Development of a Taxonomy of Human Performance:

Design of a Systems Task Vocabulary

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Robert B. Miller

Technical Report 11

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Difficulties of developing a viable descriptive taxonomy are described. The author's previous formulation of a "functional" approach to task description and analysis is reviewed and a useful format consisting of four major "dimensions" of description is proposed. The rationale for development of a transactional language for describing and analyzing military tasks and duties is presented together with a new system task vocabulary created according to that rationale.

The new approach assumes that the human is an information processor. He can code one class of information into other classes of information where the second class is symbolic of the first. Symbols, when communicated from one individual or device to another, take the form of "messages." Input reception, memory, processing, and output effectors are the concepts found useful in developing the set of terms which constitute the systems task vocabulary.

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DEVELOPMENT OF A TAXONOMY OF HUMAN PERFORMANCE: DESIGN OF A SYSTEMS TASK VOCABULARY

Robert B. Miller

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PREFACE

The AIR Taxonomy Project was initiated as a basic research effort in September 1967, under a contract with the Advanced Research Projects Agency, in response to long-range and pervasive problems in a variety of research and applied areas. The effort to develop ways of describing and classifying tasks which would improve predictions about factors affecting human performance in such tasks, represents one of the few attempts to find ways to bridge the gap between research on human performance and the applications of this research to the real world of personnel and human factors decisions.

The present report is one of a series which resulted from work undertaken during the first three years of project activity. In 1970, monitorship of the project was transferred from the Air Force Office of Scientific Research (AFOSR) to the U. S. Army Behavior and Systems Research Laboratory (BESRL), under a new contract. This report, completed under the new contract, is among several describing the previous developmental work. It is also being distributed separately as a BESRL Research Study.

EDWIN A. FLEISHMAN
Senior Vice President and
Director, Washington Office
American Institutes for Research

FOREWORD

The American Institutes for Research (AIR) Taxonomy Project is concerned with new ways of describing tasks and duties. The objective is to develop theoretically-based language systems (taxonomies) which--when merged with appropriate sets of decision logic and appropriate sets of quantitative data--can be used to make improved predictions about human performance. Such taxonomies should be useful when future management information and decision systems are designed for Army use.

In the present document, a working paper, the author explores the capabilities of a "transactional" information-processing systems language approach to taxonomy development. He describes an initial attempt to design a new systems task vocabulary in which human beings are considered to be information processors within the total system. The current version is presented. Since the vocabulary is still in a developmental stage, it would be inappropriate to quote from this paper or to cite it as a reference. Those who wish to make comments and suggestions should correspond directly with the author.

J. E. UHLANER, Director
U. S. Army Behavior and Systems
Research Laboratory

AUTHOR PREFACE

This paper is one in a series which report on several alternate approaches to developing and evaluating taxonomic systems for describing human tasks. The goals of the project, carried out at the American Institutes for Research (AIR), are a) to improve generalization of research results about human performance and b) to develop a common language for communication between researchers and decision makers which would help organize human performance information for maximum use in such areas as selection, training, and man-machine system design. This paper was written in connection with my activities as consultant on the AIR project.

In past years, I have been diffident about proclaiming the task analysis categories I have been writing about and working with as a "taxonomy". This diffidence was in part professional caution (or timidity) and in part an early hope that perhaps some magic talisman would show that the human is a collection of black box functions, and that the boxes could somehow be identified.

In the early 1950s, Jack Folley and I made a pass at breaking out the maintenance job into task families. We had five or six: checking, adjusting, troubleshooting, replacing, repairing, and preventive procedures. We found a limited number of action verbs to apply to activities within each of these task families. It became apparent that "checking" was generic for input information, "troubleshooting" (really decision-making) was generic for processing, and "replacing" or "repairing" was generic for task output. We tried to insist that the half dozen verbs we used within each of these rubrics formed the definitional heart of these terms, and that our purpose was to put communicable order into literally thousands of pages of observed behavioral data. It was an armchair job because we found we could think better in an armchair.

I recall my anxiety when I showed these two pages of terms and definitions to Robert M. Gagné (our contract monitor at the time) because, in fact, they had been "armchaired", and my gratitude at his own quick enthusiasm that this was a way of putting useful structure into job description aimed at anticipating training needs. Behavioral phrases such as "discriminate an in-tolerance from out-of-tolerance condition" and "infers trouble is in chain with good input and bad output" made psychological sense. Although not so identified at the time, we were certainly grappling then with the problem of "task taxonomy". I must emphasize that this first attempt at classification was for convenience and not in the belief that any profound psychological revelation was being made.

The publication of the task family names and their definitions was rather quickly challenged by competing nomenclatures from competing psychological contractors and among competing sponsoring agencies. I did

not believe we had a task taxonomy; as a part of nearly every research report submitted, I would add--with a gesture towards relevance--that the applied (and even the non-applied) psychological community needed a task taxonomy. This was between 1953 and 1957. I could find no other references to the need during those years. In 1957, Dr. Denzel D. Smith, then with the Office of Naval Research, was prepared to fund a small development contract at AIR, but I was constrained to other activities. At the turn of the present decade, and due to "missionary work" by others (primarily, I think by Dr. A. W. Melton and Dr. Gagné, as well as Drs. Fleishman and Fitts) the idea that there might be gold in the taxonomic hills caught on.

I am now skeptical that a mother lode exists for rigorous psychological taxonomies developed strictly from experimental procedures. If I ever toyed with the notion of "psychological entities" like functional black boxes remaining to be discovered, I disavow it now. Task "dimensions" are a similar trap. The dimensions of length, height, and width are human abstractions and projections on physical phenomena. They can be defined by operations that will make them independent of each other. But when the expression "dimension" is used metaphorically, with the assumption that what is discovered is intrinsic to the entity rather than a characteristic of observation, the morass should be evident. The scientific method will reveal the common physical structures and properties of objects and collections of objects. But the structure of adaptive programs--i.e., their "functions"--acquired by purposeful entities is essentially an arbitrary imposition made by the analyst for convenience in his decision-making.

The taxonomic tool I have proposed in this working paper is designed to help solve practical problems as they exist today. It has been invented rather than discovered. The major criterion for its evaluation is the same as that for any other invention: Is it useful? How can it be made more useful? Readers with suggestions along these lines are invited to correspond with the writer.

I wish to gratefully acknowledge the critical comments provided by my colleagues at AIR who reviewed this manuscript. The contributions of Drs. Edwin A. Fleishman (principal investigator on the project), Albert S. Glickman, and Warren H. Teichner were most helpful. Special acknowledgment is due Dr. Robert W. Stephenson, project director, and Mrs. Halaine Cary, technical editor at AIR, for their suggestions and revisions of the final draft.

Robert B. Miller

DEVELOPMENT OF A TAXONOMY OF HUMAN PERFORMANCE: DESIGN OF A SYSTEMS TASK VOCABULARY

BRIEF

Problems in developing a viable descriptive taxonomy are described. The author's previous formulation of a "functional" approach to task description and analysis is reviewed and a useful format consisting of four major "dimensions" of description is proposed. The rationale for development of a transactional language for describing and analyzing military tasks and duties is presented together with a new systems task vocabulary created according to that rationale.

The new approach assumes that the human is an information processor. He can code one class of information into other classes of information, where the second class is symbolic of the first. Symbols, when communicated from one individual or device to another, take the form of "messages". Input reception, memory, processing, and output effectors are the concepts found useful in developing the set of terms which constitute the systems task vocabulary.

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DEVELOPMENT OF A TAXONOMY OF HUMAN PERFORMANCE: DESIGN OF A SYSTEMS TASK VOCABULARY

PREVIOUS FORMULATION OF A FUNCTIONAL TASK CHARACTERISTICS APPROACH

My earlier formulations of task description and analysis(1) were primarily directed towards obtaining data for design decisions in various aspects of the personnel subsystem (see Table 1). Task information was useful in anticipating and setting up training content and training devices, cross-training and selection hypotheses, procedure design, manuals of instruction, human engineering, simulation exercises and evaluative procedures. It was not intended or expected that the rubrics used in task description would be useful in organizing the research and applied literature to permit quantified predictions of performance.

Table 1

MILLER'S (1962) SCHEME OF THE BEHAVIORAL STRUCTURE OF A TASK

Goal Orientation and Set
Reception of Task Information
Search & Scan
Identification
Noise Filtering
Retention of Task Information
Short Term Retention
Long Term Retention
Memory for Codes
Interpretation & Problem Solving
Motor Response Mechanisms

Categories for Task Analysis

The categories for task analysis developed from a flowchart conceptualization of a generalized information processing automaton with adaptive properties. It must scan its environmental field in order to detect task relevant cues and perhaps filter these cues through irrelevances and disturbances. Cues must be responded to as message entities or patterns or organizations which are relatively stable and can have names attached to them--these are identifications. (Identifications enable the support of verbal-conceptual behavior.) When the data presented to the human seem incomplete or inadequate for selecting an effector action, reference information stored in the human may be necessary to "interpret" the pattern of cues--give it "meaningfulness" in terms of task context. "Meaningful" may be defined in cognitive terms or with respect to the selection of a goal-directed action.

Since the automaton must respond to data in the immediate (or not so immediate) past, as well as to data active on the sense organs, a buffering capability is necessary for storing transient task information. The coding of the contents of the buffer is not necessarily the same as the form in which the data are apprehended--indeed this would be inefficient from many standpoints. In any event, the function of short term memory is a necessary postulation. (In computerese, short term memory is equivalent to "storage registers", but in machines these registers are simple and have little dynamic effect on what is stored, whereas the reverse is true of human short term memory.)

The information content of "procedures" or programs is stored in long term memory. These contents are used in processing input data, complex mediating processes, and organization and selection of output processes. Long term memory is, of course, the equivalent of the content of what has been learned and its associative linkage structure with all orders of task data. (I am not attempting to differentiate information from data in this paper because an expression such as "Information is meaningful data" or the like would unnecessarily complicate exposition.)

If an input or stimulus pattern does not immediately lead to the selection of an "appropriate" response, further mediating activities must occur. These processing activities were lumped into a grab-bag category called decision making. On pragmatic grounds, distinctions were suggested between convergent and divergent problem solving, computational and formally logical reasoning.

I expected that some day I or some more enterprising colleague would push the analysis of information processing structures or transactions into the decision making region. Recently, I have been able to extend the definition of transactional models in problem solving and decision making (2).

Motor and other effector processes are output activities. No attempt was made to differentiate among classes of motor activity largely because my analytic structure was free of "task content".

One-for-one decoding tasks were specified as a separate class of activity (e.g., typing, keypunching, telegraphy and similar activities that literally translate a stream of signals in one code to an output in another code according to an absolutely unambiguous set of translation rules). But I was unable to place this activity in the scheme outlined above, except in a most arbitrary fashion.

Task Structure Versus Task Classification

Naming and defining the functions that make up an information processing automaton is an enterprise that differs from an examination of all the kinds of goal-directed clumps of activities that people do or can do and the sorting of these into subsets according to formal principles of categorization.

I have always called my task analysis terminology a "task structure" rather than a taxonomy. It is a structure because practically every human task has some degree of all the constituents I have named and identified. Some tasks weight more highly for some rather than other functions in the list. Even a piano mover should scan and detect a marble on the stairs, interpret its potential significance, and devise a foot-moving strategy that will avoid its untoward possibilities.

Recently, I have come to believe that a commonality-oriented task structure approach (as opposed to a difference-oriented task classification approach) may be the most workable approach to the development of a useful taxonomy.

Mission and Task Analysis

The task description/analysis structures and procedures I have proposed obviate the need to make artificial boundaries between one task and another. The method proposes a statement of the job mission with a starting point and an ending point, and a structure which, within some range of variation, tends to be constant from one mission cycle to another. The mission is broken into time segments. A segment is concluded when the human can--so to speak--empty the contents of short term memory, fill it with new content, and adopt a new "set" to respond. True, this unbuffering is generally only a matter of degree; hence the need to treat the mission as an organic entity. A fighter-bomber pilot who, far enough beyond takeoff to be committed to a mission, detects an offbeat rhythm in one of his engines and notices small but atypical fluctuations in his gauges, adopts a strategy which is contrapuntal to much of what he does during the remainder of the mission.

Only the most superficial observer watching the most artificially simple "task" exercise can fail to note the great variety of contingencies which can beset every cycle of the task and its behavioral context. It is the capacity to deal with the great proportion of these contingencies, at least with statistical effectiveness, that differentiates good and poor performers. When a computer analyst-programmer attempts to automate a human information processing task in real life and compare the outcome with the work of even a fairly dull human, the variety and complexity of even simple human acts and their environments are revealed.

ANALYSIS OF A DECEPTIVELY SIMPLE TASK

The difficulties of developing a viable descriptive taxonomy may be suggested by analysis of a simple task--that of a soldier in the field who is concerned with rust spots on his rifle after a day in the swamps. In this analysis I have applied my own task structure schema (1). The treatment pivots mainly about "scanning and detection".

The issues that are illustrated include: mutual exclusivity in categories describing activities or functions; micro-actions and macro-actions and levels of description; consistency in a classification schema; the search for generalizations about identifiable task activities; definition of the concept of "task"; reliability in classification decisions and meaningful classification form; and "task requirements" in objective terms and behavioral context.

Requirement: "If there is rust on a rifle, find it and get it off."

The army manual would probably classify the following as a procedural task: "When there are rust spots on any metal part of the rifle, remove them with rust remover (specified) and a swab."

It is twilight, after evening meal in a bivouac. Some cue, external or implicit to the soldier, turns his attention to having his rifle clean. (Note: Scanning behavior must be initiated by a cue; if this cue is unreliable, scanning will be unreliable.)

Goal Information

In this case, goal information would be knowledge that the rifle is "clean" and that it has "no rust spots", or some set of perceptual references as to the appearance and feel of a "clean rifle". Here, the quotation marks indicate that the reference is not likely to be an

absolute one. The condition of acceptability may differ from soldier to soldier and from soldier to officer. The criterion may also differ according to environment in terms of the operator's concept of practicality. In combat, a clean rifle may be a matter of life or death. Yet, in combat there are priorities that compete with rifle cleaning. Basic Training criteria of cleanness may not fully apply.

Motivational variables can be seen to interact with the concept of the goal state. The goal criterion may also interact with the performance of the task. Severe difficulties in achieving a predefined goal level may reduce the level of aspiration.

Scanning and Detection

Scan and detect involves differentiating a work cue in a "neutral field"--a field of "non-work cues". This would be looking at the metal parts of the rifle for places that are not, according to the task criterion, "clean". The scanning may have to be preceded by a procedural set-up, such as finding the right amount and angle of reflecting light. The actual scanning may be a habit sequence for examining segments of the field--the barrel, the breech, and so on.

Assume the soldier has detected a deviation from the smooth, bright surface of the barrel. He may or may not at once identify it as rust. Assume that he does not.

Identification

Is the difference he perceives rust or dirt, a cast shadow or something else? He may shift his scanning field--examine the suspected area more closely. He may apply procedural tests--spit on it to see if it rubs off (if it does, it was dirt). (Hypothesis formation may precede an identification.) He may try additional scanning modes--rub his finger over the suspected area (if it is rough, the chances are increased that it is rust). (If he has identified rust elsewhere on his rifle a few moments ago, he is more ready to accept the hypothesis of rust than if, after inspecting most of his rifle, he has found none.)

The operation that is important here is obviously not that of <u>naming</u> what was detected as "rust". The operationally important ingredient is a cognitive definition of the detected cue as a selector of the next response. This consideration is important to the understanding of the information processing continuities necessary and sufficient for task behavior. It has practical implications. The implicit <u>naming</u> operation, redundant though it may be, can have important bearing on short term memory and what it will hold; a name

may be a good mnemonic shorthand for a complex sensory impression and use less short-term storage capacity. Applying the label "rust" tells the soldier that he can check against other labels—on the can of rust remover or in the table of contents of the rifle manual.

The identification (rust spot) may initiate the procedural task of reaching for the rust remover and swab.

Interlude

If we were doing a micro-motion analysis, we would have to notice that the soldier scans and identifies the work area in locating the swab before he picks it up. We might discard this action as being irrelevant to anything "important" we want to take notice of in this context; but, this would be an act of judgment on the part of the task analyst. Any description of any process must involve innumerable instances of similar judgments. Thus, task description is a technology that can never be completely explicit in data collection.

It should be noted that there may be several loops of scan-detect-identify before a next step in task structure is entered, as would be the case if the swab had been used before and the soldier went into scan mode to detect and identify a clean area.

Interpretation

An act of interpretation may be involved before the soldier starts cleaning the rust spot he has identified. One rust spot may suggest to him that the rifle has been exposed to moisture and that there are probably more rust spots. The inference—"exposure to moisture, hence more rust spots"—is the addition, to his observation, of information in the soldier's head and the drawing of a conclusion. The conclusion may be called the product of the interpretation.

Interpretations may be based on some context in which the cue is one of several manifestations. An interpretation may be a hypothesis as to how a number of different signs are related to each other because of some pattern which is projected upon them (like an overlay) by the operator. An interpretation involves a generalization, hence an order of conceptual classification and abstraction.

The result of the soldier's interpretation may be that he rescans the field he has examined, but with greater care (examining smaller areas at a time). He may also take apart the actuating mechanism and reexamine the bore of the rifle for rust.

Note here, however, that a procedure may eliminate (or try to eliminate) the need for an interpretation and resulting change in action. The soldier may have been taught: "Whenever you find a single rust spot on any part of your rifle, dissassemble it completely and clean it completely, using rust remover." Obviously, this changes the cognitive requirements of the task.

Long Term Memory

The function is that of recalling the contents of long term memory through a process of accessing the relevant content and converting that content into a task action directly, as in automatic motor performance, or indirectly, by means of verbal content, imagery, or both.

Long term memory is a short-hand expression meaning the summoning of stored information on the basis of identified/interpreted cues, where that information links the cue to the task response. One should call it "long term memory for procedures", because long term memory applies to scanning habits, detection, identifications and interpretations; recognizing this, some special treatment will need to be found for long term memory and short term memory in our formal taxonomy structure.

The soldier's long term memory for procedures provides the information for selecting and using the rust remover and swab to remove the rust. Each step in the procedure will have many micro-elements of scan-detect, and so on.

Short Term Memory

Short term memory is defined as the application of stored information peculiar to the task cycle and relevant to it. ("Relevant" here implies selectivity.) Short term memory may assist in interpretation--the soldier remembers he walked briefly beside a shallow river during the day, thus he can account for the rust. In cleaning the rifle, short term memory carries the location of the rust spot on the rifle while he is getting the swab, soaking it in rust remover, and so on. More or less continuously, he recalls what parts of the rifle he has cleaned and what still remains to be cleaned.

Decision Making

Decision making is defined here as choice behavior in which the recall of procedures does not in itself eliminate choices, or no procedure has been learned that can be recalled (or generalized) to the demands of the task situation. Our rust removing soldier chooses to

clean the first spot of rust he identifies, or to do a complete job of using rust remover on all the metal parts, or to delay cleaning until he has identified a few more spots. If the rust remover does not remove the entire bad spot, he has another decision to make. If the rust has left a pitted area, he may have a choice--to rub it with crocus cloth. He makes a choice as to when to stop cleaning--when his perception of the result of cleaning and his level of aspiration coincide.

Some amount of decision making probably enters into every task, even one that is highly routinized. How important any or all of this choice-making (and sometimes choice-creating) behavior is depends on the context and purpose of the task examination.

At the operational level, choice-making logically (and, in general, psychologically) follows an interpretation, and may even be a part of it, such as in the preference for one among several hypotheses which may occur to the operator. It is of major operational significance when contingencies arise (unexpected task environments, operator overloads, error by human or machine) for which the operator lacks a procedure for choice and action in recallable storage at the moment. Characteristically, the operator has contributed stored information to the decision making situation. Furthermore, real life problems demand tradeoffs among values that are qualitatively and quantitatively complex.

Motor Behavior

The soldier folds the swab awkwardly and upsets the can of rust remover because he does not put down his rifle while wetting the swab with the remover. He drops his rifle in an attempt to retrieve the can before its contents are entirely lost. The swab has fallen; dirt has adhered to the moist surface. The soldier makes a gesture or two of wiping off the dirt and applies the swab to the rifle. He may start with longitudinal strokes. If the rust does not come off, he will bring more pressure to bear by holding the swab in his fist closed around the barrel and twisting. If the rust still resists, he may try flaking it off with his fingernail. The longer he works without grossly apparent results, the lower settles the level of his aspiration. He resists losing physical contact with the tools and objects he is working on and with, while he works.

Careful observation of much motor behavior does reveal many elements of low comedy. Our image of "motor behavior", however, is usually founded on a picture of a virtuoso performing a complex skill--the billiard champion, the skiing champion, the expert racing car driver. Motor considerations are indeed significant in delicately timed

operations. In complex skills, however, the utility of separating perceptual from motor components is dubious. (My taxonomy does not extend to manual tracking tasks--a proper category in its own right. This category would arise when we dealt with the soldier sighting an enemy with his rifle.)

Few modern tasks require high orders of "dexterity". Like cleaning the rifle, motor elements of tasks tend to be procedural. This seems true even of driving an automobile where proper perceptual behavior requires only intermittent, discontinuous adjustments on steering wheel, brake and accelerator. Grossly inadequate motor performances often lack adequate task strategy in procedure--setting down the rifle before wetting the swab with the solvent, or finding a level spot for setting down the open bottle of solvent before opening it. The absence of good models from which to copy a procedure and thus learn it during training may impose the ability requirement to "invent good procedures" as an inadvertent (and unrecognized) variable in selection procedures. That is, the operator may have to be able to compensate for what he was not taught in training.

General Comment

This analysis of a few moments of activity has indicated the intermeshing of one component with another in real-life behavior. Applying any single expression presumably characteristic of the activity called "cleaning a rifle" would be misleading. The terms goal image, identification, interpretation, short term memory and long term memory, decision-making and motor activity made analytical sense in that sequence. Practically no procedural step was taken without some manifestation of each and every one of the task elements.

Some investigators might hold that all these difficulties about level of descriptive detail can be effectively sidestepped by making a performance specification. One might specify what actions would be completed according to what criteria by what amount of time. But the result may be specified as "time to clean rifle to criterion," or it may be specified in terms of "time to detect presence of rust on rifle".

We should also remember that a performance specification is meaningful to the extent that input conditions that make a difference in performance have been identified. If these conditions do vary widely, then the range of "performance" viewed only as an output must have expanded tolerance limits or standard errors. If, however, performance specifications are subsetted according to variations in input conditions (and other factors in the operational setting), we are right back to the problem of what level of description is useful and by what operations can that level of useful description be identified. Human judgment based on expertise continues to be necessary.

WHAT IS A "TASK"?

The Reader's Image of Task

Abstract discussions about theory and methodologies may spring from and subtly be referenced to the image of "task" held by each discussant relating to some particular set of experiences. Because of these differences, it is possible for discussions to appear to have agreements in principle but not in substance or in content. Thus, there may seem to be a consensus about the value of the "information processing" approach, with quite bitter disagreements about the behavioral and methodological universes implied by "information processing". It seems likely that in many cases disputants may appear to communicate with one another when in fact they are not. The reverse may also be possible. Different frames of reference held by individual behavioral specialists lead to different views as to the important and realistic objectives of a classificatory system and legitimate methodologies. Four or five major kinds of reference image of th term "task" are apparent.

In one kind, a task is considered in a real world context of human purpose, interruption, ambiguity, motivation, noise, concommitance, and contingency. The image is in the form of a scenario of transactional events. Examples would be: the bomber pilot in a bomb run; the maintenance mechanic making a diagnosis from a chart and manual; the engineer making a logic design of an information network; the platoon sergeant making a jungle foray.

A second archetype image of task may be an abstract of transactions which could be called "task functions". The maintenance functions of "checking for symptoms of malfunctions", "diagnosing cause of symptoms", and "correcting cause of symptoms", are examples. The picture in mind tends to be a "functional block diagram" of a sequence of work stages that may be classified either according to the work objective (such as "diagnosis of trouble") or the main ingredient of the activity ("diagnosing"). There may be a wavering between these characterizations.

Relatively "pure" laboratory activity is a third kind of reference image. Examples include: the subject controlling a cursor pip on a CRT screen so as to coincide with a target pip; the subject moving a joystick control to a position signalled by one of four lights; the subject pressing one of 12 buttons depending upon what sequence of cues is presented to him.

A fourth type of reference image, seemingly more abstract in distance from the real world operator, is that of "ability" as a statistical derivative from a body of empirical data. As a hypothetical example, "discrimination of contour" may be considered from this point of view as "task ingredient" or, indeed, as a "task" on operational grounds. That is, if an "ability" is defined as the interaction of a

mechanism with a given kind of environment with an outcome measurable on some criterion variable, then it is legitimate to think of a factor derived from factor analysis in terms of "task".

Perhaps the most remote is the concept of task as a term in an equation representing a processing "model". Task is considered equivalent to the transmission of information (in the formal sense of bits) from one interface to another. The behavior properties of the device (such as its programmability) are meaningless except as represented in transmission characteristics. Task meaning and purpose are not relevant here, apart from information flow. Work getting done, or purpose being formulated, or any other means whereby, from the standpoint of a human operator, information is created, is also not relevant. The universe of information transmission is itself a logically closed system, which enables a logical elegance and parsimony in characterization. By such a definition, a problem must be reduced to measurements like "bandwidth" to be relevant. The model asks, "What is the probability that in a given time, a given act will be correctly completed?" The expression "task" itself is likely to be gratuitous. Representative examples can be seen in the literature (3).

I believe that any one, or combination, of these kinds of ideas of task "substance" can be translated into one or more forms of "transactional structure" of behavior and performance with the intent of deriving a classificatory schema. As indicated later, some will be more useful for practical applications than others.

A Transactional Definition of Task

A task classification system would characterize the expression "task" in perhaps the most meaningful way by pointing to the members which together make up the meaning of task. In certain philosophy of science circles, it is "operationally valid" to define a set by pointing out members that comprise the set. Some would insist that this treatment begs the question and I would agree.

Distinctions have been made between defining a task as "performance" and defining it as "behavior". In large part, differences between the concepts of performance and behavior can be bypassed by employing the concept of transaction, especially information processing transaction. The definition I offer here, although not rigorous, is operational.

> "A task consists of a series of goal-directed transactions controlled by one or more 'programs' that guide the operations by a human operator of a prescribed set of tools through a set of completely or partially predicted environmental states."

This definition says that a task is not characterized only by a succession of transactional relationships between the operator and the environment on which he is working; it is also characterized by a succession of states within the operator.

The definition is stated merely in terms of operators and operations. Because it combines both structural factors (e.g., programs) with process activities (e.g., transactions), it is possible to infer that every task and even every task cycle is unique. This is by intent. A classification scheme for inclusion and exclusion of members must be added and superimposed on this definition.

Let us examine some components of the definition.

Series. The beginning and end specifications for a series of transactions that make up a task are not specified in the definition. A useful (although perhaps not universally valid) starting point for identifying the beginning of a task series is the initiating operation of getting set with a given pattern of intentions, expectations and preparatory responses. The series is completed with a sense of having completed a performance cycle with a subjective state of an opportunity grasped or missed for a consummation. At least in part, setting the task boundary is a condition for learning and performance.

Goal direction. The goal direction and goal image establish criteria for what is relevant in what is responded to, and in the selection of the response that is made to the situation. The goal image also establishes the conditions that complete the task. This latter concept supplements the subjective characterization of the conclusion of a task series cited above.

Transaction. A response that creates a change of state which defines the condition either for a subsequent response, or of a goal state.

Program. A relationship between a state or condition (stimulus) and a tool plus the action to be taken by the tool (response). The tool may be an effector mechanism. This relationship may be fixed and invariant (when it is called routine or procedural) or it may include subsets of response alternatives to planned (identified) environmental contingencies. The latter include decision-making and problem-solving activities. The relationship of the stimulus may be to a response hierarchy such that the cues of inadequacy from making Response A increase the probability that on the next try Response B will be made.

Programs may be preplanned, such as when a procedure is designed, or they may be improvised. The repetition of situations which once elicited an improvised response will tend to elicit a procedural response. That is, a response once relatively low in the hierarchy becomes high in priority.

A program may inhibit sets of response relationship with a given state of affairs, as well as activate a response.

Prescribed tools. The facilities available for performing a task are usually given or stipulated in a task environment. This stipulation may be based on a combination of precedent and what task "management" provides.

A tool is any instrument that enables (a) a device to be made or (b) an action to be taken that changes an environmental state in some way consistent with reaching a goal state; the foot, hand or voice-box may be an implementing instrument. A tool may be (c) an instrument for sensing and interpreting a state of the environment (eye or ear).

A tool is also any physical device for accessing more information about the state of affairs relative to the task.

Environmental states. The conditions which manifest the problem--in other words, the conditions which separate a goal state from a present state. Also, the environmental conditions under which the task transactions must be performed which affect, helpfully or adversely, the mechanisms for performing the task. The human operator is one of those mechanisms.

The weaknesses of this definition stem from its attempt at inclusiveness. It is intended as a conceptual start for programmatic organization of ideas, rather than a termination.

Work Has a Holistic Context

Any observed pattern of activities associated with a goal (either as perceived by the operator or the external observer) will be a transcript from a mass of other antecedent, concurrent and following activities. While the mechanic is diagnosing a fault by organizing symptoms and making inferences, he is also setting up test instruments, comparing test readings with nominal values, searching for references in a manual, watching the clock signalling an overrun of allowable maintenance time, and so on. He becomes fatigued by awkward positions, exasperated by test probes that fall off, anxious about inadvertently touching a high voltage line, or about turning on power and, due to an error on his part, blowing out the entire equipment.

Any task characterizations and classifications intended to generalize to the world of work must at least enable--if not actually foster--the integration of the psychological and operational setting of which that task (however it is identified) is only one excerpt. Principles of selection or behavior identified for the task or the task archetype will require sets of conditional considerations.

A USEFUL FORMAT FOR TASK DESCRIPTION

I propose that a useful format for the description of tasks for cross-comparison purposes include four major dimensions of description: discriminable task functions, task content, task environment, and level of learning. Unless behavior or performance is characterized in dimensions such as these, judgments about applicability of data sets to each other will produce necessarily vague or potentially misleading generalizations.

Task Functions

Discriminable task functions were briefly identified earlier in this report and are expressed more extensively in an earlier work (1) and are extended and characterized as transactions in the appendix to this report. The names and definitions of these functions characterize transactions and are subsets of the process of reception, memory, mediating processes, and effector processes. In current parlance, these are called input, memory, processing, and output activities. A transaction is some process on a task message. A transaction begins when a stimulus field is searched and a potentially relevant task stimulus is detected. A series of transactions or "functions" may follow in identifying the components of the message, interpreting it, and selecting courses of action. (These latter activities imply that the human is adding information to the message as received). Ultimately some action results in an effector operation on the environment. A "message" may be "natural" such as a roadway or aircraft in the sky, or it may be symbolic such as an instruction in English text, or the message may combine elements of both as in a map.

The number of functional terms that "exhausts" all the classes of transactions in a system must be determined. One can explain or analyze the behavior of a computer with as few as four or five terms, while some current computer glossaries of functions at the technical level include hundreds of terms. The number of terms in a glossary of system behavior is dependent on the convenience of a class of user specialists. In general, a new term is invented when there are alternatives in some class of design actions. It is indeed difficult to control the proliferation of technical vocabularies. It can't be done by edict. Thesauruses are necessary even in such "objective" disciplines as chemistry. Technical vocabularies become stabilized by acculturation.

A variety of pragmatic criteria will, therefore, be exercised in the invention and/or adoption of the functional categories. Indeed, it may be possible to "human engineer" the selection of the vocabulary and its reference meanings as a set. Some sets of terms and reference meanings will be better than others, although the nature of the subject matter induces some arbitrariness in choice.

Task Content

Task content is the subject matter with which the task deals. Thus, "diagnosis" in electronic maintenance may be differentiated from identification of a disease in medical practice. (Diagnosis of a fault in a computer program is different in that it represents an attempt to localize a design error. The other examples diagnose a failing entity in a design that has previously worked.) It is true that some kinds of errors made in electronic diagnosis are also made in medical diagnosis, but it is likely that each subject matter content also has characterizations peculiar to that subject matter.

An ideal taxonomy would be content-free, but a conservative classification of data would include a statement of the content. This provision would enable proper cautions to be applied, for instance, to the hypothesis that "diagnosing" a failing component in an electronic system by means of strategic choice of a series of tests is psychologically similar to diagnosing the cause of a phenomenon through strategic choice of a series of experiments--which constitute a kind of "test". The *a priori* conclusion that performance in both these samples of "diagnosis" can be predicted from a single set of behavioral principles seems very risky.

The reasonable question to ask is: Can a taxonomic dimension of task content be established? Description always imposes the problem of selection of terms, and the constraints to be imposed on this selection. I have no substantive answers on how to approach the classification of task content. Factor analysis may suggest at least an idealized conceptual approach to the extent that factor analytic methods and test construction enable one to differentiate task structure from task content, as well as to relate or factor task contents. Until better procedures are available, the relevance of a task content A to a task content B may have to be implied more by connotation than by denotation.

In order to clarify the distinction between task function and task content, [1] let us consider another example. "Coding"--or encoding and decoding--is defined as rules and operations translating messages in one symbolic form to another symbolic form, presumably without loss of information content. There is generous evidence that programming a mathematical problem in, for instance, APL, Fortran, Cobol or a computer assembly language imposes different kinds of demand and liability on the programmer, even though it is logically and operationally possible to translate the expression of the problem from one language into another. Decoding a program from Fortran statements into ordinary English has, according to the definition above, the same structural operations as decoding telegrapher's Morse into its English equivalent, but we should expect quite different behavioral problems relevant to selection, training and job supports. Still different problems would attend decoding the information on a circuit schematic into a description in English of the electrical phenomena and properties represented by the elements and pattern of elements in the schematic.

Teichner's concept of "constraints" (4) has promise as an approach to characterizing these differences. As I understand the concept: decoding of telegraphese into English would be highly constrained by one-to-one translation rules; translating a Fortran program into a machine language program would be somewhat less constrained because there would be a fair number of logical and operationally equivalent translations; translating the circuit schematic would be comparatively unconstrained because of the many alternatives that could be treated as functionally equivalent to the schematic but not logically equivalent to each other; decoding a road map into information that would support one of a set of preferred route conditions might be a still less constrained decoding.

The importance of this concept notwithstanding, qualitative judgments of similarity and difference in the content on which a task structure is exercised will be necessary for the indefinite future. The indifference of information theory to any but the communication properties of signals and devices abstracted from their other properties makes for explanatory power and elegance, but like Ohm's law, it is incomplete for a design job. Technological innovation consists largely in exploiting actual and potential properties of physical components and devices.

1/ Laboratory investigators preoccupied with tracking task phenomena may consider the distinction made above between task structure and task content to be virtually meaningless. Although I am not convinced that this is true for most real world tracking tasks, the point may be conceded.

Task Environment

Task environments are of two major kinds. One is the physiological and psychological environment of the operator in terms of stress, impairment or handicap. Examples may range from oxygen deficiency while recomputing a course to manipulating a trigger with heavily gloved hands. A second major class of "task environment" is goal-directed activity which is more or less concomitant with the subject task. A task that is time-shared with other tasks may have different implications for selection, training, evaluation, procedural design, work space design, than a task that is treated as an independent performance entity.

This last point raises a serious and quite central matter of psychological definition of "task". The tendency is to avoid the issue, as I have generally done. The question is: Does it make operational or psychological sense to speak of "task" as some thread of activities connected with a particular goal or subgoal, or should "task" always mean the total activities ongoing at the same psychological time?

I hold the view that, in a psychological sense, all concurrent activities by an operator sum into one "task". When serving as a human factors consultant, this is the way I think of the performance problem (at least part of the time during my investigation and forming of recommendations). I am aware that short order cooking in a diner may have no task components that differ from those of a housewife preparing meals for a family, but the organization and concurrencies among these components make each a quite different job in many practical ways.

Steering an aircraft and navigating may be concurrent at times so that the processing required is more than the sum of both, but a vast amount of psychological knowledge about each, independent of the other, is of practical utility in personnel subsystem design, and hence in overall system design. When wearing a designer's hat one must be prepared to jettison (however reluctantly) consistency to a theoretical position and seek workable compromises. One may be solaced by recognition of the vast amount of pragmatic information that is thrown away in achieving and asserting a generalized formulation.

I propose that behavioral and performance data and principles associated with a task function, such as "identifying", should include a description of other goal-directed activities temporally associated with the task function. This will allow the opportunity for judgment to qualify the generalization of the data or principle from the context in which it was obtained to that in which it is to be applied.

The environment may have deleterious physiological effects that threaten effectiveness in task performance. There is, however, a very

practical issue to consider here before jumping to conclusions. Very rarely is the operator working at his maximum performance limits, either in terms of physical work or of information processing work. Generally he has substantial reserve capacities for greater arousal, the outcome of which can be more quantitative output, or greater vigilance about quality of output or both. This means that the operator can generally compensate by greater effort when he is physiologically below par. We do in fact perform many activities even with a headache, a hangover, a slight fever, or a distended bladder. It is only when the task demands a maximum effort from us when we are in peak shape that any reduction of that peak shape means, by definition, inadequate task performance. This argument need not be expressed in absolutes; it can also accommodate a probabilistic view of the reliability of a performance. Some kinds of activity may deteriorate more quickly than others. Drowsiness and other stressors may affect vigilance and field of scan more severely than performance of a well-learned serialized procedure, for example, and may affect the amount of variable information that is held in short term memory more than the content of long term memory.

To summarize: Whether or not a physiological stressor or deteriorator will affect performance depends on the extent to which the operator performs (or needs to perform) the task at a high degree of arousal. If the operator is physiologically depressed below the level at which he habitually performs the task--or needs to perform it--this factor is a threat to the mission. Discomfort is a form of stressor, and its interaction with goal motivation is well known at the man-in-the-street level.

Clearly, the identification of these environmental factors should be part of the context from which any performance data are generalized.

Level of Learning

Fleishman has offered experimental evidence (5), (6), (7), Fleishman and Ellison (8), and others have offered less formal evidence, that tasks are performed with qualitative as well as quantitative differences among individual operators at different levels of practice. Fleishman interprets this as evidence of the appearance of individual differences that are not the same in late learning of a skill as those shown in early learning.

For example, a student who is rapid at rote verbalization of procedures may quickly master the early stages of a procedural ability, but as greater speed is required and the verbal mediators have to drop out of the behavior, the individual with better "eye-muscle" learning ability will surpass the good verbal learner. (This example is a supposition not based on empirical evidence.) The example is useful in pointing out that high degrees of practice do lead to automatization of habits--the dropping out of verbal-conceptual mediating behavior--so

that the habit in the form of a skill is a different organization of response than it was when performed as verbal-mediated behavior. Not only are there different "ability" implications, but different human engineering and training implications at different levels of learning.

This suggests at least two levels of learning: mediated and non-mediated.

Level of learning also has an oblique, but significant, relationship to task functions used in describing behavior. The relationship can be summarized in a principle: "The higher the degree of practice with a given population of stimulus situations, the lower the complexity of the kind of task function (or number of processing transactions) which mediates the response to the stimulus situation."

An example may help clarify this assertion and explain its relevance to task analysis. An intern is learning to diagnose common ailments. In the course of examining each patient, he scans and detects, identifies symptoms and non-symptoms (sometimes confusing one with another), interprets clusters of signs one way and then another, and goes through a complex set of "pattern matching" operations in reaching a decision--that is, naming the ailment, if any. The decision is reached after sifting through uncertainties and assessing risks. With more practice in diagnosis, he is likely to develop a strategy for converging on the disease entity, and rather quickly narrows the field to several possibles, making the conclusive checks that rule out all the remaining alternatives. With still better mappings of disease patterns in mind, along with range of differences of a given kind of symptom among different patients, he makes an interpretation of the symptoms as a pattern as he fits the data elements together. He projects diagnostic meaning into the [illegible]ts he makes in the act of making them; he is rejecting disease symptom "maps" as he proceeds.

As an accomplished internist, having diagnosed thousands of patients (many of them successfully) he is able to identify by name the common ailment almost as soon as he looks at the patient. The name of the disease springs almost spontaneously to mind, and his further checks tend merely to be confirmatory. The careful practitioner takes precautions against his own quick identifications, of course, but a spontaneous process has been described which is, from the standpoint of behavioral efficiency, adaptive.[2] (It is sometimes maladaptive operationally, but that is not the present issue.)

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[2] Procedural guides and supports can truncate this process. Decision-tree types of format have enabled laymen within a few hours to make diagnoses from X-rays of disorders in the chest that compared reasonably well with diagnoses from the same X-rays by internists (9).

We have seen a task situation, which at one stage of practice consists of almost formal decision-making behavior, shift to interpretation and finally to identification (practically recognition).

Such examples can be found abundantly among jobs of practically every kind. The novice driver trying to make up his mind whether or not to pass a car on a winding, hilly two-lane road; the expert driver identifying at a glance that he has ample distance for passing because of his stored knowledge of the capability of his car, the probable maximum rate of an approaching car, and an estimate of the line-of-sight distance necessary to pass. In an analogy contained in computer jargon, he develops a "table-lookup and a simplified search argument for searching the table."

Of course, the larger the universe of variations, and the larger the number of variables in that universe, the greater the amount of practice required to move from one level to a lower level of information processing function for effective performance. And the more subtle the differences, and the greater the unique interaction effects among the variables, the greater the difficulty in generalizing a "recognition" instead of engaging in more deliberate decision making with awareness of risk-taking and implications of alternatives.

Clearly, level of learning is an important dimension for generalizing data obtained from one sample to the situation imposed on another sample, even with practically identical task requirements. A time-driven task that is practically impossible if performed at the "decision making" or the "interpretive" level, may be performed quite reliably at the "identification" level of behavior. These are highly oversimplified characterizations of behavior in real life, and of task organizations.

Incidentally, the economic and other practical exigencies of laboratory research tend to rule out levels of learning much beyond the relatively early stages of bare mastery. The psychological literature shows practically nothing about the development of complex, meaningful skills examined in terms of transfer of training, ability, susceptibility to deterioration from various influences, type and frequency of errors, habit flexibility, and so on. The literature of learning is essentially that of novice behavior in cognitively deprived tasks; this may be a substantial reason for its general lack of utility--even in terms of learning principles--in the practical milieu.

Summary of Task Description Requirements

In order to organize and generalize from the literature on human performance and behavior, four major dimensions have been proposed for characterizing task information: (1) the name of the task function; (2) a statement of task content--the kind of information with which the operator deals and its meaning references; (3) the task environment, including physiological and psychological stressors and conditions, extent of requirement to operate at maximum performance limits, other temporally associated goal-directed activities; and (4) the stage of learning stipulated for the task, taking into account that different amounts of practice change the psychological mechanisms of performance and modify the kind of information transaction (or function) used in accomplishing the task.

These four dimensions could be used as the basis for indexing a library of task descriptions. Establishment of such a readily accessible reference library of tasks would serve one of the major needs of the researcher.

GROUNDRULES FOR THE DEVELOPMENT OF A TRANSACTIONAL SYSTEMS TASK VOCABULARY

A utilitarian taxonomic glossary may derive from classical methods of behavioral research, though it will be many years in the future. For the present and the immediate future, workable alternatives are needed. The growth and proliferation of information systems in which men and computers converse more or less at human problem solving rates makes at least interim techniques for mapping and naming system behavior imperative.

From a practical standpoint, there is an intimate relationship between a useful language for describing and analyzing human tasks and a useful taxonomy; they may be parts of a single descriptive procedure.

A rationale for creating a descriptive and analytic terminology of general system design and reference utility is presented here which is based on the transactional definition of task presented earlier. A tentative set of transactionally-designed "information processing" categories, based in large part on this rationale, is offered as an exhibit in the appendix of this report. Its claim to validity is not so much on the repeatability of its derivation as on its utility to system designers.

As stated previously, a language, including its classificatory structures, for system or subsystem design is not an end in itself. It is a mediating tool with three anchoring positions. One anchor is embedded in the operational phenomena, the non-verbalized universe of

system events, both hypothetical and actual. The second anchor is in the creative conceptual chambers of the designer's mind. The third is in the resources available to the implementer.

Here is the rationale in condensed form. It is not necessary to agree with all of the arguments in order to accept the outcome. Beside providing a rationale for development of the appended terminology, the commentary is intended to serve as guidance for those choosing to add to or change that terminology, or start anew. The rationale may also suggest a basis for the development of quantification techniques with this kind of transactional definition of functions.

1. Assume that the human is an information processor. He can code one class of information into another class of information where the second class is symbolic of the first. Symbols, when communicated from one device to another, take the form of "messages". Humans, capable of symbolic behavior, are "message processors". (The concept of message is explored in a later topic.)

2. Stipulate that an analytic, descriptive vocabulary of general utility for a group of designers, working singly or in teams, should be limited to about 25 terms. Indeed, fewer would be better, but precision may be a tradeoff to discriminability beyond some limited number of transaction types.

3. Assume that a workable vocabulary for human tasks will also be a workable vocabulary for man-machine tasks. We can at least agree that it would be highly desirable, other things equal, that the same terminology be useful to designers in both contexts.

4. Stipulate that identifiable transaction operations be required of the definitions of the terms to be developed. This does not mean that in all cases there will be unanimous agreements on the classification of an observed phenomenon. It does mean that the observer should be able to justify the term he selects on the basis of the transaction he has identified.

5. The activities denoted by one term may be component activities of those denoted by another term. Terms need not be mutually exclusive of each other. The compounded meaning may be desirable when properties or usages emerge that are not the direct sum of the constituent elements or transactions.

6. Assume the necessity of judgment in applying these terms to the phenomenal world, hence of training and sharing of observations with a common reference background by observers examining the same phenomena. That is, the terms can be expected to have some degree of ambiguity when applied to real life situations.

Minimum System Functions

A well-established minimum characterization of an adaptive (programmable) system consists of the following functions: input reception, memory, processing, output effectors. These four terms are a useful starting point for deriving and organizing a transactional terminology.

Definition of Message

The concept of "message" may, like stimulus in psychology, be a fundamental one. Only a brief and tentative statement of the implications of this concept is offered here.

The concept of "message" seems necessary for a system that is more than a physical transducer--that is, one which works also with symbolic representations. A message embodies a unit of structure of information. (Structure refers here to syntactic rules and relations.) A declarative statement is one class of message. Among its syntactic elements are subject, predicate and object. A message has semantic, syntactic and pragmatic dimensions--those of reference (or meaning), of structure and of utility. Messages are transmitted in a medium; the medium imposes constraints on what may be communicated, in what patterns, and how rapidly. The variable elements in a message consist of code. A code is a set of rules for selecting, or interpreting, the symbols that transmit the content of a message. Ordinarily, a message may reach its maximum level of potential effectiveness when the recipient shares the same rules for decoding a message with the source that encoded the message. It is not necessarily assumed that source or recipient is a human being. Potentially, a message is a means of transmitting control from a source to a recipient.

The concept of message deserves more extensive and rigorous treatment than that given above. Because the concept implies both data and structure, the idea of message could become an important supplement to, or replacement for the classical concept of stimulus (with its vague generality) and for the information theory concept of "bit" with its quasi-precision but limited range of applicability.

Pragmatically, the term message may be offered as an undefined term, except for a variety of examples, in a descriptive system. A term which lacks formal definition gains its meaning from the context in which it is used. Probably every analytic system contains one or more undefined terms. An undefined term is not necessarily undemonstrable (10).

Defining a Functional Term

Each term in the vocabulary was developed more or less as follows. An image of a generalized information processing system was held in mind. It had receptor input channels, a processing facility, a modifiable memory for both data and procedures, and output facilities for doing symbolic work by emitting code that would select and activate physical work mechanisms. This generalized and abstract entity was conceived as being in an environment which developed patterns of signals which we have called "messages". Messages and the system exist in time; therefore, a message must be either in a state of being transmitted, or stored, or being processed, or some combination of these. This is a highly significant consideration in developing a set of consistent and operational definitions of functions.

The concept of system "purpose" or "goal" can be sidestepped by treating system purpose as the result of a supersystem design entity embedding implicit purpose into both the design of the system facilities and the control programming of these facilities. In human task analysis, the concept of goal and goal image must enter as a processing criterion or reference test imposed by the human system selectively on message class accepted, program subset selected for processing, preselection of memory content, and preselection of class of output activity. Translated into simple English, when we are thirsty we look for signs leading to water; we attempt to recall or deduce how the available cues were used to find water in the past, and we select those actions which we expect will lead to water. When we are looking for a book about careers in psychology (purpose) we tend to ignore signs and instrumental acts about water. This treatment enables goal or purpose to be made consistent with an information processing approach. Novel insight is not implied here. Others have treated "purpose" in more or less the same way (11), (12).

The invention (or identification) of processing concepts is facilitated by an imaginary sequencing of activities performed on a message from the time that it is available for entering an input queue (where it must compete with other messages and with irrelevant perturbations or noise) until an appropriate or inappropriate action is emitted by the system into its environment. The partition between "system" and "environment" is, of course, an arbitrary one.

The development of processing concepts is also facilitated by sampling from different kinds of message format and content that imply different treatments by the system in selecting appropriate outputs. In simple processing there tend to be one-for-one relationships between the format and variable content of a message and the code for selecting the output response. But messages may be incomplete, in this sense, or contain irrelevant data or require code translation. Some messages

may have to be combined with other messages as context; the source of the other messages may be the environment (implying short term storage control) or the memory of the system (long term storage retrieval). The message may require "decoding" in the form of conceptual or logical operations. System facilities or functions are required for transforming these inputs into a code for selecting output actions.

The realist understands that messages may fail to arrive, may be garbled, or contain false information, arrive with missing information, or be confused with other messages. Furthermore, any facility can generate noise or error either through solid or transient failure, or because of an error in "programming". Facilities therefore create the need for functions entailing their own management. Hopefully, no unique terms will be required for the analysis of transactions of the failure class.

One curious example of a function does derive specifically from a facilities requirement. That is the function called "reset". From one viewpoint it is similar to the concept "purge". However, the latter has been defined as a systematic form of reduction or elimination of information contained in some entity by an information processing activity, whereas "reset" is defined as the physical expunging of a content from a facility so that the facility can start working at its nominal starting position (in the case of a counter, being set at zero).

Framing the concept of a function in an operational definition is done by means of a simple conceptual model consistent with the entire approach described thus far. A function is defined by stating the significant feature of: (a) the input mode, message, or source; (b) the processing rule or operations for translating the input into the output implied by the concept of the function; and (c) the output condition or result of the operation.

In some cases, the function results in a transformation of the input message, or combination of messages; an example is "compute". In other cases, another order of information may be derived, while the message itself may be unaffected; an example is "count". In other cases, the message may be changed from an active to a passive state; for example, "store". Notice that an operational definition of store properly includes (or at least can be linked to) the operations of "putting the message into store" and of "retrieving the message from store", as well as "holding in store".

These rules for making a definition enable terms that are linked to each other to maintain a picture of continuous process flow. This is an essential requirement for a useful analytic and design language. The requirement of linking transactions does impose some redundancy among terms, but this seems a small price for comprehensiveness.

Notice also that, as with operational definitions in general, the name of the function becomes almost gratuitous when the transactions have been defined. In fact, the name of the function becomes merely a mnemonic handle for the human analyst/designer.

Current Version of a Systems Task Vocabulary

Now that I have described how I would design a systems task vocabulary, it is appropriate to present my current working version of a systems task vocabulary based on these groundrules. The vocabulary, in abbreviated form, is shown in Table 2. The colloquial phrase given for each term is intended as a mnemonic aid, rather than a definition. In addition to providing definitions of each term, the appendix includes a brief statement of objectives and guidance in use of the language in practice.

The terminology has one notable omission. The concept of "power" is absent. Physical operations on signals require energy and entail energy loss or change. The psychological analogue of physical power is, of course, motivation. The logical requirements of an inanimate mechanism may be usefully treated independently of physical implementations (i.e., mechanisms that do physical work). It is only a hypothesis that a methodology for the analysis of human behavior or performance which ignores this vexatious class of variables can be effective beyond preliminary analytic stages of design.

Table 2

A SYSTEMS TASK VOCABULARY IN SIMPLIFIED FORM

Term	Simplified Description
MESSAGE	A collection of symbols sent as a meaningful statement
INPUT SELECT	Selecting what to pay attention to next
FILTER	Straining out what does not matter
QUEUE TO CHANNEL	Lining up to get through the gate
DETECT	Is something there?
SEARCH	Looking for something
IDENTIFY	What is it and what is its name?
CODE	Translating the same thing from one form to another
INTERPRET	What does it mean?
CATEGORIZE	Defining and naming a group of things
TRANSMIT	Moving something from one place to another
STORE	Keeping something intact for future use
SHORT TERM STORAGE (BUFFER)	Holding something temporarily
COUNT	Keeping track of how many
COMPUTE	Figuring out a logical/mathematical answer to defined problem
DECIDE/SELECT	Choosing a response to fit the situation
PLAN	Matching resources in time to expectations
TEST	Is it what it should be?
CONTROL	Changing an action according to plan
EDIT	Arranging/correcting things according to rules
DISPLAY	Showing something that makes sense
ADAPT/LEARN	Remembering new responses to a repeated situation
PURGE	Getting rid of the dead stuff
RESET	Getting ready for some different action

CONCLUDING COMMENT

This paper does not provide a solution to the task taxonomy problem. It does attempt to define the problem in a full range of contexts relevant to the practical world of people performing tasks, and the complexities and ambiguities of decision making in system design. I have tried to characterize a much needed methodological tool. In the appendix, I have indicated what I think this tool should look like.

Task analyses are being performed. Names are being given to tasks and to behaviors, to duties, requirements, jobs and position descriptions. In previous reports (1), I have outlined what I and some of my colleagues have found to be a useful way of characterizing task structure. I regard this and my present proposal as examples of what is needed, rather than a final product.

By context, rather than systematic analysis, I have tried to show that a useful descriptive/classificatory structure should view behavior as transactions rather than as properties or attributes. In this and an earlier paper (13) I have insisted that any tool used by humans must depend to some extent on human judgment and interpretation, therefore on a human skill that varies from person to person and from one circumstance to another. The translation of observations of events to useful data inevitably requires a human semantic operation, and this is an act of judgment in greater or lesser degree. A candid description of a technical tool should include specification of those acts of human judgment and interpretation. This kind of explicitness will establish when--and to what extent--a problem has been solved rather than begged.

It is my hope that creation of a useful task taxonomy in the near future has been aided by my attempts to define the application problem and to provide a method for development. Readers with comments about my own efforts in this regard are urged to contact me.

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Attributes of a Useful Transactional Language

1. The language should provide a vocabulary and a set of variables for stating in qualitative and quantitative terms the objectives of the system: what it is supposed to do in terms of inputs to the system to be converted in terms of outputs. The same vocabulary should be applicable to describing internal functions in the system.

2. The terminology should be sufficiently complete to enable the chain of functions between system input and system output to be set down. Functions that arise internal to the system--such as control functions, or reliability functions--should be expressible in the same terminology and notation.

3. The terminology should reference transactional definitions that point both to the transformation operation and the information necessary to make the transformation denoted by the term.

4. The terminology should be independent of the mechanism that might perform the function.

5. The terminology should be applicable to gross and to fine levels of system operation. That is, it should apply to micro operations and to macro operations.

6. For human convenience in learning and application, the terms in the vocabulary should be less than 25 to 30 in number.

Notation for Use of Terms

The notation for using the following terms is that of a flow diagram representing a sequence of transactions from a given input condition, or pattern of conditions, to the system (or some subsystem of interfaces) through to the output. The transaction must in some way account for the information required to perform the function. Making a "check" requires that a reference be made to stored information of the limits of a normative state for the check result; thus, checking is a measurement of an actual, a compare with a reference, and a decision; it also implies an inference about the limits of the chunk of activity (or of facilities) that has been checked.

Practical Use of the Language

In practice, the language is used in the following way. A scenario is prepared of the sequence of activities in the operational use of the

system. For example, a human user of a semi-automated "information system" initializes a conversation with a terminal (and computer) by inserting his identification card. This might be step 1 in the scenario. It sets a train of events in motion. This train of events is described by the systems language in the notation of a flow chart. Thus, a power switch is activated, the terminal seeks a communication line, the identity is checked for valid use of the system, a domain of data and programs appropriate to the tasks of the user is summoned from remote storage, and so forth. This sequence of actions is represented by a flow diagram in the systems language. In psychological terms, this is equivalent to a cue which initiates a task "set", or particularized predisposition to respond.

The next step in the scenario may be a request for a format for entering a query of a given class. This sets in motion another train of functions or activities, i.e., another sequence of processing flow functions is initiated. This sequence is diagrammed like the first, but a different pattern of information functions will be drawn. As additional steps in the operational scenario arise, they are similarly analyzed for their information processing content and operations.

The scenario should be time ordered, so that concurrencies can be identified. This enables determining what activities must be performed in parallel (i.e., as a pattern) and identified action nodes (what activities must be brought together at some local terminus in order for a decision of some specified kind to be made).

Combining the processes that must occur with each step in the scenario sequence with all the steps in the scenario results in a time-ordered mapping of the information processing required of the hypothetical system--or of an actual system in an operational environment performing a task. This mapping enables processing "nodes" to be abstracted in approaching the design of the system, whether it is a human entity, a machine entity, or a combination of both. This is a fundamental step in conceptualizing a design, and in the ability to make significant tradeoffs about the physical organization of functions at the time that such tradeoffs count most--before the physical structure and the procedural structure are frozen.

It must be emphasized that the functional mapping must be revised with each step in the physical design of the system. Each physical facility imposes its own pattern of "requirements" on the system--its own channel capacity, its delay functions, its reliabilities, and its limitations.

Strategic principles for the organization of functions may be developed as a body of "system science". The characteristics and properties of various devices for implementing given processing functions, singly and in combination, become a branch of applied systems knowledge.

The following terms and definitions have had application at the conceptual stages in the design of an information processing system. The system was intended to include humans and programmed devices.

A Systems Task Vocabulary

1. MESSAGE
2. INPUT SELECT
3. FILTER
4. QUEUE TO CHANNEL
5. DETECT
6. SEARCH
7. IDENTIFY
8. CODE
9. INTERPRET
10. CATEGORIZE
11. TRANSMIT
12. STORE
13. SHORT TERM STORAGE (BUFFER)
14. COUNT
15. COMPUTE
16. DECIDE/SELECT
17. PLAN
18. TEST
19. CONTROL
20. EDIT
21. DISPLAY
22. ADAPT/LEARN
23. PURGE
24. RESET

A Systems Task Vocabulary in Simplified Form

1. MESSAGE - A collection of symbols sent as a meaningful statement.
2. INPUT SELECT - Selecting what to pay attention to next.
3. FILTER - Straining out what does not matter.
4. QUEUE TO CHANNEL - Lining up to get through the gate.
5. DETECT - Is something there?
6. SEARCH - Looking for something.
7. IDENTIFY - What is it and what is its name?
8. CODE - Translating the same thing from one form to another.
9. INTERPRET - What does it mean?
10. CATEGORIZE - Defining and naming a group of things.
11. TRANSMIT - Moving something from one place to another
12. STORE - Keeping something in tact for future use.
13. SHORT TERM STORAGE (BUFFER) - Holding something temporarily.
14. COUNT - Keeping track of how many.
15. COMPUTE - Figuring out a logical/mathematical answer to defined problem.
16. DECIDE/SELECT - Choosing a response to fit the situation.
17. PLAN - Matching resources in time to expectations.
18. TEST - Is it what it should be?
19. CONTROL - Changing an action according to plan.
20. EDIT - Arranging/correcting things according to rules.
21. DISPLAY - Showing something that makes sense.
22. ADAPT/LEARN - Making and remembering new responses to a repeated situation
23. PURGE - Getting rid of the dead stuff.
24. RESET - Getting ready for some different action.

<u>Note</u> that the colloquial phrase for each term is intended as a mnemonic aid, not as a definition. Definitions and examples are given on the following pages.

MESSAGE

A collection of symbols sent as a meaningful statement

A pattern of input symbols* that is "meaningful" and purposeful in that it activates (or can activate) some processing capability of the system in generating a useful response.

The formal features of a message consist of a set (as "vocabulary") of elements and of the pattern (syntax, grammar) in which the elements are arranged.

1. The elements or symbol set consist of a limited number of "defined" terms.

2. The patterning of the symbols are grammatical rules for organizing them into meanings.

Example: In human discourse the message unit is the sentence. A sentence consists of words (elements) patterned by rules of grammar. The meaning of a sentence is based on both the words chosen (i.e., from a vocabulary of English) and their grammatical arrangement. An operational message consists, in its simplest form, of subject, predicate, and object as in : "Store number 9 in cell 12."

In system behavior, a message about a state (or stimulus condition) must ultimately be linked to a response action or response decision. In other words, "data" must eventually be linked to an "instruction" for operating with or on the data.

What is "data" and what is "instruction" content in a message is relative, not absolute. It is relative to the operations performed with or on the message by the system.

In operational terms, the "meaning" of a message is identified by the response it can or does generate.

A message is the smallest conceptual unit of action that produces a system response that is useful to a user of the system. This is in contrast to a signal which is defined as an instigator of action localized to one or more system components.

Pressing a machine STOP button introduces a message. In effect, the message is: "Whatever the present activity or the state of affairs right now (subject) stop (predicate) it (object)." The linkage from the STOP button to the stop controls contains the context of the message introduced by pressing the STOP button.

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* A symbol is a pattern of signals that can initiate or direct a given processing action.

INPUT SELECT

Selecting what to pay attention to next

Rules for admitting a message or message channel into the internal system.

These rules may include system turn-on and turn-off schedules, or power-up on input lines.

Input select rules may operate at the information source to compose a message eligible for entry into the systems according to criteria of (a) format, (b) content.

Examples

1. Polling procedures for accepting from an input channel.
2. Rejection of message lacking pre-established fields of information.
3. Rejection of message containing illegal symbols.
4. Composing of source message for entry to system.
5. Selective response to patterns of auditory input signals.
6. Rejection of a given signal-to-noise relationship.

Variables in Designing Input Select Rules

1. Physical mode of sensing: auditory, optical, mechanical, electronic, etc.

2. The symbol set or vocabularies permissible for acceptance.

3. The "grammar" or syntax variables that structure symbols into words, fields, stimulus (data) or response (instruction) and other format characteristics.

4. Channels to be made available from sensor to processor-memory.

5. Size of chunk of information acceptable at one time: e.g., symbol, word, sentence; information field length.

Principles

1. The fewer the alternatives in message form (symbol set, formats and length of message), the cheaper and faster to decide to accept or reject. The penalty for limited, standard messages comes from increased limitations in range of message content and increased effort to compose messages within the constraints.

2. The smaller the alternatives allowed in message options, the greater the number of messages that may have to be stored and collated where a meaningful system action requires more information than a single message can carry.

3. The greater the rigidity of message structure, the fewer the users and the smaller the range of users.

4. In summary, there tends to be a tradeoff between the ease of accepting the processing messages by a system and the ease of generating and composing messages from the information source.

FILTER

Straining out what does not matter

Procedures for reducing or eliminating irrelevance and disturbance from signals and messages.

Principle

Signal or message elements that do not serve a system purpose are costly to transmit, process, store and retrieve, and can interfere in carrying out system purposes.

Comment

Major sources of irrelevance (and inaccuracy) are usually at the human input to information processing. For this reason, attention to a discipline for input formats (language terms, syntax, and user concept of purpose) is perhaps the most important type of filtering device for a processing system. Some degree of redundancy usually helps the human in composing and checking his own output (which is also a message to himself). This redundancy may be filtered out by the non-human portions of the system to which it is a nuisance.

QUEUE TO CHANNEL

Lining up to get through the gate

Rules to organize random arrivals at one or more entrance gates into a waiting line.

Purpose of Queuing Rules

1. To attempt to minimize extreme fluctuations in length of waiting lines.

2. To minimize delay in assigning processing priority if the priority is based other than on serial order of arrival.

3. To minimize conflicts among those in the waiting line.

4. To sample from waiting lines at a rate that optimizes between:
   a. arrival frequencies and average waiting times
   b. length of input messages
   c. system response capabilities (throughout time)
   d. number of channels required for given population of demand

Note: Queuing rules interact with INPUT SELECT rules for the formatting of messages into the system. They may interact with rules for the formatting of output in real time systems where an input channel is also an output channel.

Principles

1. If no user ever has to wait at all, the system is probably more expensive than it needs to be--or is being underutilized.

2. Human users can accomodate their expectations of delay and delay probability in getting attention.

3. Humans with different kinds of purpose will tolerate different kinds of delay in getting attention.

4. Where possible, message priority should be established without having to process all the messages, and ideally would occur immediately when (the message) or sender (joined) the queue.

5. Unused channels should be switchable to overcrowded queue lines, but without jeopardizing relative positions in the waiting line. Thus, diverting the tail of queue to a new ticket booth is unfair to those forward of the break.

6. Any evaluation of thruput speed of a system should include waiting line statistics.

7. Humans are probably less patient in waiting for attention than in any other context.

8. Unless constrained or trained to do so, humans will not spontaneously organize themselves or their inputs into a serial order according to arrival.

9. If more than one equally accessible entrance gate is available, newcomers should be directed so that all wait lines are of equal length.

10. Qualify item 9 above as follows: Specialize queues for long and short inputs. A short input will endure a longer line if it is perceived to move quickly. Average wait time for short (or fragmentary) messages should be less than for long (or complete) messages.

DETECT

Is something there?

Procedures and mechanisms for sensing the presence or absence of a cue or condition requiring that some form of action should be taken by the system.

Detection requires the discrimination of an action-stimulating cue from some background of stimulation.

What is detected may consist of normal work cues, or of exceptions (such as errors). The source of these cues may be inputs to the system, or feedback from the monitoring of outputs. The sensing function does not analyze or classify the cue.

Note: Detecting, as defined here, is confined to a sensing operation which excludes interpreting activities. In human terms, detecting results in sensing a stimulus to which attention will be paid. In many practical situations, however, detecting and identifying are a single process. See IDENTIFY.

Scanning and Detecting

Unless the sensor is a part of a fixed channel, it must scan segments of its environment so that the sensor is exposed to signals. The sensor is preset to respond to certain kinds of change or discontinuity in the field being scanned.

Principles

1. The response lag of the detecting device must be less than the cycle time of the stimulus to be detected.

2. The greater the contrast between the stimulus to be detected and its background, the greater the reliability of detection.

3. For given kinds of signal patterns to be detected, some scan patterns and frequencies are better than others.

4. In human behavior, what will be detected is related to "set" or pre-established tendencies to respond. More simply, we tend to notice what we expect to see, or what we are looking for, or what we are attending to. A number of principles in addition to Item 2 influence human detection, as well as other sensing and perceptual behavior.*

Comment

In digital processing activities detect and IDENTIFY cannot be separated. But in analog activities a sensor may detect a pattern of frequencies representing a speaking voice, but not be able to identify it or its content.

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* See the chapter on perception in any general psychology text.

SEARCH

Looking for something

Rules for selecting a set of entities for inquiry, for sequencing an inquiry among members of the set to be searched, and rules for applying criteria of "same" or "different" between the objective (search image) for searching and the objects in the search set being examined.

Selecting a Set of Entities for Inquiry

The set of entities for inquiry make up the "universe" to be searched, like the file room or file drawer in which a document is sought. The search request must contain or embody a code which identifies and subdivides the physical or logical universe to be searched.

Sequencing an Inquiry

The rule or principle for selecting for examination each next member or element in the searchable set. For example, this may be done by serial order, binary techniques, probability, recency of insertion to the file set, index linkages and others.

Matching Search Image and Object Examined

The search image is by definition the necessary and sufficient information for establishing either "yes, this is the object I want in this search set" or "no, I don't want this object in this search set". The process of making this decision will consist of a set of rules for sequencing a pattern of steps for trying to match successive attributes of the search image with the object examined. Matching may be a step-by-step comparing of each attribute of the search image with the object examined, or simultaneously on the principle of an optical mask. Undoubtedly both principles require the support of an indexing structure.

Comment: The identity which is searched for may be coded by location, relative position or by category code. The identity may also be based on one or more physical characteristics if the information is analog.

IDENTIFY

What is it and what is its name?

Methods for characterizing a message by type or by source.

In ordinary usage, to identify is to recognize an object or entity and apply some label to it.

> Thus: Identify a sender, a Type I instruction, a location, a previously received message.

Identification requires a referencing action. This action produces the name or similar symbolic response to attach to the sensed input.

> (In human behavior, the content of this symbolic response may not always be explicit: you "recognize" an individual and treat him as a "recognized" individual even though you don't recall his name or other explicit reference in your experience with him.)

In information processing, two sets of reference codes may be necessary. One reference structure may apply to the universe outside the processing system (for example, the name and address of the sender of the message). The other reference structure is to the physical (and/or functional) location of the message as an identity within the system. These two identity codes may require a set of cross-referencing rules or codes.

<u>Principles</u>

1. The identifying operation generally requires information in addition to that necessary for the detecting operation.

2. Once an identification is made, cues inconsistent with that identification tend to be ignored.

3. In human behavior, expectancies and recent experiences strongly influence how a set of cues will be "identified" even though inconsistent cues are present.

4. The labels making up an "identity" may consist of one or more of the following kinds of symbols:

   a. Arbitrary serial number (library accession number of books, street numbers on buildings, serial numbers starting from zero and progressing continuously).

   b. Individual or class name (George Washington, emergency code, shelf number of library book, title of book).

   c. Combination of class identity and individual identity (social security number which contains region digits and individual's digits; changed part number consisting of original part numbers plus suffix).

Note: The most efficient and unambiguous labelling or identity coding, from standpoint of symbols required in an open-ended acquisition series, is by ordinal number where the code name given to each new acquisition is one increment larger in the symbol series than the previous acquisition. Thus 1, 2, 3, ...n.

An object or message may have two cross-referenced identifications: an accession code (which is unambiguous) and a content or attribute code based on its attributes. The latter has high probability of ambiguity but may simplify preliminary phases of search in a file.

CODE

Translating the same thing from one form to another

Encoding and decoding: rules for translating messages in one symbolic form to another symbolic form, presumably without loss of information content.

Example: The decimal number 12 coded as the binary number 1100.

Recoding of messages standardizes their symbolic format so that they can be processed by a standard device and a standard instruction set.

Properties

1. Symbols are more readily (cheaply) checked and corrected automatically in some codes than in others.

2. A small variety of symbols may be compensated by a large number of symbol positions. Thus, there are 10 different decimal symbols, but only two binary symbols. On the other hand, the decimal 12 is expressed in two symbol positions (the tens position and the units position) whereas the binary expression of the decimal number 12 requires four positions.

3. Coding may apply to a symbol (m), a word (MILE), an expression (the miles from New York to Chicago), or a statement (the message went from New York to Chicago). Position information may be coded (18° latitude, 42° longitude), but always requires a position reference to be explicitly or implicitly identified.

4. Recoding is often necessary when changing from one type of transmission medium to another.

5. Recoding can eliminate redundancy from a set of symbols (or a language) and thereby increase system efficiency. These gains are somewhat reduced by the cost of logic for the recoding operations.

INTERPRET

What does It mean?

Rules for translating the symbolic context of a message into a reference or meaning, usually by addition of reference context from within the message itself, or reference context outside the message itself.

Examples

1. Automatic analysis and "recognition" of an English word as a pattern contained in the physical wave form of an utterance.

2. Human conclusion that the unannounced approach of foreign aircraft, detected and identified on radar screens, means invasion and war.

3. Human conclusion that a given pattern of symptoms signifies that a system failure must be caused by a programming error rather than a machine failure.

4. Language translation from Greek to English expressions.

Note: Interpreting requires response to a pattern of cues, and applies to events on conditions that go beyond the input data (or symbols) as such. The input data are only a part of the total information required to make the interpretation. This differentiates interpretation from decoding.

An interpretation is an inference about a condition, or state of affairs, or source of data.

Process Variables

1. Degree of statistical certainty of correctness required of the interpretation.

2. Amount of redundancy in the form of context available in the message.

3. Range of variability among elements in the pattern to be determined.

4. Proportion of irrelevant transients in the message which act as noise to interpretation.

5. Number of elements sufficient and necessary to make matches with a reference set (or "dictionary") of meanings or interpretations.

6. Number of alternative meanings or identifications in the reference set available for trying to make matches.

7. Opportunity for interpreter to query message source for additional information for testing hypotheses about an interpretation.

CATEGORIZE

Defining and naming a group of things

Rules for classifying data, information or intelligence according to its source, format, purpo e or content in order to organize messages into meaningful groups, or in order to selectively retrieve them for decision making and control.

Examples

1. All messages about John Doe are categorized (Labelled) "John Doe" and go into the "John Doe file".

2. Data describing the functions of a system are classified as "input", "processing", or "output".

3. "Age of applicant" data are entered in the third "field" in each applicant's record.

Categorical Structures

A set of categories may be in the form of a list where each member category is independent of every other member ("age, height, weight") is an example. A set of categories may be arranged in trees or hierarchies: "safe drivers under 25 years of age, safe drivers over 25 years of age".

Ambiguity in Classifying

Classification rules are unambiguous only when the classification is based on some arbitrary counting of discrete units (e.g., men with 5 children) or natural dichotomies (e.g., males or females) or physical location (e.g., cell no. 121). Rules for classifying by attribute (blond vs. brunet) are always ambiguous in application.

Design Principle for Category Structure

An efficient category structure is one which permits the largest number of purposes for using an information file to be performed with the fewest decision operations in (a) classifying incoming messages for the file and (b) in searching the file for messages relevant to purposes.

This principle suggests that a classification scheme for information coming into a system should be designed around the categories of purpose and the options of control available in the system or subsystem. In short, develop categories around the ways you will use the information, not on the ways in which messages may differ from each other. Control options tend to be fewer than the variety of input conditions requiring a control decision that selects a control option.

Example

A given control switch can be set in either position A or position B. No matter what varieties of information come into this mechanism, there are only two valid and useful categories for this information: Category A that sets it in Position A and Category B that sets it in Position B. (The argument that a category exists which is information that interferes with these choices is irrelevant.)

Comment

The central design issue in any information-retrieval system is category structure, and the interaction between filing categories and searching categories.

TRANSMIT

Moving something from one place to another

Rules and conditions for transmitting a message from one location to another.

Serial Versus Parallel Transmission

In serial transmission, message elements are transmitted one after another such as the dots and dashes of Morse code. In parallel transmission, the message as a whole, or chunks of it, is transmitted at the same time , e.g., the optical projection of an entire image through a lens. In wire facilities, parallel transmission is faster but costs more in hardware.

Bandwidth

This is the rate at which discriminably different elements at the receiver can be transmitted through a medium. Bandwidth is a measure of channel capacity to transmit signals. (It is also a term sometimes used to describe a processing thruput rate.) Greater bandwidth usually requires higher dollar cost.

Open Versus Closed Transmission Lines

An open line (also called "dial-up") is one which is continuously open to a message source for transmission. A closed line requires the sender to request to be switched to an open path, or to wait until a path is periodically opened to him.

Coding and Buffering

Long distance transmission often requires changes in the physical form of the message, and in transmission rate. These changes require coding and decoding logic and physical changes in the signal carrying the message.

Tradeoffs

1. Speed of transmitting input messages in segments of all-at-once is a tradeoff against facility costs.

2. Reduction in mean waiting time to send a message is bought at higher cost whenever there are queues.

3. Local processing with fewer and shorter messages to transmit versus centralized processing with heavy communication traffic and facilities.

4. Error detection and correction operations impose redundancy in message content and delay in transmission throughput.

5. Identification of message (and message segments) by physical or logical location of source versus by code identification transmitted with the message or message parts.

6. Time slicing with fixed message length and predictable time of transmission versus total message transmission regardless of length but unpredictable time of initiating transmission of any given message from an origin.

7. Polling each of multiple source channels in sequence in order to determine if a source message awaits transmission versus demand for attention signals to the message sink and queuing lines.

STORE

Keeping something intact for future use

Rules for holding messages for retrieval in terms of where and how. These include rules for filing and retrieval search. The contents of storage are data or programs or combinations of both.

Essential Operations

1. Labelling the stored content by code or physical position.

2. Determining units of physical store required by the stored content.

3. Locating the physical place of available storage space.

4. Loading the content into the physical storage.

5. Safeguarding from physical deterioration.

6. Identification of the stored content.

7. Selective unloading of the stored content.

Tradeoffs

1. In non-associative memories, as memory size increases, the information required for identification of a storage cell (or content) may become greater than the information content of the cell.

2. Serial access to stored information (e.g., magnetic tape) is cheaper in storage cost per message, but more costly in search time than random access (e.g., magnetic core).

3. The savings in processing gained from tables of precalculated answers is offset by time to search the table and by the filling up of physical storage space.

4. Simplicity and reliability in filing a message or message content (such as by serial access number) is counterbalanced by complexity and unreliability in searching for the message content.

Associative and Non-Associative Memory

In a non-associative memory, the label or name attached to a message for filing or retrieval has no meaningful relevance to the content of the message. The label may be an arbitrary cell number or position (e.g., "message number 1101").

In associative memory, the content of the message is, in part or in whole, the symbolic basis for filing and/or retrieving the message (e.g., "message containing 'winning horse' ").

In non-associative memory, selection logic in search applies only to message labels. In associative memory, selection logic in search applies to message content.

SHORT TERM STORAGE (BUFFER)

Holding something temporarily

Rules for holding in temporary storage a message or parts of a message for use at a later time during a task cycle, or for combining with other information during the cycle.

Examples

1. A human typist reading a sentence and holding it in mind while her fingers key the symbols.

2. A register in a computer.

3. The retention of symbols or messages in a buffering device for translating into a different transmittal rate or frequency.

Operations

These are equivalent in principle to those in STORE.

Comments

1. The greater the number of channels, variables, codes and chunks of information input that must be integrated in order to reach a decision or select a response, the larger the short term storage that is needed. Human short term memory is limited, but can be functionally increased by practice and by regularizing or formatting the input, by mnemonic aids, and by map-like job aids.

2. The greater the variations among message sizes and message rates of transmitted and processing data, the more important the design of short term storage facilities to the efficiency of the total system (e.g., time-shared, remote terminals).

3. Information elements in short term storage must be addressable as parts to the decision to be reached or problem to be solved. These addresses use up system channel capacity (or bandwidth). Some address codes will be more efficient than others in a given system. (For humans, standard spatial patterns--map like or chart like--are good as a matrix for displaying elements of information as they arrive.)

4. Short term memory may store partial solutions in heuristic, semi-algorithmic problem solving, or in trying out of strategies (e.g., troubleshooting and other diagnosis, or in game-playing). If the human must make judgments and intervene in further steps, the codes and pattern in which partial solutions are displayed will be critical to human effectiveness in participation.

5. In human behavior, unaided short term memory is flexible but unreliable.

Note: The concept of short term storage is among the highest in importance to human problem solving capability. The computer in conversational mode can be of great aid to the human in retaining and effectively displaying short term task information in such tasks as information searching, diagnosing, decision making, constructing.

COUNT

Keeping track of how many

Identifying an entity or unit of something and incrementing or decrementing a storage and readable device by a unit of magnitude.

An expansion of the definition:

a. The counter must sense the presence of the entity to be counted. (This might include specialized detecting and identifying mechanisms.) The presence or absence of the entity or characteristic of the entity must be all-or-none.

b. Incrementing or decrementing some numerical value--which could be zero.

c. Storing the new count.

d. Displaying the count to a mechanism which reads it in order to fulfill some purpose of the system. The reading mechanism may be human or machine.

e. Resetting the counter when a new counting cycle is initiated. If the counter is not reset, a log must be kept of the count when a new cycle is entered.

COMPUTE

Figuring out a logical/mathematical answer to a defined problem

Rules for solving arithmetic and mathematical problems involving numerical data, or the logical reduction of logical statements (equations).

Comment

Any class of computation problems can be solved by a large variety of equally valid patterns of logical manipulation. The general tradeoff is space (number of channels holding and processing in parallel) versus time (number of operations performed in series). Computation requires both short term memory (intermediate results) and long term memory (sequence of logical instructions).

Operational Tradeoffs

1. Computing an answer by logical means versus obtaining the answer from a table in storage.

2. Digital computation (counting) versus analog computation (adding or subtracting physically continuous properties such as voltages).

3. Various specific mechanisms for given logical operations and few program instructions versus "general purpose" logical mechanisms and many program instructions.

4. Parallel computing operations (with high speed but more facilities) versus serial computing operations (with lower speed and less facilities required).

5. Higher speed from local short term storage of intermediate results (more facilities) versus lower speed by storing and retrieving intermediate results in long term memory (fewer facilities).

DECIDE/SELECT

Choosing a response to fit the situation

Rules for selecting a response alternative to given states of affairs. Conceptually, the simplest decision mechanism is a two-way switch where the input may be in one of two relevant states each of which selects response alternative.

In symbolic behavior, an operation implicit in a hardware mechanism must be explicit: a "compare" action. Decision results from the comparison of one or a set of input states with reference criteria for each of a set of response alternatives. When a match is found between the input conditions and the criteria for a response alternative, that response is selected and the alternatives rejected.

Human decision making requires an extended analysis.

The variables of the "input state" consist of:

- goal variables and priorities
- situation variables and their data content

The output variables are characterized by :

- the set of response alternatives and their respective implications

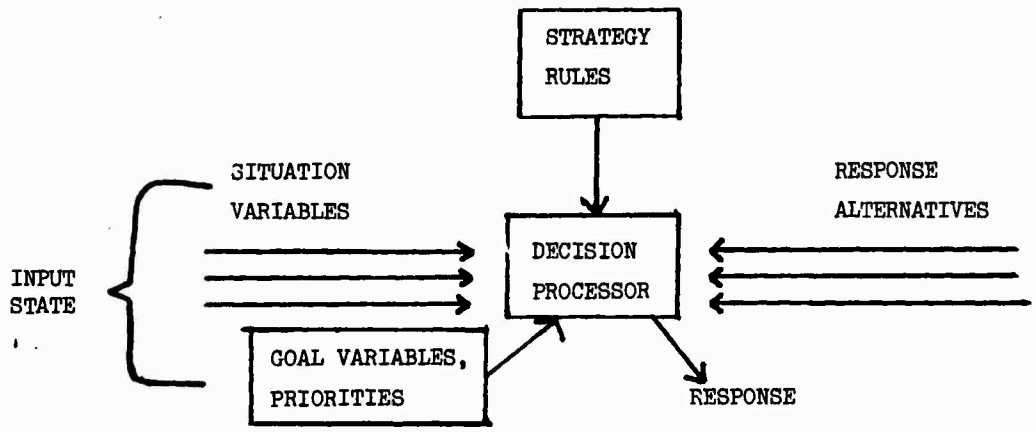
Another kind of information in probabilistic or ambiguous situations consists of:

- strategy rules for selecting a response alternative from any given input state

A strategy rule seeks the best fit between a "profile" of needs expressed in a problem statement and the "profile" of capabilities of each of the response alternatives.

Note: The term SELECT has the same operational meaning as DECIDE, although its connotation emphasizes the executive action implied by the choice reached in a decision.

DIAGRAM OF HUMAN DECISION MAKING VARIABLES



Reference: Paradigm showing the relationships among the types of human decision making difficulty cited on the following page.

DIFFICULTIES IN HUMAN DECISION MAKING

INPUT INFORMATION

1. Input variables incomplete, or include irrelevant variables.

2. Classification structure of input variables inappropriate to this problem (can't properly label potentially relevant information).

3. Information absent on one or more variables.

4. Information on various input variables arriving out of time phase.

5. Input noise disturbing the perception of relevant signals.

6. Inadequate interpretation of the meaning of the situation (failure to organize data about the situation variables as a whole or pattern).

GOAL VARIABLES

1. Inadequate definition of goal variables.

2. Incompatible priorities among goal variables.

RESPONSE ALTERNATIVES

1. Inadequate set of alternatives recognized.

2. Inadequate definition and classification of alternatives.

3. Improper premises for combining or compromising alternatives.

4. Inadequate data on consequences of respective response alternatives in this kind of situation.

STRATEGY RULES

1. Processor unable to identify and select appropriate strategy rule.

2. Conflicting strategy rules.

3. No strategy rule available for this combination of situation and response alternatives that are recognized.

PROCESSOR

1. Inadequate short term memory (buffering) to handle all the data.

2. Inadequate logical capability to process all the data.

RESPONSE EFFECTOR

1. Lack of channel for transmitting or executing the decided-upon response.

2. Lack of appropriate message code for converting output response into control behavior.

PLAN

Matching resources in time to expectations

Rules for predicting what future sets of conditions will occur and what responses to make to them and in what order.

Planning is a subset of decision making.

Functions in Planning

1. Predicting the future--using historical and present information to anticipate which of a set of alternative states will occur at some future moment or time interval.

2. Exercising priority rules for determining which of several anticipated states to give priority of attention.

3. Determining the set of response capabilities required for effective response to the expected condition or state.

4. Scheduling the resource for making the response so that the resource is available when the expected condition occurs.

Summary

The planner combines the functions of predictor, resource selector and resource scheduler.

Rules and procedures for deciding on the integrity of (a) a signal, (b) a message, (c) a mechanism.

A Signal Test is made as follows:

1. Sensing and measuring some one or more attributes of the test signal.

2. Comparing these measurements with a set of normative or reference values.

3. Deciding whether the test signal fell within the prescribed tolerances for that signal.

4. An indication of that decision.

Note: A "mask" may be used to compare several variables in the signal set at one time.

A Message Test consists of:

1. Identifying the class of message.

2. Deciding whether its contents do or do not match:

   a. the reference set of symbol elements
   b. rules for combining symbol elements into words
   c. format rules for combining words into messages.

Note: Tests for the validity of the "meaning" or content of a message must be made in a context of "meaning" references. Ordinarily this requires a redundant expression of the message. A check and confirmation with the source is an example of such redundancy.

A Test of a Mechanism requires:

1. A controlled or known signal or signal pattern as input to a mechanism.

2. Measurement of relevant characteristics of the corresponding output of the mechanism.

3. A comparison of the input-output relationship with a set of reference values prescribed for that relationship.

4. A decision as to whether or not the actual output falls within the prescribed tolerance limits.

Note: A test may also be a decision based on a comparison of outputs from redundant mechanisms that use the same input.

CONTROL

Changing an action according to plan

Physical Control

Changing the direction, rate or magnitude of a physical force that may be acting on objects, processes or symbols. The stimulus may be embedded in a fixed serial order, or it may consist of feedback Test Signals.

Physical control is observed in the human nerve and muscle that manipulates a tool, in the electromagnetic yoke which directs the electron beam in a cathode ray tube.

Symbolic Control

The source of instructions as to what will be done next with what facility.

Symbolic control appears when an instruction in a computer program reads and interprets an input message and, despite competing claims for a particular input channel, opens that channel to more messages from the source of that input message. Control resides in that instruction, in the location that holds that instruction and in the physical mechanism that executes the command contained in that instruction.

Factors in the Process of Control

1. A signal of status based either on instruction count, or on Test feedback.

2. A decision or other selection mechanism for eliciting an instruction.

3. The instruction that directs a change in some set of physical behaviors.

4. The mechanism which converts the instruction into a physical action or initiates a train of physical actions.

5. The jurisdiction (set) of physical actions which can be physically modified at some time by the instruction and its location.

Note: the concept of control includes the function of coordination in time and space according to plan.

Feedback control inplies both a monitoring—testing and an executive function.

Rules for arranging information (or symbols) into a message according to prescribed formats.

Editing may have as its purpose the structuring of data or information for machine handling purposes or for human handling purposes.

Examples

1. Suppressing non-significant zeros.

2. Breaking a chain of symbol element into component strings.

3. Arranging a listing of bookkeeping data into a display of rows and columns according to tabs and headings.

4. Correcting a misspelled word or ungrammatical sentence.

Note: Editing changes elements in the structure but not the operational content of a message, nor the symbol set by which the message is expressed.

DISPLAY

Showing something that makes sense

Arranging messages into a prescribed format and symbology for human perception and interpretation.

A convenient, but by no means exhaustive, distinction at a primitive level may be made between displays in such symbolic forms as:

Signals--such as a flashing light associated with a label or spatial position.

Alphanumerics--words, phrases, sentences in English.

Graphics--pictures, maps, charts, graphs.

ADAPT/LEARN

Making and remembering new responses to a repeated situation

Structural modification of the behavior of a system as the result of experience, where the behavior change carries over from one cycle of operation to another.

A learned act requires that: Response B becomes substituted for Response A to Situation X, and that when Situation X recurs, Response B will tend to recur rather than the old Response A. The information handling process must account both for the acquisition and substitution of Response B for A when Situation X occurs, and also for its retention and recurrence when Situation X recurs.

Information Handling Requirements

1. A transcript of the effective stimulus in the situation.

2. A transcript of the goal being sought or intent being realized in the situation.

3. A transcript of the original response that was made.

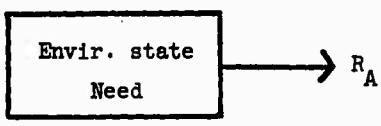
4. A record of the consequence of that response.

5. Some record of a "corrective" response or hypothesis for a corrective response.

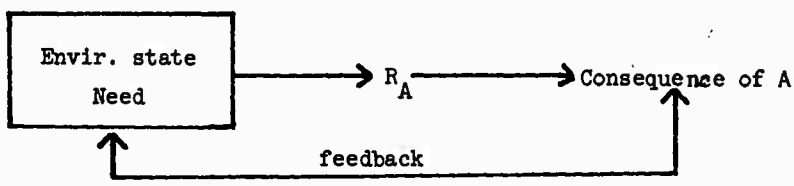
6. An associative link between (a) a mechanism for recognizing the old stimulus in a new operational cycle and (b) the "corrected" response--i.e., a mechanism for superseding the old maladaptive response to the stimulus and goal.

Process Paradigm of Structural Adaptation or Learning

1. A combination of need and environmental state elicit R_A. R_A has been previously "learned" to this situation.



2. The consequence of R_A fails to satisfy the need.



3. Response A is extinguished and Response B in the device's repertory is substituted. The consequence of Response B does reduce the need.

4. The adaptive device substitutes the linkage or Response B to this need and environmental state in its memory.

   The environmental state and need recur on a later occasion. The device identifies the recurrence of the old stimulus and old need. Assume the linkage or R_B has been effectively stored. Response B is emitted. Learned behavior is demonstrated.

Comments on Process Paradigm of Structural Adaptation or Learning

An automatic monitor-controller may be considered an adaptive mechanism by some definitions. It often is. But control behavior as defined above has a fixed response selection and response hierarchy built into it. It is structurally fixed. It does not carry over the results of experience from one cycle of confrontation with the situation to a recurring cycle of confrontation with the situation and show a change of behavior between the old and the new confrontation.

One might say that a learning mechanism is a monitor-controller with a memory for experience. The feedback produces a structural change in the response organization.

Notice that the model can account for learning new discriminations and new generalizations as well as substitutions of overt responses. The paradigm does not account for new responses entering the response repertory or range of capability of the device.

The paradigm can handle probabilistic changes in behavior as well as the deterministic example described here.

Rules for eliminating unwanted information from storage.

Example: All files, except those marked with an asterisk, reaching their tenth year will be thrown out.

Requirement for Purging

As new messages arrive, storage space is used up and search time is increased. Methods for systematically clearing storage are therefore essential.

Purging Policy

Aside from the special case of legal requirements, files or messages are discarded when the probability of referring to them goes below some value, or when the importance of finding them shrinks to some value less than the cost of maintaining the message or file in a given medium--or retained at all.

Purging policy may specify how purged messages are to be abstracted and retained in condensed form, or statistically summarized and retained as a summary.

Purging policy may specify exceptions, and how exceptions to purging rules will be identified and treated.

Comment

Humans tend to be irrationally reluctant to discard their files except under conditions of space crisis or other pressure, and then they may be equally irrational in what they discard. Purging policy is a planned discipline against these tendencies.

RESET

Getting ready for some different action

Purging an old context of status and readiness to respond by substituting a new context of status and readiness.

Example: A clock completes timing the runners in a foot race and is reset to zero in readiness for the next race. In another example, an English-speaking person is addressed in French and shifts his language context and speech patterns into French.

The reset operation is meaningless except as preparation for a new action context. It is therefore necessary for the system to identify the new context to which the reset is relevant. The mere return to zero of an indicator or control is irrelevant to a concluded action, but relevant to some next action.

Reset of Short Term Memory

This is equivalent to turning the clock or indicator back to a zero setting in preparation for a new cycle or context of system action.

Reset of Instruction Readiness

A reset may include any changed readiness of a mechanism to respond. Thus, a new instruction set loaded into active memory and controls is a reset operation by this definition. The human who shifts from speaking English to speaking French has had a reset operation.

Note: The concept of reset makes the term "set" unnecessary. After the first occasion on which a mechanism is set, it can only be reset. Note that the expression set is used throughout this page in the sense of "prepare".

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