Elementary Thinking and the Classification of Behavior

A hierarchy of information-processing abilities parallels development of the brain's reasoning power.

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Intelligent behavior in man is commonly associated with efficiency and versatility in information retrieval and learning, as well as with behavior which generates new information which serves to answer old questions and create new ones. This article, therefore, is concerned with phenomena which are likely to increase efficiency and versatility in problem solving; it presents logically necessary operations which (i) move or motivate an organism (that is, cause it to generate behavior); (ii) enable it to accumulate new information about the structure of the environment as well as about its own structure and operations; (iii) enable it to use such information in finding responses or answers to stimuli, questions, or problems presented by the environment or arising within the organism; (iv) enable it to accumulate information about within-brain answer-finding operations (that is, to remember how it found answers); and (v) enable it to use all the information available about the environment as well as about its own operations in the process of generating new combinations of available information. The new combinations then serve not only as answers to questions but as new questions as well, which the organism may then continue to consider.

Memory, considered here as the altered probability of within-brain pattern appearance, has always played a central role in psychology (*1*). The theory to be presented stipulates that it is the brain's capacity for relating within-brain activity patterns, and the brain's memory for those relating operations, which primarily increase efficiency. Versatility, according to the theory, is primarily increased by the fact that in higher biologic forms, behavior (including problem-solving behavior) can be initiated, maintained, and terminated through memory (*2*). This capacity in more complex organisms stands in contrast to the stimulus-bound or rigid behavior that characterizes less complex organisms. In these simpler organisms, behavior is largely a function of information received from the environment, or is regulated largely as a function of rigid regulatory feedback mechanisms (homeostats) (*3; 4*, pp. 11–57) which display within-brain error patterns. Since Lashley (*5*) first showed that memory may be used to pre-program future output operations, such as those activating the finger-movement sequences of a violinist, efficiency in answer finding has received considerable scientific attention. A discussion of efficiency therefore precedes the discussion of versatility.

Efficiency: Effect of Learning on Pattern Availability

The effect of learning on the probability of appearance of within-brain activity patterns, and therefore on the availability of such patterns during answer-finding operations, is shown in Table 1. Lashley first focused attention on the extremes of the effects of learning by demonstrating that prompted or primed central initiating mechanisms must be invoked to account for many types of programmed movements. He showed that the facts about reaction time and rapidity of movement exclude the possibility, in many cases, that rapid movement sequences are ordered by kinesthetic feedbacks from prior movements. The importance of Lashley's work here is that it suggests that every programmed central activity pattern (such as those which activate movement) is potentially capable of acting as a placement and timing control which coordinates the initiation and inhibition of other activity patterns (*6*, pp. 127–150). Such programmed central activity patterns may serve as answers as well as subanswers during an answer-finding operation, without necessarily activating individually observable outputs. The memory of the program itself may contain shortcuts. It is clear that the ultimate shortcut of programmed within-brain operations in answer finding is the immediate activation of the end-product activity pattern or answer (*7*), or the activation of a pattern which can serve as an estimate or prediction of an acceptable answer. In normal human development the number of programs increases with age. While this produces a more rigid and efficient answer-finding system, part of the rigidity at least is mitigated by the increase in combinational operations available to the organism.

It may be helpful to make a closer examination of the relationship between rigidity, flexibility, and learning, as shown in Table 1, before considering versatility in problem solving. The complete range of probabilities of pattern appearance shown in Table 1 has been arbitrarily divided into seven (unequal) ranges of probability values arranged along a discrete scale from −3 to +3. The −3 and +3 ranges include the extreme probabilities—that is, probabilities of pattern appearance near 0 or near 1. Response inhibition and programmed movements can be cited, respectively, as examples in these two ranges. The middle or zero range consists of a small number (group) of "acceptable answer" activity patterns all of which have roughly equal probabilities of appearance. The patterns in the zero range are distributed among a large number of available and unacceptable displayed activity patterns during any one answer-finding operation. Each of the acceptable patterns which appears as an answer to a question then has an increased probability of

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Table 1. Pattern availability. The effect of learning on the appearance of a small number of conceivable answer patterns among the large number of unacceptable answer patterns in the "possible" answer area—that is, in the zero range.

	I	II	III	IV	V
	Range No.	Probability of pattern occurrence	Effect on answer finding	Size of search area as a major factor affecting efficiency	Partial operational description of typical answer-searching process
	+3	Extremely high	Rigid and very efficient	Very small area and likely to be spatially continuous	Direct addressed chain activating a specific pattern
	+2	High	Structured and quite efficient	Small area and possibly spatially partially continuous	Direct addressed chain activating a small field highly concentrated with potential answers
	+1	Likely	Flexible and effective	Large area or more than one "time field" spatially noncontinuous	Addressed chain to field(s) of medium concentration with potential answers
Learning	0 ↕	Possible	Tractable and inefficient	Large area and more than one field	Scanning and sampling of fields with diluted answer concentration
	−1	Unlikely	Flexible and effective	Large area or more than one "time field" spatially noncontinuous	Addressed chain to field(s) of medium concentration with unacceptable answers, and inhibiting that field
	−2	Low	Structured and quite efficient	Small area and possibly spatially partially continuous	Direct addressed chain inhibiting a small field highly concentrated with unacceptable answers
	−3	Extremely low	Rigid and very efficient	Very small area and likely to be spatially continuous	Direct addressed chain inhibiting a specific pattern

reappearance when that question is again presented. Thus, learning moves that specific activity pattern into the +1 range. (The converse holds for each one of the large number of available unacceptable patterns; its likelihood of reappearance is decreased, and it will eventually move into the −1 range.) The pattern in the +1 range then becomes part of other "increased likelihood patterns," which may be viewed as a field of such patterns existing within a group—that is, a field within a small number of patterns which could serve as acceptable answers when selectively activated among a large number of unacceptable or "background" nervous system activity patterns. In this way, a field is formed within a group by virtue of the likelihood of appearance of patterns during a given time interval following the presentation of a question. Thus, the field may be considered a "time field"; it need have no other spatial continuity among its parts than an initiating timing control linked to the question.

As the patterns within the field within the group increase their probability of appearance, the opportunity for activation of other patterns in the group is reduced. In time, the field decreases in size and moves toward the positive end of the scale. The same learning process then moves patterns and fields from the ±1 range to the ±2 range, each time narrowing the field. The effect of this process is to increase search concentration and identify areas of unacceptable answers, thus increasing efficiency and at the same time increasing rigidity. There is some evidence that in the extremely high probability range, the field is actually so narrow that it acquires spatial continuity—that is, cells and cell units may actually grow together into assemblies and chains (*6, 8*), making the most rigid and also the most efficient answer-finding system. Learning thus may be viewed as a dialectical process which polarizes the probability of pattern appearance. The process may be described as dialectic because it increases the probability of appearance of one pattern while simultaneously decreasing (that is, inhibiting) the probability of appearance of others. Pavlov has shown this to be true for conditioned responses. There is also neurophysiological (*9*) evidence to show that unlearned initiation of activity patterns, as well as programmed or learned initiation, consists of a double process of excitation and inhibition. This dialectical process (among other important factors such as motion) plays an important role in distinguishing the aroused or displayed activity patterns from the background activity (*10*), thus allowing for ever greater refinements in discrimination.

Reinforcement Rate as a Function of Motivation and Memory

In lower biologic forms with a low memories-to-homeostats ratio, the frequency of appearance of displayed error patterns is largely a function of the structure or map of the organism. Errors which appear primarily as a function of an organism's metabolism (such as anoxia, for example) appear with greater frequency. The reduction of such types of errors, therefore, appears with greater frequency. In organisms with memory, the operations involved in reducing errors can be remembered. When these memories for operations themselves initiate error-reducing behavior, these memories may be considered pleasure signals. It is clear that in such organisms the frequency of appearance of pleasure signals will also be greatest when these signals appear primarily as a function of the organism's metabolism. As the memories-to-homeostats ratio increases in more complex animals, however, the rate at which a pattern will be reinforced—that is, the rate of moving a pattern from the zero range to the extremes of Table 1—is a more complex function. Specifically, the rate at which a pattern will be reinforced is a function of the frequency of appearance of the errors which are reduced by the pattern; it is also a function of the frequency of appearance of pleasure signals and other displayed patterns which tend to be more consistently associated with the appearance of errors.

The rate at which an organism can be reinforced, therefore, is a function of (i) the place of the organism on the phyletic scale or its stage of development, both of which determine the number of memories, and (ii) the directness of the linkage and association with repetitive, periodic, regulatory biologic processes, such as basic metabolism and hormonal changes, which produce errors repetitively and periodically at various frequencies.

Organisms whose behavior can be motivated by pleasure signals (that is, by memories for reducing errors) may be viewed as anticipating and forestalling trouble. They reduce vital errors before the errors are actually displayed. Such mechanisms undoubtedly have great survival value for organisms. In man, ultimately, question seeking becomes synonymous with pleasure seeking—that is, man looks for problems (errors) so that he may solve (reduce) these. The manifestations of this are ubiquitous. Man's favorite leisure-time occupations may be cited as examples, ranging from mountain climbing and puzzle solving to the reading of mystery novels and the pursuit of science. Man anticipates pleasure in these activities because he has picked errors which he predicts he will be able to reduce successfully. Error reduction may, therefore, be considered a basic motivation in all biologic forms, including man.

Versatility: Flexible Motivators and Logic

In the learning process just described no restrictions are placed on the type of stimuli or questions with which the appearance of activity patterns in the various probability ranges is associated. Next to be considered is the case where the triggering stimulus or question is part of a feedback mechanism such as one or a series of internally connected nonrigid homeostats. In such a situation the effect of learning on activity patterns in the zero range of Table 1 is classification of the patterns into groups of ever-narrowing fields which contain operationally equivalent activity patterns. That is to say, learning classifies patterns and answers according to the effect they have upon existing errors. To state this somewhat differently, learning classifies activity patterns according to their motivating characteristics—that is, their characteristics in initiating, maintaining, and terminating a search for an answer. Such classification involves a basic logic which in effect says that pattern *a* or pattern *b* will have the same effect upon an existing error or problem. One pattern may, therefore, be substituted for the other. The addition of a logical operation allowing for substitutions to the less complex relational operation described in Table 1, column V, increases the opportunities existing for a system to learn the structure of its environment. For example, the same pattern may well be activated by two different external stimuli or questions. In this way, the system classifies the external structures which activated these displayed errors according to their similarities as well as their differences with respect to the effect they have had on the motivators. Versatility is increased simply by virtue of the fact that more possibilities exist for motivating the system. Learning, then, permits the system not only to classify within-brain activity patterns on the basis of operational equivalence but also to classify external stimulus pattern similarities and differences by the same operational criteria. This allows for the possibility of substituting one extertal pattern for another and, therefore, for conditioned intra- and intermodality discrimination. Abstractions such as words can then become what the Russian scientists (*11*) have called "secondary signals," which are substituted for primary signals emanating directly from the real object or situation, thereby vastly increasing both efficiency and versatility.

[It might be pointed out that this view of operationally equivalent effects on errors or problems permits us to handle behavioral phenomena which have traditionally forced investigators to invoke concepts of brain equipotentiality, or field or configurationalistic (*12*) concepts. The concept of time and space fields proposed here is more compatible with the compromise between configurationalism and connectionism proposed by Hebb. It does not require an assumption that the brain acts as a volume conductor, and the theory is, therefore, compatible with neurophysiologic evidence which suggests that the basic units are organized precisely in such a way as to prevent volume or field conduction.]

Predictions and Measurements

The establishment of external stimulus pattern equivalences or "similarities" holds for temporal patterns as well as for spatial patterns. Learning and remembering the order of appearance of patterns further increases the combinational possibilities already so greatly enhanced by classification of similarities and differences of spatial patterns. Such a memory, as has already been suggested, ultimately allows the programming of sequences and the establishment of algorithms and memory for "sequence end products," or answers. Knowledge of the sequence of incoming patterns (that is, the automatic within-brain programmed appearance of a pattern sequence which is initiated by the appearance of the first external pattern in an ordered external sequence) is operationally equivalent to a prediction of the appearance of the external pattern. The logical operation combined with the basic relational operation now has become an even more complex statistical operation allowing for predictions based on previous associations. The violinist's familiarity with the structure of the music permits him to predict with great accuracy specific visual patterns which will appear on the page as he moves his eyes. Similarly, a person carrying on a conversation has familiarity with the structure of the language which permits him to predict, with considerably less certainty, various fields of acoustic patterns which he will be likely to hear next. The more complex predicting operation thus permits a human listener to anticipate the "question" raised by his conversant and modify his "answers" into continuous answer sequences based on continuous sequences of new input questions. The violinist who "prints out" all his "answers" in the form of movement sequences in response to the visual "questions" in front of him may be viewed as engaging in continuous answer finding. The human listener who does not need to transform all his answers into individual outputs may actually stay ahead of his conversant. He may already have answers to questions not yet uttered, and thus be considered capable not only of continuous but actually of overlapping answer finding. Human language and communication may thus be viewed as a continuous brain-environment problem-signaling operation in which both communicating brains continuously measure the error in a cooperative endeavor to reduce its magnitude—that is, in an effort to come to an agreement.

Continuous and overlapping answer predicting, feedback from continuous inputs, and memory for the distribution of errors ultimately allow the system to develop a complex statistical operation involving averages and variances which permit the system to develop within-brain criterion measurement scales for classifying the magnitude of similar patterns as well as the magnitude of differences between patterns. The significance of such measurement criterion scales may be seen even in the relatively simple operations of differentiation and integration required for perceptual tasks such as tracking the parabolic curve of a thrown ball. In such a perceptual task, tracking can now be based on memory. It is no longer totally dependent upon error patterns based exclusively on sensory feedbacks, which often are subject to severe limitation due to input factors or time loss in energy transformation. Perhaps even more important than such aids in perception is the fact that the statistical operation of associations can become a quantitative operation of measurement. Such operations ultimately lead to the relating of measurements to each other—that is, to an abstract numbering and measuring system for describing similarities and differences among real phenomena. Such a measuring system is perhaps man's most powerful tool for learning the structure of the environment.

Reasoning Power and Intelligence

The operations performed by the brain have been grossly classified in the hierarchy just presented, because unique identification of each category in living organisms is possible on the basis of behavioral tests alone, where only the input and output patterns are known. Such identification permits estimates of a system's total intelligence, during some time interval, on the basis of (i) sampling of the various levels of reasoning or relating power of the system, and (ii) sampling of the total number of originally built in, of acquired, or of prompted ("prompted" includes self-prompted) questions a

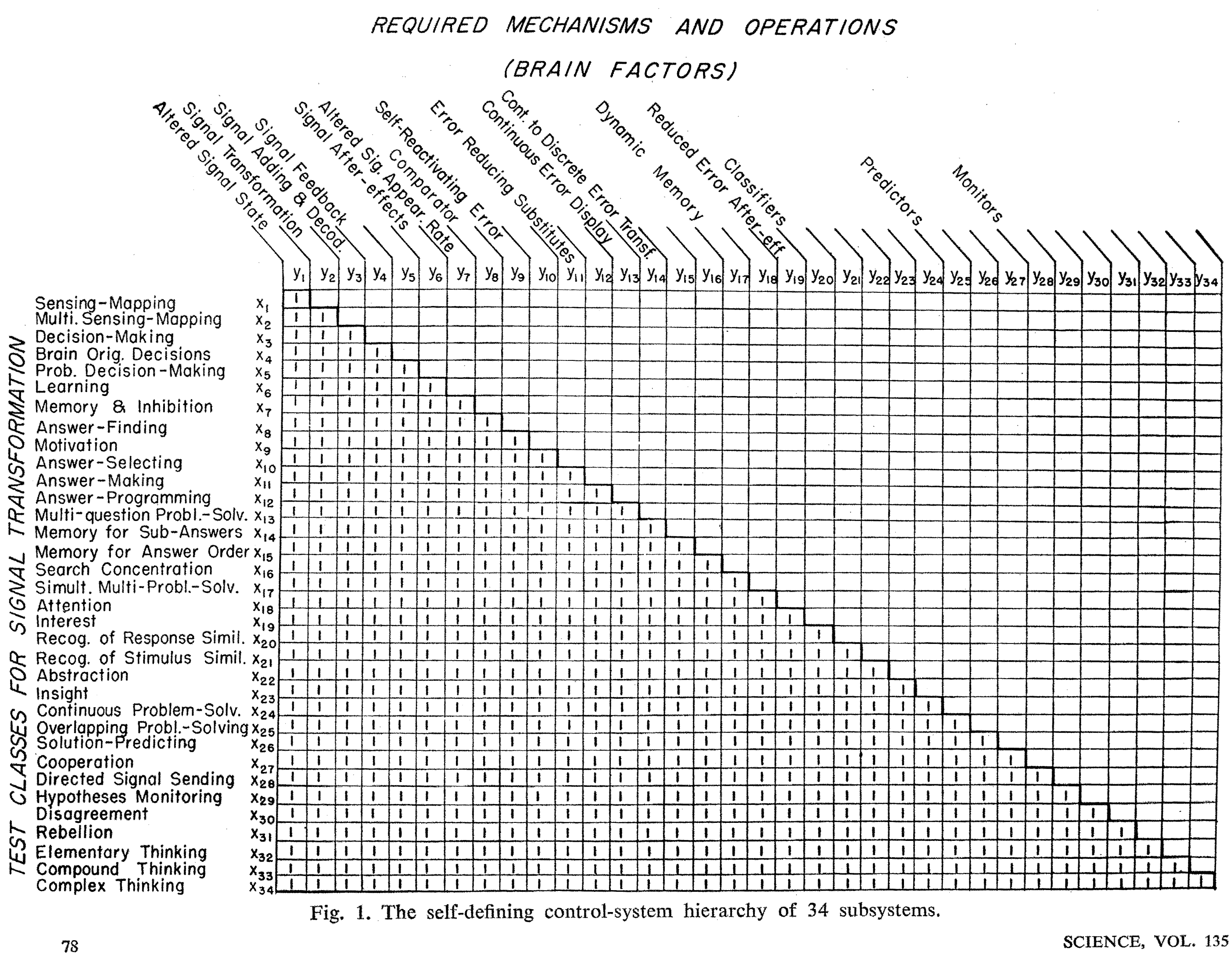

Fig. 1. The self-defining control-system hierarchy of 34 subsystems.

system can answer. At the lowest operational level of simple relating (the ±3 ranges of Table 1), the system's reasoning power is exclusively a function of the rate of relating separate units of information. At all levels involving more complex operations than simple relating (that is, when other than the ±3 ranges of Table 1 are involved), the reasoning power used by the system in any one operation may be estimated by considering the reasoning power an inverse function of the probability that the system guessed or was prompted (or rigidly programmed) in relating an answer to a question. The effect of learning on programming activity patterns and moving them into the number 3 availability range, therefore, is to reduce the reasoning power required by a system in many operations. Thus, at all levels above the simple relating level, care must be taken to avoid the identification mistake of erroneously crediting a speedy system (such as a rigidly programmed computer or violinist) with performing the higher-level operations described. To use a single measure of intelligence is reasonable in many clinical situations. However, separate samplings of (i) the system's reasoning power and (ii) the total information available to the system during some time interval are required for a comparative estimate of the intelligence of animals (*13, 14*) and humans (*15*), or a comparative estimate of human intelligence at different age levels (*16*).

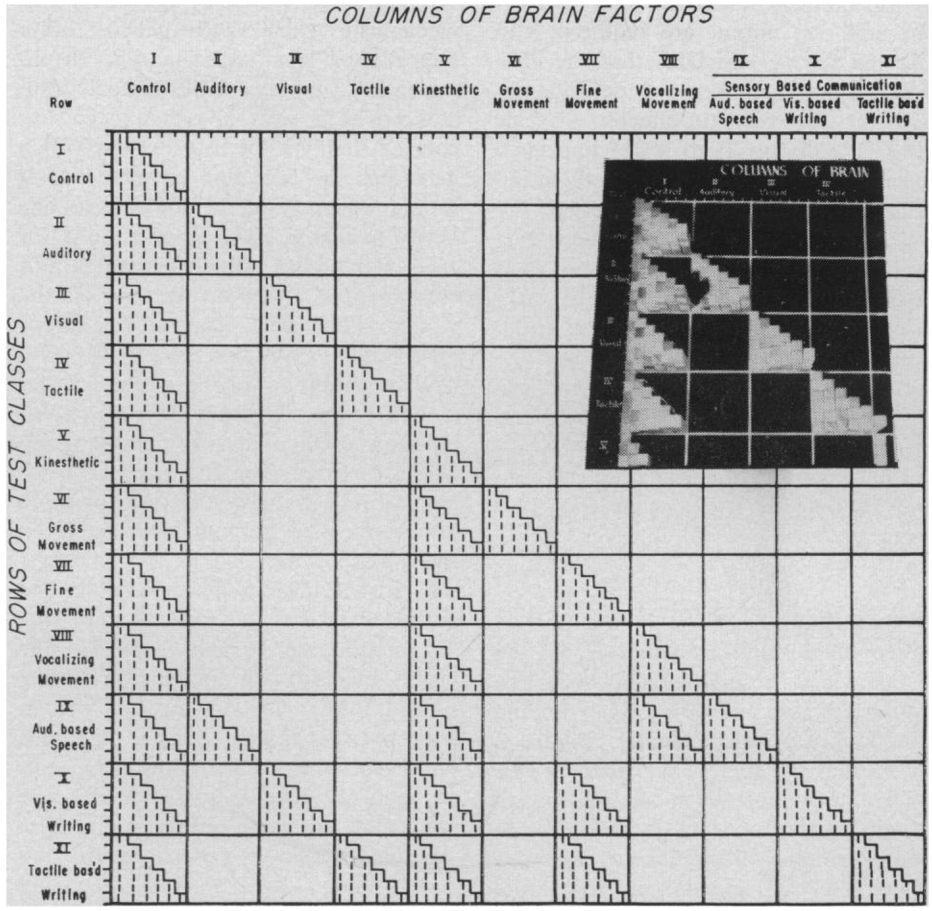

Fig. 2. Relationship between the control-system hierarchy (row 1, column I) (given in detail in Fig. 1) and the receptor- and effector-system hierarchies and special combined receptor-effector hierarchies (columns II to XI).

Behavioral Classification Scheme To Support the Theory

Thus far, information-processing operations have been described which enable a system made of nerve cells and nerve-cell assemblies to acquire great efficiency and versatility in answer finding. The theory of thinking now further stipulates that all operations performed by the brain are a function of the operations of different types of signal-processing systems involving operations such as those already described. Such systems existing within the brain are viewed as operating singly or in combination during brain activity underlying observable behavior. In support of the theory a behavioral classification scheme is presented next which utilizes behavioral input-output techniques for unique identification of the various operations in the reasoning hierarchy.

The operational hierarchy already described is built into a behavioral hierarchy represented by Fig. 1. This behavioral hierarchy (*17*) may be viewed as a hierarchy of increasingly complex signal-processing systems, where a system at one level always includes a combination of all systems at previous levels. To state it somewhat differently, success with an operation required for the stipulated signal transformation at one level in the hierarchy always implies success at all previous levels; failure at one level always implies failure at all subsequent levels.

Clinical usefulness of the classification scheme. Figures 1 and 2 show the formal organization of the behavioral classification scheme. Figure 1 shows a control system of 34 test classes which may be compared to the "control system" of Newell, Shaw, and Simon's (*18*) theory of problem solving in that this hierarchy stipulates no specific input or output modality. The control system, therefore, consists of those within-brain operations which act on transformed inputs into the brain and serve the receptor-effector systems by carrying on all the within-brain operations described so far, including the activation of outputs or effectors.

The relationship of the control system to the receptor-effector systems is shown in Fig. 2. It is important to stress that the number of test classes and brain factors in each of the triangularly shaped stepped hierarchies shown in Fig. 2 (as well as in the three-dimensional view) was reduced for representational purposes only; the number of test classes and steps in each hierarchy should actually be the same as the number of test classes and brain factors shown for the control system hierarchy in Fig. 1. Thus, Fig. 2 represents 11 rows with 34 test classes each, or 374 test classes. The practical significance of Fig. 2 is discussed briefly later. Here it is only important to note that (i) for behavioral testing of the control system at least one input and one output are required, and (ii) the theory stipulates that the control system can serve independently each of the receptor-effector systems (Fig. 2, columns II to VIII) and each special receptor-effector combination (Fig. 2, columns IX, X, and XI).

Use of logical equations. Each level in the hierarchy of Fig. 1 and each actual (rather than shown) level within one row of Fig. 2 is a logical equation which can be represented by logical symbols where $\bar{x}$ reads "not x," $\wedge$ reads "and," $\vee$ reads "or," and $x \rightarrow y$ reads "x implies y."

For example, the equation for answer finding at level x_{11} in Fig. 1 is given by:

$$x_{11} \rightarrow y_1 \wedge y_2 \ . \ . \ . \ y_{11} \qquad (1)$$

If success at that level in the control system hierarchy is demonstrated by a behavioral test involving vision, a similar test for auditory answer finding can be given independently. Figure 2 shows that the subject, in order to pass such a test, must have all the control system factors at level x_{11} (these he is known to have on the basis of the prior visual test) and in addition, that those control system factors must serve the auditory input. If the control system factors fail to do so, this will be recorded at level x_{11} (Fig. 2, row 2). The Boolean profile for this failure would be adequately represented by the entries in columns I and II in the top half of Fig. 3, which show a normal control system which only partially serves the auditory system up to the level of failure.

Self-defining hierarchy. Figure 1 shows how information acts on existing structures and drives them. When the output of the structure thus driven activates another structure—that is, when the output is fed into the second structure—the two structures in operation are considered a mechanism. (A feedback mechanism is the special case where the output of the second structure is fed back as an input into the first structure. A feedback mechanism which maintains a system's existence in time is called a regulatory mechanism, or in biologic forms, a homeostat.) When the x-axis is viewed as a test which requires the transformation of a known signal into an expected output, Fig. 1 may be considered a continuously self-defining table. Success at level x_{n+1} is always dependent upon the output generated by the last y-axis mechanism (henceforth called "brain factor") of level x_n. The type of information generated by the mechanism at level x_n is thus always a necessary part of the type of information which generates the behavior at level x_{n+1}. It is that information, in addition to one newly available class of operations for each x-axis level, which generates new combinations of brain factors on the y axis. (The new class of operations may become available as a result of a new or different type of structure capable of new functions, or a new combination or hookup of already available structures. For the sake of readability, only the new structures or more important new hookups are listed on the y-axis of Fig. 1. The entire operation at each level, however, is described in the text.)

Limitations of logical equations. The block diagram of an answer-finding system (Fig. 4), is helpful in visualizing the fact that the logical equations only represent what Ashby (*3*) calls a "logic of mechanisms." It may be seen that the mere presence of these factors, as shown by successful answer finding at time t_1, does not assure subsequent successful answer finding at time t_2. Thus, it is not true that

$$y_1 \wedge y_2 \ . \ . \ . \ y_{11} \rightarrow x_{11}$$

If it were true, we would in effect be able to predict, on the basis of the previously established presence of these brain operations, that these systems will again function correctly—that is, that they will go through a predetermined relating process and select the correct answer. The hierarchy, then, would have predictive characteristics such as Guttman scales (*19*). Prototypes of these hierarchies have indeed been used clinically because the hierarchies do have useful predictive characteristics (*20*). In biological forms, however, it is quite possible to have normally or pathologically time-dependent variable or changing systems. Such systems may well be able to find an answer at t_1 and be unable to find the same answer to the same question at t_2. Expletive speech (*21*) in aphasic patients may be cited as an example of a condition where only extensive and often irrelevant stimulation occasionally permits the patient to activate his speech mechanisms. In general, individuals with recent traumatic head injuries, or individuals who have experienced recent cerebral vascular accidents may be cited as examples of physiologically unstable systems.

Block diagram to show topology of connections and to suggest additional sources of failure. A block diagram (Fig. 4) focuses attention on the connections between the brain factors during an answer-finding operation. The single lines in the diagram represent timing controls, while the tubes represent the propagation of activity patterns or messages. Single or repetitive excitation and inhibition, and propagation of activity patterns with varying degrees of added noise, are well-known physiological phenomena. If it is true, as the theory stipulates, that these physiological phenomena serve as timing and addressing controls, then these physiological characteristics ought to be reflected in behavioral phenomena. Examples of such behavioral phenomena in health and pathology are not difficult to come by (*22*). Stutter may be considered repeated activation of the correct address; in patients with central nervous system damage, we often observe that the patient himself recognizes wrong addresses or "in-class errors" which he is unable to correct (he may consistently call a fork "knife" and shake his head to indicate his awareness of the mistake). Even some of the normal phenomena of dreaming can be cited as examples; dream distortions, for instance, can be viewed as the simultaneous activation of two messages interfering with each other, causing distortions, contaminations, or super-impositions. A child waving to a train then becomes a train with the face and the waving arms of a child.

The examples are presented in some detail in order to show that single as well as repeated signal or pattern activation during any one operation may be clinically normal or abnormal; similarly, the addressing of a signal or pattern (message) may be clinically normal or abnormal, and pattern clarity or pattern distortion may be clinically normal or abnormal. The block diagram thus helps one to visualize a large number of possibilities for generating classes of conceivable thinking and behavioral phenomena such as those already listed. When these classes are checked against phenomena actually found in nature, computers can then be used, as suggested by Ledley and Lusted (*23*), to

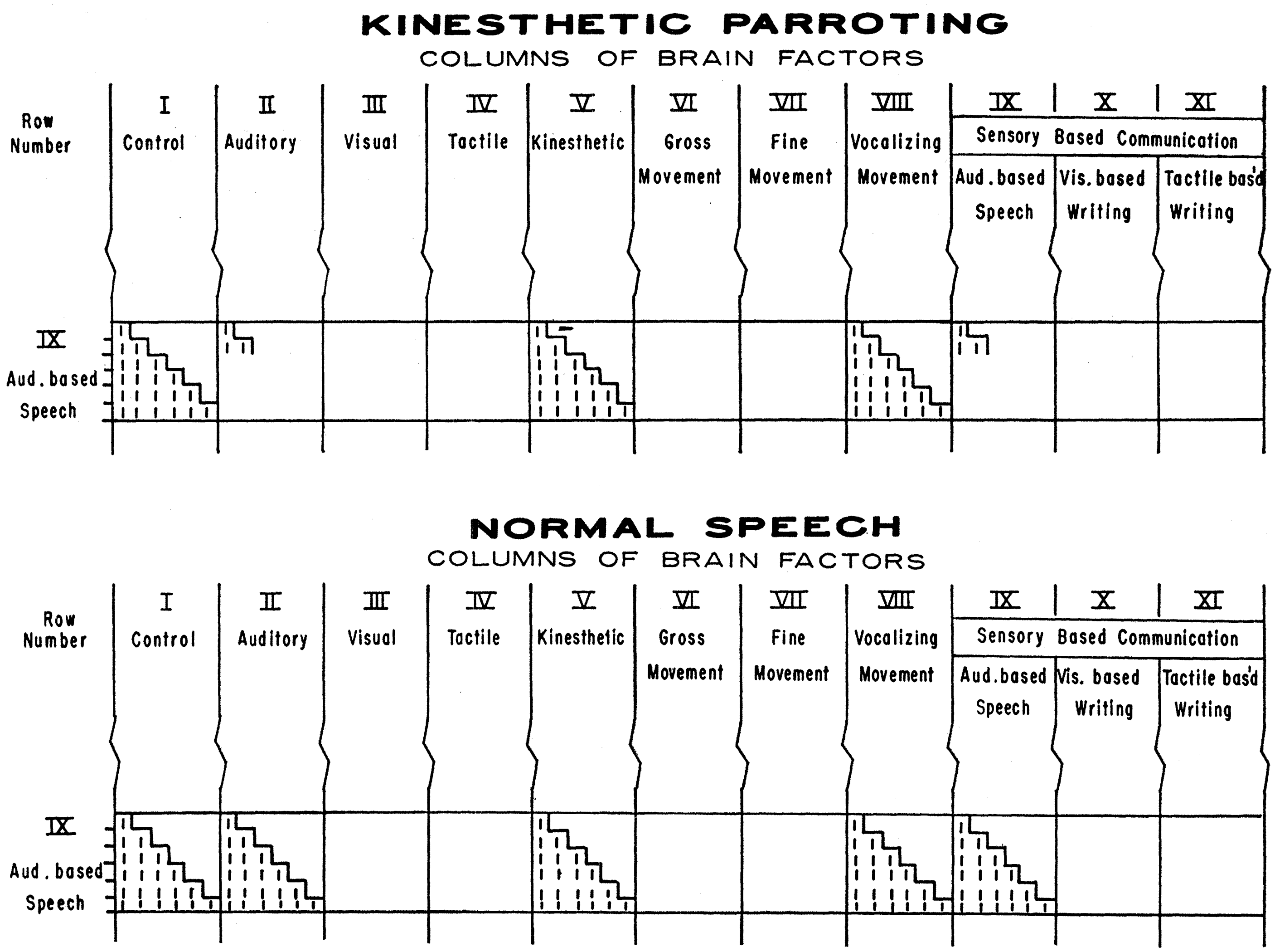

Fig. 3. Boolean profile of kinesthetic parroting and normal speech.

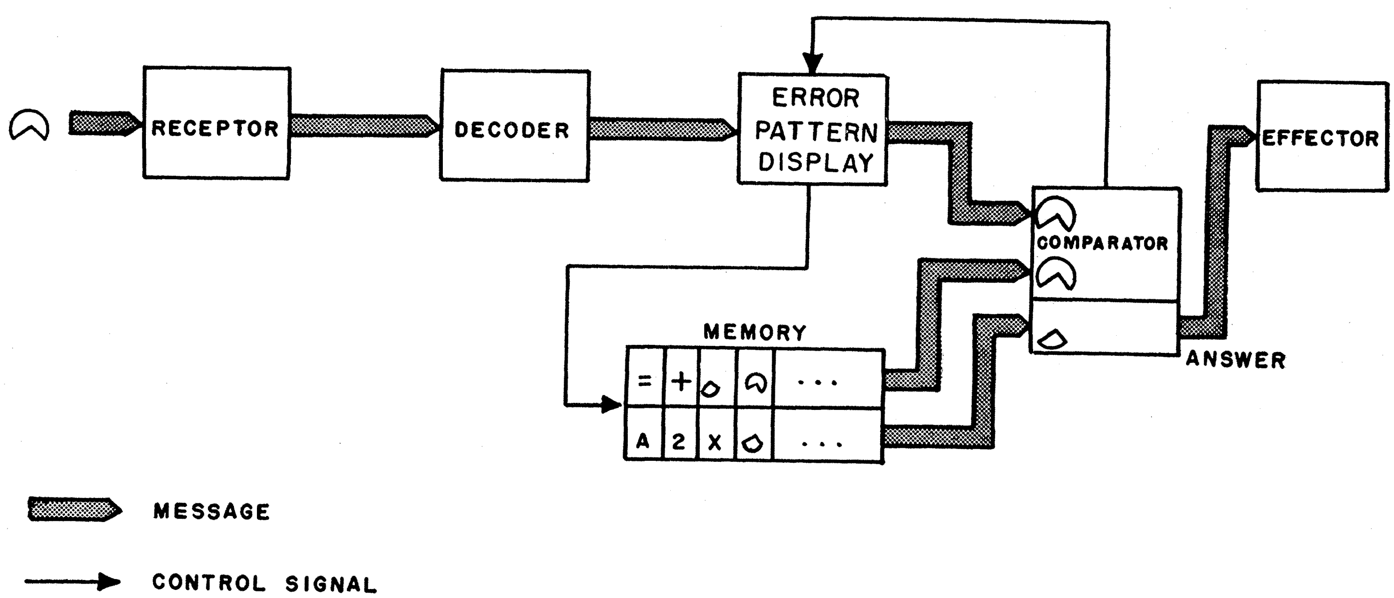

Fig. 4. Block diagram of an answer-finding system.

identify combinations of normal as well as abnormal phenomena. The techniques applied to more elementary timing and addressing controls can also be applied to the more complex brain factors.

The formal organizational characteristics of Figs. 1 and 2 may be summarized by stating that these figures are Boolean matrices consisting of ordered lists of logical equations. In Fig. 1 and within each row in Fig. 2, the equations are arranged in a hierarchy characterized by the equation

$$x_n \rightarrow y_n \wedge y_{n-1} \ . \ . \ . \ y_1 \qquad (2)$$

The next two sections of this article deal with the control system in greater detail.

For the sake of clarity, the 34 levels or subsystems of the control system are described in groups as well as individually. Wherever possible, descriptions are provided in a number of alternate or equivalent terms, which are selected to show elements of previous as well as future characteristics in brain operations. It will be shown that criteria are available for the unique identification of the minimal presence of each of the 34 subsystems in the control system—that is, for distinguishing minimal success at any level from success at all previous levels.

The Signal-Processing Systems of the Control System

Deterministically driven externally regulated systems (*levels* x_1 *and* x_2). The pattern sensing and mapping systems driven entirely by information contained in the environment are the first of 34 levels in a behavioral hierarchy. They also correspond to the first level of a hierarchy of operations relating activity patterns. This hierarchy begins when an entire system forms one pattern by relating two units of information in space or time—in other words, when it forms one pattern out of two patterns. For an observer, the entire system thus minimally acts as a counter or code which changes one number system into another. In relating the two events, the system as a whole performs the simplest operation. The observer knows that two events have taken place when he sees one output. The hierarchy of operations continues with systems which respond selectively to information contained in the environment. Organisms such as bees and ants, for example, extract (or subtract or select) information from the environment and channelize that information into mechanisms which drive the available outputs—that is, generate a specific behavior, behavior pattern, or behavior sequence. Such animals are rigidly stimulus-bound (*24*), and initiation of activity is entirely dependent upon information contained in the environment.

The only possibility for regulation exists when the output of the system alters the information contained in the environment. An ant of certain species, for example, may be driven by chemical stimuli laid down by other ants (and itself) during locomotion. The regulation is thus largely between systems rather than within a single system; this arrangement contributes to the preservation as well as the destruction of ant colonies (the milling phenomenon in ants may be cited as an example which is often nonadaptive). These levels are designated x_1 and x_2.

x_1, Pattern sensing and mapping, or "invariable" directing of an input pattern into an output pattern.
x_2, Multipattern sensing and mapping, including multiple inputs and outputs as well as within-system input-output chains.

External and internal regulation (*levels* x_3 *and* x_4). An equally deterministic but more adaptable system is one which adds information originating within the system itself to incoming information and is so coded that the output is activated only when both the external and the internal signals are present. The eating characteristics of fish may be cited as examples. Some species snap at a visual stimulus almost every time such a stimulus is recorded on the retina; others eat only when they are hungry. In the former (as in ants) there is no within-system regulation, and in captivity such fish are very likely to overeat. The same visual mechanism has been shown to underlie between-fish regulation of movements in species which swim in schools (*25*). In nature, therefore, the danger of overeating may be reduced simply by a supply-demand relationship which provides effective external regulation.

As for the species of fish that snap at food only when they are hungry, an observer who knows how long such fish have been deprived of food can predict accurately whether a food-snapping response will take place. Such fish may be viewed as having within-brain regulation involving a feedback mechanism or homeostat capable of regulating the individual. The object of regulation is no longer the food supply in the environment but the behavior of the fish; the object of regulation thus is closer to the regulating source, and the fish is no longer totally dependent upon the presence of other fish for regulation of intake of the available supply.

x_3, Decision making, or an invariable pattern originating within the system, added to a mapping sequence.
x_4, Within-brain deterministic decision making where added signals originate within the brain of the system, thus allowing for within-brain regulatory homeostatic mechanisms.

Probabilistically driven self-adapting systems (*levels* x_5 *to* x_7). The importance of probabilistic considerations in learning and memory may be reviewed in Table 1. Designations in this group are as follows:

x_5, Probabilistic decision making where the added within-system patterns appear with fixed probability; this fixed probability may change with physical changes in the system due to maturation.
x_6, Learning or unidirectional change in probability of pattern appearance associated with an external stimulus; such learning may also be considered compound decision making.
x_7, Memory and inhibition, or increased probability of pattern appearance and nonappearance as a function of learning.

Discrete error patterns (*levels* x_8 *to* x_{11}). The answer-finding systems in this group are distinguished from the problem-solving systems (level x_{13} on) in that the error patterns are discrete or pulsed in the former and continuous in the latter. To state this somewhat differently, a problem may be viewed as a continuously activated multistate question with an "answer" feedback. Initially, the discrete error pattern is activated by an individual extrabrain originating source or question. Later, an error pattern is repetitively triggered by a rigidly programmed within-brain source, which "remembers" to initiate itself until it is actively turned off by an acceptable response. Such a system is said to have "motivation." The rigidly programmed motivated answer-finding operation is then changed at the next level (x_{10}) into a system capable of trial-and-error answer selecting from a number of available answer patterns. At the last level in this group flexibility is further enhanced by the use of operations to combine two available units of information which had never before appeared as one pattern, and by experimentation to determine whether that combination will serve to eliminate the error. If it does, the new combination establishes a new answer-question relationship which is operationally equivalent to a feedback relationship.

x_8, Answer finding or externally initiated one-trial matching (by a comparator) of one selected pattern with a memory. If the two patterns match, an output is activated which eliminates the error; if the two patterns do not match, no further search is maintained unless the error is again externally triggered.

x_9, Motivation, or repetitive initiation of internal memory search, or maintenance of internal search.

x_{10}, Complex decision making or selecting one of a number of possible memory patterns existing in a field during a multitrial answer-finding operation.

x_{11}, Reasoning, or answer-trying, or internal answer-making or discovery (originality), or internal trial and error, in a system trying different combinations which may eliminate an error.

Level x_{12}. Mapping and programming answers and answer sequences to a series of repetitively activated pulsed error patterns (which may undergo a partial change in time) allows for continuous responses to continuous error patterns in the subsequent levels.

x_{12}, Programming or answer mapping.

Single continuous error patterns (levels x_{13} to x_{18}). Reduction of continuous error patterns, such as thirst which decreases with water intake, enhances the learning effects described in Table 1 by saturating the time field with acceptable answers. These in turn are rapidly moved into the +3 range of Table 1, so that even a less intense thirst stimulus gives rise to programmed drinking behavior. The motivator thus becomes less rigid by acquiring a lowered threshold, and it may eventually initiate a multistate error pattern.

The difference between the original physiologic threshold and the learned threshold at any point in time may be described as "internal interest." Different threshold points or points of interest can then serve to initiate and maintain problem-solving behavior and can also serve as guideposts or memories for obtaining subanswers in directing operations toward problem solving. Efficiency is thus increased by search concentration, and flexibility is actually enhanced by efficiency, because programmed problem solving allows for the relating of two simultaneous problem-solving operations. In effect, two subproblem operations can then combine to eliminate one problem or error. (This complex operation is easily interfered with by nervous system dysfunctions which are behaviorally manifest in peculiarities of attention. The well-known standard psychiatric "digits backward" test, as well as visual and tactile perceptual tests involving figure-background relationships, are often sensitive to such peculiarities of attention.)

x_{13}, Problem solving, or continuous answer-to-question feedback with initiation of multistate internal memory search, or "internal interest."

x_{14}, Memory for subanswers, or division of a solution into subsolutions or guideposts to the final solution, or conversion of continuous error patterns to discrete error patterns.

x_{15}, Memory for order of appearance of subanswers.

x_{16}, Internal memory pattern search concentration.

x_{17}, Independent though simultaneous solving of multiple problems.

x_{18}, Attention, or dependent and simultaneous solving of multiple problems, as in time sharing of one motivator; this level may also be viewed as multipattern search concentration.

Multiple continuous error patterns (level x_{19}). When one multiple continuous error pattern has an aftereffect manifest in a markedly lowered maintenance threshold and the organism continues a postsolution search, it is said to have interest on external stimuli or questions.

x_{19}, Interest, or postsolution continuation of external search, or internal error aftereffect.

Approximating the structure of the environment (levels x_{20} to x_{32}). The significance of levels x_{20} to x_{32} in the theory presented has either already been discussed or should be apparent from the description of the levels given below. It might be pointed out that "insightful problem solving" (*14, 26*) (level x_{23}) probably does not appear below the level of primates. To demonstrate insight in champanzees as in tasks involving the use of a stick as a tool, we usually found it necessary to compare rates of problem solving in animals with previous stick-playing opportunities and rates in animals lacking such experiences.

x_{20}, Recognition of response similarities or comprehension of answer equivalence or compound substitution.

x_{21}, Recognition of stimulus or question-pattern similarities or comprehension of question equivalence or compound substitution.

x_{22}, Abstraction or complex substitution (double substitution) or conditioned discrimination.

x_{23}, Insight or internalized trial-and-error problem solving.

x_{24}, Continuous problem solving.

x_{25}, Overlapping problem solving.

x_{26}, Solution predicting by successive approximations in problem solving or concept formation.

x_{27}, Cooperation (*27*) or brain-environment problem sharing.

x_{28}, Directed signal sending (*28*), or brain initiation of cooperation, or elementary hypothesis testing, or internal-to-external-to-internal error reducing, or elementary communication.

x_{29}, Continuous communication or continuous hypotheses monitoring.

x_{30}, Disagreement or questioning or interest on internal and external answer pattern differences.

x_{31}, Rebellion, or question-pattern manipulation, or stimulus restructuring.

x_{32}, Elementary thinking, or continuous problem solving by question-pattern manipulation where the original problem has a within-system origin.

Origin of the problem (levels x_{33} and x_{34}). The origin of the problem is important because humans are unique in having a culture which permits them to pass on problems, problem structures, and solutions from generation to generation. This vast extrabrain memory storage compartment allows the educated individual to begin rolling back the frontiers of knowledge where others left off.

x_{33}, Compound thinking where the original problem has a within-brain origin—that is, where the person experienced the error himself.

x_{34}, Complex thinking or complex communication where the original problem was structured by another brain, —where the person was told by someone else that the error or problem exists; he may or may not want first to convince himself of the existence of the error before attempting problem solving.

Unique Identification of Subsystems

Distinguishing between minimal success at a higher level on the one hand and minimal (or greater) success at a lower level on the other hand poses no problem between levels x_1 through x_{12} (programming). Thus, reflexes and mapped responses (the first two levels) can be identified by establishing a criterion for "extremely high probability of occurrence" and demonstrating that this probability does not change with time. Within-system regulation of drives, such as regulation by homeostatic mechanisms, can be recognized by the demonstration of feedback. To demonstrate feedback by behavioral tests alone, it is always necessary to demonstrate that outputs constitute subsequent necessary inputs into the brain. As has already been shown, identification of systems with learning and memory by behavioral tests alone requires only an observation of a change from the initial to the final probability of response occurrence. A unidirectional change in this probability is considered to be learning. The mathematical criteria for the probability ranges of pattern occurrence described in Table 1 (possible, likely, high, extremely high, unlikely, low, and extremely low) can be arbitrarily selected to suit the examiner's needs for defining memory and inhibition in any one type of investigation. To distinguish motivation (level x_9) from other answer-finding operations which initiate, maintain, and terminate answer finding, it is necessary to demonstrate (i) that the answer-finding activity is maintained after removal of the external signal which was previously necessary to initiate the operation and maintain it, and (ii) that at some time in its history the system did not maintain answer-finding operations as it does now. That is to say, motivation at level x_9 must involve memory, and it is not sufficient to demonstrate the presence of a signal arising within the system.

To distinguish answer selecting (level x_{10}) from answer finding (level x_8) it is only necessary to show that the system has considered more than one possible answer—that is, has rejected some answers. To distinguish answer making from answer selecting it is necessary to show that the pattern which served to eliminate an error was never presented as such to the system—that the system, in fact, made up the pattern by combining two previously independent units of information. Distinguishing programmed responses or answers (level x_{12}) from originally mapped responses presents no problem. It is only necessary to demonstrate that a response or response sequence was not a part of the original equipment of the organism and does not become a part of every member of a species of developing organisms, irrespective of experience, on the basis of within-system growth or developmental changes alone.

A special problem arises with attempts to distinguish between the higher levels in the hierarchy, involving more complex operations on the one hand and the lower-level, programmed responses on the other hand. As discussed in an earlier section, at all levels in the hierarchy subsequent to x_{12}, an estimate of the reasoning power of the system is required. The reasoning power for any one operation was considered an inverse function of the probability that the system guessed or was prompted ("prompted" includes self-prompted or rigidly programmed). Therefore, assessment of the likelihood that a system was mapped or prompted or programmed in any one operation may require comparison of estimates of the frequency of occurrence of that response (i) among different species of systems, (ii) within that species of systems, and (iii) within the age range of that species of systems. One criterion for distinguishing between programmed answers and answers based on nonprogrammed memories or related operations, therefore, is the criterion of probability of pattern appearance, discussed earlier, which in this case is the probability of answer occurrence.

A second technique for estimating whether an operation involved a series of within-brain operations or a single programmed thought sequence or memory for an answer is available. The technique is based on the fact that the time factors involved in direct memory initiation on the one hand and message sequence propagation on the other hand are of an entirely different order of magnitude. The technique essentially applies Lashley's technique of comparing measured time to within-brain operations. For example, if we select at random a man in the street and ask him "How much is 9×15?" and he provides the correct response in less than 3 seconds, the likelihood is great indeed that the operation involved hypothesis monitoring (level x_{20}) based on answer predicting (level x_{20}). It is unlikely that he had an absolute memory for the answer, or that it was programmed (level x_{12}). It is impossible that he arrived at the answer by an efficiently preprogrammed series of relational operations (simple additions) which he terminated just at the correct time (level x_9), just as it is impossible for the violinist to order his movements on the basis of kinesthetic feedback from previous movements. That it does take longer to relate even well learned but still independent sequences, such as the famous *Gelaeufige Reihen*, than to arrive at the correct answer by direct memory initiation, the reader may demonstrate to himself by performing (without vocalizing) the serial addition of 2 up to 18. That is to say, adding 2 nine times minimally takes on the order of 2 seconds, not counting the time lost in energy transformation for activating an output. Finding 9×2, however, probably takes on the order of milliseconds or microseconds when we do not count the time lost in energy transformation in activating the output.

Identification of the remaining test classes does not require such probability estimates, and the techniques for identifying each class should be evident from the explanations offered in the text. Thus, for example, level x_{16} (search concentration) still requires a probability estimate based on the likelihood that the subject did not guess but actually selected an answer from a field in which there was an increase in the concentration of acceptable answers over the concentration in the field from which he selected an answer on the first try. At level x_{18} (attention) it is only necessary to show that the subject is able to relate two problems to each other. A simple test such as the standard psychiatric test of "digits backwards" suffices. Identification of level x_{19} requires only that a subject continue to spend time on an external stimulus after that stimulus has served the purpose of eliminating an error.

Support for Theory in Psychopathology

So far, support for the theory of thinking has consisted of showing that each of the various signal-processing systems exists alone in nature in the form of artificial or biological organisms and can be uniquely identified. The fact that increasing signal-processing complexity is associated with increasing structural anatomic brain complexity in biologic forms (*29*) is advanced as additional suggestive evidence in support of the theory. I now present further support for the theory by showing (i) that the theory of thinking allows for the classification of a finite universe of classes of thinking disorders (*30*), and (ii) that when a disorder has been identified, its mechanisms (*31*) can then be explicitly and entirely described in terms used to describe the theory. Exhaustive description of pathological thinking phenomena thus requires, in addition to a description of the mechanism, a description of the information content upon which the mechanism operates.

Clinical identification of disorders. Figure 5 and the three-dimensional insert in Fig. 2 illustrate the technique for identifying thinking disorders. The step arrangement in the three-dimensional view represents the ontogenetic or developmental time difference between the emergence of one brain factor and the emergence of the next adjacent brain factor. In Fig. 5 this is represented by the double line. This figure, representing a section through a test class, shows the clinical application of the classification scheme. The horizontal section of the double line for each factor represents the time at which the factor first emerges (for this illustration, arbitrary time or age units are selected rather than chronological or mental-age-equivalent scores, because the first factors actually emerge in the growing embryo). For example, the factor y_4 first appears at age 5. The top horizontal line for each factor represents the time at which the factor is expected to reach full development—for example, y_4 matures at age 8.5. The vertical distance between the bottom double line and the top single line, then, shows the time during which the factors are in a stage of development and may, therefore, be used as an index of changing mental age.

Suppose, for example, that the subject completely fails all tests for factor y_7. Then we may infer that the subject's age is less than 11.5 time units. The theory stipulates that no factors numbered beyond y_7 (such as y_8, y_9, and so on) can be present. (If we know that the subject's chronological age in fact exceeds 11.5 time units, such failure at y_7 would be evidence of retarded development or, with respect to that factor, retarded mental age.) Suppose, as another example, that a subject passes a test for y_8 with an age-equivalent score of 14 and passes no test with a higher score. Age 14 is then the plane of maximum expectancy, represented by line *A* in the drawing. All factors for which the subject scores below this age level, such as y_6, with an age-score of 11 (represented by the short dashed line in Fig. 5), are indexed as dysfunctions and must be accounted for in the clinical report. If the y_4 age in this example is up to maximum factor development (age 8.5) it will, of course, not be indexed. Only those factors whose sensitivity ranges can be cut by the plane of maximum expectancy are indexed. [It should be mentioned that Fig. 5 is really a simplification which obscures the fact, previously suggested, that factor development for each test class occurs along two separate scales: (i) the amount of information handled (acquired, available, and so on) and (ii) the reasoning power employed. The actual clinical report on the subject presents separate estimates of the amount of information handled and the relating power employed.]

For clinical report writing it is neither feasible nor necessary (nor would it be desirable) to describe individually all of a subject's assets in problem solving. The report, instead, is based on the assumption that, given the subject's chronological age, the reader knows (or can find out) what to expect from the subject in terms of intelligence (if the mental age is greater than the chronological age, expectation based on the mental age should replace expectation based on the chronological age). The clinical report is designed to list and describe only "surprises"—in other words, it first presents data to establish a reader expectancy and it then shows where the subject deviates from the expected findings. The clinical report is divided into (i) a statistical section, (ii) a descriptive section, and (iii) a prognostic section.

The statistical section reports the maximum expectancy score for both available information and relating power, and gives a separate listing of all those test classes of Fig. 2 in which the subject was expected to reach these scores but fell below.

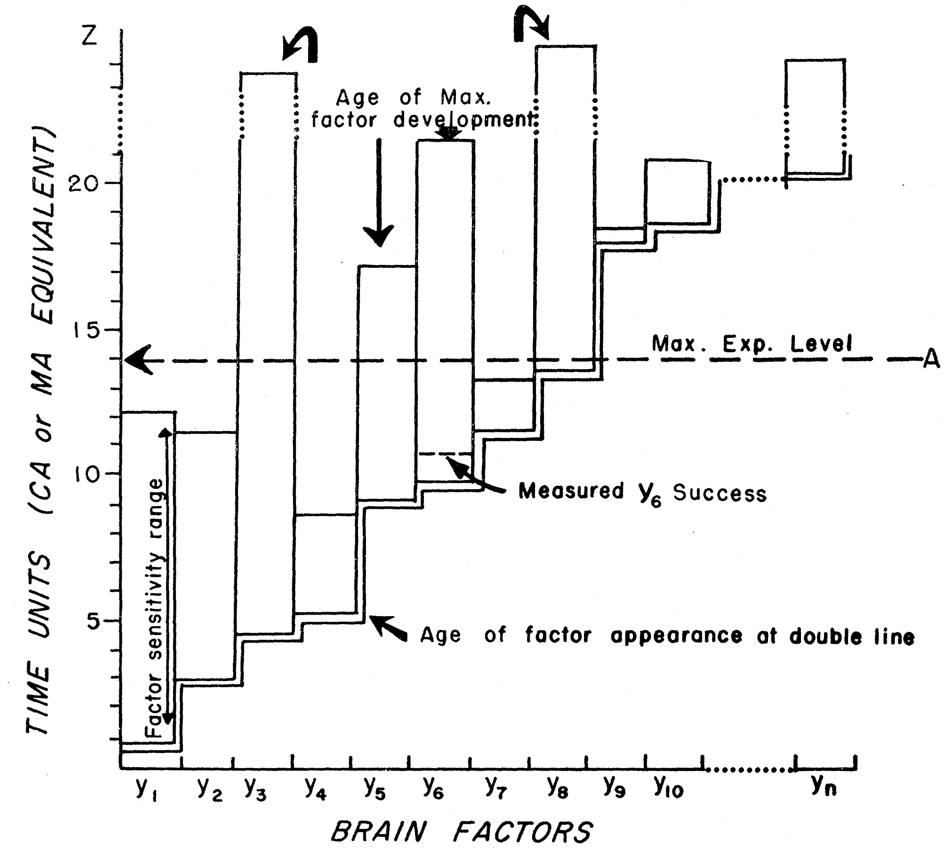

Fig. 5. Cross section through a test class x_n to show clinical use of a third dimension.

The qualitative verbal descriptive section of the report consists of statements with respect to the functional effect which below-expectancy-level functioning of a factor may have on problem solving. Such statements are framed in terms of the theory of thinking.

The prognostic section makes predictions based on (i) rigid policy statements to conform with the logic of the theory, such as the statements described next in the clinical example of the agnostic child with parroting ability; (ii) experimental pretesting of recommendations for establishing more favorable information-acquisition and information-forgetting rates, especially in such dysfunctions as communication disorders and reading disabilities; (iii) known or estimated remission rates where data are available; and (iv) frequency of within-patient associations of dysfunctions, as recorded in the classification scheme.

Clinical example. A brief example of one systematic differential diagnostic procedure used to classify neuropsychiatric patients will serve to illustrate the salient features of the classification scheme. The example to be considered is a bright 5-year-old child with a typical central communication disorder (*32*)—a congenital auditory agnosia combined with good parroting ability. The child will receive credit for all control system test classes, and his highest achievement in a sensitive test will be his maximum expectancy score. If all his other control system abilities fall within an arbitrary range of this score (such as 20 I.Q.-equivalent points), no specific control system disabilities will be recorded.

All the inputs, outputs, and special combinations in Fig. 2 that are expected to appear at the 5-year mental age level must now be examined separately. These may all be found to be normal, except for the auditory system, where the child shows good sensitivity and abilities up to level x_4 but fails to discriminate between grossly different sounds. Parents of such a child often report that the child is able to identify some words, such as *apple*, *baby*, and so on. Examination shows this report to be correct. This would be an apparent violation of the auditory hierarchy unless it can be demonstrated that the identification is made on the basis of kinesthetically learned speech. In a child with good parroting ability, this is quite common. The child hears a word, parrots it, and associates the parroting movement with the object or situation which accompanies the word in the real world. Later on, the child hears the word, parrots it, and identifies the object on the basis of his memory of his own vocalizing movements. The sole function of the acoustic pattern, therefore, is to lead to a vocalizing movement. The child then identifies the movement by remembering the object or situation associated with it.

If the vocalization is interfered with, such a child should not be able to make a correct object or situation identification through hearing. Such interference can be easily introduced by having the child vocalize some nonsense syllable (or if the child is too young, by having him chew gum vigorously) during the auditory pattern identification task. The experiment is critical, for if the child identifies the auditory pattern through hearing alone without the aid of kinesthetic memory, a rigid recommendation for sound discrimination training should be made. The prognosis for a great deal of usable normal speech (Fig. 3, bottom) in such a child is excellent. If the child, however, does not identify sound patterns without the aid of kinesthetic memory, an equally rigid recommendation not to proceed with sound discrimination can be made. The prognosis for normal speech is extremely poor (*33*) (see Fig. 3, top), and other avenues of training should be substituted.

Addition of the third dimension to the Boolean profile of Fig. 3, top, would then reflect the child's generally adequate efficiency and versatility in information retrieval and learning, as well as his modality-specific handicap. Such a three-dimensional profile serves as the basis for establishing educational goals for such a child. The high expectancies or goals set up for the child in the example are based on the tenet, implicit in the theory, that man's unique and unquestionable position at the head of the thinking hierarchy is attributable to the complex structure and operation of his central nervous system—that is, his control system—rather than to any other factor or combination of factors, such as use of spoken language or manipulative skills, important as such factors may be in everyday living.

Summary

A theory of thinking is presented which attributes the human brain's outstanding efficiency and versatility in problem solving and learning to two memory functions. The brain's efficiency is considered to be largely a function of the capacity to remember previous operations involved in finding answers to questions. Man's outstanding versatility in problem solving is basically attributed to memory which can activate, maintain, and terminate activities independent of, or only indirectly related to, environmental or physiologic regulatory factors. Within-brain activity patterns which have unidirectionally alterable probabilities of appearance allow for adaptation (learning). The fact that the probability of appearance of nervous system activity can be altered to approach zero or unity allows nervous system units to act as their own timing controls during answer finding; the fact that units are combined into pathways allows for propagation of addressed messages at rates of the same order of magnitude as those of the timing controls.

All behavior is viewed as being driven by information which exists in the organism's environment, within the system, or within its brain. Organisms with within-brain feedback controls (homeostats) whose activation can be initiated and maintained by memory patterns in the absence of the original physiologic triggering mechanisms are considered to have nonrigid probabilistic motivators. The existence of such motivators allows for logical operations of substitution in addition to the relational operations of addressing and timing controls which exist in systems with only rigid motivators. Flexible motivators allow for pattern substitutions based on the functional effect of a pattern on eliminating a within-brain displayed error or on solving a problem. Organisms thus can learn to classify internal as well as incoming patterns as similar or different. This ability is considered to be a powerful tool which (i) permits a system to recognize the structure of the environment and (ii) further increases the system's operational capacities, ultimately leading from classification to statistical operations of predictions and an operation of measurements.

Pleasure is viewed as the reduction of errors. Probabilistic motivators

activated by memory serve the function of relating basic regulatory mechanisms to problem-solving activities—that is, to pleasure. Memory for such activation frees the system of rigid dependence upon basic regulatory mechanisms and leads to a frequent initiation of programmed problem-solving activities. Man is thus ultimately motivated to apply his efficiency and versatility in learning and problem solving to a quest for new knowledge—that is, man is motivated to engage in scientific activity. His motivation thus generates a feedback, further increasing efficiency and versatility.

A behavioral classification scheme is presented here in the form of a two-dimensional list structure with a third, metrizable time dimension. When the third dimension is treated as a mental-age-equivalence scale, the scheme is useful for classifying thinking disorders in neuropsychiatric patients. The classification scheme presented constitutes the basis for a systematic procedure for analyzing thinking disorders which will ultimately allow technicians to administer tests and allow computers to write clinical reports (*34*).

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33. No case of congenital auditory agnosia (with or without parroting ability) where the patient has acquired more than 50 understandable consistent vocalizations which he can produce at will is known to me or to W. G. Hardy and his staff at the Johns Hopkins Hearing and Speech Center, nor are any such cases reported in the literature.

34. This research was supported by an Alfred P. Sloan Foundation, Inc., grant to the Division of Laryngology and Otology, Department of Surgery, of Johns Hopkins University, as well as by the U.S. Children's Bureau and the Maryland State Department of Health. I am greatly indebted to Robert Ledley of the National Biomedical Research Foundation and Johns Hopkins University for his encouragement and contributions throughout the various stages of this work.