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The Structure of Concepts

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Abstract

The application of the term concept, though widespread, is varied and inexact. The important role of concepts is seen throughout the areas of psychology, education, and artificial intelligence. A brief survey is made of the meanings of concept evidenced in psychological research in concept attainment, word association and semantic mediation, and information processing. From these data, desiderata are developed for an operational definition of concept. Finally, a definition meeting these criteria is offered. The term systemic concept is thus introduced. This definition reflects the two principal characteristics of concepts uncovered: concepts as data and concepts as processes. It is suggested that the systemic concept offers a framework for analysis of diverse psychological problems and will facilitate comparison among distinct conceptual skills.

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The Structure of Concepts

Frederick Hayes-Roth[1]

The notion of concept pervades the field of psychology. It is considered, in some sense, to be a primary element of human behavior. It is so common that it seemingly obviates a need for definition. At the same time, it is so gross that it successfully resists most attempts to investigate it in depth. No author, to my knowledge, has proffered a definition of concept which cannot be subsumed by Kendler's simple stimulus generalization paradigm, shown in Figure 1 (Pikas,1966,p.138). The implicit notion of concept here is of a generalized response to dissimilar stimuli.

The work of most researchers in concept attainment has focused upon the characteristics of the stimuli and the conceptual response in an attempt to explain the way in which concepts are acquired (Bruner et al.,1956; Vinacke, 1951). In most cases, the only behavior being acquired was a method of categorization. No loss of meaning would result from replacing an occurrence of the word concept by category rule anywhere in these studies.

If a category is a concept, the question arises whether, conversely, a concept is a category. If concept, as a

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1. The author is a research associate at the Sloan School of Management, MIT, Cambridge, Massachusetts. This work is part of a research effort in Intelligent Systems within the Managerial Information for Planning and Controls group and has been supported by the Ford Foundation Grant #690-0143 under the direction of Zenon S. Zannetos.

signifier, is more extensive than category, we can attempt to construct a framework which illuminates this difference. The values accruing to such a framework are many. A concise operational meta-language for the description of concepts will faciltate investigation and discussion concerning diverse relationships formerly globally considered as conceptual relations. It was this need that emerged in the author's current research and to which this paper is addressed.

1. Uses of the Term "Concept"

In this section, we will consider a few of the innumerable meanings emanating from concept. These variants are our basic data. Any proposed definitional framework must at least maintain the salient distinctions which these data embody. The value of such a framework derives from its capacity to illuminate these as a particular subset within the universe of potentially realizable distinctions which can be drawn about concepts and conceptualization. We will begin by briefly discussing a few of the uses of the term concept in studies of concept attainment, word association and semantic mediation, and information processing.

Experiments in Concept Attainment

Hull's famous Chinese character experiment (1920) established the basic stimulus generalization paradigm for concept attainment. Each subject was shown a series of Chinese characters composed of common primary radicals. Each character was paired with a nonsense syllable. After the

initial training series, new characters were shown, and Ss were asked to identify the type of character by responding with the appropriate nonsense word. Ss were able to "learn these concepts" even when unable to explain "how" they identified an occurrence of the concept. Concept learning[1] does not require awareness of category rules.

Let us define informational structure as the system of relationships or properties which must be perceived or manipulated for the proper execution of a specific discrimination task. In the Chinese character experiment, the informational structure was primarily relevant to the senses. Moreover, Hull demonstrated the adequacy of purely visual perception in providing information for the attainment of a concept. Thus, a concept was learned whenever a common sign could be consistently affixed to dissimilar referents.

A more complex but systematically designed stimulus set was used in the experiments reported by Bruner, Goodnow, and Austin (1956). Ss were asked to discover the underlying rules for category membership for graphic designs varying on each of several simple stimulus dimensions. The experimenters studied the "strategies" which Ss employed to discover the basis of a concept (See also Vygotsky, 1962). Of particular interest to them was the variation of strategies exhibited in response

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1. Throughout this paper, we will use the terms concept learning, concept attainment, and concept formation interchangeably. Much difficulty exists in distinguishing these, and the cause of brevity can best be served by avoiding this issue, at least temporarily.

to three basic alternatives of informational structure: conjunction, disjunction, and relation. Conjunctive rules were represented by category members all possessing two or more required stimulus properties in common. Disjunctive rules were represented by category members each possessing at least one of several acceptable stimulus properties. Relational rules were represented by members each exhibiting a common stimulus pattern more complex than in the other two cases (e.g. less than three borders; number of borders equal to number of figures).

In these experiments Ss were asked to discover rules of discrimination which involved logical conditions among visual primitives in the stimulus set. The introduction of logical relations into concept attainment tasks reflected a belief in the general relevance of logical informational structures. Each stimulus dimension was a priori semantically equivalent. Tasks focused on the identification of the exact logical rules for combining stimulus values to define a category. The concept to be acquired was a logical condition which would obtain (be true) for all items within a category and for no others. In contrast to the structure of Hull's task, visual perception, as a vehicle of concept attainment, was of little importance in this task.

The work of Gagné (1965(a), 1965(b), 1966), Lee (1968), and Lee and Gagné (1969, 1970) has further pursued the logical structure of concept attainment tasks. Several research directions

were followed. Gagné (1965(a)) attempted to distinguish concept learning from seven other learning modes. Concept was restricted to the identification of patterns of properties which could provide the basis for complex discriminations. Purely visual discrimination, such as separately identifying nine sorts of automobiles, was not conceptual. Identifying the middle item between two others was conceptual. How one is to determine which learning is which type is not known exactly. What do we consider the identification of a boundary, like a wall, if not something of both of these types of discriminations?

Following Berlyne, Gagné (1966, pp. 82 ff.), suggested that concepts were of two types, situational and transformational. Situational concepts were properties of a problem context. Both mass and acceleration are situational concepts, presumably because they are measurable or specifiable aspects of a problem environment. Multiplication, which is required in this problem to compute force (itself a situational concept), is an example of a transformational concept. That is, multiplication operates on other concepts (force = mass X acceleration).

From this distinction, Gagné reasoned that concepts which are learned by definition (e.g. force, mass, acceleration) are distinct from concepts which are simply rules for pattern recognition. He called these concepts and their interrelating definition principles. A principle is not "point-at-able." Instead, "mass is learned when one is able to demonstrate that

the principle relating the concepts force and acceleration depends upon mass in an inverse way" (Gagné, 1966, p.89).

Moving in another direction, Lee and Gagné explored how complex conceptual rules of categorization are learned (1969, 1970). A complex conceptual rule (A-C) consists of an integration of an attribute-coding rule (A-B) with a contingent rule (B-C). For example, the attribute-coding rule may require labeling a given subset of items as a. The contingent rule may require that for all items labeled a, S must report the color of that item (not necessarily the same for all items labeled a). The complex rule thus requires, for all items which are a, one behavior and, for those which are not a, another.

In this experiment we see two kinds of conceptual processes as components of yet a third, called complex, conceptual process. The informational structure of this concept is indeed more complex than for simple categorization or transformation rules. It requires, at once, criteria of categorization, transformation, and systematization.

As used here, systematization means the integration of component primary rules by the addition of internal constraints. In this example, systematization is achieved by the introduction of sequential constraint. Specifically, S is required to unite sequentially (chain) each appropriate contingent rule and attribute code. Thus, if there are two attribute codes (a; b) and two contingent responses (color; size), the complex rule requires the development of a system of ordered pairs: (a-color;

b-size). These orderings constrain the codes and responses to observe special arbitrary sequences.

The notion of systematization is equally applicable to principles, as discussed above. A principle can be considered the systematization of a set of component categories (variables) and transformations (operations). The structure of the system is expressed in terms of constraints which may take the form of sequences, orderings, equations, and so forth. In systemic concepts such as these, the informational structure embodies both the fundamental informational components (categorization and transformation rules) as well as the systemic relations (constraints).

It is of interest that Lee (1968) chose the term complex higher-level concept to describe the biconditional category rule. "It is classified so because it can be broken down into three simpler lower-level concepts: a conjunctive, a conditional, and a joint-denial concept" (p. 930). What Lee implies is that a concept is a category rule. Further, concept complexity is determined by two properties of the informational structure: (1) the number of relevant stimulus dimensions and (2) the number and type of component logical conditions.

He suggests the existence of inherently simple logical rules upon which hierarchies of more complex concepts are constructed. Clearly, he has demonstrated the feasibility of such a situation. It is not necessary, however, to assert that

any of the possible non-trivial Boolean binary operations[1] is generally simpler than any of the others. This, algebraically, is not the case. Each binary operation is a priori equally complex as any other. A complete logical system can be formulated with many different subsets of Boolean operations as bases.[2] If we have gained exceptional facility with some of these (conjunction, for example), it may be as a result of educational and cultural training (Bruner et al., 1956, p. 57). It is not surprising, then, that the most common--as opposed to the simplest--logical operations facilitate the learning of new operations which are composed of them.

Experiments in Word Association and Semantic Mediation

In word association and semantic mediation research much has been made of the conceptual relations which are presumed operative. In many respects, explanations of phenomena in these two areas are similar. Basically, the belief is that words or figures are tokens for concepts. These concepts relate two or more properties of a referent (e.g. its color, use, and name) by the association of the sign (word or image) to the entire property set conditioned to it.

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1. A Boolean binary operation is a mapping

$$B: \{0,1\} \times \{0,1\} \rightarrow \{0,1\} .$$

If we have two true-false variables, g and h, then there are sixteen possible mappings of g and h into the values of true and false. Trivial mappings take all values into true or false, thus leaving fourteen others.

2. Consider a logical system which is founded upon primary operations corresponding to biconditional ($\equiv$) and inclusive or ($\vee$). In such a system, the "simple" conjunction (.) would become a higher-order concept, as defined by Lee. That is, $g.h = (g \vee h) \equiv (g \equiv h)$.

It is possible, in fact, to elicit verbal associations on based on three general relationships. These have been called verbal generalizations by Cofer and Foley (1942). Generalization can occur on any of the following bases: (1) in relation to the name (sign) of a conditioned stimulus object; (2) in relation to the object of a conditioned word (sign); or (3) in relation to words (signs) semantically or phonetically related to a conditioned word (sign) (pp.515-516).

It is not yet clear what the basis of semantic generalization is. Many attempts have been made to arrive at a method of organizing semantic associations (Woodworth, 1938; Osgood, 1961). In general, word association researchers have divided on methods of classification. Some proposed logical or evaluative category systems which would include headings like superordination and egocentric. Others, notably Deese (1965), have developed methodological techniques to measure associative strengths of words which generate similar patterns of semantic generalization.

Both approaches suggest that word associations reflect relational information structures interconnecting the concepts which the words signify. Words are associated with one another, it is implied, because they are semantically related: directly, as in woman-girl, or indirectly, as in bank-wallet (both related to money in some way). Unfortunately, these word association experiments do not provide a clear notion of concept. At most, they provide a gross statistical procedure for evaluating the average referential content of a concept.

Because association experiments typically restrict a S's response to a single word, they introduce a constraint of some significance. A single word, it can be seen, is not identical with the conceptual information structure it reflects. Words are only suggestive of portions of these structures. When the S of an association experiment responds with a word, he has undoubtedly completed a complicated cognitive process of which the response (word) is only a by-product. The actual critical attributes of the entire information structures which are operative in association are unknown.

In the solution of problems, the association among concepts is eminently important. Solving a physics problem concerning the concept work, for example, necessitates an association between force (mass X association) and distance. In general, problem solutions represent assemblages of conceptual macro-processes, each element of which is composed of systems of elementary conceptual rules. To the extent that pre-learned component conceptual rules speed solution of the larger task, their mediation is facilitative. Conversely, mediation can be inhibitory.

The mediating role of verbal concepts has been explored directly in syllogistic reasoning problems (Frase, 1966, 1968; Pezzoli and Frase, 1968). In these experiments, values of word association strength taken from population norms could be considered a surrogate for degree of conceptual relationship (this being consistent with Deese). The researchers clearly

demonstrated that conceptual mediation of reasoning did occur. The mediation was either facilitative or inhibitory as the syllogisms to be evaluated were valid or false, respectively. No attempt was made to distinguish several types of distinct conceptual associations in these experiments.

Experiments in Information Processing

The final area of research we will consider is that relating specifically to information processing and artificial intelligence. Work in this area can be divided into concept attainment models and concept processing systems. Notable among the researchers in concept attainment are Hunt (1962) and Bourne (1968). These researchers have both considered concept learning as a problem solving situation wherein salient and relevant stimulus dimensions are to be discovered by the organism. Models of concepts constructed by Hunt utilize binary decision trees for the representation of the informational structure. Those of Bourne employ mathematical descriptions of the cue contexts and learning rules. In both cases, concepts are categorizing systems dependent upon relevant cues which must be learned.

The artificial intelligence group has taken several distinctive approaches to conceptualization problems. A "semantic memory" designed by Quillian (1968) portrayed concepts as networks of all possible associations between words. An association between two words in the network was a partial component of the total concept of each word. All associations were statically defined and of equal significance in all contexts.

Weizenbaum (1967) constructed a machine able to recognize

certain significant concepts occuring in natural man-machine dialogue. Eliza, the machine, would then generate a communicative response the content of which would be appropriate to the theoretical implications of the identified concept. For instance, in an application of his program which emulated a Rogerian psychoanalyst, the word "everyone" in "Everyone hates me," was a concept of special significance. "Everyone" was interpreted as a universal assertion. The program was constructed to respond to universals by generating requests for specifics. Thus, it might respond, "Can you name someone in particular who hates you?"

Weizenbaum considers concepts to be highly contextualized. A rose is not simply a rose. Each interpretation of a concept depends upon its true significance in the specific context. A rose in a garden means something different than a rose in a vase. A concept can be relevant or irrelevant only in relation to a specific problem. Concepts are not restricted to categories, but can imply rules for behavior which will guide the machine in its subsequent activity. In short, an attained concept can alter the state of the machine.

The last example from artificial intelligence is Winograd's very recent program for the translation of natural language (1971). This program is a robot for the manipulation of toy blocks. Winograd did not specifically address the question of what a concept is, but his work abounds with implications for this problem.

In his program, all potentially salient relationships among elements of the universe of the machine are identified and systematically enumerated. Each relation (e.g. height, time, purpose) is a potential property of those things for which such properties are relevant. Height is relevant to toy blocks but not to colors; purpose is relevant to the machine's actions but not to the table. Each realizable relation can occur as a _fact_ (a _tall_ _block_ is seen on the table) or can arise as a _problem_ to be solved ("Put a tall block on the table").

Every potential relation, every thing, and every fact are _concepts_ in the machine's world. Each concept is associated with explicit logical conditions which verify its occurrence. Each approach to theorem proving (problem solving)--as in proving that there are no tall blocks on the table--is a conceptual process or problem solving _paradigm_. Most important, _concepts are both simple data and complex procedures for problem solving, simultaneously_.

For instance, a yet unrealized relationship like _middle_ ("Put the small block in the middle of two large blocks") is a concept which means _how_ to put the block between two others. Any block which meets the criteria for "having been put in the middle" _is_ in the middle. A concept of noun, for example, means a method of finding anything that can satisfy the requirements of _noun_--including, in some cases, either an infinitive or a gerund. Things which can be proven to meet the requirements for finding

a noun are nouns.

The contrast that is being made here is very important for the definition of concept that will be offered in this paper. It is a contrast between ideas _being_ and _becoming_ or between _has a property_ and _can be shown to have a property_. As Winograd's work has suggested, concepts are not simply categories or transformations. _Conceptual structures_, as commonly discussed, include methods of discrimination, classification, transformation, integration into systems, and organization of behavior. The diversity of these properties will be prominent in the next section where we consider desiderata for a definition of concept. The extent of the concept of _concept_ has now been nearly displayed.

2. Desiderata for an Explication of Concept

Any explication which is proposed for _concept_ must facilitate consideration of the distinctions which we have discussed above. These are the stock of relations which operationally circumscribe the feasible set of possible explications. Five major types of considerations emerge in this paper. These can be named as: (1) the attainment, demonstration, and utilization of concepts; (2) the systemic nature of concepts; (3) the encoding and measurement of complexity of concepts; (4) the semantics of concepts; and (5) the role of concepts in problem solving. In this section, we will specify the principal desiderata of an explication of concept with respect to each of these five separate considerations.

Concept Attainment, Demonstration, and Utilization

The attainment of a concept is marked by the acquisition of a stimulus generalizing behavior conforming to the rules of the

concept definition. Subsequent to concept attainment, any stimulus which satisfies the conditions of occurrence provides a context in which the conceptual response can voluntarily occur. The attainment of a concept is testable by requiring the demonstration of the conceptual response in an appropriate stimulus situation. Utilization of a concept means voluntarily responding with the conceptual response in such a stimulus situation.

Concepts as Informational Systems

Concepts may include rules for attribute coding, contingent behavior, constraining relations, transformations, and context dependent determination of significance. Concepts can always be considered as rules for explicating how one property set of the environment is to be converted to another property set. These rules need not be verbalizable. They are evidenced when demonstrated under the test conditions discussed above. An example of such a rule, from Hull's experiment, explains how one particular Chinese character is to be labeled "JAG" by prescribing the requisite stimuli for this criterion response.

The informational system[1] embodied by a concept must include: (1) determiners of the relevant stimuli and their attributes; (2) the rules for effecting a transition from the stimulus property state to the response property state; and (3) the criterion conceptual response to be associated with the transition to the response (outcome) property state. For example, a S in the Hull experiment who is being trained in attaining a concept

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1. This use of informational system is to be distinguished from that in control theory. In this paper, informational systems are the specific relations requisite to the attainment and demonstration of a conceptual rule. Control is not considered.

of "JAG" must: (1) perceive the exhibited character; (2) recognize the criterion "JAG" pattern in the perceived character; and (3) respond "JAG" when he successfully recognizes the pattern or "not JAG" in any other case.

The informational system of a concept must fully organize component stimuli and conceptual rules. Thus, the concept will entail rules pertaining to attributes of the concept itself. In the case of the complex conceptual rule of Lee and Gagné, already discussed, the informational system necessarily includes rules of specific sequencing of component parts. In cases of higher-level concepts, those of Lee for example, the conceptual system prescribes logical conditions of coordination of three component conditional rules.

From this point of view, diverse concepts are similar in their conformity to the general property-transformation paradigm. They can be distinguished or compared in terms of the relevant (1) stimuli, (2) properties, (3) responses, and (4) internal organizing constraints.

Encoding of Concepts and Conceptual Complexity

In view of the four components of concepts just identified, any meta-language or encoding system for concepts must, at least, distinguish these separate entities. In addition, we desire a system of encoding that meaningfully reflects the presumed increase in complexity of higher-order concepts. Certainly, the encoding system should facilitate comparison of various concepts on the basis of complexity as well as manifest similiarities and

differences in the four primary components.

The particular method of encoding of concepts should be reducible in appropriate circumstances to a deterministic binary tree representation, or a probabilistic representation, or a problem solving procedural system. That is, the chosen notation of concept expression should be as general as needed without resulting in loss of specificity.

Concept Semantics

The meanings of concept and semantics have much in common. A concept signifies a specific system of relations. The semantic content of a word is just that system of relations pertinent to the concept for which the word is a sign. A representation of concepts should be sought which facilitates this semantic analysis. Insofar as semantic content is non-empty, the systemic concept provides a map of the semantic space.

In many cases, metaphor for example, the semantic content of a concept is the result of conceptualization on one or more concepts taken as data. "The fog comes on little cat feet," means just those stimulus conditions to which such a description is applicable (Bar-Hillel, 1964). The applicability of a description (attribute coding) is determinable by examination of the logical transformations which have been effected on the concepts (words) utilized. If the above statement is intended to signify the event, fog moves silently, then the statement is applicable insofar as "comes on little cat feet" can denote moves silently. A conceptual system, being the basis of semantic

meaning, cannot disregard it.

Concepts in Problem Solving

It is clear that problem solving paradigms, the rules for how to solve a particular problem, are coextensive with concepts themselves. The principle of work can be employed in solving just those problems in which a concept of work is relevant. The principle of work, for instance, can be utilized in the transformation of a problem of forces into a problem of energy conservation. This is achieved simply by application of the property-transformation rules embodied in the work concept: (1) work = potential energy; (2) work = force X distance. Conversely, knowing how and when to convert problems involving force into problems of energy conservation is itself a conceptual paradigm.

A definition of concept must reflect its dual nature. Concepts are both representation schemes for data and methods for the re-organization of property systems in problem contexts. This dual nature of concepts can best be realized through an example. Consider a machine that knows the following facts: (1) Baboons, chimpanzees, and humans are primates; (2) parrots, parakeets, and pigeons are birds; (3) in a controlled learning experiment pigeons exhibited greatest resistance to extinction when trained on a fixed ratio reinforcement schedule while baboons in the same task were most resistant when trained on a variable ratio schedule. Each of the three facts represents a single concept, in this

case concepts for data classification (attribute coding). These concepts of class inclusion could be labeled as relations $\wp_1$, $\wp_2$, and $\wp_3$. Then, a fact as "Henry is a primate" could be recorded in a manner like $\langle \wp_1 : \text{Henry} \rangle$. This is the role of concepts in encoding.

The other role concepts can play is that of transforming property systems. Consider what might occur when the statement "Henry is a primate" is a stimulus to our machine which <u>prompts</u> it to conceptualize about "Henry." It may, first of all, perceive Henry as a thing, an entity with intrinsic significance. Secondly, the conceptualizing machine may automatically transform the factual stimulus, "Henry is a primate," into a temporary hypothesis about the potential relationship that the machine will have with "Henry." For example, the machine might generate the hypothesis: "With respect to birds in general, Henry (the detected thing) will be more resistant to extinction of learning when trained on a variable reinforcement schedule as opposed to a fixed ratio schedule." This it could <u>reasonably</u> <u>suppose</u> if guided by certain general principles of inductive and deductive logic.

Going beyond this, we can imagine a psychological system which never attains the capacity to recognize as a salient property of Henry his own identity (<u>Henry-ness</u>). Instead, such a system might recognize in Henry, and employ as its own <u>perception</u> of Henry-ness, only an occurrence of a poten-

tiality for the demonstration of the extinction relation just cited.

The meaning of a thing, its thing-ness, is always an arbitrarily relative conceptual framework. Within this framework, the thing is defined (perceived) precisely in terms of the relationships it shares with other things. The selective application of one of several alternative conceptual schemes (attributes) to a given stimulus is often solely responsible for the difference between a successful or an unsuccessful problem solving effort. The systematic tendency of an organism to attempt the solution of a problem with a selective orientation is identical to problem set (Krech and Crutchfield, 1958, pp. 96 ff.; Woodworth and Schlosberg, 1954, pp. 830 ff.).

3. Systemic Concepts

In the last section, those features of concepts which would optimally be preserved by an explication of concept were discussed. In this section, we will propose a particular definition of concept which satisfies these conditions. At the outset, we must agree that any framework or partitioning of events into discrete attributes and operations is always arbitrary.

> Any dynamic system can be made to display a variety of arbitrarily assigned "parts," simply by a change in the observer's point of view" (Ashby, 1968, p. 110).

The framework which is proposed in this section is one of many that could possibly be designed as an explication of _concept_ consistent with the functional desiderata established in the last section. The specific components of this explication seem, however, to satisfy these desiderata inherently and naturally.

The label we will apply to the conceptual structures discussed is _systemic concepts_. Formerly, these were called _functional conceptual structures_ (Hayes-Roth, 1971) and that, though precise, is too unwieldy. What is common in both names, however, is the suggestion of the coexistence of a static structural concept with a dynamic procedural system. This, we have shown, is at the crux of the notion of concept.

A systemic concept is, in its simplest interpretation, a rule for transforming property sets. Thus, under this definition, one example of a systemic concept is the rule for labeling a particular Chinese character "JAG." Another example is the rule for transformation under multiplication of two numbers (multipliers) into a single numerical value (product). Any such rule can be represented by the functional mapping

$$C: \Theta \rightarrow \Theta.$$

Here, the rule C is the systemic concept and Θ is the set of properties of the environment that are perceptible or conceptualizable. For example, multiplication is just

that rule:

$$X: (m_1, m_2) \rightarrow p, \text{ where } p = m_1 \times m_2.$$

This explication of concept is, however, inadequate. It does not consider (or facilitate a consideration of) the utilization, structure, or complexity of concepts. For these problems, we must further partition the simple functional rule.

The complete structure of a systemic concept is shown in outline in Figure 2. The four major components of a systemic concept are <u>primary elements</u>, <u>elemental attributes</u>, <u>environmental contingencies</u>, and <u>the process system</u>. The primary elements are the indivisible <u>wholes</u> or <u>primitives</u> upon which systemic concepts are built. Attributes are rules for classifying the elements according to arbitrary criteria. Contingencies are the conditions that determine the applicability of the concept to a situation. And the process system is the integration of inputs and operations in order to produce the conceptual outputs. Each of these components is more fully discussed below.

Primary Elements

The primary elements of systemic concepts include <u>input and output variables</u>, <u>operations</u>, and <u>conditional relations</u>. A concept can be thought of, as suggested above, as a rule for transforming one property set into another. The <u>things</u> which are exploited in the transformation are inputs. Those produced by the transformation are outputs.

The total transformation is itself expressible in terms of systems of component primary operations. Conditional relations, as here defined, are those elementary discernible characteristics of patterns which are employed in the expression of logical conditions of truth and falsity. Such conditions are the basis for the verification and identification of criterion events. Relations of this sort are used in defining the structure of a concept's process system and its environmental contingencies.

<u>Example</u>. In the Lee and Gagné (1969, 1970) experiment of learning a complex conceptual rule, we have:

Inputs: Stimulus designs provided by E.

Outputs: Verification or rejection of category membership of an input.

Operations:

(1) Attribute coding.

(2) Contingent response.

Some conditional relations from Lee (1968) are:

(1) Conjunction (A.B = A and B).

(2) Conditional (~A.B = not A and B).

(3) Joint-denial (~A.~B = not A and not B).

Elemental Attributes

Every component of a systemic concept can be attributed. Attributes are rules for differentiating two or more things, and every attribute rule can thus be portrayed as a particular

systemic concept. The attribution of a thing requires the organization of three attribute components: (1) the salient dimensions(s) (aspects, properties) of the environment serving as a basis for discrimination; (2) a specific discrimination method; and (3) a range of values which can be associated with the results of this discrimination.

In many actual discrimination problems, it may be impossible to identify these components. This may be true even for the most common discriminations. The attribute dog is one such example. At present, we might at best prescribe several surrogates for the dimensions and methods presumably employed in such discrimination. It seems that the recognition of the attribute dog is an example of case where the attribute is inseparable from the dimension. That is, the dimension of discrimination, in this case, is dog-ness, the discrimination method is perception, and the single possible value applied is dog.

In other cases, however, the method of attribution is quite determinable. For example, the potential role of measurement in an assessment of the attribute volume conserving is clear. The discrimination by a person of short, medium, and tall buildings, though not deterministic, is subject to excellent modelling which utilizes probabilistic and subjective scaling techniques.

Attributes can be applied to input and output variables, operations, conditional relations, contingencies, process

systems, and to attributes themselves. As an example of this reflexive property, consider the concept of <u>continuous scale</u>. The attribute of continuous is applicable to just those attributes which structurally permit infinitesimally fine degrees of discrimination (e.g. color, weight, position, time). As an example of attributes pertinent to conditional relations, recall the <u>lower</u> vs. <u>higher-level</u> distinction which Lee proposed to discriminate the conjunctive and biconditional conditions.

> <u>Example</u>. Continuing the example from Lee and Gagné, the learning task first required labeling different combinations of red or blue and large or small stimuli as <u>a</u>, <u>b</u>, <u>c</u>, or <u>d</u>. Subsequently, the criterion response was contingent upon these intermediate attribute values. Associated with each attribute value was a unique property of the stimulus which was to be reported to E. For stimuli labeled <u>a</u> the property was shape, for <u>b</u> texture, for <u>c</u> outline, and for <u>d</u> background. These operations necessitate two separate attribution rules.
>
> (1) <u>Attribute</u> <u>coding</u> attribution rule:
>
> Dimensions: color and size.
>
> Discriminable values: large-red; small-red; large-blue; small-blue.
>
> Discrimination method: visual perception.

(2) Contingent response attribution rule:

Dimensions: attribute code assigned in the rule (1).

Discriminable values: a; b; c; d.

Discrimination method: Invoke the systemic concept for attribute coding task (see below).

Environmental Contingencies

Environmental contingencies are the conditions of interdependency and exclusivity which govern the viability and validity of applications of systemic concepts. Basically, these contingencies are requirements which link the systemic concept or some of its components to external factors which are otherwise irrelevant to the internal structure of the concept. They are expressed, partially at least, in terms of conditional relations among environmental attributes. Contingencies may be of two types, initiatory and contextualizing.

Initiatory contingencies can be considered as conditions of deficiency or sufficiency which prompt the utilization of a concept. These include condtions of pain, deprivation, satiation, and desire which instigate intelligent control behavior. For example, thirst, as an environmental contingency, can initiate the systemic concept that drinking (operation) water (input) provides relief (output) from thirst.

Contextualizing contingencies are apparently much more

common than initatory contingencies in adult concepts. These conditions establish the boundaries of feasible or likely (in a probabilistic sense) application of concepts. The restriction of the use of the functional definition of work (force X distance), to problem solving situations in physics, is such an example. Intelligent organisms which simultaneously possess several systemic concepts of work (e.g. force X distance; physical effort; mental effort; employment; task; output of an artist; place where one pursues an occupation) are guided in the discriminating application of these, to a substantial degree, by what we have called the contextualizing contingency.

Example.

Systemic Concept	Contextualizing Contingency
Newtonian mechanics	Velocities $\ll$ speed of light
Work (place of occupation)	Location modifying
Legal driving	Vehicular, not in golf
Conservation of energy	Physical systems
"JAG" (the Chinese letter)	In psychological testing
"JAG" (Jaguar automobiles)	Automotive reference

Process System

The content of a concept, in its traditional sense, is explicated by the process system of the systemic concept. The process sytem organizes the inputs, operations, and outputs

by the introduction of internal constraints. These constraints may be rules for sequencing the inputs and operations, for coordinating the sets of contingencies logically, or for maintaining any other condition of internal consistency. The process system expresses the systemic concept as a series of operational transformations of the inputs and intermediate outputs. The analogy to economic input-output models or, more generally, to cybernetic systems is a rich one. Every conceptual act is the utilization of the process system of at least one systemic concept. Conceptualizing is production.

It is possible to differentiate several major types of organization used in common process systems. Among these are included the constraints of sequence, configuration, hierarchy, and feedback. For example, the process system integrating the two component rules in the acquisition of the complex conceptual rule (Lee and Gagné) employs a sequential constraint, as already established. The concept of middle is configurally constrained. The concept of supervise is constrained simultaneously by conditions of hierarchy (authoritative) and feedback(supervisory detection and control).

It is only in providing a complete structural description of systemic concepts that their meaning is fully understood. Here we display how the complex conceptual rule is amenable to description as a process system.

Example.

(1) Attribute coding process system:

The operation is selection of the appropriate response.

The range of possible stimuli maps one-to-one onto the responses.

The input is the stimulus supplied by E.

Stimulus	large-red	→	a
	small-red	→	b
	large-blue	→	c
	small-blue	→	d

(2) Contingent rule process system:

The operation is selection of the appropriate response.

The range of possible stimuli maps one-to-one onto the responses.

The input is the attribute code of a stimulus supplied by E.

Attribute Code	a	→	shape
	b	→	texture
	c	→	outline
	d	→	background

(3) Complex conceptual rule process system:

The operations are attribute coding (a systemic concept) and contingent rule response (a systemic concept).

The input is the stimulus supplied by E.

The operations are constrained to observed a specific order: (1) attribute coding operates on the input and produces an attribute code as output; (2) contingent rule operates on the output attribute code as its input, and produces a contingent response as its output.

The integration of the component concepts into the complex conceptual rule is illustrated in Figure 3.

The Naming of Concepts

How concepts are _named_, that is, which signs are associated with which systemic concepts, is of great import. Concepts have been variously named for the inputs they use (_hair_ brush), the outputs they produce (_tea_pot), the operations they employ (_burn_er), the attributes they relate to (_weight_, _weigh_, _heavy_, _light_), and so forth.

Concepts frequently represent complex systemic structures in contradistinction to a single point-at-able object which, standing alone, is the total semantic meaning of the concept signified by a word. Therefore, the use of the concept name (word) to signify a particular aspect of the systemic network is likely in any application to be only probabilistically effective. Conversely, the myriad of associations which can be generated in response to a single word is potentially explainable as a result of the selection of various attributes of the systemic concept represented by the word (Cofer and Foley, 1942; Deese, 1965; Mandler, 1968). The efficiency of information handling owing to the signification of systemic concepts by common words is, thus, gained at the expense of forsaken semantic precision.

Examples of Concepts

Until this point, the impression may have been created that all human concepts are essentially computer-programmable procedures for classification and transformation. This is not true on two accounts. First, concepts provide a means for the self-organization of the human. Secondly, it seems likely that the bulk of human conceptual information is occupied not by such procedural systemic concepts, but by vast numbers of their examples. The concept of snow, for instance, has many examples in our experience: snow falling at Christmas, snow to be shoveled, snow balls, snow mobiles, snow cones, snow for skiing, etc. Somehow, these experiences unite to anchor the systemic concept snow and make it tangible.

Examples, like these, represent parameterized instances of systemic concepts. That is, each conceptualizable experience can be viewed as the occurrence of a systemic concept with various substitutions having been made for the parameters. The actual substitutions which are made for the concept components arise for various reasons. In this sense, the row-column entry in a child's multiplication table, where 5 X 7 = 35, is an example of the systemic concept of multiplication (as defined earlier). Here, 5 and 7 have supplanted the input variables (multipliers) and 35 has replaced the output (product).

One objection to this point of view can be anticipated: "5 X 7 = 35 is not an example of a concept of multiplication,

but counting 7 piles of 5 objects and arriving at the sum 35 is." This assertion, however, is not correct. It is a fundamental requirement that examples be parameterized occurrences of the specific process which defines a concept. The example of counting piles is an example of another systemic concept of multiplication, not identical to the first, but one coincidentally yielding identical results.

To see this more clearly, we will describe two separate hypothetical multiplication machines. The first machine possesses a concept of multiplication which is defined as follows: for any two numbers (m_1 and m_2) retrieve from memory the value from a table P corresponding to p_{m_1,m_2}. The second machine's concept of multiplication is defined as follows: for any two numbers (m_1 and m_2) produce the sum of a series of terms of length m_2 in which each term equals m_1. These concepts of multiplication produce identical outputs if and only if P is a multiplication table and $p_{i,j}$ contains the value i X j. But the structuresof the two concepts manifested in these machines are utterly different. The same name applies to distinct concepts yielding empirically equivalent results in a limited case of problems. The flexibility of the two machines will be different according to the environmental conditions to which they are exposed.

The role of examples in the functioning of human intelligence cannot be overstated. Examples from experience are the data on which conceptualization primarily operates.

Analogical reasoning is typical of the higher mental processes. Analogy between two systemic concepts can be established on the basis of a single common example or attribute thereof. Alternatively, two events can be placed in analogical relation on the basis of their roles as examples of concepts with common systemic structures. Much of the author's current research is concerned specifically with the role of examples in the structure of cognition and problem solving.

Comparisons of Systemic Concepts

One of the immediate benefits of the systemic concept framework is the ability to compare diverse concepts. It is clear that concepts can exhibit similarity or difference along many dimensions. The development of methods of assessment of the relationship between distinct concepts seems both valuable and promising.

For example, two concepts may use similar inputs or operations and thus be classified for a specific type of commonality. Or they may produce similar outputs and thereby qualify for consideration as alternatives. Concepts which operate under similar contingencies are subject to higher-order organization; an example is the set of behaviors that can be observed in response to extraordinary informational uncertainty in a concept attainment task. Concepts may be considered <u>instrumentally</u> <u>compatible</u> on the basis that the output of one is an input of another. The variety of structure

and dimensionality of comparative conceptual relations could potentially be used to explore the major functional features of cognitive organization.

4. Conclusions and Prospects

At the outset of this paper, concept was a rather abstruse idea. It was shown how the notion of concept pervaded diverse areas of research yet resisted attempts at clarification. The best paradigm for concept learning was taken to be Kendler's stimulus generalization paradigm. Nevertheless, it was clear that most of the significant characteristics of human conceptual behavior were totally absent in that simple model.

As we interpreted the research in concept attainment and artificial intelligence, dual functions of concepts crystallized. Concepts were both rules for encoding observations and means of transforming the environment into novel property systems. That is, concepts were seen to be both systems of data as well as problem solving procedures operating on these data.

The dual functions of concepts have been integrated into the definition of systemic concepts. Concepts are procedures (1) for the determination (validation) of the occurrence of members of a concept class or (2) for the production (demonstration) of such members. Thus, the "complex conceptual rule" of Lee and Gagné is a procedure

for producing a conceptual response. Conversely, the "higher-order biconditional concept" of Lee is a procedure for indentifying members of the biconditional category class. In addition, concepts are data for the transformation by other concepts, providing a mechanism for the re-organization of conceptual bases. The use of modifiers like complex and higher-order evidences such conceptualization about concepts.

It seems possible with the notion of systemic concepts to pursue deeper explanations of many old problems. It is the author's hypothesis that Ss can be shown to exhibit highly differentiated cognitive structures reflecting discrepancies in the systemic concepts they employ. For example, Ss may exhibit both differentiated patterns of retention and problem solving which are predictable from observed characteristics of those systemic concepts they employ in experimental test situations.

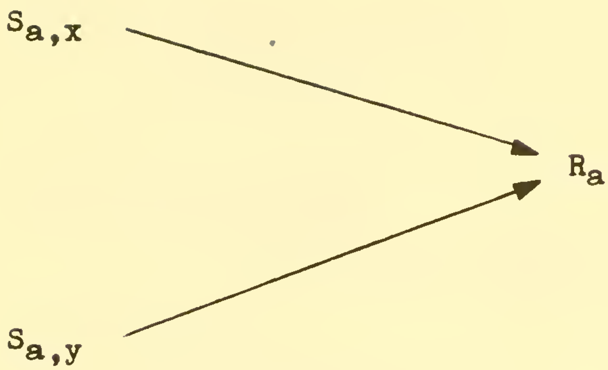
The potential utility of a systemic conceptual orientation to word association experiments seems equally great. For example, we might speculate that semantic generalization occurs predictably along specific component-component relational dimensions under some conditions of activity or training. The potential for studying individual differences, as in clusters of Ss exhibiting similar conceptualizing patterns, is promising.

Finally, the applicability of the systemic conceptual framework to educational and learning systems is great. We can

investigate the structure of hierarchical systems of knowledge both from issues of information representation and from consideration of conceptual transformation. For example, we can explore the development of machines which teach on two levels. First, they will convey methods of encoding the environment (facts and examples). Secondly, they will systematically control the development of skills of set, re-organization, and analogy which are the facts of Level II.

In sum, experimentation and simulation oriented about systemic concepts can be expected to produce valuable results. By isolating significant parts in the <u>whole</u> of a <u>concept</u>, we are afforded the opportunity both to examine conceptualization and concept learning systematically and to compare diverse findings in an encompassing perspective.

Figure 1



Kendler's paradigm for stimulus generalization: also an operational definition of the concept a. When a occurs in either context (a,x or a,y), it is <u>abstracted</u> and leads to the criterion response, R_a.

Figure 2

SYSTEMIC CONCEPTS

<u>Primary Elements</u>

(1) Input variables
(2) Output variables
(3) Operations
(4) Conditional relations

<u>Elemental Attributes</u>

(1) Dimensions
(2) Discriminable value range
(3) Discrimination method

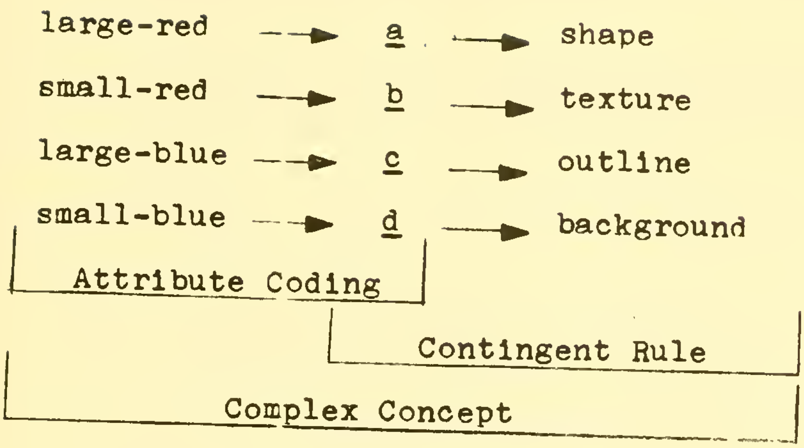
<u>Contingencies</u>

(1) Initiatory
(2) Contextualizing

<u>Process System</u> (Constraints)

Every concept and conceptual process can be described in terms of a systemic concept. Comparisons of diverse concepts can be made on the basis of common components or levels of complexity of component structures.

Figure 3



The complex conceptual rule of Lee and Gagné (1969, 1970) can be analyzed as the nesting of two systemic concept systems in the third (complex) concept.

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