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**USER INTERFACES FOR GEOGRAPHIC INFORMATION
SYSTEMS:
REPORT ON THE SPECIALIST MEETING**

Edited by
David M. Mark and Andrew U. Frank

National Center for Geographic Information and Analysis
Report 92-3

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Preface and Acknowledgments

In this technical report we summarize the discussions from the Specialist Meeting for Research Initiative 13, "User Interfaces for Geographic Information Systems". The goal of the meeting was a free exchange of ideas about the current research needs between researchers interested in GIS user interface design. The success of the meeting is primarily due to the unselfish sharing of experiences and knowledge among the participants (listed in Appendix A). Position papers and numerous other extensive contributions were made, and this report shows, where practical, the names of contributors and rapporteurs from group meetings. It has not been possible, however, to attribute every idea to a person, and many ideas were certainly the product of contributions from different sources. We thank all participants for their willingness to venture explanations, report on experience, and to do other things that made this endeavor a success.

The main goal of this report is to make the results of the discussion available to other researchers. The report follows closely the activities of the meeting, but we regrouped some of the discussions in a topical manner to help readers who were not present at the meeting grasp the ideas in a more coherent fashion. The report then presents the majority of the Position Papers for the meeting, most of which were circulated to the participants before the workshop. A few were revised after the meeting, but all were last revised in the period from June to August of 1991.

We wish to thank all the participants in the 1- 13 Specialist Meeting (see Appendix) for their input to the agenda; special thanks are due to those who led discussion groups during the meeting. Some of the material in this report was included in "User Interfaces for Geographic Information Systems: A Research Agenda," by David M. Mark, Andrew U. Frank, Werner Kuhn, Matthew McGranaghan, Langley Willauer, and Michael D. Gould, which appeared in the Proceedings of the 1992 Annual Meeting of the American Congress on Surveying and Mapping. The assistance of a few graduate students during the meeting was extremely helpful, in particular Langley Willauer's organizing of the written notes after the meeting. Local arrangements and technical support by Connie Holoman and others in the Buffalo office of NCGIA were crucial for the smooth proceeding of the discussions. We thank all who contributed!

This paper is a part of Research Initiative #13, "User Interfaces for GIS", of the National Center for Geographic Information and Analysis, supported by a grant from the National Science Foundation (SES-88-10917); support by NSF is gratefully acknowledged.

EXECUTIVE SUMMARY

This report describes the Specialist Meeting of 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." The report also contains 35 position papers that were circulated to the participants before or during the meeting.

USER INTERFACES FOR GEOGRAPHIC INFORMATION SYSTEMS: DISCUSSIONS AT THE SPECIALIST MEETING

compiled and edited by

Werner Kuhn¹, Langley Willauer², David M. Mark³, and Andrew U. Frank⁴

National Center for Geographic Information and Analysis

1. Introduction

"Are users really necessary?"

Selected as the quote of day 3 of the meeting

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). As participant Will Craig of the University of Minnesota pointed out in commenting on a draft version of this report, the report contains many ideas throughout, and thus no summary or abstract could do justice to the contents of the Specialist Meeting. Thus we advise against skipping to the summary, and instead suggest that those who cannot read the document word-by-word should skim through the entire document to get an impression of the topics covered.

The problem of Human-Computer Interaction (HCI) for Geographic Information Systems (GIS) has been noted in the GIS literature (see especially Porter, 1986; Gould, 1989; and Mark and Gould, 1991), but has recently been highlighted by the NCGIA. 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 HCI community. Fifteen participants had attended at least one earlier NCGIA Specialist Meeting; also, 12 participants were from the private and public sectors, and 29 were university-based researchers. Eight of the official participants were graduate students, five from outside the NCGIA. The participant list, with affiliations, is included as an Appendix to this report.

The Specialist Meeting began with a half day on the campus of SUNY at Buffalo. Following introductory remarks and background information, the participants spent several hours in the Geographic Information and Analysis Laboratory (GIAL) viewing software demonstrations, mainly by participants. The remainder of the workshop was held at a conference center in Chautauqua County, New York, about 90 miles from Buffalo.

The meeting alternated between working group sessions and plenary sessions. The working group sessions provided opportunities for focussed discussions on narrowly-constrained topics by 6 to 10 self-selected participants. In the plenary sessions, representatives of the working groups presented summaries of the groups' discussions and findings to the entire group. On the final day, working groups defined an agenda of researchable questions on a six-month to two-year time scale. Longer term research issues were raised and recorded, but mainly to provide further perspective.

David Mark and Andrew Frank, the Co-Leaders of Initiative 13, opened the meeting. Frank indicated that it was inappropriate to start with a discussion defining a GIS as most of the participants had extensive experience in the area. The demonstration of actual geographic information systems can serve as a pragmatic replacement for a concise definition.

Why is the discussion about user interfaces for GIS timely? Fifteen years ago, producing maps with computers and computing overlays was a major achievement. Now this can be done routinely. However, in the past the question of how these systems would be used was rarely addressed; it was enough just to be able to do these tasks and some rudimentary spatial analysis. The general attitude was one of 'miraculous computers' and dumb users-and users were inhibited from admitting problems and errors. Now the frontier is being pushed back, and convenience for the user is becoming most important. The cost of educating users in the use of a new system is currently estimated to be of the same order of magnitude as the acquisition of hardware and software. The rapid growth of system functionalities, as

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well as the growth in the numbers of users and the variety of user communities, means that usability concerns become primary. The user is now the most important consideration in system design. Recently, one company responded to this situation by doubling the size of its software's user manuals-this does not seem to be optimal progress towards better usability of GIS! Instead, it clearly shows that a usability problem exists today. Systems often do not perform the functions the users really want, and the users do not know how to translate their needs into operations the system can execute. Systems should generally be designed by first asking what the interface should be, then building a system to support it, not vice versa. The position papers for this meeting approached the issues from a high level perspective, and left the details for later. This is exactly as it should be and we hope that the resulting research will start at this high level and work backward to the details.

David Mark commented that there were still many unsolved technical issues, but that the usability issues are now highlighted. At the May 1991 Environmental Systems Research Institute (ESRI) User Conference in Palm Springs, consumer advocate Ralph Nader gave a keynote address on public access to information. It is of little use if a government agency or large corporation complies with "access to information" regulations by supplying the citizen with a digital data tape in a proprietary format. To meet the spirit of "access to information" regulations, organizations will need to deliver easy-to-use software to allow 'citizen-scientist' end users easy access to the information. Nader suggested that usable GIS could play a key role in providing information to the public. But this can only be achieved if the GIS user interface can communicate with a lay person, rather than requiring months or even years of professional training.

1.1. Expectations for this Workshop

Frank briefly stated his expectations for this Specialist Meeting. From an engineering perspective one would wish for directly applicable rules and guidelines that lead to usable interfaces. Enormous progress in user interface design was made when Apple Computer Corporation published its guidelines for the Macintosh Interface (Apple Computer 1987). The guidelines defined a consistent style for a user interface, independent of a specific application, and allowed users to transfer knowledge acquired with the use of one program to others, thus shortening learning and improving usability. Could we produce similar guidelines for GIS user interfaces, which could be applied across application areas, platforms and products?

A number of specific questions are related to the results from research in spatial concepts (Mark and Frank 1989; Mark et al. 1989; Mark and Frank 1991):

1. How do spatial concepts influence the usability of GIS?
2. How does the fact that GISs have predominantly been developed by 'first world' speakers of Germanic languages influence usability by people from other language groups and cultures? Are there aspects of the way certain products handle space that makes them difficult to use in some cultures, e.g., in southern Europe?
3. There are at least four classes of GIS users. Novice users want an intuitive, easy-to-learn system; casual users normally cannot remember arcane commands; expert users may have no interest in computers; and system designers are often not familiar enough with actual use situations. What are the different interface issues for these four groups?
4. What paradigms do we use in design? Is the concept of "virtual reality" influencing GIS interface design?
5. What channels should we use for interaction? Should bad data smell like bad cheese? Can we multiplex data through several channels?

A common question underlying all these concerns is what is special about spatial data? This should be the basis for I-13 research, and discussions about general user interface issues should be limited to cases where there is a need from a GIS perspective. At a workshop on "User Interfaces for GIS" at CHI '91 in New Orleans, Brad vander Zanden raised that issue by asking if and how spatial data were different from other data. To us, it seems that both the data and the tasks are different, but it proves quite difficult to pin down exactly what the differences are. Certainly there are GIS-specific user interface issues in vehicle navigation systems, in navigation systems for the visually impaired, and in a wide range of other areas. But it is not clear whether a large proportion of general GIS tasks also occur in other disciplines.

Frank concluded the opening session by saying that GIS tends to uncover demands on information systems long before mainstream applications discover them. This happened in the early 1980s with database systems and is now also happening with user interfaces. The results from this research initiative will have applications beyond GIS. The role of spatial cognition as a source of metaphors for abstract reasoning is so pervasive, that issues discussed at this meeting will have applications to non-spatial information processing as well.

1.2. Previous User-Interface-Related Activities at NCGIA

Other NCGIA research initiatives have been dealing with questions related to human-computer interaction and user interfaces. As the initiatives have been designed to follow in a sequence where later ones build on previous ones, a brief review of some of the previous initiatives is appropriate.

1.2.1. Initiative 2, "Languages of Spatial Relations."

This Initiative covered questions about formal descriptions of space, and how people think and communicate about space. At the I-2 Specialist Meeting, the distinctions and relationships between spatial concepts, spatial data models, and spatial data structures were clarified. Results from I-2 were presented and discussed at a NATO Advanced Study Institute on "Cognitive and Linguistic Aspects of Geographic Space." A book from that institute has been published (Mark and Frank, 1991), and includes five papers that specifically address user interface issues. The findings of I-2 are especially important for user interface design issues in GIS. GIS user interfaces revolve around the users concepts of space and spatial objects, and it is critical that the system deal with space in a way that the user can relate to.

1.2.2. Initiative 3, "Multiple Representations."

Initiative 3 dealt with questions arising from the need to have multiple representations of space (e.g., space at different resolutions) in one system. I-3 has specifically addressed cartographic generalization problems (McMaster and Buttenfield, 1991). Multiple representations, both in databases and at the user interface, are crucial for effective human-computer interaction.

1.2.3. Initiative 4, "Use and Value of Geographic Information in Decision Making."

Although I-4 did not specifically address Human Computer Interface (HCI) issues, it relates to Initiative 13 covering topics of public access to Geographic Information Systems. The major tenet is that geographic information is only as valuable as it is usable, thus the user interface is relevant, as it is a precondition for the effective use of the data collected (Onsrud et al. 1989).

1.2.4. Initiative 5, "Architecture of Very Large Spatial Databases."

A relevant outcome from Initiative 5 was that user interface issues received more attention than expected. The discussion repeatedly focused on how to make the user aware of what data are in a database, and how they can be accessed (G nther and Buchmann 1990; Smith and Frank 1989). (This was also a central topic in Initiative 12 on Remote Sensing and GIS.)

1.2.5. Initiative 6, "Spatial Decision Support Systems."

User interfaces are also a critical part of SDSSs. The quality and timeliness of spatial decision making are a direct function of the adequacy of user interfaces for these systems. Spatial Decision Support Systems are by their very nature highly interactive (Densham and Goodchild 1990).

1.2.6. Initiative 12, "Remote Sensing and GIS."

Access to large databases on satellite images, especially browsing, was also identified as a central topic in Initiative 12.

1.2.7. Initiative 7, "Visualizing the Quality of Spatial Information."

Initiative 7 conducted its specialist meeting about two weeks before initiative 13. Initiative 7 is treating a specific human-computer interaction problem in depth: that of how to communicate quality aspects of spatial data to their users. The topic has practical implications-in a recent book (Monmonier 1991) it was noted that people have been lying with maps better and longer than they have been lying with statistics (Beard and Buttenfield 1991).

1.2.8. Initiative 13 Workshops and Panel Discussions

The way for Initiative 13 was also prepared by several special sessions at professional meetings in 1990 and 1991. These included a workshop at CHI '90 on Visual Interfaces to Geometry (Kuhn and Egenhofer, 1991), a Special Interest Group on GIS User Interfaces at CHI '91 (conducted by Kuhn and Mark), two panel sessions at the 1991 annual meeting of the Association of American Geographers (organized by McGranaghan and Mark), and a panel discussion at the 1991 ESRI User Conference (organized by Gould and Mark).

1.3. Software Demonstrations

In order to provide some concrete examples of existing GIS user interfaces, there were five software demonstrations at the SUNY-Buffalo Geographic Information and Analysis Lab (GIAL). These were especially impressive in that in no case was the software running at Buffalo before the workshop.

- Kurt Buehler presented a direct manipulation user interface for the GRASS GIS product. In this case, a Sun hard disk loaded with the program and data was shipped to Buffalo; it was attached to a Sun in the GIAL, and the Sun was re-booted from the disk.
- Joe Ferreira showed an Urban Planning System that can be run over a network. (The demonstration was actually running on a Sun back at MIT, some 600 km away.)
- Jeff Jackson demonstrated ArcView, a new ESRI software product for interacting with ARC/INFO databases. Jackson brought a Sun CPU as carry-on baggage; the GIAL provided the keyboard and monitor.
- Bruce MacDougall presented an operational prototype for exploration of spatial data on the Macintosh through statistical visualization and dynamic graphics
- Jonathan Raper gave a demo of HyperArc, a HyperCard program running on his Macintosh portable, that provides a front-end for ARC/INFO running on a host machine (in this case, a VAX at SUNY Buffalo).

1.3.1. Short Presentations of Specific Projects

Three short presentations of specific projects were made Monday afternoon:

Ostberg introduced MITI's FRIEND 21 Project from Japan. It is based on a generic television metaphor, allowing users to choose their favorite TV show as a metaphor source for application tasks. There is an anchorman in the lower right corner of the display who acts as a liaison between the user and the internal model (Nonogaki and Ueda 1991). Part of the project is building a Japanese standard for user interfaces.

Two video presentations were shown. Shapiro presented CUBRICON, a natural language, map-based, multi-media system developed at SUNY Buffalo (Neal et al., 1989; Neal and Shapiro, 1991). The second video, presented by Steve Smyth, was a demonstration of a virtual reality combat simulator.

2. Structuring GIS Tasks

Sunday afternoon and most of Monday were devoted to discussion of GIS tasks. One of the major results from the meeting was the recognition of an urgent need for a classification of GIS tasks. It was observed that many of the decisions during the design of a GIS interface were strongly influenced by the task the user wants to perform.

2.1. GIS Tasks in Different Application Areas

Frank started the late Sunday session with the question "What is special about spatial data?" He asked the participants to focus on tasks that are specific to GIS and to spatial data-handling. The participants were to break out into four smaller groups to collect and discuss such tasks. The result of the sessions would be small lists of user-level tasks that are typical for this application area. These could then be used by human factors specialists and others as guidelines for research.

Martin Helander provided some background for the session. People who work in human factors typically test users in real work situations. This is done by

- collecting performance data,
- thinking about the tasks, and

- studying errors people make.

In general, one differentiates between strongly structured and unstructured tasks. A common strategy is to break down tasks into levels of abstraction. It proceeds from abstract functions to the physical functions and their form. The HCI community has not yet studied GIS tasks.

Frank's intent for the group sessions was to look at abstract functions that people perform. Three examples are overlay, pan and zoom, and finding a place on a map. He suggested that each group attempt to come up with 6 to 12 tasks. The goal of this exercise was to define questions for the HCI community and others.

Several participants raised questions about the exact meaning of this task notion. The definitions of goal, task, and function were brought up (Raper and Bundock 1991). Is a functional taxonomy of GIS capability needed? If the function set for GIS is stable, should the focus be on user's needs (Lanter and Essinger 1991)? Should tasks be discussed at a higher level? Does the user really want to do "pan and zoom" or is this notion only an artifact of today's systems? Turk suggested that the appropriate task taxonomy dimensions, hierarchy and granularity may be determined by the chosen HCI theoretic model and task analysis procedure.

2.1.1. "Planning and planning-like applications," reported by Will Craig

What are the tasks in planning and planning-like applications? There are many ways to look at this issue. The first problem is to decide whether to consider Planners with a capital 'P' (that is, professional planners), or planners with a lower case 'p' (that is, anyone who makes plans). The former were chosen.

There are certain routine planning tasks that are easy to implement today; "someone just needs to write the AMLs¹". For example,

1. Determining whether a given building permit application was in conformance with zoning;
2. Creating a mailing list for a notice to be sent to adjacent land owners;
3. 'Cook book' planning tasks such as environmental impact analysis, e.g., collecting data, organizing it, and presenting it according to stated rules;

Other tasks are non-routine. For example, exploratory analysis and design; identifying emerging problems; allocation of space to a 'locally unwanted land-use', e.g., a jail. They involve, however, a few general steps that may be identified as typical tasks for professional planners. Each of them can or could be helped by a GIS:

1. Exploring available data (planners often have no data collections of their own; therefore it makes sense for them to tie into available data).
2. Extracting and transforming those data. Data are not usually in the right form; therefore they need to be reworked, summarized, etc. Examples include address matching and aggregation.
3. Discovering solutions. This is usually done with diagrams, pencil and paper. Frequently, there are multiple iterations. One idea is to start with a solution and see how a GIS could have supported it.
4. Generating high quality maps and diagrams. This is an education and persuasion task; the results must be communicated to an audience.

2.1.2. "A Natural Resources Environment," reported by Dana Tomlin

What are the tasks in a natural resources environment? The group identified five "players" in the process of resource management. Listed in order of increasing problem difficulty, they are the scientist, the engineer, the warden/manager/person-in-the-field, the politician, and the public. For each player, the group determined what GIS technology could do for them and what qualities of the users are important.

The scientist is the repository for multiple representations of data, and her task is primarily to create models of processes. They are generally based on smooth space-time transitions.

The engineer does not just need to know about processes, but has to act on this knowledge and make decisions. He tries to use data that the scientist has collected for design work. In his design, he must consider both that the data are uncertain (and therefore there is some risk), and that the implementer would not necessarily do a good job.

The warden is in the field on a day to day basis. She is confronted with (and has to reconcile) discrepancies between the database and the real world. (Wouldn't it be nice if this person were able to correct the database in the field?) An idea of Nick Chrisman's from the Initiative 7 meeting was mentioned here: If wardens were given small head-mounted displays, which would overlay the GIS data and their field of view, they could see both 'reality' and 'GIS' and immediately fix discrepancies, perhaps using a 'virtual reality' mode of interaction-just 'grabbing and moving' the pipes (in the GIS) to make them conform to reality.

¹ AML is the "ARC Macro Language" within ARC/INFO.

Since the politician is a policy maker, he has to reconcile differences between supply and demand, relying on data from the technical community. He poses a problem to the engineer and then has to account for any differences to the public. There is also a connection with the warden in an administrative role.

The public (as client and landowner-citizen) wants information and needs appropriate visualizations and plans. It usually acts in groups and needs to be able to use the technology to state its case. This is difficult because emotional connections of certain groups to particular spaces and phenomena in space cannot (yet) be accommodated in a GIS. The public interacts mostly with the warden and the politician, rarely with the engineer or the scientist.

Tomlin felt that these players were a necessary and sufficient group for looking at tasks. Others (Turk, Ostberg) questioned whether the operators and assistants who actually use systems for these players should not have been included. One might even add the software developers, as another group of "indirect" players.

The connections between players are not linear. A GIS serves as a link not only between data and players, but also between different players. The process models are as much a part of the GIS as data are and must be linked. It is especially important with naive users that the data "speak for themselves." A problem with realistic models and representations is that they often appear to be of higher quality than they are. Also, many important phenomena are fuzzy. In soils, the transition from gravel to loam is not a sharp line, but an engineer builds structures that have sharp lines. These inherent discrepancies must be accounted for.

Some participants held that interfaces should stimulate the public. One cannot present information without giving a viewpoint. The animations in the GISTutor tell a story, and therefore capture attention; however, whether the public actually gets information from such techniques is another question to be answered from the HCI literature or from experimentation. Golledge asked whether the public generally understands the information it is supposed to get. A research question is how much and what kind of information people actually acquire from the presentations they receive. This also raises the possibility of yet another important player in this scenario-the press, who often provide most members of the public with their only link to the scientists, engineers, and politicians.

2.1.3. "Spatial Decision Support Systems," reported by Marc Armstrong

What are the tasks in Spatial Decision Support Systems (SDSS)? In order to overcome the imprecision in the understanding of 'task' and a large group, the SDSS group decided to use example problems.

Most SDSS tasks fit in with Helander's category of ill-defined and unstructured problems. It is difficult to determine a well-defined set of steps to solve them. For example, take a location analysis problem. Do you build two or three fire stations to optimize various fire response variables? The factors to take into account may vary from town to town.

The first example problem was where to locate cellular telephone transmission towers, how to orient antennas, what power to give them, and how to design and model the network for optimum performance. As mobile telephones are concentrated in areas of high traffic volume, this is a dynamic problem. Inputs are a radio propagation model and actual ground measurements of signal strength. The modelers need to ask questions like how high to make antennas, how big to make coverage areas (cells), and how much volume a given cell can handle. System users for this problem are process engineers who develop models of expected system behavior, planning engineers who actually place the tower, and customer service personnel, who field complaints from users. Three categories of these users were considered: naive users; applications people or "SAPPies"¹; and system designers. In addition, these users would need to work together. In Computer-Supported Cooperative Work (CSCW), the goals and objectives of various users are taken into consideration. Specific sub-tasks were identified: identify demand/supply locations; locate antenna site; and allocate area to point.

The discussion moved to combining different functions, algorithms, etc. to form new functions. There is a need to accumulate analytical functions into tools. One could use a model-based management system to do this.

Buehler introduced the example problem of designing an Army Training Task: Design a system to assist in planning optimal training procedures, given a certain area, weather conditions, training requirements (e.g., amount of realism needed), environmental impact guidelines, safety boundaries for artillery, and other conflicting uses. Specific tasks would be

- allocate an area to a point
- evaluate a training plan
- identify demand for points of use
- specify a candidate location

¹ Spatially Aware Professionals-this term was introduced by Jonathan Raper and his Birkbeck colleagues in several papers on user interfaces for GIS.

- display maps which show results of model
- determine a study area

Lanter then described a system to plan wood cutting he had worked on for the U. S. Forest Service. The system replaced a printed data report generated by a model in the MIS department. The report would indicate how much wood to cut, but the model was inaccurate. Lanter's system took the printed data and displayed it in color, and then applied two models:

1. show result of spreading damage over all compartments
2. reduce cut to sustainable levels for all compartments

Specific tasks would be

- determine what model was used to support a decision (audit trail)
- find an optimal answer.

Turk stated that user-system interactions at this level are too complex for existing task analysis procedures. For instance, the 'levels of cognitive control' approach requires that general process objectives be decomposed to particular cognitive tasks. It is based on Rasmussen's theory of levels of cognitive control (Rasmussen and Jensen, 1974; Rasmussen, 1986) which is not easy to apply. In particular, we often do not know what mode of cognitive control we are dealing with. McMaster compared this with GOMS analysis (Card et al. 1980). There are only very limited parts of a well defined, strongly structured task that are analyzed in great detail. GIS as a whole must first be broken into smaller, more homogeneous pieces.

2.1.4. "Remote Sensing and Image Processing Applications," reported by Jeff Jackson

What are the Remote Sensing and Image Processing tasks? The most general task is to derive models of the world. However, the user's model and the system model are particularly far apart in image processing applications, one being for example land use categories, the other being the signal strength observed in different wavelength bands. The two models need to be brought closer together; ultimately, the system model should disappear.

Users want to transform data into information, i.e. into something which answers questions they have. They need to know:

- what data there are
- where it is in the world
- how it relates to other data.

Like planning tasks, determining what data are available is a problem in organization management and categorization of data, lineage, metadata, etc. Many of the basic operations in image processing are well understood, but it is not clear how to present them in a comprehensive manner to the user. The problem is aggravated in remote sensing by the huge data volumes. Ellis pointed out that handling these very large data sets poses technical problems, which limit the freedom to design user interfaces from a conceptual level. The following problems are posed in particular:

- How does one present the location of data to the user in an easily-understood way?
- How does one set of data relate to another?
- Is looking for correlations a task that is typical for GIS?

2.2. HCI Theories for Task Analysis (Monday Afternoon)

2.2.1. Cognitive Task Analysis

Martin Helander began the afternoon session by giving a presentation on cognitive task analysis.

Following the methods advocated by Jens Rasmussen, there are three categories of human behavior that are relevant for modeling the cognitive processing involved in performing tasks. The first level is skill-based behavior, in which tasks are performed automatically, with no conscious information processing, e.g., braking an automobile. The next level is rule-based behavior, where one goes through a set of steps to determine action. If the foot brake fails, one has to step to the next means of stopping the car, namely the emergency brake. Finally, knowledge-based behavior relies on the development of complex patterns that must be interpreted and applied in a given situation. It involves reflection, optimization, etc. If the emergency brake fails, one must steer the car appropriately, shift down, and apply judgments based on one's learned understanding of automobile physics.

The level of cognitive control adopted by the operator may be influenced by the context (creativity, knowledge, available rules, acquired skills, naive reasoning patterns). For example, for operators trained in digitizing,

closing a line is a task at a skill-based level in general (done without thinking), but it becomes a task at the knowledge-based level, if something goes wrong (e.g., if there is not enough disk space to store the next point). Further, knowledge-based situations arise when the situation is unfamiliar and previously learned rules do not apply.

Rasmussen was concerned with systems for controlling nuclear power plants. In those kinds of environments, one strives to avoid knowledge-based tasks for operators. One technique used in controlling such complex processes is mapping complex sets of variables about processes to a simple display. This can make knowledge-based operations become rule-based. There is a general need to support changes in task levels. Understanding tasks in GIS within a Rasmussenian framework is a promising research direction.

Design can be approached top-down or bottom-up. Top-down design is simpler, because it can be based on rules. Bottom-up design is rather knowledge based, because the problem fans out as one proceeds. An example of a top down design approach is shown below.

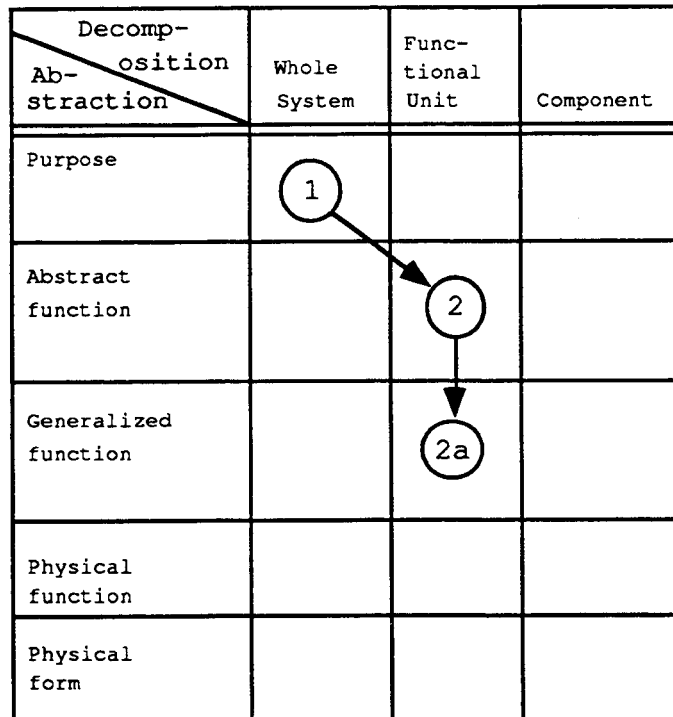


Figure 1: Diagram of steps followed in a typical design process.

Rasmussen uses diagrams to analyze the effectiveness of a design. Figure 1 shows how an interface designer works with different levels of a system, as well as at different levels of abstraction.

Turk has related these levels to Heidegger's modes of engagement (Heidegger 1962), in order to supply emotional aspects to cognitive modeling (see Turk 1990):

Level/mode 1 Theory (knowledge based or 'present-at-hand')

Level/mode 2 Principles (rule based or 'unready-to-hand')

Level/mode 3 Automated (skill based or 'ready-to-hand')

For example, when one uses a hammer, one is not conscious that the hammer is separate from oneself. (However, if one misses the nail and hits one's thumb, it is present-at-hand!) A computer's mouse can be viewed in the same way. Sarah Douglas questioned the second level, which is motivated by Rasmussen's schema, but not present in Heidegger. Gould suggested air traffic control as a GIS-related application area that has been studied extensively, and which is close enough to the domains studied by Rasmussen.

2.2.2. GOMS and Key-stroke Level Models

Douglas gave an introduction to GOMS and key-stroke level models.

GOMS is one of the predominant models resulting from HCI research. The acronym stands for Goals, Operators, Methods, and Selection rules. It has been applied to, among other domains, industrial engineering. Alan Newell did early work in this field and Card, Moran, and Newell (1983) is the original work on GOMS. In that book, a CAD/CAM system was analyzed. The methods work well for task analysis of skill-based behavior, but start to fall apart as the tasks are at higher, non-procedural levels. Newell was interested in mental activity during problem solving—a mental space formed by all perceived solutions. He started by studying puzzle spaces, then moved to more complicated examples.

Problem solving is finding a sequence of operators that accomplish a task. To do this, it may be necessary to use trial and error. There is a continuum between procedural and knowledge-based activities:

procedures	<----->	problem solving
routine	<----->	creativity
goals	<----->	goals
operators (certain)	<----->	operators (uncertain)
methods (sequences of operators)	<----->	selection rules (heuristics)

All human behavior can be said to be goal directed—therefore GOMS starts with goals. Establishing a goal is also important in being able to measure when a task has been completed. A GOMS analysis allows a task to be broken down into arbitrarily small pieces. Goals can be described as actions or as states to be achieved. In the end, the goals actually fall out, and sequences of operators are left.

To provide a concrete example, Douglas then applied the method to the task of displaying an image.

GOAL: Display an image

Sub goal: select image from the group of available images

Sub sub goal: Select a menu

operator: locate menu, move cursor, click

Sub sub goal: Select a specific file from a menu

operator: locate file we want, move cursor, click

Sub goal: view the image

GOMS does provide a way to look at particular, well-defined tasks. In particular, GOMS has been used to study text editing. It is important to note that GOMS does not (yet) work for the creative, problem solving stage. It assumes trained operators; the idea is to attach times to the operations, in order to optimize an interface for expert users. It is assumed that the operators are trained to the level that they make no mistakes.

GOMS implies a very detailed analysis and can be used at different levels of subdivision of a task. In practice, keystroke modeling is most often used. The keystroke model analyzes a task at the level of individual keystrokes (or comparable, small activities). It is a predictive model for the performance of highly trained users, achieving an explanation of between 80 and 85 % of observed behavior. It follows the tradition of MTM (motion time measurement) studies and is based on elementary, observable operators (or events) and measurements of the time they require:

<u>Event</u>	<u>Time (seconds)</u>
Keying	0.2
Pointing	1.4
Mental operation	1.8
Homing ¹	...
Drawing Line	...

The total time of interaction is equal to the human performance time plus the system response time, usually assumed to be instantaneous. As an example, consider a simple line-drawing task in a paint program:

select draw icon, draw line segment

mental operation

¹ "Homing" is the HCI term for moving one's hand between a pointing device and the keyboard.

pointing
keying

mental operation
pointing
key press
draw
key release

GOMS works for post hoc analyses, not for design in the early stages. The method is based on an established subdivision of task, and identified scenarios. Different scenarios can be evaluated and the expected performance times can be compared, before actual implementations are done. It does not include error-but there are extensions. GOMS can be used to predict consistency of interfaces (with a production rule representation) and the transfer of knowledge between programs (e.g., text editors). It was mostly applied to text editors, but the results have rarely been used to design new editors. Market forces and users' aversion to change have limited the application of HCI results in this case, as in other cases.

The basic question is how much of GIS tasks are knowledge-based, and which are rule-based? GOMS applies best to tasks at the "skill" level. Mark points out that there may be value in these methods for routine GIS work, e.g., digitizing, which should not be ignored. Ellis reported on a different approach taken at Guelph. They work on design rationales based on Carroll's theory of task-artifact life cycles.

2.2.3. Rasmussen's Theory

Several participants felt that further clarification of the methods to analyze GIS tasks was needed. In particular, the considerable theories promoted by Rasmussen (Rasmussen and Jensen, 1974; Rasmussen, 1986) were mentioned. The group studied whether these theories could be applied to GIS task analysis, and tried to clarify the terminology used.

As an example, the group looked at the particular task of locating a new ambulance station (report by Turk). As input they assumed some data describing the past performance of established stations under a given call distribution. How can one reconcile a pattern of unacceptable response times?

First an attempt was made to understand the axes of the Rasmussen model in terms of GIS. Figure 2, below, clarifies the vertical axis of the previous diagram (Figure 1).

Term	GIS Use	Example
Purpose	Overall objective-- reason for turning to GIS	Locating new ambulance station in optimal location
Abstract function	Main steps in re- solving problem (implicit)	Comparing existing regions with proposed new ones (with additional station) in terms of current and pro- jected number of service deliveries
Generalized function	Parts of GIS func- tionality (i.e. soft- ware menu options) explicit	E.g. polygon join, overlay, buffer, cross--functionality would be content dependent.
Physical function	Execution of GIS functionality step	Acquire data set, replot, mathematical comparison, choropleth maps, display
Physical form	How aspects of GIS functionality are physically held	Old and new data sets on disk, map on screen

Figure 2: Clarification of Vertical Axis of figure 1

Horizontal axis (of Figure 1):

- whole system: service system
- functional unit: service subsystem (e.g., supply, demand, transport..)
- component: geographical primitives (nodes, links, attributes)

Vertical axis:

- purpose: overall function / reason for using GIS
- abstract function: main steps in resolving the problem (implicit)
- generalized function: parts of geographic functionality (as appearing in commands)
- physical function: execution of GIS operation
- physical form: how are data held (data storage)

A problem seems to be that there are too many different viewpoints in this taxonomy.

The results obtained from the discussion of this example were inconclusive. Rasmussen's abstraction levels seemed like arbitrary steps. HCI people would be interested in meta-design: What is the sequence of aspects that get analyzed? One seeming paradox was that "make a map of the response times" was just one step in the task breakdown, yet automated map-making was earlier thought of as too complicated to use as an example!

Given that there are other design methodologies, similar to Rasmussen's, which ones are best for GIS interface design? A possible next step for testing Rasmussen's methodology is to apply it to a problem where a solution is known, and see if the method reproduces an acceptable solution.

3. HOW DO PEOPLE THINK ABOUT SPACE

Mark opened the Monday morning session with a talk on spatial concepts and other cognitive science issues: How do people think about space, and how can user interfaces support these concepts?

A fundamental subdivision in spatial thinking is the conception of space as fields or space as a collection of features. A field is something that can be measured continuously varying over space, e.g., temperature or topographic elevation; it could be expressed as a function of position in space or space-time. Feature collections can be roads, lakes, cities, and islands, which are typical examples of geographic features; location may be included among their properties.

Our senses record our environments as fields of stimuli that excite the nerves of our sensory systems, but our sensory cortexes convert these sensory fields into features before they reach our consciousness. This is indicated by the fact that people describe space in terms of features. For most phenomena, fields are not really experienced as such; they represent abstractions. A similar process can happen in system use: even if a system is built entirely on a field concept, using images composed of pixels, users may interpret displays as if they are populated by features, a view which then cannot be easily and fully supported by the system. (For example, if a user asks "What is the area of this?", and clicks on what the user sees as a wetland, a raster-based system might respond in an unexpected or inappropriate way, such as by providing the area of a pixel.) The user observes then a discrepancy between his intentions related to features and the systems command language, which offers operations on fields.

In cartography and GIS, both fields and features in the world are modeled. A generalized view is Brian Berry's characterization of geographic observations as a geographic matrix of places (space), characteristics (theme), and time (Berry, 1964). In fact, this division of the world into space, time, and theme goes back to Kant and Newton (Blaut, 1961). David Sinton later related this directly to computer applications for geographic information by classifying situations according to which of space, time, and theme was fixed, which was controlled, and which was measured or observed (Sinton 1978)¹. Multiple views of the same reality lead to multiple representations (Buttenfield and DeLotto 1989).

A special implementation-oriented model of space is the map layer. It carries over from manual cartography, the map library, and the light table. It was used metaphorically to organize early GIS and was theoretically analyzed by Dana Tomlin (Tomlin 1983, 1990). Michael Goodchild has described tessellations (or coverages) as special cases of fields, where the response variable is nominal (Frank and Goodchild 1990). Formally, the field and feature models can

¹ Apparently, the same schema, that of fixing one of space, time, and theme, controlling another, and observing the third, was presented by Deiter Steiner in a German-language article around 1972 (Tim Nyerges, personal communication, April 1992).

be seen as equivalent, and represent a duality perhaps similar to the particle and wave theories of electromagnetic energy in physics.

In the context of implemented GIS, there is the basic distinction between raster and vector data models (as well as data structures). Grid cells, rasters, or pixels are used to divide up space. In the Sinton model, time may be fixed, location controlled by the pixels, and theme observed or measured for each pixel. On the other hand, the vector model uses coordinates, lines, and polygons to describe geometry, either of spatial features or of boundaries within a partition. Again time is usually fixed, but now theme is controlled, and the locations of features are observed. In general, raster models are often used to represent fields, while vector models are used for feature views.

How should these two data models be used in a GIS? In what terms do people think in the real world, with and without computers? Are there different schemata? Does the choice of data models make a difference for the user? Should the difference even show up at the interface level? Do people mix spatial concepts or switch between them? Are there cases where a bad decision was made as a result of the user's view and the system's view of the world being different? How does training affect spatial conception? Should we limit the discussion of spatial concepts to subjects with likely GIS backgrounds?

A feature can be different in different contexts. For example, to a traffic engineer a road is a link in a network; it has length, traffic volume, etc. However, to a conservationist studying turtle and frog migrations, the road is a barrier; to an electoral geographer or demographer it may be just another zone boundary, and to an urban child it may be an important play area. This context dependence has implications for the choice of data models. The crux is that GISs should whenever possible be developed to serve a multitude of user communities with different conceptions of spatial phenomena. Frank had observed that GISs based on a single spatial concept were easy to learn and to use but also were limited in functionality. GISs that included more than one spatial concept showed complex user interfaces and were considerably more difficult to learn.

3.1. Different users use different concepts (report by Tim Nyerges)

Features could also be called occurrences. An occurrence has location, magnitude, identity, and time associated with it. With two occurrences, distance, proximity, similarity, etc. are introduced. With more than a pair of occurrences, one gets a spatial distribution, with properties like density, pattern (independent of scale and boundary), and dispersion (spatial variance: clustering, uniformity, etc.). Finally, with many occurrences, concepts like regionalization, dominant and subordinate relationships, paths, etc., are introduced.

The medium through which spatial information is acquired influences performance of tasks. In way-finding, photographs or spoken directions may work better than maps, depending on the individual, the task, and the visual cues that are required. Each medium has a different wealth of cues, and novices sometimes need additional cues. When people are navigating, they want to know only where the decision points are and what they have to do at these points. Specifically, it has been found that many United Parcel Service drivers cannot work with maps, but do work well with a select set of still photographs. We do not understand how people use various forms of locational information-this requires human subject testing.

Education and training may affect what medium people prefer. Teaching map reading skills on a particular map should make this the preferred medium and other media are then less effective. For example, troops might not use image maps if they had not been trained in how to use them. On the other hand, United Parcel Service drivers might have maps as the preferred medium if they were given a map reading course.

Several phases of spatial information processing by humans have to be distinguished. What cues are relevant in each phase? Input, processing, and output of spatial information in a GIS should obviously be linked by common spatial concepts, but in practice this is not always achieved, as these correspond to entirely separated design phases. There is a difference in levels of geographic knowledge (landmark, route, and survey knowledge), which parallels the different general types of knowledge (procedural, declarative, configurational).

Image schemata (Johnson 1987; Mark 1989) are elementary spatial concepts that can be presupposed for any user population. They are expected to be 'universal' and not culturally dependent, and their semantics may be as precise as that of natural language (see Kuhn and Frank, 1991).

Do different user groups (professionals, normal population, special segments of population) require support for different concepts of space? Users must not only be differentiated by level of understanding or function in organization, but by concepts used, including cultural differences. Some modalities are better for some users (abilities, cognitive preferences). Distinguishing "special" and "normal" populations is not very precise; maybe different mental models would be a better approach. How can users be distinguished by mental models rather than by function, expertise, or abilities?

One useful tool is cognitive task analysis (see section 2). Cognitive tasks analysis attempts to model tasks by a hierarchy of increasingly complex cognitive activities. This hierarchy is different for experienced and inexperienced users. One cannot handle too many independent variables, but an experienced person stores mappings between variables. This requires an adaptive user interface, or selectable levels.

3.2. (Carto)Graphic output (report by Steve Smyth)

Modeling means chunking, simplifying, and abstracting from the external world as we experience it. Computers deal with limited models (discrete representations), which are often not in the preferred form of interaction. In fact, the representations are sometimes uninterpreted, as in remote sensing. What is the preferred mode of interaction? The naive answer is that the representation should resemble direct perception of the world. But this notion needs to be refined.

Consider intentional and deliberate distortions of output. Cartographers produce cartograms that specifically distort one aspect of space in order to communicate some variable or distribution. Generally, cartography distorts space in order to display it. Choosing appropriate distortions (not only in map projections) is a standard problem in cartography. Should inappropriate distortions be restricted in a GIS? If so, how? GIS should help to make displays flexible, provide anchors for easier interpretation, and reduce the amount of data in order to increase comprehension of what is shown. But there may be a clash between what is supported by the data and what the user wants to see.

A view of space as fields seems to be adopted whenever a feature view is unsuitable. Is it too abstract for a general user population (as opposed to geographers, soil scientists, foresters, etc.)? On the other hand, special populations like radio engineers think about fields all the time. The field/feature distinction has consequences for the perceived quality of data. Feature concepts tend to be understood as being more accurate than field concepts.

3.3. Congruence between internal and external structure (report by Jonathan Raper)

Can a user interface hide internal structures and in particular the spatial concepts that lie behind them? A "vote" among the group participants revealed that all but one felt that spatial concepts could indeed be hidden.

Specialized interfaces are not meaningful to the public—we need more generic concepts, but these are difficult to capture. Current interfaces describe geographic space and features mechanically—they do not persuade, but instead they must be 'read'. There is a need for persuasive means in interfaces, and in a sense, all representations are means for persuasion (Frylinger). We do not know very well how to draw attention, to make features persuasive—for example, how to convince politicians. Flashing and highlighting are very limited means and are often used in annoying ways. GIS often emphasizes concepts which are not features of the real world (points, lines, polygons, pixels etc.). Are the common 0, 1, 2-dimensional building blocks close to cognitive representations of space? How can we close the gap between these concepts and those which are more immediate to application specialists or politicians? Practically, a very disturbing issue is that professional (spatial) languages are not complete, and translations between different models are very difficult. They carry a cognitive load.

Three more deficiencies in current interfaces were discussed:

- the lack of a dynamic view,
- the weakness in representing fuzziness, and
- an unbalanced load across available sensory channels.

In the first case, there is a strong need to show processes. However, state-of-the-art GIS interfaces are generally not dynamic and consist of static pictures. How can a process be mapped to the interface? Secondly, we have difficulty representing fuzziness, the distortion caused by non-discrete atomic objects in the real world. How can we represent them as crisp concepts for administrative use? And thirdly, how can we exploit additional sensory channels? In a virtual reality situation, one might forget that one is using a GIS. To some extent, this already happens in games (for example, in SimCity), which are GIS-like in their functions, but are much easier to use.

On the other hand, GIS and cartography rely heavily on appropriate abstractions, which cannot always be perceived as such. So, what is reality for a GIS? Not necessarily the stuff "outside." What are the features that administrations and legal organizations deal with?

3.4. Levels of spatial cognition (report by Sarah Douglas)

Maps and GISs are systems that represent space, and are task related. The task determines which representation is appropriate. For example, wayfinding, data inventory, thematic or statistical visualization, and

analysis of causal relations each may require a different representation of space and spatial phenomena. To recognize and accommodate the interconnections between tasks and representations is crucial for improved user interfaces.

One can differentiate various levels of spatial cognition, from the concrete to the abstract:

1. Pre-cognitive experience of space. Just being in the world.
2. Spatial relations. With the introduction of language and culture, our spatial sense is developed (here and there, near and far, etc.). These concepts are crucial for locating objects.
3. Mapping. Representation of the physical world may lead to a map, or another visual representation (although this depends on culture).
4. Thematic mapping. Geographic distributions of abstract features (e.g., population density).
5. Abstract 'spaces' represented in graphic spaces. Dimensional variables distributed by value in a

spatial distribution (e.g., a three-dimensional visualization of corporate organizational structure such as those shown using the "Information Visualizer" of Card, Robertson, and Mackinlay, 1991).

All of these can be multi-modal, including sight, sound, motion, and tactile perception. They are also influenced by different perceptual and cognitive abilities and skills of the user. Some relevant cognitive abilities or skills include:

- detection, recognition and categorization of objects
- orientation of self or another entity in 2- or 3-dimensional space
- relative direction
- depth perception
- path finding by a sequence of landmarks
- movement of an object relative to a frame
- translation to 2-dimensional space
- mathematical manipulation of spatial relations

Clearly, there are individual differences with respect to these abilities and skills; it is less clear whether there also are differences that can be attributed to language and culture. If such cultural or linguistic influences can be documented, does it follow that they are also relevant for the design of GIS user interfaces? Elmes suggested that psychological studies of lacking or lost spatial abilities might provide valid background. Unfortunately, noted Golledge, much of that literature is wrong.

The design of any user interface requires an assessment of the kinds of abilities of the expected users, and either the adaptation of the system to the user, or the training of the user to use the system. Or both. We need to be aware of individual and cultural differences. The concept of a 'cognitive coprocessor', described by Card, Robertson, and Mackinlay (1991, p. 185), may be useful here.

4. INTERFACE STYLES AND PARADIGMS

New breakout groups were established Tuesday morning to discuss interface styles and paradigms. The WIMP (windows, icons, menus and pointing device) interface style has found wide application even in GIS software. Is this the optimal choice for the special requirements of GISs, and what alternatives must be explored? Obviously the choice of interface style and the corresponding paradigm are closely related to the available technology to build input and output devices.

4.1. Modalities: What channels for what tasks? (Shapiro)

Many interfaces are still designed around a command language paradigm (e.g., regular GRASS and ARC/INFO) but a host of alternative paradigms are available.

- WIMP (Windows, Icons, Menus, Pointing devices),
- Natural language (NL),
- Direct manipulation (DM),
- Dynamic querying with successive refinement (DQ), and
- Virtual reality (VR).

These paradigms are often more appropriately referred to as interface styles. An orthogonal classification would differentiate paradigms of system use as such, focusing on what users think they are doing rather than on how the interface looks and feels. Among these are:

- high-level programming,
- tool use,

- dialogue, and
- delegation to agents.

Some, if not most, interaction paradigms are metaphorical. A typical example is navigation. More on these distinctions can be found in Werner Kuhn's position paper for this meeting (this volume).

It is not clear a priori that one paradigm or style is superior to another, either in general or for a particular application or user group. Command languages are useful for experts, as they offer abbreviations for frequent operations. WIMP interfaces become complex when they go beyond single level menus. Direct manipulation has become very popular due to its intuitive appeal, but is sometimes lacking in expressive power. For example, selections of multiple objects based on attributes is often awkward or impossible to do in a direct manipulation interface. This represents, however, a frequent operation in GIS. It also seems questionable whether direct manipulation is appropriate for high-level operations, dealing with goals (knowledge level). Extensions to direct manipulations include visual languages like "Query by Example" (Zloof 1977), Programming by Example (PBE; Myers 1990), and iconic programming languages (Tsuda et al. 1990); Peterson and Kuhn (1991) have outlined the application of such a system to the definition of GIS data structures. The latter could transform a select set of GIS-related commands into icons, and provides visual tools to link those to sequences of actions.

Natural language is attractive when the interaction is conceived of as a discourse and includes gestures (which are an essential part of most natural language communication). It should be applicable, for example, to car navigation systems and to interfaces for casual GIS users. Dynamic querying means that a query remains on screen with attached "hot spots," linked to query results, which change when parts of the query are changed. The major advance brought about by virtual reality is the possibility of multi-modal feedback (e.g., tactile).

Paradigm and channel discussions generally deal with low level aspects of user interfaces. How can we treat high level concerns? How can we let the system take care of details, describing goals declaratively and processes only where necessary or desired? We need GIS languages that can abstract from the low level (i.e., implementation-required, not task-required) aspects. There is no language available for defining GIS tasks and reasoning about them. This may be the transition point between natural language or delegation paradigms and direct manipulation. CUBRICON (Neal et al., 1989; Neal and Shapiro, 1991) is an attempt to leave low level operations to the system. Can we build interfaces using a 'query by example' style: give an example, extract pattern, and repeat it with some part changed?

For query and design languages, it would be beneficial to acknowledge and use different types of descriptions:

- by necessary and sufficient features
- by prototypes
- probabilistically (e.g., in remote sensing).

"Find all peninsulas in Massachusetts" is an example of a 'reasonable' query that may provide difficulties for many GISs. If we have the US Geological Surveys "Geographic Names Information System" files, with feature codes, we could simply search for peninsulas by code-if peninsula is one of the codes supported! (In fact, GNIS includes 'Cape', 'Point', 'Neck', and 'Hook', but not 'peninsula'.) So, how can we define 'peninsula' so that the system can search for them? And even if we have a database that includes a feature class called 'peninsula', how certain are we that the definition of 'peninsula' in that database matches the one we wish to use?

4.2. Technology (Ferreira)

4.2.1. Hardware

Hardware devices impose various constraints on interaction. The mouse has become a standard device. It is, however, inherently two dimensional. Although there are three-dimensional pointing devices ("flying" mice), it is said that they are unnatural and tiring to use.

Another issue is what type of device to give to novice users. Today's standard is a keyboard and a mouse (how many buttons?), but is this ideal? In the U.K., there are kiosks for tourist information. These kiosks have video disks, maps, and touch screen displays, and are simple enough to be used by most people. In informal observations, they appeared to be effective. Similar touch screen devices are now appearing in grocery stores in the U.S., and have been in use in hotel lobbies and in museums for some time (Gould et al. 1987).

Ultimately, interfaces will have more asynchronous, simultaneous input devices. They will be more like driving a car, where a user can be turning the wheel, pushing the accelerator, and looking in the mirror all at once. In order to achieve fast responses with real time interactive process control, parallel processing will be necessary.

4.2.2. Virtual Reality

With a workstation, the user looks at an image, but with VR the user is in the image. Not only can the data be viewed from multiple perspectives, but the physics of the virtual environment can also be controlled. For example, gravity can be adjusted (to make objects behave as relatively heavier or lighter than they appear) and the resulting effects can be observed.

One application for VR is data exploration. Because the user can be "inside" the data, it is possible to discern relationships that otherwise would be difficult to see. For instance, draping a SPOT image over a DEM would create a three-dimensional surface. The user could explore this surface by flying over it, perhaps using a pointing device similar to a flashlight to indicate areas of interest.

One drawback of current VR systems is the cumbersome hardware. Few if any users would want to spend eight hours a day strapped into eyephones, jumping around their offices. Today's VR systems do make sense in a military setting, where the hardware fits (or can be made to fit) into the environment. In general, what level of immersion, control, and connection is efficient and humane?

4.2.3. Multimedia

The real-time integration of multimedia data is an important research area. Birkbeck College has been developing a multimedia system (Rhind et al. 1988). One component of it was the Doomsday System, a multimedia "book" developed by the BBC to provide a look at the U.K. 900 years after the original "Doomsday Book." The system used two video disks containing pictures, sounds, and other information. One disk had an overview of the whole country, while the other detailed information about small areas. The user could navigate anywhere in the U.K. using the system.

The Doomsday System, combined with the GISTutor and HyperArc, was being shown to a group of planners. A planner would navigate to an area of interest, then HyperArc queries were executed to look at particular issues. Although this was a crude kind of integration, the effect was very powerful. Getting such a system going was a matter of choosing a small problem and figuring it out. The CUBRICON system, illustrated in the video that Shapiro showed earlier in the meeting, has several similarities.

United Parcel Systems has also worked with multimedia. They built a route planning system integrating picture and sound data. The system was used to communicate route plan information to drivers, using a series of pictures.

One problem with such a system is selecting information based on the experience of the user. A system has to know what the user knows and doesn't know. It is also important to know more about how people give other people information, for instance driving directions. When someone says, "the church on the left," what picture does the other person have in her mind? Another multimedia question is how to make sure that the user has enough information to stay oriented. For instance, with video fly by, the problem is how to let the user keep track of where he or she is on the display.

Feedback must be immediate in order to be convincing. This poses some particular problems for GIS applications, which are usually data intensive. Video disk, for example, is a very slow-access technology and the data can usually not be changed. The speed issue is currently limiting realistic Virtual Reality type systems to planning and other similar GIS applications.

4.2.4. Time as a Mode

An area of growing interest is looking at change over time. Studying temporal change with field data is very difficult, partly because temporal data are not always recorded. For example, the time that a road was built is not usually recorded. Also, because data are inherently multi-dimensional, it is difficult to tie in temporal information consistently-the data are not categorized in ways that lend themselves to scientific study. Finally, real time may be too slow or too fast to allow people to appreciate changes effectively.

4.2.5. Summary

In summary, computers have traditionally been command-driven black boxes. A user typed a command, the computer processed it and gave a limited amount of printed feedback. With the advent of Graphical User Interfaces (GUIs), it became possible to replace the black box with a "glass box." In fact, using object-oriented techniques it is possible to have the objects on the screen and the objects of a data model behave as one and the same. In this way,

changes in the state of the system are readily apparent to the user. The user is automatically informed about transitions. The objects, and therefore the data model, can be manipulated directly, with feedback about the results being immediately available to the user.

The next step will be to "break the glass" of this glass box, as Tom Furness put it in his CHI '91 closing address: Virtual reality will transform users into participants. Through realistic and reactive simulations of geographic models, with multi-sensory feedback and direct involvement, a person might "vicariously" interact with the world, rather than with a more or less static model of it in a box, or worse, on a plane.

5. FUTURE GIS (DREAM SESSION)

In an attempt to free the participants from preconceived notions of what a GIS can or cannot do, the Monday evening session was designated as a "dream session," where six groups dreamed up potential computer support for geographic problem solving from a variety of perspectives:

- GIS issues for the operators (Leader: David Lanter)
- Intelligent, high-end GIS (Stuart Shapiro)
- GIS in the public / GIS appliances for the home (Mike Gould)
- CSCW: Computer-Supported Cooperative Work (Werner Kuhn)
- Virtual reality (Steve Smyth)
- Spreadsheet equivalent of GIS / integration with other systems (Steve Frysinger)

5.1. What are the GIS issues for the operators? (Lanter)

The operator is a spatial decision maker himself, working with some external source of information and requirements. Therefore, the operator needs tools for specifying or respecifying problems, for performing transformations between existing data and required results. As it is being used, the system must keep track of different trains of thought that the user is following in solving a particular problem.

A first useful function would be a data brokerage. It would know what data are on hand, what other users have, what the government has, including information about costs and availability. The data brokerage would understand what could be computed from available resources—in effect, deduce new features. A second tool would be a method broker. Other tools would express the logic for getting specific result data, including data of a specific quality, or format data in an appropriate way (format broker).

One impediment keeping us from such systems is that we generally do not (yet) have high-level methods to express our needs.

5.2. What is possible with an intelligent, high-end GIS? (Shapiro)

A high-end GIS is not necessarily intelligent. High tech is about improving the things that computers are good at, while an intelligent system would require little operator training.

Intelligent systems would be active systems. They would behave more like an advisor reacting to a proposal, checking the assumptions of, say, the planner. The system would be based on a trusted database, although advice need not be completely accurate. The GIS should itself be able to add to the accumulated knowledge of the discipline, by recognizing patterns and trends.

Working with an intelligent GIS would come closer to interacting with an intelligent person. These systems would have lots of data available and an integrated database with a unified access (may be distributed)—an important issue.

Redundancy will be a crucial feature of intelligent systems (sensitivity, multiple models, different levels of aggregation, redundancy as in human communication). Plausible reasoning, using short chains of probabilistic reasoning steps, would become possible.

Many of the improvements in computers seem to be filters to get data in the correct form, and tools for getting the right data. One useful additional input device/sensor combination would be a portable hologram projector and a gesture sensor. With them, another parallel visual channel could be used.

5.3. What is the future of GIS for the public, or the "GIS home appliance"? (Gould)

A GIS for the home would handle queries like, "Show me where Mark Twain was born," or "Tell me about my town's mall project," or "List the travel options for a vacation to England." The system would have information about public transportation, a library reference desk, driving directions, and travel planning.

Interaction would happen through home TV sets. Some services could be incorporated into existing systems, for example the MINITEL French video text system, or the early experimental TELIDON system in Canada. If virtual reality hardware were available in the home, as may soon be the case for video games, virtual reality vacation experience clips could be provided. At least Hypermedia, mixing spoken text, video, sound, maps, and printed text and tables, would be useful.

The possibility of such systems raised many questions. Would they be based on GIS or on hypermedia systems? Where would the data be kept? On a network? On CD-ROMs? Who would provide and maintain the data? What about issues of privacy and network junk? What will the user's role be in the system? Should political voting (or at least, public opinion polls) be linked to it? Will hardware cost remain a problem?

5.4. What can be done with Computer-Supported Cooperative Work? (Kuhn)

Computer-Supported Cooperative Work (CSCW) systems have applications wherever groups make decisions or otherwise interact and demand or supply information (see the proceedings of the ACM-sponsored conferences, CSCW'88 and CSCW'90). Examples would be GISs for Congress, for a community planning processes (e.g., for siting a waste facility), for high-level political decisions, or for corporate meetings.

Thus, the users would range from the general public to technocrats to managers and high-level government officials. They might be located in a common room or in their offices, spread across space (e.g., in different states or countries) or even across time (asynchronous "meetings"). Removing time and space constraints could be a fundamental contribution of such systems.

The system could have electronic agents take a role as a player (e.g., for a person who could not participate, or to represent regulations) or as a moderator and facilitator in discussions. Some roles in group processes might actually be taken over entirely by such agents. The system would allow more manageable brain storming and provide its users with instant documentation as well as feedback about problem solving states. It could also provide simultaneous translations.

Technological features could include very large screens, both public and private displays, and sketching devices and electronic post-its. The GIS would become a dynamic network, with varying participation of human and electronic agents.

Care would have to be taken to preserve features which people rely on in group processes. Among them are the wide variety of communication channels (e.g., eye contact, observing uncontrolled muscular and other bodily reactions) or the ability to "show off." On the other hand, inappropriate solutions (e.g., skin response sensors) could lead to privacy invasion problems.

CSCW research has also revealed that an exposure of a whole decision process is not always desirable (see the work of Jonathan Grudin). People may fear a big-brother like documentation of responsibility and authorship, as well as an uncontrollable change of power structures. This is an instance of a general problem with information technology: the undesired elimination of their imperfections. There is also a questionable underlying assumption that information plays an important role in decision making.

Still, supporting group decision making and cooperation seems to be one of the things that is close to the core of what GIS is really all about. The expectations are out there, and some success stories have already been reported (e.g., for school planning). Additional benefits could be derived from powerful simulation capabilities for research and training purposes.

5.5. What can be done with virtual reality? (Smyth)

Virtual reality (VR) allows for a seductive interface. It provides a direct coupling of visual and tactile processes with human movement (proprioceptors) and a virtual world, creating a powerful medium for communication.

One application is exploring data. One can overlay various kinds of data, then actually move through the space they occupy. One could actually experience different viewsheds, or manipulate multivariate data with a data glove, with each joint connected to one variable.

5.6. What is the spreadsheet equivalent of GIS / Where does system integration lead? (Frysinger)

The key to a spreadsheet is dynamic updates of data while work is in progress. To that end, an implementation dream might be GRASS tied to a spreadsheet by some dynamic functional relationship, where multiple representations would be linked by "hot links." GIS overlays could then involve dynamic updates. Geographic Data Technologies, a company in New Hampshire (USA) markets a system called "Geo Spread Sheet" that has some of these characteristics, primarily designed for political re-districting tasks; ESRI's ArcView also links spread sheets and maps.

Appropriate system integration should primarily provide better access to data, with operations that work on these data independently. GIS might thereby become more of a data switchboard than a database (taking up the brokerage idea).

6. PARTICULAR PROBLEMS

The Tuesday evening session was devoted to particular problems that have surfaced, but were not given sufficient time for discussion. They revolved around the currently available technology and its limitations-and thus contrasted with the previous day's 'dreams'.

6.1. What experience is there with tools for design and rapid prototyping? (Elmes)

When discussing user interface design tools, it is useful to discuss four stages of design: conceptual, semantic, syntactic, and lexical. The conceptual level deals with the choice of metaphor(s) and of the objects of discourse, the semantic level with the meaning of operations, the syntactic with expressing those operations, and the lexical with the physical activities necessary to perform the operations. Today's design tools work mostly at the lexical and syntactic level, with few tools but some methods at the semantic level, and neither tools nor methods at the conceptual level. One way to get more powerful tools would be to enhance existing tools, like NextStep, to include higher levels of functionality, which would allow designers to specify GIS semantics.

To design advanced user interfaces, such as for GIS, tools are needed that work at the semantic level. These might take the form of general purpose specification languages, e.g., MIT's LARCH, which is a tool for algebraic specifications (Guttag, Horning, and Wing 1985). The current methods that exist for user interface design do not anticipate problems-some of them as simple as identifying the routine in a given library of interface techniques that performs the desired function. Thus, better browsing techniques are needed to support interface designers. Multi-modal interfaces are not only promising for GIS themselves, but for systems to design GIS, where the domain is communication rather than geography (Shapiro).

An important question for our community is whether there are unique conceptual and semantic properties of GIS operations. Today's GIS interface requirements may not be so much different from other spatial domains, such as CAD/CAM (Elmes). If GIS needs are special, however, then there is a need for object-oriented libraries with GIS functionality and possibly even for GIS-specific widget sets (Cumpston).

A hopeful note is that integration of tools is becoming standard-OpenLook, Motif and X-windows are commonly being nested and combined. Generic tools will help to connect diverse applications with a common look and feel. One such tool, Open Interface from Neuron Data (Palo Alto, California), works with Macintosh OS, Motif, OpenWindows, and Presentation Manager. It was used in designing ArcView, the new product for viewing ARC/INFO databases.

6.2. Obstructed Channels (Lupien)

For various reasons (handicaps, technological constraints, economics), it may not always be possible to use the optimal or intuitively appropriate channels for communication in GIS user interfaces. This group discussed the needs of special populations (e.g., visually impaired) as well as problems of interacting with a GIS in a sparse channel situation, such as over a telephone.

6.2.1. Telephone-Based GIS

Telephone-based GIS or GIS-like systems are not a new concept. A telephone-based system for giving driving directions was developed years ago at the MIT Media Lab by Chris Schmandt, Jim Davis, and their colleagues; Digital Yellow Pages are becoming a reality. Cellular phone users in New York can dial *JAM to get information on

alternate routes during traffic jams. In these systems, the telephone can be thought of as a terminal. It has keypad (including letters) and voice input channels, voice and the ringing bell as output channels. A telephone can also support fax machines and thereby static graphical input and output. Telephone terminals can be located almost anywhere in the world. In many areas of the United States with "911" emergency services, fixed telephones have precisely known locations. Cellular phones can be located roughly by cell station, or could use GPS receivers for precise positioning.

6.2.2 Real Time Navigation Systems for Blind Travelers

In order to navigate, one must have or obtain information about current location, orientation, proximal links or landmarks, bearing, distance, priming (for the next landmark), and choice points. Sighted people usually navigate using visual reference points, often subconsciously. A blind traveler must be enabled to sense the reference beacons by some other means-e.g., auditive or tactile.

One way to allow non-visual navigation is to borrow technology from virtual reality, and build a virtual sound space. In such a space, location and pitch can be used to give the traveler a sense of the environment. Buildings, and other items of interest, could actually "call out" to the traveler. Pay phones could then act as help stations, giving position information or providing location-specific data. Primitive examples of this type exist already in public spaces (airports, etc.). But a danger of using sound VR in navigation is that sound is a critical channel for information about features and hazards of the real world. Further research is needed to test people's abilities to move through sound spaces and use some kind of maps of them. Golledge is envisioning a laptop-based system that uses region-specific data. The system would be used by both visually impaired and sighted people. The interface does not use cartographic maps at all, but auditory and tactile information about the immediate environment.

The discussion turned into a design session for an entire system, departing from user interface concerns. It provided a good example of the primacy of user interface issues in overall system design.

6.3. How do query languages relate to interface issues? (Smith)

There are some general issues that must be considered. What do users want from a system? What information can they be expected to know? What information will they be required to know before using the system? Should a system replicate human skills or complement them? What are the specific requirements of a given application area? Is there a core family of deep languages (based on logic)? How can radial categories and prototypes be reconciled with the classical, feature-based paradigms of SQL ("Standard Query Language") and other query languages? Answers to these questions will have an impact on query language design. Opinions about query languages are as varied as the people discussing them. On the other hand, the GIS community does not have a rich set of query languages which are able to describe objects, locations, functions, and relations between objects

What are the typical queries? In administrative settings, 90% of queries are standard queries, but this is not the case for scientific databases or exploratory planning and design tasks. Applications that use a field-based geometric model (e.g., remote sensing) define problems in terms of locations and interrelationships of locations. However, there must also be a representation involving objects and their interrelationships. Concepts like shading, time, and appearance of objects have to be considered. This interaction between field-based and feature-based concepts underlies many issues in query languages.

With a feature-based model, other problems arise. Fuzziness of objects, or object edges must somehow be modeled. This can be partially solved by determining the user's purpose. Fuzziness can also be dealt with using natural language ("it is about 3 or 4 miles north of the freeway"), but this cannot yet be handled easily by formal systems.

Another important research area is building a foundation for dealing with fuzzy geometry. How do people deal with imprecise objects and geometry? From the user's perspective, there may be fuzziness in their understanding of the problem, and therefore they may not be able to formalize a query precisely. Logic based interaction languages may serve professionals, but not the public at large.

Will we need different query languages for different settings? For different scales? In general, do different kinds of spaces (everyday, manipulable object spaces; indoor transperceptual spaces¹; geographic spaces) require different query languages? How can cultural differences best be accommodated? Core concepts that are culturally independent must be identified (if they exist). There is ongoing research into whether or not different spaces have

¹ 'Transperceptual' is a word used to describe a space that cannot all be perceived from a single viewpoint, but rather must be 'assembled' in the mind from separate perceptual experiences. To the best of our knowledge, the term was introduced by Downs and Stea (1973).

formally different geometries. Can one combine different spaces in one query? For example: "find the building in this city with a room with a table with a spoon in a cup."

6.4. What are specific user interface problems with current GIS? (Potter)

6.4.1. Basic Features.

Existing GISs have problems not unlike the problems that other software products had 10 to 20 years ago. Upgrades can be inconsistent, and different parts of a system are sometimes not well correlated. Basic file management is often awkward. For instance, in one system, files cannot be replaced by other files, while in another, the system must be restarted if a valid filename is not supplied. Editing features now common in word processing software, such as an "undo" command, are lacking in many GIS situations. Some systems require excessive switching between mouse and keyboards. Error messages are often uninformative, an extreme being a system which simply stated "bailing out," and quit the current process. One system had a conflict between the representation of an object for graphic output, and its representation for analysis.

6.4.2. Advanced Features.

Beyond the basic features, GIS user interfaces also exhibit problems. They often suffer from poor macro language facilities, making the automation of repetitious tasks too difficult. There are many instances where effective expert advice could be offered, for instance in color selection.

6.4.3. Technical Issues.

There are a number of technical issues regarding underlying hardware and software components that have a direct effect on the user interface. These are often thought of as spatial database issues, but they have a major impact at the user interface level. Perhaps the most obvious issue is response time. Certain tasks with GIS take an extraordinarily long time, on the order of minutes or even hours, whereas HCI principles suggest that a maximum response time of two seconds is needed for natural interactive computing. Another issue is working with multiple files, and multiple users accessing a single file.

6.4.4. Learning New Systems.

GISs are generally very difficult to learn. This difficulty is not simply removable by switching from a command line to a WIMP paradigm. For example, although OSU MAP has a command line system with many non-intuitive commands, it is easy to teach most students how to use it. It is not clear whether training times will decrease with object-oriented designs. Furthermore, it is not clear whether there are genuinely GIS-related interface difficulties or whether these are just left-over general computing difficulties.

7. THE RESEARCH AGENDA¹

To set the research agenda for the topic, five working groups were formed on the last day of the meeting, to compile lists of researchable questions in five topical areas which had emerged during the meeting. We termed the five areas:

- Task Analysis and Taxonomies
- Testing and Experimental Design
- Spatial Concepts
- Interface Metaphors
- Issues for Decision Makers

The following sections describe specific researchable topics or key issues under each of these areas.

¹ This section of the report was previously published in the Proceedings of the ASPRS/ACSM Spring 1992 meeting. See Mark et al., 1992.

7.1. Task Analysis and Taxonomies

The overall objective in this area is to develop a framework for analyzing and comparing GIS interfaces by developing one or more taxonomies of GIS uses and associated task decompositions into component user tasks. This effort must be sensitive to different types of users. Specific questions to be addressed include:

- What taxonomies of tasks are needed?
- What are the critical dimensions for classification (user expertise, types of tasks, application areas, etc.)?
- How can task taxonomies be reconciled with GIS use situations?
- How can individual differences be accommodated?

These issues need to be pursued via the development of GIS task and user taxonomies, to be tested with different types of task analysis procedure. An understanding of which procedures are most effective, and how task analysis may be used in GIS design, will be facilitated by the development of an integrated theory-based reference model of the cognitive aspects of user-GIS interaction (Turk 1990).

7.2. Testing and Experimental Design

The need for testing and experimental work arises from:

- the desire to validate assumptions about how spatial concepts, behavior, and capabilities of users interact with system use,
- the need to compare systems and components, and
- the goal to match user interfaces to users' mental models.

Testing should provide an objective basis for assessing the quality and effectiveness of user interfaces, including the conceptualization of the user interaction with their work, and the effects of various choices of interaction devices on task performance (Freundschuh and Gould, 1991).

Many experimental methods are available in the literature (see several of the papers in Helander, 1988). Experimental design skills are valuable, learnable, and transferable. Experimental methods can be applied at several levels of system integration: whole systems, subsystems (maybe cognitive setting is operating at this level) and at atomistic levels (to test small aspects like interaction device, color choice, icon design, button placement, etc.). One important research project would be to measure the fit between systems and users within a task context; i.e., testing complete systems in context;

A reference framework should relate cognitive issues to the symbolisms, the devices, and the perceptual/motor level. Thus, it should provide a continuum from high level to lower level skills.

Three specific projects were deemed to be of value:

- A review article on existing experimental methods applicable to characterize user interfaces, relating them to the types of questions they can answer and giving examples of their application. The article should probably include a chart similar to the charts of what statistical methods to use in the end pieces of books such as Blalock's (1960) "Social Statistics" or Siegel's (1956) "Non-Parametric Statistics".
- User interface specifications for various applications that might be applied by designers.
- User interface benchmarks for various applications, particularly a set of benchmark tasks.

7.3. Spatial Concepts

It seems obvious that the concepts that appear in the user interface of a computer system must match the user's conceptual model of the phenomena under consideration, if the computer system is to provide a usable model of the world. This is often achieved by the user modifying his or her conceptual model through training or experience with the system. But the more closely the system's design approximates the user's view of either the system or the phenomena represented in the system, the easier the system will be to use. Thus a comprehensive review of the spatial concepts that underlie GIS-related tasks and other things that people might do with geographic software, must be viewed as a prerequisite to user interface evaluation and improvement. Frank and Mark (1991) have reviewed some of the links between language, spatial cognition, and GIS.

Specifically, there is a need for a reference framework that relates cognitive issues to the representations of space that are evident in the interface. Additional research issues revolve around the following points:

- A common sense understanding of space needs to be distinguished from the spatial concepts of various professions (e.g., lawyers versus planners). Are there any universals in these, e.g., image schemata (Mark, 1989)?
- How important are cultural differences for dealing with spatial relations at the user interface?
- Spatial concepts could be expressed more effectively if a variety of output modes (graphics, text, speech, other sounds, etc.) were available. For example, graphical output requires over-specification of geometry; if we know only topology, we could communicate that more honestly to the user through verbal output than through a picture.
- Is natural language a suitable interaction medium for spatial problems? If so, how can gestures be integrated?
- How declarative can a query language be?
- Are specific choices of spatial concepts and logics sufficient for a given application area?
- An "anthropology" of different GIS cultures (e.g., ARC/INFO vs. Intergraph) might reveal interesting insights into universal and system-specific conceptions.
- How can the idea of a spatial syntax be used for organizing spatial knowledge?
- Wayfinding was found to be a suitable task for observation.

7.4. Interface Metaphors

Research on interface metaphors is motivated by both GIS-specific and general HCI concerns (Gould and McGranaghan, 1990; Jackson, 1990). Among the participants, there was widespread agreement that we need to go beyond map metaphors in order to take full advantage of dynamic system capabilities. The field of HCI, on the other hand, is looking for interesting application domains where theories of interface metaphors (among others) can be applied and operationalized in actual interface designs. Therefore, the following list contains both GIS-specific and general HCI research questions on the role of metaphors in user interfaces.

- What makes a good interface metaphor good? (Find theoretical and experimental evaluation methods, analyze successful cases like the desktop or map metaphors)
- How can metaphor candidates be generated? Possible sources include: artifacts and tools used; domain languages found in documentation, regulations etc.; domain symbology; existing models; and video games
- Which generic metaphors (e.g., toolbox, desktop) are appropriate for GIS?
- What is the role of metaphors in task analysis?
- How can metaphors be integrated into a conceptual design? Can metaphors be designed to be adaptable, or even customizable?
- Does the choice of metaphors affect the syntax of interaction languages?
- What is the connection between metaphor choice and the use of a User Interface Management Systems (UIMS)?
- How can metaphors be coherently combined and nested?
- How can metaphors be communicated to users?
- What is the role of visualization for metaphors? (Image-schemata by definition have associated images.)
- How can appropriate multi-modal expressions of metaphors (combining image and sound, etc.; see Mountford and Gaver, 1990) be found?
- When is "magic" (i.e., violating a metaphor) appropriate?
- How do work space and geographic space interact (e.g., meaning of up/down on screens)?
- What are the image schemata and metaphors behind features, fields, and other concepts of space?
- Can we optimize GIS metaphors with respect to cultural invariance? Or should we exploit culturally-relative metaphors when appropriate?
- What are appropriate metaphors for interaction with three-dimensional and time-related spatial information?
- What are appropriate metaphors for Computer Supported Cooperative Work (CSCW) in Spatial Decision Support Systems (SDSSs)?
- What agent paradigms are suitable for GIS (map maker, surveyor, analyst, model maker, etc.)?
- Could there be metaphor-free GIS interfaces? If so, where and how is this possible?

7.5. Issues for Decision Makers

Decision makers, for example professionals represented in URISA or AM/FM International, have specific needs to be satisfied by a GIS that are different from those of, say, a scientist. What differences in the user interface are appropriate?

First, decision makers are particularly sensitive to the level of confidence they can have in spatial data products. Research into means to inspire confidence is necessary, and some is already underway in the NCGIA's Initiative 7, "Visualizing the Quality of Spatial Information" (Beard and Battenfield, 1991). Two of these are:

- to show 'correct' data whenever possible; and
- to get the users to understand an analysis, including limitations.

Confidence is often achieved through anecdotal evidence rather than exhaustive tests. How can this fact be usefully applied to interface design?

Second, the usability of software is essential to decision makers. They need special forms of data access, special forms of products, information on what a product represents, and safeguards against violating elementary cartographic principles in presentations.

Third, decision makers will increasingly work in distributed decentralized computing environments. This requires again appropriate access methods (e.g., browsing and intuitive query languages), the possibility to backtrack along trails of evidence, and provision of intelligent error notifications back to data producers.

Finally, Computer Supported Cooperative Work (CSCW) is likely to play an important role in future decision making processes, including SDSS. Building prototype models (e.g., of town infrastructure) from spatial data is an effective means of decision support.

7.6. Comparing Research Agendas

It is interesting to compare the Initiative 13 research agenda with the more general agenda for human-computer interaction (HCI) recently described by Marchionini and Sibert (1991). That agenda resulted from a workshop held at George Washington University (GWU), March 4-5 1991, and attended by 22 authorities from the HCI community. (There was no overlap in participants between the NCGIA meetings and the GWU workshop, and Marchionini and Sibert's paper did not appear until late 1991; however, several participants at the I-13 meeting were students of participants in the GWU meeting.) Marchionini and Sibert (1991, p. 17) identified four broad areas of concern:

- HCI Models
- Input/Output Devices and Interaction Styles
- Software Tools and Architectures
- Computer Supported Collaborative Work (CSCW)

Recall that the NCGIA specialist meeting developed a research agenda under the following five headings:

- Task Analysis and Taxonomies
- Testing and Experimental Design
- Spatial Concepts
- Interface Metaphors
- Issues for Decision Makers

How are these two sets of bullets related? "Task Analysis and Taxonomies" proposes research that would apply "HCI Models" to geographic problem-solving and GIS. Our category of "Testing and Experimental Design" would seem to be primarily focused on the practical evaluation of "I/O Devices and Interaction Styles", although hardware issues were barely mentioned in the discussions at the NCGIA meeting. Our "Interface Metaphors" would also seem to fall under this bullet, but represents a more theoretical or conceptual side of the issues. The remaining two components of our agenda, namely "Spatial Concepts" and "Issues for Decision Makers", address theoretical and practical issues, respectively, in the specific areas to which GIS is applied; domain-specific issues were not explicitly addressed by Marchionini and Sibert. Conversely, of the last two major categories of Marchionini and Sibert's (1991) agenda, "Computer Supported Collaborative Work" was mentioned briefly under our heading "Issues for Decision Makers". "Software Tools and Architectures" was not highlighted in the research agenda of our meeting, but were frequently mentioned in our discussions. These will probably become more important in the UIGIS agenda, especially

in Westervelt's (1990) idea of two kinds of users: end users and 'customizers'. Customizing the user interface will be much easier if the generic GIS supplied by the vendor has a good User Interface Management System (UIMS).

8. Electronic Dissemination of Information: UIGIS-L

In order to foster communication and interaction about these issues, we have established a BITNET Listserv called UIGIS-L on UBVM, an IBM mainframe at the University at Buffalo. Messages sent to this listserv at UIGIS-L@ubvm.cc.buffalo.edu [Internet], or simply to UIGIS-L@UBVM [BITNET] are distributed to members of an open subscription list. There is also a limited distribution of this information on Usenet (Netnews) as bit.listserv.uigis-l. If you have electronic mail access yet either cannot subscribe to bit.listserv.uigis-l, or prefer to receive UIGIS-L material as electronic mail, then send a 1-line subscription message to:

LISTSERV@UBVM.cc.buffalo.edu [Internet] or

LISTSERV@UBVM [BITNET]

and the one-line message should be:

SUB UIGIS-L 'Your name'

You will then receive any items sent to UIGIS-L. You can also post messages or questions to UIGIS-L without being a subscriber.

As of 24 April 1992, a total of 209 items had been posted to UIGIS-L (0.7 per day), with 63 people posting at least one message each. Of those, the 14 who were specialist meeting participants posted 101 items (48 percent). Twelve other people who did not attend the specialist meeting posted 3 or more messages; of these people active on UIGIS-L, 3 had been invited to attend the Specialist Meeting, but were unable to attend for personal or other scheduling reasons.

As of 24 April 1992, UIGIS-L had 237 subscribers from 24 countries. A breakdown by region (see Table 1) shows a preponderance of subscribers from English-speaking countries, much more so than on GIS-L, a more general-purpose GIS discussion list.

Table 1: UIGIS-L Subscribers by Region and Country

United States	147
Other predominantly-English-speaking Countries	45
(Australia [13], Canada [16], Ireland [1], New Zealand [2], United Kingdom [14])	
Other European Countries	35
(Austria [5], Belgium [1], Czechoslovakia [1], Denmark [1], France [1],	
Germany [3], Greece [1], Italy [5], Netherlands [5], Norway [2], Poland [2],	
Spain [4], Sweden [1], Turkey [3])	35
South America (Brazil [3], Colombia, [2])	5
Asia (Saudi Arabia [3], Singapore [2])	5
Total	237

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User Interfaces to Support Locational Decision-Making

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Introduction

A spatial decision support system (SDSS) helps a decision-maker, or group of decision-makers, explore the nature of semi-structured locational problems by enabling them to iteratively change parameters in locational models, and then to examine the effects of the changes on the resulting model solutions (Armstrong et al., 1991a). These results, however, must be placed in their correct context for decision-makers to understand spatial relationships among components of a problem because in many instances the spatial relationships between demand and supply are key ingredients in a locational decision. This implies that maps are an essential part of the decision-making process, and that they constitute an important element of the user interface. The iterative approach to problem solving that is adopted by most SDSS users also normally leads to the generation of several alternative plans. These plans may arise from changes in model parameters specified by individuals, or they may arise from suggestions made by members of a group. In either case it is also important, therefore, that comparisons between different plans be made. Because of these characteristics, SDSS interfaces must:

- provide an adaptive interface to decision-makers so that when they iterate through scenarios they may do so systematically; and
- support interfaces that allow several members of a committee or group to work with the system.

These characteristics of SDSS, described below in greater detail, are essential to their adoption in a broad range of application areas, and when fully implemented, will enable decision-makers to become more directly involved with the solution of locational problems.

Adaptation to the Decision-Making Process

When decision-makers use an iterative approach to solving multi-objective locational problems, they typically pass through several distinct stages (Honey et al., 1991), and the interface should adapt to different user requirements at each stage. The first stage involves the formulation of an initial solution strategy, during which the decision-maker typically acquires knowledge about the geographical characteristics of the study area and variables that are included in the analysis. At the second stage, the decision-maker begins to more fully explore the solution space of the problem and generates a series of solutions that are either dissimilar or that define systematically the limits of the solution space of the problem. For example, a decision-maker may wish to change the number of facilities to be located in a region while holding other elements of the problem constant. In the third and final stage, the decision-maker narrows the focus of the analysis and evaluates competing alternatives using quantitative indicators, the spatial expression of the models in map form, and both intrinsic knowledge about the problem domain and the region of interest.

Several map types can be developed to support these different stages of decision-making (Armstrong et al., 1991b). Locational maps provide the geographical context of the decision, and enable users to orient themselves. Supply and demand maps enable decision-makers to see spatial relationships among the various components of the problems. Spider maps simultaneously show the relationship between supply and demand, while delta maps are designed to enable comparison between alternative solutions (maps) and emphasize the salient differences present between solutions.

Though these maps can be created, a key issue remains: how to provide an appropriate level of support to decision-makers, yet not stifle them as they search for solutions. In many instances the maps are based on the results of locational models, and assistance in model formulation and specification may be required. Knowledge about

characteristics of locational problems can be elicited, encoded, and used to guide the problem-solving process in a knowledge based decision support system. Though present approaches are experimental, research on such systems is being pursued (Armstrong et al., 1990), and the computing environments in which the systems should be developed are being evaluated. Alan Kay, for example, has described "agent-oriented" computing environments (Kay, 1990) in which agents have "the ability to learn what types of information a user or application would be interested in seeing" (Moad, 1991). Kay posits that new interfaces will be based on teaching the system about what the user needs. The system, in practice, will then provide guidance about its use at different stages in decision-making. Because the SDSS interface must support a specific style of display tailored to stages in the decision-making process, it must draw upon a knowledge base of facts and rules that suggests how system agents should respond in a given context. An agent-oriented approach is well suited to such tasks because agents contain encapsulated knowledge and behaviors that can be invoked to anticipate and support the needs of decision-makers at various stages of decision processes. As the user progresses through these stages, messages are propagated through the system by agents as they respond to messages sent by other agents. These messages for example, would contain instructions about model parameters, defaults (e.g., map scales), and other related aspects of the decision support environment. Further research is needed, however, to determine the content of the knowledge and the kinds of agents that will be required to implement such a system.

Support for Group Decision-Making

Many important social problems are treated by government agencies through the formation of committees that are charged with making recommendations to elected officials. Within such bodies, it is a common practice to form sub-committees that focus on particular aspects of a problem, and as a result, sub-committees are often formulated when computer-based solutions are sought. In many instances, therefore, it is important to allow several members of a group to work with the SDSS environment. Though at present we usually operate through a single-user filter, we must begin to develop methods that are appropriate for computer supported cooperative work (CSCW) environments in which users exchange information and insight as alternative problem solving strategies are identified and pursued.

One CSCW model is designed around eliciting a set of issues from the group (Grudin, 1990). Group members then develop arguments that support or rebut positions that are developed to address the elicited issues. A CSCW environment for locational problems will have distinctive requirements for interaction, display and handling contention. In single-user SDSS applications for example, it is common to specify a sequence of steps that leads to the creation of a scenario that can be supported or objected to by other members of the group using statistical evidence (e.g., the value of an objective function), maps, knowledge about the problem domain, or even intuition. An SDSS based on CSCW principles must therefore provide a flexible mechanism for marshalling geographical evidence to support or rebut specific aspects of decisions. Clearly, such systems will be exploited by clever users in much the same way that "skillful" administrators can control meetings.

The SDSS also must provide a mechanism for describing a trace of the decision-making process, so group members can retrace through the logic of a scenario and alter specific components without having to reconstruct the entire sequence of steps. Such a trace facility would also serve as a mechanism for showing the types of alternatives that have been evaluated by the group in the process of making a decision (Vertelney, 1990). Researchers have noted, however, that in some instances, a trace facility is not desirable, because it would highlight any lack of unanimity present in a group, and leave the entire decision-making process open to scrutiny (Grudin, 1990).

Putting It Together: A Postscript on Interactive Design of Service Systems

In the past, decision-makers who were charged with making locational decisions either made choices using ad hoc methods, or used locational models that were designed to be used as static tools. SDSS methods have now evolved to the point where decision-makers engage in a dialog with an analyst, and together they employ an iterative problem solving strategy in which they learn about the problem as they progress toward its solution. Oftentimes, the problem is completely reconceptualized when decision-makers see the effects of applying their criteria to a particular instance of a locational problem. But working through an analyst is clumsy. The user interface for systems that will enable decision-makers to bypass an analyst and work directly with problems must be able to guide them through iterations in the problem solving process. This will require the creation of proactive systems that contain knowledge about the problem domain, and agent-oriented environments may prove to be useful in such instances.

Other work must focus on allowing decision-makers to interact with problems in real-time to interactively visualize the effects of making adjustments to the parameters that define the solution space. Although this has proven to be difficult because the locational modeling algorithms that are normally used by a SDSS are quite computationally intensive, rapid response is essential to the development of a sense of designing a service system. Users also should be allowed to interactively manipulate two parameters much like a driver simultaneously releases the clutch and presses the accelerator in an automobile with a manual transmission. By being able to visualize and evaluate the interplay between the parameters, the decision-maker gains new insight into the nature of trade-offs in multi-objective decisions. At present, such comparisons are essentially done in batch mode. Similarly, systems must be construed to allow several members of a group decision-making body to access and use systems together. Research must be performed to determine whether different computer architectures can be exploited to improve performance to a level that is required to support true interactive modeling and design of service systems in a CSCW environment.

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Biographical Sketch

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URISA Perspectives on the GIS User Interface

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I am a neophyte in the area of user interface, but was invited here because I was chairman of the committee that developed the research agenda for URISA -- the Urban and Regional Information Systems Association. As chairman of that committee, my task was to pull together many ideas into a single statement (Craig 1988). The person who pressed to have user interface included on URISA's research agenda was Joe Ferreira, and he carries his own message to this Specialists Meeting.

My charge was to present the needs of planners and public officials who would like to use GIS technology, but are frustrated by the user interface. These people may have even taken a course in how to use a particular system, but because they don't use it every day they lose touch with the arcane rules and language, they lose confidence, and eventually they give up.

What I have actually done is to survey the URISA literature and membership looking for proposed solutions. I have read through conference proceedings (URISA and GIS/LIS), the URISA newsletter, and the URISA Journal. I have contacted individuals who I know to be interested in this topic and obtained either written comments or a summary of their thoughts. I placed an article in the URISA newsletter this Spring inviting additional comments. Finally, I have included ideas from my own background and readings.¹ The results are presented below.

Shells and Macros

For many end users, a specific application macro (or shell) will suffice (Johnson 1989; Westervelt 1990). For these people, we need to figure out a way to create such tools with less effort. Now, creating a relatively simple macro can take a person-year of effort or more. Game makers have created a "video construction kit"; we should be able to do the same for application software (Robinette 1990). The video construction kit has all the tools a game author needs to create a customized game: scenery, objects that move, and scripting tools that allow the author to vary the consequences of collisions between entities of different types. Relevant tools for creating macros need to be defined by the research community; actually building these tools will be undertaken by industry if we help them figure out what is needed and might sell.

Standard Look

But planners and decision makers have very diverse applications and are not good candidates for a single-purpose macro. An approach that might meet their needs is to design the front-end of a GIS so it has a "standard look." I found three different versions of this theme.

Evatt (1990) takes the approach that the opening moves within a GIS should be similar regardless of what types of functionality might be desired. He would, for example, always have the user start by pointing at a map to define the study area. A more developed example might be:

- 1) Point at the part of map that interests you
- 2) Select a major function, e.g., "print report" or "analyze"
- 3) Respond to list of options, e.g., "print address labels"

All next-decision steps would be generated by the software and sent to the user for choice of path. The first steps will look familiar because they would be the same for all operations.

¹ As a active member of URISA since 1970, my own ideas must be more than somewhat representative of that organization.

Raper and Green (1989) have talked about creating a common dashboard which could coordinate the inner workings of any GIS. What should that look like? What is the equivalent of the shift lever? Oil gauge? Jonathan Raper is part of this Specialists Group and can say more about this.

Ferreira and Menendez (1988) at MIT use software layering and X-Windows to let the planner extract and manipulate data using their more familiar DBMS and spreadsheet packages, then sending the data to the GIS for additional manipulation and mapping.

Models¹

Many users would like to access GIS through their own software, software that models their own professional world. Software layering might allow them to access GIS using a system that is much more familiar to them. The user would interface directly with his or her software. That software package might go to the GIS to get the required data to drive the model, run the model itself, then send the results back to the GIS for mapping the results.

If the GIS cannot deliver the appropriate level of analysis, it is doomed to failure (Haines-Young 1990). This ability to connect outside models to a GIS is an important aspect of improving the user interface. Some of this modeling needs to be added to our software packages themselves, some can be added as macros, and some should be connected through software layering.

Nature of the Interface

Once inside the GIS package, Ferreira and Menendez (1988) assist the planner with extensive help screens which can be left open in one window while the planner works in another. They use an ingenious idea of presenting sample code in a help file; users are encouraged to cut and paste these modules into their own command files, making whatever modifications are necessary. This is how much JCL code was written--nothing original, but much modified. It is not clear how many and which modules would need to be available. (More of this from Ferreira himself, I hope.)

Of course a command language is only one option. The other popular option is a graphical user interface, GUI. I'd like to propose that a different option be developed for our field--the Geographical User Interface--the GeoUI? (Evatt 1990). Rather than typing-in commands, why not point at the map? Map pointing could be used to identify the study area, to identify which variables or objects are of concern, or to query the database about the values for any variable at a given point.

Let me develop one example a bit further. I could point at a road, then ask for a buffer; besides asking me to state a distance, the software should ask me to say whether I am interested--

- only in this segment
- in the entirety of this road
- in all roads of this type or
- in any road

Some software has limited GeoUI capability already. We need to know whether this helps people use GIS and how far to go with it.

Help

Finally, I want to talk about on-line help. For this section I am indebted to Charles Kindleberger (1991), chief planner for the city of St. Louis. He breaks his ideas into two classes: 1) the computer as a technical assistant and 2) the computer as tutor.

1. Computer as Technical Assistant
 - a) Ability to structure and guide the user in his or her search.

¹ It was Ken Dueker (1987) who brought the idea of models interfacing with GIS to the URISA agenda. His original concerns were with transportation models, many of which have no way of portraying results in map form.

- b) Double checking capability. (e.g. Do you really want x or would y be just as useful?)
- c) Provide a thesaurus to pull up similar commands. The user should be able to replace a previously selected command that was not quite right, with a single click.
- d) Ability to calculate the size of the job. (e.g. Your request is likely to take about 20 minutes to calculate. Do you want to proceed?)
- e) Override options so that at any time users can slip out of the structured approach and move forward on their own.

2. Computer as Tutor

- a) Ability to get quick overview as to information retrieval options in the GIS. (e.g. You can gain access to the following items for the following geographic areas.)
- b) How to use the GIS. An overview of the kinds of queries that can be undertaken, and the steps that need to be taken.
- c) Description of GIS features. What it does and doesn't do; how it differs from others; upgrade features that are in process, etc.
- d) GIS fundamentals. Ability to get "state of the art" overviews of the field at varying levels of technical detail. Why not incorporate something like the GIS Tutor (Green and Raper 1989) Hypercard stack into the system with easy access from a main menu.
- e) GIS applications. Ability to get an overview of typical applications that relate to given subjects like urban planning, public safety, or storm-water control. The narrative would illustrate generalized solutions, perhaps describe specific solutions in given communities, and contain references to the literature.
- f) Intelligent help function. User would have easy ability to ask "what do I do next?" type questions while in the course of using the system. Advanced systems would monitor where the user was, sense his or her difficulty, and provide helpful suggestions. (e.g. Have you thought about such and such? Do you really want to do x?)

With all these possible types of technical assistance and tutoring, it is useful to ask how the computer might best provide this help to the user. What are the advantages/disadvantages of getting the assistance suggested above in audio format vs. live video vs. still graphics vs. the computer text that we are currently used to?

Conclusion

There are lots of ideas and I have no idea which ones will work. Answering that question is the job that starts after this conference.

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Biographical Sketch

William J. Craig is assistant director of the Center for Urban and Regional Affairs at the University of Minnesota and adjunct professor of geography. He is a past president of URISA (1986-87) and was chairman of the group that drafted URISA's research agenda. He organized the 1987 IGIS plenary session on GIS Management and Implementation where that agenda was first presented, focusing on the needs of the user. He served on the GIS/LIS Conference Steering Committee in 1988 and 1989, chairing the committee in 1988--the initial year of this conference. Dr. Craig's history with GIS goes back to the early 1970s when he was one of the people who helped develop the Minnesota Land Management Information System, one of the first GIS in the country; at different periods of time he served as project director and systems manager. His current interests include: sharing data among systems, institutional and technical barriers to using operational data for monitoring small areas, and developing GIS in small counties. Dr. Craig holds an undergraduate degree in mathematics and advanced degrees in geography, all from the University of Minnesota.

The rain in Spain lies mainly on the plane: Languages, users, and GIS

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Definition and Focus

For purposes of discussion in this paper, a user interface will be defined as any part of the computer system that the user comes in contact with either physically, perceptually, or conceptually. Using this broad definition allows us to examine the interface from three aspects of the user's perspective: the user's tasks (goals and intentions), the user's conceptual model of the semantics of the system, and the representation of that conceptual model as manifested in the input "language" used to manipulate operations on the conceptual model and the output display which reveals the state of the model. (Note that I have tried to make both the input and output representation inclusive of both textual symbolic elements, physical manipulation, and graphics to allow incorporation of both direct manipulation and text based types of interfaces.)

A simple problem solving model of an expert user's processes in using a computer system consists of the following:

- (1) the user decides on the next goal to achieve,
- (2) the user examines the interface to determine the current state of system objects,
- (3) the user translates the goal into a task which is a sequence of system operations on system objects,
- (4) the user executes these operations using the language of the interface, and
- (5) the user examines any changes in display to verify that the new state of objects achieved the goal.

Further references to this model can be found in Card, Moran and Newell (1983) and Norman & Draper (1986).

An oft-neglected but major challenge of good interface design is to create an appropriate translation of domain tasks into the conceptual model of the system. Well-documented work argues that successful achievement of this design goal not only promotes the economical performance of these actions with a minimum of failure, but also improves learnability. For elaboration of this task analysis approach see the work by Douglas (1983; 1989), and Moran (1983) on task mapping and the work by Payne and Green (1986) on Task-action grammars.

For the remainder of this paper, I will focus on this issue of mapping (in the conceptual sense) user domain tasks to the conceptual model of the system which I feel is the source of a great many problems with existing GIS systems. I will also put forth some solutions. In the following analysis I am particularly indebted to Claude Saunders who is completing his M.S. thesis as an implementation of this approach.

An Example

A common use of GIS is in land-use planning and management: Given a regional landscape, one must allocate land of various types to human and natural activities. Tracts of land must be found which meet certain requirements. Various interests often compete for land and an optimal balance of allocation must be found. Analysis of this sort requires thematic information such as zoning and soil composition, as well as more general information

such as altitude, water bodies, and roadways. The ability of a GIS to generate custom maps from the transformation or combination of such information facilitates such planning and management.

As a greatly simplified example, I will take the case of allocating forest land to the competing interests of timber harvesting and spotted-owl preservation. This process typically takes two stages. The first involves developing a new spatial representation of owl-habitats; the second uses this new representation to answer questions.

In the first stage, the land-use planner will have definitions of what is considered suitable owl-habitat, and what is considered suitable for harvest. In the course of using GIS to extract thematic maps from the data-layers, these definitions are used implicitly. A typical GIS for this application would have the following data-layers: Tree Diameter, Canopy Type, Tree Type, Zoning, and Roadways. The next step is to define the landscape element types for the problem. In this case we plan to define patches of owl-habitat and loggable-land-tracts and a corridor type to represent the logging roadways. Since the definition of a suitable-owl habitat also includes constraints on the proximity of other habitats, we will also be completing the definition of owl-habitat. For this example, we are saying that the average distance between owl-habitat patches must be less than six miles. The distance between a loggable-land-tract and a logging roadway must be less than 50 feet. Any owl habitat must have a minimum of 3 neighbors. The user creates a new data-layer representation of owl-habitat vs. loggable-land-tracts by piecing together a sequence of primitive GIS operations and data-layers.

Typical interactions with a GIS are procedural in nature and may consist of either a textual command language or mouse-based graphical selection methods. For example, a data-layer entitled "suitable land for road development" could be defined by this sequence of primitive GIS operations:

```
Isolate ELEVATION assign 1 to 0 through 1000 feet for ELEVATION-LOW.  
Isolate LANDUSE assign 1 to 'public' for LANDUSE-PUBLIC.  
Isolate SLOPE assign 1 to 0.0 through 0.05 for SLOPE-LOW.  
Multiply LANDUSE-PUBLIC by ELEVATION-LOW by SLOPE-LOW for ROAD-DEVEL.  
Load "ROAD-DEVEL".
```

(Note, Multiply is a GIS operator which is the equivalent of a logical AND when applied to binary data-layers. Many other operators are available, such as Add, Average, Cover, Divide, Maximize, Subtract, Clump, Orient, Radiate, etc.)

In the second stage, the planner poses a set of questions, some of which may involve changing the definitions used to define the areas. For example, "What if the average distance between owl-habitat patches must be less than two miles, how much land is harvestable?" Some of these questions may require the user to repeat many of the operations of stage one; others may demand more information retrieval.

The Problem and a Proposed Solution

As this example amply illustrates, the users must map their domain problems onto the operations provided by the GIS, and, unfortunately, there is little correspondence between the language of landscape analysis and the operations provided by the conceptual model of the system. This lack of correspondence causes a lack of economy in that many low-level commands must be executed (the assembler language level) as well as possible errors of conceptual misunderstanding. Specifically, what is missing is a high level "language of landscape ecology" which would allow a more direct declaration of the problem. Providing such a language as an interface would enable the user to declare the problem, allow some interpreter to evaluate it and generate a solution composed of the GIS command language. In short, the interaction with a GIS would be in terms of the problem domain, not primitive GIS operations.

A language talks about objects, attributes and relations. What would be such a language for landscape ecology be like? Landscapes can be examined in terms of structure, function, and dynamics (Forman, 1986). The structure of a landscape involves the spatial relationships between its basic elements. To a lesser degree, the internal composition of the elements are also considered. Landscape function involves the causal relationships between elements while landscape dynamics examines the evolution of structure and function over time.

Forman (1986) proposes that landscape ecology considers a landscape to be a collection of elements, each of which typically represents a separate ecosystem. The dynamics of the landscape are determined by the flows of energy and materials amongst these elements. There are three basic element types, the matrix, the patch, and the corridor. A landscape may be partitioned into a number of regions, each belonging to one of the basic element types. While there are numerous variants of these element types, such as the network, ring, and peninsula, this discussion will restrict itself to the three basic types. The matrix of a landscape is typically the dominant land component. Patches of varying types are scattered within the matrix and corridors of various types cut through. Each of these element types has defining characteristics. In addition, the landscape as a whole has characteristics which define the spatial relationships among the primitive element types.

It appears possible to develop algorithms which can augment human development of these landscape elements from more primitive GIS data layers. For example, the matrix is the dominant element of a landscape. Although, the definition of dominant is highly context sensitive, three characteristics are used by Forman to identify dominance. The most obvious characteristic is total area. The matrix of a landscape is generally the type of land occupying the largest percentage of area in a region. The next most important characteristic is connectivity. The matrix usually exhibits high connectivity. While this is not an absolute requirement, one can see that a matrix with very low connectivity is perhaps better described as a collection of patches. The third characteristic is degree of control over landscape dynamics. The matrix is the land type which dominates the flow of materials and energy through a landscape. It generally provides the ability of a landscape to recover equilibrium after perturbation. Having identified the matrix in a landscape using area, connectivity and dynamics, additional characteristics can be utilized for description. The porosity of a matrix is the number of closed boundaries surrounding patches of a given type. The boundary shape is the degree of concavity or convexity of the boundaries of the matrix. In essence, is the boundary rounded, convoluted, or dendritic. Each of these reflects different functionality. A related characteristic is the perimeter-to-area ratio.

A patch is defined as a non-linear bounded area of the landscape which differs from its surroundings. While there is only one matrix, a landscape may have many patches. The primary characteristics of a patch are area, shape, boundary type, origin, and heterogeneity. Shape takes such values as circular, elliptical, square, rectangular, irregular. Boundary type is like that for matrix; a boundary can be rounded, convoluted, or dendritic. Origin refers to the source of the patch's existence. A patch may be the result of a natural disturbance, human endeavor, or an environmental resource. This characteristic, while having descriptive value, is generally supplied explicitly. For this reason, it does not need to be interpreted from GIS data. Heterogeneity reflects the diversity of composition in a patch. This characteristic, like dominance, is context-sensitive and must be defined for each landscape.

A corridor is defined as a narrow strip of landscape which differs in type from the matrix. The definition of narrow will decide whether some part of a landscape is a patch or a corridor. Thus the key characteristic is width, and not area. Other spatial characteristics are curvilinearity, connectivity, and node distribution. A corridor may originate and/or terminate in patches or even other corridors. A corridor may also have breaks and narrowings. Connectivity is therefore a more difficult term to define. The frequency of patches or widenings in a corridor define the node distribution. A corridor has non-spatial characteristics as well. Origin follows the same as that for patches. A corridor may also be identified by its altitude relative to the surroundings. A hedgerow is apparent as a corridor just as a drainage ditch is.

At this point, the semantics and spatial characteristics of landscape elements have been defined. The spatial characteristics alone, however, are insufficient to allow the definition of any particular landscape. Any given landscape has many different interpretations depending on the goals of the description. For example, one could take a landscape of some region consisting of forest and bodies of water. If the goal is to describe and examine the flow of water through the landscape, one could imagine the patches as lakes and ponds, while the corridors would be the rivers and streams flowing between. All other land area, eg. the forest, could be a part of the matrix. On the other hand, if the goal is to describe and examine logging practices, one may consider the landscape as a collection of cut and uncut patches of forest. The corridors may be the streams and logging roads. Here it is perhaps more difficult to define the matrix. The point is that the user must at some point explicitly describe what they are looking for in a landscape. One cannot interpret a map from purely spatial characteristics and come up with a landscape classification. Any automated system must be informed of the land type that is to constitute the matrix, patches, and corridors.

In addition to finding the component elements of a landscape, the landscape as a whole has a number of characteristics. The distribution of patches and corridors can vary considerably. A landscape can be very regular in

appearance, or it can be dominated by a distinctive feature such as a town. Characteristics can be more numerical, such as average patch size, or average patch to corridor distance, etc. These are inter-element characteristics. Previously discussed were the intra-element characteristics. The full description of a landscape incorporates both.

Thus, we can see that a high-level language of the user's problem solving domain need not be a natural language interface, but would mainly consist of the objects, attributes and relations of that domain. The implementation of such a high level language interface depends on the success of the following elements:

- 1) Providing a declarative interface language that conceptualizes problems in the user's problem solving language, specifically for landscape ecology from the matrix, patch and corridor objects;
- 2) Providing an inference mechanism that maps from the user's language into the GIS command language;
- 3) Providing algorithms that compute spatial and symbolic relationships in the database;
- 4) Providing an object-oriented knowledge base that references the cartographic information stored in either raster or vector format; and
- 5) Providing a user interface representation that symbiotically allows the computer to augment the user's problem solving.

Conclusions

I have argued in this position paper that one source of difficulty for users of GIS systems is in the conceptualization and translation of their domain problem solving tasks into the conceptual model of the existing GIS system and its language of computerized spatial data bases. I have also proposed the creation of a high level user interface language which is the language of the domain users. This language would translate into the existing GIS command language with an inferencing mechanism and an object-oriented knowledge base. While I have focused primarily on the definition of landscape elements, once the representation is constructed, other language elements of a more information seeking nature can easily be accommodated.

Research on the feasibility of this approach is currently in progress at the University of Oregon Computer and Information Science Dept. Because of our use of inferencing through constraint-based satisfaction and an object-oriented language, several problems have emerged thus far. While the new interface will improve interaction with GIS for some problems, the inferencing mechanism cannot automatically generate object definitions and attributes without some user help. Thus, the user is still forced to spend time in a definition process due to the focus on generating landscape objects although not data layers.. This is less problematic than working in the GIS language, since it is in a language more familiar to the user. However, once a set of objects is defined, they can be referenced without further effort.

Another weakness of the system is its inability to represent "degrees of suitability". Much land-use planning involves generating maps which display suitable regions, colored or marked to express the degree to which the region meets requirements. The constraint satisfaction technique of the inferencing mechanism will generate regions which meet the constraints, but no notion of degree of satisfaction is preserved.

Early work on this interface will be completed later in the summer and we are eager to begin empirical analysis with users.

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Biographical Sketch

Dr. Sarah Douglas, specializes in advanced user interface research. Since 1983 she has been a professor in the Department of Computer and Information Science at the University of Oregon. Prior to that she was a Research Intern at Xerox Palo Alto Research Center working with Dr. Thomas Moran while finishing her dissertation at Stanford in 1983. In 1989 she was promoted to Associate Professor and became a tenured member of the faculty. She is also a member of the Cognitive and Decision Sciences Institute at the University.

Dr. Douglas is particularly interested in research on user modeling in both standard and AI interfaces, natural and artificial language interfaces, and in the process of design. She teaches two courses on user interfaces, one for advanced software engineering, and the other, a graduate seminar, on AI interfaces. Dr. Douglas is currently doing research on high-level object-oriented languages for user interfaces, simulation-based tutoring systems, and the representation of spatial and causal relations in interfaces. This has been sponsored by grants from FIPSE, US West, NSF, Apple Computer, and the Keck Foundation.

She has been very active professionally both nationally and internationally. In 1989 she served on the Program Committee for the ACM CHI Conference. In 1990 she served on the Program Committee for the AAAI Spring Symposium on Knowledge-Based Systems for Learning and Teaching. She has refereed for the National Science Foundation, International Journal of Man-Machine Systems, IEEE Software, Human Factors, and The Handbook of Human-Computer Interaction 1987. She is a 1991-92 recipient of a Fulbright Foundation award.

Directions for Research: User Interfaces for GIS

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Introduction

The field of human-computer interaction is a vast, wide-spread and interdisciplinary field of research. On-going investigations include; cognitive modeling, many different aspects of human factors which include interface design, and many studies of the physical aspects of human-computer interaction. Although there are many endeavors that have specific goals and directions this wide range of topics has caused the research in these areas to be less coherent than may be beneficial to the field. It is this type of environment that researchers in Geographic Information Systems (GIS) have entered in an attempt to both interest human-computer interaction specialists into investigating user interfaces for GISs and to conduct their own research. Understandably the research initiated by GIS professionals has been tied closely to their own interests and has been slow to gain momentum due to the mass of the human-computer interaction literature that must be examined for precedent. The research initiative of the National Center for Geographic Information and Analysis (NCGIA) is an attempt to bring together the professionals in the relevant fields to advance discussion and research in the improvement of human-computer interaction in Geographic Information Systems and to set goals and guidelines for a coherent investigation into these areas. The following discussion will attempt to present some of this investigator's views of the current situation in the field and the directions that future research should take in an attempt to improve the use of geographic systems by individuals.

Current Efforts

Some of the current research into user interface issues in GIS has concentrated on understanding the meaning of spatial terms, other research has included discussion of spatial languages (e.g., Palmer and Frank 1988). These are just some of the topics that are being investigated that relate to human cognition of space. Research in these areas has had two possible goals, one being the possible use of spatial terms in natural language query systems and another being a better understanding of issues in spatial cognition. This research is valuable for both of its aspects but, unfortunately, is of limited use in current systems. These areas of endeavor, because of their potential, must be the subject of continued research but are longer term goals that are less immediate than other concerns.

In addition to the various cognitive issues and the issues of natural language that are being investigated there are other research efforts examining human factors concerns in spatial systems. Human factors issues relating to the design of the human-computer interface are a current topic of on-going investigation (Gould 1989) and are invaluable in GIS. Human factors design issues are also recognized as important by many cartographers and are considered in cartographic design research. Some potential areas for examination include, revisiting the digitizing environment and digitizing interfaces and evaluating current GIS interfaces for human factors design errors.

A related issue concerns the style of interaction and its basic metaphor. Recent research (Gould and McGranaghan 1990) has suggested that the map (and perhaps also the layer model?) is not an appropriate organizing paradigm for interaction. Further research should be conducted to investigate this idea and determine when the map is useful as an interaction object and a metaphor. Other research (Wilson 1990) has suggested that the desktop metaphor of the typical Graphical User Interface (GUI) is not appropriate especially in constructing or compiling maps. Drawing tools available on personal computers make extensive use of paint brush and spray gun tools, are these appropriate for a cartographic drafting interface? Do cartographers and geographers think and reason about space in a fundamentally different fashion than untrained professionals? This area obviously overlaps with some of the cognitive issues concerning space mentioned earlier but also needs to be investigated from this angle.

Other current developments in the GIS field include the implementation of interfaces that are meant to be system independent (e.g., Decision Images' MapBox). These interfaces are a welcome addition to the product marketplace, however more diversity is needed in this market, as well as the expansion of the products to be compatible with more systems. This separation of the interface and the system is not altogether without controversy. Recent

discussion on the GIS electronic mailing list has centered on how knowledgeable users should be about the underlying data structure and the system implementation. There is no doubt that an uninformed user has the potential to abuse the system and produce unreliable products, but how should we safe guard against this and should we? Cartographers have not attempted in an organized fashion to educate system developers of graphics packages about cartographic design. This has resulted in many mapping programs that do not take into account sound cartographic principles and thus encourage users to produce abysmal maps. How much responsibility must our profession take for the improper use of geographic analysis? There is an obvious analogy to statistics and their improper use, but the problem is not simple since it also includes graphics (maps, as well as presentation graphics) and spatial reasoning. This is complicated by the need for proper formulation of the problem and its analysis in the GIS before the presentation of the results. At all of these stages proper user education is needed since insufficient safeguards can be built into existing systems or even those developed in the near future.

This discussion has very briefly summarized some of the more recent and important research in human-computer interaction issues in GIS and related fields. The next step is to suggest some of the directions that future research should take in advancing our current knowledge and ability in these areas.

Research Directions

Probably the foremost and most important issue of user computer interface research in GIS has been started by the NCGIA as one of its current tasks. That issue is education. As discussed in the last point in the previous section, spatial reasoning is not an equally inherent ability of all humans. The community must continue to ensure that the users of geographic systems understand the complexity of the issues they address with the system and also the capabilities of the systems. This will help to erase the argument that easy to use interfaces are undesirable since they allow users to perform analyses that they do not understand and perform them incorrectly.

The second most important issue of human-computer interaction research is education. The community of professionals must continue to educate not only the users but also the vendors. Although many developers have begun to incorporate graphical user interfaces (GUI) in their systems these interfaces have not necessarily been tested or evaluated with the typical user in mind. In a recent posting to the GIS electronic mailing list Michael Gould tried to get a discussion started on the need for designers to include more formal user testing in system design. Unfortunately although this message may have sparked interest in a few individuals no public discussion on the mailing list was started.

Another area in which user interface research should be conducted in connection with geographic systems is user interface evaluation and testing. Many system vendors have integrated their products into graphic user interface environments relatively recently. How effectively have these vendors constructed these interfaces? Are the new interfaces more efficient or understandable than the old interfaces? Or were the old interfaces not correctly implemented (given our current understanding of human-computer interaction issues)? All of these issues are ones of evaluation and comparison. Perhaps the NCGIA with its resources should establish a laboratory for evaluating the effectiveness of these interfaces. The purpose of such a laboratory would not be to recommend or compare the interfaces of competing vendors but to use current and previous versions of GISs to test evaluation methodologies and prove current research. In fact the new environments used by some vendors will allow researchers to easily change and test different interface configurations. This facility would also have the benefit of providing equipment for research into how users approach solving geographical problems and could also be used to help in research related to cognition and spatial reasoning. Since the current generation of geographic systems are more flexible in the modifications that the user can make to the interface, and human-computer interface research has shown that users do little if any customization to the default environments, it is very important that our community address the issue of the effectiveness of the current interfaces.

The final issue that will be raised here is that the community should continue its current research directions. These topics, such as natural language issues, human spatial cognition and other issues will be a necessary part of the new spatial human-computer interfaces that will be developed over the next decade. The potential of return for these research topics may not be very high in the immediate future but the long term benefits of this research will undoubtedly be substantial.

Summary

The issues that have been discussed here are not Earth-shaking issues but are an attempt by the author to address the future goals and directions that the GIS community should take. Many specific issues of human-computer interaction have not been discussed, only general topics were identified. Some of the more technical issues, such as those related to the hardware interaction level should undoubtedly be left to researchers in more appropriate and knowledgeable fields. Also left untouched in this discussion have been some of the more advanced forms of interaction, such as virtual reality. Although our discipline must, of necessity, follow the research in these areas our immediate use of such technology is in doubt. The geographic information systems field of research has many issues that it needs to solve using proven human-computer interaction methodologies and other areas that we must address ourselves, before we can help advance virtual spatial interaction techniques.

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Biographical Sketch

Alan K. Edmonds graduated from the University of Kansas with a Bachelor's degree in Geography and a specialization in Cartography in 1980. After serving in the Marine Corps as a telecommunications officer Alan received a Master of Arts degree from The Ohio State University in 1987 in Analytical Cartography and is currently a Ph.D. candidate in Geography. Alan's current dissertation research concerns formal specification and evaluation of user interfaces for cartographic systems with his other interests including User Interface Design, Analytical Cartography, and Geographic Information Systems.

User Interfaces for Geographic Information Systems

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GIS databases are often engineered from the perspective of a single user population, i.e. resource management, facilities management etc. In many cases the data model used by one user domain is not suitable for another. Reasons for this incompatibility may range from professional tradition to more practical problems such as diverse problem domains where the 'meaning' of the information is very different. A popular solution to this problem is the creation of multiple database views, one for each user population. These views act as filters, including or excluding information according to a particular view.

Views of conventional relational databases are often represented as a series of pre-programmed queries which are external to the database and must be altered separately whenever the data model is altered. Because of their nature, this type of customized view is useful for studying data in established ways but not very useful for understanding new relationships within the data.

Recently, semantic databases (semantic networks) have gained a lot of interest in the GIS community. This technology offers GIS users the potential to create new knowledge by exploiting the semantic relationships between the data items. Domain specific views of a semantic database are networks of meaning which are domain specific; they embody the semantic relationships which are considered most significant to a given user domain.

Although multiple semantic networks impose multiple conceptual frameworks on a single set of data, the form of the data does not change and may be in a domain specific form. Users may find themselves attempting to interpret information which has been presented according to conventions described by an unfamiliar domain.

Another database technology, Object Oriented databases, may offer a solution to this representation problem. These databases provide a facility to include behavior in the data description. By making the representation a function of a data item's behavior and basing that behavior on the domain context of the user, these databases may be made to tailor representations for the user's domain of interest.

I intend to investigate the feasibility of incorporating multiple user models in the description of a GIS database by exploiting the ability to include behavior in the data model of an OODBMS. In this way users might be given a more useful interface to this information.

For this reason, I am very interested in attending the I-13 meeting in June to discuss my ideas and get feedback from the GIS community.

Biographical Sketch

Michael Stephen Ellis received his Bachelor's degree in Applied Computer Science from Ryerson Polytechnical Institute in 1988 (Dean's List; Digital Equipment of Canada Award for Academic Excellence; Traugott W. Alender Memorial Award for Academic Excellence), and since September 1990 has been a graduate student in the Department of Computer and Information Science, University of Guelph. His major area of interest is Human-Computer Interaction; his other areas of interest include Object-Oriented Programming and Object-Oriented Databases. Between March and August of 1990, Ellis worked for Intergraph Canada Ltd. as a Customer Engineer; his duties included customer training and helping customers to solve application specific problems in the areas of electronic drafting, electronic document management and hardware implementation. Between September 1988 and February 1990, he worked for Advanced Dynamic Systems Inc. As a computer systems analyst and working with a team, his work with ADSI centered around the design, implementation, testing and installation of PC based customized simulation environments for the smelting industries. Ellis was Technical Manager of a major project aimed at

computerizing the production scheduling/simulation of INCO Ltd.'s nickel smelter in Thompson, Manitoba. As a result of his work with ADSI, he co-authored a paper on 'Process Plant Scheduling'. This paper was presented at the ESD/SMI Expert Systems '89 conference.

ISSUES IN THE DESIGN AND IMPLEMENTATION OF THE USER INTERFACE FOR A FOREST PEST MANAGEMENT INFORMATION SYSTEM

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This position paper outlines the user interface development strategy of GYPSES, beginning with a hypertext prototype, through a fully encoded software package for decision making. The user interface plays a critical role in the adoption and successful application of GIS technology in the information management environment. Issues to be considered in the design of the user interface include: the user's calendar of needs and operating procedures; the physical communication requirements and devices; the graphical 'look and feel' of the system; the ability to establish an interchange of data and information between system and user; what happens when you make mistakes; data input mechanisms; and product output formats. GYPSES is a knowledge-based decision support system to aid the management of gypsy moth in forested environments. The graphical user interface being developed for the GYPSES project integrates several principles believed by the design team to be necessary for successful adoption of the technology in managerial environments with little or no previous GIS experience. GYPSES' central role is to provide information from multiple knowledge-based advisors (expert systems). As a result significant emphasis has been placed on the integration of the graphical appearance and system functionality of the user interface. Many of the original design ideas were worked out and refined in a hypertext prototype which was valuable for eliciting constructive criticism and suggestions for change both from selected groups of potential users and from the different development teams.

Several design decisions were made to attempt to reduce the problems associated with rapid developments in the hardware and software industries. GYPSES has a highly graphical mode of operation; the GIS component is in the public domain to permit wide dissemination and hence feedback from users. The operating system is UNIX and the software system is modular and coded in the C-programming language.

Among the several considerations in design and development of the interface have been the implementation of a proprietary X-Windows interface to GRASS to permit the use of windows, icons, menus and pointing devices (WIMPS) in a GIS context. The use of menus and icons is extended to several basic and commonly-used GIS operations such as selection, identification, reclassification, and zooming and panning. Portability of the same user experience across multiple hardware platforms is reinforced by the exclusive use of low level functions between the user interface and GIS software, and between the GIS software and graphics functions to ensure consistency. We have avoided the temptation to use high-level embellishments of higher-level windows software. Strong modularity of components permits independent software development teams to contribute to the project from widely separated fields of experience as well as separate locations.

There is considerable debate as to the desirability of single versus multiple pathways through a system. There is only one way to access a telephone but that access produces a multiplicity of results. Should a computer user interface be as simple and as powerful? Note that the telephone interface is not limited to the handset. A directory is essential equipment or failing that, user support in the form of operators and directory assistance. By means of layered flow charts the GYPSES user interface guides an inexperienced user through the most efficient use of the system. More experienced users are provided with short cuts and tools to maximize system accessibility but they are expected to have acquired expertise. How much expertise a user can or should be able or expected to acquire is an issue for study during site testing. The user interface also provides concurrent access to different subsystems for multi-tasking and windowing. The importance of guidance and navigation through the system conflicts somewhat with the need for fully flexible access to GIS tools. At the same time the user interface should act to ensure that data are not corrupted by erroneous use, by improper operations or by inappropriate changes in the scale of resolution. Automatic documentation is enabled to permit evaluation of the use of the system. The means to store meta-data, i.e. data about data including a data dictionary, data lineage; and to present error estimations to the user are considered to be essential functions of the

user interface. We are also interested to identify those elements of the decision process which are best performed externally to the computerized package and are perhaps best left to the user.

The system can be tailored to different users and user situations through the use of a profile initiated at the start of a session. The profiler manages a set of rules pertaining to the mapsets, scale of analysis and other operational details of a particular user. A knowledge-base and interpretive rules are being implemented to aid the user in the choice of cartographic analysis and for design assistance in map production. Currently the GYPSES system is being prepared for evaluation in two field test sites; one, a county on the metropolitan fringe; the other, a ranger district of a National Forest. Each test will last for one year and will record the integration or otherwise of the system into day-to-day pest management activities.

User Interfaces for Geographic Information Systems

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The large and growing base of desktop computers with color, bit-mapped graphics and million+ pixel displays has stimulated the development of many graphical user interfaces (GUI) for use in a wide range of computer applications. Since the impetus to standardize and enhance these GUIs comes from a set of interests that is much broader than GIS, we can expect GIS user interface techniques to continue to borrow from and/or conform to the broader base of GUI developments.

This broader context does not negate the value of research on GIS interfaces. But it does affect how we shape the research agenda. For example, it would be inappropriate to focus on developing a 'standard' GIS interface, since most users will want a GUI that serves multiple purposes beyond GIS. These GUIs (e.g., OSF/Motif, Open Look, Presentation Manager, Mac/OS and the windowing systems that support them) are evolving rapidly and are far from standardized. GIS use will be only a small part of the marketplace for shaping the features of these GUIs.

With this context in mind, I suggest some exploration of the following three sets of research questions:

1. What user interface techniques can help simplify, accelerate, and enrich the spatial modeling and analysis aspects of GIS use?

To date, much of the investment in GIS technologies has been driven by the need to encode, edit, geo-reference, and classify base maps and related data, or by the desire to automate frequently executed spatial queries and spatially referenced reports. Existing GIS user interfaces reflect this emphasis -- it's easy to select and edit visible features, list and modify their properties, and trigger the execution of pre-packaged reports and maps. But it's not easy for the modeler/analyst to construct spatial queries with complex SQL queries (e.g., with complex joins and subqueries), with multimedia components (e.g., sound, images, histograms, hypertext, etc.), with links between autonomous modeling components (e.g., J. Haslett, et al. "SPIDER--an Interactive Statistical Tool for the Analysis of Spatially Distributed Data," *Int. J. of GIS*, 4:3, 285-296), or with complex data manipulation pipelines (e.g., filter and then subtract 'before' and 'after' images, register them with a vector-based map linked to a snapshot of demographic data, model the spatial distribution of population changes, and correlate it with other graphically-selected features such as roads or particular land uses).

As more and more data and base maps come on line (in different forms and on different platforms), the research needs are shifting toward modeling and analysis issues for which the relevant user interface needs are more like those of simulation games, CASE development tools, interprocess communication, and analytic modeling. For example, the graphical selection aspect of many GIS queries will not be an isolated step that operates only on simple spatial features (say, parcels inside an interactively-selected region) in order to produce a single pre-constructed outcome (say, highlighting of all parcels with sales price > \$X). Instead the user might want to imbed this graphical selection step in a more elaborate, and interactive, modeling exercise. For example, the user might want to send data about the parcels to a statistical package, or highlight via color shading the difference between the sales price and some predicted value. The predicted value might be computed via a size+location model whose components (e.g., key roads, or centers of economic activity) are also selected interactively by the user. The flexibility and generality of the graphical selection tools and the management and editing of the spatial models will become increasingly important -- and amenable to good user interface design.

Another way of addressing Question #1 is to ask what are the bottlenecks peculiar to spatial modeling and analysis that might especially benefit from emerging technologies? All GUI designs involve tradeoffs -- speed, memory, complexity, real estate, etc., and new technologies are continually changing these tradeoffs. We are beginning to see the potential of parallel processing, intelligent agents, object-oriented programming, PEX pipelines, 100 Mbit networking, 24+ bit-plane graphics, etc. What aspects of spatial modeling and analysis enable these newly emerging technologies to make improved user interfaces practical?

For example, compared with ordinary 2-D and 3-D graphics, GIS applications tend to require that spatial features be dynamically linked to large, time-varying datasets. Using the data attributes to construct purposeful false coloring of spatial features can help an analyst see spatial patterns that would otherwise be hard to compute or explore - especially if the coloring of the features can be dynamically changed using a user-controlled 'dial' that, say, determines the range of data values to be highlighted (or the time period to be considered). Color table manipulation capabilities of new user interface toolkits (e.g., Motif), allow such dynamic change of coloring to be nearly instantaneous on any X-based workstation or X-terminal. [J. Ferreira & L. Wiggins, "The Density Dial: A Visualization tool for Thematic Mapping," GeoInfo Systems, Nov./Dec. 1990.] Even more extensive color manipulations and interactive 'overlays' can be supported through the manipulation and masking of bit planes. As fast graphics workstations with 24+ bit planes become affordable, visualization techniques that were too computationally intensive to be used interactively on real-sized problems will become practical -- and will require good user interface design to manage the complex choices and animation effects.

2. How can user interfaces for GIS help simplify, standardize, and enhance a 'cooperating applications' model of unbundled GIS technologies that are distributed over the network?

As the modeling and analysis applications of GIS technologies gain in importance, the packaging of these technologies is likely to change. More and more database, statistical and analytic modeling tools will be desirable and it will become increasingly difficult for the GIS vendors to include all the 'required' features as part of a single package. Likewise, the changing economics of desktop computing will entice many applications (e.g., statistical and network analysis packages) that haven't previously provided spatial analysis tools to including mapping, spatial queries, and the like. GIS vendors are already beginning to use standard database management packages (on database servers) that are linked to the vendor's graphical editing, display and processing routines. GIS vendors are also beginning to rewrite their packages in order to isolate their algorithms and 'backend' processing from the GUI (e.g., Microsoft Windows, X11R4+Motif, etc.) in the hopes of providing a user-customizable interface that is standard across many applications, conveniently modular for the software developer, and asynchronous and event-driven in design.

This trend toward unbundled and distributed GIS tools complicates the user interface design. The software 'layering' becomes more complex as the GUI, the modular applications, and other processes must communicate with each other (possibly across networked machines). This communication must handle complex race conditions (e.g., another program opened a window on top of my map before the mapping package processed my mouse click to select a feature). In addition, the nature of the communication becomes an aspect of the modeling and analysis that the user may wish to control (e.g., which statistical package, where should the query results be sent, etc.). While any number of distributed computing applications face this set of questions, spatial analysis and modeling applications are likely to face a relatively complex mix of interprocess communication, visualization, and user interface issues.

3. What must the user know in order to use GIS tools of the future for spatial modeling and analysis?

Suppose we implement some suite of unbundled GIS tools distributed over the network (as suggested in #1 and #2 above). Should the user interface hide the distributed computing from the user, permit the user to manipulate the inter-process connections graphically, or make the connections apparent only when they breakdown (as a form of context-sensitive help)? What must the user understand about the tools, the data, and the manipulation language in order to be effective? Suppose, for example, that a user wishes to model the impact of a proposed transit line extension on the surrounding community. One can imagine a SimCity-like user interface whereby the user 'bulldozes' property and graphically lays down the new transit lines (or bus routes). Meanwhile, a 'backend' model would calculate affected features, alter the appropriate parameters of a land use model, and simulate (or otherwise compute) and display the evolving land uses, changed ridership, altered modal splits, and other impacts.

To what extent can we make this exercise an exploratory modeling and analysis activity rather than a black box exercise with little opportunity for the user to access (let alone understand or change) the model components or to control the aggregation choices required to calibrate the model from underlying data? With multiple windows, intelligent agents, accessible DBMS and statistical functions, and facile modeling tools, tomorrow's professional should be able to design, discover, and explore a richer set of alternatives without sacrificing flexibility and control over the modeling process to the application developer. What programming and analytic modeling skills should this professional have, and what modularity of modeling and spatial analysis tools and user interface technology provides

the 'software layering' needed for the activity (and the professional's understanding of it) to be practical and meaningful?

Biographical Sketch

Presently, I'm a Professor in the MIT Planning Department where I teach courses on analytical methods and computer-based modeling for planning and urban management. Since I'm a strong believer in rolling up one's sleeves as part of the learning process, these courses include a heavy dose of workshops, internships and special projects involving local planning departments, transit authorities, interagency GIS task forces, and the like. My current research interests involve database design for sustainable, distributed urban information systems, and the development of visualization tools and decision support systems that will improve the professional's access to parcel-level data and relevant GIS technologies.

I am also the Director of the Computer Resource Lab for the MIT School of Architecture and Planning. This Lab provides teaching and research facilities for the Architecture and Planning Departments. The Lab's computers range from various Macintosh and IBM personal computers to more than 2 dozen Unix workstations running TCP/IP and X. These multi-tasking, multimedia workstations provide network access (via ethernet and the MIT spine) to distributed software tools for GIS, SQL, CAD, video, image processing, and analytic modeling.

My degrees are also from MIT -- S.B. in Electrical Engineering, 1967, S.M. in 1970, and Ph.D. in Operations Research, 1971. I've been on the MIT Planning Faculty since 1971 with a two-year leave of absence (1976-1978) for work in Massachusetts State Government. For the past few years, I've been a member of the URISA board of Directors.

Concepts that determine the user interface¹

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1. What is the user interface?

User interface is apparently a technical term describing the interface between the system and the user, but clearly seen from the systems perspective. In a recent paper, Grudin argued convincingly that this is a misnomer, in the same class as 'casual user' (typically an expert at a given task, for example a lawyer, but one that is not interested in computers and how they work) and other terms used in this context (Grudin 1990). Grudin indicates that the user interface should be considered broadly as all aspects of how the user (i.e. the end user in computer jargon) interact with the computer system. This does include considerably more than the command names or the color of the menus. It includes the user manual and all other literature the user sees, the training of the vendor, and the form of the output etc.

2. Why does the user interface matter?

In a first phase the major concern for GIS software designers was to find ways to construct programs that did (more or less) what people wanted on the hardware available to them. The user -planners, surveyors and the general public - stood in awe when a computer drew a map, often without sufficiently critically questioning whether the results were useful. This time has fortunately passed, as can be observed during the large exhibitions of GIS equipment, when every vendor shows very similar 'glitzy' screens and the public passes by, taking this level of achievement for granted.

Parallel to this, one might also observe a change in the attitude of reports about GIS installations (Crowell 1991). In the early days, the 'champions' reported about the magnificent plans they had and how GIS would solve important problems and would contribute to overall improvement of their agencies' performance. They listed equipment bought etc. The current focus has moved away from hardware speed (where some of the vendors would prefer to have the debate), away from functionality expressed as long lists of commands and towards solutions. Buyers at exhibits are interested in complete applications that demonstrate answers to their needs and reports are welcome if they show the real contribution to the organization. A recent research initiative of the NCGIA was centered around the concepts of 'use and value' of geographic information (not GIS). Preliminary results indicate that not all the factors that lead to adoption of GIS technology in an organization - which are the ones often discussed and studied - also lead to its contribution to the organization's goals - the value of GIS.

The difference between buying a GIS, adopting GIS in an organization and the GIS contributing to the organization's goals, is not in the hardware speed nor in the lack of basic functionality in a GIS (most GIS offer by now the most fundamental operations with sufficient performance (Denmark 1991)), but rather it is in the effective use of these tools to solve the organization's problems. The user interface is one of the major contributing factors - depending how one defines 'user interface' it may be the factor. It is well known, that cost for training of personnel is often higher than the cost for the system (hard- and software). Training of a few people for a few month quickly adds up to a man-year, with a cost of \$100,000 or more. The interest in user interfaces is therefore economically warranted.

Assuming that a GIS provides the functionality an organization needs (and this is most likely the case today), we posit the hypothesis that

the user interface is the most important factor contributing to the economic success of a system or its failure.

This is certainly justified by the observation that systems that are adopted and installed but not used are obviously economic failures because they cannot produce any benefits. Casual observations of word processing users - users that spend 50% of their working time with a given program - reveals always, that users are quickly satisfied with

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the few basic operations and (probably in their great majority) never really learn most of the commands. For the success of a program it is not relevant if a command is available but it is relevant if the user does know about it - it cannot produce a benefit otherwise. Oftentimes, the remedy is to provide more training or point to the manual that the user should read, but this first costs money (employee time) and is strongly resisted. Thus it does not address the issue.

The most important cost factor in using a system is - the time of the employees using the system. For example, the cost (not the salary) of an employee with an advanced degree is above \$80,000 per year - a single GIS workstation, software included, is perhaps \$20,000 per year (and is often shared by more than one employee). Again, productivity of personnel is crucial and the user interface certainly influences this. There was a study made by a renowned management consulting firm which indicated that productivity in comparable situations differed between an Apple Macintosh and an IBM PC considerably - the difference clearly attributable to the difference in the user interface (Command line interface vs. WIMP).

For tasks that are performed very often during a working day - repetitive operations that some workers perform hundreds of times - it is worthwhile to carefully optimize performance. There are methods known - key stroke model and later refinements (Card, et al. 1980, Card, et al. 1983)- that allow the prediction of the actual performance of real people, once they have mastered the system so they perform without error. This might be of importance for some parts of a GIS interface - digitizing tasks for example - but for most of the uses of GIS the problem is not at the level of automatic, repetitive steps but the solution of complex application problems.

3. Interface as communication

The individual using the computer program and the computer program must communicate in some form, exchanging information about the tasks and their results. This exchange is not a communication between equal partners - at least not with the current state of the technology. The behavior of the computer is fully determined by the program. The burden to adapt is on the human user. It is expected that they learn the language the computer uses (like an inflexible administrative agency - for example the IRS - where the clients are supposed to learn its jargon etc.).

Much attention has been devoted lately to details of the user interface. One of the most important achievements is the attention to consistency in the interface - mostly recommending that similar actions or similar symbols have similar meaning. Guidelines have been prepared for different interface styles which indicate how buttons, menus and icons should be used and what symbols should be used consistently. It is clear - for example from the success of the Apple Macintosh - that this is an important effort with an enormous payback (it is rather surprising to see, that this is difficult to achieve and more often than not violated in important aspects - e.g., in MS Windows 3). Consistency simplifies the user's learning as he/she has to learn only one basic vocabulary for all programs, not a new one for each one. This could perhaps be likened to the grammar and the closed class vocabulary in a language: it provides the basic structure to express complex ideas with specialized vocabulary.

4. Communication relies on context

To understand (i.e. to interpret) the symbols exchanged in a communication requires a context established. In human communication such contexts are established by the circumstances of an exchange and the commonsense knowledge shared in a culture. It was estimated that to understand 1 fact in a dialog, about 7 additional commonsense facts are used (traupel, video), but human dialog patterns contain numerous methods to establish common context and feedback mechanism to assure the commonality of the context. This is not the case for user interfaces - the computer program does not contain provisions for dealing with situations where the context of the human user differs from the one the program assumes (some context sensitive help facilities provide reminders for the user of the definitions of terms used, thus asserting the communicative context). It is the user that has to learn the context of the program - i.e. the conceptual context embodied in the program by the programmer. This leads to a second hypothesis:

Programs embody a complex conceptual context that the user must learn in order to understand the program and the required input, the output and the documentation.

This is not so obvious for the standard 'office application' programs like word processing, where the program can rely on the common sense understanding of letters, paragraphs etc. (but observe the difficulties that result from discrepancies between the commonsense definitions and the technical definitions of a paragraph in a program like Word), but is required for complex applications like accounting - where one has to learn the accounting practice of the company - or GIS. Some vendors provide a system with an "Introduction to GIS" text, which explains to the new user not only what a GIS is but also the conceptual framework for GIS this vendor uses, and last but not least, the

terminology to be used. This is an effective means to address this problem for novice users, who must learn all about GIS. It is not practical for people with a background in GIS (for example, from using another GIS) who know most of these basic principles, but expressed in a different conceptual framework.

5. Design conceptual framework should be a rational process

The conceptual framework of current GIS are the results of an evolution, not a deliberate design. They are more influenced by the demands of an implementation, the background of the software designers and programmers working on them etc. than the result of careful rational decision-making. As a consequence, they contain contradictions. The same term may mean different things under different circumstances and two different terms may describe the same idea. Most of all, they most likely contain concepts that are not really necessary to understand or perform the task from a user's perspective, but were included as they explain the internal workings of the program. It is important to note that the collection of concepts is not limited to the ones found in the 'user interface' of the program in its narrow sense, but includes all concepts that appear in the literature, user manual, training etc.

As the user has to learn all these concepts, the hypothesis that

the number of concepts in a system is related to the effort to learn the system

is justified. It would therefore be worthwhile to analyze the conceptual structure of a program and redesign it carefully to reduce the total number of concepts. If a set of concepts is carefully designed, it should be possible to explain them in a relatively short document. Programs are often constructed from the 'code' outwards - the user interface and the manual are the last effort - explaining to the user what the program does. This is of little interest to the user - he does not want to learn what the program does, but wants to learn how the program helps him doing his work.

Not only should the concepts be explained in terms of the user's task, but the whole program should be designed from this perspective - first the conceptual level design, then the user manual and the interface and then - last - the implementation. This is often proposed but very seldom done.

The 'casual' user that has to solve a complex problem using a program wants to concentrate on his problem. He is forced to translate the task from his application language and concepts to the command language and the concepts of the program. The closer the two, the easier the translation task (optimally there would not be a translation and the task is understood by the user in the conceptual framework the program uses). One could formulate a hypothesis that

users are more effective using a GIS if the task related and the GIS enforced concepts are similar.

6. Why is that of particular importance for a GIS?

The discussion so far is generic for most information systems and not particular for GIS. A major problem of a GIS is the modeling of space and spatial objects. Every information system uses a data model and specifically, every GIS uses a geometric data model. The facts about the world and the tasks must be translated into this model, which is not always possible. The geometric models of the GIS and the spatial concepts of the users are varied and translation between them is very limited. This is different from, say commercial operations, where the conceptualization of an accounting system is quite limited and implementation comparable. GIS differ most substantially in the geometric model and therefore in the spatial concepts that they can be used to represent. With the geometric model comes the appropriate operations (and other operations that are not compatible with the geometric model cannot be provided).

Today's GIS evolved from an ancestry of map maintenance systems, computerized systems to maintain a spatial data collection in form of graphical maps stored in computers. This is quite natural, as maps have served for a very long time not only as a means of communication of spatial phenomena, but as the prime method of storage of spatial data. Only with the advent of computerized spatial databases and flexible (cartographic) output programs has it become possible to sever this linkage - the cartographic representation and the internal representation for storage and manipulation (including spatial analysis) are not necessarily the same or strongly related. This has consequences for the user interface, where I see still enormous reliance on 'map' concepts and a mixing of analytical operations and their cartographic implementation. It is probably not often that the goal of using a GIS is the preparation of a map, but more often some space-related decision that must be taken. We too often assume that a map is the appropriate information product that the GIS should produce - despite the fact that we know that a large percentage of the population cannot interpret maps. Other means of communicating spatial information from the GIS to the user should be found and the GIS interface should not rely exclusively on a map metaphor.

The geometric models of different GIS vary in small details and these details are shown at the user interface. This contrasts with other areas of data management, where the interface is based on a 'reference model' of the data model - usually the relational data model - and the semantics of the operations are explained in these terms. The actual implementation may vary and may offer some additional features, but a user who has learned the reference model is most likely able to use the system effectively (SQL standard). It is important to recall that a standardization of the SQL query language is only possible, because it is defined in terms of the reference model. A similar effort is currently not possible for a spatial query language, because there is not yet agreement on a spatial data model (or a few spatial data models) as reference models. This is probably a very important research problem, which would have immediate benefits.

Goal:

Define a small set of generic spatial data models for reference purposes and define user interfaces in these terms (not in terms of the actual implementation).

Benefits:

- standardization of user interfaces
- reference models must necessarily be simpler than the current (idiosyncratic) models

7. GIS and their interfaces are classed by spatial concept

In the absence of an encompassing spatial concept and recognizing the probable existence and concurrent use of multiple spatial concepts for different tasks, GIS must be built to deal with a specific spatial concept - the raster model (or Sarah Douglas' matrix, channel, regions model of space), the coverage model etc. Each of these models relies on an implied metaphor of varying complexity and for each a geometric reference model can be established. Interfaces for these reference models can be created easily and - I assume - will be straight forward. Conceptual interfaces for any of the 'pure' spatial concepts are easy to understand - it does not take more than a few minutes to understand the concept of Tomlin's map algebra and a number of very convincing visual interfaces have been presented (Kirby and Pazner 1990).

Then - where is the problem? The problem is in the attempts to stretch these geometric data models to make them include more than one spatial concept - arguably necessary to make them practically useful, as most realistic tasks use more than one spatial concept (typically planning requires an area concept (categorical coverage) and a networked concept for e.g.. traffic). I conclude that the most pressing research problem in user interfaces for GIS is to study:

- how multiple spatial concepts are blended in actual use;
- how combinations of geometric models can be formalized; and
- how the interfaces for the single geometric models can be merged.

Realistic GISs are complex systems (and most current GIS prove that with their training requirements) - but they can be constructed from simpler parts. Mastering the complexity is the word!

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Biographical Sketch

Dr. Andrew Frank is the New England Section ACSM Professor of Land Information Studies and Associate Professor in the Department of Surveying Engineering at the University of Maine. He is also Cooperating Professor in the Department of Computer Science. Dr. Frank received his Ph.D. (1982) from the Swiss Federal Institute of Technology, Zurich, Switzerland with a thesis on Data structures for Land Information Systems: Semantical, Topological and Spatial Relations in Data of Geo-Sciences and a Dipl. Ing. (1978) from the same institute. His research is related to geographic information systems and he has published extensively on the handling of geometric data in computer systems, increasing modeling potential of database management systems, and improving the human interface of a GIS, including visualization of geographic data and cartography.

Dr. Frank is one of the Associate Directors of the National Center for Geographic Information and Analysis, and directs the operations at the University of Maine. He has served as chair and member of a number of technical committees of professional societies. In particular, he has been appointed member of the Committee on Geodesy, National Research Council for 1990-1993. In addition, he is corresponding member to the IGU GIS committee and serves on various program committees for GIS and spatial data handling conferences. Dr. Frank also cooperates with researchers interested in GIS in South America and he participated in the organization of the 2nd Latin American Conference on Geographic Information Systems Technology in Mérida, Venezuela.

Dr. Frank is an active researcher; his current work, with support from various sources, especially from industry, deal with most aspects of GIS software. He is currently working on topics in database management systems, software engineering and user interfaces for GIS, and is currently working on geometric modeling and qualitative spatial reasoning using AI methods.

Dr. Frank teaches courses in spatial database design, interactive query languages, computer graphics, and interactive land information systems.

User Interfaces for Geographic Information Systems

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There is a great deal of opportunity for human factors engineering in current GIS implementations, especially with respect to such issues as dialogue management and windowing. However, the issues I am most concerned with at present relate to the use of the GIS as a modeling tool. I am especially interested in issues of quantitative data representation as they apply to spatial data. For example, how does one represent a hydrologic parameter (such as porosity) when each spatially located point is itself a tuple describing the statistical characterization of the parameter at that point? How does one display "error bars" on spatial surfaces overlaid upon a map? Beyond the display of quantitative information, I am also interested in graphical interaction mechanisms, especially with respect to interactive modeling (a la spreadsheets). To return to the hydrology example, how might an analyst manipulate the layer of data representing the porosity in order to ascertain the sensitivity of other parameters to such changes?

Biographical Sketch

Steve Frysinger is an Environmental Systems Engineer at AT&T Bell Laboratories, specifying computer-based information systems to facilitate compliance with environmental regulations. His current research is on dynamic visual and auditory data representations for complex data analysis. He currently is developing a decision support system with a GeoGraphical User Interface to assist with modeling of groundwater hydrology relative to the location of RCRA monitoring wells. In the past, he was a Display Systems Engineer (Bell Labs), designing and evaluating GUIs for ocean acoustics analysis and modeling, and an Information Scientist (Exxon Research), investigating novel representations for complex multivariate data related to geological exploration. He has served as Chair of Township Environmental Commission, a Member of Township Planning Board, and a Trustee of Association of NJ Environmental Commissions. Mr. Frysinger holds a BA in Environmental Physics, an MS in Computer Science, an MS in Applied Psychology, has taken additional graduate courses in Environmental Planning and Management and Environmental Law.

Titles of some of his papers include "Dynamic Representation of Multivariate Time Series Data", "Communication with Sound", "Pattern Recognition in Auditory Data Representation", and "Applied Research in Auditory Data Representation".

Position Paper for A WORKSHOP on GIS User Interface

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Many potential uses of GIS have been identified. Most of these are contained in what may be called the static domain. This domain consists of output display on a computer screen, the most common display device associated with personal computers and mainframe workstations. Most screens have color capacity, and can artistically and informatively display two- and three-dimensional diagrams, surfaces, or maps and graphics. Undoubtedly, this form of display will continue to be the prime output device for geographic information systems, along with appropriate hard copy color units.

Hardware/Software

Traditional input to geographic information systems usually consists of digitized information (usually of maps), accompanied by lists of attributes and features collected in tabular form. Preparing such input is often time consuming and tedious, but it will probably continue to be the main source of input interface with geographic information systems for some time yet.

My concern is the development of alternatives to both input and output interfaces. On the input side, I am interested in exploring the potential that various optical scanning devices and associated software have for inputting map, graph, image, tabular, and verbal descriptive information. Given my interest in developing extremely detailed data sets for navigational, rather than display purposes, it is important to examine different alternatives that can provide the accuracy of information required as well as the detail, without the need for intensive field work.

On the output side, my interest in navigation, particularly for blind or vision impaired people, makes me interested in information display that is non-visual. This implies either tactile or auditory display capabilities. While tactual display requires a solution for many traditional cartographic problems (such as the amount of information presented, symbolization, relief displayed, generalization, and simplification), auditory display, whether directly through a voice synthesizer or through a virtual sound system, presents a range of problems not normally addressed by the geographer. Past NCGIA initiatives have paid attention to the problem of defining a language that can represent spatial information in a relatively unambiguous way. The conflict between natural and technical language has been identified but continues to be a source of major problems in terms of the ability to provide accurate and unambiguous directions or descriptions of places, routes, or areas. There appears to be many advantages associated with the development of virtual auditory display systems. In such systems, elements of the environment identify themselves through synthesized speech or sound. For small areas (i.e., the proximate environment) it can be potentially useful for identifying what lies in one's immediate vicinity, what hazards or obstacles have to be avoided, and to determine direction, orientation and heading for travel purposes. In larger areas, talking maps could also be developed and, using devices such as NOMAD (an auditory-tactile information system developed by Don Parkes at the University of Newcastle, New South Wales), can provide informative display systems for blind and vision impaired users.

In the domain of navigation and wayfinding, substantial gains have recently been made by interfacing GPS with GIS. This same type of technological interface can be as useful for the surveyor or geodesist, the inter-city traveller using an auto, the bus traveller commuting from suburb to city, or the pedestrian travelling in a familiar or an unfamiliar environment. My interests currently are in examining how GPS can interface with various types of data bases contained in a GIS to provide locational information and description of spatial layout at various scales. Questions of accuracy, timing, and translation from global coordinate systems to local relational systems all need to be solved in theory and practice.

As an end product, tactual maps, virtual sound systems, or speech synthesized instructions, all carry with them unique problems that require solution before GIS output can be examined and interpreted. While it is probably best to focus at this time on input and output interfaces for a simple purpose such as wayfinding in a strange environment, it

seems quite feasible that within a short time, multi-media input and output interfaces will be available and will be useful for many types of GIS use.

User Interpretations of Displays

Once the type of input/output devices have been solved, yet another important problem surfaces. Can the observer adequately interpret the output? Can the deep structure of the output be discerned? In other words, does the type of output lend itself to appropriate interpretation?

The question becomes important when we realize that selected displays can obscure what should be obvious. For example, people generally are not good at visualization of spatial association/correlation between data sets such as maps - except where very high positive or negative associations occur. Similarly, we know little about our ability to visually extract patterns from background noise - as in recognizing a regularity in, say, emergency service locations when submerged in a landuse base map.

What is needed is an examination of just how well spatial primitives and their derivatives can be perceived, and a resolution as to whether or not specific "expert" training is likely to be required to fully exploit the information processing capabilities of naive users. For example, how well can people regionalize a spatial display? Can hierarchical order be discerned? Are regionalization and hierarchical ordering two essential ways of looking at spatial data? These and similar questions beg to be examined before we can proceduralize display interpretation or evaluate the worth of different types of displays.

My primary purpose in coming to this Initiative Session is 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.

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Biographical Sketch

Professor Golledge obtained his degree from the University of Iowa in 1966 on a topic combining decision making theory and movement theory. His previous degrees from the University of New England in Australia focused on rail freight traffic. Currently he is a Professor of Geography at the University of California, Santa Barbara and has served a four year term as chair of that department. Prior to that he was a Professor of Geography at Ohio State University and the University of British Columbia and has held visiting positions at the Universities of Auckland, Texas, Sydney, and UCLA. He is the author of about 100 articles, chapters in books, and books. Many of these relate to transportation topics, particularly decision making and choice theory. His recent interests have been in behavioral geography, emphasizing such concerns as cognitive mapping, consumer behavior, and the wayfinding activities of children, adults, and special populations such as the mentally retarded and the blind. Since losing his sight in 1984, he

has focused a major part of his research on navigation without sight, a project jointly undertaken with Professors Jack Loomis and Roberta Klatzky of the Psychology Department at UCSB and Jim Pellegrino of Vanderbilt University.

USER INTERFACES FOR GIS: KEEPING UP WITH THE HCI COMMUNITY

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Introduction

The design of geographic information systems has always depended on emerging technologies in other, more mainstream, fields. GIS inherits its graphics from CAD/CAE, its database management from MIS, and many of its algorithms and data structures from general computer science and image processing. It is not yet the case that hardware/software vendors mention in their advertisements "Now compatible with XYZ GIS!" as they do for products such as AutoCAD and Adobe Illustrator. A few exceptions now appear in GIS trade magazines.

The general computing community does not yet know about GIS. In 1988 I was disturbed to hear from a vendor of plot-spooler software (to allow a computer to work on another task while a "drawing" is being plotted) that they had not heard of ARC/INFO, then and now probably the most widely-known GIS in the world. This lack of awareness is not because GIS is considered unimportant or uninteresting; one can hold the attention of nearly anyone sitting in the next airplane seat with a folksy description of "computer mapping" or "computerized environmental decision-making". It is just that GIS currently lacks the critical mass necessary to sustain its own optimized technology, high-profile marketing and, thus, a popular following. Years ago I heard predictions of technological innovations such as "polygon overlay on a chip", but even today's skyrocketing GIS market cannot support the manufacture (or even design) of such a chip. On the other hand, graphics boards are released each year by third-party vendors, designed to increase AutoCAD's drawing speed.

Now we are hearing murmurs that in the near future "everyone will have a GIS on their desk," in the same sense that we now have access to word-processing. I believe this prophecy to be true, and that public access to GIS is more a social blessing than a nuisance. I also believe that there must first exist a strong theoretical base for human-computer interaction (or human-problem interaction, Mark and Gould, 1991) explicitly aimed at geographic problem solving. Lacking this base, we-the GIS research community-will be forever adapting and reformulating ideas and technology from other fields. How long can we survive as scavengers of ideas and technology, attempting each time to modify the new innovation to suit spatial data?

Catching the HCI Community

Today's GISs have slick mouse-driven user interfaces, but let's not pretend that they are at the cutting edge. They still lag behind mainstream computer software in this area. The human-computer interaction (HCI) community, which sponsors mainstream user interface innovation, is a dynamic and a competitive community. To cite one quality-control/competition metric, most abstracts submitted to their conferences are rejected, something which cannot be said of GIS conferences. The window-icon-menu-pointer (WIMP) paradigm that is now the hottest topic in GIS marketing, was conceived in the 1970s by research groups within this mainstream HCI community, most notably at the XEROX Palo Alto Research Center. The lineage then proceeded as follows: Apple's Lisa, then Macintosh, then X-Window, then Open Look and Motif, then Microsoft Windows, and then, finally, WIMP-based GISs. It would seem that the GIS community has lost its chance to catch the HCI community as far as innovative user interface design is concerned. GIS designers are at a 20 year disadvantage: we were printing maps on lineprinters when today's WIMP interfaces were being developed.

The HCI community is currently quite strong in the following areas of the user interface research field:

- User testing
- Natural language interaction
- Ergonomics (what "feels right")
- Cross-cultural interface testing
- Iterative system design; rapid prototyping
- User interface management systems (UIMS)
- Input device testing (touchscreens, mice, stylus, etc.)
- Mental (user) models of systems

These topics, and many others, are reviewed by Helander (1988) and Laurel (1990). All of these areas are directly applicable to GIS design, but we must determine what unique modifications geographic data will demand.

There are two approaches, as I see it, to catching the HCI community in order to be in a position to provide optimal GIS user interfaces:

- 1) Pump millions \$ into HCI-for-GIS research (create the NHCIGIS!)
- 2) Join them

The latter seems most feasible and it does not involve "surrendering". It can happen without compromising one's research agenda, theoretic bent, or job title. Most HCI researchers hold positions within cognate disciplines such as applied psychology, computer science, and industrial engineering. Like cognitive science, HCI is heavily interdisciplinary. So then, why not add geography, soil science, or landscape architecture to the list? We, at Buffalo and at the Maine site as well, have found several HCI researchers to be interesting, friendly, cooperative, colleagues, who are intrigued by the variety of spatial problems yet to be solved.

We should not assume that we are designing GISs in isolation of mainstream HCI, as it affects us in nearly everything we do in support of our users. It is in our best interest to get in on the ground floor of innovative HCI research and not feel as though we are at the mercy of their next innovation.

Keeping up with the HCI Community

Once we catch the HCI community, hopefully by joining it, then we must keep up the pace! The GIS research community has much to offer the HCI community. There are a few areas in which the GIS research community has a major advantage regarding the design of interfaces for GIS and other spatially-referenced systems.

- History of geographic thought/theory (since Eratosthenes)
- Cartographic training
- 25 years of experience with GIS and GIS users

Admittedly, the GIS community knows very little about the first point (i.e., we have no coherent, overarching spatial theory). But at least we recognize it as problematic and are attempting to do something about it-among other places in several of the NCGIA research initiatives. Identification of spatial theory should remain at the forefront of our thoughts and our discussions at the Initiative 13 meeting.

In Search of Spatial Theory

Without a coherent spatial theory to guide user interface design, we will spend much of our time shooting in the dark, reinventing wheels, and other cliches which I can't remember just now. With a rough skeleton of what the spatial theory ought to be, then at least we will have a repository in which to put all of our research results that do not seem feasible for immediate implementation in a GIS. I am one of those people who think that GIS really can contribute to the general philosophy of geography.

An Example

My dissertation research finds me testing "future GIS users": professionals and students in fields such as civil engineering, geology, and sociology. I have tape recorded some 75 interviews with Spanish and English speakers (in Quito and in Buffalo) regarding spatial problem solving using paper maps. I am now beginning to analyze the transcribed (ASCII text) data using automated protocol analysis software. What I hope will be the fruit of my labor is that I will have something to say about the manner in which people structure and describe spatial relations WITHOUT A GIS, so that we might design GISs (especially query languages) that reach out to meet these common human abilities and linguistic formats. The beauty of this bottom-up approach, in my humble opinion, is that even the residual results, which do not directly relate to GIS design, will be of some value to our general understanding of spatial thought, behavior, etc.

It would be really nice if there were available a robust, coherent spatial theory for me to hang those residual results on. I see that as a major goal of this research initiative. Let some other computing sciences research initiative worry about the best way to write a C program to manage spatial data. We will best serve the GIS user, the HCI community, and ourselves if we continue to do what we do best (and many of "us" are geographers; some might say scientists).

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Biographical Sketch

Michael D. Gould received a BA in Geography from the University of Massachusetts and an MA in Geography from University at Buffalo. He is currently a Ph.D. candidate and a research assistant at the NCGIA, Department of Geography, University at Buffalo. The dissertation, to be completed summer 1991, is titled "Human-Computer Interaction for Geographic Information Systems: Natural Spatial Language in English and Spanish." His main research interests are in cultural differences in spatial language and thought, as related to user interfaces for GIS. Between degrees, he has worked as research programmer for the Harvard Laboratory for Computer Graphics and Spatial Analysis and as GIS analyst for an environmental consulting firm in Columbia, SC. After graduation, he will work in some combination of GIS industry/academia in Spain.

User Interfaces for Geographic Information Systems

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Before human-computer interaction for GIS can be discussed, much thought must be given to a further refinement of the topic. GIS is at best loosely defined; thus, designing a user interface for GIS is a task with little hope of accomplishment. In order to better our odds, the design process may be broken down into the identification of three components: purpose, audience, and format. The purpose of the GIS user interface defines the functionality of the package; the audience defines for whom that functionality is intended; and the format is the vehicle by which the functionality meets the audience.

The purpose of software is usually determined by the demands of the occasion. The demands may be from existing or expected users, such as a product specification for a display and query package which arrives on the desk of an engineer who must then meet each of the specified functions. Or the demands may come from the availability of existing resources. For example, if the development team is well educated in the field of raster GIS and image processing, a vector overlay modelling package might not be the best choice for a product. Can the design accommodate a variety of purposes and still be effective?

Defining an audience greatly simplifies the user interface design because in order to do so the user's conceptual model must be identified. The designer of a software package for existing GIS users has the luxury of drawing on a large amount of prior technical knowledge. On the other hand, the designer of a turn-key "GIS kiosk" located in the public library can work with a simplified user conceptual model and skip a great deal of details. What happens if the audience can not be precisely defined? Can the system grow as the user's experience increases? Can a variety of audiences be served by the same system?

The format of an interface defines how the functionality is realized through the interaction. Command line interfaces, menu-driven systems, and natural languages are examples of format. To some extent the format is fixed by the purpose and the audience (for example, the GIS in the public library for the casual user would certainly be more effective if driven by touch-screen rather than a mouse), but the most interesting issues still arise in this area. User interfaces that are effective use the conceptual model of the audience as a basis for format. How can we effectively use methods such as metaphor and image schema to design the format of the user interface?

The trade-offs involved in specifying the purpose, audience, and format of a system are influenced by institutional constraints. The pressure to complete a research project, or market a product often compromise the best intentions for design; however, an idealistic approach toward the design of user interfaces for GIS is necessary to advance the technology into the future.

Biographical Sketch

Jeffrey Jackson received his Master of Science degree in Surveying Engineering from the University of Maine in 1990. His work with the National Center for Geographic Information and Analysis during his tenure at Maine included research in the area of metaphors for human-computer interaction. He accepted a software engineering position with Environmental Systems Research Institute, Inc. in August of 1990, and is currently the lead engineer for ArcView, a new display and query package for GIS databases. Mr. Jackson is interested in software design for users from a variety of disciplines and backgrounds, as well as methods for the testing and evaluation of GIS user interfaces.

INITIATIVE 13 POSITION STATEMENT

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GIS users increasingly perform their work in an interactive environment that embeds spatial analysis in other, application-specific analyses. More and more the GIS user is being classified as a multi-media user as well. The GIS user has frequent requirements for mapping imagery, text, database records, sketches, video imagery, etc., as well as the normal spatial data associated with GIS. This multi-media environment is not only a challenge for the integrator but for the user who is attempting to analyze the information. The possible applications of hyper media approaches are a consideration. Since GIS is finding its home in a wide variety of user communities, the human-computer interfaces must include metaphors and user mental models appropriate to those specific applications as well as to the spatial analysis. TASC builds prototype and operational systems for a variety of government and commercial customers. In support of this work, TASC performs regularly as a beta test site for hardware and software, and carries out research and development in a fully outfitted laboratory that incorporates state of the art hardware and software components. In the process of developing practical applications systems, TASC has integrated applications with both spatial and non-spatial interaction in a variety of contexts. This experience will allow TASC to bring an industrial perspective to the initiative while making solid technical contributions. The development of complex GIS solutions which integrate other technologies and are tailored to application communities will require the resolution of several fundamental issues. For example:

- Where is the line drawn between generic spatial data analysis and manipulation approaches needed in all GIS, and specific capabilities related to an application area?
- How does the user effectively interact with the wide variety of media types and what approaches might provide a good hyper media solution?
- How do spatial and non-spatial metaphors interact in the design phase as well as during operation?
- What development methodologies are required to perform effective interface tailoring of GIS in a highly integrated system?

TASC believes these issues are candidates for under Initiative 13. Our specific experience in dealing with them on a case-by-case basis has given us insight valuable to addressing them in a more general context. We look forward to participation in the new initiative.

Biographical Sketch

Mr. Kinn is the Manager of TASC's Spatial Analysis Systems Department. He has been active in various aspects of image processing and GIS development since 1977. His activities have included work in the technical areas of Photogrammetry, Remote Sensing, GIS, Artificial Intelligence, and database management. Mr. Kinn has been involved in several systems development efforts where he performed in various technical roles, including system design. His primary activity has been software engineering for these systems. In addition to software development, these systems required hardware integration and development. He has experience developing algorithms for cartographic feature extraction and point positioning. His database management experience includes the development of approaches for the storage and manipulation of geographic data extracted from imagery. His most recent system integration effort has been a GIS incorporating a multimedia implementation.

Prior to joining TASC, Mr. Kinn was the Technical Director for the Image Exploitation Section at PAR Technology Corporation. There he performed as Project Manager for several contracts, as well as monitoring the technical aspects of all work in the section.

Mr. Kinn received his B.S., and M.S. in Environmental and Resource Engineering from the SUNY, College of Environmental Science and Forestry (ESF) at Syracuse University. He is currently completing requirements for his Ph.D. in Engineering at ESF. Mr. Kinn has taught university courses in Surveying, Remote Sensing, and Geodesy. Publications include papers in Remote Sensing and Photogrammetry. He is an active member of ASPRS where he held the office of Regional President and Vice President and Board of Directors.

Let metaphors overcome their WIMP image!

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Introduction

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 (Johnson 1987, Lakoff 1987, Lakoff and Johnson 1980) 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 (Erickson 1990) and for GIS in particular (Gould and McGranaghan 1990). 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.

The roles of interface metaphors

Projection

The key characteristic of metaphors is that they impose structure on a domain which is previously quite unstructured. The use of computers in any application is one of the "areas of experience that are not well-defined in their own terms and must be grasped in terms of other areas of experience" (Lakoff and Johnson 1980, p. 114). Thus, there are no predetermined, abstract operations which a metaphor makes appear familiar, and consequently no similarities to be detected among familiar and abstract domains.

By choosing metaphors, designers create an ontology in the application domain, i.e. they establish the concepts which a user has to master. The issue is whether this ontology is useful for solving common application tasks. In other words, the source domain has to generate an appropriate problem space (Newell 1980) for the application. Thus, choosing metaphors is also choosing a distribution of labor between users and system.

Office objects and operations, for example, provide a useful ontology for operating systems of personal computers. An alternative source domain might involve dictaphones and secretaries, based on an agent paradigm. Clearly, there would be little similarity with files and directories, but the resulting distribution of labor appears more attractive to most users than that of direct manipulation.

In the context of GIS, adopting a map overlay metaphor for the analysis of geographic data implies that the users keep track of data sets (in terms of maps) and explicitly combine them to solve problems, rather than having the system deal with these issues. The resulting ontology includes maps, scales, regions or polygons, possibly slivers and gaps, etc. Depending on the user community, these concepts may be appropriate or not. They are by no means predetermined by the application domain, however.

Conceptualization

The most important conclusion from the works of Lakoff and Johnson is that metaphors are a conceptual rather than a linguistic phenomenon. In the context of user interface design (Foley et al. 1990), this translates directly

into a requirement to deal with metaphors at the level of conceptual designs rather than interaction languages. Choosing and defining interface metaphors, thus, precedes most other design considerations.

It has been found that users will come up with metaphors of their own to explain system behavior, if none are supplied (Carroll, Mack, and Kellogg 1988). Less recognized is the fact that designers, too, always use metaphors, whether they are aware of them or not. The designers have to create target domains for applications, rather than to take them for granted. In doing this, they should be aware of existing metaphorical structure if they want to achieve coherence with new interface metaphors.

Complexity reduction and learning support

It is generally accepted that metaphors are effectively controlling interface complexity (Carroll, Mack, and Kellogg 1988). They hardly achieve this, however, by hiding abstract notions behind familiar ones. Rather, the ontology which they establish can be more or less coherent, familiar, and useful to certain user groups and consequently leads to less or more perceived complexity in the interface.

Interface metaphors are understood as stylistic means to support learning by analogy. The fact that they facilitate learning is often considered their primary justification. They are seen as fancy means of design, just as metaphorical language was traditionally seen as a special, poetic or rhetorical way of expression. Ease of learning, however, seems to result from the broader role of metaphors as 'sense makers', rather than being their primary function. We can't make a cryptic interface easier to learn by throwing in a few metaphors. We can only analyze its conceptual design for incoherent or inappropriate metaphors and redesign it.

The learning aspects of metaphors have been overemphasized at the expense of ignoring their more fundamental role in system design and use. Considering their impact on overall system structure, metaphors should be chosen for usability rather than just learnability. This would address objections against "toy" interfaces (closely linked to the WIMP notion) without necessarily diminishing learnability. There is no reason why a metaphor which is chosen for its useful task structure could not support learning equally well. Conversely, a metaphor which is geared towards learning may limit expert user performance or even functionality (Halasz and Moran 1981).

Relation to WIMPs

An interface metaphor has to be communicated to the user, often primarily by visual means. For example, the desktop metaphor is communicated by icons representing office objects like documents, folders, a trash can, etc. and by gestures and menu symbols representing operations like move, cut and paste, throw away etc. These symbols of an interaction language play the same role as the words used in metaphorical speech or writing. Their choice is essential for the power of a metaphor, but it should not be confused with choosing the metaphor. It doesn't matter much how we design icons and menus if they represent inappropriate metaphors.

Partial nature

Metaphors have been criticized for precluding 'magic' by forcing a system to act like physical objects (e.g., an operating system like a physical desktop, a GIS like a collection of maps). But metaphors are by definition partial mappings, on both sides. They take only certain aspects of a source domain and use them to structure only parts of the target domain. 'Magic' is not only possible but encouraged in a controlled way by the need to combine different metaphors (e.g., buttons with note cards in Hypercard).

Image schemas

A central aspect of metaphor theory which has been largely neglected in human-computer interaction research is the role of image schemas. They are basic cognitive structures derived from our bodily experiences (Johnson 1987). Most of them capture elementary spatial, particularly topological, notions container, surface, path, link, center/periphery, part/whole etc. Consequently, they are likely to play an important role in dealing with spatial as well as spatialized information (Mark 1989).

Image schemas, furthermore, seem to be those parts of a source domain which a metaphor generally carries over to the target domain (Lakoff 1990). The desktop metaphor is a good example of this, being essentially built around the container and surface schemas (Kuhn and Frank in press).

Additional metaphorical structure

Apart from metaphors relating specifically to the user interface, application domains receive basic structure from the way their major subject matter is conceptualized. In the case of GIS, for example, the effects and circumstances of system use depend heavily on how we think about the land or terrain as a territory (i.e., bounded, occupied space); as property (i.e. occupied and owned by humans), as a resource (emphasizing the uses of land); as an adversary (requiring containment); or as any combination of these. Such considerations, however, are beyond the scope of this paper.

Generic interaction metaphors

While the previous section discusses the key roles of metaphors in specific interface designs, it doesn't deal with some more general aspects of metaphors in human-computer interaction. The way we conceptualize the use of a system as such has a crucial impact on human-computer interaction, whether we are designers, users, managers or otherwise involved with "automation" (which, in itself, is a peculiar metaphor for the introduction of information technology!). This section points to some generic metaphors which affect our use of GIS and other systems, whether we are aware of them or not. It is an annotated, incomplete collection of metaphors which have been explicitly or implicitly applied to conceptualize the use of computers

To use is to ...

... program

the classical notion of interaction; still permeating systems, design methods, and terminology ("commands", "macros", "errors" etc.); the system is seen as an (abstract) machine, programmed and operated by the user; this limits the bandwidth of interaction severely.

... manipulate

became popular with the direct manipulation paradigm; the user is offered tools or a whole tool box; offers powerful feedback and a sense of control, but implies a largely passive and "dumb" system; tools, by nature, can be complex to use and generally require training.

... communicate

emphasizes the conversational aspects of interaction; the user is seen as a partner in a dialog or as a participant in group communication; the system is seen as a partner or a medium or both; provides important notions like context, intentions, beliefs, cooperation (see below).

... delegate

a special case of communication, often seen as an antithesis to direct manipulation; naturally associated with speech-based interaction (Negroponte 1989); the system is conceived in terms of agents, assistants, or apprentices.

... query

inherited from the database community; offers a potentially powerful, but narrow notion of interaction; the system is conceived as a database; from a conversational perspective, being able only to ask questions seems too limiting.

... browse

an attempt to break the limitations of querying, particularly for cases where the users can't describe what they are looking for.

... skim

going one step further, to cover cases where users don't even know whether there is anything of interest to them.

... produce/receive documents

a dominating influence from the office automation community; the predominant and most successful metaphor for system use "by the masses" today (cf. the desktop metaphor and its variants); often conceptualizes the user interface as a document (e.g., a letter or a table); using GIS, too, is generally regarded as producing and interpreting maps and related documents.

... play

attempts to relax the austere and often intimidating connotations of computer use; emphasizes creativity, but conflicts with work ethics in many cultures.

... cooperate

refers to both, human-computer and human-human cooperation, mediated through a computer system; Computer-Supported Cooperative Work (CSCW) is rapidly becoming a strong paradigm for interaction; it is likely to be particularly relevant for GIS, due to their interdisciplinary nature.

... see

an instance of the basic metaphor "understanding is seeing" (Lakoff and Johnson 1980); the role of visual metaphors for abstract thought is well established (Danesi 1990), but only beginning to be exploited for interaction.

... view

a variation on "using is seeing"; emphasizes the active role of the user; special cases are the standard graphical interface metaphors of zooming and panning (although they are often a far cry from the power of human vision (Kuhn 1991)).

... experience

a generalization of perception-based metaphors, motivated by the metaphor "understanding is being in the world" (Johnson 1987); lies at the heart of virtual reality (Brooks 1988); the interface essentially disappears (Tom Furness calls it "breaking the glass"); offers a radically different metaphor for GIS use "the GIS is the terrain".

... explore

goes together with experiencing, but implies metaphorical motion; the importance of motion for cognitive development, learning, and information gathering cannot be overestimated (Sacks 1990); the commonly used navigation metaphor represents a special case.

Research topics

The following is a brief list of suggested research topics, as a first step toward a research agenda on GIS interface metaphors. Some of the topics may not be researchable (yet), others may only be of marginal interest to the GIS community, but most of them seem important, if we want to advance the state of the art in user interface design

- image schemas and metaphors behind entity, field, cell (and other) views of space
- formalize basic cognitive activities in space see, move, point, pick, manipulate, etc.
- formalize metaphors for "Zubin spaces" and transitions among them
- the role of spatialization
- the role of conceptual analysis in revealing relevant metaphors in a domain
- relations of metaphors to conceptual models and user models
- integrating metaphors into the (conceptual) design of interfaces
- how metaphors affect user interface management systems (UIMS)
- artifact-based vs. experiential metaphors
- artifacts seen as formal theories
- metaphor hierarchies
- how to validate theories of interface metaphors
- how to assess and achieve coherence among multiple metaphors
- how to avoid metaphor interference (mixed metaphors)
- multimedial expressions of metaphors (combining image and sound, etc.)
- cross-cultural aspects, particularly of image schemas
- metaphors in GIS advertising and packaging
- case studies.

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Biographical Sketch

For the past two years, I have been a research associate at NCGIA Maine, working on a variety of topics in human-computer interaction and geometric modeling for GIS. My main research interests include metaphors and other aspects of spatial communication, particularly the formalization of these notions. My Ph.D. thesis dealt with the choice of metaphors for geometric construction tools in CAD and Geographic Information Systems (GIS). Last year, Max Egenhofer and I conducted a workshop on visual interfaces to geometry at CHI'90.

SOME THOUGHTS ON USER-INTERFACE DESIGN FOR GIS

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The quality of the user interface has a great bearing on the utility of a GIS. 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 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.

Traditional GIS user interfaces have resulted from an orientation towards how to best represent the software functionality rather than on how to meet the expectations of the user. This turns the user interface into an engineering problem. The problem of making GIS useful to people, however, is a user interface design problem rather than an engineering problem. Engineering typically begins by eliminating the subjective factors, but it is exactly the subjective factors that are critical to the usability of information systems. To create a successful user interface the designer must understand how people think and work. The designer must realize that users do not usually use algorithms, data structures, networks, functions or subroutines, even though as technical professionals this is typically the domain in which they work. Instead, system users push buttons, choose options, type things in, make selections from menus, give commands and manipulate controls. In other words, user interfaces are illusions that hide the underlying architecture of the technology prominent in the programmer's view and repackage it as something understandable and usable by analysts and decision makers. Some of the most successful user interfaces are complete illusions outwardly bearing no resemblance to the data processing happening inside the machine. Of course, these illusions require their own program code. It is not unusual for more than 60% of the code in a complex software system to be dedicated purely to the user interface. This stands in sharp contrast to the 35% dedicated to the user interface in the GISs of the mid 1980s.

Why do users need these illusions? One of the biggest problems for end-users is that the things computers let users do are abstract. Even the terminology they employ: files, directories, records, databases, logging on and off, function keys, scroll-bars, control-alt key combinations, etc. is often unfamiliar and grounded in abstraction. In everyday controls such as light switches, door handles and shower fittings, there is usually a fairly obvious correspondence between what a control looks and feels like physically and what it actually does. If one is not sure which light switch on a panel controls which light, one can generally try them until the right one is found. This is called "learning through exploration" and the ability to perform this significantly increases the learnability of a system. In computer software this element of physicality is lost. Almost everything relating to the internal workings of the computer is hidden and largely divorced from anything the user understands.

To make systems truly usable software, illusions are built on top of the underlying functionality. These illusions make abstract things appear concrete and give users the impression that they are controlling real objects. For example, the three-dimensional buttons and animated pulldown menus of Graphical User Interfaces (GUIs) have utility far extending beyond mere cosmetic drapery. They served to restore an element of physicality and concreteness that promotes understanding and a feeling of being in control of computer software.

Users have mental models about the tasks they accomplish with a system, and the way the system lets them accomplish those tasks. These models are defined by the user's prior experience, existing knowledge, and preconceptions about tasks. For both a task and the way to accomplish the task to make sense, they must correspond to existing knowledge the user already has. In addition, for new material to be understood, interpreted and integrated with this existing knowledge it must be introduced in a clear fashion. When new material is introduced poorly, users attempting to integrate it with their existing knowledge invent their own explanations. For example, my students can often be found blaming themselves when the GIS packages they are working with crash as the result of software bugs. On other occasions, they can be found blaming the GIS for problems they inadvertently created. This behavior is typical of many computer users. They tend to make up their minds about the function of systems based on concocted explanations for problems they do not understand. One of the jobs of the user interface designer is to make sure the conclusions they reach are the correct ones.

Each user possesses a conceptual model of the software system he or she interacts with. This model is shaped and influenced by both internal and external factors. The internal factors relate to the user's goals, expectations, intentions, experiences, preconceptions, past knowledge, and explanations. The external factors related to the system's interface as it initially presents itself to the user and as it reveals other dimensions of itself as it is used. System interfaces designed to match the user's existing conceptual models often require very little external documentation. The GIS is often designed without attention to the user. It typically requires volumes of documentation, and days of training to change the user's conceptual models to fit the system. All of these, thickness of user manuals (in inches), training time (in days), and support (in numbers of telephone calls) are indications of a failure of the system interface to map onto the user's conceptual model.

The focus of user-centered GIS interface design should concentrate on:

- 1) how to map the system interface to the user's existing conceptual models, and
- 2) how to shape and influence the user's conceptual models while they interact with the system.

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.

[These thoughts are excerpted from "User-Centered Graphical User Interface Design for GIS" submitted for publication to "Cartography & GIS"]

User Interface Lifecycle of Industrial GIS Applications

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Abstract

We build GIS applications for use within an industrial environment. We follow a user interface development lifecycle that specifies a series of reviews and documents that control changes to the interface. This lifecycle draws from both cognitive psychology and industrial engineering for its techniques. Informal and inexpensive techniques of usability testing are applied early in the lifecycle, when design changes to the interface are inexpensive to implement and relatively large in effect. Formal and expensive techniques of methods engineering are applied later in the lifecycle when design changes are expensive to implement and relatively small in effect. The methods engineering techniques produce process charts and skill trees that can be used to develop effective training programs and help systems, and evaluate the costs and benefits of making changes to an interface after it has been deployed.

Background

The software systems we build for UPS are uncommon in the GIS community. They are deployed to a single, uniform, industrial environment where they are used in a specified way by qualified operators to accomplish a few well-understood tasks. Furthermore, as system developers we are strictly accountable for all training and maintenance costs as well as savings from increased productivity.

We follow a formal software development lifecycle process that specifies documents and reviews used to monitor and control system design, implementation, testing, and deployment. The lifecycle begins with the delivery of a functional requirements document written by a study team of developers, UPS managers, and potential users of the system. It then proceeds through phases to deployment and into maintenance. Although system development typically lasts one year, software is maintained for ten years in the field.

Parallel to the development lifecycle, we follow a user interface lifecycle that specifies a series of human factors reviews we use to identify problems in an interface and control changes to it. We try to use review techniques that are appropriate to lifecycle phase. As Bias and DeRidder note (Bias, 1989), "usability changes are least costly early in a project." Our experience suggests that it is also easier to find areas for improvement early in a testing cycle. Accordingly, we use inexpensive and informal techniques early in the lifecycle to identify major changes and use expensive and formal techniques late in the lifecycle to make small refinements to an already usable interface. Figure 1 illustrates these relationships.

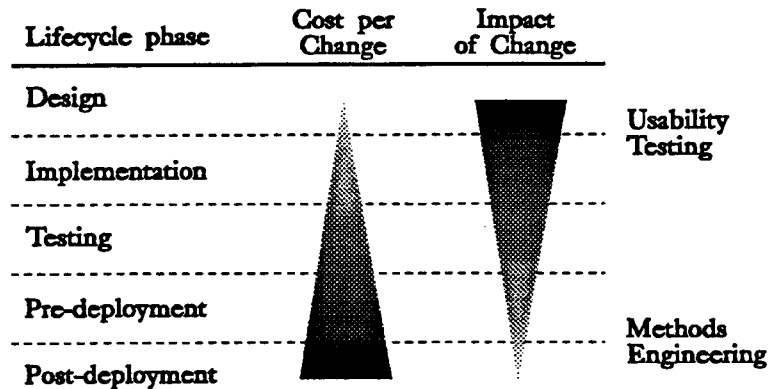


Figure 1. *We use review techniques that are appropriate to lifecycle phase*

The techniques we use early in the lifecycle are drawn from cognitive psychology and their use in interface design is well understood (Dumas, 1988; Foley, 1983). They emphasize perception, memory, and task-modelling, with an emphasis on eliminating subjective dissatisfaction. Techniques include pencil-and-paper walkthroughs, satisfaction surveys, keyword-organization tests, and user-oriented system tests. We have adapted these techniques for our environment by dividing the subject group into experts whose opinions we seek early in system design, and users whose opinions we consider once a functioning prototype system is available. We have also tailored the techniques to GIS applications by accounting for subjects' map-reading skills and by involving cartographers as expert reviewers.

Later in the lifecycle we use techniques of methods engineering, drawn from the industrial engineering discipline. Although they have not been often applied to GIS interface design, UPS has over 80 years' experience applying them to industrial processes such as sorting and delivering packages. By applying methods engineering to user interfaces, we can build GIS applications that are easier to learn and more productive to use. Furthermore, we can establish a standard of performance against which any future refinements can be compared and cost-justified.

Design Phase

During the design phase of the software development lifecycle we conduct prefunctional reviews. These are guided tours of the interface, presented to a panel of usability experts including cartographers, experienced interface developers, and UPS managers assigned to serve as user representatives. The presentation consists of slides showing the interface in various states which the panel critiques for clarity, logical organization, and adherence to interface standards.

To prepare for prefunctional reviews we make map prototypes using a commercial GIS (ESRI's ARC/INFO). For each of the application's likely map views we provide an experienced cartographer with a list of the features to be displayed, their relative importance, and the likely display scale, along with examples of any existing maps with which the user is likely to be familiar. The cartographer then produces maps using a standard symbol set. We generate slides of map prototypes and of an interface shell that we program using an interactive development tool (Sun Microsystem's GUIDE).

Prefunctional reviews clarify the functional requirements by forcing developers to interpret them sufficiently to offer examples of one possible design response. This uncovers misunderstandings about system requirements and user capabilities early in the development lifecycle, when the cost of redesign is lowest. As a bonus, the slides prepared for these reviews can be used to generate enthusiasm for the project among management and users.

Implementation Phase

During the implementation phase of the software development lifecycle we regularly demonstrate partial system functionality to groups of user representatives, cartographers, and methods analysts. These reviews identify missing functionality and control changes to the system. Over the course of several reviews a successful project will receive fewer requests for smaller changes.

We also conduct specialist reviews with cartographers and methods analysts. Cartographers suggest changes in the map symbology to make it more interpretable; methods analysts suggest changes in the layout and control mechanisms of the system to make it more ergonomically efficient to use. The experts make specific, written recommendations for improving the interface.

Testing Phase

While we test the system for reliability we conduct a user-oriented system test to assess performance of the completed interface. We place approximately 50 users with varying degrees of experience with computers, maps, and UPS operations in front of the system, individually and in pairs, to perform about 20 application tasks and subtasks, such as determining the speed limit of Charles Street. We prepare them for the test session by showing them a 30-minute training videotape, then test them for two hours and debrief them using a standardized survey (Brown, 1989) to obtain their subjective reactions to the system. We also conduct a followup test to assess their retention of system skills.

User-oriented system tests are expensive to conduct because they attempt to measure objectively users' performance with the system, in addition to their subjective impressions. We defer objective performance testing until late in the lifecycle because it presupposes an acceptable but suboptimal interface in need of refinement rather than redesign.

To measure performance objectively we monitor the time spent on each task, record any operational mistakes, and give carefully scripted hints to help the subject complete each task. Thorough preparation of the test monitor and a think-aloud environment in which each test session is videotaped and then reviewed is essential to accurate performance measurement.

The test monitor assembles the results of usability testing and reports them by task, subject group, interface function, and design objective. A high level of skill and experience is required of the test monitor to compile useful results.

- Task reports include the mean time and variance for each task, along with commonly made mistakes and frequency and usefulness of hints.
- Subject group reports describe the performance of groups of subjects having similar background experience with computers, maps, and UPS operations. For each group the report identifies tasks that were particularly difficult or easy, frequently made comments, and general impressions of the interface.
- Interface function reports present comments about the usefulness, wording, placement, and operation of each interface gadget and its confusion with other gadgets, measured by its appearance in operational mistakes.
- Design objective reports compare the users' comments about the system to a set list of characteristics of a successful user interface:

- Put the user in control
 - Be consistent
 - Minimize the burden on the user's memory
 - Offer informative feedback
 - Maintain aesthetic integrity
 - Forgive mistakes
 - Use clear terminology
- (Dumas, 1988; Shneiderman, 1987; Apple, 1987; Sun, 1990)

Pre-Deployment Phase

Frederick Taylor's work in time and motion study at Bethlehem Steel demonstrated to American industrial managers the need to monitor and manage productivity as way of developing an enterprise (Thompson, 1917). Westinghouse Electric Corporation has long applied Taylor's approach and coined the term "methods engineering" to describe the process of designing and developing work centers and then restudying them to find better ways to manufacture products (Neibel, 1982). UPS has also used methods engineering techniques to refine its package-handling operations over many years. We have applied the discipline and techniques of methods engineering to our work in building and refining productive GIS applications.

The three methods engineering techniques used prior to implementing a new industrial process are:

- Develop process charts that describe in minute detail each action that is performed "to advance the product toward its ultimate size, shape, and specification" (Neibel, 1982). There are four types of actions within an industrial process: storage, flow, delay, and inspection. Each action in a process chart is described in terms of the time it takes, the tools it requires, and its dependence on other actions.
- Develop a job analysis. Each industrial process is analyzed "to determine the skills, duties, and responsibilities of a qualified operator" (Neibel, 1982). A job such as package-sorting requires certain physical skills such as properly lifting and turning with packages while reading their labels. Job analysis is the basis of equitable wage rate and job evaluation.
- Establish time standards. To qualify for a job an operator must demonstrate mastery of its required skills by performing them within established time, safety, and quality standards. A qualified operator must also have certain job knowledge. For example, a sorter must know the proper conveyor belt for packages addressed to various Zip codes.

We follow each of these steps in preparing a GIS application for deployment. We develop process charts, perform a job analysis, and establish time standards.

Operators use our GIS applications to accomplish specific tasks, such as planning the route a driver will take to deliver packages to a number of stops. Each task is a combination of processes that together answer some question in the user's mind or produce some map or report that expresses some decision made by the user. Each process is composed of discrete, measurable actions.

We make process charts for GIS applications by dividing each process into four types of action:

- make a decision
- manipulate interface
- wait for machine
- inspect results

Figure 2 illustrates the process chart for actions within the route-planning task. It shows the steps required to add a single street segment to a route by choosing from a list of the alternative street segments found at an intersection.

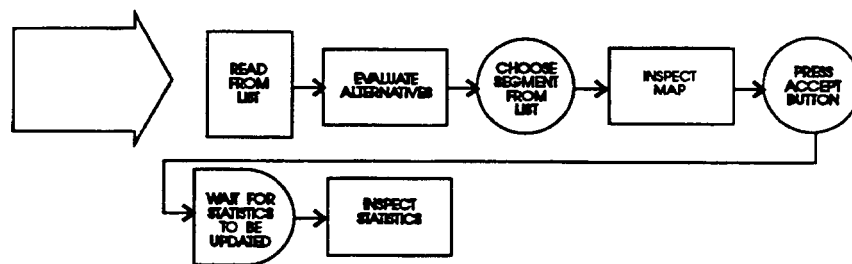
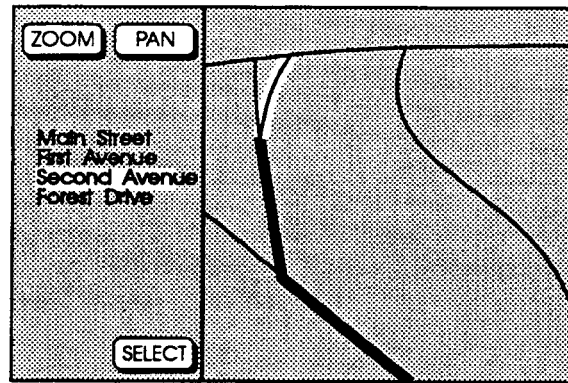


Figure 2. *Process chart for actions within the route-planning task.*

We perform a job analysis by scanning process charts to identify sequences of actions whose mastery represents a skill that is useful in one or more tasks. These skills build upon each other to enable a user to perform all the tasks of an application. Skills are combined and refined to form new skills, forming a tree structure. Figure 3 illustrates a partial skill tree for an application that includes the route-planning task. It shows that a user must first know how to pick from lists before he can trace a route by adding segments to it.

Skill trees provide the structure of a training program for our GIS applications. We develop a training module for each skill in the tree and train users skill by skill, from the bottom of the tree to the top. Although the tree-traversal scheme depends upon the application, the tree structure assures that novices learn skills in proper relation to one another.

We set time standards that operators must meet to demonstrate mastery of each skill. A user must master each skill in an application's skill tree in order to qualify as an operator. We training programs that implement only parts of a GIS application's functionality exclusively for skill-based training. Successive, independent mastery of skills maximizes the effectiveness of training time and reduces dependence on successful student/teacher relationships.

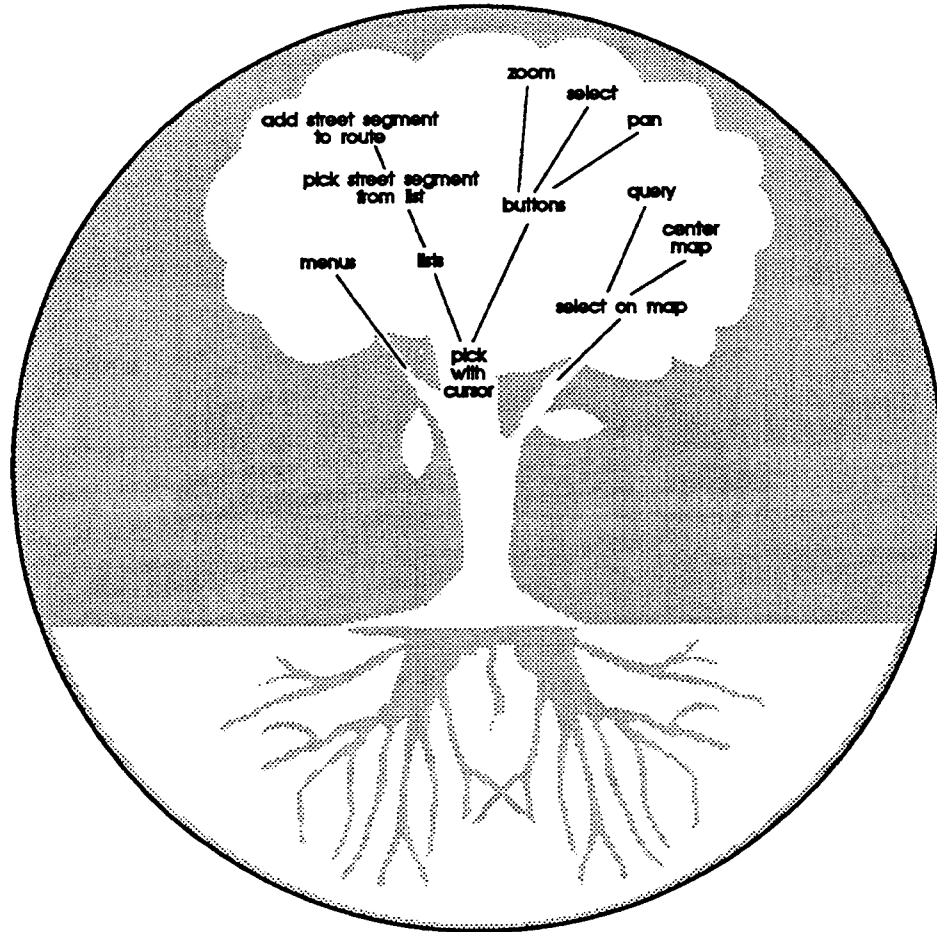


Figure 3. Partial skill tree for an application that includes the route-planning task.

The skill tree is also the basis of an online help system. Users apply the skills at the very top of the skill tree to operate gadgets in the user interface. When the user requests help for any of these gadgets, a chain of skills from the top of tree to its base is identified. Help is offered to the user about each skill in the chain. Proximity in the tree's horizontal direction also identifies related topics about which help might be useful.

Post-Deployment Phase

Once an industrial process has been deployed it is costly to modify. Before specifying a process change, the methods engineer must describe the modification in terms of the costs and benefits it will provide. Costs accrue from development of new tools, training operators in new methods, and lost work during changeover. Benefits accrue primarily from increased operator productivity.

Methods engineers perform time studies to determine the labor cost of industrial processes. Time study techniques have been used since the 1890s to determine the amount of work a skilled operator can produce using a given method. These techniques include stopwatch time trials, cyclographic analysis of processes recorded on film, and paired comparisons of operators using different methods (Krick, 1962). Organizations such as Westinghouse (Neibel, 1982) and UPS (UPS, 1985) accumulate the results of time studies into a large body of measurements known as standard data, which is accepted as accurate and can be used in subsequent analyses without re-measurement. Standard data make possible the assignment of accurate time standards for a job not yet implemented.

We conduct time studies of the processes used in our GIS applications. The optimum time required for each action in a process can be measured in a laboratory environment, and corrected by field testing of whole-process times to determine typical performance. Then, when we consider a change to the interface, we can compare the time standards and skill trees of an existing and proposed systems to make a rational decision about investing in redevelopment, retraining, and redeployment.

Status and Future Directions

We have applied various techniques described in this paper to three GIS applications over the past two years. Along the way we tried and discarded techniques as useless and moved others to different lifecycle phases that seemed more appropriate for their expense and results.

The well understood usability testing techniques used early in the interface lifecycle have proven worthwhile without exception. We have found areas for improvement in the interface each time we have sought them. These techniques are an important part of the application development process because they avoid unexpected reactions from users late in the lifecycle, when the cost to address them is unbearable. They also give users and their representatives an early stake in the success of the project and neutralize objections from experts.

The methods engineering techniques of the later lifecycle are intriguing but largely unproven. We have written process charts for parts of applications and used them to derive skill trees, which led smoothly to training programs and help systems as expected. We have not compared the effectiveness of this type of training to other approaches.

We have used the process charts and skill tree for one application to eliminate several interface gadgets by reusing and specializing skills, which reduced overall code volume as well as training and documentation costs. This experience suggests that methods engineering techniques should be applied earlier in the lifecycle, perhaps during the design phase, to build more compact interfaces from the outset.

Among the methods engineering techniques, the use of standard data to predict time standards for proposed new interfaces is most intriguing. Standard data can be of several levels of refinement: motion, element, process, and task. Industrial data typically concern small physical motions. Our focus to date has been at the process and task levels because we are just starting to compile data. Over time we hope to evaluate this technique further.

Conclusions

The usefulness of methods engineering in GIS interface development is limited because it is so easy to modify software. At any phase in their development lifecycle, user interfaces to GIS can be changed dramatically, at a very low cost when compared to factory machinery. We have accounted for this imbalance in the costs of change and change analysis by using informal techniques of usability testing until the costs of change surpass the cost of analysis. Where that crossover occurs is hard to judge.

Perhaps the methods engineering approach is suitable only for extremely mature interfaces, where improvements are hard to find. Perhaps the expense of methods engineering analyses are justified only in a corporate environment where developers must account for redevelopment and retraining costs. Despite its expense, the methods engineering approach makes explicit the required skills and performance of a system, which could be used in an academic setting to study GIS interface design with an engineer's discipline.

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(frequency of polygon occurrence) and area, (the proportion of the map area occupied). The lower left shows bar charts for the categorical variable, also by count and area. The lower right is a scatterplot, with points representing "Urban open" polygons highlighted. Note that no scales are presented; this is consistent with the idea of analysis graphics, and promoting visual thinking.

The user (GIS analyst) proceeds by looking for trends (such as central tendency, bimodality, or skewness in the histograms) and outliers, which are particularly obvious in the scatterplot. Outliers may be either blunders (such as slivers), or rogues, cases that are valid but unusual, and therefore warrant further study. The program allows one to turn off the polygon background in the map to more easily view small polygons, vary the number of histograms, and select a subset for more detailed examination. It also provides the capability to do a partitioned clustering in which distances separating polygons is explicitly included (with varying weights).

Biographical Sketch

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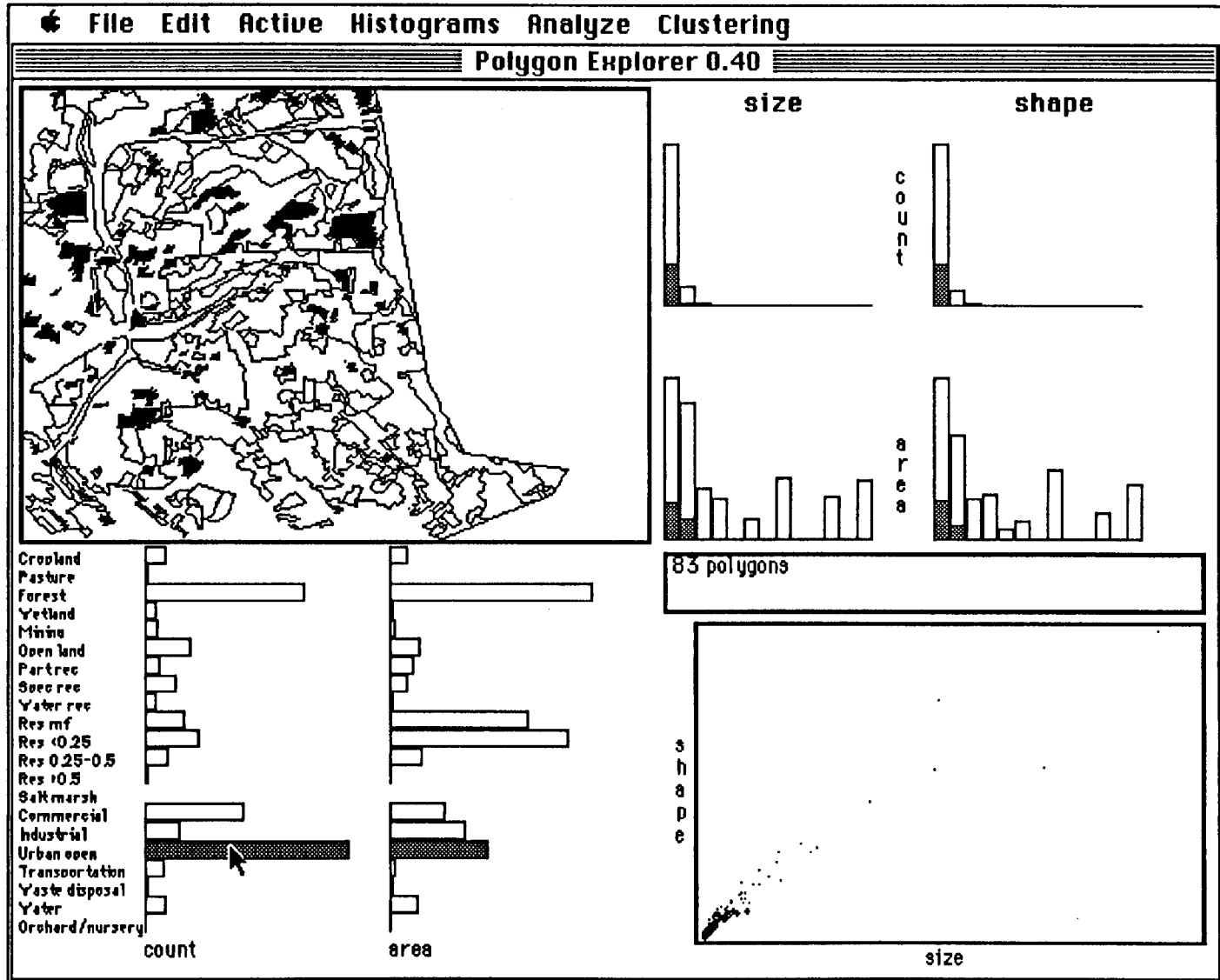


Figure 3

User Interfaces for Geographic Information Systems

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In a paper at GIS/LIS'89, I made the following claim:

"A main objective of GIS is to allow the user of the system to interact vicariously with actual or possible phenomena of the world." "If this is so, then the system which mediates between the user and the world should be as unobtrusive as possible" (Mark, 1989)

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 a device, has been discussed by Fischer and Lemke (1987). 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.

Here are some questions that I think are important for the research agenda on user interfaces for GIS:

1. **Kinds of Users.** What level of geographic knowledge and training should be assumed for the users?
 - GIS technicians. This category includes most of the people who are using GIS today. One almost needs technical training in order to use current systems. Almost certainly need to know about computer, computing, and geography/cartography.
 - Spatially-Aware Professionals. A system designed for "Spatially-Aware Professionals" (Raper & Bundock term), such as geographers, geologists, urban planners, or foresters, could borrow concepts from cartography and from those disciplines. No general knowledge of computing would be assumed.
 - Citizen-scientists. An ideal system for such users would probably be too complicated for a "Citizen-scientist" to walk up to in a public library and use to inquire about an environmental or planning issue. But, the "walk-up-and-use" system would probably be tedious for the professional to use. And some have suggested that a powerful tool such as a GIS, in the hands of a user who does not understand its basic structure, could lead to serious misuse of the technology.
2. **Level of computer knowledge.** How should level of computer knowledge and related skills interact with level of geographic knowledge in order to create an ideal user interface?
3. **Frequency of use.** How does frequency of use influence the design? A person who uses a system 30-40 hours per week as a GIS technician or operator would soon learn even the most cryptic commands; on the other hand, a person with high geographic and computer skills might still need a simple system, if they only used it for half an hour at a time, twice a month. Finally, a programmer's interface might be quite different from the interface for 'end users'.
4. **Language, Culture, and Individual Differences.** To what extent should knowledge of the user's natural language, and of how that language structures geographic space and other conceptual domains, be incorporated into the design of GIS user interfaces? And, to the extent that they can be

separated, what about cultural differences, such as "first-world - third-world" contrasts? And what about individual differences? Should the user have access to many tools for customizing the interface, or should the interface be kept as standardized as is practical?

5. **Priorities for research.** Which is more important: to improve the user interfaces and thus the work efficiency of current GIS users; or to provide user interfaces that would allow many new users, who currently are blocked by technically-complicated user interfaces, to adopt and use GISs. Both are obviously important, and worth doing in the long run, but which should the industry address first? And, should the University-based basic research community address the same aspect, or the other?

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Biographical Sketch

David M. Mark is a Professor of Geography at SUNY Buffalo, where he has taught and conducted research since 1981. He holds a Ph.D. in Geography from Simon Fraser University (1977), and a Master's degree in Geography from the University of British Columbia (1974). Mark has served as Vice-Chair (1987-88) and Chair (1988-89) of the GIS Specialty group of the Association of American Geographers, and is on the editorial boards of *Cartography and Geographic Information Systems* (formerly *The American Cartographer*) and the *International Journal of Geographical Information Systems*. He also is the Chair of the Scientific Policy Committee of the National Center for Geographic Information and Analysis (NCGIA), and has recently completed a two-year term as a member of the Geography and Regional Science Panel of the National Science Foundation (NSF). Mark's current research interests include GIS, cartography, cognitive science, way-finding, and expert systems.

User Interfaces for GIS: Opinions, Observations, and Questions

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1. Introduction

The user interface mediates information exchange between computation and user. An interface is variously considered as a layer which isolates a user from direct contact with a computational process while passing information between them, or as a direct connection of the user to a virtual existence "inside" the computer. Of necessity, it includes the various devices, and their use, in the exchange. It also includes the user's understanding of the interaction in the work context, and the response of the computer to user actions.

Clearly, the user interface is an important part of a GIS. I have argued previously that "The interface is the GIS," because it is the only part of the GIS with which most users have contact. Many GIS users have no interest in the internal workings of systems. They do not want to think about algorithms, data structures, and discrete mathematics. They want results, solutions to abstract conceptual problems. The interface must bridge the gap between the very concrete operations of the computer and the abstract conceptualizations of the user.

We are meeting to discuss interfaces because we suspect that current interfaces leave room for improvement. GIS software is evolving toward easier use. Graphical interfaces, with pull-down menus, and point-and-click icon-based selection mechanisms, are being added to existing programs, and newer programs are being created within the WIMP (windows, icons, menus, pointing) paradigm. GIS interfaces are being improved based on feedback from users to developers. This long feedback loop is useful, but is clearly not optimal for improving interfaces.

There is a better way to improve GIS usability. Developers should make a conscious effort to design, evaluate and refine interfaces more rapidly. The feedback loop should be shortened, and more of the cost of evaluation shifted from the consumers to the developers. The effort should include comprehensive interface evaluation, via ongoing human subjects testing, throughout the design, development and revision of the interface.

2. Impediments to Interface Development

Historically, software development has proceed more slowly than hardware development. Analogously, interface software lags behind other software. Both of these situations can be partly attributed to complexity. Software interactions are typically more complex than hardware interactions, and human-computer interactions are more complex than software interactions. Complexity alone though does not explain the current state of GIS interfaces; several impediments to GIS interface development are apparent.

2.1 Lack of vision of what GIS interfaces should be

The computer is a new information medium which we are still exploring. It is not yet clear how it should be used in handling spatial data. Should computers perform as simple tools, with commensurately simple interfaces? Should they be viewed as very complex tools, with complex interfaces for which training is to be expected? Should

computers assume the role of interactive partners, with task and user models to allow the system to (usually) appear intelligent? Should they be semi-autonomous agents, checking-in occasionally to see that the user's intent is met? Should they be fully autonomous artificial intelligences, told what we want and expected to go off and perform complex tasks and report their results to us or to other agents? Minsky (1986) might be expected to argue for the later while Winograd and Flores (1986) are strongly opposed to thinking of machines as intelligent or assigning them agency.

Not only must we decide what computers should be, we must also decide how to communicate with them. It is not clear what modes of communication should be used in GIS, but it is fairly clear that different GIS applications require different modes. Visual languages with pointing or gestures, command languages, natural language, and programming languages are only some of the options currently available. Which are most appropriate? Shneiderman (1991) describes an expert system for deciding among menu selection, form fill-in, command language, natural language, direct manipulation. Are his rules applicable to, or extensible for, GIS?

Given a choice of communication style, what devices should be used to support it? There are an astounding number of options available (See chapters 21 and 22 in Helander's Handbook, and also Addendum 1, below). Relatively few of these options have been tried in existing systems, and still more devices are being created. Exploring the use of each of these devices is a large task in itself.

There is a sameness in existing system interfaces which seems to stem from automating functions which were previously performed without a computer, and then copying the ways that this has been done. Interfaces draw more from what has been given to users previously than from what they have said they want. In this way, the industry has locked itself into an old vision of GIS interfaces: users can not ask for things they do not know about and do not know about what vendors have not delivered. This stifles innovation, particularly that aimed at the needs of users.

2.2 Reluctance of users to adapt to new systems

It takes time and energy to learn to use new software. Even improved software. Therefore, there is an understandable tendency in many users to continue to use software they have been using rather than switch to a new version. Unless there are obvious, demonstrable benefits to be gained, users tend to be conservative in this respect.

2.3 Lack of tools for interface development

Tools to support interface development have not been widely available. This seems to be the case even given the advances in standardized operating systems and graphics environments, computer aided software engineering (CASE), and user interface management systems (UIMS) during the last decade. These tools are now finding their way from software research laboratories into the hands of software developers. GIS developers have begun to use this technology.

The potential benefits of using tools for user interface specification and management are illustrated in the following electronic mail posting:

From: beau1029@mstr.hgc.edu (Donald Beaudry)
Subject: Neuron Data's Open Interface
Date: 26 May 91 04:40:51 GMT

Neuron Data has recently released an interface builder for Motif, Open Look, MS Windows, OS/2 PM, and Macintosh. They claim that you get the superset of all "widgets" on all platforms. I have seen a demo and it is most impressive. Wait - it gets better...

You also get every look and feel on every platform! With the click of a button, your Open Look application running on a Sun will redraw itself to look like it is running on a Mac. You can get MS Windows look and feel under X, or on the Mac.

The quality of the widget set is impressive. They have created a virtual graphics machine that runs on all platforms. Using this VGM, they developed their own widget set formed from the superset of all widgets on all the aforementioned platforms. That means that you get tear-aways and modeless menus under Motif, a multi-column list that looks very impressive, etc. Instead of relying on Xt and Widget sets, the VGM relies solely on Xlib on X platforms, and draws its own interface components on other platforms.

This was very noticeable on the Mac, running 6xx Mac OS. The application built with Open Interface had the System 7 3-d buttons. And with a click, the application redrew itself on the Mac with a Windows 3 look.

This product seems like a cure-all, perhaps too good to be true, but from what I have seen, it appears to be real.

I have only seen the product roll out so far. Has anyone used this product? Impressions?

This posting indicates that tools are now available to allow rapid and painless porting of software with graphical interfaces, between numerous platforms. Developing a logical structure for an interface is a more pressing problem. Software to do that is also needed by GIS developers.

2.4 Allocation of system development effort

Previously, bare functionality has been the criterion for evaluating GIS software. If a system could be made to work within the constraints of small, slow, machines, that was enough. Making the software friendly was much less important than making it run correctly. Obviously, market commodity software, which GIS has become, must both run and be usable; market leaders are responding accordingly.

These factors, lack of vision, conservative users, lack of tools and lack of effort, are not the only ones retarding the development of innovative GIS interfaces, but they help focus discussion on why GIS interfaces are not what they ought to be. None of them is insurmountable, and considerable progress is being made on most of them. The most difficult factor to overcome is the lack of vision about what a GIS interface should be. There is no single answer, and many creative interface designs are possible. Our task in the next several years will be to design, evaluate and build interfaces that better serve users.

3. How To Build Better Interfaces

3.1 Understand users

The most basic caveat of the design literature is "Know the user." We do not know GIS users very well. As evidence for this claim, consider the literature's lack of a "typology of GIS users". We have pieces categorizing systems and their functions (Tomlinson and Boyle 1981, Dangermond 1990), but none classifying users. We do not know their disciplinary training. We do not know what they think about the data they want to analyze. We do not know how they want to analyze it. We do not know how much effort, time and money they will expend on any given analysis. Perhaps most important, we do not know how they conceptualize system use.

How should we characterize GIS users? We need to consider users' task conceptualizations, cognitive styles, work contexts, disciplinary backgrounds, perceptual and motor abilities, and individual differences. How finely though, should we divide the user population? To what degree should the system be able to accommodate user differences? These are open questions.

How can we get a firmer understanding of how users work with GIS interfaces? The most direct approach is to do human subjects testing of GIS interfaces, at both atomistic and holistic levels. Studies at the atomistic level can answer questions about specific parts of an interface such as what is the best layout of a particular screen, or the choice of icons should be used to represent particular functions. Holistic studies assess how well the parts of an interface work ensemble. Testing allows the comparison of design alternatives. It also teaches us about users, validates our understanding of user performance, and verifies that normative user models from applied psychology (e.g., Fitts' law,

Hick's Law, GOMS - see Addendum 2) are applicable in GIS. Human subjects studies often reveal surprising things about users. My work on choropleth map interpretation (McGranaghan 1989) is a case in point. If we know about users, we can plan for, recognize, and accommodate their needs.

Human factors studies in GIS have been criticized (1) based on mistakenly identifying them with the psychophysical research in cartography and assuming that their goals are the same, and (2) on the grounds that they lack experimental controls needed for statistical analyses or are so tightly controlled as to have no bearing on "real" GIS use. Neither of these criticisms is well founded or convincing, and human factors testing remains the most viable way to learn about GIS users.

The aims of psychophysics and of human factors research are quite different. The former attempted to establish relationships between a stimulus magnitude and the strength of a response. Human factors research takes an approach which is much more closely related to information processing theories of cognition (Rumelhart 1977). It assumes that the time required to perform a task, and the errors that arise in the process are measures of the task's difficulty. (Task in this sense is taken to include the setting - tools, training, technical environment, social climate, and other factors which might effect performance.) By measuring performance under different conditions, it is possible to find settings (interfaces) that make the task easier.

In human factors research, it is often difficult to control all of the relevant properties of users (background, training, computer familiarity, task familiarity), and keeping the number of experimental variables to a workable number requires careful formulation of experimental questions and designs. However, these difficulties can be addressed with relatively few subjects by choosing reasonably representative subjects, and using within-subjects repeated measures analysis of variance techniques.

Human subjects data tend to be noisy. Trends are often apparent, though not significant at standard levels (i.e. the arbitrary .05 and .01 levels). Larger subject pools could be used, but at considerable cost in experimental time and effort. An alternative is to relax our statistical demands slightly. In designing an interface we are not concerned with conserving a "null hypothesis" but rather are deciding between new alternatives. For this, a less conservative statistical approach is justified.

3.2 Understand tasks

User's models of their tasks need to be better understood. What are the tasks the system's users want to perform? Browne et al. (1990) give a number of methods that might be employed in finding out. It is an obvious truism that software designers must understand the tasks which their programs are to perform. The importance of understanding the user's conceptualization of the task is less obvious. Task conceptualization becomes much more important in the interface software than in the "guts" of an application. The user's concept of the task determines the user's expectations about how to use the software.

We lack a good analysis of the cognitive complexity of spatial data handling tasks. Which GIS operations are difficult for people to comprehend? These must surely be more error prone, and used less frequently and less effectively than other operations. Could operations that correspond more closely with user concepts of task performance be found? Would these be easier for them to learn? Are the conceptually difficult operations the same with different data models?

Systems often provide macro languages that allow users to "build analyses" from a set of component operations, much as with a high-level programming language. This flexibility is needed because the systems need to be tailored to fit the tasks of users, but this mode of interaction does not lend itself to interfaces for naive users. It assumes at least the ability to conceptualize and construct an algorithmic solution to a task in terms of system primitives. Whether this is done using a traditional programming environment, a visual programming language (in which objects are dragged around on screen to define the operation of an analysis), or some other method seems relatively less important than that the work happens abstractly in the user's mind and concretely (and differently) in the computer.

Work by Kuhn (1991) and by Gould and McGranaghan (1990) has begun to examine the use of metaphorical understanding (conceptualization) of spatial data and spatial data handling procedures. This seems a very rich avenue.

The paper by Werner Kuhn in this collection describes some important benefits of considering metaphorical mappings early in the design of an interface. Using natural mappings should make systems much easier to use.

3.3 Understand User x Task x System Interactions In Situ

It is deceptively easy to think that we know what an interface should be, even before we see the design context. Imagine an interface for a land records system. Now, imagine one for the county recorder of deeds and another for walk-up public access to the same system. I suspect you imagined different interfaces for each of these contexts. It is necessary to look at the interactions among the user, the task, and the interface in context. This calls for in situ studies.

In situ, or ecological performance studies are often viewed as hopelessly complex due to the essentially unlimited number of uncontrolled factors that could influence measures of performance. In fact, considerable information can be gained with surprisingly little effort using verbal protocol analysis and other observation techniques. Last Fall, three graduate students in my seminar on HCI in GIS at the University of Maine, designed, executed and analyzed (Kiedrowski, Haggerty and Steiner 1990) a study comparing the learning times for three simple tasks on two commercial image processing systems, one with a graphical interface, the other with a command-line/menu choice interface. They discovered that the logic of the sequencing of the interaction mattered more than the mode of the interface. The experimental sessions quickly revealed interface weaknesses and showed which interface was easier to learn, and which was faster to use. Improvements to both of the interfaces were suggested.

4. Promising Directions

No one interface will serve for all users, for all tasks, in all environments for all times. Exasperation may drive one to provide one interface and tell users "how it is going to be." This provides technology to many different users at minimal cost, but forces the reshaping of a task to fit the system, and risks not addressing the needs of many users. A balance needs to be found.

Usability testing should be incorporated in the interface design process, and continued through development and the product's life, to "tune" the interface. Various techniques are useful for empirically grounding design choices. Atomistic studies might be used to compare individual parts of an interface in isolation, while in situ studies will give a better idea of how a complete system functions in its task environment. Structured walk-throughs, though not really human subjects testing, fall somewhere between these types of studies in scope, and are also useful for checking the organization of an interface.

GIS designers should be encouraged to employ software tools that specifically aid interface construction. Rapid prototyping environments are particularly important in this respect. Rapid prototyping technologies can greatly facilitate interface testing by allowing one to examine the look and organization of an interface without actually building the underlying product. Apple's HyperCard is quite easily used this way. Other products, such as Kodak's POP (Wilson and Rosenberg 1990) and PROTOSCREENS (Bailey 1989) exist for other platforms. More flexibility can be had by programmers using X-Window widget sets to build program facades, before the program internals exist.

The use of UIMS software should also be expanded. Interface development tools that isolate the system from the concrete aspects of the interaction allow the interface to change while the underlying application remains the same. Interfaces that can be easily altered to better fit a user - task combination are an attractive compromise between forcing the use of a single interface and developing different interfaces for each combination. Adaptive interfaces (see Browne et al. 1990), which change for different users or for a user through time, push this flexibility to the extreme, placing the burden on the interface to be user literate, rather than the other way around. This technology has been applied in varying degrees to a number of software projects. The potential benefits in GIS seem very high because of the wide range of applications that may be addressed by a common spatial data processing engine behind several interfaces.

I am confident that GIS interfaces will continue to improve. In this piece, I have tried to point out several things that I think should be done to foster this. The central issue is to make interface design a conscious endeavor. Thorough conceptualization of the needed interchange of information between system and user is required. In addition,

testing of the interface design must accompany its implementation and development. Tools and techniques for these processes are available and should be employed.

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Addendum 1: Some devices for physically moderating the interface.

Input:

various keyboards, reed-key, mouse, digitizer, light pens, touchscreens, trackballs, joysticks, "iso-point", data glove, point-of-gaze trackers, voice recognition, video motion-gesture sensors, sensor-rooms (virtual reality environments looking in at us)

Output:

CRTs, LCDs, plasma, light-shutter stereo, stroboscopic 3-D (of what size and resolution?), sound synthesis, tactile feedback, and various types of environmental control (lighting, heat, humidity, etc) (I do not know of an olfactory output device yet, but find the idea intriguing)

Addendum 2: Some performance models from applied psychology.

GOMS- Goals: states to achieve

Operators: elementary perceptual, cognitive and motor actions

Methods: fixed scripts of subgoals and operators

Selection Rules: to decide between alternative goals and methods

(Card, Newell and Moran 1983)

Hick's law (choice RT) $T = c + k \log_2 b$

b = number of equally likely alternatives

c, k = constants

Fitts' law (movement time) $T = c' + k' \log_2(d/w)$

d = distance

w = measure of size of target

c', k' - constants

(see Barnard's chapter in Shackel and Richardson, 1991)

Graphical User Interfaces and Cartographic Generalization: A Prototype Design

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My major concern with the development of GIS interfaces lies in a very specific area: cartographic generalization. Although the process of digital cartographic generalization, a significant aspect of visualization, developed quickly during the period 1965 - 1980, little progress has been made during the 1980s. Most of the initial progress resulted from work in the development of algorithms (such as the well known Douglas and Peucker line simplification routine, a variety of techniques for smoothing data, and algorithms for displacement, such as those by Nickerson), and attempts to analyze both the geometric and perceptual quality of those algorithms. Recent attempts at developing a more comprehensive approach to the digital generalization of map features--such as the application of simplification, smoothing, and enhancement routines either iteratively or simultaneously--have not been, for the most part, successful. This stems in part from our lack of procedural information--or knowledge--on generalization. Such procedural knowledge includes decisions on which techniques are applied to actually generalize map information, the sequence in which these techniques are applied, and what tolerance values, or parameters, are used. Until researchers working in the spatial sciences have access to such procedural knowledge, a comprehensive approach to cartographic generalization will not be possible. It is, without question, one of the major unsolved problems in cartography and GIS.

Currently, there are no existing logical interfaces that enable individuals to "experiment" with map generalization and ultimately to acquire such procedural knowledge. It is, however, worth mentioning a few of the previous packages with generalization capability. Perhaps the first attempt to include generalization within a mapping package was the Harvard Laboratory's SYMAP. With SYMAP, the generalization of surfaces was possible through ELECTIVE 38: Trend Surface Analysis. The user, after constructing the required database, could select both the order of the surface and the creation of a residual map. Much later, with SAS/GRAPH, the possibility for line generalization of coordinate strings was made available. SAS/GRAPH included PROCEDURE GREDUCE which applied the Douglas (Peucker) algorithm. The algorithm was controlled with two parameters: the NX value (which represented a density level of 1-5) and the EX value (which allowed the specification of a distance tolerance). The lack of any interactive user interface required a user to iterate through the NX and EX parameters until desirable output was obtained. It was a confusing, frustrating, and time-consuming process. More recently, one can point to the interface (TRANSFORMATION WINDOW) provided by the MAP II Processor as an example of a much improved raster-based design. Here, the user selects both a MAP and a FILTERING technique from a window. After this selection, a set of specific FILTERING techniques is displayed. The user may APPLY the filtering technique, view the displayed map, and immediately alter the algorithm. It is the closest design for a truly interactive user interface for map generalization that exists.

I see a need for two types of user interfaces for map generalization. The first is a user interface for knowledge acquisition on the geometric, sequencing, and basic rules of map generalization. This particular interface would a) provide users with a full array of generalization operators and tools, b) focus on the individual, as well as the sequential and interactive, effects of the generalization technique, and most importantly, c) would keep a detailed "trace" or history of activities in the generalized image. A second type of user interface, still many years away from completion, would allow the system to generalize without user intervention. We simply do not have the knowledge to complete such an interface at this time.

I feel the research community is now ready to design and implement the former type of user interface for generalization. I see eight basic objectives for such an interface:

[1] Provide the user a comprehensive set of generalization operators, including:

simplify	amalgamate
smooth	aggregate
displace	exaggerate
typify	omit

that will allow the user to manipulate the map image.

- [2] Provide a comprehensive set of tools which will assist in identifying map features
- [3] Provide the user with assistance in selecting tolerances and parameters for individual operators and algorithms
- [4] Provide the user with warnings when an illogical selection is made
- [5] Provide a "trace" or accounting of feature generalization
- [6] Provide the user with supporting documentation and diagrams
- [7] Provide the user, when possible, with a "measure of success"
- [8] Provide the user with features, or regions, on the image in need of generalization, or generalization "hot" spots. Such "hot" spots are related to "conditions of generalization", including
 - congestion
 - coalescence
 - conflict
 - complication
 - inconsistency
 - imperceptibility

Two very important aspects of this generalization user interface include (1) an on-line (hopefully hypermedia) help system and (2) the ability to, for certain operations, perform "animated" generalization. For instance, a user could request an animated simplification of a contour line where, as the line is continually reduced, the user could stop the sequence at an acceptable level.

A project in the Department of Geography at the University of Minnesota involves the development of such a graphical user interface (GUI), specifically to gain the "procedural" knowledge involved in 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 windows, each with a series of generalization operators, specific algorithms, and parameters. For instance, a user selecting the GENERALIZATION OPERATOR, SIMPLIFY, would be given a series of specific algorithms to select. After selection of a specific algorithm, the user would, after being given another menu, be able to select a tolerance value. The same structure is provided for each of the twelve operators. A component of the user interface--generalization tools--also allows a user to select individual objects or entire areas on the map to be generalized. Eventually, the user interface will be used with the generalization test data set, developed by the NCGIA, to gain procedural knowledge on generalization from trained professional cartographers. As a cartographer works with the image via the interface, a generalization "log" will be maintained. Such a log will record, for each feature, the application and sequencing of operators, along with specific tolerance values. Such knowledge will be used to determine, in a holistic manner, how maps are generalized by evaluating the relationship between operators, parameters, and features.

Biographical Sketch

Robert B. McMaster received his B.A. in Cartography from Syracuse University in 1978 and his Ph.D. in Geography and Meteorology from the University of Kansas in 1983. From 1983 to 1988 he was an Assistant Professor of Geography at UCLA and in 1988 he returned to Central New York as an Associate Professor of Geography at Syracuse. In 1989, Bob accepted a position in geography at The University of Minnesota, where he now teaches. Bob has taught classes in cartography, cartographic design and symbolization, remote sensing, quantitative methods in geography, physical geography, digital cartography, and geographic information systems at these institutions. His major research interest is in automated cartographic generalization, including the development and testing of algorithms, design of models, and the development knowledge bases. He is currently Editor of the journal Cartography and Geographic Information Systems, formerly The American Cartographer.

GIS and the Concept of Usability

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It is a well known fact that the design of the user interface for IT systems is crucial for their efficiency, effectiveness and acceptability. Yet, from a design point of view, the user interface of a GIS is often an afterthought produced only when the rest of the system is nearly complete. This leads to poorly designed interfaces which are difficult to change. It is also recognized that the design of the interface should be considered at an early stage in the overall product design process and that the interface should be evaluated to determine its effectiveness (Medyckyj-Scott et al 1990). Currently user testing of GIS interfaces is lacking. This reflects the fact that devoting human, financial and computer resources to user interface design as an element of product development is considered a luxury by many GIS developers. (When one vendor was asked how they had derived the icons they used in their system they reply was "we sat someone down in a corner for two weeks and told them to design some icons".) Hopefully however as resistance grows to poor user interfaces and the need for product differentiation in the market place becomes apparent, the design and testing of user interfaces will be seen to be a necessity.

From a research point of view, the speed at which researchers have started investigating various aspects of GIS user interfaces would lead one to think that all the problems with current systems have been isolated and catalogued. In reality this is far from true. In fact there has been no systematic empirical evaluation of what the user interface issues relating to GIS are (despite what vendors say!), most commentary on the subject being based on the anecdotal comments of GIS users. We are currently no nearer to formally isolating the unique aspects of GIS interfaces from those which are important to the user interface of any piece of software. As a result it is quite possible that considerable effort is being expended researching aspects of user interaction which users have no problems with or for which solutions already exist.

In this short paper I want to outline the concept of usability as it relates to GIS systems particularly with regards to the user interface. David Mark, in an email regarding position papers, asked for something fresh. The idea of usability is not fresh but it is important and pertinent given the current situation regarding 'ease of use' of GIS and the imminent arrival of international software ergonomics and human computer interaction standards.

Something about System usability

System usability is concerned with ensuring a system can be used easily and effectively by a user who has been given specified training and an appropriate level of support, in order to complete a specified range of tasks within a specified range of scenarios (Shackel, 1986). Typically usability testing refers to the testing of the user interface but many other aspects of a system can be evaluated. Concern is primarily about the legibility and content of the display layout; the appropriateness of the dialogue styles; the order in which procedures are used to achieve task goals, user navigation around the system, consistency in the way commands are invoked and used; and response times. It is generally accepted that it should also include consideration of any help facility and documentation.

The term 'usability' is frequently used to indicate a positive quality in a system which makes the interaction between user and computer easy. Thus a GIS with poor usability is likely to have a detrimental effect upon the use of that system. It may, for example, mean that the user has to expend mental effort which should have been directed towards the task in hand in trying to use the GIS. Poor levels of usability can lead to (i) the user refusing to use the GIS, (ii) only partial use of the GIS, (iii) the user interacting through an intermediary or local expert.

To be usable a system must have the utility to provide a benefit to the user but minimize costs in terms of user effort. Some GIS may offer many facilities but if the usability is poor users will only make use of a limited number of functions, learning a few commands 'parrot fashion', and using them with little understanding. They will resort to tried and trusted methods or functions and fail to explore the functionality on offer in the rest of the system leaving much of the potential of the GIS untapped. Usability depends then upon user characteristics (e.g. previous experience with similar systems and experience of the task domain), and the relationship between the user, the tasks the user is performing and the system. The type of task and its nature can significantly effect system usability. Users of GIS are

usually engaged in open ended types of tasks which require a lot of flexibility in the system but more choice can equate with more difficulty of use since the user has to remember a greater number of options, commands, and procedures.

Why the 'sudden' interest in Usability

The concept of system usability is becoming increasingly important within the IT field as a whole and thus GIS as well. A combination of factors are causing this, primary amongst these are -

- i) A general realization that there has been insufficient attention to the issue of 'ease of use' of IT systems. If we look at GIS in particular we see that concern in the past has been about processing speed, levels of functionality, data needs and storage requirements. It is now realized that an IT system, such as a GIS, is more likely to fail on human and organizational grounds (including usability) than on technical ones. In some instances the difficulties encountered have actually limited the use of the GIS so that the potential benefits which could be derived from the technology have not been achieved (e.g., Billingham, 1990).
- ii) Changes in national legislation will require vendors to consider the issue of usability in system design. Also, at a national and international level various organizations are working on standards for software and hardware ergonomics. Many of these contain sections on usability. For example, ISO TC159/SC4 is developing an extensive multi-part standard ISO 9241 on ergonomic requirements for office work with visual display terminals. As well as addressing job and task design, dialogue design principles and environmental requirements, this standard includes representations of information, and a major push on the formal requirement for usability statements (see below) to be stated and tested for during the design of an IT system. These are likely to become full standards during 1991/92 and there are proposals to have legislation based upon them. While compliance by a GIS vendor is not a guarantee of protection from legal requirements, non-compliance will be difficult to justify and raise the question of competence of the vendor - commonly known as 'duty of care' in the UK.
- iii) In the GIS context, we are seeing a different type of GIS user appear, one who is less technically orientated and has neither the time or the inclination to learn to use what appear complex systems. In order to make the technology available to those who want to use it, and not just experts, we need simpler more usable systems. Usability testing, from this viewpoint, is required by suppliers to ascertain whether a system is easy to use. In addition, if we treat every individual as being different (which they are) one of the aims of GIS research should be the design of systems to assist the user in their use, which removes anything that gets in the way of free and unhampered use. This may be through the design of systems which can be rapidly adapted to each user (e.g., adaptive user interfaces, records of user preferences), which promote free and flexible experimentation.

User interfaces and usability

The user interface is probably the most important aspect of GIS usability (Medyckyj-Scott et al 1990). It is the part of the GIS which the user sees and interacts with, and thus, to all intents and purposes is 'the GIS' as far as the user is concerned. It is therefore important that the interface permits the user to achieve the goal he desires easily, with minimal errors and limited task complexity. In this situation the interface must facilitate the user's completion of a task or series of tasks. To do this the interface and user must have a mutual understanding of each others way of 'thinking' in relation to the task at hand.

Vendors

Vendors generally see user interface issues in terms of isolated problems e.g., misunderstanding of a command. There is little attempt to see if the problems are the result of more fundamental problems, ones which probably would not have occurred at all if the user interface had been considered earlier in the design process and in more detail. If vendors have discovered issues of importance these have not been published so that basic research can take place at trying to solve them. Additionally, the interaction of user interface developers with users often seems intentionally limited. Their primary source of information about the current version of the GIS is often through the marketing section, who, in turn, base their information on contacts with managers in customer organizations. These customer managers are usually not end-users themselves and may not therefore be familiar with the end-users problems caused by the user interface.

Given the variety of potential GIS users that now exist however and the large number of GIS application domains, many vendors have begun to realize that building a generic interface which can be used by all types of users is not possible. Instead they now supply tools by which an organization can build and tailor the user interfaces to their own needs, thereby passing the problems of designing the user interface onto the shoulders of the users! (NB such tools form part of the usability equation and need to be evaluated when talking about GIS usability.) While the user maybe able to decide on the functions which are important to them and even the terms they want to use they have no experience of user interface building. Moreover building an interface is a time consuming business. While any interface may require some customization to users requirements this should be tinkering rather than major construction. Vendors should provide a number of generic interfaces tailored to different types of user (systems manager, analyst, decision maker, 'browser') which can be finely tuned. Just as importantly though, GIS purchasers should be educated to be more discerning about the general usability of the systems they are considering, looking at the usability of the alternative systems during bench marking as well as functionality and cost.

Measuring Usability

In declaring the usability of a GIS the producer of the system should include measures of usability. These should cover the three different aspects as defined in the standard understanding of the term usability i.e. effectiveness, efficiency, acceptability (although to this might be added learnability), as well as specifying the intended users of the GIS, and the uses and conditions of use of the system.

Fundamental is the idea of a **usability statement** against which aspects of the GIS are evaluated. This usability statement is intended to contribute to greater precision in specification and assessment of usability. The statement also has to be dynamic and extendible to take into account future developments e.g., the development of group GIS, the re-emergence of other input devices such as touch screens and pens following improvements in the technology, new visualization techniques, etc. The question arises however, of what aspects of usability concerning a GIS are important and need to be specified. Work already conducted by the author has indicated that effectiveness, efficiency, acceptability and learnability are all important:

Effectiveness: Measures of effectiveness address the following issues:

How many task goals/objectives were achieved ?

How completely were task goals/objectives achieved?

Measures of this sort are likely to require that the task(s) against which usability is defined are capable of being specified in terms of a number of independent goals or objectives, and that criteria can be defined which indicate when each goal or objective has been achieved. Such measures could be based on decomposition of task goals and objectives into subgoals. Completion of task goals may either be measured in strictly objective terms (e.g., if a task goal is for a user to produce a plot of a map containing a cross-section, then an objective measure of completeness is possible) or it may be more appropriate to consider the user's perception of when a task is completed. In this case the criteria are subjective in nature and often relate to qualitative features of the task. At a lower level we might want to consider how effectively information is presented to users based on an understanding of their needs - to verify the data, to undertake data analysis, for communication and illustration and for supporting decision making.

Efficiency: Measures of task efficiency relate to the speed and accuracy with which task goals and objectives are achieved. Specifically, they should address issues such as:

How quickly were task goals achieved?

How many errors were made in achieving task goals?

What was the balance of time spent which was relevant/irrelevant to task goals?

Acceptable: Measures of acceptability relate to: What is the level of acceptability of the system to the user? What is the user's overall rating of the usability of a system? User perceived usability may cover many facets of the system (e.g., how easy they consider it was to learn, how well documented did they consider the GIS to be). Measures of this sort address the user's individual cost/benefit trade-off for whether any problems involved in using the system

are justified by productivity or other returns. Acceptability of a GIS to others in the user's working environment is an issue which might also need to be considered.

Learnability: Measures of learnability relate to how easy the GIS is to learn, for example:

The amount of time which elapsed from the commissioning of the GIS and start of user training to the user being able to perform certain tasks?

The amount of training that was required ?

The length of time it took occasional users to re-learn the system after different period without using it?

Little has been done so far within the GIS field to go beyond these broad headings. Research is required to establish what the measures are needed within each of the headings. Fundamental to this will be the need to establish some generic top level description of the tasks users perform with a GIS, separate from any particular application area or a specific implementation of a GIS. Possible task analysis methodologies which could be used are Hierarchical Task Analysis (HTA) (see Shepard, 1985), User Skills and Task Match (USTM), or Personalized Task Representation (PTR). Following on from this an outline of a structure by which GIS usability can be specified and evaluated - the usability statement - can be developed.

Usability v. the behaviorist/cognitive approach

A usability approach to system design is very much a technological one, tending to take as its starting point the current technology. It is recognized that a full understanding of usability requires an understanding of the cognitive processes which enable users to achieve their goals. Consideration must be given to how people think and behave when using the system. Ideally one would want the system to adapt to the user's way of thinking. Practically the user, being more flexible adapts to the system. However, if ideas about how people represent and think are incorporated into the design of systems this should reduce the amount of cognitive and behavioral modification required by the user. I refer here to the work on user's mental representations of space (Medyckyj-Scott and Blades, 1991; Gould, 1991), mental models of GIS (Hearnshaw, 1991), geographical metaphors (e.g., Gould and McGranaghan, 1990) and so on.

Whilst the behaviorist/cognitive approach is appropriate to the development of principles to be followed when designing a system, particularly the user interface, there are a number of problems when this approach is used for evaluating the success of GIS in terms of it enabling users to achieve their goals. A major one is that the behaviorist/cognitive approach fails to provide a formal means for evaluating the usability of currently existing GIS or for conducting comparative evaluations.

Some other Issues of Importance

While a number of GIS usability and user interface issues are being investigated, many others await consideration, for example, the use of adaptive user interfaces, interfaces for GIS as decision support tools or command and control systems. Even where research has begun our knowledge is still limited.

An immediate problem requiring attention is the profusion of different GIS/spatial terms used different vendors. Terminology for GIS operations, etc., is used differently between vendors or, alternatively, terminology is the same but slightly different operations are performed. This causes problems for organizations who have users who migrate between different systems depending on the type of problems they are trying to solve, and for users who are learning new systems. Agreement on terms and what they mean is urgently needed and would lead to shorter learning curves for those learning new systems and fewer errors (e.g. initiating the wrong operation) by those who use more than one GIS.

With regards to the hardware and software standards, the GIS community has need for some concern. The standards seem to be very much based on an office view of information technology, although, certainly in the UK, bodies representing CAD vendors and users are trying to have an input. This is bound to have implications on, for example, icon design and screen presentation. In addition specific standards could restrict the development of GIS systems, particular regarding information presentation.

Some basic questions in need of answers

- 1) Do we know what the characteristics of GIS users are? What kinds of skills and knowledge do current users have? What kinds of skills and knowledge should users have? There are a number of user taxonomies about but these do not seem to be based upon any empirical research.
- 2) Do we know what types of task users are trying to perform with GIS? Has anyone actually carried out formal, and possibly comparative, task analysis of different user groups to determine task factors? To what extent do tasks vary from one occasion to another? How often are different tasks performed and does this vary between user groups?
- 3) Many goals have to be undertaken in a group context. How does this effect task breakdown and task allocation? Does the GIS and its interface support group work?
- 4) What aspects of usability relating to GIS are important and need to be researched ? Has anyone actually carried out formal and comparative usability evaluations of any currently used GIS? If they have, what were the findings? If no evaluations have taken place, why not?
- 5) What, if any, are the unique aspects of GIS interfaces from those which are important to the user interface of any piece of software ?

My belief is that the successful development of user interfaces for GIS in the future is likely to require an inter-disciplinary team made up of computer specialists, HCI scientists and spatial scientists. Such a team will focus heavily on usability of the GIS rather than just the design of a user interface. This will involve as much effort (through prototyping and iterative testing with real users (Medyckyj-Scott et al. 1990) as is now currently given to the design and development of the underlying GIS functionality.

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Biographical Sketch

David Medyckyj-Scott is a researcher specializing in user interface design and the organizational aspects of GIS and related technologies. He is a researcher with the MRRL working in the Department of Computer Studies at Loughborough University. Prior to joining the MRRL he trained in cartography and then conducted research for four years at the University of London (London School of Economics) under Dr. C. Board and in conjunction with the Psychology section at the Royal Aircraft Establishment Institute of Aviation Medicine under Mr. R.M. Taylor (Principal Psychologist). The research investigated the role of cognitive processes and structures used in map reading, primarily those of mental imagery, spatial representations and perception. This research culminated in the award of a Ph.D in 1988. He has a M.Sc. in Information Technology from Loughborough University where he specialized in user interface design and the organizational implications of IT. During this period he carried out user interface research for Laser-Scan Laboratories Limited who produce GIS and automated mapping products. He has worked in the past as a customer support and human factors engineer for a survey and mapping software house. Current research work

includes the design and implementation of a user interface for a computer based spatial data registry, experimental research into user interaction with computer generated maps during use of GIS, the relationship between spatial cognition and GIS use, user modelling.

David Medyckyj-Scott is a member of the British Cartographic Society (member of the British Cartographic Society GIS Special Interest Group and Design Special Interest Group), the ACM Specialist Interest Group in Computer and Human Interaction, the British Computer Society GIS Specialist Group, the British Computer Society HCI Specialist Group, and the IEATP Computer Supported Cooperative Work Special Interest Group. He has recently become a member of the UK Association for Geographic Information Standards Committee on GIS Implementations. He is also a member of the BSI Technical Committee PSM/39/25 (Software Ergonomics and Human Computer Interaction). This committee is working on the development of ISO Standard 9241.

User Interfaces for Geographic Information Systems: A Remote Sensing Perspective

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What is the remote sensor's view?

To design user interfaces for remote sensing, it is important to understand what the conceptual topics are that a remote sensing person has to deal with. A short discussion of these conceptual topics will be first described, because it is necessary that they be clearly represented at the user interface level. Remote sensing data has been defined to be important for integrating into geographic information systems (GIS) as described in NCGIA initiative 12 (Star et al. 1991).

A person dealing with remote sensing data thinks in terms of spatial, radiometric, spectral, and temporal information when trying to understand and interpret imagery. Spatial refers to the smallest size of the data element in the remote sensing image; radiometric refers to the number of levels of grey possible in the image (normally, 256 or 1024) or the most discernable detection between brightness levels within the scene; spectral refers to what part of the electromagnetic spectrum is being sensed and what is the wavelength band being recorded; and temporal refers to the time element or how often is the area revisited by an aircraft or satellite sensor. The user interface system designed to incorporate remote sensing data should then be able to communicate information about these four properties of an image.

Remote sensing data is multidimensional in nature. Data can be collected from many platforms (satellite and aircraft), thus providing multistage remote sensing data. There is research being performed on how best to merge multisensor data sets from satellite platforms (Chavez et al. 1991). Resolution issues need to be addressed when merging these multiresolution data sets, thus multiple data formats have to be considered when importing various images into the GIS system. Another factor to be considered is that many of these images are not of the same exact area as covered by the GIS, thus ways to incorporate and overlay these images spatially must be considered. Multispectral sensing is the norm for satellite and aircraft sensors. For these sensors data are acquired simultaneously of the same area on the ground for several wavelength bands. Multitemporal data sets are used very often in remote sensing studies to examine for change detection. Since remote sensing imagery can be acquired at many different times, ways to incorporate the time variable in the user display is critical. Lastly, remote sensing is often merged with other data sources for different views and interpretations of the data (Harris et al. 1990, Janssen et al. 1990, Zhou 1989). Research has been conducted on how best to integrate remote sensing data sets with GIS (Ehlers et al. 1989, Piwowar and LeDrew 1990).

Various functions related to providing geometric and radiometric corrections to the remote sensing image need to be included in the user interface. Remote sensing data is acquired by passive or active remote sensors (depending on the wavelength being sensed), thus different ways to display, analyze and interpret the data have to be included. The user interface for GIS should be able to handle these multiple interpretations of remote sensing information. Research issues for the future computing environment of GIS and remote sensing are further described in Faust et al. (1991).

Remote sensing is by nature interdisciplinary, thus there will be many users that will think and see different information about the data (agriculturalist vs. civil engineer vs. land use planner vs. scientist). For example, the agriculturalist will want to know the state or moisture status of the crop (from an interpretation of a specific wavelength band, the middle infrared), what crop types are there (from an image classification), how much is there in x and y crops (statistics from the image data), and where are they located (from the image map). However, for the same image, a land use planner may only care where the agricultural land is located, which could potentially be available for urban

growth. The scientist may only want to understand how the remote sensing signal from the landscape interacts with the atmosphere to produce a characteristic spectral signature for different earth materials. Lo (1986) gives many application examples using remote sensing data as applied to the human population, the atmosphere, the lithosphere (geology, geomorphology, and hydrology), the biosphere (vegetation, crops, and soils), land use and land cover mapping, the hydrosphere, and cartographic presentation of remote sensing data. Moving to the earth's cryosphere, a scientist wants to understand how large-scale ice features relate to field measurements of ice flow velocity. Can modelling of such ice flow mechanics translate to unusual features that one sees on satellite imagery?

Provisions should be made to accommodate these varied users of remote sensing data sets. Viewing the remote sensing data "draped" on elevation data sets (the 3-dimensional or even an n-dimensional effect) from many different vantage points is key for understanding remote sensing processes. Also, can engineering, ecological, hydrologic or any other model being developed be integrated with results from the remote sensing analysis? And last, what-if scenarios and simulations with the data sets should be a key function of the user interface. Examples are contained in Light (1990), Lupien et al. (1987), Robinson and Frank (1987), Ripple and Ulshoefer (1987), and Usery et al. (1988).

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Biographical Sketch

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THINKING WITH GEOGRAPHIC INFORMATION: USER INTERFACE REQUIREMENTS FOR GIS

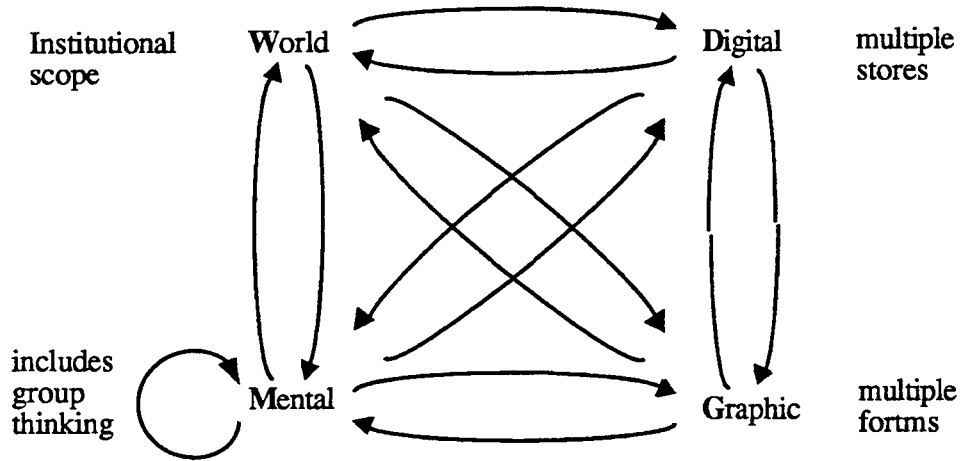
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A Geographic Information System (GIS) is intended to provide information to a user for solving problems and making decisions- perhaps among other things whatever they might be. How information is generated and processed often results from a user undertaking some sequence of both cognitive and sensori-motor activities - called cognitive and physical interaction. This interaction in many cases is not performed in a willy-nilly fashion, but in some goal-directed, systematic fashion so that in fact the process is repeatable if necessary. This systematic process can be called "thinking with a GIS". It is posited here that a user interface can have a dramatic affect on the outcomes of the thinking process, either hindering thinking or facilitating it depending on the requirements for interaction.

In the cognitive science literature Gilhooly (1988) describes thinking as a process of mental modeling that involves problem solving and decision making. The idea that individual's hold mental models within the mind-as representations of the world-can be traced to Craik (1943) who used the concept as a basis for human explanation and understanding. A thorough theoretical investigation of mental modeling is provided by Johnson-Laird (1983). He elucidates a mental model as a "state-of-affairs" of physical and conceptual things as held in the mind of animate beings, and uses this notion as a basis of human reasoning. Norman (1986) describes a mental model as an internal representation how a task is to be accomplished by a person who is using a computer, at times substituting the term user model. He does this in the context of human-computer interaction as part of a new subfield called cognitive engineering. More recently, Ackermann and Tauber (1990) consider various cognitive engineering approaches for human-computer interaction, including theoretical and empirical aspects of mental models.

Mental models are one way of characterizing the way in which people form and use thoughts about the world in directed, non-directed and creative ways (Gilhooly 1988). Several authors (Kurfiss 1988, Margolis 1987, Slater 1982) agree that critical thinking as a form of creative and directed thinking is the foundation of a well-informed society. Thus, individuals solve problems and make decisions about their world using critical thinking skills. As such, understanding the nature of critical thinking with a GIS can play a significant role in assisting professionals and/or citizens become more informed for better decision making about their worlds.

Unfortunately, the breadth and depth of problem solving and decision making that goes on with GIS is so large that it is impossible to enumerate all human interaction needs for every application that is or will be possible. However, this dilemma should not cause us to throw up our hands and rush into the night feeling that we can not provide a coherent understanding of the nature of the problem. A framework for elevating much of our concerns above the software function level, but generic enough so that every application's need not be enumerated is one that involves a process of "critical thinking" within the context of GIS-related transformations. Van der Schans (1990) has presented a model for understanding activities that occur in a GIS in terms of twelve transformations (Figure 1). Transformations occur principally between four domains: W: World, D: Digital, G: Graphic, and M: Mental. The mental domain is the domain of mental models. Forming and using mental models within a critical thinking process provides a systematic way of addressing many of the requirements for interaction that generate information.



Geographic data/information/knowledge domains:
 W:World D:Digital G:Graphic M:Mental

Transformations of significant relevance for mental model formation in the context of growth management:
 M --> W --> M : analysts sense the World and converse with others.

M --> (D) --> (G) --> M : interactive mental model formation (and use) by analysts.
 D and/or G might not be used in various sessions.

Figure 1: Data/information/knowledge domains and transformations that influence thinking in a GIS environment. (Adapted from van der Schans' [1990] WGDM Model.)

A process of critical thinking involves multiple stages of development. In a context of geographic learning, Slater (1982) describes a critical thinking process as consisting of three stages, with each of the three stages decomposed into two or more steps (See Table 1). The eight steps composing the critical thinking process act as a guideline for the kinds of questions/issues that arise in rational problem solving and decision making. Each of the steps consists of several specific questions/issues that are important for information use at that step. Limitations of space and time prohibit an exhaustive treatment here, but it is important to point out the significance of stage 2 in the framework that involves data processing for interpreting, analyzing, and evaluating information - the mainstay of GIS. The step 7 of problem solving presented by Slater (1982) is a narrower interpretation than is commonly given, but principally means the treatment of several generalizations that might be solutions to a problem.

Slater (1982) mentions that several forms of data can be useful in answering the questions in each of the steps, among these data are maps, tables, graphs, pictures and verbal scenarios. The questions at each of the steps are operational and not cognitive in character, i.e.. they focus on what is asked of the topic rather than the way it is asked by the individual. This approach focuses on what an individual needs to accomplish in critical thinking rather than how it is accomplished. However, focusing on the cognitive aspects is also important in solving problems and making decisions in a critical thinking process. A few of the important cognitive transformations that occur in interacting with a GIS according to a critical thinking process appear in the left part of Table 1.

Table 1: Cognitive Transformations Related to Steps in a Process of Geographic Investigation

Transformations¹	Stages and Steps²
Stage (1) defining the questions, issues, problems:	
MW;MM MWD	Step 1: identifying and clarifying questions and issues Step 2: gathering and organizing data
Stage (2) processing the data:	
MDG GM MD,MM	Step 3: interpreting data Step 4: analyzing data Step 5: evaluating evidence
Stage (3) reaching and applying generalizations:	
MDGM MwM MM;MW	Step 6: generalizing Step 7: problem solving Step 8: making value judgements (recommended program/policy)

1 From WDG M Framework (van der Schans, 1990):

- W : World (w is simulated world)**
- D : Digital**
- G : Graphic**
- M : Mental**

2 Steps adapted from Slater (1982)

Several authors support a view of the importance of cognitive activity in critical thinking. In one such view on critical thinking Kurfiss (1988) describes a critical thinking process as characterized by a context of discovery that adds to a more traditional context of justification as part of problem solving. The context of discovery concerns several cognitive aspects of thinking such as how people arrive at conclusions, how knowledge influences reasoning, and how certain methods are used to explore complex issues. She describes how the cognitive activities mature through stages of knowledge development. Declarative "what's known" comes first, with procedural "how to use what's known" coming next, and finally metacognitive with how to restructure the procedures. The processes are similar to those listed by Slater (1982), but different as well. They are the same in that Slater considers declarative and procedural knowledge, but leaves off the metacognitive, i.e. restructuring of what is known. In addition, Slater considers operational issues - these are fundamental to first time learners of any topic. However, Slater is much more detailed through the beginning stages, hence slightly more informative in the description of critical thinking. Kurfiss' context of justification concerns an informal reasoning process, i.e. after information are known how do we put it to use in a systematic way. She down plays this aspect of thinking, but it is a fundamental basis for making inferences which can be important in a GIS context.

Margolis (1987) provides another view on thinking by presenting a "cognitive ladder" consisting of seven steps. The first step called simple feedback is the recognition that information is present or at least sensed. The second step of pattern recognition involves a particular arrangement of sensory input. The third step, learning, involves retention of the recognized pattern. After learning, and the retention of several patterns, comes choice of one of the patterns. Then comes judgment based on evidence surrounding the choice. Reasoning as a sixth step is a sequence of

judgments in some direction of thought. The seventh and last involves calculation were some notion of prediction comes in to determine how far, how much etc.

The operational steps by Slater (1982) fall into Kurfiss' context of discovery in the first part and the context of justification in the last part. While this is occurring during the process of GIS use, a cognitive ladder is climbed, although some rungs are farther apart than others depending on the problem. Within the context of GIS, during this process a mental model is being formed and continually being reformed as data are accessed, analyzed and displayed to create information, and subsequently used to solve a problem or make a decision about some geographic issue.

Consequently, we can say that forming a mental model or models is the first part of a critical thinking process (Nyerges 1991), but proceeds through out the interaction sequence with a GIS. The formation of a mental model concerns information structuring. During information structuring, information in working memory of the user is cultivated with knowledge in a user's long-term memory. That knowledge is based on salient anchor concepts and relationships within some conceptual space that describes phenomena in (some portion of) the world relative to the problem context. Displays, views, maps, verbal descriptions, and other sensory-based messages in a GIS act as the principal carriers of social information used in forming the structural component of mental models.

Nyerges (1991) describes how image schemas (See Figure 2) can play a key role in the formation of the structural component of a mental model of geographic information -geographic information being data that have meaning and significance within a particular context. Image schemas seem to have a close correspondence to the configurational level spatial knowledge identified by Golledge (1990) (See Figure 3).

The structural component (or structural patterns of information) characterizes both the concrete declarative level of knowledge as well as the more abstract configurational level of knowledge (See Figure 4). Declarative knowledge is knowledge of "what" -descriptions of concrete occurrences in the world. Configurational knowledge is abstract knowledge of the declarative occurrences as well as abstract knowledge of the procedures of how something is done.

Structural information in a mental model is manipulated using mental processes. Mental processes compose the procedural and metacognitive levels of knowledge. Procedural knowledge is knowledge of how to act on the declarative knowledge, making use of it for concrete actions. When this is abstracted it becomes configurational knowledge. The metacognitive level of knowledge includes how to restructure abstractions. This includes how to restructure sequences of activities at the procedural level, as well as reinterpreting occurrences and categories at the level of declarative knowledge. The different levels of knowledge are useful for different parts of problem solving.

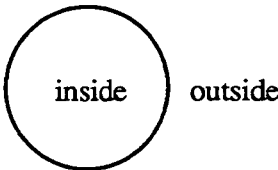
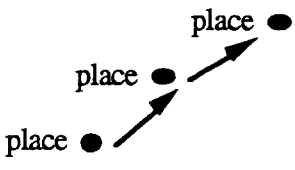
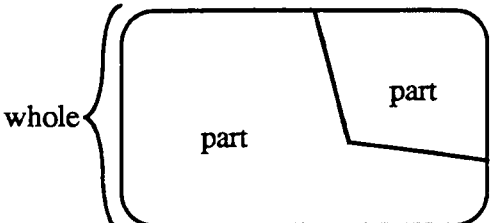
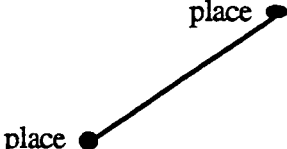
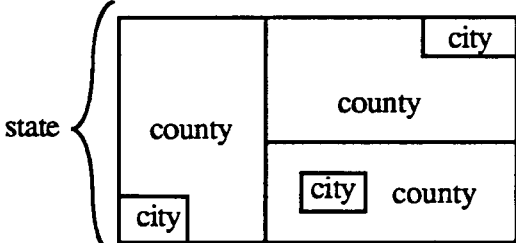
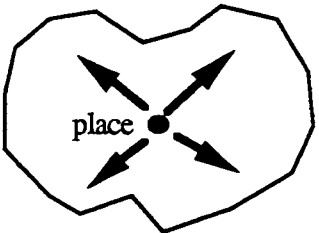

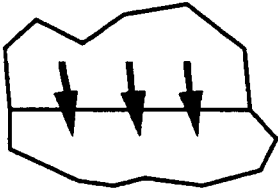
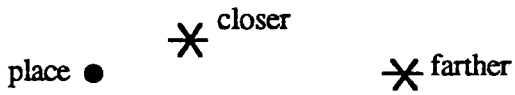
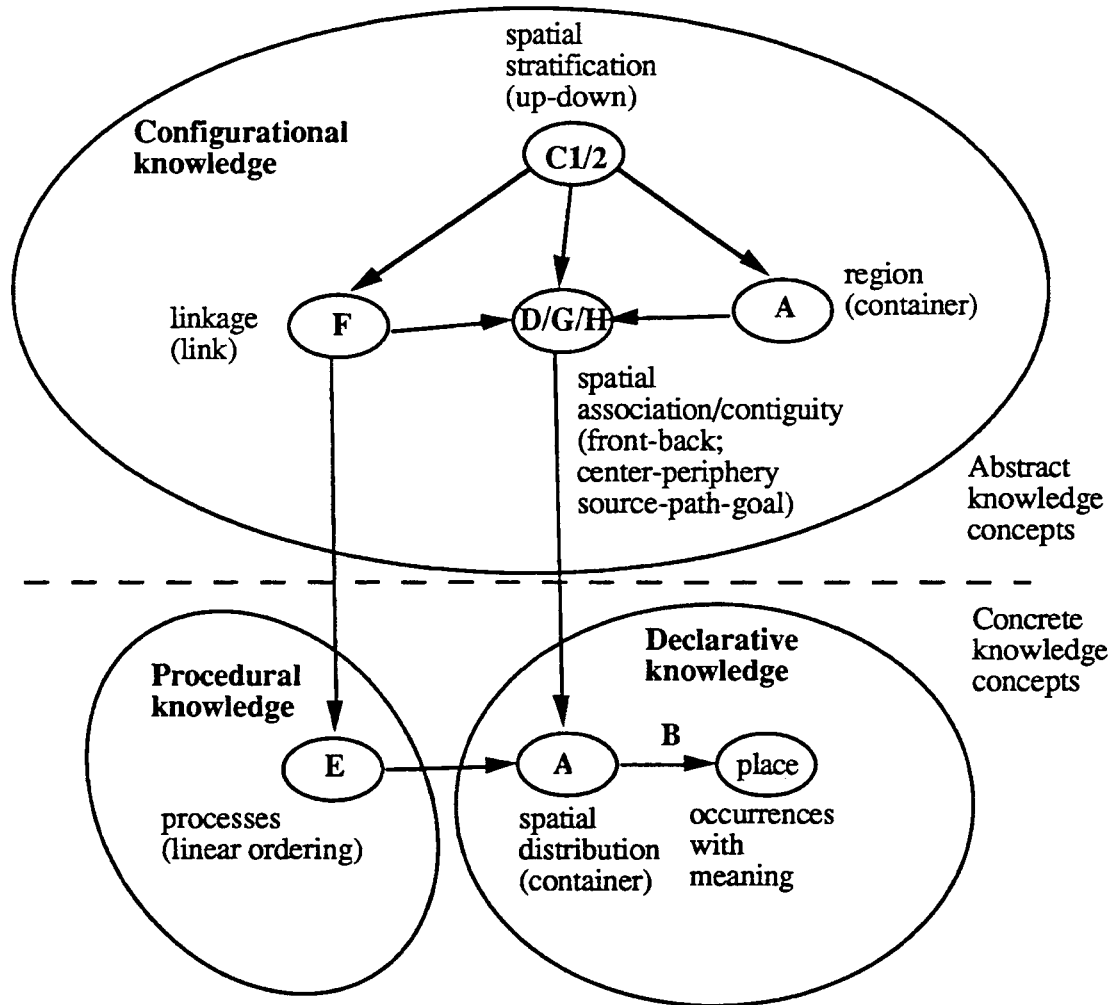
 <p>A - inside and outside of an area (container)</p>	 <p>E - sequence of places (linear ordering)</p>
 <p>B - whole and parts of a region (part-whole)</p>	 <p>F - connection between places (link)</p>
 <p>C1 - administrative jurisdiction hierarchy (up-down)</p>	 <p>G - place and its influence on a surrounding area (center-periphery)</p>
 <p>C2 - transportation infrastructure hierarchy (up-down)</p>	 <p>H - impact of one area on another (source-path-goal)</p>
 <p>D - closer or farther away from a place (front-back)</p>	<p>I - other: please describe</p>

Figure 2: Geographic relationships that correspond to image schemas



- | | |
|--|-----------------------------------|
| A - inside and outside of an area | E - sequence of places |
| B - whole and parts of a region | F - connection between places |
| C1 - administrative jurisdiction hierarchy | G - place and its influence |
| C2 - transportation infrastructure hierarchy | - on a surrounding area |
| D - closer or farther away from a place | H - impact of one area on another |

Figure 3: A comparison of Golledge's (1990) configurational spatial concepts and the geographic relationships (image schemas) used in the Vision 2020 map-use study. Golledge's (1990) spatial concepts appear below ellipses; image schema descriptions appear in parentheses. Arrows indicate necessary and sufficient relations between concepts. Concept at arrowhead must be understood in order for concept at tail to be understood.

		Conceptualization level:	
		concrete (surface)	abstract (deep)
Thinking pattern:	Structure	declarative: knowing what occurrences exist and their meaning	configurational: knowing what and how to abstract
	Action	procedural: mental operations for knowing how to use the what	metacognitive: mental operations for knowing what, how and why to restructure abstractions

Figure 4: Stages of knowledge development as a combination of thinking pattern and conceptualization level.

In parallel with the structure and process components of a mental model, Halpern (1984) describes critical thinking for problem solving as essentially composed of problem representation and problem processing strategies. She describes five types of problem representations, and thirteen problem processing strategies. Manipulating mimetic visual models is one of the representations and using analogies/metaphors is one of the strategies, both of which she describes as being widely applicable to many problems. How such representations and strategies are actually manipulated in a computer, however, depends on the user interface.

During use of a GIS, mental information structures and processes blossom or shrivel according to the support given them by a user interface. Every user interface is designed around a metaphor - a likeness of what things are and how to interact. The conversation metaphor and the world metaphor are two major metaphors in the human-computer interaction (Hutchins, Holland and Norman 1986), but in GIS the map metaphor must also be included. All three are being used to some extent, but some are perhaps more effective than others. In one sense the difference between the map metaphor and the world metaphor is a matter of what one takes to be a map. If the map must be two-dimensional then indeed there is a difference, but if the map is multi-dimensional then there in fact may not be much of a difference. In this discussion the map is taken to be multi-dimensional, thus the map metaphor and the world metaphor are taken to be the same.

How one employs the metaphor is important for human interaction. Interfaces create a distance between a user and a physical system in terms of a gulf of execution (invocation of a task by user in a system) and a gulf of evaluation (feedback from a system to a user). With "direct manipulation interfaces" within the world/map metaphor the object is to be able to direct action in the system with as much direct and meaningful input and output as possible (Shneiderman 1983; Hutchins, Holland and Norman 1986). Getting the initial description of the problem on the screen in different forms is critical. Getting the goals on the screen in some form is also critical. Comparing and contrasting an initial problem description with the goal helps clarify what is needed to solve a problem. Being able to perform this with minimum cognitive effort is the objective of direct manipulation interfaces. When cognitive effort is minimized in use of an interface then cognitive strategies for problem solving can blossom. When a system presents semantic concepts for input and output that tie into the frame of reference of a user then a user more quickly addresses the problem and

grasps the nature of the results. For a GIS that addresses problem solving and decision, an objective in the design and development of user interfaces is to produce direct manipulation interfaces that can foster critical thinking through direct engagement of a user's mental model during a problem solving session. Identifying image schemas and using fundamental spatial concepts applicable to most spatial problem solving can support the interface design.

In conclusion, a critical thinking framework can provide some organization for what information manipulation tasks need be addressed. Both structural and process components of a mental model require support when interacting within a GIS. Perhaps focusing on these issues can provide some framework for investigation without having to enumerate all of the types of application activity that a GIS can address. Although other types of thinking such as daydreaming are possible, it is doubtful that much in the way of resources should be directed at such an issue. Too many problems in society fall within the needs for critical thinking.

As part of this investigation the following questions need be considered.

- 1) What metaphor(s) facilitate critical thinking without hindering thought processes. Any kind of interaction takes time, but what takes the least time? Direct manipulation interfaces a la Shneiderman (1983) would seem to be of value here. Particularly those in a complex string of thought events.
- 2) Various systems of expressions, phrases, sounds, icons etc. can be tested within certain problem solving strategies to determine their effectiveness. What are the criteria for effectiveness? least time to solve problem? most comprehensive solution? most accurate solution?
- 3) Current interfaces are getting in the way of thinking. Perhaps metalanguages that focus on laying out-simulating-problem solving strategies are better than those that actually carry them out immediately. Again, a direct manipulation interface could be of use.
- 4) Are the questions Slater (1982) poses sufficient for determining the system requirements for much of digital GIS?
- 5) What problem solving strategies are unique to GIS? At least fourteen (micro) problem solving strategies can be enumerated, but some overlap. (Halpern 1984).
- 6) Are direct manipulation interfaces the way to proceed within the context of critical thinking to most effectively climb the cognitive ladder? In this sense a goal might be to develop a GIS user interface as a "direct manipulation critical thinking tool".
- 7) Can users develop their own icons as direct manipulation symbols? This has been done for many of the mapping systems, but what about GIS when it is used for analysis?

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Biographical Sketch

Timothy Nyerges is an Assistant Professor of Geography at the University of Washington (Associate Professor granted for 9/91). His current research interests include thinking and cognition in GIS environments, information abstraction for geographic modeling, GIS for transportation and land use modeling applications, and systems integration. His current teaching assignments include computer-assisted cartography and GIS related to urban and regional studies. He has been a software engineer, consultant, software manager and marketing representative for several organizations involved with the design and implementation of digital mapping and GIS. He holds a B.A. with distinction, M.A., and a Ph.D. (1980) in Geography from the Ohio State University. He is a former ACSM ACA Director and Chair of the Data Transfer Subcommittee of the National Committee for Digital Cartographic Data Standards.

User Interfaces for Geographic Information Systems

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Sweden has a long history of emphasizing end user aspects in the design, implementation and operational usage of new technology. In line with this philosophy, a task force was formed in 1988 to create a national R&D program on "Good Use of Information Technology in the Public Sector". GIS and image technology was one of the areas in which a user-oriented research initiative was prescribed. An ad hoc subcommittee pointed out that prior GIS research had dealt with pre-usage issues such as network infrastructure and information architecture. The day-to-day user aspects had been forgotten, and there was now a need for R&D on metaphors for user interfaces, GIS workstation design, and work organization matters such as computer support for collaboration across professions.

Such issues had previously been discussed in ULI - the National Council for GIS/LIS-Related R&D. Its 100 members (industry, government and research) collectively take an active part in bridging the gap between research and praxis. The feeling that this gap was too wide was the reason for the conception of ULI in 1986. ULI is on the right track, but its general view is that more efforts and resources must be spent in order to meet members' expectations.

To bring about a better focused GIS agenda, the Swedish government formed a public sector Consortium on Increased Exchange of GIS Data in 1991. Its charter specifies that members shall further and support development of computer support and organizational matters for the handling of GIS data, especially with regard to regional usage. A regional action program to this effect was in parallel formed in the region of North Bothnia: "GIS Technology in North Bothnia". Lulea University of Technology, located in the region, is providing GIS-related curricula and is determined to be the national leader in to research and development on User Interfaces for GIS.

Biographical Sketches

Olov Ostberg, a prolific user interface researcher, co-authored the book "Computer Terminal Ergonomics" way back in 1974. For the last couple of years, as an employee of the Swedish Agency for Administrative Development, he has been responsible for the establishment of a Swedish national R&D program on "Good Use of Information Technology in the Public Sector". As a human factors professor he has spent two years with the U.S. National Institute for Occupational Safety and Health in Cincinnati, and two years with the University of Wisconsin-Madison.

Jan Schroder received his Chartered Surveyor degree from the Royal Institute of Technology, Sweden, in 1968. As regional manager of the National Land Survey of Sweden, he is responsible for several units producing GIS data collection, data conversion, and GIS software development and support. He is a member of several steering committees on GIS related projects, and is a driving force in the North Bothnia action program on Geographical Information Technology.

User Interfaces for Geographic Information Systems

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The goal of human-computer interaction research is to research the theory and design of interactive systems that enable users to perform tasks, learn skills, and communicate in an atmosphere of competence, satisfaction, and confidence. When the user interface is well-designed, users should not only be performing well, but should also experience a sense of accomplishment and a positive regard for the designer of the interface.

The goal of the Human-Computer Interaction Laboratory (HCIL) under the direction of Ben Shneiderman is to turn from the argumentative discussions about the "user friendliness" of a system, to a more scientific approach. We emphasize controlled experimental techniques which yield more objective and reliable results. Once a specific user community and set of tasks are identified, measurable criteria for a human-computer interface include:

- time to learn specific functions
- speed of task performance
- rate of human errors
- subjective user satisfaction
- human retention of functions over time

These criteria can be established before implementation and measured during an acceptance test. These criteria also serve as dependent variables in experimental research.

Recent touchscreen results from the HCIL are of potential interest to GIS researchers. Our high precision touchscreens have been applied for home control, hypertext, museum applications, a telephone book, and a drawing environment. Multiple rapid touches and the capacity to drag images make the touchscreen attractive for many applications. We developed touchscreen keyboards that allow typing at about half the speed of normal keyboards. Our empirical tests measured typing speed on touchscreens that were 25 cm down to 7 cm wide with novices (20 wpm down to 10 wpm) and experts (30 wpm down to 20 wpm). These keyboards would be useful for portable laptop computers and for embedding in other applications such as point of sales terminals or medical form systems.

Another technique of potential interest to is a novel method for displaying tree structures. The 'tree-map' visualization method maps hierarchical information to a rectangular two-dimensional display in a space-filling manner; display space is utilized 100 per cent. Interactive controls allow users to specify the presentation of both structural information (depth limits, etc.) and content information (attributes mapped to colors, etc.). With tree-maps we can display trees containing 3,200 files in 400 directories on one 13" VGA monitor.

Biographical Sketch

Richard Potter is in the Ph.D. program in computer science at the University of Maryland. He has been a member of HCIL since 1987 and has participated in several hypertext and touchscreen research projects. Current dissertation work researches techniques that give practical programmable functionality to user interfaces.

User Interfaces for Geographic Information Systems

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General Objectives:

To design and build GIS user interfaces for 'spatially aware professionals' which increase the productive use of spatial data handling tools.

Short Summary of Research Projects Underway:

(1) HyperArc: contract research (1989-91) with ESRI/Apple to develop "an easy to use front end" for the ARC/INFO GIS. Implemented in Hypercard on the Apple Macintosh and communicating over a network to a VAX or Unix host system running ARC/INFO, HyperArc enables a user to carry out some generic geoprocessing tasks without specific knowledge of the ARC/INFO command language. HyperArc has been designed as a tool for those who need to use ARC/INFO (perhaps because it is the 'corporate' GIS available in their organization) but who do not have the time or training to become familiar with the command language.

HyperArc uses system-specific terminology such as "coverage" (meaning map sheet in digital form), or "clean" (meaning create topologically structured geometry from 'spaghetti' vector data), but explains and illustrates these terms for the user with diagrams and descriptions. The range of facilities offered by HyperArc has been defined empirically in a dialogue with users in a UK local authority and a US Federal Agency. It is also integrated with the GISTutor hypertext tutorial developed at Birkbeck, enabling the user to obtain background information on the concepts underlying any of the HyperArc options. It is currently being extended prior to becoming a commercially available productivity tool for ARC/INFO users.

The design and creation of HyperArc has been an extremely valuable exercise in identifying important 'human factors' for a GIS user interface of this kind. It has also indicated the limitations of this kind of system-specific "front-end" and pointed the way towards generic interfaces.

(2) Universal Geographic Information eXecutive (UGIX)P this is a project funded for 1990-92 by the UK Economic and Social/ Natural Environment Research Councils in their Joint Programme in Geographic Information Handling* a national GIS research programme carried out in UK Universities. It has as its primary objective the development of a generic GIS user interface based around a spatially extended Structured Query Language (SQL).

Preliminary work established a three part modular design: firstly (A), a layered interface between the GIS and the screen design; secondly (B), a help system which was a guide to concepts in spatial data handling; and thirdly (C), an expert system to help the user with tasks requiring knowledge about specific spatial problems such as generalization or symbol placement. The main development work discussed here is in UGIX (A), which is being implemented in the Unix environment: modules (B) and (C) are largely complete but were implemented in the Macintosh environment.

UGIX (A) is designed as a series of layers over the GIS: at the top, there is a graphical user interface (GUI) constructed using a standard Motif toolkit; interaction with this layer creates an instruction in the 4th generation language (4GL) Smallworld MAGIK. This is then mapped into the host GIS using an application interface model and transferred to the GIS via inter-process communication protocols. The graphical user interface has been designed around a building metaphor: functionality is expressed as furniture in rooms dedicated to specific real world problems.

Embedded in the 4GL is the spatially extended SQL (SQL-SX) which gives the interface its expressive power in spatial terms. SQL-SX is spatially extended by adding support for spatial data types, operators, and functions using the facilities defined in the draft standard for SQL such as user-defined data types (UDT's). Some GIS vendors are

already moving to support these enhancements, and as SQL3 becomes a standard it is likely that others will follow suit. A key UGIX objective is to establish a robust spatially extended SQL which will provide a model for later development is built around SQL3. UGIX is, therefore, an experimental implementation of a GIS user environment which it is hoped will demonstrate the practicability of a generic interface 'shell', and since it is currently being implemented as a working prototype, both users and vendors will be able to evaluate it.

Key Objectives for the UGIX Project:

The two projects described above overlap in time and in conceptual development. However, their most important common denominator is that they are both attempts to construct a working GIS user interface which can be used for real world problem-solving by the end user, and which can be formally and informally evaluated. This focus arises out of a concern that on the one hand vendors have implemented GUI's which are complex and devoid of supporting metaphors, whilst on the other researchers have mostly experimented with GUI metaphors and query languages in isolation from one another. The UGIX project was begun to bridge this gap by implementing a user environment which incorporated both new GUI metaphors and a query language in an integrated and generic way.

This development seems of particular value to the "spatially aware professional", who can be defined as the professional user of spatial data for analysis and querying such as the forest planner, real estate agent or utility engineer. These users are often responsible for the design of the data storage for their organizations (digital or otherwise), and have codified in detail the meaning of spatial terms in formal practice. However, whilst GIS have become functionally rich they are still difficult to use, even by such spatially aware professionals. Hence the central objective in the UGIX project is to create new user environments which are designed primarily for this kind of user. This means that research in the UGIX project does not aim to create new query languages or new metaphors suitable for all kinds of users.

The UGIX project does aim to specify and type the underlying characteristics of spatial access and analysis by spatially aware professionals such that a generic user environment can be built on top of an existing but spatially extended and customizable query language, namely SQL-SX. At present this is achieved by placing metaphorical 'furniture' inside rooms dedicated to the handling of real world spatial problems; interacting with the room generates command strings which are passed to the host GIS and database. Implemented in Motif under X Windows it is hoped that a prototype of the system will be completed in 1992, and that testing of the environment can begin.

Important Issues for Discussion

- Can we distinguish between what professionals and the public want from spatial data handling systems, and how does that affect the design of interfaces and query languages?
- Given the complexity and application-specific nature of many logical data models used by GIS, what are the generic functional components of a spatial query?
- What are the appropriate testing methods for GIS user environments?
- What metaphors other than the map can be employed to help the user understand the nature of a spatial data handling environment?
- How can we define the expressive power of a spatially extended SQL, and what kind of query best exemplifies these limits?

Biographical Sketch

Jonathan Raper is a Lecturer in GIS in Dept. of Geography, Birkbeck College, University of London. He received his BA (Hons.) in Geography, from the University of Cambridge; and his Ph.D in Geomorphology from the University of London. Dr. Raper's College responsibilities include: Computer Resources Coordinator, Department of

Geography; Director, Apple Mapping Centre; Course organiser for short courses in Geographical Information Systems (10 per year); and Supervisor, Enterprise in Higher Education projects to develop Computer Aided Learning tools. His research and consultancy activities include: Principal Investigator, ESRC/NERC Collaborative programme in GIS project "Generic spatial language interfaces to a GIS"; Principal Investigator, ESRI/Apple research project "Development of a Hypercard Interface to ARC/INFO"; Grant Holder, Central Research Fund, Holocene development of sedimentary architecture at Scolt Head Island, N. Norfolk; Advisor, EC COMETT II Programme "DEMARRAGE-Development of multimedia applications in remote sensing, risk assessment, geography and environment" (Strand Cc); Co-writer, Geographical Information Systems Tutor (College-sold software product); and Designated lecturer, Laser-Scan/ Digital Initiative in GIS. Dr. Raper's external activities include: Member of the Council, Royal Geographical Society; Member, Inter-University Software Council, Sub-committee on 'GIS software evaluation'; Member, organising committee, NATO Advanced Study Workshop on 3D modelling, Santa Barbara, California, USA, 10-16/12/89; and Participant, NATO Advanced Study Institute on "Cognitive and Linguistic aspects of Geographic space", Las Navas del Marques, Avila, Spain, 8-20/12/90. He has published over 20 research papers on spatial languages, GIS user interfaces, interactive tutor design, three dimensional modelling, geomorphology, and an edited book entitled "3D applications in GIS".

User Interfaces for Geographic Information Systems

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I am interested in pursuing what has been called the "Intelligent Agent" approach to user interfaces for GIS. In this approach we try to create an "intelligent" system to act as the interface between the human and the GIS. The human would be able to interact with such a system using a mix of natural language and gestures, just as a person would interact with another person when they had a set of maps, charts, etc. on a table they were both sitting at, talking about the information contained there.

The intelligent agent approach to interfaces can be compared to what we might call "high tech" approaches to interfaces, although, in fact, implemented adequate intelligent-agent interfaces are further in the future than high tech interfaces. By high tech interfaces, I mean those that use mouse buttons, data gloves, or other manufactured devices the user manipulates. Although I have high respect for the cleverness and utility of high tech interfaces, I choose not to pursue them for two reasons. One reason is that some training is required before someone can use a high tech interface, and I am more interested in making GISs, and computers in general, usable by untrained people. The other reason is that my long term research interests are more in intelligent systems than in computer-human interfaces, but an intelligent system that a human can interact with to perform some task is equivalent to an interface with a computer system that can perform that task.

To be more concrete, I foresee an intelligent GIS that a person can interact with using a combination of speech, pointing gestures (using hands and/or fingers on a touch screen), and typing, and that will use a combination of speech, graphics, and text to communicate with the person. This is an extension of the CUBRICON interface I worked on with Jeannette Neal et al.

To be fully flexible and natural, the intelligent interface must be able to understand and respond to requests, commands, and instructions about what to do, i.e. how to behave, as well understand and respond to requests for information stored in the GIS. Computer systems that can communicate in natural language about how to behave are still at the research stage, at best, and this is one research project I propose to pursue as part of this initiative. Other research projects motivated by this approach to GIS interfaces include: investigating the kinds of gestures people would use if such an interface were available, especially those people would use in combination with continuous speech; how a computer system could integrate gestural and continuous speech input and interpret the combination; how a computer could best make use of the various modalities of speech, graphics, and text to communicate information to people.

Biographical Sketch

Stuart C. Shapiro received the S.B. degree in mathematics from the Massachusetts Institute of Technology in 1966, and the M.S. and Ph.D. degrees in computer sciences from the University of Wisconsin, Madison in 1968 and 1971, respectively.

He is currently Professor of Computer Science at the State University of New York at Buffalo, where he was department chairman from 1984 to 1990. In 1971, he was a Lecturer in Computer Sciences at the University of Wisconsin, Madison. Between then and going to Buffalo in 1977, he was at the Computer Science Department of Indiana University, where he held positions of Assistant and Associate Professor. In summer, 1974, he was a Visiting Research Assistant Professor at the Computer Science Department of the University of Illinois at Urbana-Champaign. He spent the 1987-88 academic year on sabbatical at the University of Southern California/Information Sciences Institute.

Prof. Shapiro's research interests are in artificial intelligence, specifically, knowledge representation, reasoning, and natural language processing. His Ph.D. dissertation is considered to be one of the seminal works in the development of semantic networks as a representation of knowledge. He is editor-in-chief of *The Encyclopedia of Artificial Intelligence* (John Wiley & Sons, 1987), which was named Best New Book in Technology and Engineering for 1987 by the Association of American Publishers Professional and Scholarly Publishing Division. He is also the author of *Techniques of Artificial Intelligence* (D. Van Nostrand, 1979), *LISP: An Interactive Approach* (Computer Science Press, 1986), and over 100 technical articles and reports. He has served on several National Research Council review panels, as a consultant on Artificial Intelligence for several companies, as department editor of the journal, *Cognition and Brain Theory for Artificial Intelligence*, and has served on the editorial board of the *American Journal of Computational Linguistics*. Prof. Shapiro is a member of the ACM, the IEEE, the Association for Computational Linguistics, the Cognitive Science Society, the American Association for Artificial Intelligence, and Sigma Xi. He is listed in *Who's Who in America*, *American Men and Women of Science*, *Contemporary Authors*, *Who's Who in Technology*, and *Who's Who in Artificial Intelligence*.

User Interfaces for Geographic Information Systems

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Introduction

There are clearly a large number of issues that may be addressed in relation to interfaces for GIS and spatial database systems. The relevant issues in which I have a significant interest at present are relatively narrow, and relate to the nature of database systems that may be used to support investigations of scientific phenomena. My viewpoint is based on the following simple conceptualization:

- The core of a spatial DBS may be viewed in terms of a formal language in which one may represent the objects, relationships and operations that a user may wish to define and manipulate.
- The task of the interface designer is to translate this language into the "interface language" through which the user will view and interact with the system.

Hence in order to discuss interface issues, it is important to have in mind: a specific set of users; a specific set of applications; and the nature of the relevant set of formal languages. In the remainder of the position paper, I first describe that nature of the users and applications that I have in mind, and then I briefly list a small set of questions about interfaces that appear to be important from this perspective.

GIS Systems of Relevance

A database system and its conceptual schema provide a model of the phenomena that are represented in the database. Many non-standard database applications may be viewed as system modeling activities. For such applications, the database system must provide a means to represent and manipulate classes of complex objects; it must also provide a means to manipulate information about objects and their interrelationships; and it must also provide a facility for deriving various properties of objects and their interrelationships from information that is represented in the database in implicit as well as explicit form.

In standard database applications, modeling support has generally assumed discrete domains and has focussed largely on structural relationships between individual values. A panel that studied the achievements and opportunities for database systems indicated that the next generation of applications, such as data-intensive scientific applications, will require more sophisticated support. Such support relates to data access and type management for large and internally complex objects, capabilities for processing large numbers of rules, and the ability to handle new concepts such as spatial data, time and uncertainty. A second panel that examined scientific database management made the critical observation:

"To manipulate data and produce information, a scientist needs to access data and apply analysis tools in concert. Failure to integrate the data management and analysis environments restricts the productivity of the scientist... extant systems are not integrated... due to the fact that the data management environment was created by a computer scientist and the analytic environment... by a discipline specialist."

In order to examine issues relating to the integration of data access and analysis tools indicated above, we briefly describe a simple model of an important class of scientific investigations relating in particular to earth system science. We employ this model in an informal manner in order to elucidate critical issues relating to computational support for data and modeling in this class of scientific investigations.

The core of many scientific investigations typically involves:

- (1) a conceptualization of some relatively complex domain of investigation,
- (2) a formal representation of the conceptualization, and
- (3) an inference process based in part on the formal representation and a (frequently large) database of information in both explicit and implicit form.

A key modeling activity in such investigations is the definition of semantically important classes of entities and relationships among the entities. The complexity of the systems that are currently being modeled increasingly forces investigators to adopt computational approaches. For example, in many studies of complex environmental systems, both the conceptualization of the domain and the formal representation of the domain typically involve many classes of complex, spatio-temporal objects and relatively complex relationships among the classes. The inference procedures relating to the objects and their relationships frequently require access to large databases of objects, relationships, and observed facts. It is increasingly evident that there is a need for computational environments that provide a uniform approach to the definition and manipulation of entities and entity classes that contain objects ranging from raw dataset objects to high-level conceptual objects.

We conceptualize the computational modeling of complex natural systems in terms of a two dimensional space. One axis, which we term the "extraction" axis, characterizes the scientist's representation of the world in terms of the degree to which the objects and relationships of the scientist's conceptualization have been made explicit. The other axis, which we term the "abstraction" axis, characterizes that degree of abstraction in the computational representation of the data of interest to the scientist. To the extent that these dimensions are orthogonal, it is our contention that the scientist needs to operate in an environment that allows full access to all levels of the extraction axis, but that hides many of the issues relating to lower levels of the abstraction axis.

The extraction axis represents the key dimension with respect to scientific modeling activities. It is possible to identify four broad levels of the extraction axis with respect to datasets:

1. A primary database that contains information about objects in largely implicit form. In many applications, such a database may contain sets of images or digitized maps and sets of data obtained from measurements taken over some set of locations.
2. A secondary database that contains datasets that are typically derived from procedures applied to various datasets from the primary database and to other information. These are not necessarily the final products of computation. A database of river valleys derived from a database of surface elevations provides an example of such a dataset.
3. A tertiary database (or conceptual representation) containing complex spatio-temporal objects derived from the primary and secondary databases. Such objects and their interrelationships represent models of the phenomena in the application domain. An example of such a complex object in a database containing hydrological information might be a connected set of river links and the nested areas that they drain.
4. A quaternary level in which relationships between complex objects are precisely represented. Typically this is the domain of equations of various classes, and especially differential/difference equations, and equations relating to statistical inference.

The abstraction axis, on the other hand, represents the level of details and abstractions at which the scientist wishes to operate. In particular, issues along this axis include storage abstraction, which enables the scientists to access information without being hindered by the nature of the database; operation abstraction, which allows a scientist to execute operations or programs concurrently without being concerned about the possibility of interference in the database; and collaboration, which permits teams of scientists to accomplish a single complex task in a tightly coupled environment.

A system should attempt to support all levels of the extraction axis in the most explicit manner possible, as well as the representations and processing that relate to all but the highest levels of the abstraction axis in the most transparent manner possible. With respect to the extractive axis, important issues that require investigation, particularly in the area of large, spatial databases, include:

1. the design of adequate data models for complex spatio-temporal objects and object classes;
2. the design of (deductive- and object-based) languages to support applications involving complex spatio-temporal objects and their manipulation, including support for mathematical and statistical modeling activities that require data integration.

Although there are many other important issues relating to both the extractive and abstractive axes that require investigation, we believe that these two issues are of central importance for database systems that support scientific modelling activities.

Issues Relating to Interface Design

It seems reasonably clear that an interface should represent, in an adequate manner, the fundamental formal language and the data model that was briefly alluded to in the last section. In particular, it should support the modelling and data manipulation activities of the user. Issues that relate to an interface constructed on such a basis include:

- the relationship between the design of the interface language and the underlying formal language.
- the degree of expressiveness of the interface language, and, in particular, the match between the expressiveness of this language and the expressiveness of the underlying formal language.
- The complexity of the interface language in cognitive terms, and, in particular, the question as to whether there is an analogue of algorithmic complexity for this language. Such an analogue would obviously have to involve cognitive issues.
- The nature of the interface language, particularly in terms of the degree to which it should be graphically or linguistically oriented.

User Interfaces for Geographic Information Systems

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User interfaces that present different aspects of the same information are one of my special interests. A good example is the parallel presentation of natural language text and graphics where operations on one representation result in automatic changes in the other. In the following, I describe a research environment that contains a number of elements that I would enjoy exploring if I were developing

"User Interfaces for Manipulating Routes"

I will call such things UI4MR. My real interest is in routes through cities, traversed on foot or by car or bicycle. There are many applications that might use a UI4MR but (1) designing routes, (2) presenting route descriptions, (3) rehearsing route traversals, and (4) applying route descriptions are the subset that I care about. The end uses might be route finding, route planning, direction giving, traffic management, or vehicle navigation.

UI4MR metaphors might include (1) drawing or viewing a planimetric map, (2) indicating or observing from a bird's eye view, and (3) traversing the path, following visual and sound cues, (4) written text instructions. One or more may be appropriate to a particular application. As you may have guessed, I think that the use or availability of multiple metaphors simultaneous is very interesting (and possibly of some practical value).

Practical constraints on the delivery technology must be specified. Let's assume that a high end PC or engineering workstation with medium resolution color graphics (VGA or better, for example), a mouse, a standard keyboard, and digitized and synthetic sound capability would be available.

The environment should support for coherent (linked) multiple representations with multiple language support. The latter implies complex variations in non-text UI elements that mirror conceptual schemata that vary between languages.

Research topics include

- what is the connection between linguistic constructs and graphical UI4MR constructs?
- what is the nature of the information carried by particular UI constructs?
- what can be manipulated and how?
- what has to change when the language changes?
- what stays the same when the language changes?
- how is the linkage for conversion between representations established - how do you insure consistency - is there hidden information shared by representations or in a neutral representation?
- what is a good route description?
- are there identifiable styles?
- is there a design methodology?
- can you reliably mix styles?

- how much do styles depend on city/culture/language?
- is there a best style in a foreign city for foreigner?
- is there a best style in a city for a native?
- how do you represent spatial relationships?

My approach to answering some of these questions is to build models of small (0.1 - 0.25 sq km) areas of cities with different geometric structure and different native languages. For example, I have considered the following set:

American city area (Tucson AZ)

Irish city area (Dublin/Cork)

German city area (Munich)

Swiss city area (Zurich)

[Spanish city area]

[Mexican city area]

Biographical Sketch

I have been a developer of spatial and geographic computer applications since 1981. Large data volumes, high performance, natural language (English, German), multiple representations, nested reference frames, formal data models, data interchange standards, and perspective display are (randomly ordered) characteristics of these products. I attended the University of Washington, in Seattle, where I eagerly plowed through both the Computer Science and Oceanography curricula until I simultaneously passed my Ph.D. exam, becoming a doctoral candidate in oceanography and was drafted, becoming an ensign in the Coast and Geodetic Survey in 1971. From 1974 to 1981 I worked for the U.S. National Oceanographic and Atmospheric Administration Environmental Research Laboratories as an oceanographer. I organized a satellite image data processing laboratory, and developed visualization systems based on numerical models of the ocean and atmosphere.

Designing GIS User Interfaces to Support Environmental Learning

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Introduction

We come to understand our environment through our mental models. These are internal models of ourselves and our environment with which we interact, providing both predictive and explanatory power (Norman, 1988). We learn through a process of defining and refining our mental models - each step of refinement and re-representation helps us to further our understanding. These mental models can also be thought of as abstractions of reality.

In the traditional mapping sense, map readers form a mental model based on their perception of a map. The map itself has derived from the cartographer's mental model of the real world. Thus we see that the map reader's understanding of the environment is greatly influenced by the intervening abstractions. The user forms a mental model of the map, the map itself being a manifestation of the cartographer's mental model of the real world. In addition to being filtered, the map is static and represents only one possible view of the world.

I propose that the emphasis of a "GIS user interface" should be to more fully support the user in learning about some geographic phenomenon, rather than merely helping the user in producing a map. This goal could be thought of as placing more emphasis on the process of mapping (or other manifestations), trying to decrease the distance between the user's mental model and the real world (see Figure 2), and to make the user's interactions with the manifestation of the abstraction (the map or system) more dynamic.

This system would decrease the impact of the map producer's mental model by allowing the end user to directly interact with the geographic information of interest. However, in this system, the "end product" is not a map, rather an environment where the user can change the representation, simplification procedures, classification, symbology - in effect be in control of the purpose of the resultant display and format.

Learning Environment

This user interface would be designed to support people in their learning process and to provide tools to extend the current understanding of geographic phenomena, especially relating to dynamic processes. In effect, this will support the user in exploring, hypothesizing, and interacting with geographic information.

This type of a system provides the opportunity to place the user into a position of active, user-directed learning. Long-term understanding requires active engagement on the part of the user. A state of "mindfulness" - active mental processing that involves the creation and consideration of new cognitive categories - in the user is largely produced by allowing involvement and control. Mindful people are aware of their present mental models and can easily change them to reflect the newly learned knowledge (Bandura, Langer, and Chanowitz, 1984). Nyerges (Position paper) also discusses critical thinking in terms of mental modeling that involves problem solving and decision making. This view also holds that the learning involved in the process of going through these exercises is more important than the product(s) of these manipulations. This echoes the main tenant of the analytical cartography school of thought (Tobler, 1976 and Muehrcke, 1981). In addition, different user learning strategies (e.g., bottom-up, top-down) can be addressed.

By creating an interactive environment, emphasizing iteration and process, the user can more thoroughly investigate and understand environmental systems exhibiting a strong dynamic nature. Studies of phenomenon that change over time as well as over space can benefit from such interaction. For example, simulation modeling (also an

abstraction of the environment, but without the explicit focus on spatial phenomenon) is an additional means of understanding an environmental system but has been largely separated from current GIS and mapping systems.

Finally, since the user is actively participating and in control of the system, a creativity-limited situation occurs rather than an economically-limited one. Illich (1973) defines a convivial tool to be one that gives full opportunity and power to the person who uses it. An example of a non-convivial tool would be the television, where a very small number of people actually decide what will be broadcast to a very large number of people. An example of a convivial tool would be the telephone system, where all end user's have access to essentially the same functionality. Illich's essential principles of conviviality are symmetry, salience, and inspection. If the same tools (symmetry) are available to all users, then a creative process limited only by talent is created. Salience is the notion that the information is of pertinence to the user at the time it is presented. Finally, users of the system should have the full right of inspection, being able to "look under the hood".

Research Issues

The discussion above leads to many research issues that need to be addressed. They can be generally formed around the idea (not original) of providing the public with access to GIS. However, I wish to stress that to promote better decision making and environmental problem solving, the emphasis of the user interface design (really the whole design of a GIS) needs to be placed on one that supports learning and thinking, rather than simply providing easier access to GIS technology.

Public GIS:

Spatial Concepts:

Elicitation:

- how do people conceive of the environment?
- what are the key spatial concepts?
- do different cultures understand space differently?
- are spatial concepts used in navigation different than those used in relating to an in situ environmental problem?

Representation:

- what are the best forms to communicate these concepts?
- do metaphors have a central role in this process?

Defining Users:

- how do people differ in their spatial understanding?
- are there well formed groups or simply a continuum of users?

Uses:

- public kiosk, e.g., at library or national park
- public meeting, a subset of CSCW
- geographic education

Conclusions

In most current user interfaces, the users must spend a significant amount of cognitive resources to simply use the mapping system to achieve a goal, let alone learn anything from their actions. The argument presented above is that the user interface is really an extended learning environment and should be designed to support and aid the user in learning about the environment and the geographic phenomena of interest. This raises issues such as what are the spatial concepts that are key to understanding environmental issues, and how can the human computer interface be designed to help the user to learn these concepts?

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Seeking a Position on User Interfaces for Geographic Information Systems

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A position on user interfaces for geographic information systems? I'm not so sure I have one. While I can certainly claim an interest in the topic, I cannot claim expertise. In fact, I can't even claim that my interest in the topic is particularly well defined. Perhaps the best way to express that interest is therefore not by way of a paper but merely with a few observations.

First, I would draw attention to the research and development methodology that is implied by Initiative 13's three major goals: 1) "to investigate ways for people to interact ... ," 2) to establish criteria and methods for the design ... ," and 3) "to develop and test prototypes" It is a classic methodology with which one can hardly argue. It is also sufficiently general to allow for a good deal of latitude. But will it allow (or, more to the point, will it encourage) that kind of not-entirely-rational creativity that has accounted for many of the significant developments in GIS to date? Shouldn't a bit of outright empiricism also be encouraged? This is not to diminish or to suggest a substitute for the kind of deductive reasoning that has come to be associated with recent work in ergonomics, cognitive science, and cartographic theory; it is merely to suggest that inductive exploration still has its place. This is true not because the issue at hand is at all simple but, on the contrary, because it is so complex.

One way to take a meaningful step in this direction might be to foster the establishment of a widely and readily accessible platform for free experimentation on GIS interfaces by as broad a community as can be engaged. At the very least, this would widen the still-rather-narrow variety of interface options being explored. And it might just result in the kind of serendipity that a more conventional research program would, by nature, tend to inhibit.

Another strategy might be to simply look for meaningful precedents beyond the field of GIS. What are some of the notable examples of "interfaces" that have clearly worked well, e.g., certain musical instruments? And what about those that have not worked so well, e.g., "boom-box" controls or the door handles on many modern buildings?

The kinds of questions that might be pursued in this manner are, on the one hand, too numerous to enumerate, but on the other, too intriguing not to mention. If sound and motion are worthy of attention, how about the other senses? Is fuzziness of interaction a virtue or a fault? Should an interface self adapt? How about forms of feedback that really command attention, like a screen that darkens or a wristband that tightens when wrong decisions are made? What about multiple-user interfaces in which the participants interact not only with a machine but also with each other? Could a universal (or at least neutral and easy to learn) geo-processing language be devised to facilitate interaction between users of different tongues? And at what point should our attention turn to entirely in-field systems?

A position on user interfaces for geographic information systems? Though I'm still not at all sure I really have one, I'm beginning to see how one might develop.

Biographical Sketch

Dana Tomlin is an Associate Professor in the School of Natural Resources at the Ohio State University, where he serves as Director of the School's Natural Resource Information Systems Laboratory and Associate Director of the University's Center for Mapping. He also teaches at Yale University as a Lecturer in Geographic Information Systems. Before coming to Ohio State, Tomlin was a member of the Faculty of Design at Harvard University, where he also served as Associate Director of the Laboratory for Computer Graphics and Spatial Analysis, and where he retains a research appointment as an Associate of the Harvard Forest.

Dr. Tomlin's teaching, research, and consulting activities focus on the development and application of "map algebraic" techniques for digital cartographic modeling. He has authored a number of publications on the subject including a recent textbook. Tomlin is also originator of the Map Analysis Package, one of the world's most widely used geographic information systems.

Dr. Tomlin holds a B.S. in Landscape Architecture from the University of Virginia, an M.L.A. from Harvard University, and a Ph.D. in Forestry and Environmental Studies from Yale.

Human-Computer Interaction Aspects of GIS: A Cognitive Ergonomics Perspective

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HCI in a GIS Context

Computerized geographic information systems (GIS) are combinations of hardware, software, data, procedures and people assembled for the capture, storage, retrieval, analysis and display of spatially and temporally referenced information. GIS may be defined as incorporating software for modelling of bio-physical processes and decision support. While expert systems can make a significant contribution to such analysis processes, people play a vital role, both as individuals and as members of decision groups. GIS design and implementation must therefore aim to optimize the sharing of tasks between the person and the computer, (cognitive ergonomics), as well as the more traditional interface, documentation and training aspects of human-computer interaction (HCI).

This perspective emphasizes the need to achieve appropriate levels of cognitive control, (modes of engagement), for GIS operations through the identification and analysis of the cognitive work to be performed and the design of graphics which cogently address the decision requirements. To facilitate the efficient and effective implementation of these principles, the preparation of a theoretical 'reference model' describing the relevant variables and their interrelationships is proposed. Successively more coherent and useful 'optimization models' can be developed from the 'reference model' through a program of psychological experimentation.

HCI Goals and Research Agenda

In Turk (1990, pp 51,52) the following HCI goals and research agenda were proposed:

HCI Goals

In his presentation to the Third International Conference on Human-Computer Interaction, Shneiderman (1989) discussed the potential for enhanced HCI offered by advances in multi-media interfaces. He also advanced a list of goals for HCI. The following paraphrase of these goals will serve as a useful background to the discussion of research needs in the GIS domain:

A. For Academic and Industrial Researchers:

- utilize psychological experiments (various methodologies);
- develop theories, models, taxonomy.

B. For Commercial Programmers and System Designers:

- promote usability labs and interactive testing throughout system development;
- develop guideline documents for interaction system design;
- develop interface management software tools.

C. For Professional and General Users:

- utilize HCI potential to increase quality of planning, products, services, etc.;
- co-operate with researchers and system designers / producers to identify and refine HCI aspects.

Research Agenda for HCI in GIS

There is clearly a requirement for an integrated multidisciplinary program of cooperative research in HCI matters relevant to GIS. Such activity recently received a boost through the decision by the U.S. National Center for Geographic Information and Analysis to commence preparations for a new research initiative (I-13) on HCI issues.

The following is a list of some HCI in GIS research needs:

A. THEORETIC MODELS

- The most fundamental need is for a sound, coherent, comprehensive, understandable and easily applied body of theory for HCI in GIS. Such theoretic models should generate the minimum of dissonance with established theories in human factors / cognitive engineering, psychology, cartography, computer science, engineering, geography, linguistics, philosophy, etc.

B. RESEARCH METHODOLOGIES

- Appropriate research methodologies from psychology must be adapted and applied, preferably in an integrated fashion, to improve cognitive task analysis and system/output design;
- The usability testing approach must be optimized for GIS applications.

C. COGNITIVE PROCESSES

- Graphics aspects of cognitive style difference (and stability) need to be modelled;
- The application of cognitive analytical models to complex graphics manipulation and spatial analysis must be explored.

D. INTEGRATION OF COGNITION / AFFECT / CONATION

- Models of the impact of GIS use (under various circumstances) on affect (emotion) and conation (motivation/intent) need to be developed and experimentally validated;
- While pursuing theoretic models and practical applications considering cognition, affect and conation separately, it is important to develop an approach for integrating 'the divided mind'.

E. INTERFACES

- The design and implementation of direct, graphic interfaces in the GIS context requires further attention;
- The virtues of selectable and/or adaptive interface designs must be established for GIS operations, in conjunction with investigations of optimum training and on-line help arrangements.

F. AI, COGNITIVE ERGONOMICS AND VISUALIZATION

- The modelling of appropriate arrangements for shared cognitive responsibility for tasks in a GIS environment needs to be informed by AI research and the application of cognitive control principles;
- Understanding of the cognitive ergonomics role of visualization requires attention.

G. DECISION-MAKING AND POLICY ANALYSIS SUPPORT

- HCI research, especially cognitive ergonomics needs to be integrated with developments in decision support and policy analysis.

H. SPATIAL QUERIES AND LINGUISTICS

- Appropriate ways of expressing the logic of spatial query operations and the use of natural language for fuzzy concepts need investigation in an HCI context.

I. GROUP DYNAMICS AND ORGANIZATIONAL ASPECTS

- Interaction with GIS must be researched at group and organizational levels as well with respect to individuals."

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Biographical Sketch

After graduating with a Bachelor of Surveying degree in 1971, Andrew Turk worked with the Australian Government's mapping department for thirteen years. This activity spanned all areas of control surveys and compilation of medium scale topographic maps and included the implementation of computer mapping technology. Following completion of part-time studies for a Cartography Degree, he took leave from the government service and for a period of four years conducted research into tactual maps and graphics for blind and partially sighted persons, in the Geography Department at The University of Melbourne. Having decided to continue in the academic sphere, he moved to the Department of Surveying and Land Information where he has been employed since mid 1987 as a part-time Research Fellow while pursuing studies towards a PhD. His research concerns the optimization of human-computer interaction aspects of geographic information systems. In support of this research interest he has also undertaken a Bachelor of Arts with majors in psychology and philosophy. He spent the fall semester of 1990 as a Visiting Assistant Professor at the Geography Department, University of Hawaii, where he taught automated cartography and geographic information systems.

How to Design a GIS User Interface... Don't Bother: User Interface Design Principles for Geographic Information Systems

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Background and Introduction

We (the GIS Group at NYNEX Science & Technology) have developed two Geographic Information Systems applications that have been delivered and are currently being used in the field. They are:

- **SQS:** The Signal Quality System - a tool developed for cellular network engineers at NYNEX Mobile Communications Company to help them manage the cellular network by looking at predicted and measured radio frequency signal strength coverage, and
- **MAPS:** The Market Analysis and Planning System - developed for New England Telephone marketers, forecasters and planners to help them predict and plan for changes in the network and in the composition and location of the user community.

This position paper presents some of the lessons we have learned and describes some of the design principles that guide our work. Several of the issues concern user interfaces in general (independent of system type) and others specifically explore the difficulties of gathering geographic information from the user and presenting it to the user. Since this Research Initiative addresses GISs in particular, I will pass lightly over the general UI issues in order to concentrate a bit more on those that surround GIS development.

Our Constraints and General Principles of System Design: Don't Forget the User

Since we are in industry, the systems we build must satisfy a number of constraints that are not always of importance to researchers in this field. The systems must be easy to learn, easy to use, and hard to damage. They must, in general, solve real business problems in a cost-effective way (and, if at all possible, be delivered the day before yesterday, bug-free, and with the first set of upgrades in the mail). The best solution to all of these problems is to focus from the very beginning on the intended users of the system. This means:

- Find out who the users are: this isn't always so easy to do....
- Find out what they want: you can't do this by asking them what they want: in general, they don't know. Talk to them. Learn what their problems are. Suggest possible systems until their eyes light up. Knowledge, even when you're not building an expert system.
- Deliver a small prototype as early as possible: the old cascade style of software development (generate specifications, deliver when done, wait for the bug reports and enhancement requests) never worked very well and is simply obsolete now. The user must be involved in all aspects of the development cycle.
- Get feedback and do multiple develop-and-evaluate cycles: to get their feedback and to give them a sense of ownership of the system.

- Don't design the user interface... let the users do it: they can do a lot of your UI design work for you if you let them: just pay attention to what they're trying to tell you.

General User Interface Lessons (in brief)

In using this paradigm, we have arrived at a number of conclusions concerning user interface development. In brief, the most important of these are:

- Keep it simple: don't show anything that the user doesn't need to see. Don't clutter the screen with extraneous images - even if you think it looks nice. Don't ask the user to enter anything that the system can determine for itself.
- Keep the user informed: if some task is going to take time for completion, let the user know. If at all possible, display informative (and reassuring) messages relating the current state of processing.
- Avoid multiple input devices: don't make the user switch back and forth between the keyboard and the mouse - if you need both, segregate the input stages where possible (e.g., all keyboard first, then all mouse).
- Provide on-line help: if you know that the user must type one of N items ($N < 100$), pop up a menu. If the user will type the same thing most of the time, seed a field with the appropriate value. Add a context sensitive help key that brings up a clear concise message that will help the user enter the data.
- Allow the user to back out of dangerous situations: a user will feel more relaxed using a system if she thinks the system will provide warnings before any serious actions are taken. Asking "Are you sure?" is not a waste of time. It may be worth having an Expert flag that can be set once a user has become adequately familiar with the system.

User Interfaces for Geographic Information Systems

Because GISs are spatial in nature, certain UI issues arise that need not concern developers of other types of system. This section examines some of the more important among these issues.

- Permit the user to navigate while keeping track of current reference frame: both of our systems allow the user to traverse the terrain as well as to "zoom" into landscape to arbitrary scale. When doing this, it is very easy for a user to get "lost". The normal tendency for the user at this point is to return to terra cognita by zooming all the way back out, breathing a sigh of relief, and zooming back in to the new (or previous) location. What we have done to solve this problem is to supply a "key map" in the corner of the screen. This shows a very small (1.5 inches on a side) map of the entire dataset. Superimposed on this key map is a red rectangle showing the area currently in view. To move over the landscape, the user can zoom out and in as before or can specify a new view using the key map.
- Keep scale information available: related to the preceding point, a scale bar helps the user keep track of how "zoomed in" he is, and does this in a fairly non-intrusive way. Any change in scale should be accompanied by a corresponding change in the scale bar.
- Be consistent: where possible, make maps and menus resemble each other. If double-mouse-click-left means "help" in one modality, it should probably not mean "delete" in another. When different developers are working on separate modules, it is well worth having standards for the "look-and-feel" of the system. This applies to the development of any system, but I list it here because of its particular importance to spatial interfaces where visual coherence is crucial.

- Use appropriate symbology: users rely on the familiarity of the images they see on the screen. It is important, for example, to make a cell site look as much as possible like the map symbols already used by the engineers before our system was delivered.

Even keeping this in mind, it is sometimes useful to change symbol sets in order to reduce clutter, emphasize salient information, show greater detail, or alter the user's point of view. E.g., when we display a cell site, it could look like a numbered dot on the screen, or two concentric circles subdivided into three 120-degree sectors, each of which represents one of the six cell site faces, colored by different properties.

- Use legends: color keys should be well labelled, with specific units stated; symbols should be defined; linework should be defined and easily distinguishable.
- Provide tools for capturing, editing, and printing maps: users will always want to capture and customize maps, either to show their bosses, their customers, or their families. Once you have built a general facility that allows for this, it can be included in multiple systems.

Summary

There are a number of GIS-related issues to take into account (navigation, scale, symbology, legends, map editing) as well as the more standard UI principles (keeping things simple, keeping the user informed of status, avoiding multiple input modalities, providing on-line help, and allowing the user to back out of dangerous situations). As its name implies, the user interface is created for the benefit of the user. By keeping the user in mind, by understanding what she does for a living, by studying the problems your system is supposed to solve and watching the user interact with various prototypes of your system, you will be able to construct a user interface that meets the users needs and allows her to relax and communicate well and efficiently with the system. Your users will gladly design your user interface for you if you take the time and invest the effort to let them; in the end it will be time well spent.

Biographical Sketch

I attended Columbia College from 1980 to 1983 where I received a BA in Computer Science. From 1983 to 1985 I attended Yale University and received an MS in Artificial Intelligence; my particular interest at Yale was in spatial reasoning and my Masters Thesis dealt with the problem of gaining access to various components of a damaged machine in order for a technician (human or robot) to repair it. When I first came to NYNEX in 1986 (and for the next four years) I worked in the Artificial Intelligence Laboratory's Expert Systems Group doing knowledge engineering and systems development. Some of the expert systems I worked on were:

- USFDA: a decision support tool designed to help cellular engineers balance power levels throughout the network by allowing them to simulate changes in collected data.
- XTRA: an expert system to automate the trouble-shooting of metallic faults in wire trunks. Did initial scoping, knowledge engineering, and high-level design.
- Opera: an expert system intended to help an outside plant engineer design digital loop carrier systems.

Since August of 1990, I have been in charge of the Geographic Information Systems Group (within the Wireless Communications Laboratory) where we have been working on the systems described in the position paper. Our primary research objective is to identify GIS projects that can improve the operations of NYNEX and to develop tools for both the regulated and unregulated subsidiaries to reduce costs and generate revenues. The phone company is a place where there resides an enormous amount of spatial data just begging to be stored and accessed in a reasonable way. We've got our work cut out for us.

Incorporating Usability Measurement in System Design

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Introduction

In order to ensure that an effective as well as efficient use of technology is made, efforts should be directed towards making a system "usable," that is, user friendly, easy to learn, easy to use, easy to install, and so forth; since it is a high level of usability and not just pure functionality that yields a successful system. In other words, usability of a system, be it a Geographic Information System (GIS), is acceptability of a system by its users, not because they have to but because they want to.

An important question, however, faced by the designers of systems is: How to incorporate usability measurement in system design? In this paper, an attempt is made to answer this question based on a review of current literature. First, a product approach to usability, that is, making a system usable after-the-fact is rejected, and the approaches to establish usability specifications early in the system design cycle are discussed. Second, potential usability testing methods that can provide a rich ongoing source of information to guide the system design are presented. Finally, Contextual Research as an emergent technique is discussed.

Usability Process

Usability, not unlike design, is an ill-defined concept. Unless an operational definition of usability is decided upon early in the system design cycle and focused during the system design process, a usable system is unlikely to result (Gould and Lewis, 1985; Whiteside et al., 1988). Setting measurable objectives can help in: (1) guiding the design process, (2) comparing alternate designs, (3) terminating iterative design, (4) obtaining user sign-off, and (5) gaining a competitive edge in the market (Potosnak, 1988).

Shackel (1986) proposed the following five fundamental features of design for usability:

1. User centered design - focused from the start on users and tasks
2. Participative design - with users as members of the design team
3. Experimental design - with formal user tests of usability in pilot trials, simulations, and full prototype evaluations
4. Iterative design - design, test and measure, and redesign as a regular cycle until results satisfy the usability specifications
5. User supportive design - training, selection (when appropriate), manuals, quick reference cards, aid to 'local experts,' and 'help' systems

Gould and Lewis (1985) recommended the following three principles for incorporating usability into the design process: (1) early focus on users and tasks, (2) empirical measurement, and (3) iterative design. Implicit in both the proposals is the need to identify Usability Specifications - "...precise, testable, statements of performance goals for typical users carrying out the tasks typical of their projected use of the system" (Carroll and Rosson, 1985). This approach is claimed to be an engineering approach since it attempts "...to achieve clearly defined goals with limited resource in finite time (Wixon and Whiteside, 1985; Whiteside et al., 1988). The key feature of this approach is development of usability metrics, which are used to establish benchmarks against which the progress and success of the usability effort is measured (Whiteside et al., 1988). The usability metrics or usability specifications ensure a consensus among developers concerning the target objectives.

Whiteside, 1985; Whiteside *et al.*, 1988). The key feature of this approach is development of usability metrics, which are used to establish

Attribute	Measuring Concept	Measuring Method	Worst Case	Planned Level	Best Case	Now Level
Initial use	Conferencing task	No. of successful interaction in 30 min	1-2	3-4	8-10	?
Infrequent use	Tasks after 1-2 weeks disuse	% of errors	Equal to Product Z	50% better	0 errors	?
Learning rate	Task	1st vs 2nd half score	2 halves equal	2nd half better	"much" better	?
Preference over Product Z	Questionnaire score	Ratio of scores	Same as Z		None prefer Z	?
Preference over Product Q	Questionnaire score	Ratio of scores	Same as Q		None prefer Q	?
Error recovery	Critical incident analysis	% incidents accounted for	10%	50%	100%	?
Initial Evaluation	Attitude questionnaire	Semantic Differential Score	0(neutral)	1 (somewhat positive)	2 (highly positive)	?
Casual Evaluation	Attitude questionnaire	Semantic Differential Score	0(neutral)	1 (somewhat positive)	2 (highly positive)	?
Mastery Evaluation	Attitude questionnaire	Semantic Differential Score	0(neutral)	1 (somewhat positive)	2 (highly positive)	?
Fear of seeming foolish	Questionnaire	Obstacles related to interface	Many	Few	None	?

Figure 1: Usability Specification Table (reproduced from Whiteside *et al.*, 1988)

Whiteside et al. (1988) advocated the use of a Usability Specification Table to represent, in a compact format, an overview of the objectives; see Figure 1. A usability specification table helps both to standardize and enhance the operationally defined criteria for usability. The usability specifications are not rigid, they are modifiable based on the improved understanding of users' needs obtained from iterative testing (Gould and Lewis, 1985), and sometimes by implementation "reality."

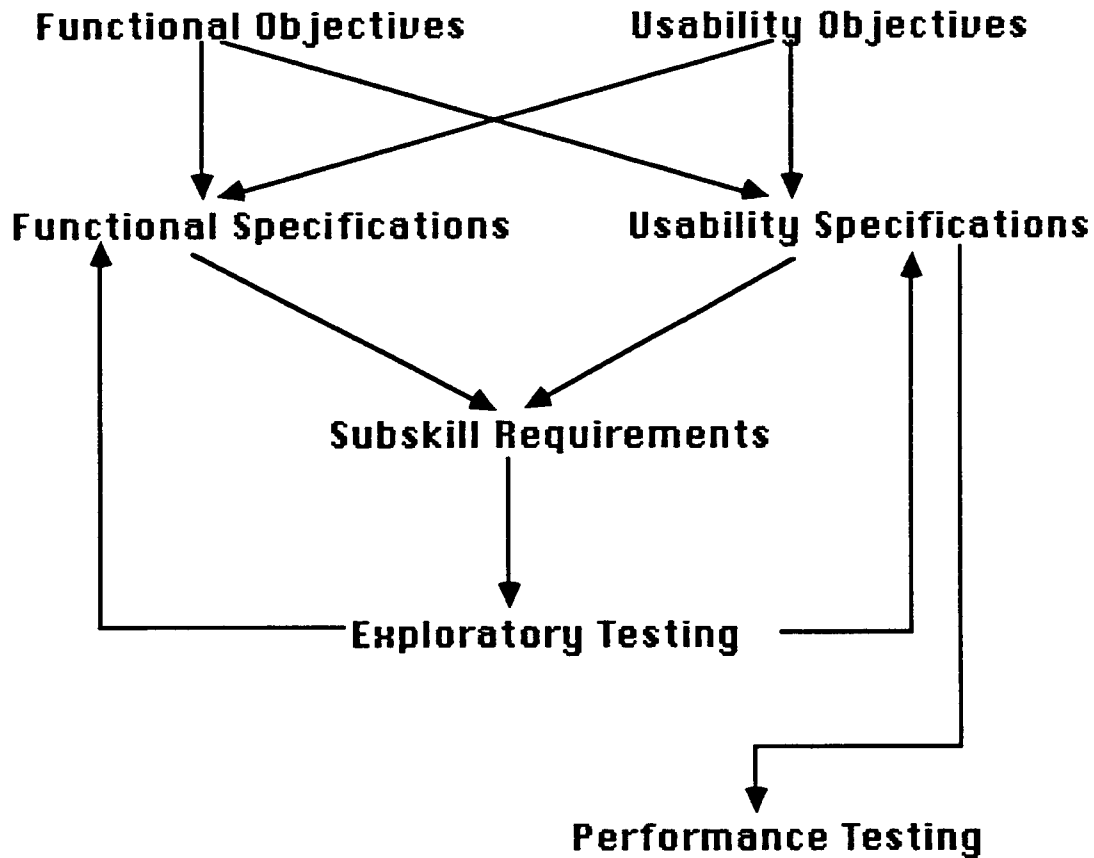


Figure 2: Behavioral Subskills Approach (reproduced from Carroll and Rosson, 1985).

However, Carroll and Rosson (1985) claimed that: "The formal evaluation of a given set of design specifications does not provide the kind of qualitative information about learnability, usability, or acceptance that designers need in order to iteratively refine the specifications, rather it assigns a figure (or perhaps a vector) of merit to the design. This could be used to order a set of alternative designs, but contrasting alternative designs is an extremely inefficient means of converging on the best solution." Carroll and Rosson (1985) suggested factoring of usability specifications into subskills or behavioral prerequisites such as verbal comprehension, so that specific problems in a design can be identified and corrected. Obviously, such an approach will be more powerful and preferred by designers over the usability specification table, since the latter does not have any specific pointers to help remedy the design problems. **The Behavioral Subskills** approach is depicted in Figure 2, above.

Both these approaches make it clear that usability testing provides a rich ongoing source of information, that can be used to improve the usability of the products designed (Dieli, 1989). Usability testing, however, is not a trivial task. There are several ways information can be collected and usability specifications compared against. In fact, the measuring method and measuring concept are established together. In the following section, the usability testing methods are discussed independent of context, but are covered in sufficient detail for the reader to establish measuring concepts corresponding to the measuring method under consideration.

Usability Testing

Wichansky (in Mills, 1986) asserted that "...there is no canned formula for conducting a successful product usability test"; however, answers to the following questions can provide a good set of guidelines and give a structure to the usability test.

1. What to test? 2. When to test? 3. How to test? 4. Whom to test? 5. What to measure? 6. How do we know it's good enough?

What to test?

The most obvious answer is: "...the features which present possible risks to the product's success in the marketplace should be the focus of usability testing" (Wichansky, in Mills, 1986). The usability features should represent what users think are important for usable design and should not be representative of consensus among developers only.

When to test?

Howard and Murray (1987) suggested that: "The shorter the distance between the generation and evaluation of a design solution, the cheaper and easier it is to implement any design change recommendations." To reap the benefits of information thus gathered usability tests should be performed iteratively and as early in the development cycle as possible (Bury, 1984; Gould and Lewis, 1985).

A rapid prototyping approach can provide "...a testbed to collect empirical data that can be used to guide design decisions and permit the application of HF (Human Factors) principles early in the design process" (Broyles, 1989; parentheses added). Gould and Lewis (1985) asserted that "...informal prototypes rather than delaying or lengthening system development, actually help get a new project off the ground, give it something tangible for others to see, and stimulates thought and process."

How to test?

The choice of testing method depends upon the 'Evaluation Environment' (Howard and Murray, 1987), see Figure 3. There is no rule-book of procedures that can be used for selecting a set of methods for a given situation. Further, each method has its own blindness. Therefore, a combination of complementary methods should be used to improve the quality of the collected data. Frequently used methods are discussed below; since verbal protocol methods are gaining popularity, they are discussed in more detail.

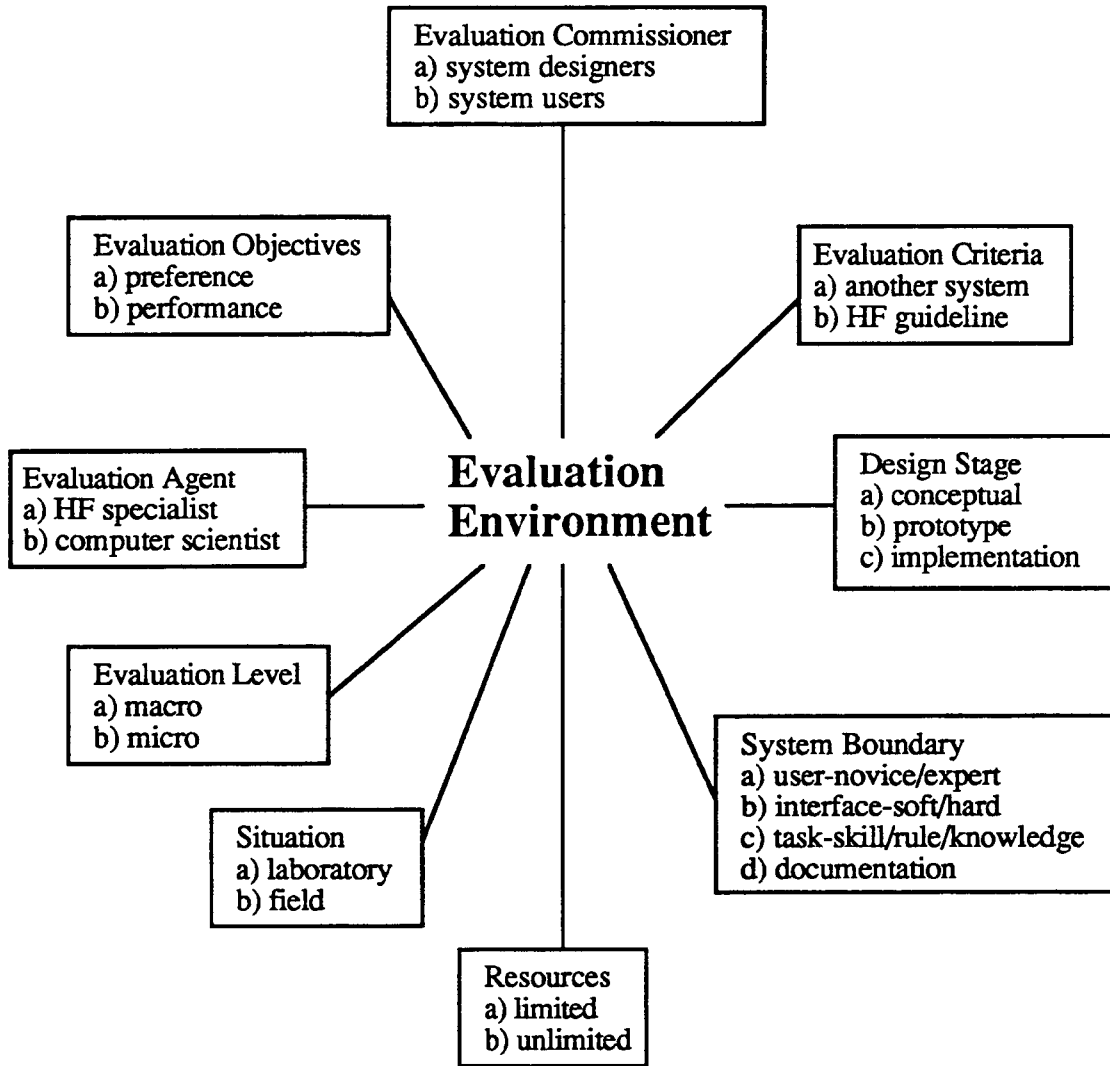


Figure 3: The Evaluation Environment (reproduced from Howard and Murray, 1987)

Observations

Stauffer (1989) classified observation methods into: unstructured observations, structured observations, and participant observations. Unlike unstructured observations, structured observations are conducted with a predetermined agenda and the observer is analyzing specific aspects of the domain or the subject behavior. In the participant observation method, the observer is a member of the group of subjects being observed. The observer, consequently, has a more intimate knowledge of the domain being studied and can "...ferret out information normally lost by the other observation methods" (Stauffer, 1989).

The method of observations is fairly nonintrusive. Subjects can be observed in the natural work setting with a high "context validity." However, the collected data often lacks details and requires interpretation by the observer and consequently could be contaminated by the observer's bias (Stauffer, 1989).

Interviewing

The interviewing techniques can also be divided into structured and unstructured type depending on whether a specific agenda is used by the experimenter to elicit information.

Questionnaires

Sinclair (1975) identified three occasions on which the use of questionnaires is relevant: (1) when the data cannot be obtained easily by other methods, (2) for corroboration of data obtained by other means, and (3) when the subject's attitudes, or strategies are likely to affect some aspects of the observed behavior in the problem situation.

The following issues should be considered while constructing a questionnaire (Sinclair, 1975): question specificity, language, clarity, leading questions, prestige bias, embarrassing questions, hypothetical questions, and personal questions.

Rating methods

Questionnaires for usability testing commonly use rating scales. A collection of guidelines for rating scales are given by Pitrella and Kappler (1988). These principles for design of rating scales are listed below:

1. Use continuous rather than category scale formats.
2. Use both verbal descriptors and numbers at scale points.
3. Use descriptors at all major scale markings.
4. Use horizontal rather than vertical formats.
5. Either use extreme or no descriptors at end points.
6. Use short, precise, and value-unloaded descriptors.
7. Use empirically determined rank-ordered descriptors.
8. Select and use equidistant descriptors.
9. Use psychologically scaled descriptors.
10. Use positive numbers only.
11. Have desirable qualities increase to the right.
12. Use descriptors free of evaluation demands and biases.
13. Use 11 or more scale points as available descriptors permit.
14. Minimize rater workload with suitable aids.

For a detailed discussion of each of these design principles the reader is referred to Pitrella and Kappler (1988).

Verbal Protocol Methods

Verbal protocol methods are widely used for usability testing. For usability testing, verbal protocols are usually videotaped and in that sense they are verbal/visual protocols; however, they will be referred to as verbal protocols in this discussion. Different techniques are available for collecting verbal protocols: retrospective protocols, think aloud protocols, question-asking protocols, and question-answer protocols. Verbal protocol methods have the ability to identify the language, concepts, and activities by which users organize their task language and consequently are particularly useful for system design (Ehn, 1988; Winograd and Flores, 1986).

Retrospective Protocols: Protocols collected at the end of the interactive session to elicit specific information are termed as retrospective protocols; they are an account of the event after-the-fact (Stauffer, 1989). This memory trace "...can be accessed from STM (Short Term Memory), at least in part, or retrieved from LTM (Long Term Memory) and verbalized" (Ericsson and Simon, 1985; parentheses added).

Retrospective protocols suffer from the following limitations (Ericsson and Simon, 1985; Stauffer, 1989): (1) identification of perceived rather than actual performance, (2) subject's account often yields summaries rather than details, and (3) incomplete information is revealed due to memory loss (retrieval from LTM).

Think Aloud Protocols. In the think aloud (TA) method, the participant's thoughts are verbalized concurrent with the task; the data are also referred to as 'Concurrent Verbalizations.' The TA method is often considered to be 'unnatural' (Bainbridge, 1990) or 'extraordinary' (Kato, 1986). Bainbridge (1990) suggested that more natural protocols can be collected by having two or more people working together, Kato (1986), on the other hand, suggested the use of Question-Asking protocols.

Greenwell (1988) listed a few variations of the think aloud technique, which include the Critical Response Method, Periodic Report Method, and Report by Commentary methods. The Critical Response method requires the user to be vocal only during the execution of certain pre-determined sub-tasks. The Periodic Report method is used when the task is very complex and users have difficulty thinking aloud and performing the task at the same time. The user, therefore, verbalizes at pre-determined intervals of time what he/she is currently trying to achieve. The length of

the interval is dependent on the complexity of the task. In the Report by Commentary method, a domain-expert is usually given a videotape of the task and his/her comments are recorded.

Question-Asking Protocols. In this method, participants (who do not have any prior knowledge of the system being studied) are asked to learn to use an interactive system without the assistance of instructional manuals. A tutor, however, is available. Participants are asked to complete a given task by obtaining information from the tutor, whose responses are based on a policy of "limited assistance."

The question-asking protocols along with observational records of operations can be analyzed to identify the following (Kato, 1986):

1. What problems participants experience in what context. 2. What instructional information participants come to need. 3. What features of the system are harder to learn. 4. How participants come to understand or misunderstand the system.

Question-Answer Protocols. In this method, the user (subject) answers questions about the interface while performing the tasks. The timing and contents of questions is critical. Unlike the other verbal protocol methods, this method is more structured and the following rules are used to guide the course of questioning when probing the users (Graesser and Murray, 1990).

Rule 1: Querying computer prompts and messages IF (computer prompt or message) THEN (experimenter asks "What does that mean?")

Rule 2: Querying user's actions IF (user performs action) THEN (experimenter asks "Why did you do that?")

Rule 3: Querying long pauses IF (user pauses for more than 15 seconds) THEN (experimenter asks "What are you thinking about?")

Rule 4: Querying goals I:F (user claims he has a goal G) THEN (experimenter asks "What are some alternative method of achieving goal G?")

Rule 4 Helps in tracing the profile of user strategies in achieving task goals.

Protocol analysis. Scientifically oriented protocol analysis is very time consuming.

Consequently, the verbal/visual protocols collected during the usability testing, on many occasions, serve as testimonial or anecdotal evidence only - used more as a selling tool. The protocols are used as "...anecdotal support for theories or points being made, without building any kind of a statistical case on the basis of verbal protocols for the assertions they are supporting" (Sanderson, James, and Seidler, 1989). To aid in the verbal protocol analysis, SHAPA (HemiSemi-Automated-Protocol-Analyzer) developed by Sanderson et al. (1989) can be a useful tool. SHAPA, an interactive protocol environment, has three principal functions (Sanderson, 1990):

1. Supporting researchers as they develop a set of encoding categories (predicates) which will have an appropriate relation to theory and which will allow the hypotheses of interest to be tested. 2. Providing a flexible, fluid interface for protocol encoding which promotes consistency, reliability, and objectivity. 3. Providing data analysis routines focusing on the analysis of content and analysis of patterns.

Playback Methods

The basic theme underlying this approach is recording a log of the user's behavior, for example, keyboard activity. This log is played back later for subsequent observation and analysis (Neal and Simons, 1984). The methodology, therefore, is both non-invasive (data collection programs are external to the product being evaluated) and nonintrusive (data collection does not infringe upon the user's activities) (Neal and Simons, 1983). The playback method is useful for objective evaluation and comparison of user interface design and software documentation. However, its applicability has often been limited to a very low level of analysis, that is, answering the question "Can a user do this task?", and not a cognitive level of analysis (Sweeney and Dillon, 1987).

Checklist Method

Johnson, Clegg, and Ravden (1989) recommended the use of a checklist method for user interface evaluation. The following usability criteria were suggested:

1. Visual clarity
2. Consistency
3. Informative feedback
4. Explicitness
5. Appropriate functionality
6. Flexibility and control
7. Error prevention and control
8. User guidance and support

The checklist is designed based on specific questions about the interface in relation to particular criteria. The suggested method requires the user to perform the task using the system before giving their evaluations of the interface. The above mentioned list can also be an answer to the question: What to test?

Whom to test?

Hewett (1986) identified four types of users for usability testing: biased, simulated, hostile, and friendly. Biased users usually refer to the members of the project staff or the design team looking for flaws to make improvements. The disadvantage, obviously, is that familiarity with the system limits their ability to think as an end-user. Simulated users are also the members of the design team; however, different scenarios are developed so as to force them to "view the system through fresh eyes." Hostile users are reasonably sophisticated. They are encouraged to find the flaws with the system. For example, computer science majors could be invited to "crash" a system to identify possible bugs. Friendly users are usually experts in the domain (not necessarily with the system). They can help give suggestions to improve training materials and system messages. What is important is that the test participants are both representative of the end-user population so as to avoid a skewed perception of the usability of a system.

What to measure?

Quantitative as well as qualitative measures can be used for evaluation of usability. Bair (1984) suggested the following measures of human-computer performance.

1. Quantitative measures
 - * Total job time
 - * Task time (several tasks make up a job)
 - * Mental workload - Number and difficulty of decisions - Effect of cognitive interferences
 - * Number of keystrokes
 - * Number of errors in command-control input
 - * Learning time (for comparative compatibility)
2. Qualitative measures
 - * Consistency
 - * Complexity
 - * Appearance and appeal
 - * Compatibility and output
 - * Predictability of system behavior

How do we know it's good enough?

As discussed in the section 'Usability Process,' it is necessary to predefine terminal usability specifications or criteria. Gottschalk (1986) suggested three methods for developing such criteria:

1. Experience-based estimates from development planners and marketing people
2. The results of previous tests using the same tasks
3. Case study input

There is nothing sacrosanct about these terminal specifications. They can be modified depending upon the feedback from continual user testing; what is inviolable is that the usability specifications represent the users' concept of usability.

Contextual Research: An Emerging Technique

The artificiality of laboratory settings and subsequent analyses questioned in the cognitive sciences (Suchman, 1987; Suchman and Trigg, 1990) is emerging as a serious concern in human factors usability testing and system design as well (Kukla, 1990). Whiteside et al. (1988) indicated two limitations of traditional usability testing procedures. First, the need for operationally defined criteria (usability specifications) was to ensure a shared meaning among developers of the focus of their work, but they were not matched against user's criteria. This is a problem of 'content validity.' Second, the data are collected in a laboratory setting, which may not be representative of a real life setting. This problem is one of 'predictive validity.' Whiteside et al. (1988) stated that: "Understanding the usability of a product from the users' point of view necessitates developing data collection techniques that can access users' day-to-day life experience...We want to be sure to access (as best as we can) experience rather than only an after-the-fact interpretation of that experience." This is the underlying theme of the contextual research technique.

Whiteside et al. (1988) suggested the 'Contextual Interview' as a means of accessing ongoing use of a product in a work-environment. It includes three parts: (1) exploring the user's work and responses to the system, (2) observing and questioning the user while the user describes the content and experience of his/her work, and (3) summarizing with the user what functionality or features were usable or missing and clarify other usability issues that emerged during the observation and interview session. The purpose of contextual research is to uncover the user's experience of usability with a product and translate these to usability dimensions that are important to the user (Whiteside et al., 1988). Thus, unlike the traditional usability approach, the usability specifications are derived from a shared understanding between developers and users; consequently, it could be claimed to have a high content and predictive validity.

In sum, the contextual research "...emphasizes the importance of context in understanding usability issues - including the work context, the social context, the motivational context, the organizational context, and the physical context" (Good, 1989).

Summary

To summarize, the answer to the question "How to incorporate usability measurement in system design?" is threefold. First, we need to make explicit the definition of usability, since usability is a loosely defined construct, as are the terms easy to use, easy to implement, easy to learn, etc. These constructs must be given operational definitions so that they can be related to the observable data or user behavior. Such an effort will also help developers and users share the same definition of usability. Second, we need to incorporate usability into the system development process. To ensure a usable system design, usability specifications must be interwoven with the system specifications. The contextual research along with the Usability Specification Table approach or Subskills Analysis Approach should be employed very early in the system development cycle. Finally, we need to test a system iteratively with representative end-users to ensure that the system development is on the right track to achieve the usability goals.

Concluding Remarks

The literature on usability appears to give one strong message: "Incorporate the users' model in the design of systems." Not all researchers agree. Wright and Bason (1982) demonstrated that "...there may be circumstances in which bending the system to the preconceptions of the user is not the most viable approach." They called this approach detour to usability and suggested that often "satisficing" solutions are sufficient rather than attempting to achieve the unattainable best solution. Bair (1984) suggested the need to overcome the misconception that "...the user can tell designers what he needs," since it is difficult for the user to evaluate something that he/she has never used before. Bair (1984), therefore, recommended gathering information concerning users' values and criteria for acceptance (success) in context of his environment, and using this information to design independent of a particular technology. Furthermore, it is also very likely that the strategies adopted by the users is "...convoluted, suboptimal, or developed in response to an

impoverished task and support environment (Roth and Woods, 1989). Consequently, users' specifications should be reinterpreted by the designer before accepting as the basis for the design (Wright and Bason, 1982). In Fitter's (1979; cited from Wright and Bason, 1982) terms it is often sufficient to "...model the work domain in a way that is comprehensible to the user" even if it differs from the users' model. Tognazzini (in Mills, 1986) stated that: "To ride the leading edge of an exploding technology, we must become calculated risk-takers, armed with accurate, streamlined testing procedures, sharpened intuitive skills, and a willingness to make solid, educated calls in a timely fashion."

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Biographical Sketches

Pawan R. Vora has undergraduate degrees in Mechanical Engineering and Production Engineering from Victoria Jubilee Technical Institute, India. He received M.S. in Industrial Engineering from State University of New York at Buffalo. His master's thesis was entitled "Developing guidelines for symbol design: A comparison of evaluation methodologies." Currently, he is pursuing the Ph.D. program in the same department. His research interests include human-computer interaction and usability engineering. He is a member of the Human Factors Society, the Institute of Industrial Engineers, and the Society of Manufacturing Engineers.

Martin Helander is an Associate Professor in the Department of Industrial Engineering at the State University of New York, Buffalo. He obtained a Ph.D. in Engineering from Chalmers University of Technology in Goteberg, Sweden in 1976, and a Docent (Ph.D.) in Engineering Psychology in 1977. He was Acting Professor at Lulea University in Sweden, where he helped establish the Department of Work Sciences, the first of its kind in Sweden. Since arriving in the U.S. in 1977, he worked for Canyon Research Group doing contract research. In 1982, he returned to academic employment. Recent research interests include: ergonomics in manufacturing, industrial automation, and human-computer interaction. He is the editor of *Handbook of Human-Computer Interaction* and *Human Factors in Design for Manufacturability*, to be published by Taylor & Francis. Martin has served HFS as chair of the Technical Standards Committee, representative to ANSI Safety and Health Standards Board, chair of the U.S. Technical Advisory group to ISO 159 on Ergonomics, and delegate to International Ergonomics Association. In 1982, he reorganized the Technical Standards Committee, and there are now about 50 HFS members actively involved in the development of human factors standards and guidelines. He is a fellow of the Human Factors Society and the Ergonomics Society.

GRASS User Interfaces

James Westervelt

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Introduction

Geographical information system user interfaces come in many different forms. These forms are based on a combination of user, software, and hardware issues. These include the following.

Definition of geographical information system - There are many software products which claim to be geographical information systems. They often provide one or more of the following: 1) map retrieval and display, 2) map input and editing, 3) map analysis, and 4) landscape modeling.

Definition of user - Users of a GIS might be secretaries, managers, programmers, scientists, GIS specialists, or ordinary citizens.

Sophistication of the user - The abilities of the users to understand, use, and manage hardware and software.

User goals and objectives - What does the user want to do with the GIS? Access and display maps, cartographic modeling, desktop publishing, statistical analyses? Generate new programs? As macros? As new programs?

Hardware/Software capabilities - Can the hardware/software support graphical user interfaces? 3-D interfaces? Natural language interfaces? Voice, or typed input?

The GRASS development sites across the world recognize the many different needs defined by the various combinations of user, hardware, software, and office constraints. The following different user interfaces are available, under development, or under consideration for GRASS.

Programmer Database Interface

USER -

GRASS C-language programmers.

DEPENDS ON -

GRASS data base design.

SUPPORTS -

Hundreds of GRASS command-line and dumb-terminal interactive driven commands. Also supports some of the graphical user interface commands.

DESCRIPTION -

About 10 libraries of more than 300 subroutines used to interface with data and users. These do exist, and are being used constantly.

DEVELOPER -

Developed by the core GRASS programming staff at the Army Corps' Construction Engineering Research Laboratory.

Programmer Algorithm Interface

USER -
GRASS C-language programmers.

DEPENDS ON -
GRASS data base design.

DESCRIPTION -
Does not exist. Requested by a few GIS development sites. Would contain GIS functionality callable by subroutines.

Command Line Interface

USER -
Most current "GRASS users" interface with GRASS via this route.

DEPENDS ON -
The Programmer Database Interface.

SUPPORTS -
Analyses, displays, data development
Fancy user interfaces (see below)
GRASS macros
Decision Support Systems

DESCRIPTION -
This provides the most commonly used interface to GRASS. It forms the backend for other user interfaces as well as a programming language for the support of decision support systems.

DEVELOPER -
Many GRASS development sites across the world have contributed to the command-line GRASS commands.

Interactive Interface for Dumb Terminals

USER -
Many current GRASS users.

DEPENDS ON -
The Programmer Database Interface.

SUPPORTS -
Only interactive GRASS users not requiring fancy interfaces.

DESCRIPTION -
Every GRASS Command Line Interface program provides a simple dumb-terminal interactive capability.

DEVELOPER -
Many GRASS development sites across the world have contributed to the command-line GRASS commands.

Window Interface for Novice Users

USER -

Novice and occasional GRASS users who plan to do simple data manipulations and displays.

DEPENDS ON -

The Command Line Interface.

SUPPORTS -

No other interfaces.

DESCRIPTION -

For the most part, this provides a graphical user interface front-end that collects information from users which is used to quietly call the Command Line Interface programs.

DEVELOPER -

Currently under development at CERL.

Window Interface for Modelers

USER -

Semi-sophisticated users.

DEPENDS ON -

The Command Line Interface.

SUPPORTS -

No other interfaces.

DESCRIPTION -

This interface provides user manipulated glyphs that represent GRASS functions. Users direct the flow of information (maps) between the glyphs (GRASS functions) graphically.

DEVELOPER -

Commercial effort in cooperation with CERL. Not yet started.

Natural Language Interface

USER -

Occasional or novice user.

DEPENDS ON -

The Command Line Interface.

SUPPORTS -

No other interfaces.

DESCRIPTION -

Natural language keyboard entries are interpreted and reformatted into GRASS Command Line Interface calls.

DEVELOPER -

NASA/Commercial endeavor.

Decision Support System Interface

USER -

DEPENDS ON -

The existence of hundreds of GRASS commands developed by programmers with the Programmer Database Interface. Hundreds of other UNIX, commercial, and public domain software analysis capabilities.

SUPPORTS -

Potentially hundreds of different end-user decision support systems that can be very location, application, and user specific. It is projected that MOST GRASS users will be using these products and will know nothing about GRASS.

DESCRIPTION -

GIS specialists become software engineers using GRASS, other GIS, UNIX, and other commands as the subroutines of large and sophisticated macros. A CERL product called XGEN provides an easy way to generate graphical user interfaces as part of these macros.

DEVELOPER -

GIS specialists everywhere.

Biographical Sketches¹

James Westervelt holds degrees of B.S. in Biology, M.S. in Science Ed., and M.U.P (Urban Planning). Currently pursuing PhD in Urban and Regional Planning. Has worked over past 10 years on all aspects of GRASS: design, development, implementation, education, data development, funding, and coordination.

Kurt Buehler received his BS and MS degrees in Civil Engineering from Purdue University. He has: designed/developed a Bayesian inference engine for a raster GIS; redesigned and developed a sophisticated application generator suitable for allowing GIS specialists to add GUIs to GIS macros; and designed and developed user interfaces for various GIS applications. He is in charge of \$200K/yr effort in creating an X-windows interface to GRASS. Mr. Buehler has been a Research Engineer at the Indiana Water Resource Research Center, Purdue, and before that was a Research Assistant at the Center for Advanced Decision Support of Water and Environmental Systems. Starting 17 June 91, he will be a Civil engineer at Army Corp's Construction Engineering Research Lab. His areas of GIS interest include: User interfaces; parallel processing; fundamental data base design; and AI application development.

¹ James Westervelt, who wrote this position paper, was unable to attend the workshop. Kurt Buehler, also of CERL, replaced him at the workshop, and his biographical sketch is also included here.