Human-Computer Interaction

Fundamentals

Edited by

Andrew Sears
Julie A. Jacko

Human Factors and Ergonomics

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Human-Computer Interaction

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PREFACE

We are pleased to offer access to a select set of chapters from the second edition of *The Human–Computer Interaction Handbook*. Each of the four books in the set comprises select chapters that focus on specific issues including fundamentals which serve as the foundation for human–computer interactions, design issues, issues involved in designing solutions for diverse users, and the development process.

While human–computer interaction (HCI) may have emerged from within computing, significant contributions have come from a variety of fields including industrial engineering, psychology, education, and graphic design. The resulting interdisciplinary research has produced important outcomes including an improved understanding of the relationship between people and technology as well as more effective processes for utilizing this knowledge in the design and development of solutions that can increase productivity, quality of life, and competitiveness. HCI now has a home in every application, environment, and device, and is routinely used as a tool for inclusion. HCI is no longer just an area of specialization within more traditional academic disciplines, but has developed such that both undergraduate and graduate degrees are available that focus explicitly on the subject.

The HCI Handbook provides practitioners, researchers, students, and academicians with access to 67 chapters and nearly 2000 pages covering a vast array of issues that are important to the HCI community. Through four smaller books, readers can access select chapters from the Handbook. The first book, *Human–Computer Interaction: Fundamentals,* comprises 16 chapters that discuss fundamental issues about the technology involved in human–computer interactions as well as the users themselves. Examples include human information processing, motivation, emotion in HCI, sensor-based input solutions, and wearable computing. The second book, *Human–Computer Interaction: Design Issues,* also includes 16 chapters that address a variety of issues involved when designing the interactions between users and computing technologies. Example topics include adaptive interfaces, tangible interfaces, information visualization, designing for the web, and computer-supported cooperative work. The third book, *Human–Computer Interaction: Designing for Diverse Users and Domains,* includes eight chapters that address issues involved in designing solutions for diverse users including children, older adults, and individuals with physical, cognitive, visual, or hearing impairments. Five additional chapters discuss HCI in the context of specific domains including health care, games, and the aerospace industry. The final book, *Human–Computer Interaction: The Development Process,* includes fifteen chapters that address requirements specification, design and development, and testing and evaluation activities. Sample chapters address task analysis, contextual design, personas, scenario-based design, participatory design, and a variety of evaluation techniques including usability testing, inspection-based techniques, and survey design.

Andrew Sears and Julie A. Jacko

March 2008

ABOUT THE EDITORS

Andrew Sears is a Professor of Information Systems and the Chair of the Information Systems Department at UMBC. He is also the director of UMBC's Interactive Systems Research Center. Dr. Sears' research explores issues related to human-centered computing with an emphasis on accessibility. His current projects focus on accessibility, broadly defined, including the needs of individuals with physical disabilities and older users of information technologies as well as mobile computing, speech recognition, and the difficulties information technology users experience as a result of the environment in which they are working or the tasks in which they are engaged. His research projects have been supported by numerous corporations (e.g., IBM Corporation, Intel Corporation, Microsoft Corporation, Motorola), foundations (e.g., the Verizon Foundation), and government agencies (e.g., NASA, the National Institute on Disability and Rehabilitation Research, the National Science Foundation, and the State of Maryland). Dr. Sears is the author or co-author of numerous research publications including journal articles, books, book chapters, and conference proceedings. He is the Founding Co-Editor-in-Chief of the *ACM Transactions on Accessible Computing,* and serves on the editorial boards of the *International Journal of Human–Computer Studies*, the *International Journal of Human–Computer Interaction,* the *International Journal of Mobil Human–Computer Interaction,* and *Universal Access in the Information Society*, and the advisory board of the upcoming *Universal Access Handbook*. He has served on a variety of conference committees including as Conference and Technical Program Co-Chair of the Association for Computing Machinery's Conference on Human Factors in Computing Systems (CHI 2001), Conference Chair of the ACM Conference on Accessible Computing (Assets 2005), and Program Chair for Asset 2004. He is currently Vice Chair of the ACM Special Interest Group on Accessible Computing. He earned his BS in Computer Science from Rensselaer Polytechnic Institute and his Ph.D. in Computer Science with an emphasis on Human–Computer Interaction from the University of Maryland—College Park.

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PERCEPTUAL-MOTOR INTERACTION: SOME IMPLICATIONS FOR HCI

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PERCEPTUAL-MOTOR INTERACTION: A BEHAVIORAL EMPHASIS

Many of us can still remember purchasing our first computers to be used for research purposes. The primary attributes of these new tools were their utilities in solving relatively complex mathematical problems and performing computer-based experiments. However, it was not long after that word processing brought about the demise of the typewriter, and our department secretaries no longer prepared our research manuscripts and reports. It is interesting to us that computers are not so substantively different from other tools such that we should disregard much of what the study of human factors and experimental psychology has contributed to our understanding of human behavior in simple and complex systems. Rather, it is the computer's capacity for displaying, storing, processing, and even controlling information that has led us to the point at which the manner with which we interact with such systems has become a research area in itself.

In our studies of human–computer interaction (HCI), also known as human-machine interaction, and perceptual-motor interaction in general, we have adopted two basic theoretical and analytical frameworks as part of an integrated approach. In the first framework, we view perceptual-motor interaction in the context of an information-processing model. In the second framework, we have used analytical tools that allow detailed investigations of both static and dynamic interactions. Our chapter in the previous edition of this handbook (Chua, Weeks, & Goodman, 2003) reviewed both avenues of research and their implications for HCI with a particular emphasis on our work regarding the translation of perceptual into motor space. Much of our more recent research, however, has explored the broader interplay between the processes of action and attention. Thus, in the present chapter, we turn our focus to aspects of this work that we believe to have considerable implications for those working in HCI.

Human Information Processing and Perceptual-Motor Behavior

The information-processing framework has traditionally provided a major theoretical and empirical platform for many scientists interested in perceptual-motor behavior. The study of perceptual-motor behavior within this framework has inquired into such issues as the information capacity of the motor system (e.g., Fitts, 1954), the attentional demands of movements (e.g., Posner & Keele, 1969), motor memory (e.g., Adams & Dijkstra, 1966), and processes of motor learning (e.g., Adams, 1971). The language of information processing (e.g., Broadbent, 1958) has provided the vehicle for discussions of mental and computational operations of the cognitive and perceptual-motor system (Posner, 1982). Of interest in the study of perceptual-motor behavior is the nature of the cognitive processes that underlie perception and action.

The information-processing approach describes the human as an active processor of information, in terms that are now commonly used to describe complex computing mechanisms. An information-processing analysis describes observed behavior in terms of the encoding of perceptual information, the manner in which internal psychological subsystems utilize the encoded information, and the functional organization of these subsystems. At the heart of the human cognitive system are processes of information transmission, translation, reduction, collation, storage, and retrieval (e.g., Fitts, 1964; Marteniuk, 1976; Stelmach, 1982; Welford, 1968). Consistent with a general model of human information processing (e.g., Fitts & Posner, 1967), three basic processes have been distinguished historically. For our purposes, we refer to these processes as stimulus identification, response selection, and response programming. Briefly, stimulus identification is associated with processes responsible for the perception of information. Response selection pertains to the translation between stimuli and responses and the selection of a response. Response programming is associated with the organization of the final output (see Proctor & Vu, 2003, or the present volume).

A key feature of early models of information processing is the emphasis upon the cognitive activities that precede action (Marteniuk, 1976; Stelmach, 1982). From this perspective, action is viewed only as the end result of a complex chain of information-processing activities (Marteniuk, 1976). Thus, chronometric measures, such as reaction time and movement time, as well as other global outcome measures, are often the predominant dependent measures. However, even a cursory examination of the literature indicates that time to engage a target has been a primary measure of interest. For example, a classic assessment of perceptual-motor behavior in the context of HCI and input devices was conducted by Card, English, and Burr (1978; see also English, Engelhart, & Berman, 1967). Employing measures of error and speed, Card et al. (1978) had subjects complete a cursor positioning task using four different control devices (mouse, joystick, step keys, text keys). The data revealed the now well-known advantage for the mouse. Of interest is that the speed measure was decomposed into "homing" time, the time that it took to engage the control device and initiate cursor movement, and "positioning" time, the time to complete the cursor movement. Although the mouse was actually the poorest device in terms of the homing time measure, the advantage in positioning time produced the faster overall time. That these researchers sought to glean more information from the time measure acknowledges the importance of the movement itself in perceptual-motor interactions such as these.

The fact that various pointing devices depend on hand movement to control cursory movement has led to the emphasis that researchers in HCI have placed on Fitts' law (Fitts, 1954) as a predictive model of time to engage a target. The law predicts pointing (movement) time as a function of the distance to and width of the target—where, in order to maintain a given level of accuracy, movement time must increase as the distance of the movement increases and/or the width of the target decreases. The impact of Fitts' law is most evident by its inclusion in the battery of tests to evaluate computer-pointing devices in ISO 9241-9. We argue that there are a number of important limitations to an exclusive reliance on Fitts' law in this context.

First, although the law predicts movement time, it does this based on distance and target size. Consequently, it does not allow for determining what other factors may influence movement time. Specifically, Fitts' law is often based on a movement to a single target at any given time (although it was originally developed using reciprocal movements between two targets). However, in most HCI and graphical user interface (GUI) contexts, there is an array of potential targets that can be engaged by an operator. As we will discuss later in this chapter, the influence of these distracting nontarget stimuli on both the temporal and physical characteristics of the movements to the imperative target can be significant.

Second, we suggest that the emphasis on Fitts' law has diverted attention from the fact that cognitive processes involving the selection of a potential target from an array are an important, and time consuming, information processing activity that must precede movement to that target. For example, the Hick-Hyman law (Hick, 1952; Hyman, 1953) predicts the decision time required to select a target response from a set of potential responses—where the amount of time required to choose the correct response increases with the number of possible alternative responses. What is important to understand is that the two laws work independently to determine the total time it takes for an operator to acquire the desired location. In one instance, an operator may choose to complete the decision-making and movement components sequentially. Under these conditions, the total time to complete the task will be the sum of the times predicted by the Hick-Hyman and Fitts' laws. Alternatively, an operator may opt to make a general movement that is an approximate average of the possible responses and then select the final target destination while the movement is being completed. Under such conditions, Hoffman and Lim (1997) reported interference between the decision and movement component that was dependent on their respective difficulties (see also Meegan & Tipper, 1998).

Finally, although Fitts' law predicts movement time given a set of movement parameters, it does not actually reveal much about the underlying movement itself. Indeed, considerable research effort has been directed toward revealing the movement processes that give rise to Fitts' law. For example, theoretical models of limb control have been forwarded that propose that Fitts' law emerges as a result of multiple submovements (e.g., Crossman & Goodeve, 1963/1983), or as a function of both initial movement impulse variability and subsequent corrective processes late in the movement (Meyer, Abrams, Kornblum, Wright, & Smith, 1988). These models highlight the importance of conducting detailed examinations of movements themselves as a necessary complement to chronometric explorations.

For these reasons, HCI situations that involve dynamic perceptual-motor interactions may not be best indexed merely by chronometric methods (cf., Card et al., 1978). Indeed, as HCI moves beyond the simple key press interfaces that are characteristic of early systems to include virtual and augmented reality, teleoperation, gestural, and haptic interfaces, among others, the dynamic nature of perceptual-motor interactions are even more evident. Consequently, assessment of the actual movement required to engage such interfaces would be more revealing.

To supplement chronometric explorations of basic perceptual-motor interactions, motor behaviour researchers have also advocated a movement-process approach (Kelso, 1982). The argument is that, in order to understand the nature of movement organization and control, analyses should also encompass the movement itself, and not just the activities preceding it (e.g., Kelso, 1982; 1995; Marteniuk, MacKenzie, & Leavitt, 1988). Thus, investigators have examined the kinematics of movements in attempts to further understand the underlying organization involved (e.g., Brooks, 1974; Chua & Elliott, 1993; Elliott, Carson, Goodman, & Chua, 1991; Kelso, Southard, & Goodman, 1979; MacKenzie, Marteniuk, Dugas, Liske, & Eickmeier, 1987; Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1987). The relevance of this approach will become apparent in later sections.

Translation, Coding, and Mapping

As outlined above, the general model of human information processing (e.g., Fitts & Posner, 1967) distinguishes three basic processes: stimulus identification, response selection, and response programming. While stimulus identification and response programming are functions of stimulus and response properties, respectively, response selection is associated with the translation between stimuli and responses (Welford 1968).

Translation is the seat of the human "interface" between perception and action. Moreover, the effectiveness of translation processes at this interface is influenced to a large extent by the relation between perceptual inputs (e.g., stimuli) and motor outputs (e.g., responses). Since the seminal work of Fitts and colleagues (Fitts & Seeger, 1953; Fitts & Deninger, 1954), it has been repeatedly demonstrated that errors and choice reaction times to stimuli in a spatial array decrease when the stimuli are mapped onto responses in a spatially compatible manner. Fitts and Seeger (1953) referred to this finding as stimulus-response (S-R) compatibility and ascribed it to cognitive codes associated with the spatial locations of elements in the stimulus and response arrays. Presumably, it is the degree of coding and recoding required to map the locations of stimulus and response elements that determine the speed and accuracy of translation and thus response selection (e.g., Wallace, 1971).

The relevance of studies of S-R compatibility to the domain of human factors engineering is paramount. It is now well understood that the design of an optimal human-machine interface in which effective S-R translation facilitates fast and accurate responses is largely determined by the manner in which stimulus and response arrays are arranged and mapped onto each other (e.g., Bayerl, Millen, & Lewis, 1988; Chapanis & Lindenbaum, 1959; Proctor & Van Zandt, 1994). As a user, we experience the recalibrating of perceptual-motor space when we take hold of the mouse and move it in a fairly random pattern when we interact with a computer for the first time. Presumably, what we are doing here is attempting to calibrate our actual movements to the resulting virtual movements of the cursor on the screen. Thus, for optimal efficiency of functioning, it seems imperative that the system is designed to require as little recalibration as possible. Again, our contribution to the previous edition of this handbook reviews our work in the area of stimulus-response translation and the implications of this work for HCI (Chua et al., 2003). We encourage those who are more interested in these issues to read that chapter.

PERCEPTUAL-MOTOR INTERACTION: ATTENTION AND PERFORMANCE

The vast literature on selective attention and its role in the filtering of target from nontarget information (e.g. Cherry, 1953; Treisman, 1964a, 1964b, 1986; Deutsch & Deutch, 1963; Treisman & Gelade, 1980) has no doubt been informative in the resolution of issues in HCI pertaining to stimulus displays and inputs (e.g., the use of color and sound). However, attention should not be thought of as a unitary function, but rather as a set of information processing activities that are important for perceptual, cognitive, and motor skills. Indeed, the evolution of HCI into the realm of augmented reality, teleoperation, gestural interfaces, and other areas that highlight the importance of dynamic perceptual-motor interactions, necessitates a greater consideration of the role of attention in the selection and execution of action. Recent developments in the study of how selective attention mediates perception and action and, in turn, how intended actions influence attentional processes, are poised to make just such a contribution to HCI. We will now turn to a review of these developments and some thoughts on their potential relevance to HCI.

Attention

We are all familiar with the concept of attention on a phenomenological basis. Even our parents, who likely never formally studied cognition, demonstrated their understanding of the essential characteristics of attention when they directed us to pay attention when we were daydreaming or otherwise not doing what was asked. They knew that humans, like computers, have a limited capacity to process information in that we can only receive, interpret, and act upon a fixed amount of information at any given moment. As such, they knew that any additional, nontask processing would disrupt the performance of our goal task, be it homework, cleaning, or listening to their lectures. But what is attention? What does it mean to pay attention? What influences the direction of our attention? The answers to these questions are fundamental to understanding how we interact with our environment. Thus, it is paramount for those who are involved in the design of HCI to consider the characteristics of attention and its interactive relationship with action planning.

Characteristics of Attention

Attention is the collection of processes that allow us to dedicate our limited information processing capacity to the purposeful (cognitive) manipulation of a subset of available information. Stated another way, attention is the process through which information enters into working memory and achieves the level of consciousness. There are three important characteristics of attention: (a) attention is selective and allows only a specific subset of information to enter the limited processing system; (b) the focus of attention can be shifted from one source of information to another; and, (c) attention can be divided such that, within certain limitations, one may selectively attend to more that one source of information at a time. The well-known "cocktail party" phenomenon (Cherry, 1953) effectively demonstrates these characteristics.

Picture yourself at the last busy party or poster session you attended where there was any number of conversations continuing simultaneously. You know from your own experience that you are able to filter out other conversations and selectively attend to the single conversation in which you are primarily engaged. You also know that there are times when your attention is drawn to a secondary conversation that is continuing nearby. These shifts of attention can occur automatically, especially if you hear your name dropped in the second conversation, or voluntarily, especially when your primary conversation is boring. Finally, you know that you are able to divide your attention and follow both conversations simultaneously. However, although you are able to keep track of each discussion simultaneously, you will note that your understanding and contributions to your primary conversation diminish as you dedicate more and more of your attentional resources to the secondary conversation. The diminishing performance in your primary conversation is, of course, an indication that the desired amount of information processing has exceeded your limited capacity.

What does the "cocktail party" phenomenon tell us about designing HCI environments? The obvious implication is that, in order to facilitate the success of the performer, the HCI designer must be concerned about limiting the stress on the individuals' information processing systems by (a) creating interfaces that assist in the selection of the most appropriate information; (b) being knowledgeable about the types of attention shifts and about when (or when not) to use them; and (c) understanding that, when attention must be divided amongst a series of tasks, that each of these tasks should be designed to facilitate automatic performance so as to avoid conflicts in the division of our limited capacity and preserve task performance. While these suggestions seem like statements of the obvious, the remainder of the chapter will delve deeper into these general characteristics and highlight situations in which some aspects of design might not be as intuitive as it seems. Because vision is the dominant modality of information transfer in HCI, we will concentrate our discussion on visual selective attention. It should be noted, however, that there is a growing literature on cross-modal influences on attention, especially visual-auditory system interactions (e.g., Spence, Lloyd, McGlone, Nichols, & Driver, 2000), that will be relevant in the near future.

Shifts and Coordinate Systems of Attention

Structural analyses of the retinal (photo sensitive) surface of the eye has revealed two distinct receiving areas—the fovea and the perifoveal (peripheral) areas. The fovea is a relatively small area (about two to three degrees of visual angle) near the center of the retina, which has the highest concentration of color-sensitive cone cells. It is this high concentration of color-sensitive cells that provides the rich, detailed information that we typically use to identify objects. There are several important consequences of this structural and functional arrangement. First, because of the foveas' pivotal role in object identification and the importance of object identification for the planning of