Cognitive Factors in Design: Basic Phenomena in Human Memory and Problem Solving

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ABSTRACT

This tutorial provides a "hands-on" (actually, "minds-on") exploration of several basic processes and phenomena of human memory, and problem solving. The emphasis is on developing both intuitive and formal knowledge which can serve as background knowledge which will be useful in interpreting design guidelines and in making educated design judgments when design guidelines fail, conflict, or are nonexistent. The demonstrations used emphasize basic general phenomena with which any theory of memory or problem solving must deal. In addition, the tutorial suggests some of the implications of these phenomena for designing interactive computing systems.

KEYWORDS: Memory, Problem Solving, Design, Models of the User

INTRODUCTION AND CAVEATS

The emphasis in this tutorial is on demonstrations and exercises which highlight some of the quite remarkable things human beings do in interacting with, in learning about, and in making sense out of the world around them. These things often seem to be quite ordinary simply because we do them regularly, often without deliberation. Nonetheless, some of them are quite complex and not well understood. Many of the demonstrations replicate phenomena studied under controlled laboratory conditions and some are drawn directly from research studies.

Since this tutorial emphasizes the development of an intuitive feel for the material, it is important to recognize that an intuitive understanding must be informed and validated by research results. Ever since its founding, the findings of Experimental Psychology have taught us not to trust unsupported personal hunches and intuitions about the reasons for human behavior. There are a variety of ways in which ordinary day-to-day intuitions about behavior, both our own and that of others, can lead one astray (some are illustrated in the tutorial). Most of the demonstrations used in this tutorial are designed to

replicate phenomena which have been studied or validated under controlled laboratory conditions. In fact, several of the demonstrations are drawn directly from research studies, although some procedural license is taken for purposes of demonstration.

MEMORY

In one model of memory, short-term memory (STM) is described (e.g., Solso, 1994) as having a limited storage capacity (seven plus or minus two chunks) for a relatively brief duration (estimates range from 12 to 30 seconds without rehearsal). Information can be maintained in STM for longer periods of time with maintenance rehearsal (MR), although this simple repetition of material does not appear to be very efficient at transferring information into Long Term Memory (LTM). Rather, elaborative rehearsal (ER) appears to be the most effective set of processes for the transfer of information into long-term storage. Although the information in STM is usually thought to be represented by one of a relatively limited number of codes, there are several reasons to believe that any organizational structure in LTM is accessible as a basis for forming the chunks that are held in STM.

LTM has a large capacity for storage of information for long periods of time. There is, however, no easy or obvious way to determine the limits of how much can be stored, or for how long it can be stored. Several types of information are represented in LTM, including such things as facts and events, motor and perceptual skills, knowledge of physical laws and systems of mathematics, a spatial model of the world around us, attitudes and beliefs about oneself and others, etc. This information is more or less well organized in a variety of ways and varies in its accessibility as a function of several factors. The factors determining accessibility of the information in LTM include such things as the conditions which existed at the time the information was stored, the recency of its last use, its degree of inter-relationship with other knowledge, its degree of uniqueness relative to other information, etc. Most discussions of failure to recall information from LTM focus on explanations such as interference, the absence or inappropriateness of retrieval cues, or some type of organic dysfunction such as brain damage.

An alternative model of human memory holds that there is no need to postulate a STM. Rather, there is a working memory which is part of the larger memory system and not a separate memory. Different degrees of persistence of information in memory are thought to be a function of the elaborateness or the depth to which information has been processed. The greater the degree of processing, the longer the retention period. In this model, chunks are organizational units in LTM and the capacity limitation is on how much information can be actively scanned or held in working memory at any time.

While the bulk of the evidence supports the model which includes working memory (Anderson, 1994), there are basic phenomena with which any theory of memory must deal. For example, regardless of whether one thinks of the seven plus or minus two capacity limitation as the result of a limited capacity memory or as a result of a limit on the amount of information which can be activated and maintained in an active state in working memory at any given time, it is clear that there is a capacity limitation. Similarly, regardless of whether one thinks that memory rehearsal processes have different degrees of depth and elaboration or that there are two different kinds of rehearsal processes, each associated with a different memory store, it is clear that elaborative rehearsal is more effective than maintenance rehearsal in insuring that the information will be accessible in memory for a long period of time.

PROBLEM SOLVING

A major turning point in the literature on problem solving occurred with the work of Newell and Simon (1972). In their view, a problem can be analyzed by means of a "problem space" representing various states of knowledge of the problem solver, a series of transformations between states, and a set of operators which produce those transformations. A problem exists when we have a gap between an initial state and a goal state. The means of solving the problem involves applying the appropriate set of operators required to complete a series of state transformations that will eliminate the gap. These transformations must be accomplished without violating any of the conditions on the operators.

As a result of repeated experience with problems, solvers build up an organized body of knowledge or information about the properties of a particular type of problem and the operations or steps required to solve it. This organized body of information is usually referred to as a problem solving schema (e.g., Norman, 1982). Humans develop a wide variety of familiar problem schemas (Hayes, 1981), and the typical individual has built up a wide stock of such schemas which come into play in solving problems with which one has prior experience. Some schemas are so familiar they are activated almost automatically and without much thought.

Typically, the effect of problem solving schemas is to help provide reasonably efficient methods of solving frequently encountered kinds of problems. Sometimes, however, a schema can interfere with the problem solving process. Since it influences the problem solver's early analysis of the problem and determines which schema, or schemas, will be brought to bear in solving a particular problem, the way in which that problem is represented can make a vital difference in how easily the problem can be solved. When a problem is not solved as easily as expected, it is often quite fruitful to look to the adequacy of the representation of the problem, and to give thought to somehow modifying or changing that representation.

SOME IMPLICATIONS FOR HUMAN-COMPUTER INTERACTION DESIGN

In considering the nature of human memory it is clear that designers need to take account of the fact that there are a limited number of "chunks" of information with which a user can actively cope at any given time. While the size of those chunks can be affected by the development of

additional new knowledge structures, that growth of knowledge requires that the user be actively engaged in elaborating and assimilating that knowledge. In addition the demands upon human learning and memory can be reduced by providing appropriate mnemonic cues in the interface and the flow of interaction. In considering the nature of human problem solving it is clear that designers need to take account of the fact that users will bring to bear established problem solving strategies which are developed from having solved problems encountered frequently in the past. While these established strategies can be used to facilitate usage they can also create process blockages which may only be solved by changing the way the problems of interaction are presented to the user or by creating a working environment in which the user has the flexibility to redefine, reconceptualize or re-represent the tasks or problems which the software is being used to solve.

Among the more general implications of the phenomena described above for human-computer interaction design, two stand out. The first, derived from consideration of the nature of long term memory and the processes governing storage and retrieval of information, is that humans interacting with computers can and do use existing memories and memory structures to assign an interpretation to a wide variety of things, regardless of whether that meaning was intended by the designers. The

second major implication, derived from consideration of the nature of the way people solve problems is that, people, "...do not do what designers want them to do; instead they tend to get actively involved and to think and plan and solve problems (Carroll & Mack, 1985)."

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