NCGIA Initiative 13
"User Interfaces for Geographic Information Systems"
Closing Report

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1995

Abstract

This report describes the results of NCGIA Research Initiative 13 "User Interfaces for Geographic Information Systems." It assesses the work in detail against five criteria: 1. Research Accomplished; 2. Research Agenda Development; 3. Contribution to GIS Education; 4. Implications for Science Policy; and 5. Comments on the Research Initiative Process.

1. Background

This Research Initiative on User Interfaces for Geographic Information Systems was adopted by the NCGIA in December 1989, and was the first new initiative to be adopted after the original NCGIA proposal to NSF. David M. Mark (Buffalo) and Andrew U. Frank (Maine) were co-Leaders of the Initiative from its adoption to its closing. Initiative 13 addressed human-computer interaction and related issues in the design and implementation of user interfaces for GISs and other geographical software packages. This initiative was introduced partly as a natural outgrowth of the applied side of Initiative 2 ("Languages of Spatial Relations"), and partly in response to the URISA research agenda.

The research initiative had as its broad goals:

- to investigate ways for people to interact with computers when solving problems concerning geographic space and spatial phenomena;
- in particular, to model some of the ways in which factors such as disciplinary background and training, problem domain, culture, natural language, and individual differences, influence human-computer interaction involving geographic information;
- to establish criteria and methods for the design of GIS user interfaces, and user interfaces for other geographic software;
- to develop and test prototypes of GIS interfaces and interface development tools.

Research Initiative 13 was established to focus on human-computer interaction for GIS, and on the design of improved user interfaces for such systems. Specifically, cognitive and linguistic models dealing with geographic space were to be formalized and further developed in order to provide a sound basis for the design and evaluation of user interfaces. Examples of relevant cognitive and linguistic models are image schemata, metaphors, radial category structures, spatial grammars, semiotic systems, etc.

1.1 The Initiative 13 Specialist Meeting

The Specialist Meeting for Initiative 13 was held June 22-26, 1991, in Western New York. Of the 41 official participants in the meeting, about three-quarters were from the GIS community, and one quarter from the Human-Computer Interaction (HCI) community. Also, 15 participants had attended at least one earlier NCGIA Specialist Meeting, and the remaining 26 were at their first such meeting. Finally, 12 participants were from the private and public sectors, and 29 were university-based researchers. Eight of the official participants were graduate students, five of whom were from institutions outside the NCGIA. The Specialist Meeting began with a half day on the campus of SUNY Buffalo. Following introductory remarks and background information, the participants spent about two hours in the Geographic Information and Analysis Laboratory (GIAL), viewing software demonstrations, mainly put on by participants. The remainder of the meeting was held at Peek'n Peak, a conference center in Chatauqua County, New York.

Almost all the participants submitted Position Papers for circulation before the meeting, and they were expected to read the position papers before the meeting. Thus, we did not need to have any formal presentations by participants, but immediately began a cycle of alternating sessions of two types: "break-out" sessions, with 4 to 6 small groups for intense discussion, were interspersed with full group sessions that included 'break-out' reports, general discussions, and occasional tutorials. We had about six rounds of 'break-outs', starting Sunday late afternoon and ending Wednesday morning. There were evening sessions each day after dinner. The revised position papers and a summary of the meeting were published as NCGIA Technical Report 92-3.

There was very little discussion of user interfaces at a 'surface' level (for example, icon design). Rather, the discussion concentrated on conceptual issues, and on needs for evaluation and testing. The needs for typologies of GIS tasks on the one hand, and users and use types on the other, was deemed to be of high priority. Other themes included:

- recognition that spatial concepts are critical to the design of user interfaces for GIS;
- the process of user interface design (as practiced in the HCI community) has many striking similarities to the process of "GIS Design", in which a potential adopter's needs and uses are identified and compared to existing or potential software system;
- the issue of trade-offs between learnability on the one hand, and performance for experienced users on the other, is central;
- public access to information is primarily a user interface problem, combined with a legal problem. Public access to computerized information is of almost no use if usable, natural user interfaces are not provided along with the data.
- experimental testing is a critical part of the research agenda. Many researchers with little or no training in experimental psychology would benefit from a "cook-book" approach to testing needs, situations, and methods, similar to the charts of what statistical methods to use in the end-pieces of Blalock's "Social Statistics"
- a specific issue of concern to the agencies and other large organizations is how to write SPECS (product specifications) for the user interfaces of systems, and how to determine whether the contractor or vendor has met those specifications

1.2 Outline of this Report

The remainder of this report addresses five points of discussion posed by a subcommittee of the NCGIA Board of Directors, to be answered in closing reports for Initiatives. Under "Research Accomplished," we describe specific research projects and related activities. Under "Research Agenda Development," we comment on the user interface issue in the GIS research agenda, in 1989 and today. Under "Contribution to GIS Education," we document the high level of involvement by graduate students in all phases of the Initiative. We also make a few comments under the headings of "Science Policy" and "The Research Initiative Process," and close the report with an annotated bibliography of Initiative 2 publications, and participant lists for the Specialist Meeting and the NATO Advanced Research Workshop conducted at the end of this Initiative.

2. Research Accomplished

What do we know now that we did not know before about the questions addressed by the initiative?

User interfaces and human factors for GIS progressed a great deal since 1989. It could be argued that this would have happened without NCGIA Research Initiative 13, but the activities under this initiative almost certainly increased awareness of the topic among the research and user communities. In 1990, we discussed potential for additional funding with John Hesthanes, who directed the Interactive Systems program of the Information, Robotics, and Intelligent Systems Division of the Computer and Information Science and Engineering (CISE) Directorate at the National Science Foundation. He asked whether there was a unique research agenda within the overlap between general HCI (Human-Computer Interaction) and geographic information, or whether separate solutions to HCI and GIS problems could later be put together to form usable systems. In 1994, it seems likely that much of the basic research needed to provide more effective GIS user interfaces lies in the definition and formalization of geographic concepts and spatial cognition. In our original proposal to the National Science Foundation, we decided not to address 'Artificial Intelligence and Expert Systems,' one of the five basic research bullets in the solicitation, as a separate item, but rather to research AI and ES developments within the context of spatial analysis, visualization, etc. The same may also be true for user interfaces, that is, human-computer interaction for geographical systems may best be investigated as a component of basic research on analysis and display procedures themselves, rather than as a separate topic.

2.1 Conceptual Frameworks for GIS User Interface Design

At Maine, Gary Volta and Max Egenhofer proposed a three-tier framework for the design of GIS user interfaces. The three steps are interleaved, but different enough to warrant such a separation. Each step requires from the user-interface designers distinct qualifications and command in a number of areas.

- First, formal systems with well-defined behavior and properties are investigated with respect to the problem. This process uncovers the pertinent objects, operations, and behavior of the problem that must be dealt with in the user interface. During this phase, the designers lay the ground for what the system will be able to do and what it will not.
- Second, different interaction procedures are investigated to allow prospective users to perform the intended manipulations. The formalism is used as a consistent foundation from which various user interfaces can be developed according to different interaction techniques such as command-line, windows, and icons. The formalism of objects and operations identifies the core functionality necessary for all the various user interfaces. Therefore, the evaluation of the user interface can focus on the different interface techniques.

- Third, each visualization- and interaction-design is implemented on a particular platform with its operating system and specific user-interface management system, toolbox, graphics library, etc.

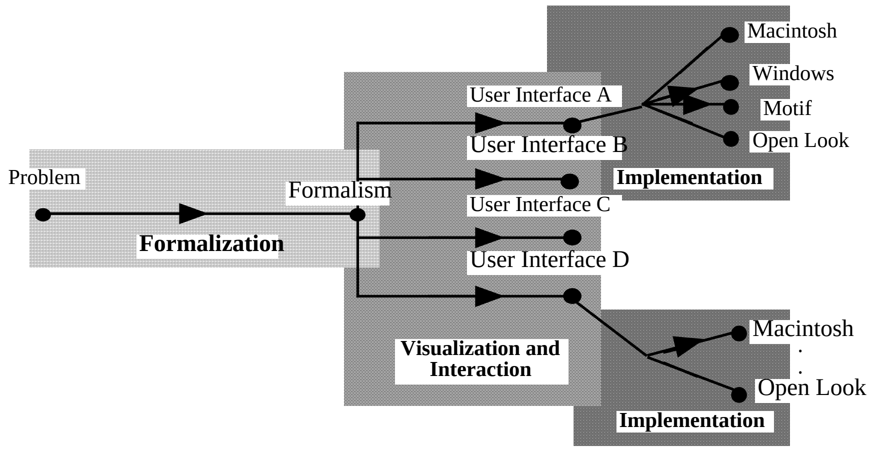


Fig. 1. User interface design process.

The background knowledge necessary in each of the three areas is fairly distinct and the fallacy of many GIS user interfaces is that too often a single user interface designer is expected to master all of them.

- In order to formalize the objects and operations with which a future user will deal, a designer has to know about the problem domain and needs sufficient knowledge of and practice with the formalization tools (e.g., specification languages, algebras); therefore, we will call them the domain experts. Without their active involvement in the design process, any user interface will be something made by a designer society for a user society.
- During the second phase, the designer must be proficient in cognitive analysis, psychology, human-computer interaction techniques, and graphics art. This may be what is commonly understood by the user interface designer. The focus during this phase is on the translation of the domain experts' specifications into a particular interface environment and it involves giving feedback to the domain experts so that they can improve their design in close cooperation with the user interface designers.
- The third phase of the user interface design requires extensive expertise in user-interface programming, graphics packages, and user-interface management systems. We call these experts the user-interface software engineers.

Within this framework, two master's theses were completed: Gary Volta studied a user interface to manipulate categorical coverage data. The same framework also was used in Jim Richards' master's thesis. Richards investigated the visualization and interaction with geographic data based on the map overlay metaphor by comparing two different designs. He developed a quantitative comparison method, by defining tasks users can perform in both interfaces and counting (1) the number of concepts a user has to know before executing a particular operation; (2) the number of individual interactions necessary to perform the task; and (3) the number of errors the user can run into while performing the task.

A refereed paper by Volta and Egenhofer on the framework and the visualization of the categorical coverage user interface was presented at COSIT'93. An article by Egenhofer and Richards on the "cube and template" user interface is in press with the Journal of Visual Languages and Computing, and a second article that compares the two interfaces is in preparation. Some of this work is discussed in more detail in section 2.2, below.

As an application of this conceptual work on user interface design, three NCGIA Maine graduates, Jim Richards, David Pollock, and Khaled Hassan, designed an oil-spill system that excelled through its user interface; the project was awarded a first prize in the poster competition at an ESRI user conference, and the poster design was heavily influenced by the interface design.

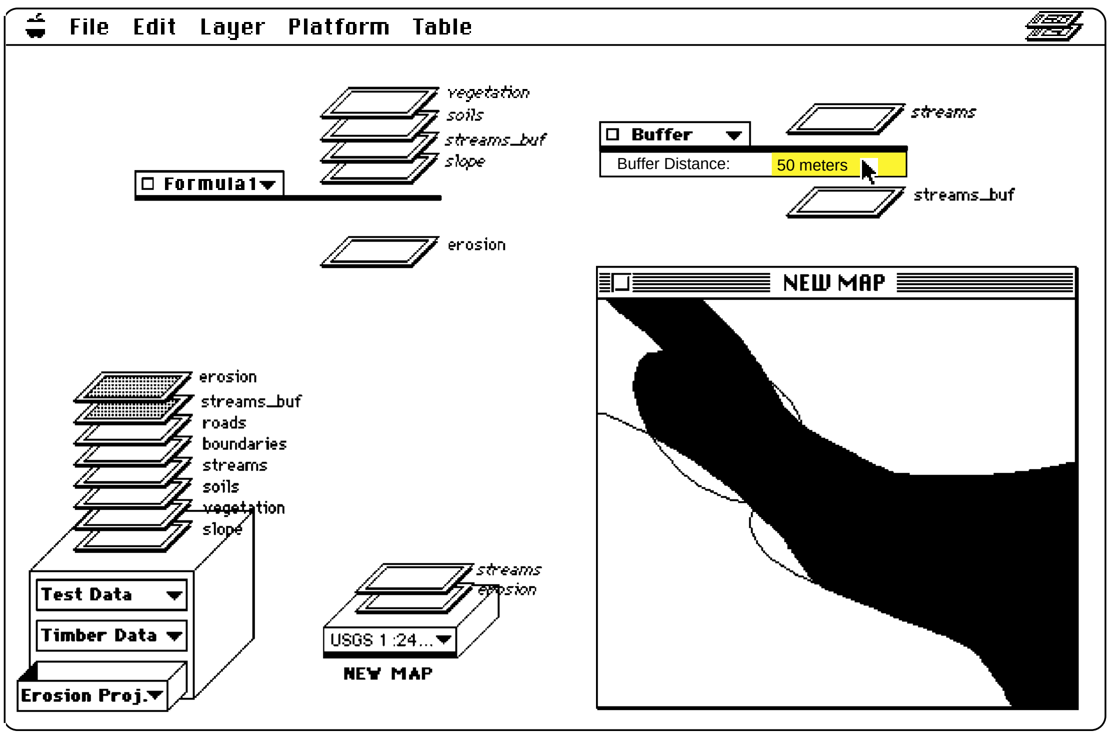
At Santa Barbara, David Lanter and Rupert Essinger developed a graphical user interface (GUI) specifically for designers of GIS applications. Mr. Essinger was in residence Fall 1991 - 1992 to continue this work. Their interface was targeted at helping both the beginning and expert applications designers visualize what the GIS application does and how it works. This supports code writing, testing, and debugging. They created an iconic language that they believe communicates the nature of spatial analytic applications. This language is discussed in the NCGIA publication "User-Centered Graphical User Interface Design for GIS." Experiments were run to test the way users interpret and use this iconic language and graphical user interface. This research generated an empirical basis from which to evaluate the use of icons and graphical user interfaces for GIS.

2.2 Visual Map Algebra and the Geographer's Desktop

In response to the observation of the gap between user interfaces for business applications such as word processors and the user interfaces in commercial GISs, NCGIA researchers at the University of Maine investigated the design of *direct-manipulation* user interfaces for GIS. Direct manipulation is a metaphor for a user's physical activity. Actions that users would normally perform in their own environment, such as pointing and moving objects, are metaphorically mapped onto 'direct' manipulations of objects on the computer display, typically using a mouse or other pointing device. When accompanied by visual metaphors, direct manipulation creates a powerful interactive environment. Users see and recognize the object that they want to interact with. They physically select this object and perform actions on it 'directly'. The appearance of the object then changes to inform the user of the result of the interaction through visual and at times auditory feedback.

During the preparation phase for Initiative 13, we gained experience with some aspects of direct-manipulation user interfaces when we investigated *pan and zoom* metaphors (Jackson 1990). At the University of Maine over the last two years, we increased our efforts in this direction and designed a comprehensive GIS user interface, employing direct manipulation, that allows users to perform GIS operations typically associated with MAP algebra. The goal of these investigations was to find a way to interact with maps on the computer as easily as one interacts with files, folders, and the trash can on a Macintosh or Windows user interface. Since GIS and business operations differ considerably—GIS users often want to combine maps, whereas business users are primarily interested in organizing and retrieving documents—it was necessary extend the primary user objects of a desktop with those specific to operations with geographic data.

We developed an environment, called the *Geographer's Desktop*, and designed an iconic direct-manipulation language, called Visual Map Algebra, with which a user performs operations within Tomlin's Map Algebra (Tomlin 1990) operations. We found that three concepts are necessary: *map layers* (as a new type of document), a *computational platform* to allow users to perform operations on map layers, and a *viewing platform* on which layers may be placed in order to be displayed (and manipulated) in a window. This type of interaction differs considerably from the commonly found direct-manipulation user interfaces for GISs employing windows, icons, menus, and pointing devices (WIMP), and makes it easier for inexperienced users to learn a system and do interesting analysis.



The design of the *Geographer's Desktop* user interface was evolutionary, as it contained several iterations, including prototyping of several mockups, analytical evaluation and comparison of the user interface designs, and informal user testing. In particular, we found:

- In our initial design, data and their graphical presentation parameters were separated, in order to allow users to combine them freely. Novice users found this separation to be irritating, whereas more advanced users thought that such a mix-and-match was extremely powerful.

- The integration of data and presentation into a single user interface object—a layer—overcomes some of these initial concerns, but it requires two distinct operations to be performed on such a layer: some operations change the content of a layer (by database query or analysis), whereas other operations modify the presentation parameters. For this purpose, we designed an icon with two parts. This user interface object acts like a single object for selection and dragging, but exposes different behavior under double-clicking, depending on which part of the icon was pointed at.
- Operations such as "display" or "calculate" can be effectively implemented through iconic user-interface objects (e.g., placing map icons on the viewing platform or the computational platform). Users perform direct manipulations on what is to be displayed by dragging and dropping a data layer onto the corresponding object.
- For similar operations, metaphors that share the same basic image schema can be combined and can coexist on the user interface. For example, the viewing platform and the computational platform are both SURFACE image schemata, which afford the same type of operations, such as stacking things on top of them. While such a combination of metaphors was easy to learn and understand, combinations of metaphors that underlie different image schemata were more difficult to handle, for example, a combination of a viewing platform with a calculator, which is based on a CONTAINER image schema.

A series of papers has been published on the evolution of the *Geographer's Desktop* and the development of Visual Map Algebra. Papers discussing the initial design with cubes and templates appeared in a refereed conference proceedings (Frank 1992) and as an article in a refereed journal (Egenhofer and Richards 1993a). A paper at Auto Carto 11 discussed the lessons learnt from the first round of the user interface design (Egenhofer and Richards 1993b), and a manuscript presenting analytical comparisons between the cubes-and-template interface and the layer interface (Egenhofer and Richards 1994), is under review with a refereed journal.

A summary of the computational platform was published in the IGUG newsletter (Egenhofer and Bruns 1994a), and a manuscript on Visual Map Algebra has been submitted to a refereed conference (Egenhofer and Bruns 1994b). A survey article comparing different user interfaces for map algebra is in preparation (Bruns and Egenhofer, to appear) and will be submitted to a refereed journal. Furthermore, two master's theses were completed at the University of Maine (Richards 1993; Bruns 1994).

2.3 Geographic Problem-Solving in Spanish and English

It is common to solve spatial problems—deciding where to locate a house or determining the shortest route between home and an unfamiliar location—using paper maps. Today, Geographic Information Systems use multiple digital maps and may permit far more complex problems to be addressed. In order best to assist automated problem-solving we must design GISs so that they accommodate the natural manner by which people solve spatial problems. However, we knew of no prior research that has studied the structure of map-based problem-solving with the goal of human-computer interaction (GIS design). At Buffalo, Michael D. Gould's dissertation research used protocol analysis to analyze the words used in geographic problem-solving by English-speakers and Spanish-speakers. Human subjects in Quito, Ecuador, and Buffalo, New York, were given four sub-tasks (locational questions) using a set of maps of the island of Puerto Rico. The subjects described their own problem-solving during the tasks, and these descriptions were encoded and analyzed quantitatively using several pattern analyses. Nonparametric statistics were used to test for significant differences in the structure of the problem-solving dialogs (protocols), between Quito and Buffalo subjects.

SHAPA, a PC-based protocol analysis system, was used to provide pattern and content analyses. The vocabulary chosen to encode the spatial problem-solving behavior was based on Donald Norman's (1986) "seven stages of human action." Results show the absence of strong problem-solving patterns in either the Quito or Buffalo protocols. Furthermore, nonparametric statistical tests showed no significant differences between the two linguistic groups. These results seem to indicate that the encoding chosen was too coarse and, thus, did not catch structural, cross-linguistic subtleties. Extrapolating, it is suggested that to represent this coarse problem-solving structure, the user interfaces for GIS might be translated rather directly from English, without special regard to cultural-linguistic differences. Future work should be directed at the use of a finer-grained encoding vocabulary, and perhaps also an alternative philosophical basis such hermeneutics.

2.4 Other Research at Buffalo

At Buffalo, David Mark prepared and presented a number of papers and book chapters that emphasized conceptual models relevant to GIS user interfaces, or reviewed spatial cognition in a GIS user interface context. These papers are listed below.

In addition, S. L. Shapiro and D. M. Mark were awarded a small grant from Environmental Systems Research Institute (ESRI), for summer 1990 research on "Interfacing an Intelligent, Multi-media User Interface with ARC/INFO." The work led to a "proof-of-concept" prototype (see Shapiro, Chalupski, Chou, and Mark, 1992).

Michael Mulligan, a US Defense Mapping Agency employee on advanced training at Buffalo during 1990-92, completed a Master's degree, including a research project entitled "User Interfaces: Some Issues for Larger Spatial Data Handling Organizations," in September 1991.

In May of 1993, Todd Crane completed his Master's degree at Buffalo by submitting his research project entitled "A Graphical User Interface for Map Production within the Environmental Restoration Program at Los Alamos National Laboratory." The project reported work conducted during the summer of 1992 at Los Alamos National Laboratory. Crane expects to publish two papers from this research.

2.5 Research in Vienna

Two key people from the Initiative 13 group at Maine (Andrew Frank, Werner Kuhn) subsequently moved to the Technical University Vienna. There, research continues in the area of GIS user interface design. The two main issues investigated are the role of spatial concepts and of metaphors in the design and use of these interfaces. Werner Kuhn presented a paper on "Paradigms of GIS Use" at the Fifth Spatial Data Handling Symposium in Charleston. Adrijana Car, who has previously worked on car navigation systems at TU Graz, has joined the group and is working towards a Ph.D. on cognitive and algorithmic problems in navigation.

From June 9 to 12, an interdisciplinary workshop on Task Analysis in Human Computer Interaction was held in Schaerding, Austria, and had over thirty participants. A special session had been organized on task analysis for GIS. Werner Kuhn, who had been a member of the program committee, presented a paper on "The role of metaphors in task analysis" and chaired a session on task analysis methods. Additional GIS related papers were presented by Andrew Turk (Univ. of Melbourne, Australia) and Wolf-Fritz Riekert (FAW Ulm, Germany). A book containing some twenty fully refereed papers and discussions of the workshop results is being published.

A Master's thesis in Vienna on applying the keystroke level model to manual digitizing is making good progress and has produced very encouraging results as well as a rich resource of experimental data. First results were presented at COSIT'93, Elba, Italy, September 1993.

In a related Master's project in Vienna, the ergonomics of modern surveying instruments (total stations) is being studied using motion-time methods, producing similarly positive results with respect to the applicability and economic value of such methods.

Another Master's thesis at Vienna involves a task analysis of cadastral operations in Austria, and is using the result to evaluate a new cadastral module of a major GIS platform.

In a series of experiments, Andrew Frank and Werner Kuhn (Vienna) have collected some 200 sketches which various subjects produced to show their mental images of the surroundings of a given location. The sketches contain abundant material on spatial concepts and will be described and analyzed.

2.6 Additional Funding

Additional funding for work related to Initiative 13 was obtained from:

- Intergraph Corporation (Principal Investigators: Max Egenhofer and Andrew Frank).
- ARPA (Principal Investigator: Max Egenhofer)
- ESRI (Principal Investigator: Max Egenhofer)
- Maine Mathematics and Science Alliance (Principal Investigators: Max Egenhofer and Kathleen Hornsby)
- National Science Foundation (Michael Gould's dissertation; also International travel grant to Tim Nyerges, University of Washington, for additional support for the NATO ARW that closed the Initiative)

- North Atlantic Treaty Organization (NATO ARW grant to Tim Nyerges, University of Washington)

2.7 Other Activities

2.7.1 Activities at Professional Meetings

CHI'90: Werner Kuhn and Max Egenhofer organized and led a workshop on "Visual Interfaces to Geometry" at the annual meeting of the Computer-Human Interaction special interest group of the Association for Computing Machinery during the spring of 1990. The purpose of the interdisciplinary workshop was to explore and integrate advanced approaches to the visual representation and interactive manipulation of geometric information. The workshop's content is described in some detail in the accompanying bibliography (see Kuhn and Egenhofer, 1990); however, the workshop also played a key role in making many members of the human-computer interaction community aware of the interesting problems involving spatial data in general and GISs in particular.

AAG 1990: David Mark organized a Special Session entitled "GIS Specialty Group: Natural Language, User Interfaces and GIS," at the annual meeting of the Association of American Geographers, April 21, 1990, in Toronto, Ontario.

AAG 1991: Two panel sessions, the first entitled "User Interfaces for GIS: User Needs" (panelists: W. Craig, A. Williams, G. Elmes, M. Armstrong, and R. Aangeenbrug) and the second on "User Interfaces for GIS: Possible Solutions" (panelists: M. McGranaghan, T. Nyerges, and D. Mark) were held at the Association of American Geographers' meeting in Miami (April 14-17, 1991).

CHI'91: A "Special Interest Group" (SIG) session was held at the ACM Computer Human Interaction meeting (CHI'91) of the Association for Computing Machinery in New Orleans (April-May 1991); this was organized by Werner Kuhn, and included David Mark.

ESRI User Conference, 1991: A panel discussion was conducted at the ESRI User Conference (Palm Springs, late May 1991).

AAG 1992: A special session entitled "Interacting with Geographic Information" was held at the 1992 meeting of the Association of American Geographers in San Diego in April. It included papers by two Specialist Meeting participants from outside the NCGIA (MacDougall, Nyerges), two by other non-NCGIA personnel (Freundschuh, Knapp), and an overview of the NCGIA I-13 research agenda by Mark. A panel session at the San Diego AAG, organized by Mark, was entitled "Representation of Geographic Information," and included noted human-computer interaction expert Donald A. Norman, of the University of California at San Diego, as well as Helen Couclelis, Andrew Frank, Tim Nyerges, and David Mark.

CHI'93: Werner Kuhn conducted an interdisciplinary workshop on 'Spatial Metaphors' at the ACM Conference on Human Factors in Computing Systems, INTERCHI'93, in Amsterdam, April 24-25, 1993. The 23 participants came from the US (12) and Europe (11) and discussed approaches to spatialization in human-computer interfaces both from spatial (such as GIS or CAD) and non-spatial domains. A report will be published in the ACM SIGCHI Bulletin, a book with revised and extended position papers is in preparation.

2.7.2 BITNET Listserver

A BITNET Listserver called UIGIS-L was established on July 1, 1991, for discussion of these and other issues related to "User Interfaces for Geographic Information Systems." On October 6, 1994, UIGIS-L had 513 subscribers, and was available as a Usenet news group, bit.listserv.uigis-l, but the group has had very little discussion recently.

2.7.3 NATO Advanced Research Workshop

The major International Conference at the end of Initiative 13 was a NATO Advanced Research Workshop entitled "Cognitive and Linguistic Aspects of Geographic Space," that was held at Playa de Palma, Mallorca, Spain, March, 1994. The ARW received financial support from NATO, ARPA, and NSF International Programs, and also had partial support from the NCGIA. Timothy Nyerges, University of Washington, was the Director of the ARW, and David Mark was the co-Director. A major product of the ARW is a book, edited by Nyerges, Mark, Egenhofer, and Laurini (1995). The program and participants list for the Workshop are included in Appendix B.

3. Research Agenda Development

How has the research agenda in this area changed as a consequence of activities of the initiative?

The prominence of user interface issues and human-computer interaction (HCI) in the research agenda for geographic information and analysis has increased greatly since 1989. By establishing this as a research initiative topic, and by conducting several workshops at professional meetings in 1991, the NCGIA promoted this topic within the GIS research and software development communities. We certainly cannot claim to be the reason that usability of geographic software has improved sharply over the last five years; however, the GIS community now is well aware of usability as a key issue.

It now appears that issues of human factors and human-computer interaction for GIS may be best addressed in the context of particular classes of GIS and GIA problems and use contexts, rather than as a separate problem. This was not evident in 1989. It may be that there are few ’generic’ issues for HCI in GIS that can be easily separated from geographic problems. Initiatives 10 ("Spatiotemporal Reasoning and GIS") and 8 ("Formalizing Cartographic Knowledge") have substantial HCI components, and human factors and user interface design and evaluation are a key element in the Digital Libraries grant recently awarded by NSF to the NCGIA consortium members. User interfaces also are a critical part of computer-supported cooperate work for spatial decision-making, a topic that has been approved in principle as the theme of another future research initiative of the NCGIA (Initiative 17).

4. Contribution to GIS Education

How has the education of GIS scientists been enhanced by the initiative?

No new educational materials have been developed at the NCGIA within Initiative 13. However, students have been involved in many aspects of the Initiative. Seven of the Specialist Meeting participants were students at the time of the meeting, four of those from outside the NCGIA.

Graduate degree research has made up a substantial proportion of accomplishments under Initiative 13. Six graduate degrees on user interface topics were completed; abstracts for some of these are given in the publications section, below.

1991 Michael P. Mulligan, "User interfaces: Some issues for larger spatial data handling organizations." Master's project, Department of Geography, University at Buffalo, September 1991.

1993 Todd Crane, "A graphical user interface for map production within the environmental restoration program at Los Alamos National Laboratory," Master's project, Department of Geography, University at Buffalo, May 1993.

1993 Michael D. Gould, "Map Use, Spatial Decisions, and Spatial Language in English and Spanish," Doctoral Dissertation, Department of Geography, University at Buffalo, August 1993.

1993 James Richards, "Interaction with Geographic Information Based on the Map-Overlay Metaphor," Master Thesis, University of Maine, Department of Surveying Engineering.

1993 Gary Volta, "Interaction with Attribute Data in Geographic Information Systems: A Model for Categorical Coverages," Master Thesis, University of Maine, Department of Surveying Engineering.

1994 H. T. Bruns, "Direct Manipulation User Interfaces for GIS Map Algebra," Master's thesis, University of Maine, Department of Surveying Engineering.

5. Science Policy

Does NCGIA have any recommendations to Academe, Professional Organizations or to NSF on policy decisions that would promote the further advancement of knowledge in the research area addressed by the initiative?

Future research on user interfaces for geographic software, or on human-computer interaction in geographic problem solving, should be conducted as part of the conceptual design and the implementation of the systems themselves, rather than as an orthogonal research topic on its own. In fact, topics of the form "GIS and X" may imply separability of substantive and technical aspects which cannot and should not be separated.

6. The Research Initiative Process

What were the strengths and weaknesses of the research initiative process in facilitating the research in the initiative?

The initiative process continues to work very well. Specialist Meeting participants seemed to accept the format and nature of the meeting without question, and the plan of alternating plenary sessions and break-out groups, with few presentations per se, worked extremely well. There is an impression that Specialist Meeting participants from outside the NCGIA did more post-Meeting research on the topic than in Initiative 2. (See also William J. Craig's 3rd comment in section 7, in which he comments on the initiative process.)

Problems in the management of an initiative may arise when an initiative co-leader who leaves the NCGIA. Participation in the basic research can be expected to happen regardless, but participation in reporting annually, or preparation of the closing report might be harder to achieve if there are no resources tied to these activities. This may also be a problem for initiatives co-led by non-NCGIA researchers from the start. In retrospect, there was also perhaps too much overlap on NCGIA personnel involved in Initiatives 13 and 10 ("Spatio-temporal Reasoning and GIS"), with human resources drawn away from Initiative 13 too soon. Overlap in key personnel might be given more consideration in the scheduling of initiatives.

7. Comments By Researchers Outside the NCGIA

7.1 Marc P. Armstrong

On April 13, 1994, Specialist-meeting Participant Marc P. Armstrong, of the Department of Geography at the University of Iowa, sent the following comments about the Initiative:

> *I have enclosed references and abstracts for papers that have been influenced by I13 in some way or another. As you can see there are several "threads", the most prominent of which is my work on group decision-making which has its roots somewhere on Peek'n Peak (or whatever). The other thread is my work with Paul [Densham] on improving interaction for SDSS. The two Mallorca papers are certainly relevant...*
>
> *I hope this helps and that you find my "contributions" useful as you compile the final report for I13. I know that it altered my view of work in GIS (for the better, I think).*

Publications not including NCGIA Co-Authors:

Armstrong, M. P. (1992) GIS and group decision-making: problems and prospects. *Proceedings of GIS/LIS'92*, Volume 1, Bethesda, MD: American Congress on Surveying and Mapping, pp. 20-29.

While GIS technology has developed rapidly during the past decade and many successful implementations are now in place, the focus of most research and development activity has been placed on the development of single-user systems. However, GIS technology is not being used to its fullest measure because it does not accommodate the needs of decision-making groups. GIS methods must be expanded to encompass group decision-making processes and new tools must be developed that will enable group members to generate, evaluate, and illustrate the strong and weak points of alternative scenarios and come to a consensus about how to proceed toward a decision.

Armstrong, M. P. (1993) Perspectives on the development of group decision support systems for locational problem-solving. *Geographical Systems*, 1(1): 69-81.

Many locational problems contain aspects that cannot be rigorously defined and that require the integration of information from multiple sources and expertise from several disciplinary perspectives. Solutions to such problems are often formulated by groups whose members bring distinct expertise to the search for solutions. Geographic information systems and spatial decision support systems (SDSS), however, have failed to provide tools that can be used effectively when groups are charged with making decisions. Consequently, they are ill-suited to group decision styles commonly used in public and private sector organizations. Developments in hardware and software technology have led to the emergence of computer supported cooperative work (CSCW) computing environments. Though CSCW research, to date, has mainly focused on business applications, it can be used to provide the conceptual basis for group locational decision-making. This paper describes the process through which groups apply SDSS to locational problems and addresses the deficiencies of current systems in supporting such activities. Improvements to existing systems must enable group members to collectively observe, manipulate, and evaluate alternative plans and provide mechanisms for conflict resolution.

Armstrong, M. P. (1994) Requirements for the development of GIS-based group decision support systems. *Journal of the American Society for Information Science*.

Though GIS technology has progressed rapidly during the past decade, the focus of most research and development activity has been placed on the development of single-user systems. A mismatch exists, however, between the widespread single-user model of GIS and the group-based approach to decision-making that is often adopted when semi-structured public policy issues are addressed. GIS-based spatial analysis and display methods must be

> expanded to encompass group decision-making processes, and new tools must be developed that will enable group members to generate, evaluate, and illustrate the strong and weak points of alternative scenarios and come to a consensus about how to proceed toward a decision.

7.2 William J. Craig

On April 13, 1994, Specialist-meeting Participant William J. Craig, of the Center for Urban & Regional Affairs at the University of Minnesota, sent the following comments about the Initiative:

> *1. My involvement with this initiative was one of the major factors in seeking out the feature map item from CSIRO in the Spring 1993 issue of the URISA Journal. (As you know, I was the map editor then.) The article was by Ken Yap and Steve Jones--"An Object-Oriented User Interface Incorporating Multiple Views." I originally encountered their work at the 1991 AURISA conference in an award winning presentation by David Abel. In that earlier presentation he had not emphasized the user interface.*
>
> *2. My impression is that the vendor community was ready to move forward on this whole topic and our meeting helped them justify this move. I've seen no academic writing on this topic--we're sitting back right now, watching things unfold. We're moving from the tool box approach to easier to use GUIs. The next question will be "how is the simpler tool constricting analysis?"*
>
> *3. Regarding the Specialists Meeting (a. k. a. Research Initiative Process). I have since attended I-9 and was impressed with the results of holding a competition to see who attends. The writings for that were first-rate--better than our collection. On the other hand, I wasn't particularly impressed with "conclusions" of either. I'm not convinced there is a need to come to consensus. There is too much to do to force everyone towards a single agenda.*

7.3 Stephen Smyth

Steve Smyth, an I-13 Specialist Meeting participant who now works for Microsoft, reported the following in email he sent on June 20, 1994:

> *I-13 has had a great impact on the design of several forthcoming products here at Microsoft. They are not announced yet, but are in active development with large teams. I have been able to make especially good use of Werner Kuhn's contributions on metaphor.*

8. Annotated List of NCGIA Publications Resulting From Initiative 13

8.1 Articles in Refereed Journals

Armstrong, M. P., **Densham, P. J.**, Lolonis, P. and Rushton, G. (1992) Cartographic displays to support locational decision-making. *Cartography and Geographic Information Systems*, 19 (3): 154-164.

A functional taxonomy is developed which describes the kinds of maps decision-makers can use to evaluate changes in the locations of activities to serve distributed demand. Chorognostic, monoplan, and delta displays can be used for a variety of purposes during all three stages of the decision-making process: problem research and definition; the generation of alternative solutions; and selection of a course of action. Implementations of these display types are described. Finally, we argue that in a visual interactive modeling environment, linkages between the objective space of mathematical models, and the graphical space of cartographic displays, will enable decision-makers to select more appropriate analytical models and to intervene and change their decision criteria. These results contribute to improved decision-making in complex geographical contexts.

Egenhofer, M. Spatial SQL: a query and presentation language. *IEEE Transactions on Knowledge and Data Engineering* 6 (1): 86-95.

Recently, attention has been focused on spatial databases which combine conventional and spatially related data such as Geographic Information Systems, CAD/CAM, or VLSI. A language has been developed to query such spatial databases. It recognizes the significantly different requirements of spatial data handling and overcomes the inherent problems of the application of conventional database query languages. The spatial query language has been designed as a minimal extension to the interrogative part of SQL and distinguishes from previously designed SQL extensions by (1) the preservation of SQL concepts, (2) the high-level treatment of spatial objects, and (3) the incorporation of spatial operations and relationships. It consists of two components, a query language to describe what information to retrieve and a presentation language to specify how to display query results. Users can ask standard SQL queries to retrieve non-spatial data based on non-spatial constraints, use Spatial SQL commands to inquire about situations involving spatial data, and give instructions in the Graphical Presentation Language GPL to manipulate or examine the graphical presentation.

Egenhofer, M. and **Richards, J.** (1993a) Exploratory Access to Geographic Data Based on the Map-Overlay Metaphor. *Journal of Visual Languages and Computing* 4(2): 105-125.

Many geographic information systems (GISs) attempt to imitate the manual process of laying transparent map layers over one another on a light table and analyzing the resulting configurations. While this map-overlay metaphor, familiar to many geo-scientists, has been used as a design principle for the underlying architecture of GISs, it has not yet been visually manifested at the user interface. To overcome this shortage, a new direct manipulation user interface for overlay-based GISs has been designed and prototyped. It is characterized by the separation of map layers into data cubes and map templates such that different thematic data can be combined and the same kind of data can be displayed in different formats. This paper introduces the conceptual objects that the user manipulates at the screen surface and discusses ways to visualize effectively the objects and operations upon them.

Lanter, D.P. (1994) Removing Redundancy and Propagating Updates in a Spatial Analytic Database. *Cartography and GIS*.

This study presents techniques for using lineage metadata to address problems of data redundancy and update propagation in a spatial anlaytic GIS database. Source and derived equivalence tests are presented as a basis for identifying data sharing, and removing redundancies within a database created by distinct spatial analytic applications. These tests also support automatic integration of lienage knowledge representations to created a global schema for a GIS database. Techniques are presented for manipulating the resulting global schema to identify and update derived data made obsolete by a change to a source map. Extending lineage metadata with temporal attributes is demonstrated as the basis for a technique that tracks obsolete data and control the propagation of new source materials within a spatial analytic database.

Mark, D.M. and **Gould, M.D.** (1991) Interacting with geographic information: a commentary. *Photogrammetric Engineering and Remote Sensing* 57(11), 1427-1430.

Instead of interacting with a computer peripheral or its user interface, GIS users should instead interact more directly with geographic information. To allow for this, user interface designers should look beyond the support of windows, menus, icons and pointing devices, toward the support of geographic thinking and geographic communication. Perhaps focussing attention on the concept of human-computer interaction is myopic or misguided. Instead, the GIS user community should be advocating that vendors support human-problem or human-phenomenon interaction more directly. A research initiative of the National Center for Geographic Information and Analysis, designed to address this and other aspects of the GIS user interface, is described.

8.2 Articles in Refereed Proceedings:

Egenhofer, M. and **Kuhn, W.** Visualizing spatial query results: the limitations of SQL. In E. Knuth and L. Wegner (eds.) *IFIP WG 2.6, 2nd Working Conference on Visual Database Systems, Budapest, Hungary*. Elsevier.

Several extensions to the relational database query language SQL have been proposed to serve as a spatial query language; however, they do not sufficiently address how to visualize query results. This paper investigates the requirements for an ad hoc language describing the graphical representation of spatial query results from the perspective of a geographic information system with frequent map output and assesses several spatial SQL extensions with respect to their treatment of the graphical representation. It concludes that the SQL framework is inappropriate for this task at the user interface.

Frank, A.U. Beyond query languages for geographic databases: data cubes and maps. In G. Gambosi, M. Scholl and H.W. Six (eds.) *International Workshop on DBMSs for Geographical Applications, Capri, Italy* .

After several years of efforts to extend query languages for Geographic Information Systems (GISs), the limits of SQL-like languages for the selection of geographic data to be displayed in map form became evident. While SQL provides a means for selecting data based on well-specified criteria, it does not support the exploratory access geo-scientists need. Traditional work methods of cartographers provided the concepts for the layer-based GIS, where overlay is the central operation (similar to the physical overlay of maps drawn on transparent material). The inspiration for a visualization of these operations for the user interface can be borrowed from the same source. Two different concepts are identified, one is "data sets" the other "maps," and a representation as icons is proposed. Operations can be succinctly expressed by dragging data cubes onto maps and the icons show by "repelling forces" if the user is about to do an illegal or meaningless operation. We describe the interface and its operations and conclude with open questions and describe a formal method that will be used to further develop the interface design to achieve consistency.

Kuhn, W. (1991) Are displays maps or views? *Proceedings, Auto-Carto 10, Baltimore MD* 6: 261-274.

Metaphors are powerful means to design and learn user interfaces for computer systems. This paper discusses metaphors for display operations in Geographic Information Systems. Specifically, the metaphor DISPLAYS ARE VIEWS is proposed and analyzed. It is presented as an antithesis to the metaphor DISPLAYS ARE MAPS which is consciously or unconsciously adopted by designers and users of most GIS interfaces. Displays are understood here as graphic screen presentations of geographic space, maps as static (paper) maps, and views as visual fields, containing what humans see in a given situation. The major advantage of the visual field as a metaphor source is that it naturally accommodates scale changes. Thus, analyzing its structure also sheds light on the generalization problem for displays.

Volta, G. and **M. Egenhofer, M.** (1993) Interaction with GIS Attribute Data Based on Categorical Coverages. in: A. Frank and I. Campari (Ed.), *Spatial Information Theory, European Conference COSIT '93, Marciana Marina, Elba Island, Italy*. *Lecture Notes in Computer Science* 716, pp. 215-233, Springer-Verlag, New York, NY.

The human-computer interface is a crucial element in the design of the next generation of Geographic Information Systems (GISs). We discuss the user interface design process by separating the *formalization* of the problem domain (identifying the objects a user manipulates, and their pertinent operations) from its *visualization* (describing human-computer interaction techniques such as windows and dialog boxes). This framework is used to examine the process of manipulating *attribute data* in a GIS on the basis of the common cartographic concept of a *categorical coverage*. The characteristics of categorical coverage data and the user requirements for interacting with this data are formalized in the form of a set of fundamental objects and operations. A visualization for a windows-icons-menus-pointing devices (WIMP) interface is presented.

8.3 Articles in Other Outlets

Armstrong, M.P., **Densham, P.J.** and Lolonis, P. (1991) Cartographic visualization and user interfaces in spatial decision support systems. In Proceedings of GIS/LIS '91, Volume 1. Bethesda, MD: American Congress on Surveying and Mapping, pp. 321-330.

Armstrong, M.P. and **Densham, P.J.** (1995) A conceptual framework for improving human computer interaction in locational decision-making. In Nyerges, T., Mark, D., Egenhofer, M., and Laurini, R., editors *Cognitive Aspects of Human-Computer Interaction for Geographical Information Systems*, Dordrecht: Kluwer Academic Publishers.

Bruns, H.T. (1994) *Direct Manipulation User Interfaces for GIS Map Algebra*, Master's thesis, University of Maine, Department of Surveying Engineering.

The increasing utility of Geographic Information Systems (GIS) has not been matched with an increasing usability. Improvements in GIS user interfaces will make more users capable of performing more tasks. Graphical, direct-manipulation user interfaces based on metaphor offer increased usability for GIS. The Geographer's Desktop is a direct manipulation environment for

GIS, within which interfaces for various GIS functional groups are created. This research investigates the design of user interfaces for GIS Map Algebra. Used by planners, geographers, and other spatial scientists, Map Algebra facilitates the analysis of geographic phenomena. Historically, Map Algebra was performed manually by overlaying thematic map layers. This process offers a rich source domain for interface metaphors. A direct manipulation interface has been designed and prototyped that allows users to construct Map Algebra expressions on the Geographer's Desktop by stacking iconic representations of thematic map layers onto an interface called the computational platform.

Crane, T. (1993) A Graphical User Interface for Map Production Within the Environmental Restoration Program at Los Alamos National Laboratory. Unpublished Master's degree project, Department of Geography, State University of New York at Buffalo.

A successful implementation of a Graphical User Interface (GUI) requires an understanding of the tasks that need to be performed and the objects that are being worked with. Geographic Information Systems (GIS) provide toolkits for building these types of applications. While there has been rapid technological improvement in computer hardware and software over the past 20 years, the incorporation of design principles has lagged behind. This research focuses on the system design and implementation process as applied to the Environmental Restoration Program's Geographic Information System Interface (EGI), a case study at Los Alamos National Laboratory.

Densham, P.J. and Armstrong, M.P. (1993) Supporting visual interactive locational analysis using multiple abstracted topological structures. Proceedings of the Eleventh International Symposium on Computer-Assisted Cartography (Auto-Carto 11), Bethesda, MD: American Congress on Surveying and Mapping, pp. 12-22.

Data structures for automated cartography traditionally have been either vector-based or tessellation-based. We describe a set of topological abstractions, derived from a vector approach to the representation of geographic space, that were developed to support interactive solution of location-selection problems. When augmented with an appropriate representation of geometry, these abstractions are used to generate cartographic displays to support interactive decision-making. The advantages of this approach include: the use of the same data abstractions for analysis and display purposes; support for multiple representations of networks and,

therefore, a degree of scale independence; and, finally, support for highly interactive problem-solving and decision-making because map generation can be decomposed into parallel processes.

Densham, P.J. and Armstrong, M.P. (1995) Human-computer interaction: considerations for visual interactive locational analysis. In Nyerges, T., Mark, D., Egenhofer, M., and Laurini, R., editors *Cognitive Aspects of Human-Computer Interaction for Geographical Information Systems*, Dordrecht: Kluwer Academic Publishers.

Egenhofer, M., and J. Herring (1993) Querying a Geographical Information System. in: D. Medyckyj-Scott and H. Hearnshaw (Eds.), *Human Factors in Geographical Information Systems*. pp.124-136, Belhaven Press, London.

GIS query languages have been traditionally based on database query languages. There are a large number of proposals for spatial extensions to what fundamentally are abstract data query and manipulation languages. Due to the particularities of spatial data and their semantics, the requirements for both the spatial database and for the spatial query language differ from the ones of standard database applications, which have their roots in nongraphic business applications. This chapter reviews efforts in designing spatial query languages and compares the results with the spatial concepts humans employ commonly about geographic data. We find an increasing gap between the standardization efforts of SQL, the predominant database query language, and our human, intuitive spatial concepts.

Egenhofer, M., and **Bruns, H.T.** (1994a) Bringing Maps onto the Desktop: GIS User Interfaces Beyond Menus and Buttons, *International IGUG News*, Fall 1994, pp.8-9.

An alternative to the common windows-icons-menus-pointers (WIMP) user interfaces is presented. It consists of a direct-manipulation user interface with map layers, the viewing platform, and the computational platform as the primary user-interface objects. Users can perform map overlay operations by dragging map layers onto a compurational platform, and results can be visualized by moving the corresponding icons onto a viewing platform.

Egenhofer, M., and **Bruns, H.T.** (1994b) Visual Map Algebra: A Direct-Manipulation User Interface for GIS, (submitted for publication).

Geographic Information Systems (GISs) store, analyze, and present spatial data and information about geographic space and geographic phenomena. Virtually all aspects of a GIS have inherent spatial, graphical, and visual characteristics. While the database and analytical aspects of GIS have enjoyed considerable advancement in recent areas, a user’s access to and interaction

with spatial information has not. For such a highly visual system, GIS is often characterized by its distinctly non-visual user interfaces, where command-line and window-icon-menu-pointer (WIMP) user interfaces are most common, whereas visual, direct-manipulation user interfaces are rare. Direct-manipulation user interfaces based on metaphor offer increased usability for GIS. This paper extends the Geographer's Desktop, an innovative direct-manipulation environment for viewing data in a GIS, by integrating a new method for GIS Map Algebra operations. Used by planners, geographers, and other spatial scientists, Map Algebra facilitates the analysis of geographic phenomena. Historically, Map Algebra was performed manually by overlaying thematic map layers, a process that offers a rich source domain for user interface metaphors. *Visual Map Algebra* is a direct-manipulation query language that allows users to construct arbitrarily complex combinations of map layers by stacking iconic representations of thematic map layers onto an interface object called the computational platform. Users visualize such calculated map layers by moving them onto an interface object called the viewing platform that manages cartographic display parameters and is associated with a viewing window. Visual Map Algebra enables exploratory analysis by changing parameters of the overlay and immediately observing the outcome, and adding or removing map layers on the fly.

Egenhofer, M., and **Richards, J.** (1993b) The Geographer's Desktop: A Direct-Manipulation User Interface for Map Overlay. in: R. McMaster and M. Armstrong (Ed.), *Autocarto 11*, Minneapolis, MN, pp. 63-71.

Many spatially aware professionals use the manual process of map overlay to perform tasks that could be done with a GIS. For instance, they could be using GIS technology for work in environmental sciences and design fields, however, they are often not doing so because they lack the computer expertise necessary to run a GIS. The user interface of current GISs has been frequently cited as a major impediment for a broader use of GISs. Popularity and success of metaphor in other areas of human-computer interaction suggests that visual, direct manipulation user interfaces are especially attractive and easy-to-learn for non-computer experts. Many GISs use map overlay as a command-line based interaction paradigm. An interface to GIS that is a visualization of the map-overlay metaphor would enable experts in the spatially aware environmental sciences to more easily use GIS as a regular tool. To overcome this shortcoming, a new direct manipulation user interface based on the map-overlay metaphor has been designed and prototyped. It is well embedded within the successful Macintosh desktop and employs the particular characteristics of metaphor, direct manipulation, and iconic visualization. We create a *geographer's desktop* by replacing the familiar notions of files and folders with the concepts of *map layers* and a *viewing platform* on which layers can be stacked. A visualization of this user interface is presented. Particular attention is given to the way users can change the symbology of layers placed on the viewing platform.

Frank, A. (1992) Beyond Query Languages for Geographic Databases: Data Cubes and Maps. In: G. Gambosi, M. Scholl, and H.-W. Six (Eds.), *Geographic Database Management Systems*. *Esprit Basic Research Series* pp. 5-17, Springer-Verlag, New York, NY.

Frank, A., Volta, G., and **McGranaghan, M.** (1992) Formalization of Families of Categorical Coverages (submitted for publication).

Categorical coverages have gained widespread use as a map type and routines for their preparation are included in most GIS software. Categorical coverages are simple to implement and are easily understood. The popularity of the categorical coverage is intimately related to the simple rules that determine its behavior. This paper presents a formalization of their properties based on the concepts of a partition of space and the refinement of such partitions of space. We do not address the cartographic rendering issues. A family of categorical coverages is defined as all categorical coverages that can be produced from a data set through aggregations of categories. It is shown that categorical coverages are partially ordered by 'refinement' of partitions. This ordering is preserved in the mapping from the ordering of the partition of the attribute domain to the partition of space. This formalization is not only useful for implementors of GIS, but the list of possible operations and their properties is the base for the design of a user interface to produce and manipulate categorical coverages.

Freundschuh, S.F. and **Gould, M.D.** (1991) Empirical user testing for validation of GIS design. *Proceedings, GIS/LIS'91*.

GIS design is driven by introspection and assumption on the part of GIS developers, resulting in systems which may not match the spatial cognitive style of certain users. Therefore, GIS users often devote excessive cognitive processing to computer operation rather than to geographic problem-solving. Optimal human-GIS interaction will be such that the human and computer share cognitive responsibility. Toward this ideal, user preferences, abilities, and needs should be tested empirically as an integral component of GIS design, beta-testing and implementation. User testing can involve surveying human cognition and/or the tasks humans wish to perform with and without a GIS. Two examples of user testing are described: cognitive experimentation to assess how level of spatial knowledge relates to environmental complexity, and protocol analysis to elicit and encode the natural language used to describe spatial problem-solving.

Golledge, R. G. (1995) Spatial Primitives. In Nyerges, T., Mark, D., Egenhofer, M., and Laurini, R., editors *Cognitive Aspects of Human-Computer Interaction for Geographical Information Systems*, Dordrecht: Kluwer Academic Publishers.

In this paper I discuss a set of spatial primitives and some of their higher order derivatives. A universe, physical or cognitive, is said to consist of occurrences of phenomena. Occurrences have 4 basic attributes: identity, location, magnitude, and time. These are suggested as first order spatial primitives and the first task is to unpack their meaning and to define a set of derivatives from these primitives singly and in combination. Collections of occurrences are defined as spatial distributions which also have a minimal set of attributes. These are examined for derivatives solely, in combination, and in combination with the original primitives. The result is an expanding web of geographic/spatial concepts that may provide the basis for a geographic algebra, and may at least to provide a frame for understanding how higher order functions are derived from primitives and their derivatives. A parallel is drawn between such sets of primitives and the cognitive processes associated with them and the formal structure of many GIS systems. It is also suggested that because of the measurement errors or fuzzy language associated with particular segments of this web of primitives, different human-computer interactions may be more or less suited to different functions or operations or commands in a GIS. Finally the question is raised as to whether or not humans interacting with GIS can understand what they are doing when activating GIS processes and whether or not humans can be expected to understand the type of output common to today’s GIS.

Gould, M. D. (1991) Cultural and linguistic aspects of designing geographic information systems for Spanish-speakers. *Yearbook of the Conference of Latin Americanist Geographers, 1990 Auburn Proceedings.*

Gould, M. D. (1991) Elicitation of spatial language to support cross-cultural geographic information systems. In D.M. Mark and A.U. Frank (eds.) *Cognitive and Linguistic Aspects of Geographic Space*. Kluwer, Dordrecht.

There exists a conceptual gap between the methods people naturally use to structure spatial relations and the functionality of user interfaces for geographic information systems to support these methods. Spatial cognitive methods may be inferred by eliciting subjects’ verbal description of "real world", everyday spatial relations. The resulting collection of natural spatial language may then be used as a realistic goal in the GIS user interface design process, especially in query language formulation. Furthermore, because many potential GIS users are non-English speakers it is also helpful to survey the cross-cultural extent of spatial-linguistic terminology; to do so foreign subjects should be tested in their native environments. Verbal descriptions of geographic space may then be empirically compared to performance in executing simple geographical analyses using GIS-like testing software, or may directly support theories of spatial cognition. It is suggested that instead of teaching users to perform better using current GIS technology, we may support the design of more intuitive GISs by studying the way people naturally think about, and describe, geographic space. A summary of such a study, a related pilot study, and a methodological template for testing Spanish and English-speakers are each described here.

Gould, M. D. (1991) The GIS user: make no assumptions. *Proceedings of the Eleventh Annual ESRI User Conference* 2: 519-523.

This paper is aimed at the GIS manager and is a call-to-arms. Because GIS installations are increasing at a rate which cannot be matched by the output of GIS training institutions, it is not surprising that many of today's "typical GIS users" are not trained specialists in spatial data handling. The user community is becoming so diverse that it is impossible to assume what any one user is capable of performing, or what he/she needs in a user interface. Assumption on the part of a GIS manager that operating ARC/INFO is intuitive or that the user is a "spatially aware professional" is, unfortunately, unfounded and potentially dangerous to the integrity of a GIS project. The technically-trained GIS manger is uniquely qualified to demand and specify general improvement in user-GIS interfaces, by observing user behavior and then passing on suggestions to the vendors. To optimally represent typical users, however, the GIS manager must put aside all assumptions, to objectively observe and report what users need to work more naturally and efficiently.

Gould, M. D. (1993) Map Use, Spatial Decisions, and Spatial Language in English and Spanish, Doctoral Dissertation, State University of New York at Buffalo, October 1993.

It is common to solve spatial problems—deciding where to locate a house or determining the shortest route between home and an unfamiliar location—using paper maps. Today Geographic Information Systems (GIS) utilize multiple digital maps and may permit far more complex problems to be addressed. In order best to assist automated problem-solving we must design GIS so that they accommodate the natural manner by which people solve spatial problems. No known researcher has studied the structure of map-based problem-solving with the goal of human-computer interaction (GIS design). Therefore, this study utilizes a form of task analysis, from the engineering field of human factors, and applies it to four spatial sub-tasks where human subjects are asked to select locations on standard topographic and tourist maps of the island of Puerto Rico. To test for possible cross-linguistic differences, data from 20 subjects in Buffalo, New York and 22 in Quito, Ecuador is compared using pattern and content analyses provided by SHAPA: a PC-based protocol analysis system. The vocabulary chosen to encode the spatial problem-solving behavior is based on a modification of Norman's (1986) "seven stages of human action". Results show the absence of strong problem-solving patterns in either the Quito or Buffalo protocols. Furthermore, nonparametric statistical tests showed no significant differences between the two linguistic groups. These results seem to indicate that the encoding chosen was overly coarse and, thus, did not catch structural, cross-linguistic subtleties. Extrapolating, it is suggested that to represent this coarse problem-solving structure, the user interfaces for GIS might be translated rather directly from English, without special regard to cultural-linguistic differences. Future work should be directed at the use of a finer-grained encoding vocabulary, and perhaps also an alternative philosophical basis such hermeneutics.

Gould, M. D., Mark, D. M., and **Gavidia Gadea, C.** (1991) Resolucio de problemas geograficos en igles y español: Implicaciones para el diseño de los sistemas de información geográfica. (Geographic problem-solving in English and Spanish: Implications for the design of Geographic Information Systems.) *Proceedings, III Conferencia Latinoamericana sobre Sistemas de Informacion Geografico,* Viña del Mar, Chile, October 21-25 1991, v. 1, pp. 32-41.

Jackson, J. (1990) Visualization of metaphors for interaction with geographic information systems. M.S. thesis, University of Maine, Orono ME.

The emphasis in the design of Geographic Information Systems (GISs) has historically been placed on architecture, database management, and data structures. Unfortunately, little attention has been paid to the development of a system which will effectively manage the interaction between the user and the software. This thesis details the work done by the author in the human-computer interaction area to develop a suitable theory for the application of metaphors to human-computer interaction. A theoretical framework has been developed for describing the metaphoric process as it applies to human-computer interaction, by separating the process into a series of mappings between three domains: the source domain, the target domain, and the user interface domain, or visualization. Formal specification methods have been used to describe the domains involved and identify similarities and dissimilarities between them. The theoretical principles have been tested through the implementation of a family of pan and zoom metaphors for handling scene selection in GIS.

Kuhn, W. and **Egenhofer, M.** (1991) CHI '90 Workshop on Visual Interfaces to Geometry. *SIGCHI Bulletin* 23(2): 46-55.

The purpose of this interdisciplinary 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, in order to improve the communication between users and systems when dealing with geometric information.

Geometric data are used in many areas, such as Computer Aided Engineering, Geographic Information Systems, Computer Graphics, and Graphic Arts. While data structures for their representation and algorithms for their manipulation have received ample attention in order to minimize memory requirements and processing time for systems, there has been little emphasis on user concerns: how can geometric information be presented and manipulated at the user interface, while optimizing the user's "memory" requirements and "execution speed". Eighteen participants from five countries and three continents attended this two-day workshop. They had been selected based on position papers. Five participants came from industry, the rest from academia. The range of application areas represented included Computer Aided Design (CAD) and Engineering (CAE), Geographic Information Systems (GIS), Image Processing, and Computer Graphics in general.

Kuhn, W. and **Frank, A.U.** (1991) A formalization of metaphors and image-schemas in user interfaces. In D.M. Mark and A.U. Frank (eds.) *Cognitive and Linguistic Aspects of Geographic Space*. Kluwer, Dordrecht.

Sound engineering approaches to user interface design require the formalization of key interaction concepts, one of them being metaphor. Work on interface metaphors has, however, been largely non-formal so far. The few existing formal theories of metaphor have been developed in the context of natural language understanding, learning, or reasoning. We propose to formalize interface metaphors by algebraic specifications. This approach provides a comprehensive formalization for the essential aspects of metaphorical user interfaces. Specifically, metaphor domains are being formalized by algebras, metaphorical mappings by morphisms, and image-schemas by categories. The paper explains these concepts and the approach, using examples of spatial and spatializing metaphors.

Lanter, D. (1991) Geolineus: an intuitive GUI for spatial analysis. *Proceedings of the Eleventh Annual ESRI User Conference* 2: 531.

Custom AML, hyper-text, and natural language interfaces for ARC/INFO do not address the basic issue of how the native GIS software should look to the non-novice user engaged in spatial analysis. They are bolt-on interfaces designed to simplify operations for users with predictable and predefined tasks to carry out. As such they do not solve the larger problem of what is the best interface for a GIS. Geolineus (a generic system which is currently implemented within ARC/INFO) offers a superior approach that reorients the GIS around a graphical representation of the database model. The result provides meaningful direct manipulation of iconic representations that reflect what is going on in the GIS user's mind, novice and expert alike.

Lanter, D. P. (1992) GEOLINEUS Data Management and Flowcharting for ARC/INFO. NCGIA Technical Software Series S-92-2.

Lanter, D.P. (1993) Method and Means for Lineage Tracing of a Spatial Information and Processing and Database System. United States Office of Patents and Trademarks. U.S. Patent Number: 5,193,185.

A lineage information processor enables a user to obtain information concerning the various data layers in a spatial data base which contributed to any particular data layer of interest. The component software parses input commands and determines if those commands to the spatial data processing and information systems are valid. The lineage information processor also creates a knowledge representation of the spatial database comprising a meta-database consisting of a semantic network that describes the various data la;yers in the spatial database and the relationships among these layers. By means of a rule-based processing, the lineage information processor does not permit combinations of data layers that are incompatible, and creates commands that can alter incompatible data layers so that the layers can be combined in the desired fashion. A query capability is also provided that enables a user to query in a flexi ble fashion, the lienage information processor concerning the lineage of data layers in the spatial database.

Lanter, D.P. (1994) Comparison of Spatial Analytic Applications of GIS. In *Environmental Information Systems and Anlaysis*, Edited by W. Michener, Chapter 25.

Lineage metadata are an abstract representation of maps and logic used within a spatial analytic application of a GIS. This chapter details the structure of such metadata and presents a series of comparison tests useful for identifying commonalties in logic applied within GIS applications to explicated spatial relationships between cartographic features encoded within a set of source maps. Comparative analysis of lineage metadata across different GIS applications offers the possiblity of automatically detecting and isolating patters of spatial reasoning applied within GIS-based environmental models.

Lanter, D.P. and **Essinger, R.** (1991) User-centered graphical user interface design for GIS. Report 91-6, National Center for Geographic Information and Analysis, Santa Barbara CA.

The quality of the user interface has a great bearing on the utility of a geographic information system. The user interface, however, has not been a strong point of GIS. To increase the efficiency of GIS the user interface must provide a simple conceptual model of what is happening to the database. It must be easy to learn, appear natural, and be independent of implementation complexities such as data structures and algorithms. In order to do this, the user interface of the GIS should show itself to its user as a system, and not as various collections of data. This paper discusses how traditional user interface design focuses on how to best represent the software functionality rather than on how to meet the expectations of the user. User-Centered Design is offered

as an alternative that focuses on the two-way mapping between system functionality and the user's conceptual model of the system. Graphical user interface techniques are discussed as ways of creating the necessary two way mapping and facilitating the usability of GIS systems.

Mark, D.M. (1991) User interfaces for geographic information systems: Toward a research agenda. *Proceedings of the Eleventh Annual ESRI User Conference* 2: 525-530.

Recently, the National Center for Geographic Information and Analysis (NCGIA) announced a new Research Initiative on "User Interfaces for Geographic Information Systems." Initiative 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 research initiative has three broad goals: to investigate ways for people to interact with computers when solving problems concerning geographic space and spatial phenomena; to establish criteria and methods for the design of GIS user interfaces, and user interfaces for other geographic software; and to develop and test prototypes of GIS interfaces and interface development tools. A workshop in June 1991 will attempt to establish priorities for the research agenda on this topic. It is expected that the following factors will be important: users' geographic knowledge; users' computer skills; frequency of use; types of tasks and analysis procedures; cultural and linguistic factors; and individual differences. However, the relative priorities for these factors are largely unknown, and opinions of current users and system designers are solicited. This paper reviews some of the issues under four main headings: "Why do organizations use GISs?"; "Human-Computer Interaction"; "Who are the 'Users'?"; and "The Research Agenda."

Mark, D. M. (1992) Spatial Metaphors for Human-Computer Interaction. Proceedings, Fifth International Symposium on Spatial Data Handling, Charleston, South Carolina, v. 1, 104-112.

This paper first discusses defines metaphors and discusses their role as a fundamental process in human cognition and knowledge representation. Next, three kinds of spaces and spatial knowledge are discussed: haptic (based chiefly on touch), pictorial (based primarily on vision), and transperceptual (based on exploration and wayfinding experiences). It is proposed that these form a hierarchy, with the second and third set of concepts being understood in part by metaphorical extensions of the concepts that precede them. Next, major paradigms for human-computer interaction, in the form of user interface metaphors, are related to the above kinds of spatial metaphors for understanding the world itself. Lastly, the implications for these models for the design of user interfaces for geographic information systems are discussed.

Mark, D. M. (1993) Human spatial cognition. In Medyckyj-Scott, D., and Hearnshaw, H. M., editors, *Human Factors in Geographical Information Systems*, Belhaven Press, 51-60.

Human spatial cognition is fundamental to human life itself, in both obvious and subtle ways. The obvious way is that almost all of us move around each day, and must deal in real time with a wide range of geographic concepts, features, and hazards. Spatial concepts also are a basis for a great many metaphors that help us understand more abstract conceptual domains. In this paper I will concentrate on reviewing a variety of ways of categorizing and conceptualizing spatial concepts, especially geographical ones. Then I will comment on the implications for human-computer interaction involving geographical software.

Mark, D. M., and **Frank, A. U.**, editors. (1992) User Interfaces for Geographic Information Systems: Report on the Specialist Meeting. Santa Barbara, CA: National Center for Geographic Information and Analysis, Report 92-3.

The report contains a summary of the meeting and 35 position papers by Specialist Meeting participants, including 10 by NCGIA personnel.

Titles of Position Papers by NCGIA Personnel, with some abstracts:

Frank, A. U. (1992) Concepts That Determine the User Interface. Report 92-3, pp. 67-72.

Golledge, R. R. (1992) Position Paper for a Workshop On Gis User Interface. Report 92-3, pp. 75-77.

The author's primary purpose in coming to the meeting was to discover the state-of-the-art in both input and output user interfaces, beyond the typical graphic user display that traditionally dominates output and beyond the digitizer that usually dominates input. However, since navigation is likely to be an increasingly important user of GIS technology (land, sea, and air), I suggest that paying some attention to non-traditional interfaces may be a significant and worthwhile pursuit.

Gould, M. D. (1992) User Interfaces for GIS: Keeping Up with the HCI Community. Report 92-3, pp. 79-82.

Kuhn, W. (1992) Let metaphors overcome their *WIMP* Image!. Report 92-3, pp. 87-92.

Clearly, metaphors are important for the design and use of computer systems. It is still largely unclear and controversial, however, what exact role(s) they play. My position is that their role has largely been underestimated and misunderstood so far. Cognitive linguistics suggests an understanding of interface metaphors which is broader and deeper than the current view, which essentially treats metaphors as a matter of WIMPs

(windows, icons, menus and pointing devices). This paper is motivated by the observation that metaphors impact user interface design practice, but are virtually absent from design methodologies in general and for GIS in particular. There is a clear need for a better basis of theoretical and empirical work in this area. Section two of the paper is a rough sketch of a proposed new understanding of interface metaphors; section three lists some generic metaphors inherent in the design and use of computer systems; section four contains some input toward a research agenda on interface metaphors in GIS.

Kuhn, W., Willauer, L., Mark, D. M., and **Frank, A. U.** (1992) User Interfaces for Geographic Information Systems: Discussions at the Specialist Meeting. Report 92-3, pp. 1-38.

This report describes discussions at the Specialist Meeting of Research Initiative 13, "User Interfaces for GIS", of the U.S. National Center for Geographic Information and Analysis (NCGIA). The report contains many ideas throughout, and thus no summary or abstract could do justice to the contents of the Specialist Meeting. This paper is followed in the technical report by position papers by the workshop participants.

Lanter, D. P. (1992) Some Thoughts on User-Interface Design for GIS. Report 92-3, pp. 93-94.

Information, tasks and methods provided by a system interface will be more likely to be understood and learned if they fall into existing conceptual frameworks that the user has. If these are not readily available, conceptual frameworks will have to be invented that clearly communicate the functioning of the system to the user. The domain of GIS user interface design centers on the creation of specifications that express system capabilities throughout the system interface in ways that match, adapt, or create conceptual models held by the user.

Mark, D. M. (1992) User Interfaces for Geographic Information Systems. Report 92-3, pp. 109-110.

Geographic information systems (GISs) should provide users with a way to experience geographic phenomena, or solve geographic problems, in the office or the laboratory. When the user sits at a terminal and uses the GIS, he or she should be thinking about real-world phenomena, not about computers, or data structures, or GIS commands. This idea of human interaction, or communication, with a problem domain, rather than with a device. In this view, the computer becomes the medium, rather than a participant in an interaction. We need to reexamine Marshall McLuhan's work ("the medium is the message") in light of GIS interface issues.

McGranaghan, M. (1992) User Interfaces for GIS: Opinions, Observations, and Questions. Report 92-3, pp. 111-118.

Shapiro, S. C. (1992) User Interfaces for Geographic Information Systems. Report 92-3, pp. 153-154.

Smith, T. R. (1992) User Interfaces for Geographic Information Systems. Report 92-3, pp. 155-158.

Vora, P., and Helander, M. (1992) Incorporating Usability Measurement in System Design. Report 92-3, pp. 175-187.

Mark, D. M., Frank, A. U., Kuhn, W., McGranaghan, M. Willauer, L., and **Gould, M. D.** (1992) User Interfaces for Geographic Information Systems: A Research Agenda. *Proceedings, ASPRS/ACSM Annual Meeting*, Albuquerque, New Mexico, pp. 311-320.

This paper describes the National Center for Geographic Information and Analysis (NCGIA) Research Initiative on "User Interfaces for Geographic Information Systems". The initiative addresses 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 (workshop) for the initiative was held in June 1991 to set and prioritize a research agenda. The discussion concentrated on conceptual issues, and on needs for evaluation and testing. Several important themes for research were identified. Development of typologies of GIS tasks and of GIS users and use types were high priority elements of the research agenda. Spatial concepts are critical to the design of user interfaces for GIS; the issue of potential trade-offs between learnability and performance for experienced users is central; experimental testing is a critical part of the research agenda; agencies and other large organizations need guidelines on how to write product specifications for user interfaces. The paper provides details for these and other elements in the research agenda regarding "User Interfaces for Geographic Information Systems."

Mark, D. M., and **Freundschuh, S. M.**, (1995). Spatial Concepts and Cognitive Models for Geographic Information Use. In Nyerges, T., Mark, D., Egenhofer, M., and Laurini, R., editors *Cognitive Aspects of Human-Computer Interaction for Geographical Information Systems*, Dordrecht: Kluwer Academic Publishers.

McGranaghan, M. and **Volta, G.**, editors (1991) An annotated bibliography on human computer interaction for GIS. Report 91-15, National Center for Geographic Information and Analysis, Santa Barbara CA.

This document contains a collection of references gathered by the instructor and students in a course on human computer interfaces for GIS offered by the Surveying Engineering Department at the University of Maine in the Fall of 1990.

McMaster, R. B. and **Mark, D. M.** (1991) The design of a graphical user interface for knowledge acquisition in cartographic generalization. *Proceedings, GIS/LIS'91, Atlanta GA*, v. 1, pp. 311-320.

This paper presents a research project designed to elicit the procedural knowledge used in generalizing maps. The project is based on the development of a specific graphical user interface (GUI) for map generalization. Using a SUN SPARCstation, a user interface (designed under X-windows) is being developed. The basis for the user interface is a series of pull-down menus, each with a series of generalization operators, specific algorithms, and parameters. A component of the user interface also allows a user to select individual objects or entire areas of the map to be generalized. As a cartographer works with a plotted map image via the interface, a generalization "log" will be maintained. The log will record, for each feature, the application and sequencing of operators, along with specific tolerance values. Such knowledge will be used to determine how maps are generalized by evaluating the relationship between operators, parameters, and features.

Petersen, J. and **Kuhn, W.** (1991) Defining GIS data structures by sketching examples. *Proceedings, ACSM-ASPRS Annual Convention* 2: 261-269.

This paper presents an approach to modeling the data structures of a GIS by sketching simple but representative examples of objects and relations to be included in the GIS database. The objective is to collect information about the data structures needed in the GIS by potential users, and to provide this information as a knowledge base supporting the development of requirements for a GIS. From the process of sketching, object classes and relationships between objects are inferred and this approach is chosen to bridge the abstraction gap between the cartographic representation of a GIS user's view of reality and a formal representation of the database schema. Prior to implementation, the sketched examples together with the inferred database schema serve as a prototype of the GIS.

Richards, J. (1993) Interaction with Geographic Information Based on the Map-Overlay Metaphor, Master Thesis, University of Maine, Department of Surveying Engineering.

Many spatially aware professionals who could be using GIS technology for work in environmental sciences and design fields, are not doing so because they lack the computer expertise necessary to run a GIS. Many of these professionals use the manual process of map-overlay to perform tasks that could be done with a GIS. Likewise, many GISs use map-overlay as a command-line based interaction paradigm. The popularity and success of metaphor in other areas of human-computer interaction, and more recently in some GIS applications, suggests that visual, direct manipulation user-interfaces are especially attractive to non-computer experts. An interface to GIS that is a visualization of the map-overlay metaphor would enable experts in the spatially aware environmental sciences to more easily use GIS as a regular tool. This thesis presents two different visualizations of the map-overlay metaphor which utilize the separation of database query and presentation into components that can be independently accessed by the user.

The first visualization has two principle objects, data cubes and templates, which allow the user access to the two components. The second visualization has a single object, the layer, which allows for independent access to both components. In both visualizations, users stack objects on a viewing platform, which is much like a light table in map-overlay, in order to build views of database themes. The two visualizations are compared with a method that is an extension of task analysis, and it is shown that the layer visualization has a significantly less complex interaction than the cube and template visualization.

Richards, J., and **Egenhofer, M.,** (1994). A Comparison of Two Direct-Manipulation GIS User Interfaces for Map Overlay, (submitted for publication).

We have designed two different direct-manipulation user interfaces for Geographic Information Systems that are based on the map-overlay metaphor. In both interfaces, users explore geographic information by moving themes of spatial data onto a *viewing platform*, on which they can examine them in an integrated fashion. The first user interface separates the content of a theme and its graphical presentation into two different parts, referred to as the *data cube* and the *template*. Both parts are manipulated independently enabling users to view the same data in different ways by replacing one template with another. The second user interface combines the content of a theme and its presentation into a single representation, called a *layer*. For both user interfaces, iconic languages are introduced that resemble the manipulations on the Macintosh desktop. To compare the two visualizations of the user interfaces, we developed a quantitative model which measures the conceptual and operational complexities of a direct-manipulation user interface. This new method is based on the cognitive walkthrough analysis and considers (1) the number of concepts a user has to learn before performing a particular operation in the user interface; (2) the number of individual actions the user has to perform when executing a particular operation; and (3) the number of errors a user might run into when executing an operation. Applied to a set of most common tasks undertaken when manipulating geographic themes, the comparison reveals that the layer interface is less complex than the cube-and-template interface in all three categories.

Shapiro, S. C., Chalupsky, H. and Chou, H.-C., and **Mark, D. M.** (1992) Intelligent User Interfaces: Connecting Arc/INFO and SNACTor, a Semantic Network Based System for Planning Actions. *Proceedings of the Twelfth Annual ESRI User Conference*, v. 3, pp. 151-165.

This report describes an interface between ARC/INFO, a geographic information management system, and SNACTor, the SNePS acting component. It also shows a small example interaction that demonstrates how ARC/INFO and SNACTor can interact using the new interface, and how more sophisticated future applications can make use of its functionality. The interface was designed and implemented during a two-month research project carried out in Summer, 1990 at the State University of New York at Buffalo.

(Note: A version of this paper was published in 1991 as NCGIA Report 91-11, under the title "Connecting ARC/INFO and SNACTor," by Shapiro, S. C., Chalupsky, H. and Chou, H.-C.)

Sorensen, P.A. and **Lanter, D.P.** (1993) Two Algorithms for Determining Partial. Visibility and Reducing Data Structure Induced Error in Viewshed Analysis. *Photogrammetric Engineering and Remote Sensing*, Vol. 59. No. 7, pp. 1149- 1160.

In geographic information systems, viewshed analysis is used to caluculate the areas on a topographic map that can be seen from a specified set of locations. Grid cell ("raster") based viewshed routines typically create binary map results, in which each cell is listed as being entirely visible or entirely not visible. Prior research has shown that sampling errors in elevation data can reduce the accuracy of the resulting visibility maps. This study demonsrates that further errors may be introduced in binary viewshed maps by the geometry of the raster data structure itself. Two techniques are illustrated for reducing data structure induced error in viewshed analysis.

Volta, G. (1993) Interaction with Attribute Data in Geographic Information Systems: A Model for Categorical Coverages, Master Thesis, University of Maine, Department of Surveying Engineering.

The human-computer interface is a crucial element in the design of the next generation of Geographic Information Systems (GIS). In order to design and build intuitive GIS interfaces, a basic understanding of the underlying processes available within a GIS is essential. Formalization is a means to identify the necessary objects and operations to provide in a user interface. The design component must consist of identifying the processes, formalizing the related tasks, and applying the appropriate human-computer interface principles to those tasks. The categorical coverage is a type of map in which every unit of geographic space is mapped to exactly one value of a mutually exclusive and collectively exhaustive set of attribute values. This thesis examines the process of manipulating categorical coverage data in a GIS. A formal model is set forth to identify the pertinent operations such that they can be used as the basis for the interface prototypes. The characteristics of categorical coverage data and the user requirements for interacting with this data are presented. The principles of this design process result in a set of fundamental objects and operations which serve as the foundation for user interface implementation.

8.4 Other Publications Related to Initiative 13

8.4.1 Publications Previously Reported Under Initiative 2

"User Interfaces for GIS" (UIGIS) emerged as an important theme within Research Initiative 2, and several papers were published on this topic before I-13 was proposed and adopted. Some other UIGIS papers were published between December 1989 and August 1990, but acknowledged under Initiative 2. UIGIS papers listed in the Initiative 2 report include: Egenhofer (1989), Egenhofer (1990a), Egenhofer (1990b), Egenhofer (1991), Egenhofer (in press a), Egenhofer (in press b), Egenhofer and Frank (1990), Frank and Mark (1991), Gould (1989c), Gould and McGranaghan (1990), Jackson (1990), Kuhn (1990a), Kuhn (1990b), Kuhn and Frank (1990), Mark (1989b), and Mark, Gould, and Nunes (1989).

8.4.2 Additional Publications from Vienna by Former I-13 Personnel

Kuhn, W. (1992). Die Benutzerschnittstelle als Schlussel fur die Verwendbarkeit von geographischen Informationssystemen. In O. Gunther et. al: Umweltanwendungen Geographischer Informationssysteme, (pp. 217 - 221). Ulm, Deutschland.

Kuhn, W. (1993). User Interfaces for Cadastral Systems. In Proc. First Sharjah Conference on Geographic Information Systems and Applications (GISA 93), (pp. 1.1-1.9). Sharjah, U.A.E.: Sharjah Municipality.

Kuhn, W. (1993). Various Perspectives on Interface Metaphors. In J. Harts, H. F. L. Ottens, & H. J. Scholten (Ed.), EGIS'93, 1 (pp. 456-463). Genoa, Italy: EGIS Foundation, Utrecht, The Netherlands.

Kuhn, W. (1993). Was ein GIS lernen muss, um seine Benutzer zu bedienen. In N. Bartelme (Ed.), Grazer Geoinformatiktage '93. Graz, Austria: TU Graz.

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Cognitive Aspects of Human-Computer Interaction for Geographic Information Systems

NATO Advanced Research Workshop (ARW)
Palma de Mallorca, Spain
March 21-25, 1994

FINAL PROGRAM

ARW Objective:

Our ability to enhance an individual's use of a Geographic Information System (GIS) stems in large part from a better understanding of issues concerning human-computer interaction (HCI). The objective of the ARW is to foster an international synthesis of current research findings on cognitive aspects of HCI for GIS. This is a central issue concerning an individual's use of a GIS. The ARW will help clarify and stimulate research directions on the cognitive aspects of HCI for GIS and other issues related directly to this topic.

Organizers:
Timothy Nyerges (Director), Univ of Washington, USA
David Mark (Co-Director), State Univ of New York at Buffalo, USA
Robert Laurini, Universite Claude Bernard Lyon I, France
Max Egenhofer, University of Maine, USA
Maurici Ruiz, Universitat de les Iles Balears, Spain

March 21, 1994 - Theoretical Underpinnings of GIS and HCI
a.m.: Perspectives from GIS and HCI
- Welcome, Objectives, Introductions, Administration, Program Overview: Timothy Nyerges
- An Overview of HCI for GIS: Andrew Turk
- HCI Issues for GIS Research - North American Perspective: David Mark
- HCI Issues for GIS Research - European Perspective: Robert Laurini
- Technological Prospects for and Constraints on HCI: John Sibert
- Spatial Primitives: Reginald Golledge
- An Introduction to Cognitive Modeling in Human-Computer Interaction: Andrew Howes
Discussants: from the speaker list

p.m.: Basic Cognitive Issues in HCI and GIS
- Spatial Concepts and Cognitive Models for Geographic Information Use: David Mark
- Paradigms and Metaphors for GIS Use: Werner Kuhn
- Cognitive Issues in the Evolution of GIS User Knowledge: Timothy Nyerges
- Cultural Aspects and Cultural Differences in GIS: Irene Campari
- HCI Aspects of a Framework for the Qualitative Representation of Space:

Daniel Hernandez
Discussants: from the speaker list

March 22, 1994 - Cognitive Issues, GIS Tasks and HCI
a.m.: The Nature of Cognitive and GIS Tasks
- The Significance of Task Abstraction for HCI: Jens Rasmussen
- Task and Task Descriptions for GIS - Clare Davies
- Cognitive Task Performance When Using a Spatial Decision Support System for Groups: Timothy Nyerges
- Towards Visual Interfaces for Multi-Source Integration of Geographic Information: Robert Laurini
- A Concpetual Framework for Improving HCI in Locational Decision-Making: Marc Armstrong and Paul Densham
- Some Aspects of Hypermaps: Francoise Milleret-Raffort
Discussants: from the speaker list

p.m.: Research Issues Discussion

Group discussion of both solved and unsolved research issues plus barriers to research concerning Cognitive Aspects of HCI for GIS. Suggested focus on task taxonomy, task abstraction, error in tasks, tasks complexity/structure/content.

March 23, 1994 - User Interface Considerations
a.m.: HCI Considerations for Selected User Interface Designs
- Mallorca Litoral Landscape Taxonomy as a Tool to Assess Local Planning: Maurici Ruiz
- Geographic Interaction in a City Planning Context: Beyond Multimedia Prototype: Michael Shiffer
- HCI Considerations for Terrain Visualization: Marinos Kavouras
- HCI Considerations for Visual Interactive Locational Anlaysis: Paul Densham and Marc Armstrong
- Spatial Query by Sketch: Max Egenhofer
- Virtual Worlds for GIS: Worlds within Worlds: Robert Jacobson
Discussants - from the speaker list

p.m.: Research Issues Discussion
- Geographic Information Systems: Work Analysis and System Design: Jens Rasmussen

Group discussion of both solved and unsolved research issues plus barriers to research concerning Cognitive Aspects of HCI for GIS. Suggested focus on cognitive tasks and styles of user interfaces.

March 24, 1994 - Research Strategies for Cognitive Aspects of HCI
a.m.: Usability Studies, Task Analysis and Experimental Designs
- Algebraic Methods Applied to GIS User Interfaces: Werner Kuhn
- Analysis of Users' Information Requirements: Parallels from Medical Monitoring: Graham Higgins

- Feet on the Ground: User-GIS Interaction in the Workplace: Clare Davies and David Medyckyj-Scott
- Cognitive Ergonomics Analysis Methodology: Andrew Turk
- Process Tracing Methods in the Decision Sciences: A Comparison and Review of Methods: Peter Todd
- Low Resolution Task Analysis for Cartographic Query Language Design: Michael Gould

Discussants - from the speaker list

p.m.: Research Issues Discussion

Group discussion of both solved and unsolved research issues plus barriers to research concerning Cognitive Aspects of HCI for GIS. Suggested focus on research strategies including, but not limited to surveys, case studies and, experimental designs.

March 25, 1994 - A Research Agenda for Cognitive Aspects of HCI for GIS
a.m.: Structuring a Synthesis
Synthesis of the research directions while considering all issues and barriers to research on Cognitive Aspects of HCI for GIS identified in the previous four days.

Closing Remarks

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