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ABSTRACT

In man-computer communication, the computer responds only as it is programed to respond. A human's response is more complicated because it depends on the "pre-programed" ways that humans process information. The three functions a man performs on received information are conservation (in which messages are retained whole), reduction (in which messages are condensed), and creation. Each of these functions subsumes several more specific functions labeled transforms. These transforms or sub-functions are described and quantitative measures assigned to them where possible. The area of information conservation includes discussions of short-term memory, veridical memory span, chunking, and proactive inhibition. Transforms relating to reduction are filtering, condensation, and contingent. Information creation involves a one to many mapping of stimuli resulting in output being greater than input. The purpose of the taxonomy and of further research in human information processing is to provide a framework for predicting the speed and efficiency of the performance of various tasks. Such a framework could benefit both the designer of computer software by making possible the generalization of task requirements and the researcher in defining and delineating domains to which his data is applicable. (JK/MT)

HUMAN INFORMATION PROCESSING IN MAN-COMPUTER SYSTEMS

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PREFACE

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INTRODUCTION

Through the evolution of computer technology a sophisticated entity has emerged which is no longer simply an implement for man to use as he would a power shovel. Today this sophisticated entity is very similar in important ways to a man, and thus may be viewed as a member of a communication dyad. The resultant communication system is an appropriate subject for someone with a background in the study of human communication. However, there remains a significant difference between man and the real-time, on-line computer. The computer response is precisely predictable from its input--it responds only as it is programmed to respond. In light of this difference and an interest in human communication, the focus of this paper is on the responses of the human to generalized kinds of inputs from the computer. These responses are considered dependent upon the "pre-programmed" ways in which the human processes information.

A review of literature primarily within the rubric "man-communication" yielded a great deal of material most aptly described as "human factors" engineering which does not deal with human information processing. The overriding concern in this area is with the design of equipment at the interface in an attempt to optimize man's sensory reception and motor control, rather than the processing that goes on beyond the interface. The extensive documentation, including human factors handbooks, is adequately applied to this aspect of man-computer interaction and therefore is not germane to this discussion.

In a communication system awareness of the nature of the message, not merely the mechanisms of transmission and receception, is

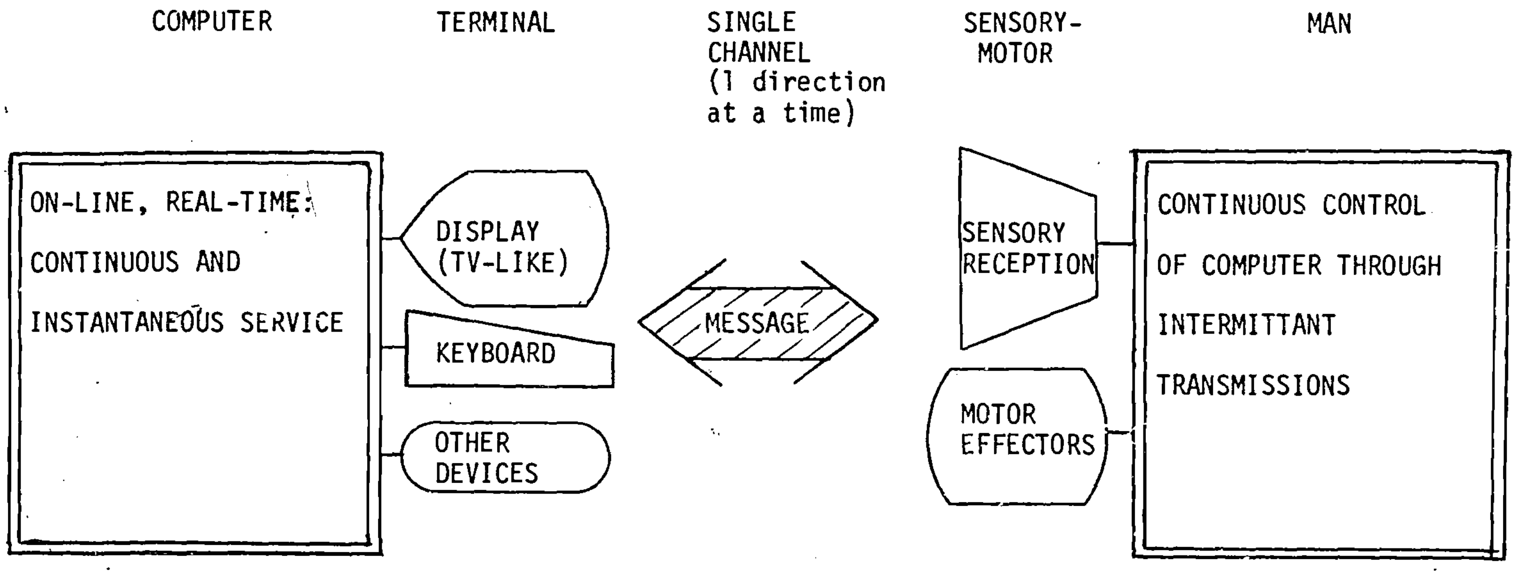

Figure 1. MAN-COMPUTER DYAD. This represents interactive or conversational man-computer communication, analogous to a dialogue between two men.

necessary. A pictorial model of message flow depicts a single channel, receiver controlled communication system with man as a continuous controller (see Figure 1). The "black boxes" receiving and transmitting messages are the man and the computer respectively. If we know the program, we can also know what is occurring in the computer box, and subsequently what can be transmitted from the computer to the man as well as the possible inputs to the computer. Such is not the case with the human, and although psychology tells us a lot about man's functioning, he remains a "black box" in this specific context. We do not know a great deal about the compatibility of the potential computer inputs and outputs with man's information processing capabilities. Unfortunately, man's wide tolerance for ambiguity and uncertainity in perceiving inputs (a virtue not shared by computers) has become a liability here. Instead of rejecting low compatability inputs as he would in most contexts, he still must perform but this performance can be significantly reduced. This reduction in performance is the danger of treating man like a "black box."

My approach, that is at least a beginning, is to characterize man as an information processor, and describe the functions performed by him in much the same way as system analysis describes the computer's (software) functional operations. This view brings to bear the research examining human information processing, from which a taxonomy of functional tasks, their characteristics, and parameters can be compiled. This compilation and related experimentation provides the basis for conclusions about the conditions under which each kind of task is optimized which are the practical consequences of this investigation.

HUMAN INFORMATION PROCESSING TASKS

The functions performed by man on received information may be divided neatly into three categories of tasks, information conservation, reduction, and creation, which subsume more specific functions labelled transforms. Information conservation requires that the subjects preserve all of the stimulus information in the output. This area includes discussion of short term memory, veridical memory span, chunking, proactive inhibition, and measures used in testing information conservation. Information reduction occurs when the input is reflected in the output in a reduced form, eg. mathematical addition. Transforms discussed relating to reduction are filtering, condensation, and contingent. Information creation involves a one to many mapping of stimuli resulting in the output being greater than the input.

The importance of this functional "taxonomy' has become increasingly apparent. Both the research scientist and the system software designer working with man-computer systems, have discovered that communication problems, where man is a controller and decision maker, are quantitative and difficult to state (Carbonell, 1967).

A taxonomy of human information processing tasks makes possible such quantitative statements and also provides a framework from which predictions involving processing time and efficiency of performance of various tasks could be made. For the software designer such a classification would make possible the generalization of task requirements based on scientific data. For the researcher it can be an invaluable aid to the process of defining and delineating domains to which his data is applicable.

INFORMATION CONSERVATION

An information conservation task requires that the subject preserve all of the stimulus information in the output (i.e. a one to one mapping of stimuli to responses). Any reduction of information in the output is regarded as error. This is typified by the standard choice reaction time situation and rote learning. Tasks of this type may differ widely in the information load placed on short-term memory, and the requirements for speed and accuracy in the output responses. These differences will be examined quantitatively, and their influence on performance discussed.

FACTORS AFFECTING MEMORY SPAN

Information load in short-term memory has long been known to be a major limiting factor in information processing tasks, especially for information conservation. Man can store and correctly recall only so many bits of information. This limit is what we refer to as man's "memory span". The concept of memory span should include a statistical definition. Melton argues for such a definition due to "intraindividual variability" in performance and the "variability of messages of the same length as perceived by the individual subject."

He establishes that memory span is equal to the number of arbitrarily arranged elements that can be recalled in correct order 50% of the time after a single presentation. The presentation of these elements must be of sufficient duration to allow complete perception of each element. The short-term memory span of man has been shown to be approximately 8 random digits, 7 random consonanats, and 5.5 unrelated, high-frequency words (4 letter nouns), under experimental conditions.

In situations in which man is acting as a transmission link in a system where the overall tolerance for error is low (i.e. Perror=.001), his actual or real-life capacity for information storage in short-term memory (Veridical Memory Span) is lower than his memory span (Melton, 1967). The Veridical Memory Span (VMS) for random digits and letters is 6.0 and 4.3 respectively for sequential auditory presentation, and 6.0 and 5.1 with simultaneous visual presentation. Melton (1967) has shown that the VMS for a string of unrelated 4-letter nouns, when presented visually, was slightly greater than 3.0. Consideration of this limit in programming a display would result in a presentation of no more than 4 mnemonics at a time when the screen is to be erased for the user's next action step.

It was thought that the important factor in determining VMS and memory load was the number of interrelated bits of information pertaining to a subject area in a message. Miller (1956) showed in a classic paper that the number of integrated units to be remembered are not as important as the number of "chunks". A chunk is defined as the element encoded in memory as a single unit, such as high-frequency nouns. For example, when the three letters C-A-T are presented to a subject, they are more likely to be encoded in memory as a single unit (chunk), CAT, rather than as three individual units, C-A-T. Such a chunking process has the overall effect of reducing memory load by decreasing the number of units to be stored and recalled from memory (from 3 to 1 in the above example). The utility of such a process is that by building larger and larger chunks, the bits of information per chunk will increase, but the number of units-to-be-remembered remains the same or decreases. Therefore, by rearranging or using those elements which can be easily encoded into chunks, man's capability to store and recall information can be made more efficient.

The ease of encoding the message-to-be-remembered into chunks is dependent upon the interaction between intrastimulus interference and the subject's perceptual and conceptual framework (his set of previous experiences). Intrastimulus interference results from the similar identity of two elements at two positions in the message as well as from acoustic and semantic similarity. Intrastimulus interference from letter to letter is greater than from digit to letter, and it appears that one way of decreasing this interference is by mixing letters and digits. However, the mixing of letters and digits are encountered at such a low frequency in computer presentations as to be incompatabale with prior habits (with a few exceptions, such as A-1 and K-9). Similarly, a sequence of 3 letters (CCC) is less likely to be remembered than a high-frequency, non-word trigram (DAF), but more likely to be remembered than a low frequency, non-word trigram (DGM) (Melton, 1967). This will aid in the selection of mnemonics (such as commands) but more important is the ease with which the presentation to be recalled can be encoded into chunks. It has also been found that this facilitates long term memory as well.

Another factor which is important in the successful storage and recall of messages from memory is proactive interference, the inability to recall a message due to prior messages with similar semantic, acoustic, and structural characteristics, and similar length. One effect of proactive interference is the overt intrusion of words from previous messages into the presently-to-be-remembered message (Melton, 1967). Such interference can be eliminated or reduced by separating the elements in the messages with rest intervals, changing the semantic categories of the words in elements, chunking and/or changing the sensory modality input of the message. For example, Loess (1967) did a study where a shift from one taxonomic class to another afforded a 73% release from proactive interference. This is particularly appropriate when textual data is presented on-line for subsequent user decisions.

TRANSFORMATION AND MEMORY LOAD

Memory load can be reduced in many tasks by various encoding transforms such as storing the information in coded form, chunking, (as discussed above), and changing the recall order of a stimulus list. For example, Miller (1956) had one subject who was able to increase retention from 12 to 40 digits by recoding binary digits into octal digits. Posner (1964) was able to increase the performance of his subjects in recalling a list of 8 digits by having them recall the last four digits first, followed by the first four.

The effect of such transformations on memory may vary greatly from individual to individual due to a variety of individual differences, but some general statements can be made. An increase in the similarity of items to be stored with those in memory decreases performance due to proactive interference. The ability to select relevant characteristics from the stimulus items is reduced. One way of lessening this interference is to reorder stimuli only when the stimuli are presented at a rate slow enough to allow complete recoding of the list. In this way, the reordering transform does not interfere with the retention of items already in store.

In general, a transform which is efficient in reducing storage load, also causes systematic effects upon the material already in store, and imposes limitations upon the rate at which a subject can perform an overall task.

INFORMATION MEASURES

Variance

When measuring or discussing the effect of a transform on reducing memory load, the concept of the "amount of information" in the system was used, and the greater the amount of information in the output, the more efficient was the conservation task. However, the concept of variance (change) has replaced the concept of the amount of information in a communication system. Variance is more useful since it shows the relationship between input and output, although the concepts are not independent. When there is increasing variance in the system there is a decrease in knowing what the human output will be. Therefore, by observing the output, there is an increase in the total amount of information gained. When there is very little variance, the output is generally known, and very little information is gained by observing the output (i.e. a decrease in the amount of information). Anything that increases the variance also increases the amount of information in the system (Miller, 1956).

In a communication system, a comparison can be made between input and output with the output dependent upon the input (or correlated with it). If this correlation is measured, the amount of output variance, not due to random fluctuations or "noise", can be found. In an information conservation task the input variance is the amount of information in the stimulus, while the output variance is the information contained in the response (information refers to what was not previously known). The correlation between response and stimulus information is the response correlation or the transmitted information (Miller, 1956).

Processing Time

The time required to respond to a stimulus is linearly related to the transmitted information in conservation tasks. Hick (1952) called the time to respond to a stimulus the reaction time (Rt) and simply stated it in the equation Rt=a+bHt. Ht is the amount of information processed, and a and b are the experimentally determined constants dependent on the nature of the task such as differences in stumuli and response codes (Pew, 1965a). While Rt is directly related to the transmitted information, other factors may effect the overall time to respond to a stimulus.

STIMULUS-RESPONSE COMPATABILITY

The human factors psychologists have shown that if the input codes are less than perfectly discriminable due to acoustic confusibility, or to the inability to distinctly see the visual stimuli because of blurring, the rate of reaction time decreases. A conflict between stimuli and the material in store may also be involved. However, compatibility between the input and output codes is a major factor in decreasing or increasing processing time. If a response code is highly compatible with a stimulus code, such as touching an appropriate light when lit, the amount of time required in processing the stimulus and then deciding which response to use is minimized (i.e. a decrease in reaction time). The closer a response code is to stimulus code, the faster the reaction time, the less the uncertainty, and the greater the confidence level. Practice decreases the reaction time, but more so if the task was initially an incompatible one, such as pressing a series of keys to a visual display. This renders questionable the common practice of using only the computer display for presentations. If the computer input keys available for selection were lit, a significant increase in performance appears possible.

ATTENTION SET

The orientation, or attention set of the subject to the task is important, particularly when the user is cued for speed or accuracy. The expectation concerning which input signal will occur, when the signal will occur, and the relative importance of speed versus accuracy, will affect reaction time, per cent of error, and the decision strategy to be used. Fitts (1967) reported that as the relative importance of speed versus accuracy changed, there was a corresponding change in reaction time and in the number of right versus wrong responses. When the subject was told of changes in payoff, eg. from a maximum bonus for accuracy to maximum bonus for speed, performance changed to measure favorably with the new criteria. However, when both criteria are emphasized, processing capability significantly decreases, usually with an increase in anxiety and frustration. It is difficult to adjust payoff criterion to encourage the subjects to generate less than 5% error under laboratory conditions. Cueing users to produce errorless performance, especially where speed is important, should be avoided. By de-emphasizing speed, the user can be provided codes, or simplified checking procedures, to minimize persistant error.

The concept of attention set is not limited to cueing performance expectations, or to information conservation tasks. The psychological construct, perceptual cueing, applies to all communication reception, and in some profound ways. But the effects on performance are elusive, and we have been unable to uncover additional relevant data. A somewhat speculative idea affects the interrelationship of the processing tasks. Cueing an individual to perform a specified task (eg. conservation or reduction) could improve performance by lessening uncertainty and increasing confidence in the particular process being performed. Sureness that what one is doing with the information is correct is intuitively an asset. Whatever the case, this is certainly an area for further research.

INFORMATION REDUCTION

Although studies of information conservation tasks provide a useful insight into how humans process information, these tasks "are not the sole nor even the typical information processing situation" (Posner, 1965b). The usual situation is one in which man sifts though incoming information to continually reduce his uncertainty about the state of his environment. Any task in which the input is reflected in the output in a reduced form is an information reduction task (a many to one mapping of stimuli). In such tasks as concept learning and classification, a reduction of information in the output is not error, but a necessary equivocation in memory to perform the task.

Data from Morin and Forrin (1961, 1963), Fitts and Biederman (1966), Posner (1966), and other investigators, has shown that the rate of human information processing varies sharply with stimulus-response codes in information reduction tasks. A linear relationship between time and information is apparent in each case, but the slopes of these curves vary with different coding systems. The degree of stimulus-response compatibility is a useful variable for determining task difficulty.

One measure of stimulus response compatibility is the quantitative difference between stimulus and response information (transmitted information). Posner (1964) has hypothesized that the difficulty or the amount of mental processing required in an information reduction task is directly related to the amount of transmitted information. That is, the greater the amount of mental processing or thinking required by the task, the greater the decline in performance with increasing speed. By holding certain aspects of the task constant, performance measurements can be made. For example, if stimulus uncertainty (i.e. input variation) is held constant, the transmitted information is the inverse of the information input, but if response uncertainty (i.e. output variation) is held constant and stimulus uncertainty varied, the transmitted information is independent of the information input. Data taken from studies using these measurements as well as the familiar processing studies represent quantitatively a more complete picture of how humans process information.

Information reduction tasks can be classified as one of three kinds of transforms: filtering, condensation, and contingent processing, each having peculiar characteristics and parameters.

FILTERING TRANSFORMS

Certain information reduction tasks, such as those utilizing man as a monitor, allow the subject to ignore various aspects (dimensions) of the input during task completion. A dimension is a set of similar characteristics which describe one aspect of the input. For example, a set of plane geometric figures would comprise one dimension of a stimulus described in terms of geometric shape, tilt, color and so on (color, tilt, etc. would be other dimensions of the stimulus). This is important when large quantities of textual information are reviewed for a specific predetermined item.

When the filtering rules are well learned there is no increase in difficulty with increasing irrelevant information. Irrelevant information is the information contained in the input unnecessary for completion of the task, and is a member of the filtered out dimension. However, when a subject is required to filter within a dimension (such as filtering out parallelograms from the rest of the plane geometric figures), there is a marked increase in difficulty with increasing irrelevant information (Posner, 1965a). In the case where an entire dimension is to be filtered out, the irrelevant information appears perceptually different from the other relevant stimulus dimensions. In this way, the possibility of intrastimulus interference is minimized.

Filtering within a dimension poses a more difficult problem for the user. In this case all of the irrelevant information is in the same class as the relevant information (i.e. both belong to the same dimension). Where there are similarities between two signals (such as belonging to the same class, semantically, and/or acoustically), intrastimulus interference exists. Increasing irrelevant information increases the probability that such information will become more and more similar to the relevant information thus increasing intrastimulus interference. Generally, increasing irrelevant information increases the processing time per input thereby decreasing overall performance. If the relevant dimensions are sufficiently different from those dimensions not requiring a response, little or no interference occurs, and the processing time parameters for the information conservation tasks apply to the information filtering as well (Pew, 1965b).

CONDENSATION TRANSFORMS

Tasks which require the user to represent all of the stimulus information in the output, but in a reduced form, are called condensation. In condensation tasks, such as classifying stimuli into categories and arithmatic addition, all of the dimensions of the input must be processed to properly perform the task. For example, in addition, all of the stimuli (digits) must be processed in order to produce the desired, condensed output: the sum of the digits.

It has been shown that input information cannot uniquely account for varying human performance in a condensation task. When input information is held constant, and is adequate for perception, difficulty is dependant upon the amount of condensation and the compatibility of the input with the condensing requirements. Little can be said about the latter that is not intuitively obvious. Performance does decrease with increasing variance between input and output requirements. This suggests dividing a task into steps when a great deal of condensation is necessary. When input information is varied, and output held constant (as in classification tasks), difficulty increases with greater inputs. However, as Posner concludes, the quantity of information reduced is the most pertinent measure of condensation processing difficulty.

Melton (1967) has hypothesized that different amounts of information reduction employ a varying amount of the subject's information processing capacity. With an increase in the information reduced, more of the processing capacity is required and the rate of loss of information from short-term memory increases, as well as decreasing the capacity available for the conscious or unconcious rehearsal of previously stored information. Rehearsal of stored information increases the probability that information will be retained in long term memory. This is a viable explanation for the performance parameters in condensation transforms.

CONTINGENT TRANSFORMS

Biederman (1967) has conceptualized a contingent transform as one structured so that the processing of some components serve to direct the processing of the remaining components. Such a task has two sets of dimensions, a primary dimension, and a set of two secondary dimensions. The primary dimension, such as geometric shape, is processed first and serves as the basis for selecting the relevant secondary dimension (such as position, or color of the figure) for processing. When one secondary dimension is determined to be relevant through processing the primary dimension, the other secondary dimension is ignored.

Concept formation as described by Hunt (1962) involves contingent processing. The elements to be processed in on-line concept formation are sequentially tested in a predetermined order, the outcome of each test determining the selection of the next. The test of elements to determine the concept they are to be subsumed under is contingent upon the features (dimensions) of the concepts. The performance of this transform is very important for higher order interaction, such as on-line problem solving.

In reaction time studies, both reaction time and errors increased with increasingly irrelevant secondary dimensions. However, the magnitude of the differences in performance declined with practice (Biederman, 1967). Montaque (1965) showed that information intermittantly irrelevant, significantly degraded performance. The locus of this interference was in the competition of correct and incorrect responses due to implicit response tendencies to nonrelevant dimensions. In effect, a contingent task would require more time and involve a greater percent of error due to increased response uncertainty than a comparable filtering task. However, a contingent task tends to be more efficient and less time consuming than a condensation task. The utility of the contingent transform compared to condensation is the sequential processing of dimensions. Processing one dimension at a time, the primary first, greatly enhances performance.

It is not clear that the transforms are mutually exclusive kinds of processing. In the case of contingent processing there is a basic difference. Reduction is contingent upon specific dimensions or characteristics of the input information. Condensation involves a parallel consideration of the input which is usually subliminal. By delineating dimensions when possible, a conscious control over the processing occurs providing the basis for a more orderly and efficient task. Filtering could involve contingent as well as parallel examination of input to determine its relevance.

INFORMATION CREATION

The information creation task requires the subject to perform a one to many mapping of stimuli resulting in a greater output than input. The classical example of such a task is multiple word association where one stimulus word leads to a chain of output responses. Hunt (1962) has proposed that probabilistic learning (information production) can also be placed in this category. In a probabilistic learning situation, the subject must decide at each trial which one of several events will occur. The events occur in random sequence and there is usually no information available to aid him in his decision (Hilgard and Bower, 1966). However, through the use of feedback an individual can combine whatever information he has learned about the event probabilities, thereby reducing the response uncertainty (Schipper, 1967). As Posner (1965a) noted, the subject "leaps" beyond the input to arrive at a decision.

Except for the studies of Morin and Forrin (1963), and Shepard (1963), there has been very little quantitative research in information creation tasks. The generalization that task difficulty increases with increasing transmitted information has been shown to be not entirely applicable to information creation tasks. In information creation tasks, reaction time is more closely correlated with response uncertainty (variance) rather than transmitted information. However, these studies barely begin to quantitatively describe human information processing in information creation tasks, if indeed it is possible. Since information creation reflects human concept generation and decision making, much more work needs to be done in this area.

APPLICATIONS AND FURTHER RESEARCH

Underlying this investigation has been the pragmatic assumption that the taxonomy parameters and conclusions about performance will result in a significant difference when applied to actual man-computer systems. There are many software packages designed to accomplish specific jobs which operate successfully in an operational environment. As stated above, improving man-computer communication is not vital because of man's tolerance for ambiguity and uncertainty. Thus, the assumption requires testing as an hypothesis. We must have full cognizance of the programing effort required to fully implement the software changes that are necessary to comply with human performance criteria. We may find that only those principles which can be incorporated into the initial design of software, such as the structure of the command language, will be cost effective.

Our experience indicates that at least the latter will be true. Experience with systems such as the GE-600 Text Editor (on which this paper was prepared), and management information systems (for retrieval of form-oriented data) has indicated that the qualitative difference is largely a function of communicative effectiveness. How the file structures correspond to user's thought patterns, the characteristics of the dialogue language, and the options available are critical in selecting a software system for a given application. These considerations are intuitive at present , altough I am beginning to discover applications of material in this paper; for example, in deciding what should be displayed by management information software to enable a user to decide which retrieval function to select next, or selecting the mnemonic abbreviations of retrieval values.

To verify these conclusions we are planning to use two in-the-house management information systems with identical data bases to compare the performance of similar inquiries. There are a number of comparisons that can be made using these operational systems. However, until more supportive data is gathered, it is not appropriate to program test routines which would permit experimental rigor.

In addition to testing the hypothesis with available software, investigations which have provided the basis of this paper need to be continued. The extensive experimental data is a substantial distance from a comprehensive description of human information processing. In our in-the-house efforts, we are further limited to the ideas outlined in this paper which do not even exhaust that data. What I have attempted is a beginning and a framework from which to proceed.

A promising direction is to establish the semantic dimensions of words. The implications of meaning are relatively profound due to the extensive higher order cognitive processes involved. Wickens (1970), in devising an "empirical approach to meaning", uses the degree of interference with performance to determine the semantic category into which words will cluster. That is, the greater the proactive or retroactive interference between words, the more semantic similarity. Wickens discusses a number of shifts or changes in input that cause release from interference. These shifts are dimensions, such as those used in information reduction, along which input information could be defined. To avoid interference and the resultant lessened performance, a shift could be provided to reorient the user. This exciting possibility focuses on a need for further experimental data to establish the pertinent dimensions.

Eventually, pertinent experimental data from the psychology laboratory could be compiled and systemized into a handbook for system programmers as a reference for the design and modification of software. Traditionally, programmers program for programmers, i.e. they assume an intimate knowledge of computer language and hardware constraints on the part of the user. Design specification writers in particular might welcome guidelines and principles for building software for people in general.

CONCLUSION

The taxonomy of human information processing is a means of delineating the information flow through man as one member of a man-computer communication dyad. With each category of tasks, conservation, reduction, and creation, there are performance parameters and some conclusions about application to man-computer interaction. This "systems analysis" of the on-line computer user utilized emperical data from psychology to elucidate the user's functioning to move a minute distance toward knowing him as well as we know the computer. After all, effective human communication requires as thorough an understanding of the audience as possible. If we are ever to realize the man-machine symbiosis modern computers render feasible we must examine the domain of human behavior. This kind of analysis sometimes incites skepticism about the seeming inhuman rendition of man. My purpose is my answer: to humanize the computer, not de-humanize man.

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