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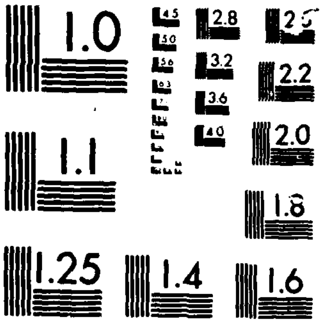

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State-of-the-art GIS are growing in complexity and scope. The operation of these systems require a mix of sophisticated intellectual and motor skills. Scientists at the U.S. Army Engineer Topographic Laboratories (USAETL) recognize the need to establish total system (e.g., hardware, software, and human) performance standards for the next generation GIS used for the extraction of Terrain information and the synthesis of digital terrain products. Planned activities include examination and adjustment of GIS hardware, software and associated instructional components to facilitate the work of the GIS user. A prototyping capability will be developed to

generate rapid; low cost user interfaces for system performance test and evaluation. Results of the studies will include recommendations for revised GIS hardware and software components and the associated performance and cost trade-offs regarding their implementation. (Keywords

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HUMAN FACTORS DESIGN CONSIDERATIONS FOR THE NEXT GENERATION GIS

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1. INTRODUCTION

The increase of computer usage outside the domain of the computer professional has necessitated the development of user interfaces which are less machine-like. This paper describes the theoretical basis and some of the current tools that can be used to develop more human-like methodologies for computer-human interaction. Implementation of human factors design methodologies that successfully facilitate system use is not an easily attainable goal. Although a plethora of studies and technological gagetry have been proposed to solve the problem, the predicted era of so-called "user-friendly" systems has not yet arrived. This is particularly evident in the development of Geographic Information Systems (GIS).

The primary reason why truly "user friendly" systems have not been developed is that the design process has not been adjusted to accomodate the human component of the system. Adjustment of the design process involves discarding the strict top-down approach for a modified approach that accomodates experimental iterations. Unfortunately, there is no algorithm or agreed upon technique that will ensure a user-friendly design (Shneiderman, 1979). Designing an effective user interface is where the easily quantifiable domain of machine interaction meets the complexity of human communication and cognition.

Designing for the human element is almost always a very costly portion of the system design process because it usually requires making repetitive trials with alternative approaches to reach the design goal. Research and Development (R&D) centers not directly involved in human factors studies have generally lagged in addressing the human component in system design. Such is the case in R&D activities for GIS. R&D activities in GIS technology have concentrated on expanding system functional capabilities or improving machine processing speed and storage efficiency. Most GIS development activities have not attempted to accomplish these tasks in a design framework which facilitates system user performance. Human performance studies and consequent design plans have been perceived as frivolous, unnecessarily expensive, expendable components of GIS design. Conciliatory attempts to improve the user-machine interface usually occur after the design has been completed and often result in system performance degradation rather than optimization.

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1.1 SYSTEM DESIGN INCLUDES THE HUMAN COMPONENT

The primary goal of system design is to develop a system which optimally achieves its design objectives. Design objectives must be geared to achieving a defined and measurable level of performance. System performance is the result of actions involved in working to achieve the system objectives. The key to developing economic and efficient systems is to design the system to meet specified performance standards. Unfortunately, many system designs evolve as a by-product of utilizing a particular technology or some existing components rather than having been carefully formulated to meet required performance standards. Frequently, performance standards are confused with system component specifications, which are standards for hardware or software operations. True performance standards incorporate all system components: the hardware, the software, and the user working together to achieve the system objectives.

State-of-the-art GIS are growing in complexity and scope. The operation of these systems require a mix of sophisticated intellectual and motor skills. Scientists at the U.S. Army Engineer Topographic Laboratories (ETL) recognize the need to establish total system (e.g. hardware, software and human) performance standards for the next generation GIS used for the extraction of terrain information and the synthesis of digital terrain products. To address the essential element of designing for the human component of these systems, work will begin on developing prototype human-machine interfaces for the rapidly evolving digital systems. The purpose of the Army GIS work effort is to optimize system performance by adjusting hardware, software and associated instructional components to facilitate the work of the terrain analyst.

1.2 GIS PERFORMANCE STANDARDS

The most common performance standards applied to Geographic Information Systems/Terrain Analysis Systems are accuracy and user processing time. Meeting the required map accuracy standards for compiling the information on the system is one performance standard for the terrain analyst. User speed of performance, the rate at which an analyst can perform a specified activity, is another measure of system effectiveness. Utility of output product is another performance standard. Other important performance standards include skill development time and user satisfaction. Performance standards for an Army GIS should be established as an adaptive system which accomodates both skilled and novice users. If performance standards are developed for only the skilled user, measuring the quality and quantity of work before necessary skills are developed can be misleading as an index of total system performance. To encourage the continuous development of skills, the system design should establish performance standards that become stricter as the analyst develops skill proficiency with the system. Army terrain analysts generally occupy one or several specific roles within their field for an average of six or less months. Job rotations are frequent. The system must be able to be a productive tool for the large pool of novice users. Therefore, separate performance standards should be established for the novice user. Skill development time must be kept to a minimum. As the novice gains experience, provisions should be available to switch to a more sophisticated level of interface.

User satisfaction is a related measure to skill development in system design. Skill development requires a commitment of time and effort on the part of the user. It is unlikely that an analyst will be highly motivated towards using a complex GIS if initial attempts at its use are unrewarding, unsuccessful, or overly tedious. User satisfaction is difficult to quantify but can be gauged indirectly by using interviews or questionaires.

2. HUMAN PERFORMANCE DESIGN CONSIDERATIONS

In determining the minimum acceptable levels of performance for a system, there are specific human limits and differences that must be accounted for in the design (Bailey, 1982). Army GIS design must evaluate the potential user population, the basic abilities and skills of the terrain analysts, their limitations and performance motivating factors. Because the anticipated operational use of the GIS could be in a variety of settings, the contextual (environmental and social) conditions that may impact performance should be assessed and contingencies made to cope with these. Contextual constraints include a wide range of conditions, such as situational duress, component failure, or transiency of user population.

As in any system design effort, the cognitive processing limits of the user population must be assessed. For instance, to what minimum accuracy can a hasty product be generated for it to retain its usefulness in aiding decision making? What is the maximum duration of time that can elapse between computer responses to user queries that will not cause the user to lose his or her train of thought and consequently lower system productivity? Certain design considerations can facilitate human cognitive processing. It is the objective of the Army GIS design effort to evaluate techniques applicable to general purpose computer interfaces, as well as those specific to the GIS interface, which take into account the capabilities of and limits to human sensing and perceiving, problem solving and decision making, memory, motivation and skill acquisition.

2.1 SENSING AND PERFORMANCE

The terrain analyst will depend primarily on visual sensing to receive information from the GIS. Tactile sensing will be used to send information from the analyst to the computer. Although some important cues from the computer may be transmitted as auditory signals, a voice interface probably would not facilitate performance in a scenario which potentially could involve a lot of background noise in the environment from multiple user workstations housed in close quarters. Although, the GIS interface relies primarily on the visual sense, the design should not place total reliance on one method of visual stimuli. The design should include redundant visual means to alerting the terrain analyst user. For example, use of graphic icons to supplement text messages or color highlighting on graphic displays provides a redundancy that should reduce the opportunity for missing or misinterpreting signals.

A skilled user is characterized by having learned to operate a system by "feel", intuitively knowing where the spatial placement of the controls are. The skilled user has built a perceptual map of where the controls lie. Such sensing is called kinesthetic sensing, and it is useful (if not essential) in operating a complex device. Kinesthetic sensing frees up the visual sense for other tasks, so that the operator does not have to watch where hand or foot placement occurs in using the device controls. GIS functions, such as digitizing and measuring, depend upon the user's ability to kinesthetically sense, because they require simultaneous use of the tactile sense for controlling the device and the visual sense for ascertaining that proper control has been made. Some GIS input devices (e.g. analytical stereoplotters, light table systems, etc.) require use of both hands and sometimes feet to properly control the device. With this degree of complexity in sensing, errors will likely occur if distortion is perceived in the kinesthetic sense. Techniques should be utilized for those devices that will reinforce rather than distort kinesthetic sensing. (For example, differentiate the shape and movement of controls and provide direct computer feedback to the user's visual sense that confirms that proper movement control has been achieved.) Kinesthetic perceptual distortion is especially likely when using spatially separated controls and displays (Bailey, 1982). Spatially separated controls and displays tend to be the norm in the current generation GIS. (For example, most digitizing stations are equipped with a remote display device that enables the analyst to view what has been digitized. This forces the analyst user to switch his or her attention back and forth between the graphic object on the device and the computer display.) Design studies should determine the impacts on kinesthetic sensing that this configuration causes, and formulate alternative approaches if they are warranted.

2.2 PROBLEM SOLVING AND DECISION MAKING

Two key user processes for GIS operation are the intellectual skills of problem solving and decision making. A problem is a situation that does not have a ready response (Davis, 1973). Problem solving requires the accumulation of ideas to formulate possible alternatives and the subsequent formation of a new combination of ideas to reach a solution. Decision making is similar to problem solving; however, the alternatives are known, and the analyst must select the most desirable alternative. Although on a cognitive level, problem solving is more complex than decision making, decision making can be quite complex if uncertainty exists regarding the outcome of choosing each of the alternatives.

Problem solving can be achieved through either trial and error or systematic performance. When the analyst has no experience solving similar problems, the method of problem solving is through trial and error performance. Trial and error is often time consuming, and may result in a failed attempt to solve the problem. A systematic method for problem solving requires a significant investment in training (which is also time consuming and costly). Therefore, systems with a high level of user turnover should rely on problem solving only when situations cannot be adequately addressed using decision making techniques. If problem solving is required to achieve a GIS performance goal, the analyst should be presented useful information pertinent to solving the problem. The first step in problem solving is recognizing that a problem exists. As obvious as this sounds, many current GIS do not provide basic problem recognition aids such as status displays, historical displays and explanatory error messages that alert the user that problem solving skills are required to proceed with processing. Once a user is alerted that problem solving skills are required, the GIS can provide problem solving aids such as checklists or attribute listing of information related to the problem.

Decision making is also a skill which can be developed through training and practice. To minimize the required level of training to operate the GIS, the computer should present all alternatives available to the user and simulate or predict the consequences of selecting each alternative. Decision making can be facilitated through direct manipulation interfaces (Hutchins, Hollan and Norman, 1985) because all alternatives are presented and the user can actually select each of them to view the outcome of the choice. If the selected alternative is not the most desirable, the action can be readily reversed and the original condition restored. When designing system decision aids, the following four human decision making characteristics (from Bailey, 1982, page 144) should be understood and appropriate compensations should be made. (1) Users usually wait longer to decide than needed (over-accumulate information). (2) Users tend not to use all available information. (3) Users tend to be hesitant in revising original opinions, even if new information warrants revision. (4) Users usually consider too few alternatives.

Whether the required approach to achieving a performance goal is via decision making or problem solving, the GIS design should provide ways for automatically executing the user's specified actions. It is a waste of skill development time and could potentially introduce more errors to require the terrain analyst to explicitly carry out numerous steps to achieve one desired action.

2.3 MEMORY AND PERFORMANCE

Both short and long term memory affect human performance. An effective user interface should be designed with an understanding of the limits to human memory.

Many current GIS rely heavily on the user's short term memory. (For instance, remembering a command sequence, a previous plot of a map area, or the list of map names or identifiers). This is a very poor design; it taxes the user's mental energy and does not assist in achieving any performance goal. Army GIS design will seek ways to avoid placing the burden of short term memory on the terrain analyst. If a system must rely on human short term memory, no more than six or seven units of information should be provided to the user (Bailey, 1982). Information to be memorized should be kept as brief as possible. In most cases, on-line historical, status or explanatory displays can assist the analyst in maximizing the use of his or her short term memory.

Long term memory is a prerequisite for skill acquisition. Learning, remembering and forgetting how to use a system are processes associated with long term memory. A GIS can be designed to take advantage of long term memory. It should draw upon the knowledge base of the terrain analyst, using the terminology of this applications domain. Training, on-line instructions and cues should facilitate long term memory. User selection should emphasize recognition and not require recall. The use of techniques such as mnemonics, reductions, elaborations, and imagery cues (e.g. icons) can facilitate memory.

2.4 MOTIVATION AND PERFORMANCE

The Army GIS should consider the motivating factors specific to Army terrain analysts and in general to the process of task accomplishment in a work setting. Motivation is an internal or external condition or state that facilitates user performance. There are a number of theories on what conditions lead to user motivation. By attempting to create these conditions, a system may be a motivating factor in user performance. Porter, Lawler and Hackman (1975) believe users will respond favorably to work when the user feels responsible for a meaningful portion of the work, the user considers the outcome of his or her performance worthwhile, and sufficient feedback is provided for the user to assess his or her performance. Therefore, if designing a GIS subsystem to be operated by one specialized analyst, that subsystem should generate a tangible portion of the work. Studies on motivation may provide data on whether user subsystem specialization is the best means to structure GIS operation.

Recently, studies in computer user interface design look at the utility of direct manipulation interfaces. One strong argument favoring this method of interface is the sense of control and consequent motivation it provides the user. A direct manipulation (DM) system utilizes a highly interactive graphical interface that permits the translation of a user's thought into physical actions required by the system (Hutchins, Hollin and Norman, 1985). DM systems close the motivational gap between performance goals and user actions. So-called "technophobia" can play a detracting influence on system user motivation. DM systems may alleviate user anxiety because the system is easy to learn, provides immediate tangible results, is comprehensible and because actions are easily reversible (Shneiderman, 1982). One danger of DM systems is that they could be designed to oversimplify complex operations and restrict user flexibility in task accomplishment. In any type of interface, an analyst will probably lose motivation quickly if user alternatives are too constrained, or if a person's responsibilities are relegated to button pushing or "idiot" menu selection. Users seem to need an attainable degree of challenge to their work.

2.5 SKILL ACQUISITION

Skills differ from abilities in that skills are acquired behavior while abilities are inherent individual traits. Assuming all potential system users possess the necessary abilities to operate the system, specific skills must be learned to execute the operations. A skilled user is one who has attained a level of proficiency at a specific activity. Skilled performance implies a seemingly automatic execution of cognitive processes that produce rapid and accurate performance (Bailey, 1982). GIS operations require the acquistion of both intellectual and movement control skills. Intellectual skill requires the efficient linking of perception to appropriate action based on problem solving or decision making. Movement control skills are well practiced movements required to accomplish an activity. Examples include driving an automobile, putting paper into a plotter device or moving a digitizing cursor around a map sheet. Another skill germaine to the GIS user is perceptual skill, the ability to key sensory cues to memory. Photointerpretation requires a high degree of perceptual skill.

Army GIS design activities will analyze each process involved in GIS operation and determine which of the three main skill types dominate. Then training requirements for each activity can be developed to address whatever particular type of skill is needed. Training and practice are the essential ingredients of skill acquisition for all types of skills. Proper training to develop the correct skills from the start of system use is essential. Studies indicate that errors made in the first few trials of performing a new activity tend to become ingrained (Bailey, 1982; Kay, 1951 and Von Wright, 1957). "Unlearning" early errors is a major obstacle in achieving performance goals (Kay, 1951).

Another important consideraton in skill acquisition is achieving accuracy standards for performance. Training and practice should strictly enforce accuracy standards before instituting time constraints. Human factors studies (Howell and Kreidler, 1963; Fitts, 1966) indicate accuracy remains fairly constant in skilled performance; however, speed can be increased with practice. Therefore, if speed is emphasized over accuracy initially, the chances of significantly improving performance accuracy is slim.

Army GIS skill acquisition studies will explore training techniques for the terrain analyst. Training is a very costly component of system development, and these costs could compound dramatically given the transiency of the user population. Therefore, on-line instructions, clear comprehensive user guides, and computer based training (CBT) techniques will be explored in favor of classroom based instruction. The advantage to CBT is training delivery can be made when and where it is needed. CBT can be performance activity based; therefore, users can develop and enhance skills required at the time they are needed. CBT can be designed to monitor and record trainee progress, to provide feedback to the developers on the efficiency of the course.

A full array of CBT modules for GIS skill acquisition can be a costly and time consuming development effort. One approach is to phase in CBT for the Army GIS by initially providing it for one or two activities. Until the CBT effort is complete, other design techniques can facilitate skill acquisition, such as clear on-line and manual instructions; on-line help facilities and a focused division of activities (Katz, 1983).

3. PLAN OF IMPLEMENTATION

This paper introduced the psychological theory underlying the need for incorporating human factors considerations in GIS design. Work has begun at ETL on developing requirements for an operational GIS. Total system performance standards are being formulated. GIS operations and functions are under examination on an activity by activity basis.

A prototyping capability will be developed to generate rapid, low cost user interfaces for system performance test and evaluation. Candidate interfaces will be demonstrated with potential system user participation in the laboratory and in a series of field exercises. The development will progress on a workstation by workstation approach. Each workstation will be studied as a series of performance activities with a variety of capabilities. The first workstation examined will be the digitizing station, followed by photogrammetric source extraction workstations (light table mensuration system and analytical stereoplotter) and the analytical and product generation workstation. Results of the studies will include recommendations for revised GIS hardware and software components and the associated performance and cost trade-offs regarding their implementation.

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