardware - technological innovation will continue to influence GIS as long as new ideas continue to drive the computer industry. The cost per cycle will continue to drop in the next few years, as will the cost per megabyte of RAM. The 1990s will see the proliferation of 3D technology, as high performance graphics display processors become available for mass-produced workstations from vendors such as Silicon Graphics. The recent generation of workstations, typified by the IBM RS/6000, include 3D adapter options with display rates as high as 10^6 3D vectors per second, with polyhedral rendering capabilities, in a platform running at 25-45 MIPS. GIS will no longer be confined to the plane, and the DEM display capabilities of today will seem very primitive in a few years. It will become possible to model and visualize subsurface conditions, and to analyze distributions over the surface of the earth without the distortions and interruptions produced by conventional map projections. In 3D the map metaphor is completely inadequate, and the user interfaces for these systems will have to explore entirely new territory. How, for example, should a system allow the user to build knowledge of subsurface conditions from a variety of different types of evidence? In 2D this task of map compilation takes place on paper, but in 3D it can only take place in the abstract domain of the digital database. What tools does a user need to explore a model of the subsurface once it has been built? What icons should be provided in an appropriate user interface?

If GIS has been dominated by the map, then fundamental changes now occurring in mapping will have significant effects in the coming decade. Low-cost GPS receivers are already available with higher accuracy than the base mapping available over most of North America (1:100,000, 1:24,000 in the Continental US), and provide a significantly cheaper method of primary data collection for many mapping activities. GPS is already being used to map road and rail networks, and to track vehicle movements. At the same time the funds available to support large, public-sector mapping programs are diminishing.

There seem to be two contrasting views of the prospects for GIS in the coming decade. The first is negative and the second positive, and it seems more likely that the second will prevail. However there are actions that can be taken to strengthen the odds, and it is important that the Center play a role in this process.

In the negative view, GIS will fragment and disappear, and by the end of the decade will be nothing but a memory. Geographers often draw a parallel between GIS and the introduction of quantitative methods to geography in the late 1960s (Taylor 1990), and comment on the lack of interest in quantification, at least in human geography, in the 1980s. GIS will fragment because it is too loose to hold together, and because the glue is too weak and abstract. Users of IBM's GFIS, Intergraph's TIGRIS and Map/Info will cease to see any reason to attend the same conferences. The consortium of five organizations responsible for the North American GIS/LIS conference series will break up and each will concentrate on its own agenda. GIS will be seen as the Edsel of EDP, too awkward, complex and expensive except in some specialized applications.

In the positive view, the GIS consortium will continue to converge. A constant supply of better tools seems assured, particularly in computing speed, software integration, network communication, graphics and storage capacity. The infrastructure of the GIS community will continue to improve, with better magazines, organizations, textbooks, meetings, and all of the symbols of an emerging specialty. Less assured but essential is a constant supply of new players in the industry, since the pattern has been that new players are the source of a disproportionate share of technological innovation. New players such as Prime/Wild with System/9, Small World, or ATLAS*GIS bring new ideas to the industry.

The Center's research programs are aimed at resolving the common issues that transcend GIS technology and pervade all of its applications. GIS can survive by constantly developing new and exciting capabilities, or by constantly finding new applications, but the really fundamental issues in GIS are those that are common to all users of geographic information - how to capture a complex and dynamic world in a digital database and provide access to it for analysis and modeling in a useful, accurate and cost-effective manner.

2. SUMMARY OF MAJOR ACTIVITIES

A. Research

Research in the Center takes place within the framework of a series of Research Initiatives. Each Initiative begins with a Specialist Meeting attended by professionals from outside the Center, in which the most important problems in the subject area of the Initiative are identified and ranked and a feasible research agenda for the Initiative is defined. Research continues intensively for 18-24 months with teams of faculty (NCGIA or other), postdoctoral fellows, or advanced graduate students, as well as representatives from private industry or government agencies, working in teams on specific problems. The Initiative ends with a national forum to present the research results. Results are also announced in articles in refereed journals, presentations at conferences, bibliographies, algorithms or models for analysis, NCGIA Technical Papers, and short courses or workshops. During the second year two Initiatives were closed and two begun, leaving a total of five active Initiatives at the end of Year 2:

1.   *Accuracy of Spatial Databases*. Leader: Michael F. Goodchild (Santa Barbara). Specialist Meeting: Santa Barbara, December 1988. Ended: Fall 1990.

2.   *Language of Spatial Relations*. Co-Leaders: David M. Mark (Buffalo), Andrew U. Frank (Maine). Specialist Meeting: Santa Barbara, January 1989. Ended: Fall 1990.

3.   *Multiple Representations*. Leader: Barbara P. Buttenfield (Buffalo). Specialist Meeting: Buffalo, February 1989.

4.   *Use and Value of Geographic Information*. Co-Leaders: Harlan Onsrud (Maine), Hugh Calkins (Buffalo). Specialist Meeting: Maine, May 1989.

5.   *Design and Implementation of Large Spatial Databases*. Co-Leaders: Terence R. Smith (Santa Barbara), Andrew U. Frank (Maine). Specialist Meeting: Santa Barbara, July 1989.

6.   *Spatial Decision Support Systems*. Co-Leaders: Paul J. Densham (Buffalo), Michael F. Goodchild (Santa Barbara). Specialist Meeting: Santa Barbara, March 1990.

12.   *Integration of Remote Sensing and GIS*. Co-Leaders: John E. Estes and Jeffrey L. Star (Santa Barbara). Specialist Meeting: Sioux Falls, December 1990.

Several other Initiatives are in various stages of planning, and are included in the following discussion where significant activities have occurred.

Initiative 1: Accuracy of Spatial Databases (ending Fall 1990). This initiative has focused on methods and techniques for dealing with error and uncertainty in geographical data. Its major goals have been to improve models of uncertainty; to develop methods for encoding and tracking uncertainty in databases; to formulate methods of computing and communicating error in GIS products; and to identify policies that encourage the implementation of accuracy assessment. The third circular describing activities under this Initiative was distributed in December 1989. Research continued at a reduced level throughout 1990, and the Initiative was formally closed by a series of presentations at GIS/LIS 90 in Anaheim CA in November 1990.

A group of researchers at Santa Barbara led by David Lanter worked during the summer and fall of 1990 on the development of a lineage system to track database uncertainties through GIS processes. As part of this work, doctoral candidate Howard Veregin extended his previous results on error propagation. The error model developed during the Initiative for representing uncertainty in area class maps was simulated using a grant of supercomputer time from IBM by Sun GuoQing with additional funding from USGS. During the fall of 1990 the model was implemented in the GRASS raster GIS package by Yang Shiren, and used to obtain confidence limits for some simple GIS operations. Also at Santa Barbara, work was done by Yang Shiren and Shu Shourong to build a prototype global GIS using the triangular tesselation proposed by Geoffrey Dutton and the 3D capabilities of the IBM RS/6000 workstation provided under the IBM-NCGIA Joint Study Agreement.

One Santa Barbara PhD student (Mark Kumler) worked this summer at USGS Menlo Park on comparisons between TIN and DEM elevation models, and a recently completed MA dissertation by David Theobald described the artifacts that arise in modeling

hydrologic flows over TIN models because of errors. Work continues on a project funded by the California Department of Forestry (PIs Goodchild and Davis) on accuracy of timber estimates from GIS.

At Buffalo, Stewart Fotheringham and David Wong continued work on a long-term project on the modifiable areal unit problem. This work is reported in more detail under Initiative 3.

At Maine, Kate Beard and David Pullar continued their work on modeling error in polygon operations, including overlay, and two papers on error in GIS were written by David Zhang.

Nine papers were accepted for presentation at GIS/LIS in Anaheim in November as the formal wrapup of Initiative 1. Please see attached Appendix 2 for a list of authors and titles.

Several additional conference presentations on I-1 results were made during the year by Goodchild, and results will also be presented in the form of a workshop to be given at the Association of American Geographers meetings in Miami in April 1991, at the ESRI Users' Conference in May, and at URISA in San Francisco in August 1991. Goodchild will also be the keynote speaker at a two-day symposium on spatial database error in Australia in June.

Initiative 2: Languages of Spatial Relations (ending Fall 1990). There are substantial differences in the ways spatial data are structured and processed in GIS, and in the ways people learn and reason about spatial information. This Initiative has focused on the nature of spatial relations, their expression in natural language and in digital databases, and on the development of formal theories of spatial representations.

Two chapters of the forthcoming text *Geographical Information Systems* (D.J. Maguire, M.F. Goodchild and D.W. Rhind, editors, Longmans (1991)) are related to I-2 and were written by NCGIA personnel. The 18-month review submitted to NSF in April 1990 included abstracts of 46 papers describing I-2 research.

Max Egenhofer and Robert Franzosa have completed their work on a theory of 'topological relations' and have submitted a paper on this topic to the *International Journal of Geographical Information Systems*. Spatial query languages are a topic of much current interest and Egenhofer has published several papers on the design of query languages for GIS.

Werner Kuhn and Max Egenhofer organized a workshop on "Visual Interfaces to Geometry" at the CHI'90 conference in Seattle, WA, April 1-2, 1990. They invited 17 regular participants and 3 keynote speakers from computer science, cognitive sciences, and engineering. Kuhn and Egenhofer have been invited to be guest editors for a special issue of the *Journal of Visual Languages and Computing*. Interesting applications of results from the geographic spatial language investigation to virtual reality and the general editing task were found. This will be published as an NCGIA technical report and will also appear in the SIGCHI Bulletin.

Jeffrey Jackson and Werner Kuhn have studied the formalization of interface metaphors by algebraic specifications and have developed a new understanding of pan and zoom metaphors, based on fundamental properties of human vision. A theoretical paper will be published as a book chapter.

Andrew Frank and Michael Goodchild attended a conference on GIS Design Models organized by the Midlands Regional Research Laboratory at the University of Leicester in March. Frank presented results from I-2 research and the consequences for GIS database design, while Goodchild's paper presented a review of geographical data modeling from the perspective of spatial analysis. Extended versions of both papers have been submitted for publication in a special issue of *Computers and Geosciences* and have also appeared as a Center Technical Paper.

An approach to the visualization of spatial relations and their manipulation was formulated in a paper by Werner Kuhn for the Fourth International Symposium on Spatial Data Handling in Zurich, July 23-27, 1990. The visualization of metaphors for user interfaces has been analyzed in Jeffrey Jackson's MS thesis, "Visualization of Metaphors for Interaction With Geographic Information Systems." A paper submitted to "Visualization 90" develops further the discussion of this work.

Andrew Frank has started work on 'spatial reasoning', formalizing quantitative methods to reason about spatial relations and to infer other properties from a set of spatial propositions. A first paper will be presented at the Auto-Carto 10 meeting in Baltimore in March 1991 and a more comprehensive journal article treating distance and cardinal directions is in preparation. Max Egenhofer is extending his previous work on topological relations in a similar direction.

NCGIA Buffalo members participated in two I-2 sessions at the Annual Meeting of the Association of American Geographers in Toronto. One session concentrated on verbal driving directions, and included presentations by speakers from Buffalo (Freundschuh, Gould) and Santa Barbara (Couclelis). The other session, on user interface issues for GIS, included a presentation by Gould.

In July 1990, the major international conference toward the end of Initiative 2 took place in Las Navas del Marques, Avila Province, Spain. There, a NATO Advanced Study Institute entitled "Cognitive and Linguistic Aspects of Geographic Space" brought together about 65 researchers from 14 countries. David Mark was Director of the Institute and Andrew Frank was co-Director, and participants included representatives from all three NCGIA sites. A book consisting primarily of papers presented at the ASI will be published by Kluwer.

Three I-2 papers were presented by graduate students from NCGIA Buffalo at the Fourth International Symposium on Spatial Data Handling in Zurich, Switzerland in July 1990. Scott Freundschuh (PhD candidate, Geography, Buffalo) presented a co-authored paper on driving directions that including co-authors Mark and Gould (Buffalo), Couclelis (Santa Barbara) and Gopal (formerly Santa Barbara; currently at Boston University). Michael Gould (PhD candidate, Geography, Buffalo) presented a paper on metaphors for user interfaces, co-authored with McGranaghan (University of Hawaii), and Susan Haller (PhD candidate, Computer Science, Buffalo) presented a paper co-authored with Mark, on production of locative expressions by computer.

Mark continued to research the general implications of I-2 results for metaphor-based cognitive models. Also, work applying the Rosch/Lakoff concepts of prototypes is being applied to the meanings of prepositions. A general overview paper on the implications of I-2 for Geography was submitted to a journal in June of 1990 (authors Mark and Frank), and an overview of the technical issues will appear as a book chapter (authors Frank and Mark). Both papers have been published as a Center Technical Paper.

One of the themes identified within I-2 was the user interface, which is an obvious place where cognitive science and GIS come together. This theme was of sufficient importance that it was established as a new Research Initiative I-13, on "User Interfaces for GIS".   Some I-2-related projects from the fall of 1990 are listed under Initiative 13, below. I-13 will address human-computer interaction methods and related issues in the design and implementation of user interfaces for GISs and other geographical software packages. The Specialist Meeting is planned for June, 1991.

Initiative 3: Multiple Representations. Many databases must include multiple representations of the same geographical features, because of the difficulties associated with the processes of generalization and abstraction. This Initiative has focused on the development of improved methods for cartographic generalization, and on database models and structures that address the multiple representation problem directly.

One of the research concerns for this Initiative relates to the formalization of rules for map generalization, and this includes issues of database management as well as graphic display. In April 1990 a Symposium was held in Syracuse to bring together researchers to present their proposed solutions, and to begin formulating a collective framework within which a rule base for map generalization might be implemented.   The Symposium was jointly funded by NCGIA and Syracuse University, and co-hosted by Barbara Buttenfield and Robert McMaster (University of Minnesota). Fourteen researchers from Canada, the US, the UK, the Netherlands, and Switzerland participated; only 3 of the participants had attended the I-3 Specialist Meeting. Subsequent to the Symposium, a book contract was negotiated with Longman House to publish revised versions of the Symposium papers; the book will go to press in January 1991, and is expected on the market in the late summer of 1991 at the same time as the Maguire, Goodchild and Rhind text *Geographical Information Systems*, also from Longman.

One of the most exciting follow-up activities from the Symposium has been the development of collaborative efforts by several of the participants. Two paper sessions reporting these efforts were held at the November 1990 GIS/LIS '90 conference in Anaheim, with submissions by Marc Armstrong and David Bennett (University of Iowa), William Mackaness (private consultant in London), Jean-Claude Muller and Paul Mouwes (ITC, the Netherlands), and Robert McMaster (in addition to NCGIA researchers Beard, Buttenfield and Mark).

Professor Jean-Claude Muller spent October and November in residence at Buffalo to collaborate with Buttenfield on a follow-up project to inventory existing topographic map series from various national mapping agencies (Swiss, German, French, Dutch, and American) to ascertain if rules for treatment of map features are consistently applied at all scales and if those rules are comparable between agencies. Work on this project will continue at Buffalo. Buttenfield will present early results in a keynote address to the IGU Conference on Multiple Representations to be held in Brno, Czechoslovakia, in April 1991. Robert McMaster is developing prototype interface designs for generalization of linear features, and Mackaness and Beard are collaborating upon an

interface design for generalization of thematic maps.

Stewart Fotheringham conducted research with graduate student David Wong on the modifiable areal unit problem (MAUP) in multivariate statistical analysis. Using Buffalo census data, the sensitivity of parameter estimates to variations in both aggregation level and partitioning were examined to understand further the nature of this problem. Parameter estimates were derived from two models: a multiple log-linear model and a multiple logistic model. This research is also related to I-1, "Accuracy of Spatial Databases" and I-6, "Spatial Decision Support Systems".

Original scheduling for Initiative 3 anticipated completion of formal activities in the spring of 1991. While no further national symposia or conferences are currently being planned, it is expected that research to implement multi-scale database architectures and algorithms and to formalize map generalization procedures will continue both in and beyond the Center. Efforts to secure external funding have been successful, including a grant from USGS (Fall 1989) to implement guidelines for differential line generalization of line features, and a grant from the US Soil Conservation Service (to begin Winter 1991) to explore the use of multiple scales of source data to refine soil parcel identification.

Kate Beard and Renato Barrera have been the primary Maine participants in I-3. They have submitted a proposal to USGS on Linkages Between Multiple Representations.

A significant activity under I-3 has been the development of a multithematic database as a joint project between NCGIA and the US Bureau of the Census. The results of the pilot project, which provides a number of different data themes provided by various federal agencies for Lee County, FL, was released by the Center in 1990 as a set of diskettes and supporting documentation. The project aims to provide a standard multiscale multitheme digital dataset for experimentation in a number of areas of cartographic generalization.

Initiative 4: The Use and Value of Geographic Information. This Initiative is the first to address the social, economic and institutional issues that arise from the adoption of GIS technology. It focuses on how geographic information is used in the decision-making process; how the introduction of an automated geographic information system impacts the quality and quantity of spatial information; and how to put a monetary value on any changes that occur in the decision-making process as a result of the adoption of GIS.

Following presentations at GIS/LIS in November 1989, and to the NCGIA Board of Directors in December 1989 and June 1990, personnel working on I-4 have been active in continued research and proposal writing. Harlan Onsrud, Jeffrey Pinto, and Gary Jeffress completed several tracer studies of adoption of GIS innovations in local government and prepared a questionnaire and analytic procedures towards development of a diffusion model. Survey returns are almost complete and a draft research paper has been prepared for submission to the *International Journal of Geographical Information Systems*.

Gary Jeffress is completing work for his PhD dissertation on the use and value of geographic information and Hamdy Tealeb is aiding Onsrud and Pinto in furthering the diffusion work. A proposal for a NATO conference on "Modelling Diffusion and Use of Geographic Information Technologies" has been prepared by Onsrud, Ian Masser (University of Sheffield) and Lyna Wiggins (MIT).

Nancy Obermeyer completed a literature review and expert jury procedure in constructing a classification scheme for uses of geographic information with the results submitted to the *Annals of the Association of American Geographers*.

I4 researchers submitted an overview proposal and three subproposals to several federal agencies on frameworks for assessing the local level use and value of federally generated geographic information. Onsrud and Pinto submitted an additional proposal towards a diffusion model in implementing infrastructure management systems to the Engineering Directorate of NSF as well as an exploratory research proposal to the Automated Mapping/Facilities Management industry on the same topic.

George Benwell of the University of Otago, New Zealand, visited for two weeks in July to work with Hugh Calkins and Holly Dickinson on Initiative 4 issues. Research into the use of Petri nets to model the use and value of geographic information in decision making has continued with the submission of four journal articles describing how the Petri net approach will be used. Continuing development of software to analyze Petri nets for this purpose in conjunction with the Department of Information Sciences, University of Otago, Dunedin, New Zealand, has led to three versions of prototype software. Current efforts center on creating test Petri nets for two or three applications from the two major case studies being pursued under I-4: forestry and municipal government. The prototype software will be evaluated and modified as needed based on the first trial runs of the software. Hugh Calkins and Nancy Obermeyer have submitted and revised an article entitled, "Value of information, taxonomies of information use,

and diffusion of technology" for the *Journal of the Urban and Regional Information Systems (URISA)*.

Initiative 5: Architecture of Very Large Spatial Databases. The large volumes characteristic of many geographical databases cause enormous problems for current technology, and the problem will grow much worse if trends continue. This Initiative is concerned with the development of techniques for dealing with very large spatial databases, including metadata, hierarchical data structures, and novel data models.

Papers presented at the Symposium on Design and Implementation of Large Spatial Databases held in conjunction with the I-5 Specialist Meeting in July 1989 have been published by Springer-Verlag, Lecture Notes in Computer Science, and were released to participants in March, 1990. The Specialist Meeting report, NCGIA Technical Paper 89-13, "Architecture of Very Large GIS Databases: Initiative 5 Specialist Meeting Report" was published in the *Journal of Visual Languages and Computing*.

Santa Barbara research focuses on the efficiency of user interaction, overlaying an object-oriented database layer with a deductive layer. Also important is the concept of a metadatabase allowing both user and system searches for data satisfying given constraints. The concept of metadata is being clarified and a prototype metadatabase is being designed and implemented.

At Maine, Kate Beard has prepared a proposal to the USGS for development of a prototype Map Generalization and Display System.

The I-5 specialist meeting identified the need for a 'map algebra', ie a formal description of commonly used GIS operations. Previous work in this area exists for raster and vector representations. However, the work either lacks a rigid formalization or has no indication of completeness. Tomlin's Map Analysis Package (MAP-Algebra) is based on the overlay methodology. Research is under way on map algebras at Santa Barbara by Terry Smith using the 'multimap' conceptual data model of several thematic layers, and at Maine by graduate student Claus Dorenbeck. Khaled Al Taha has prepared a research paper on 'spatial algebra'. We have applied rigid algebraic specification methods to describe the operations used. Renato Barrera with graduate student Hayri Sever, is reviewing object-oriented database management systems. Research has been carried out on the efficient transmission of updates among different view states.

The analysis of map algebra has clear applications for the optimization of queries in spatial databases. Research by Doug Hudson for his completed PhD thesis on the maintenance of materialized views developed an algorithm to find the optimal break into relations to minimize the efforts necessary to update materialized views. This is relevant for very large distributed spatial databases, where data that change rarely will be replicated and stored at multiple sites to reduce communication cost.

The optimal execution of queries in a distributed spatial database, where the same data is represented at multiple levels of resolution and accuracy, is being studied by Renato Barrera. The goal is to construct a query execution plan where the result matches the quality requirements of the user at minimal cost; ie primarily minimizing communication cost for the transfer of data from remote storage sites.

Initiative 6: Spatial Decision Support Systems. I-6 examines the possible role of GIS and associated technologies in supporting the decision-making process. The premise underlying I-6 is that GIS provide only limited capabilities for supporting sophisticated forms of spatial analysis and decision-making. The purpose of I-6 is to develop and implement a research program that will merge geographical analysis and GIS.

The Specialist Meeting was held in Santa Barbara in March, 1990 with a group of over thirty participants, primarily academics, but with strong representation from the private sector. The meeting was concerned with design issues and with the extent to which work on SDSS could shed light on the decision-making process or provide an experimental environment in which to study it. The range of application areas was narrowed to marketing, retailing, location theory and socioeconomic models.

Four research themes emerged at the Specialist Meeting, and are described in full in the meeting report, NCGIA Technical Paper 90-5. The first theme, decision-making processes and SDSS, asks what system architectures can best support an SDSS that acquires knowledge from a decision-maker, how transformations should occur between exploratory resolution spaces for ill-defined problems, and what exploratory strategies are most appropriate for ill-structured problems. A proposal to NSF by Gerard Rushton (San Diego State University), Marc Armstrong (University of Iowa), Suranjan De (University of Iowa) and Paul Densham addresses the issues involved in designing and implementing a knowledge-based SDSS for locational planning. Alternative strategies for locating bank branches that function as an integrated network rather than as isolated, largely unrelated sites have been investigated by Paul Densham, David Willer (PhD student), and representatives of M & T Bank (Industrial Affiliate).

The role of modeling and data within an SDSS is the second theme. Research issues in this context include the development of taxonomies of spatial models and the common elements relevant for SDSS, and a knowledge base on the sensitivity of these models to a wide range of factors. Research on the modifiable areal unit problem by Stewart Fotheringham and Paul Densham is investigating the sensitivity of linked population projection models and location-allocation models to both the number and the spatial pattern of data units used. Rajan Batta is designing and implementing a SDSS for locating emergency facilities in congested environments. A comparative study of the sensitivity of existing locational models to a range of environments is a key part of this research.

The third theme is the technology and implementation of SDSS, including the scope for object-oriented programming techniques in SDSS; how a system adapts during decision-making; how to identify the forms of representation/visualization needed to support spatial decision-making; and how knowledge is elicited, represented, and used in an SDSS. An opportunity to examine how a SDSS changed during the course of solving a complex, ill-structured problem - in terms of the addition of new capabilities and the evolving definition of the problem as results of analyses became available - is provided by work with M & T Bank (Industrial Affiliate) by Paul Densham and David Willer. The same project has investigated the generation of displays depicting the solutions to locational analyses within TransCAD, a commercially available GIS. Jim McKinney (MA student) is investigating the utility of various visual depictions of the results of location-allocation models to people with different backgrounds in cartography and locational analysis. Marc Armstrong (University of Iowa), Paul Densham, Gerard Rushton (San Diego State University), and Panos Lolonis (PhD student, University of Iowa) are developing a classification of visual displays for use in locational analyses and a framework for their production in a SDSS. Rushton and Densham have developed a series of implementation strategies for heuristic location-allocation algorithms that exploit the spatial structure of the problem to reduce solution times. They are also working on a new heuristic which is derived from these strategies. Densham and Armstrong have submitted a proposal to NSF to investigate the role of parallel processing in SDSS for locational planning. Research will focus on the use of parallel computation to solve models and to generate cartographic displays. Densham and Mark MacLennan (PhD student) are using ARC/INFO on a Sun SPARCstation to investigate the utility of a multi-tasking environment in integrating locational modelling and a GIS.

The final theme focuses on user requirements and organizational issues. Meeting participants recommended development of a taxonomy of spatial problems. This requires carrying out case studies of SDSS applications, as well as a literature search to identify factors in ill-defined spatial problems and the tools required to solve them, and an evaluation of the significance of a number of selected problem factors. The resulting taxonomy can be used to identify gaps in the models that may be used in SDSS and to further our understanding of how SDSS are used in decision-making. Goodchild and Lanter are developing a series of alternative taxonomies of GIS functions and tools at Santa Barbara, and Lanter is researching the use of data lineage information in spatial problem-solving. A project funded by the US Forest Service (PIs Church and Lanter) is building an SDSS for timber allocation by adding a spatial component to the FORPLAN optimization model.

Initiative 7: Visualizing the Quality of Spatial Information. Technology currently allows fast display and processing of large volumes of information. Information on the quality of data is also important for effective use of GIS data: it affects the credibility of data representation and it affects the reliability of decision-making and interpretations. Clearly, the quality of information varies spatially, and visual tools for display of data quality can only improve and facilitate use of GIS. At present, those tools are either unavailable (in existing GIS packages) or not well developed (error models and the process of visualization are only recently beginning to be addressed directly as research topics).   This initiative is scheduled to begin activities during the Spring of 1991, and planning has been underway for several months in preparation.

The quality of spatial data and databases is a major concern for developers and users of GIS. The quality of spatial information products relates to accuracy, error, consistency and reliability. Implications for spatial analysis and for spatial decision-making are too complex for comprehensive inventory, but can be identified in theoretical work (for example in spatial statistics) as well as in GIS applications (for example in resource management). The goal in this research initiative is to focus on effective means of managing and visually communicating components of data quality to researchers, decision-makers and users of spatial information, particularly in the context of GIS.

Topics that tie I-7 to ongoing research initiatives include development of measures for spatial accuracy and error (I-1), variation in data quality that accrue with changing resolution (I-3), impact of data quality displays on spatial decision-making (I-6), the role of visualizing data quality in remote sensing (I-12), and implications for GIS user interface design (I-13). I-7 will be led by Barbara Buttenfield (Buffalo) and Kate Beard (Maine).

To maximize visibility of the start-up of this initiative, a panel session will be held at AUTO-CARTO 10 meetings March 23-29 1991 in Baltimore. Panelists will include representation from the academic, federal and private sectors in addition to one or more presentations from NCGIA researchers.   The Specialist Meeting will follow June 8-12, in Castine, Maine. The meeting will focus around four major themes, including Data Quality Components (error modeling and derivation of indices of data quality), Data

Models and Database Issues (management of data quality within databases during manipulation and update), Representational Issues (visual tools to facilitate internal representation and graphical display), and Evaluation of User Needs (analysis of user demands for data quality information). The bibliography for I-7 is being compiled jointly with NCGIA-Buffalo. Sarah Clapham is working on this initiative and has submitted an abstract for presentation at the annual ACSM Convention.

Initiative 8: Expert Systems in Cartographic Design. No timetable has been set for this Initiative.

Initiative 9: Institutions Sharing Geographic Information. This Initiative will begin in late 1991 and focus on the organizational problems inherent in shared spatial databases.

Initiative 10: Temporal Relations in GIS. A literature survey on temporal knowledge representation and temporal databases has been completed. Technical Paper 90-8: "Models in Temporal Knowledge Representation and Temporal DBMS" has been published and is available at the NCGIA in Santa Barbara.

Renato Barrera organized a preparatory workshop on "Temporal Relations in GIS" held at the University of Maine, Orono, October 12-13, 1990. The purpose of this workshop was to invite graduate students currently working on topics related to time and GIS, and specialists in GIS and Computer Science to present recent research and to discuss promising research topics. There were short talks on the temporal approach to object oriented databases, temporal query languages, the display of temporal data, temporal logics, etc.

Several sessions of discussions on specific topics were held. For each session the group was separated into subgroups and discussed a particular research topic. Some of the workshop's results were: the detection of two paradigms of users' requirements - one that necessitates a continuous model of time in which evolution is based on differential equations and another described by a discrete model in which events are related by mathematical logic; the need for including exploratory mechanisms appropriate for searches in large datasets; the appropriateness of including views that reflect a user's need - eg temporal/spatial aggregation, and rules to construct the views and to enforce consistency; the need for the manipulation of inexact or approximate information, including provisions for approximate queries, for assessing the quality of data (i.e., its fitness for use), and for evaluating the error propagation to derived data; and the necessity of a closer communication between GIS specialists and computer scientists.

A report on this meeting is in preparation and will appear as an NCGIA technical report.

Initiative 11: Time-Space Models. No timetable has been set for this Initiative.

Initiative 12: Integration of Remote Sensing and GIS. Remotely sensed images continue to offer a cost-effective and popular source of data for GIS. At the same time GIS data is increasingly used as a means of improving image classification. However the coupling of the two technologies raises numerous questions. I-12 is directed at investigating these issues. There was a pre-meeting in Denver, CO on May 17, 1990 to plan Initiative 12. A second planning meeting was held at the Stennis Space Center, Mississippi on August 1, 1990. Participants present were from academia, industry, and government organizations.

The Specialist Meeting for I-12, led by John Estes (Santa Barbara) and Jeffrey Star (Santa Barbara) was held December 3-6, 1990, in Sioux Falls, SD, at EROS Data Center (USGS). Discussion centered on five topics for the integration of remote sensing and GIS: institutional issues, data structures and access, data processing flow, error analysis, and future computing environments. Each topic was presented as a multi-authored position paper, and reviewed by discussants, and subsequently refined in working groups. Revised versions of the papers are to be published in a special issue of *Photogrammetric Engineering and Remote Sensing*, with Manfred Ehlers (Maine) having the lead in the data structures paper. ASPRS has agreed to host an international symposium on remote sensing and GIS in conjunction with their annual convention - Manfred Ehlers and John Estes will be in charge of this.

At Santa Barbara, PhD candidate Ken McGwire is studying the effects of classification accuracy of remotely sensed images used as GIS inputs.

Initiative 13: User Interfaces for Geographic Information Systems. I-13 will address human-computer interaction methods and related issues in the design and implementation of user interfaces for GIS and other geographical analysis software packages. This Initiative was introduced during the December 1989 meeting of the Scientific Policy Committee, and is the first Initiative to be formally adopted since the original proposal was submitted to NSF. It is now scheduled to hold its Specialist Meeting in the Buffalo area in June of 1991.

Preparatory work for this Initiative is underway. Max Egenhofer will work on novel, not SQL-based query languages for GIS. Werner Kuhn formalized the metaphor concept to be used in the design of user interfaces for GIS. Matt McGranaghan and a group of students developed an annotated bibliography on GIS user interface questions.

During the summer of 1990, Stuart Shapiro (Computer Science, Buffalo) directed a project which successfully linked the SNePS artificial intelligence system to ARC/INFO. This was funded primarily from NCGIA NSF funds, but was supplemented by a grant from Environmental Systems Research Institute (ESRI). Since previous projects have implemented intelligent multi-media user interfaces, natural language understanding, spatial inference, and database front-ends within SNePS, the possibilities for a 'natural' and somewhat system-independent SNePS front end for ARC/INFO and other GISs seem very promising. Shapiro was assisted in the project by Hans Chalupsky, graduate student in Computer Science, and Hsueh-Chen Chou, graduate student in Geography. David Mark presented a brief summary of the project to the Northeast ARC/INFO user group meeting as part of his Plenary Address "Interacting with Geographic Information".

In September 1990, a preliminary announcement of Initiative 13 and its goals was circulated widely using electronic media. It was distributed to subscribers of the BITNET Listservers GIS-L and GEOGRAPH, and posted on several Usenet news groups, including comp.cog-eng, comp.ai, and sci.lang. Responses were very encouraging, especially from private sector firms involved in user interface research. An electronic mailing list for news and information about Initiative 13 was established from responses to these postings and from other sources.

B. Education

The testing phase of the Core Curriculum project ended in late April, 1990. Over 100 institutions participated by reviewing and, in many cases, teaching the materials, and many reviews, comments and suggestions were received from the participants. Revisions based on this feedback were completed in late June, and the revised version was ready for distribution by the end of July. The availability of the curriculum has been announced in newsletters and in a brochure, and over 450 orders had been received by late December 1990. The vast majority of orders have come from educational institutions, but the curriculum is clearly also of interest to vendors, consultants and public agencies. Over half of the orders are from the US, but there is also substantial interest world-wide, and requests have come from over 40 countries. Like the test version, the final version consists of 75 units, each intended as the basis for a one-hour lecture. Each unit includes 6-8 pages (average) of instructor's notes; exam and discussion questions; and references, handouts and overheads. The package also includes a set of slides and the text in digital form on diskette. The 75 units are grouped into modules, distributed among three 25-lecture courses.

Curriculum User Group meetings were held at GIS/LIS '90 in Anaheim in November 1990, and at the AAG Annual Meeting in Toronto in April 1990, and are planned for similar meetings in the future. Workshops on the project and other issues in curriculum development were sponsored by the Center at the Fourth International Symposium on Spatial Data Handling in Zurich in July and at GIS/LIS '90 in Anaheim in November, and similar workshops are planned for the future, including one at the European GIS conference in Brussels in April 1991.

The major Center effort in education in 1990/91 is the development of a comprehensive approach to practical lab exercises. The intent of this "Volume IV" project is to provide a top-down, conceptual framework for labs, as well as developing specific exercises both within the Center and in conjunction with vendors. The labs will support the Core Curriculum by providing convincing practical illustrations of its key concepts. They are not intended as training materials in specific software packages or as stand-alone tutorials.

The proposed framework for "Volume IV" consists of four major groups of concepts: the database as a presentation of reality; GIS as a management tool; GIS investigates the world; and implementation and design. The framework was presented for comment at the GIS in Higher Education conference in Columbus in June, and has been distributed widely through the NCGIA newsletter. During the summer, labs were developed within the framework in cooperation with the IGBP-sponsored Global Change Diskette Project; in cooperation with ESRI; and in conjunction with the I-3 multiple representations database. The labs distributed with the test version of the curriculum were also updated. The Center is also collaborating with TYDAC Technologies in the development of training materials for SPANS. Current plans call for the release of "Volume IV" in the summer of 1991. Much of this work continues to be sponsored by the UCSB Office of Instructional Development under a curriculum development grant.

A paper describing the initial development of the Core Curriculum will appear in the *Journal of Geography in Higher Education*. Two further papers are in preparation, one on the testing program and one on the role of GIS education in Geography and related disciplines. One consequence of the development of the Core Curriculum has been an increasingly focused debate on the

nature of GIS education, as distinct from GIS training, and its relationship to established disciplines.

C. Outreach

The circulation of the twice-yearly newsletter (June and December) increased to over 2,000 in the second year. Overview presentations on the work of the Center continue to be made at conferences and stories on the Center appear in magazines, newspapers, and journals, including *ACSM Bulletin*, *GIS World*, *Geo Info Systems*, *Mapping Awareness*, *International Journal of Geographical Information Systems*, and *Government Information Quarterly*.

At the present time there are 29 papers in the Technical Paper series and six other miscellaneous publications, and over 160 papers were listed in the 18 month review document. Requests for publications average about 30 per week, in addition to the Core Curriculum.

ISPRS International Workshop, University of Maine (January 1990). The Maine site hosted an international workshop on "Advances in Spatial Information Extraction and Analysis for Remote Sensing" on January 14-17, 1990 at the University of Maine. The workshop was directed and organized by Manfred Ehlers and co-sponsored by the International Society for Photogrammetry and Remote Sensing (ISPRS) working groups WG II/2 "Systems for the Analysis of Remotely Sensed Data", WG VII/2 "Spatial Information Extraction and Manipulation", WG VII/7 "Expert System Applications for Remote Sensing", the Department of Surveying Engineering, University of Maine, and the American Society for Photogrammetry and Remote Sensing.

Topics of the workshop included: advances in hardware and software for image processing; low cost systems; integration of GIS with remote sensing; standards for data transfer and exchange; man-machine interaction; database design and data management systems; expert systems for image processing and GIS; knowledge acquisition and uncertain reasoning for environmental modelling; expert systems and AI for thematic and terrain mapping; computer vision and image understanding techniques in remote sensing; modeling in remote sensing; large shared databases; and algorithms for information extraction from image data of high spatial and spectral resolution. About forty participants from Canada, the US and Germany attended the workshop. Proceedings of the workshop will be published by ASPRS.

CHI'90 Workshop on Visual Interfaces to Geometry, Seattle, WA (April 1990). The two-day workshop was organized by Werner Kuhn and Max Egenhofer (Maine) and sponsored by the Association for Computing Machinery's Special Interest Group on Computer-Human Interaction (ACM SIGCHI), as part of its annual conference, CHI'90, April 1-5, 1990, in Seattle, WA. The purpose of the workshop was to explore and integrate advanced approaches to the visual representation and interactive manipulation of geometric information. The approach taken was to establish desirable properties of interfaces, identify problems in achieving them, and suggest new approaches to solve these problems.

Seventeen participants, from five countries and three continents, attended the workshop, having been selected based on submitted position papers. Five participants came from industry, the rest from academia. The range of application areas represented included Computer Aided Design and Engineering, Image Processing, Geographic Information Systems, and general Computer Graphics. The pre-workshop position papers were printed in a workshop manual and a comprehensive report will appear in a future issue of the ACM SIGCHI Bulletin.

States, Space and Development in the East Asian Pacific Rim, Santa Barbara (March 1990). The Center was co-sponsor of this conference March 22-25 in Santa Barbara, along with ESRI, UCSB and the UC Pacific Rim Program. Thirty-five prominent scholars from Asia, Europe and North America met for four days of discussion on the newly-industrializing countries of East Asia, focussing on changes in the spatial organization of the regional economy, and on the impact of state policies on economic development. Sessions examined individual countries; key economic sectors; labor markets and social policy; and the spatial analysis of economic development. In November 1990 a smaller meeting was held to develop a proposal for major funding on the subject of commodity chains.

GIS Education and Training, Leicester, UK (March 1990). Also in March 1990, the Center was co-sponsor of a meeting on GIS education at the University of Leicester, and presentations on the education program, particularly the Core Curriculum, were made by Michael Goodchild and Karen Kemp. Considerable interest in the curriculum has been expressed outside the US, and two UK test sites (Birkbeck College and the University of Leicester) provided substantial commentaries. The conference was followed immediately by one on GIS Design Models and Functionality with NCGIA presentations by Andrew Frank and Michael Goodchild.

Third Annual TIGER Workshop, Santa Barbara (September 1990). About 100 people from agencies mostly located in California attended a one-day workshop affiliated with the State Census Data Center and hosted by NCGIA at Santa Barbara.

Presentations focused on the US Bureau of the Census TIGER database and its applications.

GIS and the Social Sciences, Santa Barbara (March 1991). As part of its effort to promote GIS applications in the social sciences, the Center will sponsor this conference in late March 1991. Ross MacKinnon (Buffalo) and William Skinner (Board of Directors) are currently developing the program, which will include papers on four major topics: ecological inference and individual behavior; social and political consequences of racial, religious and class spatial mobility; spatial and non-spatial dimensions and scaling; and the redistricting problem. We anticipate about 20 presentations, and the publication of a book after the conference. In addition to this effort, the Center is participating in a book on GIS and the Social Sciences to be edited by Leonard Hochberg (Stanford) and published by Blackwell.

At Santa Barbara, a major equipment grant from Sun Microsystems has established a network of workstations for GIS research in the social sciences. A total of ten workstations have been installed with ARC/INFO in the Social Science Computing Facility and in the research labs of faculty in Anthropology, Economics, Political Science and Sociology.

GIS in Municipal Planning, University of Maine (May 1990). The Maine site sponsored a conference on "GIS In Municipal Planning" on 18 May, 1990 at the University of Maine. The conference was organized by Kate Beard and was co-sponsored by the University of Maine's Department of Surveying Engineering, Environmental Studies Center, Bureau of Public Administration, and Soil and Water Conservation Society (Pine Tree). The purpose of the conference was to explore current strategies for using GIS in municipal planning and resource management; identify specific steps to improve coordination between federal, state, and local governments; and identify resources for local officials who need better data analysis for decision-making.

At the Maine site, Max Egenhofer is in the process of forming a Special Interest Group on Geographic Information Systems, tentatively called SIGGIS, within the Association of Computing Machinery (ACM). This interest group will cooperate with the AAG Specialty Group on GIS and will provide a focal point for computer scientists interested in GIS.

A brochure entitled "Geographic Information and Your Future: Careers for a Fragile Planet" is being designed and written by Harlan Onsrud. This brochure is being written to attract more high school students into analytically rigorous university programs in geographic information.

Geographic Information Systems in Maine: An Overview is a new publication from the Environmental Studies Studies Center, University of Maine. This status report on GIS activities in Maine was produced with cooperation from the University of Maine Department of Surveying Engineering and the College of Forest Resources.

Several agreements were signed between the Center and other organizations and institutions, to promote cooperative efforts and coordination of activities. Memoranda of Understanding signed in 1990 include agreements with:

Research Libraries Group (RLG) Inc.
University of Wales (South West Regional Research Laboratory)
Ohio State University (Center for Mapping)
Stanford University (Laboratory for the Study of Regional Systems and Social Processes)
Environmental Protection Agency
Oak Ridge National Laboratory

Negotiations are continuing with other organizations.

D. Management

Board of Directors. The Board of Directors oversees the reporting of Center activities to NSF, and acts in an advisory role to the other Center committees. Several changes occurred in the membership of the Board of Directors in Year 2. Linda Sullivan (Defense Mapping Agency) joined and Lowell Starr was replaced by Joel Morrison (US Geological Survey). At its June meeting in Orono ME, the Board elected Joel Morrison as its Chair, replacing John E. Estes. The standard meeting format begins with a half day of presentations on ongoing research at the host site, with emphasis on presentations by graduate students, followed by one and a half days of discussion, including executive sessions. The members of the Board at the end of November 1990 were:

Joel Morrison (US Geological Survey), Chair

Robert T. Aangeenbrug (University of South Florida)
Vincent Barabba (General Motors Corporation)
John R. Borchert (University of Minnesota) (Member, National Academy of Sciences)
John Bossler (Ohio State University)
Jack Dangermond (ESRI)
Herbert Freeman (Rutgers University)
John B. Garver, Jr. (National Geographic Society)
Patrick E. Mantey (University of California, Santa Cruz)
D. David Moyer (University of Wisconsin-Madison and URISA)
Franco P. Preparata (University of Illinois at Urbana)
Chester R. Richmond (Oak Ridge National Laboratory)
John R. Rosati (TRW)
Gerard Rushton (University of Iowa)
G. William Skinner (University of California-Davis) (Member, National Academy of Sciences)
Linda Sullivan (Defense Mapping Agency)
Shelby Tilford (NASA)
 M. Gordon Wolman (Johns Hopkins University) (Member, National Academy of Sciences)

The period of service of four members - Aangeenbrug, Barabba, Preparata and Wolman - was due to end after the December, 1990 Board meeting.

Executive Committee. The Executive Committee is made up of the Co-Directors and Associate Directors. The Co-Directors are responsible for overall management of the Center, and the Associate Directors for management of operations at each site. David S. Simonett resigned from the position of Co-Director in June 1990 and was replaced by John E. Estes. NSF approved a change of PI from Simonett to Michael Goodchild. At the end of November 1990 the membership of the Executive Committee was: Michael Goodchild and John Estes, Co-Directors; Terence Smith (Santa Barbara), Ross MacKinnon (Buffalo) and Andrew Frank (Maine), Associate Directors.

Scientific Policy Committee. During the year from December 1, 1989 to November 30, 1990, the Scientific Policy Committee (SPC) held formal meetings in Santa Barbara in December 1989, and in Maine in June 1990. Some SPC members also met informally at the AAG meeting in Toronto in April 1990, and at the GIS/LIS meeting in Anaheim in early November 1990. David Mark (Buffalo) served as Chair of the SPC throughout the period. There was one change in the SPC membership during the period: Jack Estes replaced David Simonett ex officio when he replaced Professor Simonett as co-Director of the NCGIA.

During the Santa Barbara meeting, the SPC discussed two possible new Initiatives, and also examined all of the Initiatives in the original proposal that had not been formally scheduled (7 through 12). A new initiative, to be numbered 13, and entitled "User Interfaces for Geographic Information Systems", was discussed and approved, and it was also decided that I-13 would replace Initiative 8 ("Expert Systems for Cartographic Design") in the timetable. A second new Initiative, on exploratory spatial data analysis, was considered to be interesting yet premature. The committee also decided to place Initiatives 8, 10, and 11 on indefinite "hold", because human and financial resources needed to start them could not be identified. Conversely, Initiative 12, "Integration of Remote Sensing and GIS", was moved earlier in the timetable because resources were available. Further refinement of the Initiative timetable took place at the Maine meeting. Thus the plan for year 3 of the NCGIA (December 1990 through November 1991) was expected to include Specialist meetings for three Initiatives (I-7, "Visualization of the Quality of Geographic Information"; I-9, "Institutions Sharing Geographic Information"; and I-13).

Space. At Buffalo, both the Center and the Department of Geography moved into their new quarters late in the summer. The final phase of the move and the rehab process was finished in mid-November. The NCGIA has a suite of administrative offices on the third floor of of the Wilkeson Quadrangle in the Ellicott Complex. This suite includes space for the director, a visiting scholar, the administrative assistant, and the secretary, and also has a small conference room/library. The Lab facilities (GIAL) are housed in 5500 sq ft, nearly triple their previous size. This rehabilitation project cost the University approximately $750,000. At least one third of these costs are directly attributable to space used for Center activities. This is a very strong indication of institutional support for the NCGIA.

At Santa Barbara, remodeling of two teaching laboratories is taking place under the Center's $2.3 million IBM Joint Study agreement: a 22-station PS/2 lab for GIS and remote sensing and a 10-station RS/6000 lab for GIS and automated cartography. Both

will be "showcase" facilities. Work on the PS/2 lab was completed in September 1990.

At Maine, work has begun on a new building addition to house the Center and the Department of Surveying Engineering. The addition of 16,000 square feet is scheduled for completion in December 1990. Total cost is estimated at $1.2 million, and about half of the space will be used by NCGIA. This is a similarly strong indicator of the University's commitment to the Center, and all the more noteworthy in a year of extreme budget constraints.

3. EXTRAMURAL SUPPORT

A. Grants and Contracts Awarded as of 11/30/90

APPLE COMPUTER INC. - "Image Processing on the Macintosh II"; $23,950. PI: Ehlers.

BARKER CENTRAL SCHOOL DISTRICT - "Enrollment Projection Models for School Districts"; $4,000. PIs: Calkins, Rogerson.

CALIFORNIA DEPARTMENT OF TRANSPORTATION - "Geographic Information Systems"; $15,000. PI: Goodchild.

ENVIRONMENTAL PROTECTION AGENCY (EPA) - "Remote Sensing & GIS Technology Demonstration and Basic Research Cooperative Agreement"; $87,725. PIs: Estes, Scepan.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI) - "Interfacing an Intelligent, Multi-media User Interface with ARC/INFO"; $3,600. PIs: Shapiro, Mark.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI) - "Locational- Allocational Modelling with ARC/INFO's Network Analysis Module"; $5,650. PI: Densham.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI), DEPARTMENT OF NATURAL RESOURCES, WASHINGTON - "Support to Conduct Case Studies Relating to Initiative 4"; $5,000. PI: Calkins.

LAWRENCE LIVERMORE NATIONAL LABORATORY - "Design and Implementation of a Logic-based Object-oriented Data Model for Very Large Spatial Databases"; $14,988. PI: Smith.

LOS ALAMOS NATIONAL LABORATORY - "Development of GIS for LANL Environmental Restoration Program"; $10,000. PI: Goodchild.

MAINE RESEARCH FOUNDATION - "Foundations for Casco Bay GIS"; $18,190. PI: Beard.

MERCHANTS AND TRADERS' (M&T) BANK - "Location Analysis of Bank Retail Functions"; $9,000. PI: Densham.

MERCHANTS AND TRADERS' (M&T) BANK - "Industrial Affiliate"; $10,000. PI: Densham.

NATIONAL FISH AND WILDLIFE FOUNDATION - "GIS Analysis of Biodiversity in Southern California"; $135,000. PIs: Davis, Scott, Estes, Csuti.

NATIONAL GEODETIC SURVEY - "Measurement-Based Multipurpose Cadastre: Pre-Implementation"; $9,994. PIs: Frank, Kuhn.

NATIONAL SCIENCE FOUNDATION (NSF) - "Nonlinear Model Sensitivity"; $3,186. PI: Lawrence Band, University of Toronto (adjunct faculty, NCGIA-Buffalo).

NATIONAL SCIENCE FOUNDATION (NSF) - "Spatial Human-Computer Interaction Strategies for Geographic Information Systems"; $5,460. Dissertation enhancement grant for Michael Gould (PhD candidate and NCGIA research assistant), Project Director: Mark.

NATIONAL SCIENCE FOUNDATION - "Presidential Young Investigator Award"; $54,000 ($25,000 annual base budget renewal for 1990-1991, plus about $29,000 in matching money). PI: Rogerson.

NORTH ATLANTIC TREATY ORGANIZATION (NATO) - "Cognitive and Linguistic Aspects of Geographic Space"; approximately $54,000 (2 million Belgian francs). Support for a NATO Advanced Study Institute in Spain, July 8-20, 1990. Conference Director: Mark.

PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, FOREST SERVICE, USDA - "Developing Tactical and Operational Forest Planning Decision Support Systems"; $51,117 (including $11,374 in contributed overhead by UCSB). PIs: Church, Lanter.

SOIL CONSERVATION SERVICE - "Resource Inventory and Soil Surveys Using Geographic Information Systems"; $47,500. Project Director: John Kick, SCS Syracuse. NCGIA subcontract PI: Buttenfield. Funding includes $10,000 for NCGIA equipment, and commitment for 1 year paid residence at NCGIA for SCS representative to collaborate on research.

TOWN OF AMHERST - "GIS Requirements Study for the Town of Amherst"; $7,551. PI: Calkins.

UC PACIFIC RIM RESEARCH PROGRAM - "Computer modeling and theory of sacred geography in California, China and Japan"; $13,000. PI: Grapard.

US FOREST SERVICE - "Integrated Information Management Program - Performance Validation Preparation"; $14,000. PIs: Calkins, Smith.

US GEOLOGICAL SURVEY - "Organizing Information for Improved Groundwater Management"; $37,106. PI: Beard.

US GEOLOGICAL SURVEY - "Image Processing and GIS Development"; $35,202. PI: Estes.

US GEOLOGICAL SURVEY - "NCGIA I-12 - Remote Sensing and GIS"; $30,000. PIs: Davis, Estes, Star.

B. Equipment and Software Grants Awarded

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI) - $38,500 software grant. PI: Lanter.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI) - The Buffalo site received additional site licenses to run ARC/INFO on the new SUN workstations. The Santa Barbara site has received site licenses for its temporary IBM RT network and for its PS/2 lab, and has agreed to be a beta test site for the IBM RS/6000 workstation version. In September 1990 an agreement was concluded between the three sites of NCGIA and ESRI covering all future licensing of ARC/INFO.

ERDAS, INC - ERDAS has agreed to donate a site license for their image processing software to teach a remote sensing course in the spring semester 1991. PI: Buttenfield.

IBM CORP - "Joint Study", $1,036,000 (about $2.3 million before discounting) (in addition, $70,000 for software purchases, and funding of a fulltime liaison person at Santa Barbara). PI: Goodchild. In summary, the agreement provides:

> Instructional Center: 11 PS/2 models 70 and 80 (in addition to 11 PS/2s already installed) and supporting peripherals.

> Graphic Analysis: 7 IBM RTs, currently being replaced by RS/6000 workstations, plus server system and peripherals.

> Scientific Image Analysis: 2 high end graphics workstations (RS/6000 model 730) plus peripherals.

> Cartography Lab: 10 RS/6000 workstations, server system and peripherals.

> Faculty Workstations: 10 PS/2s, 11 RS/6000 workstations for faculty offices.

> Departmental Mainframe: 2 temporary RT servers, to be replaced by an RS/6000 model 930.

ULTIMAP CORPORATION - The ULTIMAP Corporation has donated a copy of ULTIMAP GIS package for use on the Apollo UNIX workstation. The donation also includes a loan of a workstation from Apollo Computer. PI: Calkins.

UNIVERSITY AT BUFFALO, OFFICE OF THE PROVOST - As a part of the move to the new facilities, the Center received a $20,000 donation of Ethernet boards and Novell networking software.

The following equipment and software grants have been received at the Maine site:

> 3 DECstation 3100
> 2 VAXstation 3100-30
> 1 VAXstation 3100-40

1 MicroVAX 3500
1 CD ROM Drive
3 Macintosh IIci
3 High-resolution RGB Monitors
3 80Mb Hard Drives
4Mb RAM
40SC Tape Drives
1 Apple Scanner
1 Ultrix 4.0
1 VMS 5.3
1 DecNet/Ultrix Connection
1 Soft PC
1 AlisaTalk
1 AlisaShare
1 AlisaPrint
1 DecWrite
Intergraph MGE Software
Symantec Utilities II
Tigris upgrades

APPENDIX 1 - PUBLICATIONS

A. Articles published or formally accepted in refereed journals

Anselin, L. Spatial dependence and spatial structural instability in applied regression analysis. *Journal of Regional Science* 30:185-207 (1990).

Anselin, L. Some robust approaches to testing and estimation in spatial econometrics. *Regional Science and Urban Economics* 20:141-163 (1990).

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Armstrong, M.P. and P.J. Densham. Database organization strategies for spatial decision support systems. *International Journal of Geographical Information Systems* 4:3-20 (1990).

Armstrong, M.P., G. Rushton, R. Honey, B. Dalziel, S. De and P.J. Densham. A spatial decision support system for regionalizing service delivery systems. *Computers, Environment and Urban Systems* (to appear).

Batty, M., P.A. Longley and A.S. Fotheringham. Urban growth and form: scaling, fractal geometry and diffusion-limited aggregation. *Environment and Planning A* 21(11):1447-1472 (1989).

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Carson, Y. and R. Batta. Locating an ambulance on the Amherst Campus of State University of New York at Buffalo. *Interfaces* 20(5): 43-49 (1990).

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Dickinson, H.J. and H.W. Calkins. Comment on 'Concerning "The economic evaluation of implementing a GIS"'. *International Journal of Geographical Information Systems* 4(2):211-212 (1990).

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Eagles, M. Sources and variation in working-class formation: ecological, sectoral, and socialization influences. *European Journal of Political Research* (to appear).

Egenhofer, M. Extending SQL for graphical display. *Cartography and GIS* (1990) (to appear).

Egenhofer, M. Interaction with geographic information systems via spatial queries. *Journal of Visual Languages and Computing* (1990) (to appear).

Egenhofer, M. and A. Frank. LOBSTER: combining AI and database techniques for GIS. *Photogrammetric Engineering and Remote Sensing* (special issue on Knowledge-Based Expert Systems) 56(6):919-926 (1990).

Egenhofer, M. and R. Franzosa. Point-set topological spatial relations. *International Journal of Geographical Information Systems* (to appear).

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Scott, S., P. Scott, J.W.F. Smith and J. MacLeay. Reorientation of historic maps of Old Fort Niagara using computer-assisted cartography. *Journal of Field Archaeology* (to appear).

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APPENDIX 2 - PRESENTATIONS BY NCGIA PERSONNEL

Ehlers gave an invited presentation, "Image Processing of Remote Sensing Data on a Macintosh: The DIRIGO Example", Vassar College, Poughkeepsie, NY in December 1989.

December 7 - Obermeyer presented "The NCGIA" to faculty, staff, and students of the University of Maine at a Breakfast Seminar organized by the Dean of Student Services.

10 December - Beard gave the opening and concluding remarks at "Geographic Information Systems in the Marine Environment: Applications for Policy Makers and Managers" at the Conference "The Gulf of Maine: Sustaining Our Common Heritage". NCGIA was a partial sponsor of this event.

10-15 December - Frank, Goodchild, Smith and Ehlers attended the NATO Advanced Research Workshop on "Three-Dimensional Modeling with Geoscientific Information Systems", Santa Barbara, CA.

21 December - Kuhn and Frank presented "Object-Oriented Modeling and User Interface Design" to the Digital Equipment Corporation External Research team at the DEC Plant, Augusta, ME.

Tobler was on sabbatical leave in the Winter Quarter of 1990 and gave presentations at the University of Leicester; University College, London; and the Institute for Demographic Studies, Paris.

January 14-17 - Frank and Egenhofer presented a one-day workshop on "Object-Oriented Databases for GIS", at the ISPRS International Workshop on "Advances in Spatial Information Extraction and Analysis for Remote Sensing" at the University of Maine. Ehlers, Hsu, Jackson and Pullar presented papers.

7 February - Ehlers gave an invited lecture on "The Integration of Digital Image Analysis and Information Systems in Remote Sensing" at the University of Stuttgart, West Germany.

Mark gave an overview of Initiative 2 to the Department of Geography, Syracuse University, February 9.

Frank gave a two-day workshop "First Course on Geographic Information Systems: Knowledge and Application" in Quito, Ecuador on 19-20 February.

Goodchild spoke on "GIS and Geography" at the University of Wisconsin, the University of British Columbia and Simon Fraser University in February. He also presented "Building Global Databases using GIS" and "Accuracy of Spatial Data" at the University of Victoria and "GIS Benchmarking" at Simon Fraser University.

Kemp presented a paper on the NCGIA Core Curriculum at a Geographic Information Systems and Digital Image Processing Workshop for CSU Faculty, San Diego State University, in February.

Kumler and Goodchild presented "The Elusive Population Center of Canada" at Statistics Canada in March, and Goodchild spoke on "GIS Data Models" at Energy, Mines and Resources Canada.

Mark presented an overview of NCGIA research results to the "Canadian National Conference on Geographic Information Systems: Challenge for the 1990's", Ottawa, in March. He also was a panelist in a discussion entitled "Geographical Developments in GIS".

Hendriks presented a talk on menu driven user interfaces for the presentation of spatially indexed data and a demonstration of the user interface of WODAN, a system developed for the Dutch Ministry of Physical Planning and Housing to generate prognosis of housing related variables at various spatial levels, at NCGIA Santa Barbara in March 1990.

Obermeyer gave invited presentations on "Bureaucratic Factors in the Adoption of GIS by Public Organizations, Evidence from Planners and Public Administration Generalists," at Indiana State University and the University of South Florida in March, and at the University of Utah and the University of California, Berkeley in April.

20-22 March - Frank, Goodchild and Kemp attended the conferences "GIS Design Models and Functionality" and "GIS in Education and Training" at the Midlands Regional Research Laboratory, University of Leicester, UK, and made presentations.

26-30 March - Ehlers, Onsrud, Kuhn, Buyong, Moreno, Jackson, Haggerty, Steiner and Jeffress attended the 56th Annual Convention of ACSM/ASPRS in Denver, CO, and made several presentations.

31 March - 5 April - Frank, Egenhofer, Kuhn and Jackson attended CHI'90, ACM SIGCHI Conference on Human Factors and Computing Systems, Seattle, WA. Kuhn and Egenhofer organized a workshop "Visual Interfaces to Geometry".

Mark presented at overview of the NCGIA to the Department Geography and Earth Sciences at the University of North Carolina, Charlotte, April 4.

Mark visited the Department of Geography at the University of South Carolina, April 5-6. His visit included a colloquium presentation about NCGIA Initiative 2.

Goodchild gave two presentations at the Advanced Computing in the Social Sciences conference, Williamsburg, in April.

Buttenfield, Macaness and Mark presented papers at the Special Symposium, Towards a Rule Base for Map Generalization, Syracuse, NY, April 15-17.

Buttenfield, Densham, Fotheringham, Mark, MacKinnon, Rogerson, Goodchild, Kemp, Couclelis, Golledge, Frank, Beard, Kuhn, Obermeyer and several other NCGIA graduate students and staff members attended the annual meeting of the Association of American Geographers (AAG) in Toronto, April 18-21. NCGIA research was presented in numerous sessions. Two panel discussions organized by Barry Wellar (University of Ottawa) reviewed the progress of the Center.

Goodchild gave the keynote address, "GIS and Cartography," at the annual meeting of the Australian Institute of Cartographers, Darwin, in April.

1 May - Kuhn attended the Mid-America GIS Symposium, Overland Park, KA, and gave an invited opening address, "Recent Innovations in GIS Technology."

Densham represented the Center at the New York State Program in Geographic Information and Analysis Workshop on Spatial Information, May 8th - 10th, Blue Mountain Lake, New York.

J. Smith, M. Gould and a large group from Santa Barbara attended the ESRI Users Conference in Palm Springs, California, in May. Lanter presented "Trimming Large Spatial Databases with Lineage Analysis".

Hendriks spoke on "WODAN: A Spatial Decision Support Window on Housing Market Related Data" at the University of Colorado, Boulder, in May.

Calkins met with representatives from the Mid-American Remote Sensing Center at Murray State University in Murray, Kentucky, May 14-18.

17-18 May - Frank attended the AM/FM Regional Conference, Siegen, West Germany, and gave the keynote address, "The Role of Information Infrastructure in the New Decade."

21 May - Goodchild spoke on "GIS Futures" at IBM, Southbury, CT.

20-24 May - Steiner attended the International Geoscience and Remote Sensing Symposium, College Park, MD, and presented the paper "A Digital Database from Satellite Images for Glacial Studies in Antarctica" (co-authored with Ehlers).

23-28 May - Egenhofer presented an invited paper "Prospective Views of GIS Technology and Applications" at the Brazilian Symposium on Geoprocessing, May 23-25, Sao Paulo, Brazil. Egenhofer also visited the Instituto de Pesquisas Espacias, the Brazilian Space Research Institute at Sao Jose and gave a lecture on NCGIA Activities and GIS Technologies.

25 May - Goodchild spoke on "Accuracy of Spatial Databases" at Ohio State University.

30-31 May - Frank gave the keynote address, "Telecommunication and GIS: Opportunities and Challenges" at the Networking Spatial Information Systems Seminar sponsored by Telecom Australia Research Laboratories in Melbourne, Australia.

30 May - Goodchild spoke on "Tiling options for the Digital Chart of the World" to a DCW project review meeting, University of Redlands.

31 May - Goodchild gave the keynote address at the North Texas GIS Workshop, Denton.

Rogerson presented a paper entitled "The Role of Changing Age Composition and Labor Supply Pressure in Regulating the Pace of Interregional Migration" at the Canadian Regional Science Association meeting in June (David Plane, co-author).

June 2 - Goodchild presented "A Hierarchical Spatial Data Structure for Global Geographic Information Systems" at the CAG annual meeting, Edmonton.

8-10 June - Beard, Goodchild and Obermeyer attended the third "Ohio State University Workshop on Geographic Information Systems in Higher Education," Columbus, OH. Goodchild made a presentation on the Core Curriculum Project.

Gould presented a paper on GIS and oil-spill management in Gerona, Spain, in June.

June 10-19 - Frank and Onsrud attended the FIG International Federation of Surveyors XIX Congress, Helsinki, Finland and presented papers.

June 21-22 - Ehlers attended the "International Symposium on Mapping and Geographic Information Systems," San Francisco, CA, and presented a paper.

Goodchild spoke on "Accuracy of Spatial Databases" at the US Geological Survey, Reston, VA, June 26, and presented "The National Center for Geographic Information and Analysis" at GIS East, Washington DC, June 27.

5-6 July - Frank was invited to speak at a Basic Goods Workshop in Rome, Italy (EEC/ESPRIT research program) and gave a talk on the NCGIA research agenda with an emphasis on I-5.

Goodchild spoke on "Issues in Next Generation GIS" to the AM/FM Executive Seminar, Keystone, CO, July 10.

8-20 July - personnel from all three Center sites attended a NATO Advanced Study Institute (ASI) on "Spatial Language, Spatial Cognition and Geographic Information Systems" in Las Navas del Marques, Spain. Mark and Frank were co-directors of the ASI and gave several presentations on
the formal aspects of spatial languages: Egenhofer presented "Why Not SQL!" and Kuhn presented "Formalizing Metaphors". The papers will appear in the ASI proceedings published by Kluwer and edited by Mark and Frank.

July 16-17 - Haggerty and Steiner presented poster papers at the "13th Canadian Symposium on Remote Sensing," Fredericton, NB, Canada.

Buttenfield, Freundschuh, Gould, Haller, Goodchild, T. Smith, Frank, Beard, Egenhofer, Kuhn, Pullar and Kemp presented papers at the Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland, in July. Workshops were given by Goodchild, Kemp, Frank, Egenhofer and Smith, and Goodchild gave the keynote address.

Fotheringham visited the Wales and South West England Regional Research Laboratory in Cardiff, and also GMAP at the University of Leeds, during the summer.

12-16 August - Onsrud attended the Urban and Regional Information Systems Association Convention, Edmonton, Alberta, Canada. He presented "The NCGIA Research Agenda", in the Super Session on GIS Research.

22-24 August - A group from Maine attended the Atlantic Institute Seminar at the University of New Brunswick, Fredericton, NB and presented several papers.

Goodchild gave keynote addresses at the Joint NESTVAL/Middle States AAG meeting, Norwich CT, and the GIS Seminar and Exhibition, Toronto.

September 8-14 - McGranaghan gave an invited presentation on "Geographic Information Systems and Databases" at the Workshop on Artificial Intelligence and Systematic Biology, Napa, CA.

Goodchild spoke on "GIS futures" at the University of Connecticut, Storrs, in October and at Environment Canada in September.

September 12-26 - Frank participated in the design and implementation of a rural cadastral system, Quito, Ecuador.

September 17-20 - Onsrud attended the International Society of Photogrammetry and Remote Sensing conference on Global Environmental Monitoring, Victoria, British Columbia, Canada, and presented "Legal and Institutional Issues in Sharing Information Through Distributed Databases."

Goodchild presented "Interpreting individual behavior according to space-time models in a GIS: Halifax, 1971" at the Social Science History Association meetings at Minneapolis in October.

October 2-4 - Ehrlich, Estes and Scepan were authors of "Extracting Agricultural Information from Satellite Imagery for Mapping Purposes" presented at the International Symposium on Thematic Mapping from Satellite Imagery, Paris.

October 4-6 - Kuhn attended the 1990 IEEE Workshop on Visual Languages, Skokie, IL, and presented the paper "Manipulating the Graphical Representation of Query Results in Geographic Information Systems".

Smith gave presentations at Lawrence Livermore National Labs on "Object Oriented Approaches to Spatial Databases" and at Hewlett Packard Research Labs on "Logic Based Approaches to Spatial Databases" in October.

October 26 - Beard gave a talk on the NCGIA at a University of Maine Physics Department Colloquium.

October 26 - Gould, Mark and Smith attended and presented papers at the Annual Meeting of the Conference of Latinamericanist Geographers in Auburn, Alabama.

October 29-31 - Densham and Fotheringham attended the Fall Meeting of the Operations Research Society of America and The Institute of Management Science in Philadelphia and presented two papers in special sessions on Locational Analysis and Marketing.

November 8 - Frank gave a presentation on the potential of GPS for GIS to the National Academy of Science Committee on Geodesy, Washington, DC.

Lanter, Mark, Stoms, Veregin, Tobler, Theobald, Yang, Beard, Mackaness, Buttenfield, Muller and Goodchild presented papers at GIS/LIS '90 in Anaheim, CA, November 7-10, and Goodchild and Kemp gave workshops. Special sessions were organized on I-3 and I-1 research.

November 9-10 - Fotheringham and Wong presented a paper "The Modifiable Areal Unit Problem in Multivariate Statistical Analysis" at the North American Regional Science meetings in Boston, Massachusetts.

November 15 - Goodchild spoke on "Accuracy of Spatial Data" at the Indiana GIS Workshop.

November 15 - Hudson gave a talk on the NCGIA to the Perth chapter of AURISA, Australia.

APPENDIX 3 - VISITORS TO NCGIA SITES

Bob Aangeenbrug, University of South Florida
Bernie Armstrong, U.S. Forest Service
Andrew L. Baffes, ERDAS
Robert Barr, University of Manchester
Joyce Berry, Osford University Press
Lou Bivens, U.S. Navy
Michael J. Carey, University of Wisconsin, Madison
Dave Case, Applied Research Corporation, Landover, MD
S.K. Chang, University of Pittsburgh
C.K. Chow, IBM Corporation
Bill Cody, IBM Almaden
Greg Cole, Los Alamos National Lab
Pat Conway, California Department of Transportation
Roger Cooley, University of Canterbury, United Kingdom
R. Coote, Royal Australian Survey Corps
Peter Croazedale, British Broadcasting Corporation, Radio 4
Robert Cromley, University of Connecticut
Ferenc Csillag, Research Institute for Soil Science, Budapest
Paul Dodd, New York State Conservationist, Soil Conservation Service
Ron Eastman, Clark University
Chuck Ehlschlager, U.S. Army Corps of Engineers
Robert Fincham, University of Natal
Robin Flowerdew, Lancaster University
Bruce Fogarty, IBM
Mike Hamilton, UC Riverside
Jerry Hart, MapWorks
Paul Hendriks, University of Nijmegen, The Netherlands
Robin Heron, GIS World
Gary P. Herring, US Postal Service
Steve Hine, Government of South Africa
Pat Holligan, United Kingdom
Inger Marie Holm-Olson, Tromso Museum, Norway
Trevor Imhoff, Australian Bureau of Statistics
Takeshi Inouye, Mitsubishi Electric Corporation
Mark Jadkowski, Sewall Co
Don Jamieson, U.S. Forest Service
Terrence Keating, KORK Systems
Jeff Kennedy, UC Natural Reserve System
Vasheslav Kharuk, Krasnoyarsk, Siberian Institute of Forest Research
John Kick, New York State GIS Coordinator
John Kineman, National Geophysical Data Center
A. Kumar, Wildlife Institute of India
George Lapis, IBM Almaden
Ned Levine, UC Los Angeles
Weldon Lodwick, University of Colorado, Denver
Guy Lohman, IBM Almaden
David Longbrake, University of Denver
Hal Luft, UC San Francisco
Giulio Maffini, TYDAC Technologies Inc.
David Maguire, University of Leicester
Bob Maher, ESRI
Bernard Marchand, University of Paris
Gerald Martin, Asia Foundation
Ian Masser, UK Regional Research Laboratories
Alaric Maude, Flinders University
Robert McMaster, Syracuse University
B.K. Mishra, Wildlife Institute of India

Rene Molner, Statistics Canada
Scott Morehouse, ESRI
Don Myers, University of Arizona
Stan Nichols, Fletcher Challenge, British Columbia, Canada
John Nicholson, Western New York State Area Conservationist
Jurg Nievergelt, ETH Zurich
J.J. Olivier, Pretoria
Michael Orren, University College, Galway, Ireland
Jack Palgen, NASA/GSFC
Dennison Parker, GIS World
Micha Pazner, University of Manitoba
Paul Perrett, Department of Lands, Australia
Jesper Petersen, Technical University of Denmark
S. Narendra Prasad, Wildlife Institute of India
Marc Putterman, IBM Corporation
Linda Roth, Caltrans
Stan Ruttenberg, National Geophysical Data Center
Alan Saalfeld, Statistical Research Division, US Bureau of the Census
Jeannie Savage, IBM Corporation
Diane Scott, IBM
P. Sharma, University of Queensland
Tony Shupin, EOSAT
Howard Slavin, Caliper Corporation
James Smith, NASA Goddard Space Flight Center
Terry Smith, Digital Equipment Corporation
Steve Smyth, Spatial Data Research
Jim Springer, Caltrans
Bob Streeter, U.S. Fish and Wildlife Service
D.H. Sullivan, Sullivan Publications Inc.
Matt Svantesson, Defense Research Establishment
Norman Thrower, California Mapping Society
Jack Treiber, MapWorks
Professor Trinder, University of Sydney
Bill Ubbens, US Forest Service
Agnes Voisard, INRIA Paris
Paul Walker, CSIRO, Australia
Al Watkins, Eros Data Center
James Weatherington, US Postal Service
Eric Weiner, IBM
Hal Welch, University of Michigan
Jim Westervelt, U.S. Army Corps of Engineers
John Whitney, Erie County District Conservationist
Ian Williamson, Gary Hunter, University of Melbourne
Mike Wilson, Wavefront Technologies
Eric Wolf, University of Michigan
Neil Wrigley, University of Wales
Vasily Zhivin, Moscow State Forest Committee

APPENDIX 4 - COURSES TAUGHT BY NCGIA FACULTY

1. Santa Barbara

Cartographic Design (Geog. 118C) Spring 1990; Lanter

History of Cartography (Geog. 126) Spring 1990; Tobler

GIS Applications (Geog. 176C) Spring 1990; Goodchild

Issues in Planning (Geog. 185B), Spring 1990; Church

Seminar in Remote Sensing (Geog. 215), Spring 1990; Estes

Advanced Location and Transportation Systems (Geog. 294), Spring 1990; Church

Introductory Cartography (Geog. 118A), Fall 1990; Lanter

Cartographic Transforms (Geog. 127), Fall 1990; Tobler

Introduction to GIS (Geog. 176A), Fall 1990; Goodchild

Geographic Data Analysis I (Geog. 172), Winter 1990; Michaelsen

Data Analysis Laboratory (Geog. 172L), Winter 1990; Michaelsen

Technical GIS (Geog. 176B), Winter 1990; Goodchild

2. Maine

Advanced Computer Usage for Surveyors (SVE 281), Spring 1990; Ehlers

Geometry and Computer Graphics (SVE 452), Spring 1990; Kuhn

GIS Applications (SVE 498-02), Spring 1990; Beard

Geographic Theory and Models (SVE 498-03), Spring 1990; Obermeyer

Algebraic Specifications (SVE 698-03), Spring 1990; Frank

Image Processing in Remote Sensing (SVE 498-01), Spring 1990; Ehlers

Advanced Database Management Systems, Spring 1990; Barrera and Latour

Introduction to GIS (SVE 271), Fall 1990; Beard

Engineering Databases and Information Systems (SVE 451), Fall 1990; Egenhofer

Selected Topics - Human Factors in GIS (SVE 698-08), Fall 1990; McGranaghan

Legal Issues in Spatial Data Handling (SVE 598-01), Fall 1990; Onsrud

3. Buffalo

Maps and Air Photos, Spring 1990; Mark

Multivariate Statistics in Geography, Spring 1990; Fotheringham

Special Cartographic Topics (Map Animation), Spring 1990; Buttenfield

Theory, Techniques and Applications of Locational Analysis, Spring 1990; Densham

Remote Sensing, Spring 1990; Calkins

GIS Applications, Spring 1990; Calkins

GIS Algorithms and Data Structures, Spring 1990; Mark

Models, Algorithms and Data Structures in Locational Analysis, Spring 1990; Densham

Geography of Economic Systems, Fall 1990; Rogerson

Maps and Air Photos, Fall 1990; Mark

Cartographic Internship, Fall 1990; Buttenfield

Univariate Statistics in Geography, Fall 1990; Fotheringham

Introduction to Geographic Information Systems, Fall 1990; Densham

Introduction to Geographic Information Systems, Fall 1990; Mark

Human Computer Interaction, Fall 1990; Buttenfield

Computer Cartography, Fall 1990; Buttenfield

Spatial Decision Support Systems, Fall 1990; Densham

GIS Design, Fall 1990; Calkins

Spatial Statistics, Fall 1990; Fotheringham

APPENDIX 5 - GRADUATE DEGREES GRANTED AT NCGIA SITES

1. Santa Barbara

David Theobald, MA, Winter 1990, Automated Delineation of Hydromorphological Features on a Triangular Irregular Network-Based Digital Elevation Model. (Goodchild, Davis, Dozier).

Jeffrey Sandberg, MA, Winter 1990, Reliability, Resiliency and Vulnerability of the Central Valley Project-State Water Project System: A Pilot Study. (Loaiciga, Church, Michaelsen).

Martin Landsfeld, Winter 1990, Analysis of the Effects of Spatial Data Aggregations on Hydrologic Modeling: A Geographic Information Systems Approach. (Jones, Dozier, Davis).

Joddi Leipner, MA, Spring 1990, Multi-Temporal Historical Aerial Photography for the Detection, Analysis, and Verification of Hazardous Waste Disposal. (Estes, Jones, Loaiciga).

Teresa Morris, MA, Spring 1990, Trafficability Assesment and Decision Making Using Geographic Information Systems and Remote Sensing. (Estes, Tobler, Goodchild, Star).

James Damkowitch, MA, Fall 1990, The Capacitated Maximal Covering Location Problem Revisited. (Church, Jones, Anselin).

Chiu-Wen Ray, MA, Fall 1990, Remote Sensing and GIS: Establishing Consistency between Raster and Vector Data Models. (Goodchild, Tobler, Estes).

Jerome Collin, MA, Fall 1990, An Estimation of the Primary Production in the Antarctic Ice Edge Zone. (R. Smith, Siegel, Brzezinski).

Gao Peng, PhD, Winter 1990, Spatial Data Structures and Spatial Access Methods for Knowledge Based Geographic Information System III. (T. Smith, Simonett, Estes, Davis).

Donald Lauer, PhD, Winter 1990, An Evaluation of National Policies Governing the United States Civilian Satellite Land Remote Sensing Program. (Estes, Simonett, Davis, Botkin).

Sun Guoqing, PhD, Spring 1990, Radar Backscatter Modeling of Coniferous Forest Canopies. (Simonett, Davis, Dozier, Strahler, Elachi, Richards).

James Frew, PhD, Fall 1990, The Image Processing Workbench. (Dozier, Simonett, R. Smith, Davis, R. Kemmerer).

2. Maine

Nemmara Chithambaram, MSc, Fall 1990, Generating Polygon Skeletons for Map Generalization.

Douglas Hudson, PhD, Spring 1990, Autonomous View-Stages: Materialized Support for View Update Propagation.

Jeffrey Jackson, MSc, Spring 1990, Visualization of Metaphors for Interaction With Geographic Information Systems.

3. Buffalo

Holly Dickinson, Fall 1990, Deriving a Method for Evaluating the Use of Geographic Information in Decision Making.

Viswanathan Venkatachalam, Fall 1989, Demand Point Approximations for the Planar, Euclidean Metric, p-Median Problem, with and without Polygonal Barriers to Travel.

Eleazar Hunt, A Consideration of Environmental, Physiographic and Horticultural Systems as they Impact Late Woodland Settlement Patterns in Western New York State: A Geographic Information System (GIS) Analysis of Site Location.