Interacting with Geographic Information: A Commentary

David M. Mark and *Michael D. Gould*
National Center for Geographic Information and Analysis, Department of Geography, State University of New York at Buffalo, Buffalo, NY 14261

ABSTRACT: The GIS community is beginning to focus attention on the study of human-computer interaction, in an attempt to increase system usability and user productivity. However, it may be that the explicit focus on the interaction between a user and a device is misguided. Instead of interacting with a computer peripheral or its user interface, GIS users should instead be able to interact more directly with geographic information and geographic problems. A focus on human-problem or human-phenomenon interaction will better enable the design and implementation of optimal user interfaces for GIS and related software. This approach is supported by researchers from both the engineering and artistic perspectives on human-computer interaction.

INTRODUCTION

"We'll fix the user interface after we decide what to do and when we have time to work on it."

(Comment in the documentation for the Macintosh public-domain program *NCSA/BYU Telnet*)

UNTIL RECENTLY, THE ABOVE COMMENT could just as easily have come from a producer of GIS software. Lately, however, the GIS community has turned some attention to user interfaces for GIS. The title of this paper reflects our philosophical position on user interface design – the prime objective should be to enhance user interaction with *geographic information* and with *geographic problem-solving*, rather than with software or hardware. This paper provides a brief introduction to critical issues regarding user interfaces for geographic information systems. The introduction includes an overview of key issues and approaches in human-computer interaction (HCI) research. Then, after a discussion of paradigms for design, we point toward some elements in an emerging research agenda on user interfaces for GIS.

HUMAN-COMPUTER INTERACTION

Human-Computer Interaction (HCI) is a field concerned with evaluating how people use computers, and how they might use them more effectively. HCI is the computer side of Human Factors, an engineering discipline concerned with human interaction with technology and the built environment. HCI is also the applied side of Cognitive Science, a field which studies how humans conceptualize and reason about phenomena. In summary, HCI is a methodological dichotomy, representing some mixture of a cognitive approach and an engineering approach to the design and evaluation of user interfaces. A review of the breadth of HCI is presented in Helander (1988) and relations between HCI and GIS are discussed in Gould (1989) and in Turk (1990).

In some ways, the term "Human-*Computer* Interaction" is unfortunate, because it focuses the designer's attention on the interaction between a person and a computerized device rather than on a person and a problem to be solved. The term does, however, accurately reflect the traditional (majority) view of work in user interface design. Exemplary of this traditional view, Walker (1990) defines five generations of human-computer interaction in terms of modalities of operation:

- Plugboards, dedicated set-up;
- Punched card batch;
- Teletype timesharing;
- Menu systems; and
- Graphical controls, windows.

It is interesting to note that today we find it humorous to consider Walker's first and second generations as user interfaces. The early days of computing required users to enter programs and data through the medium of hard-wired connections. In the 1960s, punched paper tape and then Hollerith cards revolutionized programming and data entry. Almost all computing in the late 1960s and early 1970s was "batch mode;" the user interacted with the computer by punching program or data cards on a key-punch machine, walking to another room, or perhaps another building, submitting a card deck to an operator, and waiting hours or perhaps even days for the output. Now, almost all computing is interactive: the better accepted form of user interface. At present and in the near future, five basic forms of human-computer interaction are important, as discussed below.

COMMAND LINE INTERPRETER

This is the familiar method in which the user types commands at some prompt, and the computer then executes the command. If required parameters or arguments for the command are missing, the computer may prompt the use for them, or may give the user an error message. Almost always, each command is executed when complete (or when the user hits "return" or "enter"), and then the user must completely specify the next command or query. Most systems require a "verb-object" syntax similar to commands or queries in English. OSU MAP-for-the-PC, a personal computer-based geographic analysis system, uses this form of interaction.

FORM FILL-IN

In this approach, the computer specifically prompts the user for each parameter or argument needed for the current command or query. An example of this type of interaction may be found in IDRISI, another personal computer-based geographic analysis system. Form fill-in relieves the user of much of the burden of remembering command names and syntax, but may appear slow and inflexible to the more experienced user.

MENU SELECTION

Menus can be permanent on-screen features, or the now well-known "pull-down" menus of the Macintosh and many other systems. Either the cursor keys or a pointing device (such as a mouse) is used to select from a menu of possible commands or actions. An example of this type of interaction is found in PC ARC/INFO, a personal computer-based GIS.

DIRECT MANIPULATION

In the direct manipulation approach, the user employs a device (usually a mouse) to select, "grab," and "move" objects

0099-1112/91/5711-1427$03.00/0

on the screen. Such movements may rearrange directory structures, select files, execute procedures, redesign screen layouts, or create and edit images or text. Direct manipulation and menu selection also more easily lend themselves to "object-verb" syntax. (For example, on a Macintosh the user can first select a file icon, and then choose some command or operation to apply to it, such as "open.") Popular examples of systems utilizing this form of interaction are ARC/INFO, ERDAS, MAP II, and TIGRIS. Touch-screen technology, rapidly growing in both resolution and economy, will almost certainly make direct manipulation an even more powerful and natural approach to HCI, compared to a mouse (Sears and Shneiderman, 1991).

Natural Language

Natural language is a term used to refer to human languages such as Spanish, English, Hopi, and Japanese. (The modifier "natural" is inserted to distinguish them from computer languages such as Pascal, FORTRAN, or C.) Keyboard entry of natural language is not a very practical method of HCI; however, with the advent of real-time speech-understanding systems (see Mountford and Gaver (1990) for a general overview), spoken natural language is likely to become a very important form of system interaction for GIS (Haller and Mark, 1990). Ideally, users will be able to express their needs through a combination of speech and gestures (pointing at items on CRTs, using mouse, track ball, tablet, or touch-screen technologies). Mark *et al.* (1990) discuss several GIS applications for which natural language interaction would be preferred over more "traditional" HCI methods. Examples of natural language interaction are not currently found in today's commercial GISs. In fact, some members of the GIS community have considered the idea to be close to science fiction (personal communication with several participants during the Fourth International Symposium on Spatial Data Handling in Zurich, July 1990). However, such systems *do* exist already in prototype form in the laboratory, including CUBRICON, to be discussed later in this paper.

USING GEOGRAPHIC INFORMATION: WHO ARE THE "USERS"?

Differences among users of GISs, both currently and in the future, are an important focus of any research agenda to investigate user interfaces for GIS. Nevertheless, we really know very little about GIS users. There has been almost no systematic testing of users of geographic information, either with regard to current GISs or for geographic problem-solving in general. Thus, many questions are unanswered. One important question is, "What level of geographic knowledge and training should be assumed of the user?" A system designed for "Spatially-Aware Professionals" (Raper and Bundock, 1991) such as geologists, urban planners, or foresters, could borrow relevant concepts from cartography and from those disciplines. But an ideal system for such users probably would be too complicated for a "citizen-scientist" to walk up to in a public library and use to enquire about an environmental or planning issue. Furthermore, some of the simplification needed for the hypothetical "walk-up-and-use" system would be compensating for low computer knowledge and skills. How should the level of computer knowledge and related skills interact with the level of geographic knowledge to influence the design criteria for an ideal user interface? And how does frequency of use influence the design? Experience has shown that a person who uses a system 30 to 40 hours per week as a GIS technician or operator would soon learn even the most cryptic commands. But even the most knowledgeable and skilled users might need simple user interfaces if they only used the systems for a half an hour at a time, once or twice a month. To further complicate the problem, a programmer's interface might be quite different from the interface for "end users." Westervelt (1991) has claimed that, in the near future, there will be two kinds of GIS users: GIS experts who will develop domain-specific applications using GIS as a sort of programming language, and the end users of such applications. The latter will include intelligent novices, managers, and scientists using GIS as a research instrument. The design of current GISs has been aimed primarily at GIS experts.

USER INTERFACE DESIGN

In almost all cases, people use GIS because they, or their organizations, or their clients, must deal with features or phenomena or problems in geographic space (that is, in the "real world"). However, practical constraints often make field study unrealistic. Use of a GIS is one way to "interact vicariously with actual or possible phenomena of the world" (Mark, 1989, p. 551), thus avoiding the monetary and temporal expenses inherent in field work. (Historically, maps have long played a similar role.)

A GIS brings a representation of the world to the user's desk. Of course, in order for the GIS user to make decisions, predictions, or hypotheses about geographic phenomena, that representation should be as faithful as possible to relevant aspects of the world. For this to be achieved, "the system which mediates between the user and the world should be as unobtrusive as possible" (Mark, 1989). When the user sits at a workstation and uses a GIS, he or she should be thinking about real-world phenomena, and not about computers or peripherals, commands or syntax, layers or pixels. Again, we claim that, in the context of GIS design, it seems that the term "Human-Computer Interaction" may represent misguided or tangential effort. Perhaps the use of this term focuses too much attention on physical tools (such as the mouse), and not enough attention on problem-solving. Woods and Roth (1988) have claimed that such a perspective characterizes most HCI work:

> ". . .one often speaks of the interface, the tasks performed within the syntax of the interface, and human users of the interface. Notice that the application world (what the interface is used for) is deemphasized. The bulk of work on human-computer interaction takes this perspective." (Woods and Roth, 1988, p. 6)

They go on to describe an approach to user interaction one step closer to the phenomena of interest:

> "A second perspective is to distinguish the interface from the application world... . The interface is an external representation of an application world, that is, a medium through which agents come to know and act on the world... . It is in designing interfaces and aids for these applications where it is essential to distinguish the world to be acted on, from the interface or window on the world (how one comes to know that world), and from agents who can act directly or indirectly on the world." (Woods and Roth, 1988, p.7)

Continuing this de-emphasis of the interface as an object, we suggest that the user should be interacting with a problem domain — a phenomenon or set of phenomena — and not a computer, an application, or even an interface. In a sense, the GIS user should be looking *through* the interface rather than *at* it. If this is to be the ultimate goal of user interface designers, then perhaps attention to on-screen widgets, such as pop-up menus and slider bars, is an unnecessary drain on creative resources and should be considered a secondary activity (Norman, in Rheingold (1990)).

Design is a complicated and very human process that has elements of both engineering and art. The engineering approach emphasizes studies of people using existing systems, or people solving problems, and then generalizes from these to develop designs. In a book entitled *Understanding Computers and Cognition*, Winograd and Flores (1986) approached the problem of design of computer systems from a general perspective of human cognition and artificial intelligence — the subtitle of the book is "A New Foundation for Design." The book is a wealth of information and informed opinion on the role of computers in society, on the relations between computers and their users, and on design criteria for enhancing the efficacy of such human-computer relations. One of the examples treated by Winograd and Flores is decision-support systems. Underlying the design of such systems are questions such as, "What can people do with computers?", and the even more fundamental question, "What do people do?" Answering the question, "What do GIS users do?" for various sets of GIS tasks would be a prerequisite to the design of user interfaces under Winograd and Flores' approach.

This idea of human interaction, or communication, with a problem domain rather than with a device, has been discussed by Fischer and Lemke (1987), Mark (1989), and Gould and McGranaghan (1990), as well as by Woods and Roth (1988; see above). In this approach, the interface and the computer hardware and software become a transparent medium, rather than a participant in an interaction. In principle, the goal is to build systems such that the users cease to be aware of the hardware and software, and think only about the problem domain: soil science, or environmental design, or forestry, or whatever they are working on. Winograd and Flores (1986) use the term "breakdown" to describe a situation in which a tool ceases to function properly. A familiar example occurs in writing using a word processor. Many people have experienced a word-processing session in which their consciousness was fully occupied by the virtual document on the screen and by the underlying ideas that the writer is attempting to express. But if the writer wishes to set a particular phrase in italics, and cannot remember how to do that, then there has been a breakdown, and the writer may (quite suddenly) "see" the word processor as menus or function keys. Winograd and Flores (1986) give the example of a writer noticing that the letter "w" fails to appear when typed. Here, the breakdown is at an even deeper level, and the writer becomes aware of the keyboard, and perhaps even of the device driver that mediates between the keyboard and the CPU.

User interface design also can be viewed as an art. This is the philosophical stance of the editor Brenda Laurel, and of most of the authors, of the recent Apple Computer-sponsored book *The Art of Human-Computer Interface Design*. The average computer user may be surprised to learn from this book that much of "the user interface problem" is not a programming problem, but rather a conceptual and a human problem. In an interview published in the Laurel book, HCI researcher Don Norman stated:

> "The computer industry focuses an enormous amount of energy on the human-computer interaction. That's a lot better than no concern at all, but I think it's the wrong focus. *We ought to be asking what tasks people need to accomplish, what tools are the most appropriate for those tasks.*" (Rheingold, 1990, p. 7; Rheingold's emphasis).

The tools that Norman speaks of are at the conceptual level of user interface paradigms, such as metaphor and direct manipulation. From the engineering point of view, these paradigms may support increased user productivity. The artistic view of these paradigms, however, is that they allow the user to become immersed in the problem-sølving domain and to direct cognitive processes toward that problem (e.g., soil erosion) rather than toward operating the "system" for effectivety. To return to the word-processor analogy, the goal of the user interface should not (necessarily) be to increase a typist's words-per-minute, but rather to allow the creation of more original and effective documents. In fact, an optimal interface might eliminate altogether the job title "typist" in favor of "writer," or might eliminate "GIS operator" in favor of "geographic analyst."

As a final word on design, we note Winograd and Flores' statement: "Design is always already happening." If the people developing software for geographic data handling or analysis do not consciously design the user interface, the unconscious design that happens "by default" is unlikely to approach optimality.

SOME STEPS IN THE RIGHT DIRECTION

As noted in the introduction, the GIS community has recently recognized the need for more effective user interfaces for GIS. Such interfaces would allow people to interact more naturally with geographic information than is possible using the GISs of the 1980s and earlier. In this section, we provide brief overviews of three systems that incorporate some of the design principles discussed above, and mark the beginning of a generation of more useable GISs.

HyperArc

HyperArc is a prototype GIS user interface which runs on a Macintosh and is part of the UGIX project underway at London's Birkbeck College (Raper and Bundock, 1991a, 1991b). UGIX (which stands for Universal Geographic Information Executive) attempts to provide a user interface based on users mental models of geographic space, and on generic geographic concepts. However, implementation as an independent "front end" for an existing GIS required some compromises. "HyperArc forces the user to work with ARC/INFO concepts, but tries to connect them with the user's view of the problem under study" (Raper and Bundock, 1991a, p. 281). If the spatial concepts in the user's mental model are not equivalent to the data models, commands, or functions in the GIS, then such concepts cannot be fully implemented in a "hybrid" system.

CUBRICON

CUBRICON (Neal *et al.*, Neal and Shapiro, 1991) is a prototype system to support air force mission planning. It was developed in part as a demonstration of applications for an artificial intelligence system for natural language understanding and production.

The conceptual model for CUBRICON is two people developing a plan for action, standing next to a wall map and a blackboard. But in CUBRICON, the part of one of the people is taken by a computer program. The inputs to the system include discrete speech (speech with distinct pauses between words, a limitation due to current speech-interpretation software), gestures (with a mouse), data from files or databases, and keyboard entry if and when needed. Output from the system includes synthesized speech, maps on a color display screen, "gestures" (produced by arrows, flashing circles, etc.), and text and tables on a monochrome screen. CUBRICON is written in SNePS, the Semantic Network Processing System (Shapiro and Rapaport, 1987). SNePS in turn is written in LISP and runs on a variety of platforms. An important feature of CUBRICON is that human-computer interaction is modeled as a discourse or dialog, rather than as a sequence of commands and queries. The computer keeps track of previous user actions, and uses a model of these to reduce ambiguity in further interactions.

In the summer of 1990, SNePS was linked to ARC/INFO in such a way that, when a user types a request such as "display the soils map," SNePS uses its knowledge base to "translate" the request into a set of AML commands, which are then executed by ARC/INFO (Shapiro *et al.*, 1991). The combination of the CUBRICON interface with ARC/INFO should thus be relatively straightforward, although again the limits imposed by the data models and commands of the particular GIS might "show through" to the user as was the case with HyperArc.

ArcView

As noted above, ArcView is a new software product from ESRI, which the company claims "provides a major breakthrough in the usability of GIS" (ESRI, 1991, p. 1). Unlike HyperArc, ArcView does not attempt to provide full GIS functionality to the end user. Rather, a restricted set of commands, primarily visualization and plotting, selection, spread sheet functions, and statistical tools, allows the ArcView user to get access to complex GIS data sets. ArcView is seen as a way for current GIS users "to provide electronic access to their data for people who need access to it, but could not afford the time to learn a complicated technology" (J. Dangermond, quoted in ESRI (1991), p. 2). It provides potential for public access to ARC/INFO data through a graphical user interface, and will be available on personal computers (Macintosh, DOS) as well as on workstations. However, at least initially, ArcView will not provide users access to spatial analysis tools and procedures. The design of ArcView reflects the opinion that full GIS functionality may be too complicated for untrained users to use properly, and that an interface for the general public should provide only limited functionality, chiefly viewing and browsing.

A RESEARCH AGENDA

As can be seen, some progress is being made in the area of user interfaces for GIS. It remains to be seen, however, what direction future research in this area should take. How can research in several disciplines, each having different methods and goals, ever reach agreement on the "big issues"? For example, research in the area of natural language understanding may have little relevance to researchers favoring a direct manipulation approach, and these groups may not be aware of each others' progress. One solution, though not a panacea, is for a central body of researchers to synthesize and disseminate information among these many groups and sources, and to suggest research directions. Recently, the National Center for Geographic Information and Analysis announced a new Research Initiative (number 13) on *User Interfaces for Geographic Information Systems*. The initiative will address human-computer interaction methods and related issues in the design and implementation of user interfaces for GISs and other geographical software packages. The research initiative has as its broad goals:

- to investigate ways for people to naturally interact with computers when solving problems concerning geographic space and spatial phenomena;
- to establish criteria and methods for the design of GIS user interfaces, and user interfaces for other geographic software; and
- to develop and test prototypes of GIS interfaces and interface development tools.

With the help of GIS users, and with focused research from the GIS and HCI communities, we anticipate that greatly improved, powerful, and "natural" user interfaces will be available within a few years. These interfaces will, hopefully, address the tasks most common to geographic analysts and not just the operation of GISs as machines. These interfaces will provide not only increased speed and ease of access to geographic information, but also improved geographic problem-solving as well.

ACKNOWLEDGMENTS

This paper represents part of Research Initiative 13, User Interfaces for Geographic Information Systems, of the National Center for Geographic Information and Analysis, supported by a grant from the National Science Foundation (SES-88-10917). Support by the NSF is gratefully acknowledged. Two anonymous referees provided useful comments on an earlier draft of this paper. Mention of specific hardware or software products in this paper does not constitute endorsement by the authors or the NCGIA.

REFERENCES

ESRI, 1991. ArcView – The Ultimate Window to Spatial Data. *ARC News* [Environmental Systems Research Institute], Vol. 13, No. 2, pp. 1–3.

Fischer, G., and A. C. Lemke, 1987. Construction kits and design environments: Steps toward human problem-domain communication. *Human-Computer Interaction*, Vol. 3, pp. 179–222.

Gould, M. D., 1989. Human Factors and its Value to GIS User Interface Design. *Proceedings, GIS/LIS'89*, Orlando, pp. 542–550.

Gould, M. D., and M. McGranaghan, 1990. Metaphor in Geographic Information Systems. *Proceedings, Fourth International Symposium on Spatial Data Handling*, Zurich, pp. 433–442.

Haller, S. M., and D. M. Mark, 1990. Knowledge Representation for Understanding Geographical Locatives. *Proceedings, Fourth International Symposium on Spatial Data Handling*, Zurich, pp. 465–477.

Helander, M. (editor), 1988. *Handbook of Human-Computer Interaction*, New York: North-Holland.

Laurel, B. (editor), 1990. *The Art of Human-Computer Interface Design*, Addison-Wesley, Reading, Mass.

Mark, D. M., 1989. Cognitive image-schemata and geographic information: Relation to user views and GIS interfaces. *Proceedings, GIS/LIS '89*, Orlando, pp. 551–560.

Mark, D. M., M. D. Gould, and J. Nunes, 1990. *Spatial Language and Geographic Information Systems*. Technical Paper 90–2, National Center for Geographic Information and Analysis, Santa Barbara, California.

Mountford, S. J., and W. W. Gaver, 1990. Talking and Listening to Computers. *The Art of Human-Computer Interface Design*, (B. Laurel, editor), Addison-Wesley, Reading, Mass., pp. 319–334.

Neal, J. G., and S. C. Shapiro, 1991. Intelligent Multi-Media Interface Technology. *Architectures for Intelligent Interfaces: Elements and Prototypes* (J. W. Sullivan and S. W. Tyler, editors), Addison-Wesley, Reading, Mass., pp. 11–44.

Neal, J. G., C. Y. Thielman, Z. Dobes, S. M. Haller, and S. C. Shapiro, 1989. Natural Language with Integrated Deictic and Graphic Gestures. *Proceedings, DARPA Speech and Natural Language Workshop*, Morgan Kaufmann, Inc., Los Altos, California, pp. 410–423.

Raper, J. F., and M. S. Bundock, 1991a. UGIX: A GIS Independent User Interface Environment. *Proceedings, Auto-Carto 10*, pp. 275–295.

———, 1991b. UGIX: A Layer Based Model for a GIS User Interface. *Cognitive and Linguistic Aspects of Geographic Space* (D. M. Mark and A. U. Frank, editors), Kluwer Academic Publishers, Dordrecht, in press.

Rheingold, H., 1990. An Interview with Don Norman. *The Art of Human-Computer Interface Design* (B. Laurel, editor), Addison-Wesley, Reading, Mass., pp. 5–10.

Sears, A., and B. Shneiderman, 1991. High-precision touchscreens: Design strategies and comparisons with a mouse. *International Journal of Man-Machine Interaction*, Vol. 34, No. 4, in press.

Shapiro, S. C., H. Chalupski, and H.-C. Chou, 1991. *Linking ARC/INFO with SNACTor*. Technical Paper 91–11, National Center for Geographic Information and Analysis, Santa Barbara, California.

Shapiro, S. C., and W. J. Rapaport, 1987. SNePS considered as a fully intensional propositional semantic network. *The Knowledge Frontier, Essays in the Representation of Knowledge* (N. Cercone and G. McCalla, editors), Springer-Verlag, New York, pp. 263–315.

Turk, A. G., 1990. Towards an understanding of human computer interaction aspects of geographic information systems. *Cartography*, Vol. 19, No. 1, pp. 31–60.

Walker, J., 1990. Through the Looking Glass. *The Art of Human-Computer Interface Design* (B. Laurel, editor), Addison-Wesley, Reading, Mass., pp. 439–447.

Westervelt, J., 1990. The Two Classes of GIS Users. *GIS World*, Vol. 3, No. 5, pp. 111–112.

Winograd, T., and F. Flores, 1986. *Understanding Computers and Cognition*, Addison-Wesley, Reading, Mass.

Woods, D. D., and E. M. Roth, 1988. Cognitive Systems Engineering. *Handbook of Human Computer Interaction* (M. Helander, editor), North-Holland, New York, pp. 3–41.