MACROCOGNITION: LINKING COGNITIVE PSYCHOLOGY AND COGNITIVE ERGONOMICS

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ABSTRACT

Interest in cognitive ergonomics is a healthy sign that designers and developers appreciate the importance of cognitive processes. The purpose of this paper is to try to strengthen the connections between researchers studying cognitive processes, and those working in the field of cognitive ergonomics. We believe that each field has a great deal to offer the other. Cognitive ergonomists can benefit from a deeper awareness of investigations into macrocognitive processes such as attention, memory, and reasoning. Further, we can all learn more about basic cognitive processes through the field projects performed in cognitive ergonomics.

INTRODUCTION

Many practitioners working in the field of cognitive ergonomics ignore the research of cognitive psychologists. Articles and books on topics related to cognitive ergonomics rarely cite publications from journals such as *Cognitive Psychology, Cognition, and Memory and Cognition.* We suspect that few of the practitioners in cognitive ergonomics subscribe to or regularly read these journals, attend conferences on cognitive psychology, or actively follow developments in the field. Although the Cognitive Science Society holds annual meetings to bridge the gaps between a number of disciplines, including cognitive psychology and cognitive ergonomics, the gaps appear to be growing rather than diminishing.

One reason for this disconnect is that much of the basic research has been at the microcognitive level, with a time scale of tenths and hundredths of a second. Practitioners have not been convinced of the relevance of microcognitive research to their needs. They see most problems in the domain as extending over time and having considerable complexity. They need to understand the phenomena, rather than reductionist studies of disconnected processes.

A related problem exists in the cognitive psychology community, which is not concerned with having an impact and usually does not try to appreciate the needs of the ergonomics community. Cognitive psychology researchers need either to explain the relevance of their research or expand their focus to include the topics that designers are trying to understand. The research itself could benefit by taking a greater interest in the everyday phenomena that need to be explained.

We offer two suggestions for improving the linkages. The first is to identify areas of "macrocognition" where the interests of both groups converge the most strongly. We propose the term "macrocognition" to designate the more complex cognitive functions. These functions would include decision-making, situation awareness, planning, problem detection, option generation, mental simulation, attention management, uncertainty management, expertise, and so forth. This is in contrast to more microcognitive topics, which include studies in psycholinguistics of the time course of word activation (Simpson, 1994) and models of speech errors in language production (Dell, 1986).

The concept of macrocognition provides a framework for studying and understanding cognitive processes as they directly affect performance of natural tasks. The time scale of macrocognition is seconds, minutes, hours, or longer, rather than tenths and hundredths of a second. Macrocognition can be a useful complement to microcognition. Whereas research at the level of microcognition may attempt to provide a reductionist account of phenomena, macrocognition could maintain a focus on the phenomena themselves.

Macrocognition might require different methods than microcognition. The fields of situated cognition and naturalistic decision-making would seem to be examples of macrocognition.

The second suggestion is to assert that even studies of microcognition can be relevant for cognitive ergonomics. In the remainder of this paper, we describe four areas where research on microcognition can be useful to the cognitive ergonomist. We examine phenomena such as categorization, reasoning, and language processing. We examine four questions that face the cognitive ergonomist, and show how findings from cognitive psychology can be applied. These four questions are: (a) how to design more useful menus in human-computer interfaces, (b) how to design interfaces for user populations in different cultures, (c) how to support both intuitive and analytical decisions, and (d) how to design better database structures.

These are all clearly applied questions, relevant to the field of cognitive ergonomics. What can cognitive psychologists contribute to cognitive ergonomics? What can the practice of cognitive ergonomics contribute to cognitive psychology?

HOW TO DESIGN MORE USEFUL MENUS IN HUMAN-COMPUTER INTERFACES

The aspect of cognitive psychology that we wish to apply here is research on categorization. Many tasks in cognitive ergonomics depend on how people categorize their worlds. To build a human-computer interface, we need to know which functions to classify together in a menu. Cognitive psychology can tell us how people simplify and organize raw data and how people develop task-relevant categories. Cognitive psychology has explanations for how context affects categorization, and practitioners can appreciate the value of understanding contextual effects.

Menu-driven systems were created because of the difficulty of interacting with the original command-based procedures. People had trouble remembering the vast numbers of commands required unless they used them daily, and fluency was hard to develop. To ease memory constraints, and to impose a structure on the program command options, menu-driven systems were developed. These quickly became the norm for many applications because of their success in presenting options in an organized way. However, as the systems to which they were grafted have become more complex, menus have struggled to keep up. One problem is deciding how to group the multitude of different commands into a reasonable structure. Menus end up having some groups for the functions one can do to the document and other groups for structural changes in the document. Still other menus give options about physical and aesthetic characteristics. The fact that menus use different types of categories can lead to confusion.

Research in cognitive psychology explores the distinction between taxonomic and thematic categories (Markman, 1991). Taxonomic categories are connected by a common structural feature. Thus, a "dog" is linked to other mammals. A thematic category is based on functional features. Thus, a "dog" is linked to items such as "bones," and "mechanical rabbit." Cognitive ergonomists must know when to use taxonomic and thematic categories in designing interfaces. In the Microsoft™ Word program, we find some taxonomic menu items such as types of fonts (e.g., Courier, Times New Roman, Palatino). Other menu items are thematic: actions we can take on the whole file (e.g., open a new file, print a file), and editing actions we can perform within a file (e.g., cutting and pasting). Cutting and pasting are functionally related; they do not form a clear taxonomic category. Finally, help menus combine both taxonomic and thematic organizations, and are notoriously unhelpful.

Not only does research on categories inform the interface designer about the optimal grouping mechanism, but the application to cognitive ergonomics also sends the researcher back to the lab with questions. What happens when a category contains both taxonomic and thematic information? Is a mixed category more difficult to understand than a pure one? Does the blend of two types of information, as in the help menu, hurt comprehension and ease of use?

One of the hypotheses in cognitive psychology was that children might use thematic (functional) categories, but adults in industrial societies did not. Recently, Lin & Murphy (in press) showed that adults could use thematic categories. However, common experience in using word processing programs could have provided evidence of the utility of thematic categories in menus. This illustrates how an interest in cognitive processes can be divorced from direct experience, and how cognitive ergonomics can help inform research in microcognition.

The study of categories appears to be linked to macrocognitive phenomena such as information seeking and attention management. The types of categories a person uses can affect the way information seeking is carried out. Another linkage is between categorization and situation awareness, in that the categories used to describe a situation also determine the way meaning is assigned. Categorization is further linked to decision making—skilled decision makers may rely on functional (thematic) categories as much as structural (taxonomic) categories.

HOW TO DESIGN INTERFACES FOR USER POPULATIONS IN DIFFERENT CULTURES

Most work in interface design has assumed that cognitive processes are universal. This assumption is reasonable in the microcognitive domain. Reaction times, for example, appear to be similar over national groups by age. Macrocognition, in contrast, has considerable variability attributable to national cultural differences. As interface applications gain use around the world, designers face new challenges. Researchers have shown cognitive differences between cultures with regard to tolerance for uncertainty, hypothetical reasoning, and so forth. We will use one example to illustrate the importance of these differences—the tolerance of uncertainty.

Uncertainty avoidance is the extent to which uncertainty is perceived as a stressful event and as requiring action. (Dorfman & Howell, 1988; Hofstede, 1980). People who are high on uncertainty avoidance assess a state of uncertainty as riskier than those who are low.

Smart cars are now being designed to make driving safer. They are designed to provide alerting information at the most useful time. But what time is this? If the information comes too late, that will create problems for the risk averse driver who performs best with early warning information. Providing a great deal of information improves their performance. Contrast this with the driver who shows little uncertainty avoidance. If the information comes too early there will be higher levels of false alarms. The driver may start to ignore danger messages. Many of us have been in the cabs of drivers who ignore danger messages.

Individuals within a culture will vary on their degree of risk and uncertainty tolerance. The differences between cultures on these factors, however, may be much larger than the variability within a culture (Hofstede, 1980). The setting of time parameters, therefore, demands an understanding of the range of national variations in uncertainty tolerance. Designers need to know this range so that vehicles available in different markets can accommodate the needs of the greatest numbers of potential drivers. Currently, the timing is geared to the typical tolerance for uncertainty displayed by Western drivers. Cognitive psychologists can help the cognitive ergonomics community, by providing guidance for more appropriate timing parameters.

In addition, cognitive engineers working in multinational settings can be a valuable resource for identifying cognitive dimensions that separate national groups. When new medical equipment, for example, is rejected or is difficult to sell in other national markets, it may be pointing to cognitive barriers to adaptation. Cognitive psychologists, who frequently confine their work to the microcognitive level, would not typically encounter these problems in their laboratories. Cognitive ergonomists who work with users are in a position to identify fruitful departures for cognitive research.

Differences in uncertainty avoidance are related to a number of macrocognitive processes. These include problem detection and uncertainty management. They will also affect situation awareness; a person's tolerance for uncertainty will likely be a strong influence on the perception of a situation. Finally, uncertainty tolerance should affect planning and replanning: the types of options generated, and the evaluation of consequences of those options, will be shaped by the person's comfort with uncertainty.

HOW TO SUPPORT BOTH INTUITIVE AND ANALYTICAL DECISIONS

We need to learn how to apply new technologies to design effective decision support systems. One issue in designing a decision support system is what types of support to provide. One approach is to support recognitional and pattern-matching processes, whereas another approach is to support analytical decision strategies.

Most system developers realize that this is not a forced choice, and that there are conditions under which you need to support the recognition of patterns, and other conditions where you want to assist with analyses of data. The questions now deal with defining these boundary conditions, and with discovering how to permit transitions between recognitional and analytical modes.

Cognitive researchers have already been working on these issues. Sloman (1996) discussed two forms of reasoning, associative and rule-based reasoning. These categories conform fairly well to the recognitional/analytical distinction. He described how people use both types of reasoning. Some tasks only require associative reasoning, and others require rule-based reasoning, but there are many tasks that require both types of reasoning. Sloman explained how both the associative and rule-based reasoning systems could be operating in parallel, and if the two reasoning systems generate different solutions, this can result in apparent inconsistencies.

This debate is being conducted outside of the attentional field of cognitive ergonomics. The work of Sloman can be useful in analyses of how to support the decision making of users.

Research on different reasoning mechanisms will obviously have implications for our macrocognitive understanding of decision-making and decision support systems. Research on reasoning mechanisms could also deepen our understanding of macrocognitive processes such as situation awareness (particularly the assignment of meaning to a situation), mental simulation, and problem detection. Thus, an associative reasoning system might provide early alarms that do not correspond to a rule-based analysis.

HOW TO DESIGN BETTER DATABASE STRUCTURES

The aspect of cognitive psychology that we wish to apply here is research on language processing. Language is one of the most widely used complex systems. Language is a tool, and the study of language can help us understand how tools are used and modified.

One informative language phenomenon is polysemy. With homonyms, different meanings are called by the same phonetic unit (bank as river's edge or financial institution). In contrast, with polysemy, one word, such as paper, develops multiple senses that are related. The material meaning of paper ("he needs some paper to draw on") is related to the news source meaning ("I read the paper every morning"). Research in microcognition demonstrates that while people are capable of generating a new sense as needed (Nunberg, 1979), the usual case is for frequent senses to be stored separately (Klein & Murphy, submitted).

Further, these senses evolve with time and experience. Although dictionary compilers would prefer that word meanings remain static, they do not do so. They change for individuals, and for groups.

The design of databases, however, appears to run counter to the research on polysemy. Part of the flexibility of the tool of language is that as people become more skilled, they are able to extend and adapt words, rather than being restricted to a fixed set of meanings. Part of the inflexibility of databases is that they often serve to lock people into a fixed set of dimensions and categories, and they discourage the type of growth and learning characteristic of tool users. We would expect that people should want to modify the database structures as they learn more about a domain, and as their understanding and mental models mature. Users typically prepare their databases when they are just starting out in an area, so we can expect that these structures will quickly be outgrown. The challenge to designers is to understand how people extend and adapt their tools, and to provide design concepts to support these types of cognitive development. Research on polysemy may offer some clues about how this could be accomplished.

Another connection between ergonomics and language is the design of multi-function interfaces. Polysemy is the mapping of several meanings to the same word, just as with a computer several functions can be assigned to the same key (as in a multi-function interface). In both cases, context is used to disambiguate the meaning. This allows for economy, because fewer entities are required, but it creates a condition for confusion and errors.

Yet, this confusion is rarely a problem where the senses are related. People have a wonderful ability to deal flexibly with their environment. Not only can people easily understand polysemous words, which can be ambiguous, but they are constantly pushing these words to do more. Senses are created when needed, and people can easily understand and adapt each new transformation.

While complex systems generally lack this flexibility and creativity, remembering that humans excel at disambiguation can allow system designers to let the different components (humans and machines) each do what they are best at.

Research on polysemy may have links to macrocognitive processes such as the development of expertise in a domain. Polysemy is a means for studying the natural evolution of functionality. As new needs arise, people do not invent new words. Typically, they adapt and reshape existing words. This perspective sees expertise as a form of reshaping in addition to inventing.

This perspective also raises deeper questions for the field of cognitive ergonomics. Too often, the field posits a front-end analysis of a mission to try to determine *a priori* how a task will be performed. However, in many cases, systems are designed with one mission in mind, but are used in very different ways than originally intended. AWACS is a good example. Designed to handle slow moving, non-agile Soviet bombers, AWACS now is often used to track enemy fighters. It is important that cognitive ergonomics develop tools to support flexibility and evolution of functionality.

CONCLUSIONS

This review of research in cognitive psychology in just four areas illustrates the value added for cognitive ergonomics. Hopefully, as interest in cognitive ergonomics grows, designers, practitioners, and planners will tap the scientific roots of their applications.

If research in microcognition can be relevant to cognitive ergonomics, work in macrocognition should be even more applicable. Findings from cognitive psychology should open up applications and opportunities in cognitive ergonomics. Similarly, the issues faced by practitioners, such as how to help people build and communicate situation awareness, could raise useful questions for the basic research community.

There is another reason to encourage the linkage between cognitive ergonomics and cognitive engineering. If this linkage is not strengthened, then the term "cognitive" in cognitive engineering may lose it's meaning, and the interest may turn out to be a fad, with no substance. It will be a term like "user friendly" that quickly erodes into the status of a cliché. If that should occur, then all of us will lose, cognitive researchers and cognitive ergonomists and also the users of complex systems.

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Proceedings

5th International Conference on Human Interaction with Complex Systems

April 30 – May 2, 2000
Urbana, Illinois

Edited by:

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