Improved Integration of Remote Sensing and Geographic Information Systems: A Background to NCGIA Initiative 12

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The National Center for Geographic Information and Analysis (NCGIA) was awarded by the National Science Foundation (NSF) to a consortium of universities in August of 1988. The three universities forming the NCGIA are the University of California, Santa Barbara (UCSB), State University of New York (SUNY) Buffalo, and the University of Maine at Orono. The official start of activities at the NCGIA occurred in November, 1988. NCGIA was established by NSF to remove impediments to the broader application of Geographic Information Systems (GIS) and Geographic Analysis (GA).

NCGIA conducts activites in three areas: research, education, and outreach. Education and outreach activities involve curriculum development, participation in workshops and conferences, and cooperative activities with public and private organizations. Research at the National Center to date has been primarily centered around the conduct of initiatives. In the consortia proposal 12 research initiatives were proposed. These initiatives, which would be conducted over a three-year period, were

- I-1. Accuracy of Spatial Databases
- I-2. Languages of Spatial Relations
- I-3. Multiple Representations
- I-4. Use and Value of Geographic Information in Decision Making
- I-5. Architecture of Very Large Spatial Databases
- I-6. Spatial Decision Support Systems
- I-7. Visualization of the Quality of Spatial Information
- I-8. Expert Systems for Cartographic Design
- I-9. Institutions Sharing Spatial Information
- I-10. Temporal Relations in GIS
- I-11. Space-Time Statistical Models in GIS
- I-12. Integration of Remote Sensing and GIS technologies.

Through the fall of 1990, initiatives I-1 through I-6 were held. Based upon recommendations from the NCGIA Board of Directors, I-12 was moved forward. I-12 focuses upon identifying where research is required to remove impediments to the integration of remote sensing and GIS. A primary objective of the initiative process is to define a prioritized research agenda and to initiate research aimed at improving Remote Sensing/GIS integration.

Earth observing sensor packages on aircraft and spacecraft provide researchers and resource management and policy making personnel with powerful tools for producing spatial and temporal information. Geographic Information Systems (GIS) provide researchers, resource managers, and decision makers with a tool for effective and efficient storage and manipulation of remotely sensed data and other spatial and non-spatial data types for both scientific, management, and policy oriented information. As such, GIS can be used to facilitate measurement, mapping, monitoring, and modeling of a variety of data types for both scientific and commercial applications.

Remote sensor technology has been used for over a century to acquire data concerning a variety of environmental applications. From the acquisition of data employing tethered balloons in the 1850s to the satellite platforms of today, the amount and type of data that can and are being acquired has increased dramatically. Figure 1 depicts the increasing complexity of remote sensor technology. We who are involved in the application of remote sensing technology have watched the increase in complexity of sensor systems, the amounts and types of data provided to the analyst, and the types of analyses we undertake using these data.

Remote sensor data then are providing a variety of spectral information with a range of spatial resolution and areal coverages. A variety of measurements can be made utilizing these data which can either be employed to create map like products or used as inputs to models. The output of remote sensor systems acquired through time, whether it be the direct measurement or derived products of analysis such as maps or model outputs, can then be employed in the management decision and policy-making process.

Geographic Information Systems and remote sensing are linked, linked in both an historic context and functionally. In the historic context some of the early work leading to the development of GIS revolved around methods to better access aerial photographic coverage of specific areas.

GIS technology facilitates the storage of and access to many types of data. Correctly employed GIS systems also permit data held within a database to be readily updated. Indeed, the synergism between (1) remotely sensed data for updating GIS information, and (2) the use of GIS for improving the information extraction potential of multisensor data is a major advantage of the improved integration of these two powerful technologies. Geographic information systems

- facilitate the storage of measurements and the creation, updating, and modification of maps;
- increase our ability to model important science and management problems;

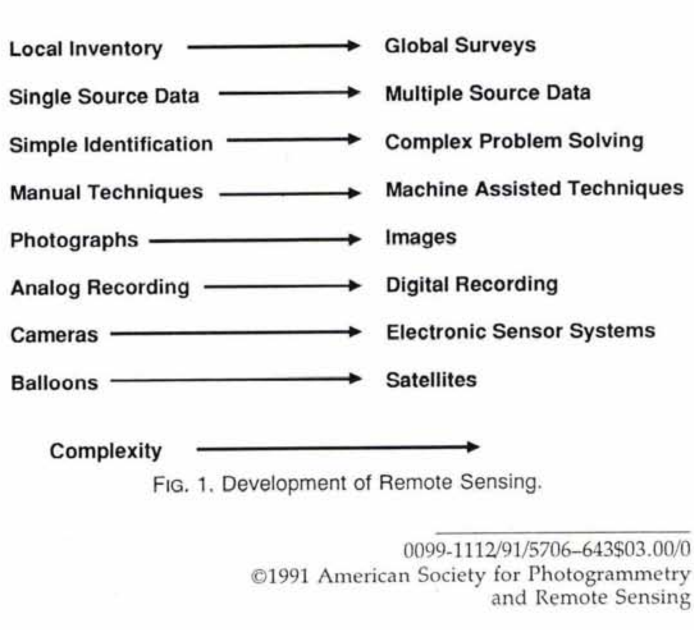

Fig. 1. Development of Remote Sensing.

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- provide a tool for enhancing decision making;
- permit graphic display of complex phenomena; and
- can reduce costs and facilitate access to information.

There is an increasing awareness of the importance of GIS technology. The trend toward more emphasis on the application of geographic information systems stems in part from

- improvements in the quality and quantity of remotely sensed data available,
- improvements in computer hardware and software,
- increasing population and competition for resources,
- decreasing resource availability and environmental quality,
- recognition of the global nature of problems, an
- increase in the number of public and private organizations working on national and international problems, and the
- creation of larger and larger databases to provide information on these matters in various scales.

Yet, important as these trends are, they only mirror broader trends in society in general. These trends make it imperative for us not only to improve remote sensing—and more specifically GIS technology—but also to widen our focus in order to examine a greater range of information that can lead to better policy and management decision making.

To begin the process of identifying a prioritized research agenda to remove impediments to the fuller integration of remote sensing and geographic information systems, NCGIA I-12 leaders held a small planning meeting in Denver, Colorado in May of 1990. Participants in this first planning meeting began to flesh out the components of a research agenda and to identify potential participants for an initial specialist meeting. Attendees at the Denver meeting included Bill Anderson (Ohio State U.), Bob Best (EG&G), Manfred Ehlers (U. Maine/NCGIA), Nick Faust (Georgia Tech and ERDAS), Dave Greenlee (USGS/EROS Data Center), Ross Lunetta (EPA Las Vegas), Tom Mace (EPA Las Vegas), and Dale Quattrochi (NASA Stennis Space Center), in addition to the authors from UCSB/NCGIA. Based on both top-down and bottom-up examinations of the research interests of the attendees and their knowledge of the research needs in the areas as a whole, a set of general areas of emphasis were developed. These areas where attendees felt research should be focused and the individuals given responsibility for putting together draft material were

- Error Analysis (Lunetta),
- Data Structures and Access to Data (Ehlers),
- Data Processing Flow and Methodology (Davis),
- Man-Machine Interaction (Faust),
- Hardware Environments (Faust), and
- Institutional Issues (Don Lauer, USGS, represented by Greenlee).

These individuals were selected then to help to organize and outline potential research topics within each of these areas, and to act as coordinators for future I-12 activities associated with each topic above. The group decided that drafts of position papers for each of the areas would be developed as starting points for discussion at the specialist meeting.

A second planning meeting was held at the Stennis Space Center, Mississippi on 1-2 August 1990. Attendees included Bill Anderson (Ohio State U.), Manfred Ehlers (U. Maine/NCGIA who had now moved to the International Institute for Aerospace Surveying and Earth Sciences, the Netherlands), Jack Estes (UCSB/NCGIA), Nick Faust (Georgia Tech and ERDAS), Dave Greenlee (USGS EDC), John Jensen (U. South Carolina), Ross Lunetta (EPA Las Vegas), Tom Mace (EPA Las Vegas), Ken McGwire (UCSB/NCGIA), Dale Quattrochi (NASA SSC), Jeff Star (UCSB/NCGIA), Fran Stetina (NASA/GSFC), and Larry Tinney (EG&G). Observers at the meeting included Tony Lewis (LSU), Merrill Ridd (Utah), Jack Hall (Houston U. Research Association), and Gil Rochon (Dillard U.). Attendees continued to flesh out the general areas in a research agenda directed at removing key impediments to the integration of Remote Sensing and GIS. Attendees also continued to refine the list of participants to insure that it would include a broad cross section of discipline interests as well as application areas. We considered the preparation of position papers on five topics (based on the list from the previous meeting, but combining man-machine interaction and hardware environments into a new topic called future computing environments).

Error is a major concern in any remote sensing application. From a remote sensing perspective, understanding the possible sources and relative magnitude of potential errors involved in the integration of ancillary or collateral data sets by means of a GIS in an analysis was considered an important research topic. Conversely, remote sensing can and does provide a significant source of input to GIS analysis. As such, GIS users are also very concerned about the types and magnitudes of errors that can occur when remotely sensed data are utilized. Just as NCGIA Initiative 1 dealt with issues related to accuracy, so too did error receive priority attention in Initiative 12.

A series of problem areas revolve around moving data and information from their sources or repositories to the analysis systems of the users. A portion of these are technical issues and protocols which govern the data structures used to encode the data and information for distribution to the users. In the current environment, there are a great many different data structures in use, which means we are constantly converting from one to another. The attendees emphasized that these conversions are not always error-free, and that the errors are not well understood and documented. Another portion of the problem consists of the mechanisms and protocols which make information about the data available to potential users. Systems used to record the existence and characteristics of spatial data are uncommon, unfriendly, and, in many cases, unavailable. Further, they may not provide a prospective user with the tools and information to evaluate the suitability of the data for the user's needs.

Meeting participants felt that there are many important research issues related to the acquisition, processing, and joint analysis of remote sensing and GIS data. The paper by Davis *et al.*, "Environmental Analysis Using Integrated GIS and Remotely Sensed Data: Some Research Needs and Priorities," focuses on two issues identified as especially important and not treated explicitly under Errors or Data Structures and Access. These relate to (1) the use of multiscale data in analysis and modeling of geographic variables, and (2) multiple, sequential transformations of remote sensing and GIS data, and the relationship between those transformations and geographic information developed through IGIS analysis. These two issues are considered within the general framework of the data acquisition and processing flows that occur during environmental analysis. The authors emphasize the need for continuing application and development of quantitative spatial analytical methods such as geostatistics and fractal analysis to improve our understanding of geographic phenomena, especially in the context of regional to global scales assessments of Earth surface transformations.

The rate of change of computing technology and computing capabilities continues to increase. Although not uniformly accepted, some of the attendees believe that we will need to be able to take advantage of new computer architectures to be able to deal with the increasing volumes and complexity of spatial datasets in the future. The paradigm of networked computing facilities is clearly evolving in the spatial data processing community, with accompanying requirements for distributed data management and computing. Some of the discussion focused on the requirements for graphic presentation of spatial data and information, and the need for relatively unusual hardware in support of the merging of remote sensing and geographic information systems.

From national to local levels, institutional issues influence the application of these technologies. Both remote sensing and GIS are technologies whose development has been to a greater or lesser extent conditioned not only by the U.S. Federal establishment but also governmental agencies around the world. Indeed, the products of remote sensing in most countries are subject to governmental control. GIS products, while currently not yet subject to the same level of restriction, could in some circumstances come under the same type of control in the future. Technology acceptance, technology integration, issues of data sharing, and the value of data in policy and management decision-making were considered by attendees in beginning an examination of what research could be directed at reducing or eliminating institutional impediments to the integration of remote sensing and GIS as a priority topic.

After these general research areas were agreed upon, the individuals given responsible for the topics were asked to assemble a group of people to draft a paper outlining priority research directions. The planning group/executive committee felt that having "strawman" discussion documents to present at the specialist meeting would enhance the science return from the meeting. These papers were to be considered strictly drafts. Discussions at the specialist meeting were to be full and frank and it was our hope that topics would be both added to and deleted from these preliminary write-ups. It is this material revised at the specialist meeting that forms the basis for the articles in this special issue.

The NCGIA Initiative 12 specialist meeting was held at the USGS EROS Data Center, Sioux Falls, South Dakota, on 3-5 December 1990. Al Watkins, director of the EROS Data Center, opened the meeting with a general welcome and an overview of the research and production activities at EDC. This was followed by a presentation by Jack Estes, who described the background of the NCGIA initiative process, as well as the goals and operations of NCGIA in general. Jeff Star discussed GIS and Remote Sensing, focusing on a historical perspective of the integration of the technologies. He then presented a charge to the meeting. The charge was to review and critically discuss the draft discussion papers that had been developed in each of the five areas discussed above. Attendees were also asked in essence to validate or reject and to give a preliminary prioritization to the research issues raised in each of the discussion papers.

Following lunch, Don Lauer (USGS EDC) presented his group's paper on institutional issues. David Goodenough (Canada Centre for Remote Sensing) and Nancy Tosta (State of California Teale Data Center) were discussants after this presentation, responding to some of the issues from Lauer's presentation from their own perspectives. Manfred Ehlers (U. Maine/NCGIA and IIAS) then presented the paper he coordinated on data structures and access. Sud Menon (Environmental Science Research Institute) and Terry Smith (UCSB/NCGIA) served as discussants for this paper.

On Tuesday, the meeting heard three more sets of presentations and discussion. Frank Davis (UCSB/NCGIA) presented the paper on processing flows. Chris Johannsen (Purdue) and Steve Guptill (USGS) served as discussants. Ross Lunetta (EPA, Las Vegas) presented the paper on error analysis. Nick Chrisman (U. Washington) then presented some of his own work on error analysis, and Mike Goodchild (UCSB/NCGIA) served as a discussant. Nick Faust (Georgia Tech and ERDAS) presented the final paper, on future computing environments. Jeff Star (UCSB/NCGIA) and John Gage (SUN Microsystems) served as discussants on this last paper.

On Wednesday, meeting participants broke into five working groups, aligned with the five general topic areas of the presentations. In each of these working groups, the goal was to assemble a prioritized research agenda. After a break for lunch, the leaders of the working groups presented their findings. One specific change that emerged from the working groups was to change the focus of the data structures and access section to one of data models. At the end of the day, a small group convened in executive session to examine the next steps required to (1) prepare for technical sessions on the five I-12 topics at the ASPRS/ACSM meeting in Baltimore in March 1991, and (2) prepare to revise the papers presented at the meeting as a submission to *Photogrammetric Engineering & Remote Sensing*. Additional discussion revolved around a future research monograph, as well as the interests of several meeting participants to spend time in residence at UCSB/NCGIA to work on priority research problems.

The material presented in this issue is very much a part of an ongoing dialogue. An attempt to define a prioritized research agenda is an area of critical concern in as open an intellectual environment as possible. In developing this agenda, however, we at NCGIA are sensitive to community concerns related to intellectual property. It is our charge from NSF to develop research agendas in initiative areas and to conduct research in topics of interest where NCGIA personnel have demonstrated expertise. NCGIA's funding from NSF at $1.1 million per year is not deemed sufficient to pursue all of the high priority research being developed out of our initiative process. It is our intent, in publishing and presenting the research needs developed in each of the initiatives as widely as practical, to stimulate increased agency and industry funding. We may in some cases compete openly for funding in some areas; we may do cooperative research in others; but just as certain in other areas we will not compete at all.

In this spirit we welcome comments and criticisms of the material presented herein. The results presented are already known to a number of U.S. Federal agencies. We will make any significant additions and/or modifications to the materials presented available to appropriate institutions and agencies as well. We look forward to a continuing community dialogue.

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