ABSTRACT

A THEORETICAL MODEL OF HUMAN LANGUAGE PROCESSING

by

Jeffrey H. Katzer

The purpose of this study was to develop and test a theoretical model of continuous-free-association behavior. The model is in the form of an information processing model; which may be thought of as a computer program. The model consists of six related hierarchical routines. The time executive routine controls the parallel processing of the other routines. Macroprocessing routine oversees the timed routines. The stimulus sorting routine takes a coded input stimulus word and attempts to recognize it in the verbal memory. The net sorting routine controls the sorting of stimulus and response codes through the binary discrimination net memory. Finding terminal routine is called whenever an unsatisfactory terminal in the memory is reached. It attempts to find a satisfactory terminal. The major routine in the model is the response giving routine. Over time it initiates associated potential responses to the stimulus words. One at a time they are examined to see if their item-availability is sufficient for evocation. If sufficient for evocation, the potential responses may serve as internal mediating stimulus words.

The current model uses a hypothetical memory. When presented with a stimulus word it evokes non-trivial responses. In producing these

responses the model operates in a complex manner. It learns over time: short-term-memory and reinforcement of internal processing have a profound effect on the responses evoked. Part of the discussion is concerned with the problems of net building and with obtaining measures of word meaning from the model by a deterministic process-oriented method.

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INTRODUCTION

This paper presents a theoretical model of human language processing. In particular, it is an attempt to relate individual continuous free association behavior to parts of a general mediation approach to meaning. The theory is in the form of an information processing model.

Two concerns motivated the construction of this theory. In the first place, an adequate theory of language behavior is essential to the general understanding of an individual's communication behavior. The model examines the relationships between a measure of the meaning of a lexical item (e.g. word, syllable, etc.) and the generation of similar items in an association task. It seems reasonable to assume that an understanding of language implies an understanding of sentences; which in turn implies an understanding of simpler lexical forms (q.v. Osgood, 1963).

Meaning is typically considered to be a major variable in the study of human communication (q.v. Mowrer, 1954; Berlo, 1960), and if an extreme stimulus-response position is not taken, it has a similar role in a more general study of language behavior. Osgood comments forcefully on the importance of meaning:

> As for myself, I am convinced that meaning is the single most important variable in human learning, verbal or otherwise -- that human adjustment is mainly a matter of acquiring and modifying the significance of signs and learning how to behave in ways appropriate to these significances. (1961, p. 91)

A second goal of this study is to evaluate information processing models as models. Some researchers in the social-behavioral sciences (e.g. J.G. Miller, 1963; Mackay, 1968; Miller, Galanter & Pribram, 1960) have argued that man can be profitably viewed as a general information processor. This view could be adopted by more communication researchers. Certainly, none of the social-behavioral sciences deals with phenomena more complex than those studied by communication scholars.

Nowhere are the concepts of process and information more central than in communication. Information processing models are a viable alternative to the linear additive models so commonly used. This is especially true when the phenomenon modeled is a complex, interactive process. For example,

> It has been argued that the problem of meaning is of major importance in the study of the nature of intelligence, and that a useful definition of meaning must include not only denotation but connotation and implication as well. To handle these important questions it is necessary to study cognitive organizations which are more complex than those upon which most psychological theories are based. (Lindsay, 1963a, p. 233)

This study is organized into five chapters. In the first, an outline of a mediation theory of meaning is presented. Certain empirical relationships found between measures of meaning and association behaviors are discussed. It is these relationships that a fully developed and fully validated model will have to duplicate, and thereby offer a sufficient explanation of their causes. Chapter 2 evaluates information processing models in terms of their potential contribution to science. The relative advantages of these models compared with other models is discussed. The last half of Chapter 2 presents several related information processing models of verbal behavior. These models form the

framework of the theory developed in Chapter 3. Chapter 3 presents a family of information processing models which, hopefully, will become a part of a general theory of individual language behavior. These models seek to explain some of the empirical and theoretical relationships found between free association behavior and several measures of meaning. In Chapter 4, one of the models will be examined by means of hand simulation. That is, the model will be followed step-by-step to see what outputs are related to what inputs. Chapter 5 evaluates the models, explores their consequences, and points the way for further research in the area.

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CHAPTER I

This chapter presents some psychological contributions to the definition and measurement of meaning. By focusing on psychological investigations I do not want to imply that other studies of meaning (notably the philosophic, linguistic and anthropologic) are of no import. Currently, the study of free association behavior and the operational definitions of the meaning of individual linguistic units (e.g. words) are mainly within the domain of experimental psychology. These are the major topics of this thesis.

The material in this chapter is organized into four major sections: (1) an orientation to the psychological study of meaning, (2) the mediation approach to meaning, (3) the association approach, and (4) relationships between the mediation and association approaches.

Orientation

Psychologists who study language are behavioral theorists -- in Alston's sense of the word. The behavioral theory of meaning identifies the meaning of a linquistic item "with the stimuli that evoke its utterance and/or the responses that it in turn evokes" (Alston, 1964; p. 12). Operationally, psychological studies of meaning seem to stem from Bloomfield's definition of the meaning of a linguistic form: "the situation in which the speaker utters it and the response which it calls forth in the listener" (1933, p. 139).

Psychological discussions of meaning may center on underlying processes of meaning acquisition and comprehension and on indices (dimensions) of meaning. A major assumption underlying these types of psychological studies is that words are the basic units of language and are, therefore, central to any investigation of verbal behavior. This assumption is also true for those studies in which, for experimental-control reasons, non-words (also called nonsense syllables) such as consonant-vowel-consonants (e.g. XOJ), consonant-consonant-consonants (e.g. XRV), and disyllables (e.g. GOJEY) have been used. Those investigators who use words and those who use non-words are equally and ultimately concerned with human processing of real languages. While concerned with both meaning acquisition and measurement, this chapter does not deal with original language learning (e.g. Brown's 1958 "Original Word Game") nor the studies of developmental differences in language behavior (e.g. Piaget, 1955, Vygotsky, 1962). The focus of this chapter will be the theoretical and empirical relationships between two approaches to meaning: the associative approach and the mediation approach. First, however, antecedents of these methods and these theories must be discussed.

In terms of methods, Creelman (1966) traced the American investigations of the experimental study of meaning from the earlier work based on classical condition to the later studies concerned with scaling, association, and operant conditioning. The work in semantic generalization (q.v. Razran, 1939) typifies the conditioning approach. In such studies a word (or object) is the conditional stimulus (CS_1). A test is then given to see if the conditioned response will generalize to a new stimulus

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(CS_2) whose primary relationship with the old stimulus is semantic (e.g. CS_1 is the word "ball" and CS_2 is a ball, or vice versa). In contrast with these procedures, contemporary approaches to meaning are based upon scaling and/or association techniques. This chapter is focused upon these two methods and their relationship with each other.

In terms of theory, forerunners of current psychological positions are the substitution theories of the early behaviorists and the dispositional view of Morris. The Watsonian behaviorists considered a linguistic item to refer to an object (i.e. name the object) if the item elicited in the receiver the same behaviors as the object itself elicited. For example, the word "food" would be considered to refer to food if upon hearing the word, the receiver salivated, chewed, digested, etc. This view is not generally held today because "it is well known that the conditioned response [to the lexical item] is seldom precisely the same as the unconditioned response [to the object]" (Carroll, 1964; p. 36). The trouble with the behaviorist view is that total equivalence of reactions (to the word and to the object) is required. It is certainly true that the receiver may have some of the reactions to the word as he would have to the object (e.g. a hungry person upon hearing the word "food" might start to salivate, but probably would not start chewing). Morris (1946) tried to avoid this problem by equating reference with an internal "disposition" on the part of the language user to react to the lexical item as if it were the object itself. This position has been criticized in depth by Alston (1964, pp. 28-30) who considers it oversimplified. In their review of psycholinguistics, Ervin-Tripp and Slobin have traced the problem of behavioral correlates

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> from 'conditioned response' through 'response disposition', 'fractional anticipatory goal response', 'representational mediating response', to the most recent candidate, Staats and Staats' 'conditioned sensory, motor, and autonomic response' ... (1966, p. 450).

The two most frequently used definitions of meaning are the topics of the next sections of this chapter.

Mediation

The mediation approach to meaning has been presented by Osgood (1952, 1957) and Osgood Suci and Tannenbaum (1957). The meaning of a stimulus word in this approach is the representational mediated responses which are elicited in the person upon presentation of the stimulus word. A representational mediated response is the internal stimulus-response (hence mediational) which is part of (hence representational) the total response the person has toward the word's referent.

Mediated meaning acquisition, according to this view depends upon the development of mediated responses. Part of the total reaction to a stimulus word or object is classically conditioned to the new word developing meaning. This self-stimulating conditioned response is the mediating response. Through numerous yet varied pairings of the new word with other words or objects, a complex pattern of mediating responses will be conditioned to the new word and will, in fact, be the meaning of the new word.

Some examples are in order. Osgood distinguished between two types of language learning. Sign learning is a process in which the meaning of a word is learned through repeated pairings of the word with the object it names. Assign learning occurs whenever one learns the meaning of a word

by means of other words -- a verbal definition. Suppose one has experienced a lemon (e.g. drank lemonade squeezed lemons, etc.) but has no name for it. Through repeated pairings of the word "lemon" with the object lemon (or lemonade, etc.) the mediation principle posits that certain portions of one's reactions to the object lemon will become conditioned to the word "lemon" and will mediate between the word "lemon" as a stimulus and the reaction to the word. This is the process of sign learning. In assign learning, the meaning of the word "lemon" may be obtained by placing it in temporal, spatial, or semantic contiguity with other words such as, citrus, tart, yellow, sour, etc. The mediation approach claims that portions of the intermediate reactions which constitute the meaning of these other words, become part of the intermediate reactions to the new word, "lemon."

A criticism of mediations approaches to meaning comes from Fodor (1965) who claims that the two-stage models (q.v. Osgood, 1952; Mowrer, 1954) differ from the Watsonian one-stage model only in terms of observability of response. In general, two-stage models posit at least one stimulus-response sequence intervening between the overt stimulus and the overt response. The one-stage models of Watson and Pavlov do not posit such intermediaries. Since the difference of observability of response is considered insignificant by Fodor, he argues that the newer mediation models are susceptible to the same criticisms as the older Pavlovian ones. Such a position, however, was not readily agreed upon by the mediationists (q.v. Osgood, 1966; Berlyne, 1966) who consider Fodor's interpretations inaccurate: a one-stage model cannot functionally separate decoding and encoding behaviors.

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Osgood and his associates posit that the meaning of a word can be operationalized by its location in _n_-dimensional semantic space. Each dimension of this space is defined by a bipolar adjectival scale passing through the origin. Consider a 2-dimensional semantic space defined by the adjective scales sweet-sour and strong-weak. The meaning of the word "lemon" could be quantified as a Cartesian point in the plane defined by these scales. Presumably, such a point would be more toward the sour-strong quarter of the plane than the sweet-weak quarter. The method described by Osgood to locate a word in semantic space is by means of a semantic differential. A semantic differential is a paper and pencil instrument consisting of a set of bipolar adjective scales on which a person rates a word or a concept. The distance between the ends of each scale is broken into (usually seven) supposedly equal intervals. The rater indicates which interval reflects his reaction to the word or concept. A typical analysis of this data entails the computation of a correlation matrix between scales. This matrix is factor analyzed. The resulting factors form the dimensions of semantic space. In this manner, ratings on a semantic differential are convertible to locations in semantic space and, therefore, constitute the meaning of the word or concept rated. There is an assumed relationship between the mediation theory of meaning acquisition and the semantic differential.

> Corresponding to each major dimension of the semantic space, defined by a pair of polar terms, is a pair of reciprocally antagonistic mediating reactions, which we may symbolize as r_{mI} and $\bar{r}_{mI}$ for the first dimension, r_{mII} and $\bar{r}_{mII}$ for the second dimension, and so forth. Each successive act of judgment by the subject using the semantic differential, in which a sign is allocated to one or the other direction of a scale, corresponds to the acquired capacity of that sign to elicit either r_m or $\bar{r}_m$, and the extremeness of the subject's judgment corresponds to the intensity of reaction associating the sign with either r_m or $\bar{r}_m$. (Osgood, Suci and Tannenbaum, 1957, p. 27)

One frequent criticism of the semantic differential concerns the appropriateness of calling the measurement "meaning". This criticism is supported by two types of arguments. The intuitive argument claims that what a person means by "lemon" is more than a coordinate position in a hypothetical space -- there is more to the meaning of lemon than can be shown with adjectives. The second argument stems from the measurement of the relationship between the meanings of words in semantic space: words lying far apart in semantic space are less related than those close together. If two words lie in the same position of semantic space (within the limits of measurement error) then one would have to conclude that the two words have the same meaning. However, few people would be willing to say that "nurse" and "success" mean the same thing even though they occupy the same position in semantic space. Criticisms similar to these have led to a re-interpretation of what is being measured with a semantic differential. The current position is that connotative meaning or affective reactions is being measured. That is, no claim is made that "nurse" and "success" refer to the same object (same denotative meaning). Rather, both words name concepts which people react to similarly (same connotative meaning).

Association

A second way to look at meaning from a psychological point of view is the association approach. This is based upon the reaction of an individual to a word. Two words, for example, may be said to have the same meaning if they evoke the same total reaction pattern within the individual. Since the associationists of interest here study verbal behavior, they limit themselves to intraverbal meaning -- the verbal reactions to a word.

Noble (1952) defines meaning in a Hullian framework as the several habit (tendency for a stimulus to evoke a particular response) strengths between the stimulus word and the class of corresponding conditioned verbal responses. Deese (1962, 1965) and Garskof and Houston (1963) compare meanings of stimulus words by comparing the patterns of free associates elicited by each. The totality of free associates elicited is, according to Deese, a sample of the intra-verbal meaning of a word.

> One difficulty encountered in defining meaning as response of a hearer (or speaker) is that any particular linguistic form, at various times, elicits a variety of responses in the same person. Therefore, the meaning of any form is not given by single response, or, indeed, by a collection of responses at some particular time, but by the potential distribution of responses to that form. (1965, p. 41).

Meaning acquisition, in an association framework, depends upon the establishment and strengthening of the links between the stimulus word and its verbal responses. This procedure has been typically explained in terms of the laws of association; the most important of these being contiguity and frequency. The more often two words, or a word and an object, are perceived together (spatially or temporally) the stronger will be the link between them.

In terms of method, the association paradigm asks a subject to respond to a stimulus word with another word or words. There are four major types of association tasks: (1) in a discrete-free association task the subject responds with the first word that "pops into his mind"; (2) in continuous-free association the subject is asked to respond with associates until either a desired number of associates have been produced or until some fixed time limit has expired; (3) a discrete-controlled association task asks the subject for one response, but that

response must be in some pre-defined category (e.g. respond with the opposite of the stimulus word); and (4) a continuous-controlled association task is similar to a discrete-controlled task except more than one associate to the stimulus word is required in the former case.

A distinction ought to be made between these approaches to meaning and the more familiar ones which use association values. Association values are numbers assigned to stimulus items (e.g. words, nonsense syllables) which reflect how many different responses the stimulus word has elicited in a group of subjects participating in one of the four types of association paradigms (q.v. Woodworth and Schlosberg, 1954; Underwood and Schulz, 1960). The higher the association value, the more responses elicited. With association values, a comparison between stimulus words is made in terms of the size or strength of the association elicited. In one situation comparisons are made in terms of similar specific responses elicited by each stimulus word. In the other situation comparisons are made in terms of the numeric association values. The former is a comparison of meaning while the latter is a comparison of meaningfulness.

To lay a proper foundation for the model of continuous free association behavior presented in chapter 3, it is necessary to examine some relationships central to the study of verbal learning and behavior. As noted above, association strength is a construct which accounts for observed differences in the strength of the stimulus (S) -- response (R) bond. Response strength is typically measured by reaction time and/or response frequency or communality (q.v. Woodworth & Schlosberg, 1954). That is, in an association task, those responses linked to the stimulus word more strongly will be emitted more quickly and more frequently (when a discrete free association task is administered to the same subject with the same stimulus word response must be in some pre-defined category (e.g., respond with the opposite of the stimulus word); and (4) a continuous-controlled association task is similar to a discrete-controlled task except more than one associate to the stimulus word is required in the former case.

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[illegible] the model of continuous free association [illegible] presented in Chapter V, it is necessary to examine some relationships relevant to the study of verbal learning and behavior. As noted above, association strength is a construct which accounts for observed differences in the strength of the stimulus (S) -- response (R) bond. Response strength is typically measured by reaction time and/or response frequency or commonality (e.g., Woodworth & Schlosberg, 1954). That is, in an association task, those responses linked to the stimulus word more strongly will be emitted more quickly and more frequently (when a discrete free association task is administered to the same subject with the same stimulus word several times). The ingredients which produce or affect associative strength are the subject of some disagreement--depending, in the main, upon the theoretical position one takes. The frequency of the S-R pairing, the recency of the pairing, the closeness of the stimulus and response objects, and the type and schedule of the pairing reinforcement are put forth by different investigators as key ingredients of associate strength (q.v. McGeoch & Irion, 1952).

The nature of an association task (but not the nature of association, _per se_) implies directionality. The stimulus is linked to the response because the S elicits the R or because the S comes before the R. This suggests that forward association (S-R) is the normal state of affairs and backward association (R-S) is an unusual state which must be discounted if the notion of directionality is to be maintained. Backward associations have been shown to exist (e.g. Murdock, 1958) and a great deal of energy has been devoted to "explaining away" the phenomenon, though no one has done so to everyone's satisfaction.

A different approach was taken by Asch and Ebenholtz who report a series of studies which support the principle of associative symmetry: "when an association is formed between two distinct terms, a and b, it is established simultaneously and with equal strength between b and a [italics omitted]" (1967, p. 481). Their studies strongly indicate that backward associations are typically weaker than the corresponding forward associations because of an experimental artifact: in learning S-R pairs, the subject experiences (evokes, pronounces) the R member of the pair more so than the S member. This uneven experience makes the R member more available than the S member. When both members of the pair are made equally avaliable to the subject as a possible response, the strength of the

S-R and R-S associations are very nearly equal (q.v. Asch & Ebenholtz, 1967; Horowitz, Brown, & Weissbluth, 1964; Horowitz, Norman, & Day, 1966).

Item availability (I-AV) and response strength are related concepts. They are not equivalent, however, because response strength reflects a long term, more stable, relationship between verbal units while I-AV can be changed much more easily [see below].

Underwood and Schulz (1960) present a two stage analysis of verbal learning: the response learning stage and the association stage. In the first stage a response is learned by integrating it into a whole unit (e.g. treating a word as a word rather than a collection of letters) and by making the response avaliable. (Tip of the tongue phenomenon might be considered as an example of integrated, but not available verbal units). In the associative phase, the integrated, available response is paired with a stimulus item.

In summarizing their research, Underwood and Schulz proposed the "spew hypothesis" which states that, "the order of emission of verbal units [in a continuous free association task] is directly related to frequency of experience with those units" (1960, p. 86). They reason that more frequently experienced items will be more available and, therefore, will start entering into an association before less frequently experienced items. While there is support for the spew hypothesis from other investigators (e.g. Noble, 1963; Osgood & Anderson, 1957; Jakobovits, 1966), other studies show that frequency alone is not a sufficient determinant of I-AV. Woodworth and Schlosberg (1954), Horowitz and his associates (1964, 1966), and Asch and Ebenholtz (1967) indicate that recency of experience and mode of experience (e.g. does subject produce the item from memory or read it) are also major components of I-AV.

I-AV is an important variable in a theory of association behavior. A researcher can only study behavior's of the subject. In a free association task this behavior is mainly the associates given in response to a stimulus. In studies of verbal learning, the verbal units are often unknown or unfamiliar (especially when the units are not words but are nonsense syllables, or strings of numbers, etc.). In these studies the subject must go through both parts of the response learning phase -- integrating the unit and making it available -- before an association can be given. However, in free recall or association tasks the subject produces responses from memory which must already be integrated. Therefore, in a free association task the role of I-AV is more directly related to overt subject behavior, than in studies of verbal learning, and I-AV is more directly a determinant of the recall of verbal units than is associative strength (q.v. Asch & Lindner, 1963).

Relationships Between Association and Mediation Approaches

The difference between the association and mediation approaches to meaning is not as great as might be inferred from the preceding paragraphs. Classical conditioning underlies both. The relationship between mediated meaning acquisition and classical conditioning was shown in an interesting study by Staats and Staats (1957). Subjects were shown a nonsense syllable paired with several different words. The words, chosen from the Semantic Atlas (Jenkins, Russell & Suci, 1958), were very similar in their affective meaning components. Semantic differential ratings of the nonsense syllables after the pairings showed a shift in the affective meaning of the nonsense syllable toward that of the words. Additional support of the role of classical conditioning in meaning acquisition was found by Pollio (1963) and Staats and Staats (1958).

I-AV is an important variable in a theory of association behavior. A researcher can only study behaviors of the subjects. In a free association task this behavior is mainly the associates given in response to a stimulus. In studies of verbal learning, the verbal units are often unknown to the subject (especially when the units are not words but are nonsense syllables or strings of [illegible]). In these studies the subject must [illegible] both parts of the response learning phase -- integrating the [illegible] and [illegible] it [illegible] -- before an association can be given. [illegible] In free association tasks the subject produces responses [illegible] already be integrated. Therefore, in a free association task the role of I-AV is more directly related to overt subject behavior than in studies of verbal learning, and R-AV is more directly related to [illegible] of verbal units than is associative strength [illegible].

<u>[illegible] between Association and Mediation Approaches</u>

[illegible] between the association and mediation approaches to meaning are not as great as might be inferred from the preceding paragraphs. [illegible] The relationship between mediated meaning acquisition and classical conditioning was shown in an interesting study [illegible] (1957). Subjects were shown a nonsense syllable [illegible] several different words. The words, chosen from the Semantic Atlas [illegible], were very similar in their affective meaning [illegible] differential ratings of the nonsense syllables after the pairings showed a shift in the affective meaning of the nonsense syllable toward that of the words. Additional support of the role of classical conditioning in meaning acquisition was found by Pollio (1963) and Staats and Staats ([illegible]).

Because of the apparent haphazard nature of contiguity (i.e. any typical or atypical word-word, word-object, or object-object pairing strengthens the association bond), and because certain responses to stimuli could not be adequately described by the association laws, there has been a strong interest in mediational interpretations of these phenomena (q.v. Cofer & Foley, 1942; Jenkins, 1963). These writers suggest that free associates are determined not only by contiguity, frequency and the other laws of association, but also by various mediation paradigms. For example, "dark" might be an associate of "heavy" because of the mediating response, "light". That is, "dark" can be thought of as being an associate of "light", and "heavy" can also be considered related to "light". Thus, in a free-association task the stimulus word "heavy" might elicit the response "dark" because of the previously formed relationship, heavy-light-dark. This type of mediation paradigm might help explain certain oddities in free-association behavior. It is known (q.v. McNeill, 1966), for example, that adults frequently give opposites of the stimulus word in free-association tasks. Opposites, however, occur less frequently together than other types of word pairs. In grammatical English sentences, "good" would be more frequently paired with a noun (e.g. boy) than with its opposite, "bad". The fact that "good" strongly elicits "bad" as an associate indicates that the simple laws of association are not sufficient as they are based on frequent pairings of words. Mediation has been proposed to explain the elicitation of opposites (q.v. Ervin, 1961; Jenkins, 1963). In fact, the notion of mediated contiguity makes it possible to abandon the more restricted

concept of primary stimulus generalization (q.v. Deese, 1965; Cofer & Foley, 1942) and adopt the more general principle of mediated stimulus generalization.

In practice, Osgood, Suci and Tannenbaum (1957, p. 20) consider the semantic differential related to a controlled association task. Bousfield (1961) views the semantic differential as a controlled association task in which the subject chooses appropriate adjectives rather than emitting free responses. Deese (1965) argues that the semantic differential ratings are derivable from associational structures. Staats and Staats (1959) state that the same operation of word-word pairings strengthens the interword association and distance from the origin of semantic space -- a mediation measure of meaningfulness related to association values. Pollio concludes a series of experiments dealing with both association and mediation responses to a stimulus word by taking,

> the position that both classes of events imply, or at least suggest, certain relations among words and that these relations can be described by a single structural conceptualization encompassing both classes of events (1966, p. 11).

Empirical relationships have been reported between the two approaches to meaning. Staats and Staats (1959) had subjects rate 10 words on a good-bad semantic differential scale and later rate the first 20 associates of each of these 10 words. Averaging over subjects and associates they found a rank order correlation of +.90 between the ratings of the ten words and the average of their first 20 associates. Jenkins and Russell (1956) report a correlation of +.71 between an association measure of meaningfulness and distance from the origin of semantic space. Wimer (1963) and Howe (1965) obtained correlations (r = +.36, +.51) between the same two measures.

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There is research reported which relates the spew hypothesis to measures derived from a mediation approach to meaning. For children, Pollio (1964) found the correlation between a word's location in semantic space and the location of its first free associate. The correlation was significant (p. $<$ .01) separately for each dimension in 3-dimensional semantic space (r= +.64, +.69, and +.44 for the evaluative, potency and activity dimensions respectively).

For adults, similar results were found except the correlation between the potency scores did not reach as high a level of significance. According to the studies reported above (q.v. Staats and Staats, 1959; Pollio, 1964) associates of a word ought to lie near that word in semantic space. One would expect frequent word-word pairings to have more of an effect (in terms of acquiring detachable portions of responses) than infrequent ones. Therefore, we would expect first associates to be closer in semantic space to a stimulus word than later associates. DeBurger and Donahoe (1965) found that succeeding associates are less similar in meaning (i.e. farther away in semantic space) to the stimulus word. In a related study, Portnoy (1961) reported that reinforcing the first associate of a word had greater effect of the word's evaluative meaning than reinforcing the third associate of the word. In continuous free-association behavior, Pollio (1966) found that responses given in rapid succession to each other formed a cluster whose average distance between them in semantic space was less than the distance between responses which were not temporally clustered by the respondant.

These studies in general support the theoretical position noted at the beginning of this section; viz. that several of the association measures and mediation measures are related.

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Summary

Psychological theories of meaning have evolved from the earlier mentalistic approaches and the strict behaviorism of Watson and his followers to the more liberal behavioral approaches today. These approaches typically consider meaning to be related to processes which occur within a person. In the main, these processes are thought of as being habit, bonds, some form of mediated response, or some combination of these.

Both mediation and association approaches to meaning, including the theory underlying each and their methods of measurement, are subject to some criticism. This does not vitiate their importance to current thoughts in the psychology of language. They are, by far, the major theories underlying most of the thinking and research in this area. This pervasiveness outweighs the criticism in terms of their importance to this study.

The research findings presented do not exhaustively survey the relevant literature. Such a task would be larger than the scope of this thesis. Rather, an attempt was made to indicate those variables and relationships relevant to continuous free-association behavior which will be major considerations in the model presented in chapter 3.

This is an appropriate place to restate the goal of this study. Simply stated, it is to specify a model of verbal behavior which ultimately will identify the theoretical relationships between association and mediation principles of meaning. Also, such a model should predict empirical relationship between both measures of meaning.

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There are several ways to organize this effort, and at this time it is impossible tc forsee which will ultimately have the greatest payoff. The strategy here, is to generate a model based upon association principles -- specifically a model of continuous free association behavior. A major conclusion of the next chapter is that information processing models are very useful in the behavioral sciences. This type of model clearly specifies procedures which hopefully will produce relationships of interest among the variables. Thus, if a model is to exhibit relationships between free association structures and mediation measures of meaning (as in the above studies) then the model must account for the generation of free associates. The model presented in this study will be a first approximation to this goal.

Before the variables described in this chapter can be organized within a model of individual continuous free association behavior it will be necessary to discuss information processing models, their construction, their relative merits, and their relationship to computer simulation of cognitive processes. Such are the topics of chapter 2.

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CHAPTER II

This chapter examines the primary method of inquiry to be used: Information Processing Models (IPMs). There are two major divisions to this examination. First, types and roles of models will be discussed -- leading to a general presentation and evaluation of IPMs and their relationship to computer simulation of cognitive processes. Next, several examples of IPMs will be presented. These are simulations of verbal behavior or language processing. The implications of this method of inquiry and of these examples will be discussed vis-a-vis the subject matter of this study.

Models and Simulation

Confounding any discussion of models in scientific inquiry are the numerous philosophic and psychological distinctions between models and theories, between various types of models, and between judgments of the relative value of the different kinds of models. Models have been distinguished from theories by separating the structure from the content of the phenomenon of interest (q.v. Kaplan, 1964, pp. 264 - 265; Rudner, 1966, p. 24). Rather than unduely magnify the importance of this distinction to this discussion, the position here is the same as that taken by Newell and Simon:

[illegible]

This chapter examines [illegible] of inquiry to be used [illegible] information [illegible] using Models [illegible]. [illegible] are two major [illegible] to this examination. [illegible] Types [illegible] to [illegible] and [illegible] particularly [illegible] of cognitive processes. [illegible] several [illegible] are presented. These are simulations of verbal be- [illegible] The implications of this method of inquiry [illegible] discussed vis-a-vis the subject matter of this [illegible].

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> . . . we shall use the terms 'model' and 'theory' substantially as synonyms. The term 'model' tends to be applied to those theories that are relatively detailed and that permit prediction of the behavior of the system through time, but the line between theories that are called 'models' and other theories is too vague to be of much use. (1963a, p. 365)

While there are other uses for models in science (e.g. the null hypothesis model is used as a straw man for comparative purposes, or models used for control purposes or approximations--(q.v. Ackoff, 1967) the point-of-view taken here is that models have a value directly related to their heuristic role or deductive fertility.

> Why should a scientist ever concern himself with a model? In one rather obvious sense, the point of employing a model belongs to the context of discovery rather than to that of validation; for models function as heuristic devices in science. (Rudner, 1966, p. 25)

Models have been classified in various ways (e.g. Ackoff, 1967, p. 104; Tatsuoka, 1968; Kaplan, 1964, pp. 273-275). For purposes of discussion the classification scheme of Springer, Herlihy and Beggs (1965) will be adopted. They classify models into one of three general categories: abstract models, symbolic models, and physical models. Abstract models are mental images (q.v. Boulding, 1956) of reality. Symbolic models are either verbal or mathematical. And, physical models are iconic (physically isomorphic) or analogic (functionally isomorphic). Of these, the model builders in the social sciences are symbolic models most frequently. This may be due in part to custom (most models a theoretician has experienced are symbolic), or practical considerations (physical models -- if applicable -- are difficult to construct), or esthetic evaluations (mental models are not rigorous enough). Of the two types of symbolic models, the verbal are more common while the mathematical are more in vogue (due to the difference in perceived rigor and the affinity of some researchers to be "scientific").

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Information Processing Models:

The task of this thesis is to construct and evaluate a model. This model is symbolic in format but is neither verbal nor mathematical in the common uses of these terms. It will be an Information Processing Model, an IPM.

Evaluating the information processing approach in psychology Reitman describes it as,

> one way of looking at psychological activity. It deals with processes and functions; it emphasizes whatever it is that any particular behaviors get done; it is also concerned with the fine structure of behavior. The accomplishments resulting from thinking, problem solving, and psychological activity generally can be accounted for only if we study them in great detail. When we do so, we discover that even simple behaviors appear to be made up of a great many steps integrated into complex sequences . . . . In other words, this approach allows us to view man as dynamic systems analyzing, seeking, and doing things, as purposive organisms manipulating objects and information to achieve ends. (1964, p. 1193)

The information processing approach is applicable to content areas other than psychology. In fact, its generality makes it applicable to non-human systems (e.g. communication networks within a formal organization, and processing within a general purpose digital computer).

Hart (1967) presents one way to specify the essentials of the information processing approach. Models employing this approach are characterized by their components, structure, and primitive processes. There are five basic types of components: (1) a set of containers or storage locations; (2) a set of possible contents of the containers -- where the contents can be (or stand for) a word, number, person, nation, process, etc.; (3) a set of links which connect the containers; (4) a set of labels which name the containers and links; and if the model is empirical, (5) a property set may be attached to any of the containers or links. One form of

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Structure of IPMs depends upon the organization of containers (regardless of content) and links. Links may be uni- or bi-directional. Usually not all containers will be linked with each other and the different resulting organizations (e.g. rings, linear) structure IPMs. IPMs can easily represent hierarchical systems. If a group of containers and links are grouped together under one name, then that name labels the contents of a hierarchical container. Hierarchies (level n+1) of subsystems (level n) can be created. Property sets, links and structure among hierarchical containers can be specified. The importance of hierarchical systems should not be minimized -- especially when dealing with complex phenomena (q.v. Simon, 1965)

> For complex phenomena there may be, and usually are, several levels of explanation; we do not explain the phenomena at once in terms of the simplest mechanisms, but reduce them to these simplest mechanisms through several stages of explanation. We explain digestion by reducing it to chemical events; we explain chemical reactions in terms of atomic processes; we explain the atomic processes in terms of the interactions of subatomic particles. Every flea has its little fleas, and the scientist's view accepts no level of explanation as 'ultimate.' (Newell & Simon, 1961, pp. 155-156)

Primitive processes in IPMs function on both hierarchical and non-hierarchical (atomic) levels. These processes can affect the structure or the state of the system. Structural processes can add or delete containers, links, hierarchical components, and change the directionality of links. State processes may modify the contents of containers, names of containers or links and the elements of property sets. Processes may be stated in conditional form. This plus the fact that the contents a property set is a set of ordered pairs. The first member of the pair specifies the dimension of the container or link (e.g. color) while the second member of the pair gives the value of that dimension (e.g. red).

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An example of an IPM would be helpful. The example is taken from an article by Gregg and Simon (1967) which will be discussed more fully later. The model was designed to represent the behavior of a subject (*S*) in a simple concept learning task. The concept to be learned is chosen by the experimenter (*E*) in advance and ~~can~~ be any one of the 2N possible concepts (where N is the number of dimensions -- each dimension has two values). In the experimental procedure *E* presents *S* with a series of stimulus instances. A stimulus instance contains a sample of the 2N possible concepts (e.g. if the dimensions were size, number, color, and shape then a stimulus instance might be five large red circles). The *S* responds to the instance by stating whether or not it contains an example of the concept chosen by *E*, but unknown by *S*. *E* appropriately reinforces *S*'s response. A concept is learned when *S* makes a predetermined number of correct responses in a row.

As presented in Table 1 the IPM consists of seven processes. In terms of the description of general IPMs, this model can be considered as composed of seven hierarchical containers, the contents of each represents a set of processes. The use of conditional processes, the linkage structure among the processes and the possible use of property sets (e.g. the number of correct learning trials may be kept in a property set) should be noted.

Evaluation of IPMs:

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Table 1. Processes in an IPM of Simple Concept Learning

Name of Process	Process
E0	Do E3, E4, S1, E2. If reinforcement = "right" then increase the number of correct learning trials in a row by 1. Call this number "tally." If reinforcement = "wrong" then set tally equal to 0. If tally equals the preset criterion defining the attainment of the concept, halt. If tally is less than the criterion do S2 then E0.
S1	If the *S*'s current hypothesis of the correct hypothesis is a member of the stimulus instance respond "positive"; otherwise respond "negative."
E2	Compare the *S*'s response with the correst response. If the *S*'s response is correct, reinforce "right"; otherwise reinforce "wrong."
S2	If reinforcement was "wrong" adopt a new hypothesis from S5.
E3	Generate a stimulus instance by sampling randomly from each pair of the N dimensions.
E4	If the concept adopted by *E* is present in the stimulus instance then the correct response the *S* can give is "positive"; otherwise the correct response the *S* can give is "negative."
S5	Generate a new hypothesis of the correct concept by sampling at random from the list of 2N possible hypotheses.

Note. -- Adapted from Gregg & Simon (1967, pp. 253-254).

models to see if the level of explanation and insight afforded by the former compare favorably with those afforded by the latter.

To make comparisons involves the application of criteria. As noted before, the term "model" is used in a manner similar to the term "theory." The proper criteria to be used to evaluate theories are a major topic in the philosophy of science. The ones adopted here are falsifiability, usefulness, precision, and parsimony. The first is the sine qua non of theories according to Popper (1961) -- theories must, in principle, be capable of being proved false. The second is important because a major purpose in the construction of IPMs is the heuristic role of the model -- criteria used to evaluate a model should not be determined without a concern for the purpose of the model. Another aspect of usefulness is applicability in terms of the model's practicality and generality. The third criterion, precision, also has two aspects. A theory is precise if it is stated clearly and rigorously, and a theory's precision is inversely related to the size of its error of prediction. The last criterion, parsimony, is adopted because of the esthetic value placed on explaining more and more with less and less. Parsimony is related to falsifiability. The less parsimonious a theory the more difficult it is to be falsified (e.g. if the number of degrees of freedom in a theory equals or is greater than the number of empirical observations, the theory is not falsifiable because the parameters will cover all instances of possible observations).

It is important to compare the three different types of symbolic models. Comparing IPMs to verbal models Kaplan believes that a generalized form of IPM is, "far more effective than philosophical dialectics in freeing behavioral science from the stultifications of both mechanistic models to see if the level of explanation and insight afforded by the former compare favorably with those afforded by the latter.

To make comparisons involves the application of criteria. As noted before, the term "model" is used in a manner similar to the term "theory." The proper criteria to [illegible] are a major topic in the philosophy of science. [illegible] usefulness, precision, and parsimony. The first is the [illegible] of theories according to Popper (1961) [illegible] in principle, to be capable of being falsified. The [illegible] pose [illegible] criteria used [illegible] retained without concern [illegible] aspect of usefulness is applicability [illegible] model's practicality and generality. The third [illegible] A theory is precise if it is stated [illegible], and a theory's precision is inversely related [illegible] error of prediction. The last criterion, parsimony, [illegible] placed on explaining more and more [illegible] Parsimony is related to falsifiability. The less parsimonious a theory, the more difficult it is to be falsified (e.g. if the number of degrees of freedom of a theory equals or is greater than the number of [illegible] the theory is not falsifiable because the parameters will account for all instances of possible observations).

It is important to compare the three different types of symbolic models. Comparing [illegible] to verbal models Kaplan believes that a generalized form of [illegible] is, "[illegible] more effective than philosophical dialectics in freeing behavioral science from the stultifications of both mechanistic materialism and mentalistic idealism" (1964, p. 292). In choosing between mathematical models and verbal models there is a general preference for the former because of its increased clarity, rigor and deductive fertility. To these Arrow adds the greater possibility of mathematical models, "to tap the great resources of modern theoretical statistics as an aid in empirical verification" (1956, p. 31).

The evaluation of mathematical models versus IPMs is most significant because of the generally held belief that mathematical models are to be preferred over general verbal models. The relationship of mathematical models to IPMs is one of inclusion. Mathematical models can be considered as special cases of IPMs, and for that reason IPMs are more general. Mathematical models rarely deal with explicit processes and therefore are less valuable to the researcher who is interested in processes, per se. In the concept learning model presented above, the processes were clearly stated and hypothesize how a person learns a concept. An analagous mathematical model predicted not processes but empirical measures of concept learning behavior (e.g. number of errors before the concept is learned). In addition, mathematical models are limited by the complexity of the phenomenon of interest.

> If the mathematics is known to the model builder or can be discovered by him, he will be able to determine the implications of his model. If the mathematical techniques for solving certain equation systems are not known or available to the model builder, he is in no better a position than if he had only a natural language model. The effect of this last condition is to constrain the model builder to consider only that class of models for which he knows solutions are available. Unfortunately this constraint may have a spurious effect on the model builder; e.g., he may oversimplify a complex situation. In general, many of the mathematical models of human behavior are elegant and simple. Sometimes, the constraints of the mathematical medium force unfortunate compromises upon the model and reduce its ability to predict. (Feigenbaum & Feldman, 1963, p. 271)

For example, mathematical techniques for dealing with non-linear systems have not been highly developed (or are unknown by many social scientists). Many of the phenomena of interest to social scientists will probably not be explained best by linear descriptions (q.v. Lindsay, 1963a). On the other hand the effect of complexity and non-linearity upon IPMs is not thought of as significant (q.v. Feigenbaum & Feldman, 1963, p. 271).

It would be helpful to compare a mathematical model with an IPM. Gregg and Simon (1967) made such a comparison between their IPM of simple concept learning and Bower and Trabasso's (1964) mathematical model of the same phenomenon.

Gregg and Simon's IPM of simple concept learning is outlined in Table 1. Bower and Trabasso's model consists of the following two statements and the analytic deductions from these statements.

> 1. On each trial the subject is in one of two states, K or $\bar{K}$. If he is in state K (he 'knows' the correct concept), he will always make the correct response. If he is in state $\bar{K}$ (he 'does not know' the correct concept), he will make an incorrect response with probability $\underline{p}$.
>
> 2. After each correct response, the subject remains in his previous state. After an error, he shifts from state $\bar{K}$ to state K with probability Π. (Gregg & Simon, 1967, p. 247)

Several criteria were applied in making the comparison between the two models. The most relevant of these are generality, rigor, parsimony, usefulness, and validation procedure.

In terms of generality, Gregg and Simon compellingly argue that IPMs are more general. Starting with a Bayesian position, they show that the <u>a posteriori</u> (i.e. after the evidence is in) credibility of a theory (or model, or hypothesis) is a joint function of the likelihood or accuracy

of the theory and the a priori plausibility of the theory. That is, more believable theories depend not only on the accuracy of their predictions, but also upon the perceived reasonableness of the theory before testing. If this position is accepted, then Gregg and Simon might say that the statement of reasonableness of the theory can often take the form of an IPM. It was from the reasonableness argument that Bower and Trabasso developed their mathematical model. Since the mathematical model was developed from the crude IPM (the reasonableness argument) it can be considered a special case of the IPM. In fact, Gregg and Simon show that the mathematical model is a special case of a family of related IPMs. Each member of the family is different from each other and the difference may be of theoretical import to concept learning tasks (for example, a different IPM would change process S5 in Table 1 to allow for sampling of only those hypotheses still supportable by the current stimulus instance). However, the same mathematical model is derivable from each of the related IPMs. Therefore, the IPMs are more general.

In terms of rigor, IPMs can be stated as rigorously as desired. It should be remembered, however, that neither mathematical models nor IPMs are as rigorous as commonly believed.

> The guarantees of unambiguity are usually overrated both for mathematics and for programs [an operationalized IPM]. The successive waves of rigorization that have swept through the mathematical world testify that what is unambiguous in one generation is not in the next. Similarly, the fact that most programs never are fully debugged indicates a similar failing in programs. (Newell & Simon, 1963a, p. 374)

In terms of parsimony, the mathematical model has two free parameters (Π , p) while the IPMs have none. Thus, the IPMs are easier to falsify. And in terms of usefulness, the following three points are noted in favor

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of the IPM: (1) having a family of IPMs for each mathematical model implies that rejection of an IPM is not fatal; (2) the IPM separates subject processes (those named with an "S" in Table 1) from experimenter processes (those named with an "E"). This separation allows the researcher to test the effects of the subject's behavior in different experimental situations. As stated, the mathematical model cannot make such investigations; (3) the IPMs generate more useful data (e.g. the model can trace and "report" the subject's actual hypotheses and responses -- which can later be compared with those of real subjects).

And finally, the validation of the mathematical model involves "proving the null hypothesis" (i.e. there is no difference between the model's performance and the performance of human Ss). Since this is not considered to be statistically permissible Bower and Trabasso place,

> their main reliance on finding 'critical' experiments that separate alternative hypotheses radically. But . . . the variant predictions in the critical experiments come . . . not from the stochastic theory but from the informal, and only partially stated, process models that stand behind the theory. (Gregg & Simon, 1967, p. 270)

Therefore, in terms of these criteria the IPM is to be preferred. Gregg and Simon also compare the two types of models empirically (in terms of prediction) and statistically (in terms of error variance). Again their conclusion favors the IPM. In their article the choice of the specific models used might have unfairly stressed the value of IPMs. With different models, some of their arguments might not have been appropriate or as telling. However, Lindsay (1963b) and Abelson (1964) arrive at similar conclusions with different models.

Certainly, IPMs cannot be perfect. What then are some disadvantages? Newell and Simon (1963a) identify a major disadvantage of these models, viz., the absence of a deductive formal system for making inferences from the model. A second consideration has to do with the amount of time needed to rigorously state an IPM. Usually such rigorous statements take the form of a computer program. This implies that the model builder must take the time to learn the programming language and an inordinate amount of time to debug the program. These, disadvantages, however, do not outweigh the benefits of IPMs.

Reviewing this comparison of models it is argued that IPMs are to be preferred over other symbolic models, especially in those situations in which (1) the actual behaviors are important to understand, and (2) a major value placed on the model is its heuristic insight.

Construction of IPMs:

Before concluding the presentation of general IPMs it seems appropriate to discuss some factors related to their construction. Building IPMs, like other models, depends upon the definition of the task, delimitation of the system's boundaries, adoption of the level of analysis, identification of the processes and relationships, etc. These considerations have been discussed elsewhere (e.g. Ackoff, 1967) and will not be presented here. The purpose of the next several paragraphs is to identify some more specific problems concerning IPM construction.

Carroll and Farace (1968) make an interesting distinction between theory-rich and data-rich models (with what they call heuristic models lying between these extremes). Theory-rich models are constructed by representing theoretical relationships within the model, while data-rich models use information obtained empirically (e.g. in giving values to parameters). While IPMs may be theory-rich or heuristic, they usually are not

data-rich (with emphasis on the word "rich"). Data-rich IPMs are analogous to simple predictive mathematical models (e.g. multiple regression) whose validity criterion is accuracy of prediction rather than accuracy plus the insight obtained from the modeling of processes.

Related to the theory-rich, data-rich dimension is the role of probability models. Stochastic processes have a proper role in IPMs of human behavior (e.g. in the generation of environmental noise, experimenter produced stimuli, or experimental situations). They also have an undesirable role in these IPMs -- when they are used because the deterministic processes cannot be hypothesized. For example, if the model cannot predict (based on some criteria) which fork in a strange road a motorist will choose, the model chooses randomly. This is considered a weakness in the model because (a) humans do not act randomly, or (b) it is better for science if scientists act as if humans do not behave randomly.

Thirdly, full use of the value of IPMs requires the construction of a family of related models. These models (which may differ in structure, content, or process) investigate differences in assumptions (often stated as processes) and differences in environmental conditions. The family of models are not very difficult to form -- each usually involves some change in the first model. Therefore, with little added expense, the heuristic payoff has increased sizeably (q.v. Newell & Simon, 1961, p. 175).

Finally, a comment is in order concerning the trade-off between model-building and practicality. Science can be considered as a series of successive approximations. First stabs into model building will necessarily be gross. Measurement precision will be low, relevant factors will be omitted (due to ignorance or a desire for simplicity), and irrelevant factors included. It is usually the later approximations which can be judged with criteria other than "future possibilities."

Computer Simulation:

The remaining part of this section is devoted to computer simulation. Computer simulation, here, is thought of as the typical method for operationalizing IPMs. The term "simulation" has been used to cover a broad range of activities (q.v. Crawford, 1966; Hermann, 1967; Abelson, 1968). In this paper the term will, in general, refer to the simulation of cognitive processes.

First, a brief comment about artificial intelligence.

> It is often argued that a careful line must be drawn between the attempt to *accomplish* with machines the same tasks that humans perform, and the attempt to *simulate* the processes humans actually use to accomplish these tasks. (Newell & Simon, 1963b, p. 279)

Machines and computer programs which are designed to accomplish by any means, task which up till then only humans could accomplish are within the realm of artificial intelligence. Machines and programs designed to accomplish tasks humans can accomplish in a (hypothesized) manner used by humans are instances of simulation. In practice, this distinction does not hold up well. Many of the techniques and principles applicable to artificial intelligence are used in computer simulation, and vice versa. Also, many researchers jump back and forth between these two areas, behaving similarly in both. In theory the distinction is not tenable. First of all, if it proves worthwhile to maintain the distinction, then at most it seems to be one of levels of explanation. If behavior is simulated at a given level of a hierarchical IPM, then at a more atomic level, the processes are determined by artificial intelligence mechanisms.

For example, Feldman (1963) believes that humans function in the binary choice experiment by hypothesizing a rule which fits the past presentations of stimuli. Therefore, in his simulations of this behavior his model uses hypotheses. But the mechanisms used to generate these hypotheses (at the more atomic level) are not purported to represent the human processes of hypothesis generation.

If behavior is simulated with a non-hierarchical IPM, the distinction between automata and human beings becomes important. Since brain processes and computer processes at the atomic levels are thought to be fundamentally different (q.v. Newell & Simon, 1961) all simulations are based upon artificial intelligence mechanisms.

More importantly, the value of the distinction itself can be questioned. In terms of producing heuristic models of behavior,

> any automaton, whether it is intended to simulate human behavior or just do man-like things, is by definition a model of behavior. If a machine accomplishes the same result that a person does, then the machine is manifestly a model of human behavior (Green, 1961, p. 86).

Therefore, at least for the purposes of this study, no unnecessary distinction will be made between the artificial intelligence and the simulation literature. Both sources will be used when applicable.

While the actual simulation is the typical operationalization of the IPM, the computer program is the theory. Or, as Frijda (1967) points out, the program only represents the theory because the program includes processes which the researcher does not believe to be true or useful (even if the model works satisfactorily) such as random processing.

Operationalizing the Simulation:

There are two steps involved in operationalizing an IPM: Programming the model and running the program. Both of these may contribute to, or hinder a model-builder. Programming an IPM clearly increases the clarity of the model's statement. Below, Lindsay, stresses the effect of simulation on psychological theories. His remarks are certainly applicable to most areas of the behavioral sciences.

> It has long been a feature of psychological theorizing that would-be theories suffer from chronic vagueness. The result is a theory which can be stretched to fit anything. The genesis of this difficulty lies in the fact that the theorist knows what he is saying and so does his audience. Hence, it is often possible to put together assumptions which logically, will not fit, or to make deductions which, logically, do not follow. These unfortunate juxtapositionings may go unnoticed by an intelligent theorist and his informed listeners, who can readily and unwittingly supply the missing pieces, ignore the excesses, and beg the answer which they know is there even if it is not. The computer, though, is a very stupid audience. From one point of view, it may prove more valuable now while it is stupid than later when it is not; for today it will not tolerate vagueness. When a theorist with an idea sits down to convey his idea to a machine he almost invariably finds that he must first sharpen it up. And when the machine attempts to simulate the idea, the theorist almost invariably finds it will not do what it is supposed to do. (1963b, pp. 50-51)

The desire for clarity, however, may force premature closure on the form and extent of the model. In addition there seems to be a Whorfian nature to computing languages. Different languages process information differently. Once a language is chosen (or forced onto a researcher because of its availability) the researcher must translate the IPM into the programming language and accept its implied assumptions. This is even true of those languages specially created for the simulation of cognitive processes (q.v. Newell & Simon, 1963a, p. 425).

The second step, running the program is beneficial for complex models which would be impractical to simulate by hand (i.e. follow the steps of the IPM or program without using the computer). Furthermore, it is only through running the program that inconsistencies become evident.

Producing a correctly working program is a long iterative process. The final program is frequently quite different from the first program. Thirdly, running the program, perhaps under different conditions, allows for the testing of the IPM and the evaluation of specific subprocesses. And finally, the actual running of the program may open new paths of study. For example, the concept of "insight" may take on a new respectability when simple deterministic processes within a computer program produce "insightful" behaviors (q.v. Newell, Shaw, & Simon, 1958).

There are several disadvantages with simulating the model on the computer -- principally time and money. In addition there are the constraints imposed by the size of the available computer. Are there enough storage locations for the model, or must it be distorted to fit? Processing speed of the computer is a related factor.

> A program can operate only in terms of what it knows. This knowledge can come from only two sources. It can come from assumption -- from the programmer's stipulation that such and such will be the case. Alternatively, it can come from executing processes that assure that the particular case is such and such -- either by direct modification of the data structures or by testing. Now the latter source -- executing processes -- takes time and space; it is expensive. The former source costs nothing: assumed information does not have to be stored or generated. Therefore the temptation in creating efficient programs is always to minimize the amount of generated information, and hence to maximize the amount of stipulated information. It is the latter that underlies most of the rigidities. Something has been assumed fixed in order to get on with the programming, and the concealed limitation finally shows itself. (Newell, 1962, p. 420)

A more detailed examination of the relationship between IPMs and computer simulation is possible. The components, structure, and primitive processes of IPMs can be compared with the components, structural arrangements, and primitive processes permitted in computer languages. The comparison between computer languages and IPMs is, however, beyond the scope of this paper, and has been discussed elsewhere (e.g. Reitman, 1965; Newell, Shaw, & Simon, 1958; Newell & Simon, 1961). Two main conclusions can be identified from these and other papers. (1) There is a class of computer languages particularly suited for simulations of cognitive processes (q.v. Green, 1963, pp. 89-99). (2) There is a reasonable correspondence at several levels between IPMs and computer languages (e.g. Gladun, 1966) -- though some language processes must necessarily be for housekeeping purposes and do not pretend to correspond with behaviors (q.v. Baker, 1967; Frijda, 1967).

At a grosser level the organization of programs and IPMs have major similarities. Baker (1967) identified the two major approaches used in simulation programs, the basic premise approach and the surface approach. The basic premise type of simulation program starts with a minimal set of rules and derives the observable data from these rules. The surface type of program starts with observable behaviors (data) and does not stipulate an overall mechanism. Thus the basic premise -- surface distinction in simulation programs parallels the theory-rich -- data-rich classification of models noted earlier.

Testing the Simulation:

Whenever a model is built it should be tested. All types of models can be inspected to see how closely they meet the criteria desired by the philosophers of science -- e.g. falsifiability, parsimony, etc. Computer simulations as models have special problems of validation. The positions taken here are the same as those presented by Hermann (1967): (1) Computer simulation models are never completely validated. Rather, models have during their growth different degrees of validity. (2) There is no

one correct validity procedure for all models. The proper procedures are a function of the purpose of the model. (3) Dependence upon one type of validity criterion is not as valuable as using several criteria.

Hermann identifies five types of validation procedures useful in judging the correspondence between IPMs and their behavioral referents. (1) The level of internal validity or reliability is ascertained through test-retest procedures: What is the size of the variability among the outcomes of several executions of the model -- with each execution having the same initial conditions? (2) Face validity depends upon the model's output "looking good" to the modeler. The dimensions for testing the goodness of the look should be specified in advance of the observation. (3) Variable-parameter validating procedure compares the values of the model's constants and variables with those in the analogous real situation. One aspect of variable-parameter validity is sensitivity testing. What are the differences in output caused by different initial values of the variables or parameters? (4) Event validity is a function of the accuracy of the model's predictions. (5) Hypothesis validity includes empirical relationships among variables similar to those represented in the model.

There are several types of techniques recommended for validating simulations of cognitive processes. The most general of these is Turing's Test (1963). This test asks an observer to distinguish between computer output and human behavior (usually in written form). The more the observer errs in identifying the two reports, the more the model as a simulation of the behavior is validated. Turing's Test takes many forms and can be applied at different levels of analysis. For example, it can be applied

to the grossest from of behavior such as the final product of the model and man (as in testing artificial intelligence models), and it can be applied to those lower level processes which produce these macrobehaviors.

Other validating procedures are protocol matching and statistical testing. Protocol matching is a form of Turing's test. It entails the comparison of a person's step-by-step examination of his own thought processes with a trace of the computer processes. Though a useful procedure, there are several problems with protocol matching (e.g. Dennett, 1968). These will not be discussed since this procedure is applicable to those models of specific individuals rather than those models of generalized individuals -- and the model presented in the next chapter is of the generalized type. In addition, this procedure assumes a consciously functioning subject, whereas association behavior is not generally thought of as being consciously planned.

Statistical testing may be considered to be more appropriate for models of generalized individuals. Most statistical comparisons will involve proving the null hypothesis (i.e. showing that the model and the modeled produce the same output), which is a questionable procedure. Also, if the model produces numerical values, it is difficult to estimate the number of degrees of freedom within the model (suppose, for example, a multiple regression type of model predicts a score representing the average score; since beta weights rather than individual scores went into making that prediction, how many degrees of freedom, comparable to individuals, should be used to test the average?). A more workable alternative is to compare the output from a family of models using one's judgment (a weak form of Turing's Test) as the criterion.

Summary:

In summary, this section of chapter 2 argues that an IPM is a very useful way of presenting a theory. This type of model compares favorably with other symbolic models used in the behavioral sciences, the verbal and the mathematical. The comparison is especially favorable whenever the goal of the theory construction includes insight as well as predictability. Secondly, computer simulation is seen as an operationalized IPM. The benefits and limitations of the conversion from an IPM to a running computer program were presented. Finally, the problems of model validation was discussed. Because IPMs have more to offer a researcher, they are harder to validate than other types of models. Models of behavior are first of all behavioral science and secondly models. If they do not explain behavior, the fact that they are consistent is of little import.

IPMs of Verbal Behavior

There are computer simulation models which are not directly concerned with verbal behavior, but do have something to contribute to a model of free association behavior. Presumably knowledge of models dealing with automatic language translation and linguistics (q.v. Garvin, 1963), semantic nets (q.v. Quillian, 1967), and answering in English (q.v. Green, et al., 1963) will aid in the construction of a model of free association behavior because all deal with natural language. Also, those IPMs of information storage and retrieval (q.v. Garvin, 1963) might suggest solutions to the problem of storing words in memory and later retrieving them in a free-association task. These models will be considered only secondarily, however, to simplify the task of constructing an IPM of free association behavior.

As primary resources, several related models of verbal learning and verbal behavior will be used. These models can be modified to handle natural language units, they present approaches to the storage and retrieval problem, and their structure is such that with the addition of some processes they can be adapted to model free association behavior.

Any complex IPM is difficult to talk about. To describe, in any depth, its structures and processes is usually prohibited because of its size and complexity. For example,

> the description of a recent version of Newell, Shaw, and Simon's General Problem Solving program covers more than one-hundred pages, and even so contains only the main details of the system. Furthermore, the discussion assumes a knowledge of an earlier basic paper on GPS and a knowledge of Information Processing Language-V, the computer language in which it is written. Finally, the appendix, which simply names the routines and structures employed takes another twenty-five pages. Unless one is familiar with similar systems, a thorough grasp of the dynamic properties of so complex a model almost certainly presupposes experience with the running program and its output. (Reitman, 1965, p. 24)

The models of verbal learning and verbal behavior described below have, for the most part, complexities on the order of that of GPS. Therefore, their description must of necessity be terse.

Five related models will be discussed: EPAM I, EPAM II, EPAM III, WEPAM, and SAL I-III. These models simulate subjects in either a paired-associate (P-A) paradigm, or a serial anticipation paradigm of nonsense syllable learning.

In the P-A situation the subject is presented with a list of stimulus-response pairs. For each pair, the stimulus item is presented to the subject whose job it is to give the correct response. After the subject responds or after a fixed interval of time, the correct response is presented. Usually the list of pairs is presented until the subject

learns the list to some criterion. Each time the list is presented, the order of the pairs on the list is randomized. In the serial anticipation paradigm, the subject is presented with one list of items. Each item (except the last) serves as the stimulus for the next item, and (except for the first) serves as a response to the previous item. When the list is presented several times, the order of the items on the list is not changed.

The five models below describe those processes a human subject goes through in such experimental situations. The interpretation of the functioning of these models provides one possible set of explanations of some psychological phenomena related to learning (e.g. forgetting, retroactive inhibition).

EPAM I:

The first and simplest of these models is EPAM I (Elementary Perceiver and Memorizer). EPAM I was developed by Feigenbaum and Simon (1962b) to account for the serial position effect. In serial anticipation learning, if the total number (or percentage) of errors is plotted as the ordinate against the serial position of the items on the list, a typical bowed curve results: more errors are made on items in the middle of the list than at either end, and fewer errors are made at the beginning of the list than at the end of the list. This curve represents the serial position effect. As described by Feigenbaum (1959, pp. 46-47), EPAM I consists of four macroprocesses.

M0: Serial Mechanism.

The central processing mechanism operates serially and is capable of doing only one thing at a time. Thus, if many things demand processing activity from the central processing mechanism, they must share the total processing time available. This means that the total time required to memorize a collection of items, when there is no interaction among them, will be the sum of the individual items.

M1: Unit Processing Time.

The fixation of an item on a serial list requires the execution of a sequence of information microprocesses that, for a given set of experimental conditions, requires substantial processing time per item.

M2: Immediate Memory.

There exists in the central processing mechanism an immediate memory of very limited size capable of storing information temporarily; and all access to an item by the microprocesses must be through the immediate memory.

M3: Anchor Points.

Items in a list which have unique features associated with them will be treated as 'anchor points' in the learning process. Anchor points will be given attention (and thus learned) first; items immediately adjacent to anchor points will be attended to second; items adjacent to these, next; and so on, until all of the items are learned.

Summary of M0 - M3

M0 establishes a serial processor, capable of doing only one thing at a time; this creates a need for deciding the order in which items will be processed, i.e. an attention focus, and M3 establishes a mechanism for determining this order. M2 provides a temporary storage, while the processes in M1 are permanently fixating the item.

To account for the serial position effect, Feigenbaum and Simon (1962b) posit that the anchor points at the beginning of the learning task are the first and last items on the list. The subject focuses on one of these items (choosing at random between them) and memorizes it. Once an item is memorized the effective beginning or end of the list is changed to the first and last unknown items -- which then become the anchor points. This process is outlined in Figure 1.

EPAM I is a powerful, yet simple model. Its simulated data agree closely with empirical data and, as a theory, is to be preferred on parsimonious grounds over the more complex explanations of the phenomenon (q.v. Feigenbaum & Simon, 1962b). On heuristic grounds, EPAM I can be judged quite favorably. For example, if certain items in the middle of the serial list are altered the characteristic curve is changed. EPAM I accounts for this (with the same processes as the serial position effect) by stipulating that these items become additional initial anchor points. Thus, "one would also expect that other items could be made unique by printing them in red ..., or by making some items much easier to learn ... or by explicit instructions ..., etc." (G.A. Miller, 1963, p. 325). The model also lends support to other learning phenomena such as one-trial learning -- an item in EPAM I is either learned or it isn't. EPAM I is limited because it cannot learn a list in which an item appears more than once -- a task subjects can do with difficulty.

The value of EPAM I, per se, to this study is negligible. Its importance lies in the fact that the EPAM I macroprocesses oversee the more specific microprocesses of EPAM II and EPAM III.

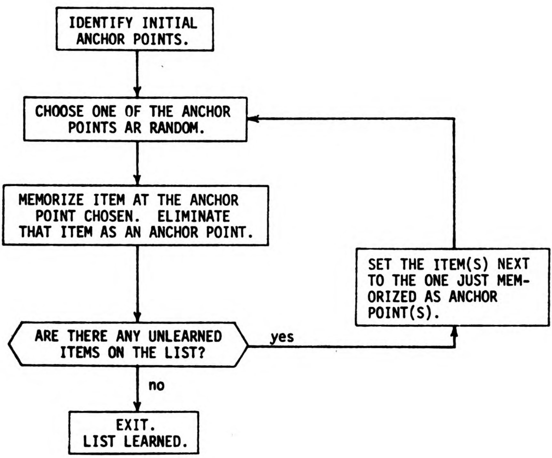

Figure 1. Item Selection and Learning in EPAM I.

EPAM II:

EPAM II is much more complicated than EPAM I because it posits one plausible set of microprocesses at the information processing level of explanation which seem to account for several verbal learning phenomena. A part of the EPAM II program simulates the experimenter and experimental conditions in a verbal learning situation (e.g. simulation of the memory drum controls the amount of time the subject has to respond). In this discussion, the major focus will be upon the microprocesses used in the simulated subject.

The inputs to EPAM II are binary coded nonsense syllables. If the program makes a response, it is also with binary coded nonsense syllables. Coded nonsense syllables are used because the routines within the program which convert the nonsense syllables to coded nonsense syllables (and vice versa) have not been developed. They are not central to the goals of EPAM II. The coding of nonsense syllables is done letter by letter. Each letter is represented by ten bits -- five of which are redundant. Feigenbaum (1959) calls the binary coded external stimulus (the nonsense syllable) a "stimulus input code" or "code."

There are two major sets of microprocesses in EPAM II. Performance processes function to produce the response associated with the stimulus. Learning processes are more complex. They work,

> to discriminate each code from the others already learned, so that differential response can be made; second, to associate information about a 'response' syllable with the information about a 'stimulus' syllable so that the response can be retreived if the stimulus is presented. (Feigenbaum, 1963, p. 301)

Figure 2 presents an overview of the performance processes. The code is sorted through a discrimination net to a terminal. A discrimination

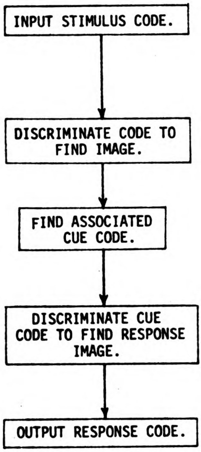

Figure 2. EPAM II Performance Processes.
(Adapted from Feigenbaum, 1963, p. 300).

net to a terminal. A discrimination net is a tree of binary testing nodes which examine bits of the code to identify characteristics of a letter in a given position (e.g. is the third letter closed?). Terminals are either empty or contain images which are more permanent representations of the stimulus (the code exists in "immediate memory" and if the memory drum turns, the code is lost; an image, on the other hand, is never lost). If the code matches the image (i.e. the code is recognized) a cue code is sought. A cue code is a subset of the response code which, at the time it was stored at the terminal, was minimally sufficient to retrieve the stored response image.

In the learning microprocesses, discrimination learning functions to correctly identify stimulus and response items. The discrimination net is modified (i.e. learning takes place) whenever identification is incorrect.

> To understand how the discrimination and memorization processes work, let us examine in detail a concrete example from the learning of nonsense syllables. Suppose that the first stimulus-response associate pair on a list has been learned. (ignore for the moment the question of how the association link is actually formed). Suppose that the first syllable pair was DAX-JIR. The discrimination net at this point has the simple two-branch structure shown in Fig. 3. Because syllables differ in their first letter, Test 1 will probably be a test of some characteristic on which the letters D and J differ. No more tests are necessary at this point.
>
> Notice that the image of JIR which is stored is a full image. Full images must be stored -- to provide the information for <u>recognizing</u> the stimulus. How much stimulus image information is required the learning system determines for itself as it grows its discrimination net, and makes errors which it diagnoses as inadequate discrimination.
>
> To pursue our simple example, suppose that the next syllable pair to be learned is PIB-JUK. There are no storage terminals in the net, as it stands, for the two new items. In other words, the net does not have the discriminative capability to contain more than two items. The input code for PIB is sorted by the net

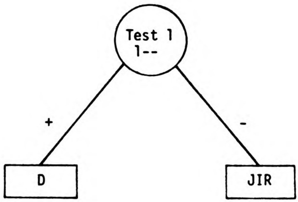

Figure 3. Discrimination Net after the Learning of the First Two Items. (Adapted from Feigenbaum, 1963, p. 303).

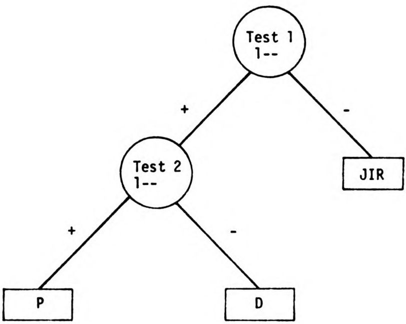

Figure 4. Discrimination Net of Fig. 3 after the Learning of Stimulus Item, PIB.
(Adapted from Feigenbaum, 1963, p. 304).

interpreter. Assume that Test 1 sorts it down the plus branch of Fig. 3. As there are differences between the incumbent image (with first letter D) and the new code (with first letter P) an attempt to store an image of PIB at this terminal would destroy the information previously stored there.

Clearly what is needed is the ability to discriminate further. A match for differences between the incumbent image and the challanging code is performed. When a difference is found, a new test node is created to discriminate upon this difference. The new test is placed in the net at the point of failure to discriminate, an image of the new item is created, and both images -- incumbent and new -- are stored in terminals along their appropriate branches of the new test. and the conflict is resolved. The net as it now stands is shown in Fig. 4. Test 2 is seen to discriminate on some difference between the letters P and D.

The input code for JUK is now sorted by the net interpreter. Since Test 1 cannot detect the difference between the input codes for JUK and JIR (under our previous assumption), JUK is sorted to the terminal containing the image of JIR. The match for differences takes place. Of course, there are no first-letter differences. But there are differences between the incumbent image and the new code in the second and third letters.

Noticing Order. In which letter should the matching process next scan for differences? In a serial machine like EPAM, this scanning must take place in some order. This order need not be arbitrarily determined and fixed. It can be made variable and adaptive. To this end EPAM has a *noticing order for letters of syllables*, which prescribes at any moment a letter-scanning sequence for the matching process. Because it is observed that subjects generally consider end letters before middle letters, the noticing order is initialized as follows: first letter, third letter, second letter. When a particular letter being scanned yields a difference, this letter is promoted up one position on the noticing order. Hence, letter positions relatively rich in differences quickly get priority in the scanning. In our example, because no first-letter differences were found between the image of JIR and code for JUK, the third letters are scanned and a difference is found (between R and K). A test is created to capitalize on this third-letter difference and the net is grown as before. The result is shown in Fig, 5. The noticing order is updated; third letter, promoted up one, is at the head. (Feigenbaum, 1963, pp. 302-304)

Association learning functions to pair the correct response to its stimulus. When an image is placed in an empty terminal a cue of the correct response is also placed in the same terminal. Thus the response is

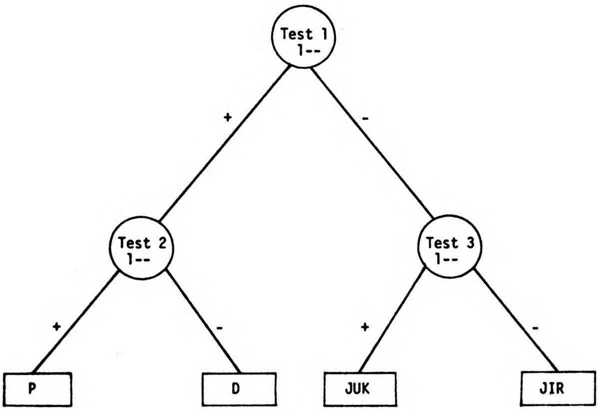

Figure 5. Discrimination Net of Fig. 4 after the Learning of the Response Item, JUK.
(Adapted from Feigenbaum, 1963, p. 304).

associated with the stimulus. The cue is determined by trial and error to be that minimal subset of the response code, which when sorted through the discrimination net will retrieve the correct response. It is important to remember that the cue is the minimal satisfactory subset. Because as learning takes place the structure of the net changes and a given cue may no longer be sufficient to retrieve the correct response. At this later time the cue may not contain sufficient information to be tested at a test node (e.g. the cue code may be the first letter of the response, while the testing node is checking the third letter position). When this happens one of the two branches below the test node is chosen randomly. One of three possibilities now exists. (1) The cue can by chance be sorted to the correct terminal and the correct response will be given (though there is no guarantee that this will happen the next time the stimulus item is presented). (2) The cue code can be sorted to an empty terminal and no response be given. (3) The cue code can be sorted to a non-empty, but incorrect terminal, and an incorrect response is made. In both the second and third cases, additional learning processes are brought into play (when the correct response becomes available in the memory drum) and the cue is modified to insure that when it is sorted through the net as it now exists, it is minimally sufficient to retrieve the correct response. If an empty terminal was found the learning processes begin to build a response image in that terminal.

The basic structure and processes of EPAM II have been presented. Before evaluating the model a more extended example of its functioning would be helpful. The example below is adapted from Feigenbaum (1959, pp. 86-96). Though this example is of serial anticipation learning, it should be evident that the same microprocesses can effect the simulation of P-A learning. In the example, the experimental situation consists of one list of six nonsense syllables: KAG, LUK, RIL, PEM, ROM, TIL. Initially the noticing order (N.O.) is first letter, third letter, second letter, and the maximum number of test nodes added to the net each time it is grown is three (it is efficient to detect several differences each time the net is grown and add more than one test node at a time). The learning criterion is one perfect trial. Macroprocesses oversee the learning and determine the order in which stimulus-response items within the list are learned. The processing of the example is outlined in Table 2 and Figures 6-10 which summarizes the "learning" of the list by EPAM II.

The effectiveness of EPAM II as a model is indicated by the verbal behaviors it simulates.

> Study of the behavior of EPAM in an initial set of about a hundred simulated experiments shows that a variety of 'classical' verbal learning phenomena are present. Referring to traditional labels, these include serial position effect, stimulus and response generalization, effect of intra-list similarity, types of intra-list and interlist errors, oscillation, retroactive inhibition, proactive effect on learning rate (but unfortuaately not proactive inhibition), and log-linear discriminative reaction time. Further experiments, especially those involving inhibition phenomena and transfer phenomena are now in progress. (Feigenbaum & Simon, 1963a, p. 335)

To illustrate how the model simulates one of these phenomena, there is an instance of stimulus generalization in the example presented in Table 2. Stimulus generalization is the name given when stimulus B's response is given to stimulus A (stimulus A and stimulus B are similar on some dimension). In Trial 4 of the example TIL is erroneously given in response to PEM. This is an instance of stimulus generalization. The test nodes do not discriminate between PEM and ROM (operationally they can be defined as similar stimuli because both meet the same testing conditions).

Table 2. An Outline of EPAM II Processing in Serial Anticipation Learning

Trial	Stimulus	Response	Internal Processing	Notes
1	KAG LUK RIL PEM ROM TIL	none none none none none ----	Discriminate KAG: Since N.O. begins with first letter tests, T1, T2, T3 are first letter tests. T1 sorts kag to the right side of the net. There is no stored cue at that terminal; no response is made. Discriminate LUK: The image of LUK is stored through the net. No additional test nodes are needed. Associate KAG-LUK: Since l-- suffices to retrieve luk it is stored with kag. The first letter, l, was chosen by N.O.	See Figure 6.
2	KAG LUK RIL PEM ROM TIL	LUK none none none none ----	Discriminate LUK: First letter tests suffice to sort image of LUK to terminal containing luk. Discriminate RIL: T1 sorts image of RIL to the right, where it is confused with kag. Three test nodes are added to the net. Associate LUK-RIL: The cue, r--, suffices at this time to retrieve ril.	See Figure 7.

Table 2. (cont'd.)

Trial	Stimulus	Response	Internal Processing	Notes
3	KAG LUK RIL PEM ROM TIL	LUK RIL none none none ----	Discriminate ROM: Image of ROM is sorted to terminal containing ril. The first letter tests do not work. N.O. is updated to 3,1,2. Three new test nodes are added to net. These are third letter tests and can discriminate between rom and ril. Discriminate TIL: Image of TIL is sorted down left side of net. T2 and T3 cannot separate til and luk. Three new nodes are added to net. New nodes are third letter tests due to N.O. Associate ROM-TIL: The first attempt at a response cue is --l. But, that will not always retreive til because tests at the top of the net are first letter tests. Therefore, the next letter determined by N.O. is added to the cue. t-l is produced and retrieves til.	See Figure 8.
4	KAG LUK RIL PEM ROM TIL	LUK none[1] none TIL[2] TIL ---	Discriminate PEM: Image of PEM is confused with rom. Hence, third letter tests do not discriminate. N.O. is updated and T13, a first letter test is added to the net. Discriminate ROM: ROM is already learned and is found with no additional changes needed in the net.	1. The cue r-- associated with luk is no longer sufficient to guarantee the selection of the correct response. In this case an empty terminal is found. Learning processes then

Table 2. (cont'd.)

Trial	Stimulus	Response	Internal Processing	Notes
				augment cue for ril so it will be sufficient for the current net. 2. Response to ROM is given.
5	KAG LUK RIL PEM ROM TIL	LUK[1] RIL none none[2] TIL ----	Associate PEM-ROM: r-- is not sufficient to retrieve rom. Cue stored with pem is r-m.	1. l-- does not suffice to guarantee retrieval of luk. But by chance it does. The net is unchanged. 2. There was not enough time in Trial 4 to link PEM-ROM. * See Figure 9.
6	KAG LUK RIL PEM ROM TIL	none[1] RIL none ROM TIL ----	Discriminate RIL: ril is found. Net is unchanged. Discriminate PEM: pem is found. Net is unchanged. Associate RIL-PEM: Cue p-m is sufficient to retrieve pem.	1. This time (cf. Trial 4) chance does not allow l-- to retrieve luk. Therefore, cue is augmented to l-k
7	KAG LUK RIL PEM ROM TIL	LUK RIL PEM ROM TIL ----	none.	See Figure 10.

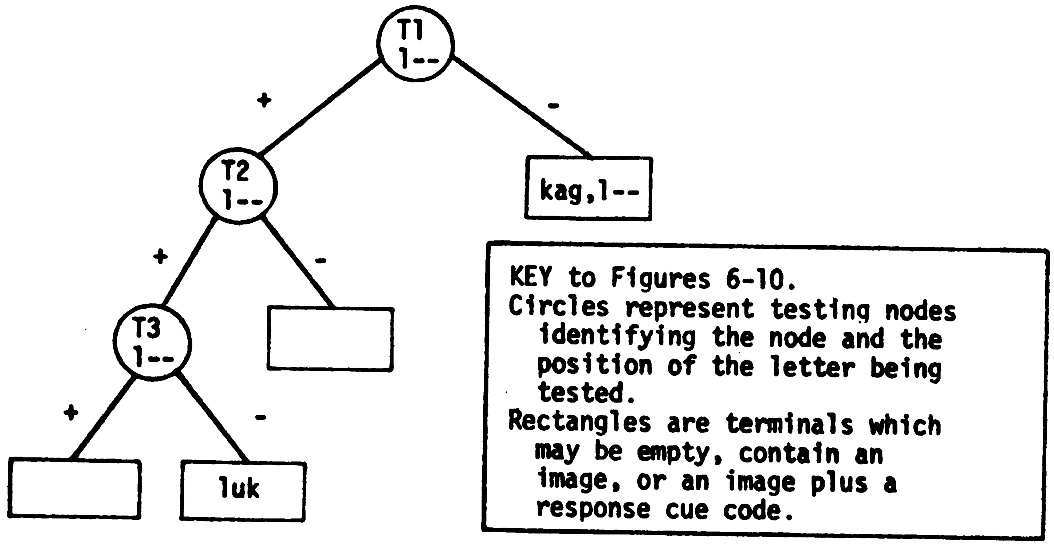

Figure 6. Discrimination Net after Trial 1.
(Adapted from Feigenbaum, 1959, p. 90).

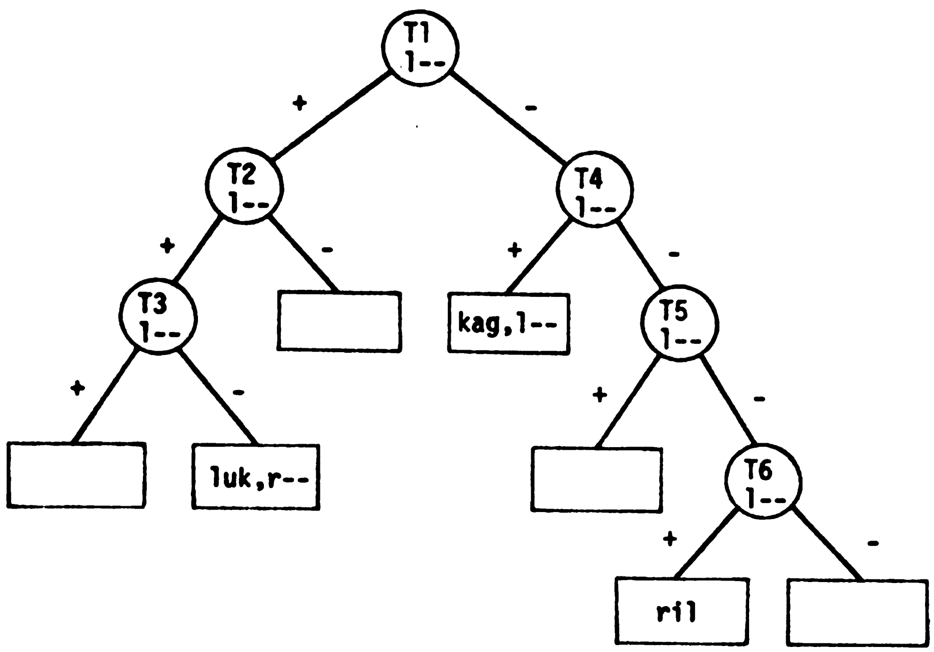

Figure 7. Discrimination Net after Trial 2.
(Adapted from Feigenbaum, 1959, p. 91).

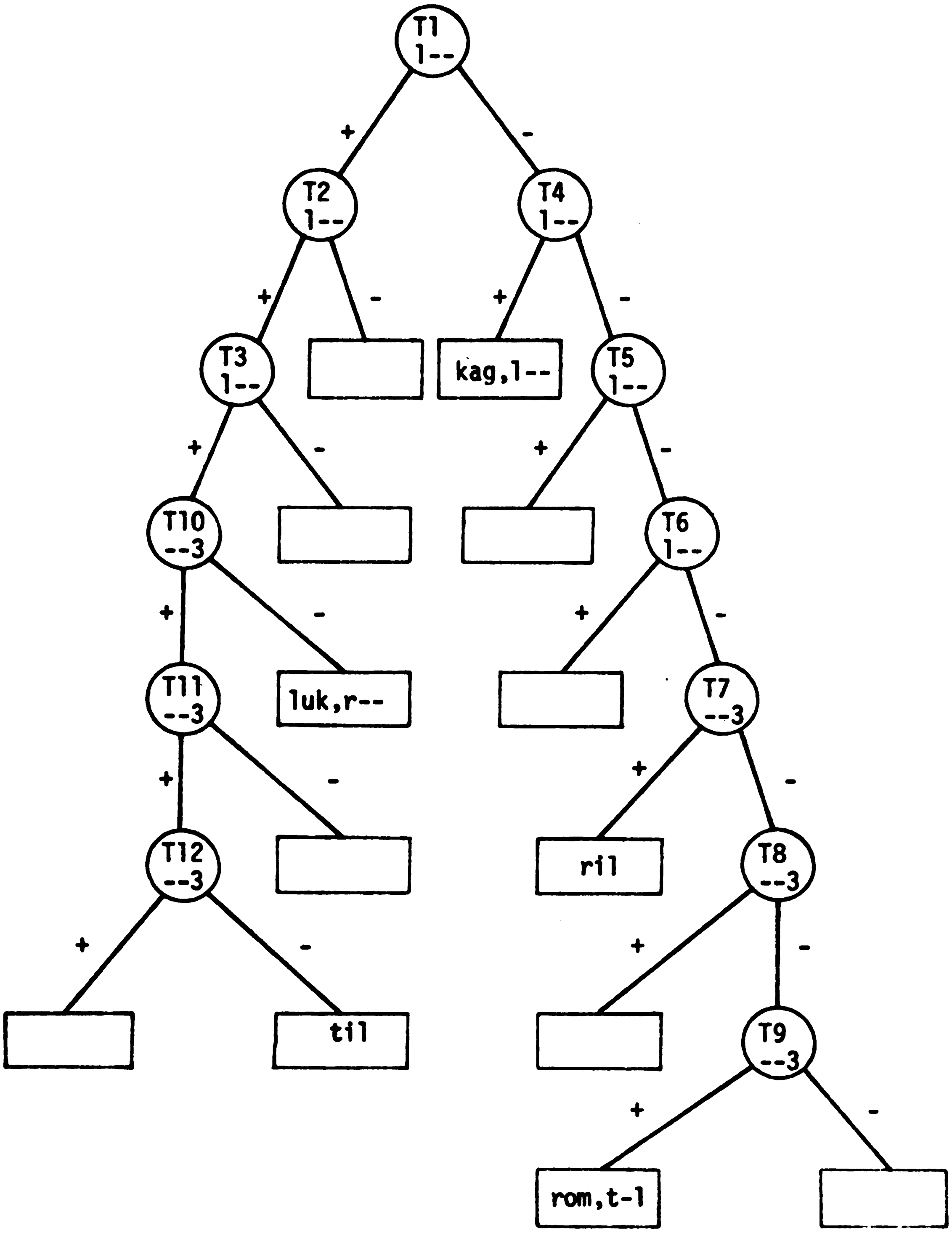

Figure 8. Discrimination Net after Trial 3.
(Adapted from Feigenbaum, 1959, p.93).

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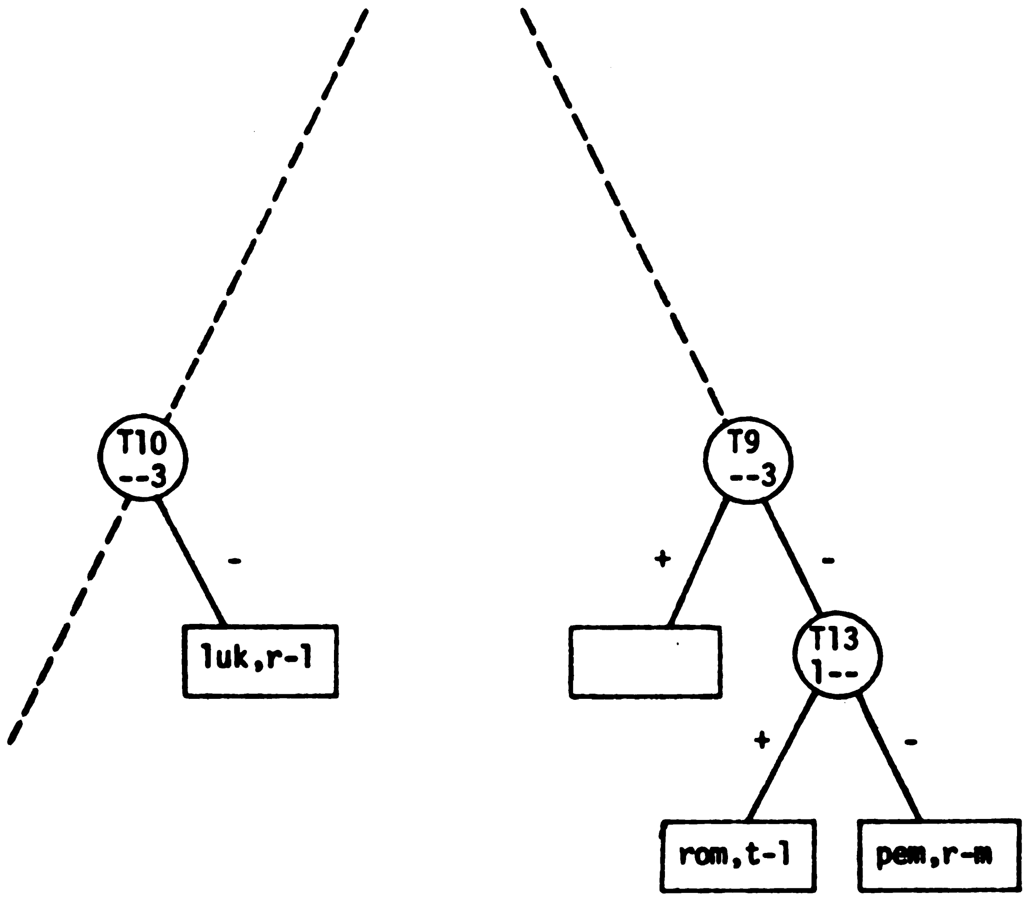

Figure 9. Changes in Discrimination Net after Trial 5.
(Adapted from Feigenbaum, 1959, p. 94).

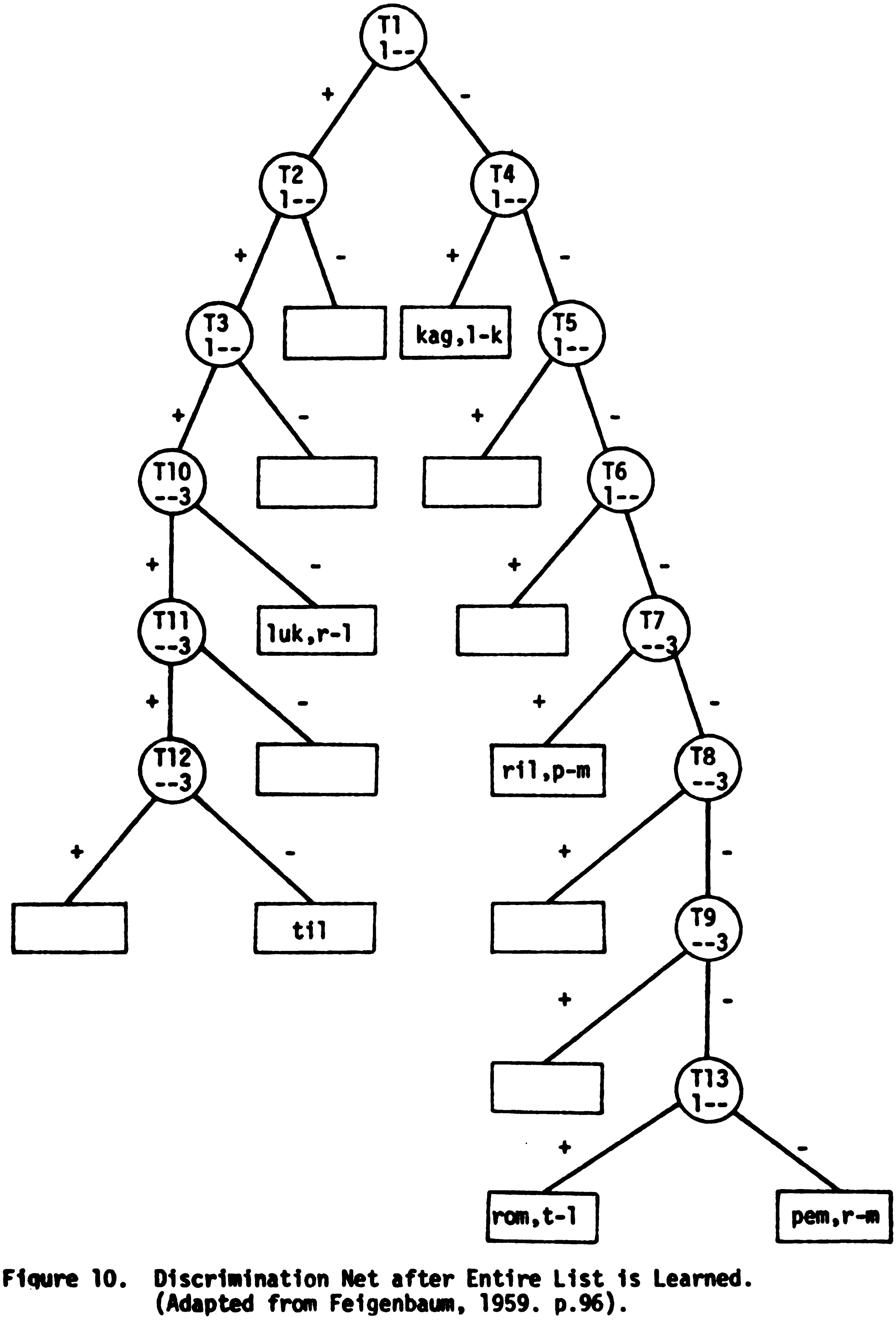

Figure 10. Discrimination Net after Entire List is Learned. (Adapted from Feigenbaum, 1959. p.96).

In addition to these phenomena, the model also contributes to a theory of forgetting (q.v. Feigenbaum & Simon, 1961). In EPAM II items are never permanently lost from memory; they are misplaced. Thus, what appears to be forgetting is, in fact, the effect of later learning (i.e. retroactive inhibition). See Trial 6 in the preceeding example for an instance of forgetting.

EPAM III:

Certain deficiencies in EPAM II (such as learning a list containing two identical nonsense syllables which differed according to some external property; e.g. color) lead Feigenbaum and Simon (1962a) to construct EPAM III. EPAM III is a much more complex IPM than EPAM II. It uses a hierarchical discrimination net (not present in EPAM II) which sorts and learns letters, nonsense syllables, and stimulus-response pairs similarily. It efficiently makes use of early learning by treating previously learned letters as syllables and previously learned syllables and stimulus-response pairs. By means of a property set attached to letters, syllables and pairs, EPAM III can discriminate between items alphabetically similar but having different contexts (e.g. coming at the beginning of the list), modes of production (e.g. oral, visual), and different external characteristics (e.g. pica type).

The discrimination net in EPAM III is composed of three related parts. The letters' portion of the net is very similar to that of the entire EPAM II net. It is composed of test nodes (which test some attribute of the encoded letter) and terminals which may be empty or contain an image of a letter. The tests in the letters' portion of the net are, in effect, binary tests checking if the encoded letters meet or do not meet the criterion being checked.

The syllables' portion of the net is composed of attribute testing nodes, subobject nodes and terminals. The attribute testing nodes are n-ary branching. They test individual syllables (e.g. what is the color of this syllable?). The terminals contain images of a syllable. The image of a syllable consists of cue tokens (analogous to cue codes in EPAM II) for each letter in the syllable.

The stimulus-response pairs' portion of the net consists of n-ary branching tests (which identify subobjects of the pair and attributes of the pair) and terminals which contain complete or partial images of pairs. An image of a pair consists of the cue tokens for each syllable member of the pair.

Since some nodes in the syllables' and pairs' portions of the net test for lower level components (i.e. letters and syllables respectively) these nodes are called subobject nodes. Figure 11 presents a partial discrimination net of EPAM III. In Figure 11 (and throughout the remaining discussion of EPAM III) 0 represents an object (i.e. letter, syllable, or pair); 0' is the terminal 0 is sorted to; and 0" is the image stored in terminal 0'. 0" may or may not correspond to 0, it is simply the image in 0'. 0' is also the cue token of 0". It names the terminal containing 0". 0" consists of a list of the cue tokens of the subobjects of an object plus a property set of its attributes.

Suppose from previous learning trials, part of a discrimination net exists as shown in Figure 11. In the experimental situation the list to be learned contains the pair CAT-DOG (which has already been completely learned). When CAT appears in the window of the simulated memory drum, the simulated subject should respond with DOG (before DOG appears in the

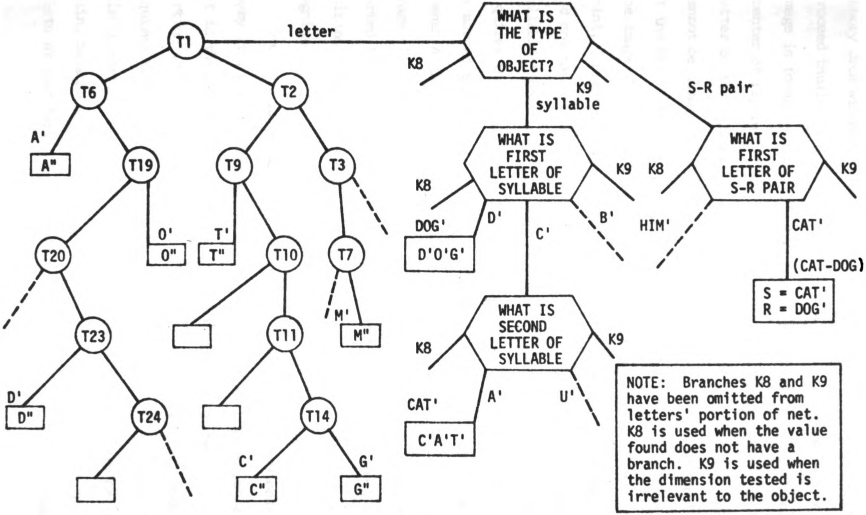

Figure 11. A Sample Discrimination Net Grown by EPAM III. (Adapted from Wynn, 1966, p. 49).

memory drum window). The performance and classification processes would proceed thusly. CAT is a syllable and will not be recognized until an image is found. In the syllables' portion of the discrimination net (center of Figure 11) the first subobject testing node asks for the first letter of the syllable. Since CAT is not yet recognized this question cannot be answered. The letter C is sorted through the letters' portion of the net (left side of Figure 11) reaching terminal C' which contains the image C". (Just as in EPAM II, if learning were not complete at this point, C might have been sorted to an empty terminal or one whose image did not match the object). C is recognized and branch C' is taken in the syllables' portion of the net. The second subobject testing node there requires the identification of the second letter of the syllable, A. A is sorted through the letters' portion of the net until it is recognized. Branch A' is taken and CAT is sorted to terminal CAT' which contains an image (i.e. CAT is recognized). Since learning is complete the terminal sorted to is, in fact, the correct one. But, in general, there is no requirement that the correct terminal be reached for a stimulus to be recognized.

Once CAT is recognized an attempt is made to make a response. A dummy stimulus-response pair, CAT'-_____, is formed (the response is not yet in the memory drum window). This dummy pair is sorted into the pairs' portion of the net (right side of Figure 11). The subobject node there requires that the stimulus member be recognized -- which it is. The dummy pair is sorted down the CAT' branch which terminates at terminal (CAT-DOG)'. Again, because earlier learning had been complete an image of the response exists at that terminal and is the correct one. Within that image is the

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cue token DOG'. This identifies the syllable terminal which contains cue tokens D', O' and G' which, in turn, identify terminals in the letters' portion of the net. Stored along with the images of the letters is information needed to make an actual response DOG. It should be noted that once the response image DOG" was found, further sorting through the discrimination net was not necessary since cue tokens in EPAM III name a terminal and do not themselves have to be sorted through the net -- as is the case with the cue codes in EPAM II. This is an example of early learning affecting the rate of later learning.

Assuming that the subject had enough time (i.e. the memory drum did not turn) to make a response, that response is compared with the correct response (when the drum finally turns) and if they do not match the net is augmented. This takes the form of adding test nodes to the net, changing or modifying existing images, and adding a new image to a terminal.

To better understand some of the processing involved in classification and learning (image building and discrimination) in EPAM III, an example of P-A learning is outlined in Table 3 and Figures 12-16. Initially the discrimination net is as described in Figure 11. The only pairs on the list to be learned which will be discussed are CAT-DOG and CAB-MAN. CAT-DOG has already been learned but neither CAB nor MAN has affected the net in any way.

If there is no interference from other pairs on the list, CAT-DOG and CAB-MAN have been correctly learned after Trial 4. Trials 1 and 2 of this example contain instances of stimulus generalization (CAB elicits DOG). While the alternating responses to CAT illustrates oscillation, a familiar phenomena in verbal learning.

Table 3. An Example of EPAM III Paired Associate Learning

Table 3. An Example of EPAM III Paired Associate Learning

Trial	Item in Window	Response Made	Internal Processing (Refer to Figure 12)	Notes
1[1]	CAT	DOG	Steps: 1, 19, 20, 21, 24, 25, 28, 29, 32, 33.	1. Net looks like Figure 11 before this Trial * No changes made in net.
	DOG	---	Steps: 1, 2, 4, 5, 33.	* No changes made in net.
	CAB	DOG	Steps: 1, 19, 20[2], 21, 24, 25, 28, 29, 32, 33.	2. CAB is sorted to terminal CAT'. * No changes made in net.
	MAN	---	Steps: 1, 2, 4, 5, 6[3], 7[4], 33.	3. Response in window is discriminated and added to net. 4. Time runs out. * Net is changed -- see Figure 13.
2	CAT	DOG	(Same as in Trial 1).	* No changes made in net.
	DOG	---	(Same as in Trial 1).	* No changes made in net.
	CAB	DOG	(Same as in Trial 1)[1].	1. CAB is not yet discriminated. * No changes made in net.
	MAN	---	Steps: 1, 2, 4, 5, 6, 7[2], 8, 9[3], 11, 13, 15, 16, 17[4], 18[5], 33.	2. Since MAN was discriminated in Trial 1 more time is available for additional processing 3. The dummy S-R is CAT'___.

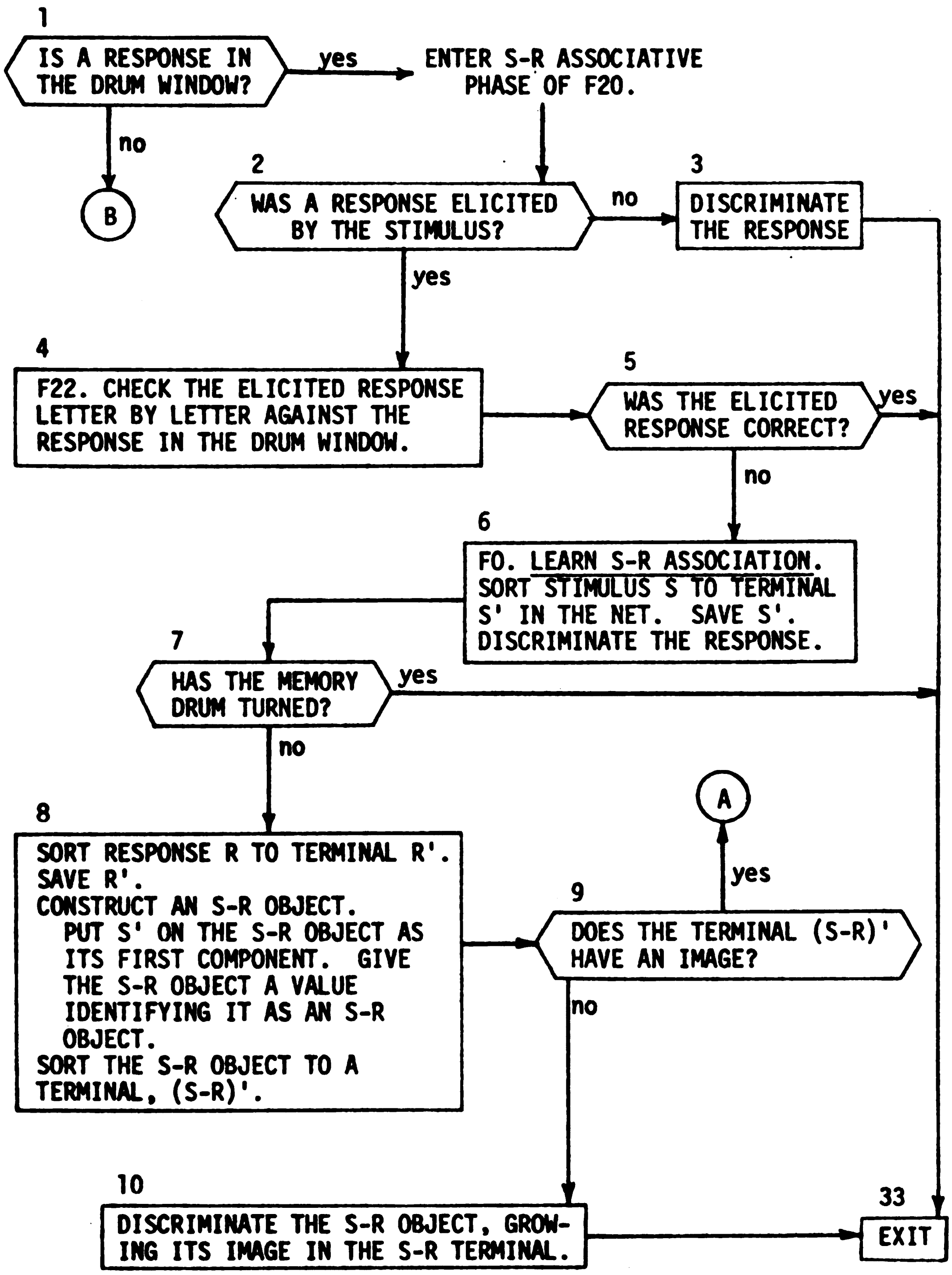


Figure 12. Flowchart of F20, the Paired-Associate Learning Routine of EPAM III.
(Adapted from Wynn, 1966, p. 53).

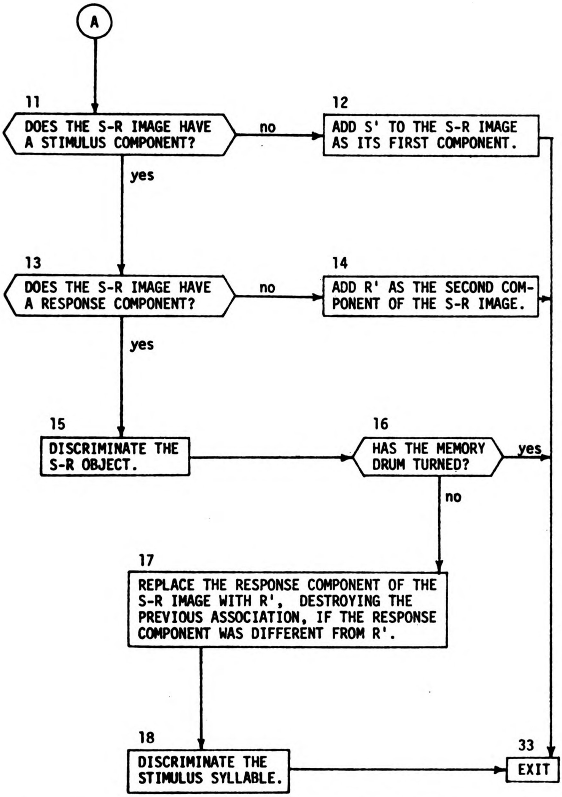


Figure 12. Flowchart of F20, the Paired-Associate Learning Routine of EPAM III (continued).

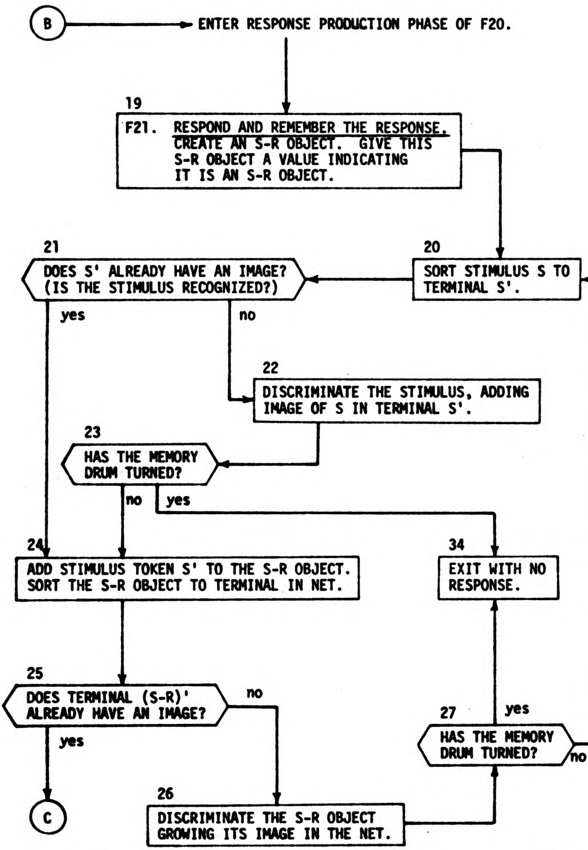


Figure 12. Flowchart of F20, the Paired-Associate Learning Routine of EPAM III (continued).

Figure 12

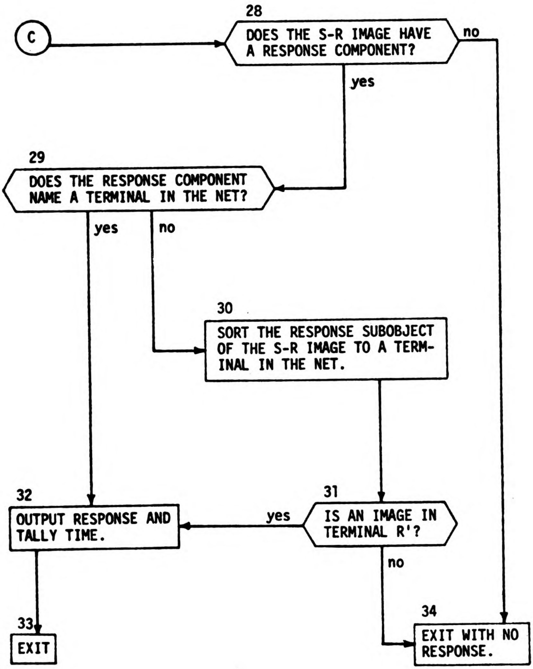
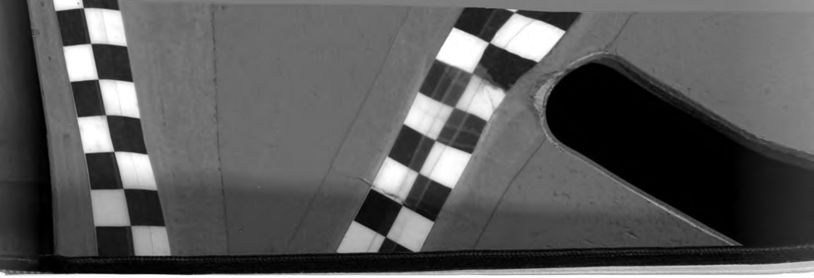


Figure 12. Flowchart of F20, the Paired-Associate Learning Routine of EPAM III (continued).



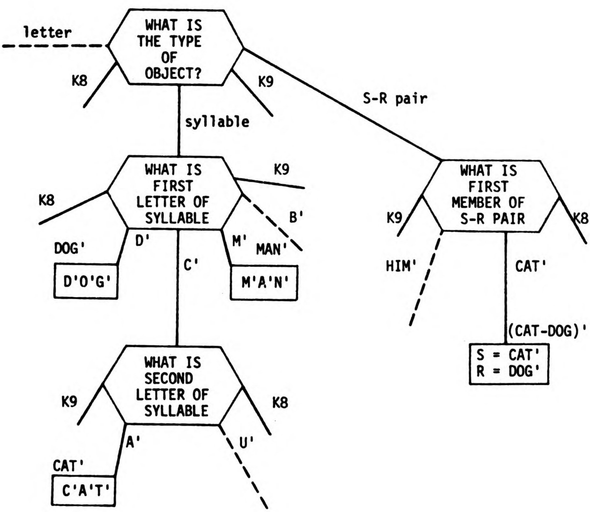


Figure 13. Discrimination Net of Fig. 11 after Trial 1. (Adapted from Wynn, 1966, p. 67).

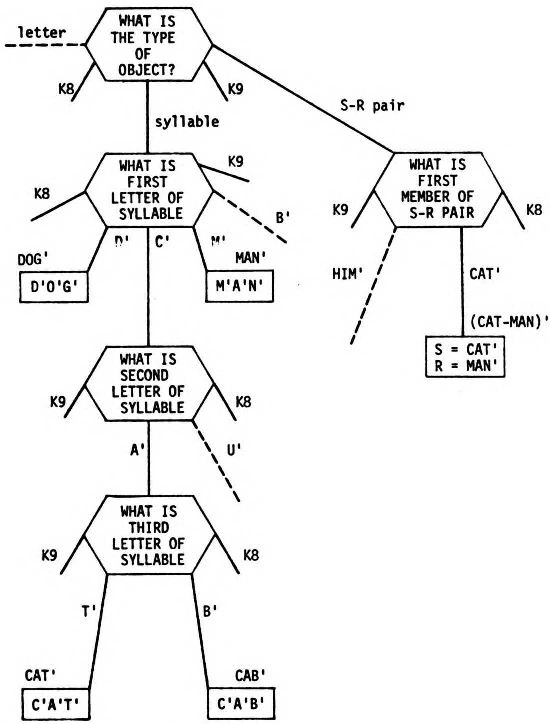


Figure 14. Discrimination Net of Fig. 13 after Trial 2. (Adapted from Wynn, 1966, p. 67).

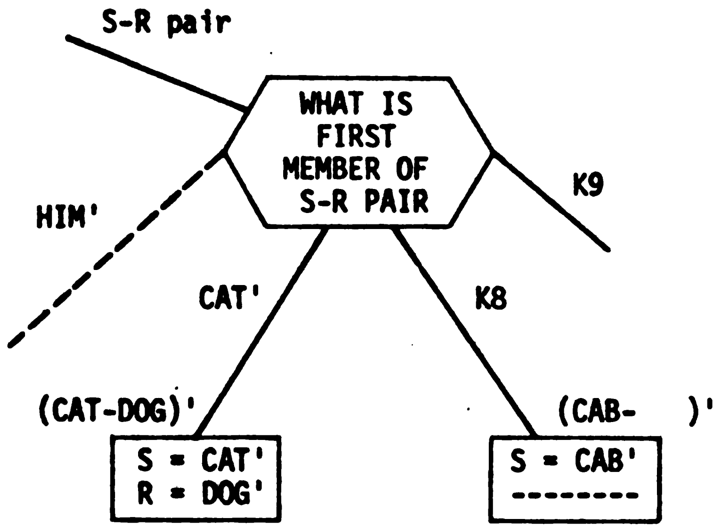


Figure 15. Discrimination Net of Fig. 14 after Trial 3. (Adapted from Wynn, 1966. p. 67).

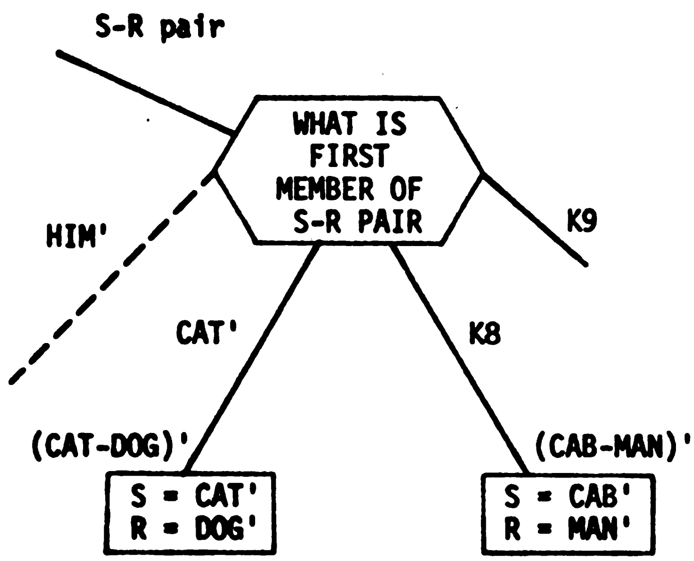


Figure 16. Discrimination Net of Fig. 15 after Trial 4. (Adapted from Wynn, 1966, p. 67.

EPAM III accounts for most of the same phenomena as EPAM II: stimulus and response generalization, oscillation and retroactive inhibition, forgetting (though in EPAM III information can be permanently lost from the discrimination net -- q.v. step 17, Fig. 12 -- which does not occur in EPAM II), effects of similarity among list items, and others. Neither model accounts for proactive inhibition, backward association, and free recall. EPAM III (but not EPAM II) contributes to an understanding of the role of meaningfulness and familiarity in verbal learning (q.v. Simon & Feigenbaum, 1964). And, EPAM III can learn lists in which the same item occurs more than once. For the purposes of this paper it is not necessary to evaluate the EPAM models further. A more thorough examination is available in Feigenbaum and Simon (1962a) and Wynn (1966). The reason for identifying the phenomena "accounted for" by these models is simply to lend weight to their credibility as models.

<u>WEPAM</u>:

The weaknesses of the EPAM models noted above, along with some theoretical and empirical considerations, led Wynn (1966) to develop a modified version of EPAM, called WEPAM (Wynn's Elementary Perceiver and Memorizer). WEPAM uses as its main structure a discrimination net similar to that of EPAM III. The net differs from earlier models in several important ways:

> a) multiple representations (images) of the same objects in memory, b) multiple retrieval pathways -- both divergent and convergent -- to these images, c) multiple responses associated with each stimulus, and d) processes by which the retrieval structure in early stages of learning incorporates redundant information which is in part later eliminated in the interests of more efficient retrieval. (Wynn, 1966, p. 138)

In addition, WEPAM employs a position testing node as well as the attribute and subobject nodes used in EPAM III. Position nodes identify the

location of a letter in a syllable. Figure 17 shows a WEPAM net early in P-A learning. In the pairs' portion of the net, there is an instance of a stimulus item (VEC) associated with two possible responses (LAJ, GIW). In the syllables' portion of the net there are three position testing nodes (P, L, G). Figure 18 shows the syllables' portion of the same net later in the learning situation. In this Figure there are examples of multiple paths to the same object (e.g. DAX, GIW) and multiple representations of the same object (e.g. VAF, LGP).

Three techniques employed in WEPAM produce these multiple paths and multiple images. First of all a noticing order (as in EPAM II) is used separately for syllables, S-R pairs, and letters. Secondly, the net can be made more efficient by bypassing redundant nodes which test, one after the other, the same attribute or the same position. And, thirdly branch recruitment is possible. Branch recruitment is a process whereby a branch in the net is duplicated at the node below. This may occur depending upon initial parameter conditions, the current N.O., and time remaining before the simulated memory drum turns.

The general learning processes of the WEPAM model will not be discussed because of their close similarity to those in EPAM III. It is important, however, to further study WEPAM's use of multiple responses stored with stimulus items in the pairs' portion of the net because of its obvious similarity with what is needed in a model of free association behavior.

In its most complex form, the image stored in the terminal node in the pairs' portion of the net consists of (1) a property set identifying characteristics of the S-R pair, (2) a stimulus token with its (3) associated response list, and (4) a response error list. When a dummy S-R pair (i.e. S'-_) is sorted to a terminal in the pairs' portion of the net, an

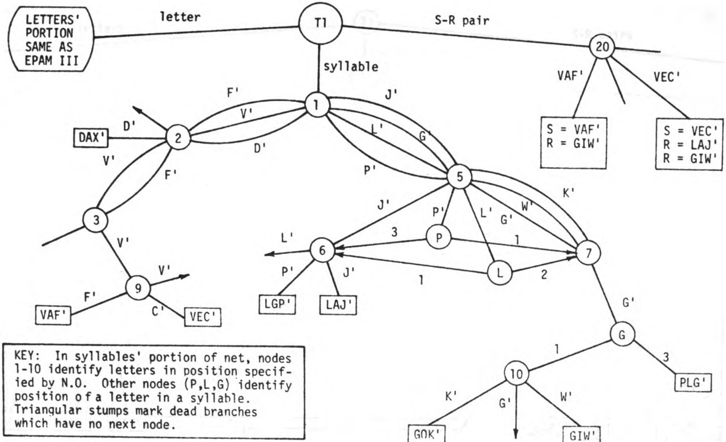


Figure 17. Portion of a Typical WEPAM Net. (Adapted from Wynn, 1966, p. 144).

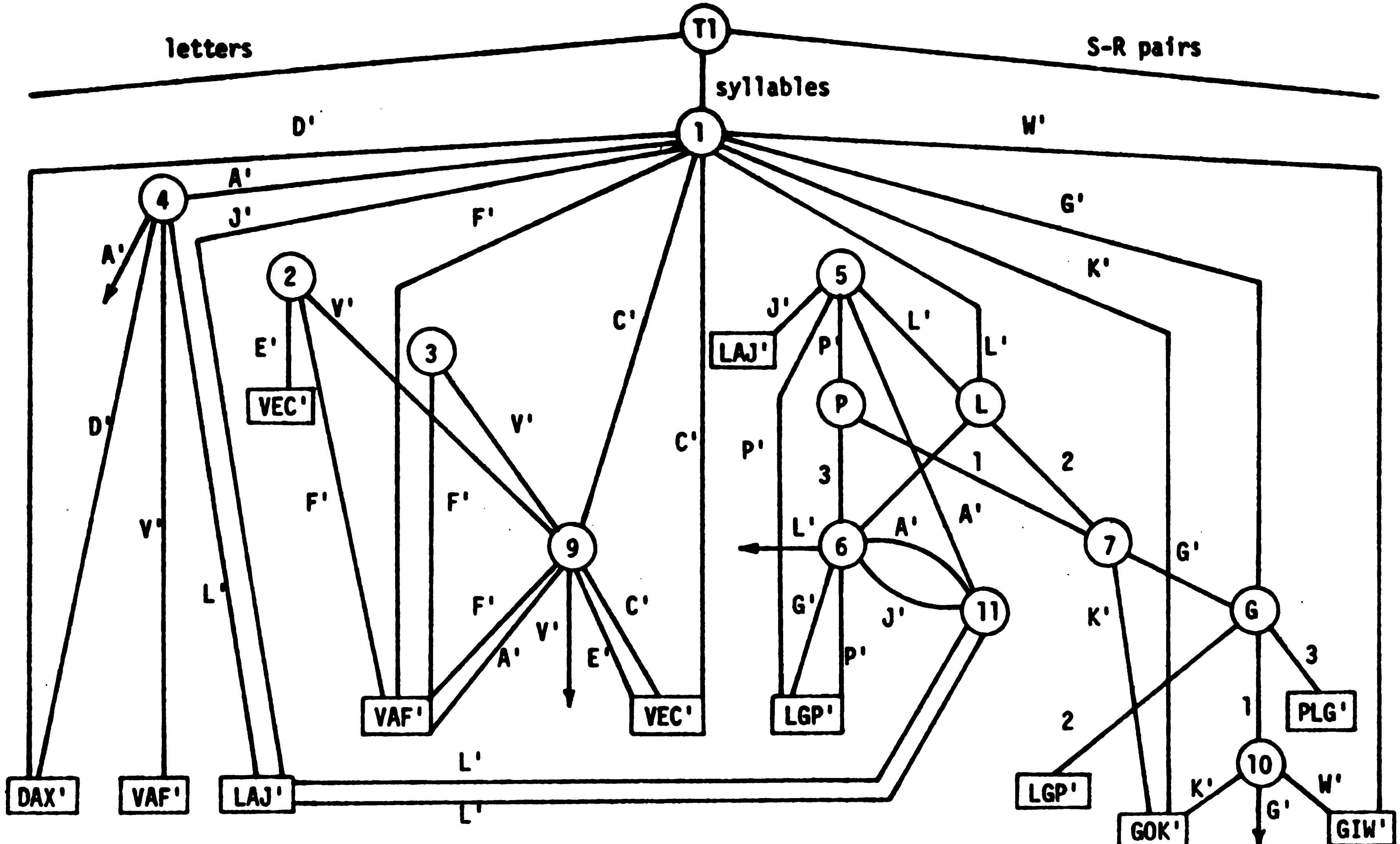


Figure 18. Syllables' Portion of Discrimination Net of Fig. 17 after Later Learning. (Adapted from Wynn, 1966, p. 161).

[illegible]

an attempt is made to match S' with S". If they match the first response on the response list that is not associated with an error flag becomes the first response candidate. If all responses in the list are marked with an error flag, the last one examined becomes the candidate.

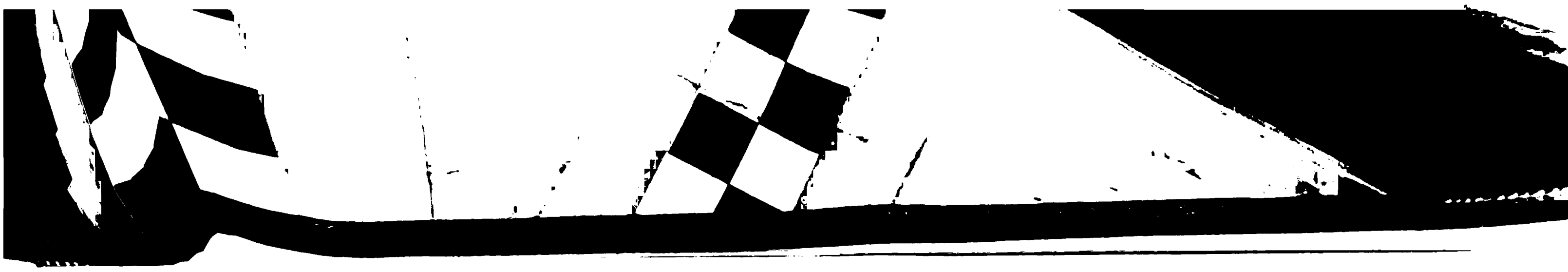
When the memory drum turns and presents the correct response, WEPAM may use one of several possible procedures to (1) add a response token to the response list, (2) augment an existing response token on the list, (3) change the value of a responses' error flag, and (4) move a response higher on the response list. All of these techniques can have a profound effect on later learning trials.

The WEPAM model simulates some of the same phenomena of verbal learning as the EPAM models do: types and frequency of response errors, stimulus and response generalization, oscillation and forgetting. Forgetting does not involve a permanent loss of information (as in EPAM III); rather information may be temporarily misplaced due to retroactive inhibition (as in EPAM II) or permanently misplaced (i.e. a node is stranded) due to bypassing of nodes.

In WEPAM most of the explained phenomena occur because of microprocesses similar to, but not exactly the same as those in the EPAM models. WEPAM also simulates the effects of overlearning (errors appear after items seem to be learned), backward association (R-S), and stimulus redintegration (an incomplete stimulus <u>object</u> may elicit the correct response). These phenomena are not accounted for by the EPAM models. WEPAM as well as EPAM fails in simulating proactive inhibition.

<u>SAL I-III</u>:

A second IPM based on an EPAM-like discrimination net and processes was developed by Hintzman (1968). He called his model SAL (for Stimulus



and Association Learner). It is not necessary to discuss SAL at great length here, because of its structural and functional similarity with the EPAM and WEPAM models. Therefore, what follows is concerned mainly with important differences between the SAL models and the earlier ones.

> Despite the common assumption of the discrimination net, SAL differs from EPAM in several respects. First, learning in SAL is a stochastic process, while in EPAM it is deterministic. If an investigator gives EPAM a list to learn, erases the memory and then presents the same list again, he will obtain two identical (or nearly identical) protocols . . . . The SAL model, in contrast, is governed by stochastic processes, and can generate any number of unique protocols for the learning of a given list. . . . It should be mentioned here that stochastic processes are used in SAL only to facilitate the derivation of prediction. They are intended as statements of ignorance, rather than assertions that learning is basically probabilistic.
>
> Second, in SAL all processes which are not necessary in order to do running simulations of PA learning have been eliminated. 'Macroprocesses,' such as those in EPAM concerned with allocation of processing effort, have been greatly simplified. Also, SAL does not make use of 'stimulus images' or of a scan for differences between the image and the presented stimulus as does EPAM. It is hoped that, since there are fewer postulated processes in SAL, it will be easier to identify specific processes or combinations of processes with specific resulting predictions. Thus, it should be easier to understand why the model makes a correct or incorrect prediction, and to make appropriate changes when needed.
>
> Third, SAL uses the discrimination net only for stimulus discrimination learning, while EPAM uses it for both stimulus learning and response integration. Accordingly, the 'task environment' of SAL consists only of lists of trigram-digit pairs, where the responses are already well known, and only the stimuli are unfamiliar. The purpose of this restriction is simple. It is felt that if stimulus discrimination learning is to be understood, it should be isolated from possible confounding processes, such as those concerned with response integration, and so on. (Hintzman, 1968, pp. 124-125)

SAL exists as three highly related IPMs. The later versions are more complex than the earlier ones and include, for the most part, all processes of the earlier ones. In SAL I discrimination learning differs from that in

EPAM in two major ways. First, there is no N.O. which "learns" (i.e. changes in N.O. based upon experience). Rather the N.O. is fixed -- always being the first, then the second, then the third letter of the stimulus trigram. Second, there are probabilistic processes. When an error occurs in discrimination learning a new test node is added to the net with probability $\underline{a}$. If an error occurs and no new test node has been added (probability $1-\underline{a}$), then the correct response replaces the old response with probability $\underline{b}$. The probabilities $\underline{a}$ and $\underline{b}$ are parameters of the model and are initially set by the experimenter before running the simulation.

SAL I simulates stimulus generalization, oscillation, perserverance (same incorrect response given to the same stimulus item over several trials), effect of stimulus similarity and other phenomena. The model fails to handle retroactive inhibition. Also since the model does not attempt to simulate response processing there are no failures to respond to a stimulus object.

SAL II was developed mainly to handle retroactive inhibition. In SAL II learning can occur after a correct response (as well as after an incorrect response) with probability $\underline{c}$. $\underline{c}$ is a parameter between 0 and $\underline{a}$. After a correct response a new test node is added to the net with probability $\underline{c}$. Below this test node is an empty terminal. In later trials, if the stimulus is sorted to a blank terminal, the model responds with any item on the list (randomly) and stores the reinforced response in the empty terminal. SAL II simulates the effects of overlearning and retroactive inhibition.

In SAL III more than one response may be associated with a stimulus item (as in WEPAM). This modification of the model was thought to be necessary if the model were to account for proactive inhibition and modified free recall. In SAL III responses to a stimulus item are stored in a push down stack (PDS). In a PDS new responses to be associated with a stimulus item are added to the top of the stack; older items are pushed down one level. Response items at the top of a stack are more available as responses than items lower in the stack. Thus, the PDS is a simple method for making response availability a function of recency. Incorporated into SAL III is a short-term memory process which functions to move all items in a PDS up one level with an a priori probability d. By this procedure newer items in short-term memory (i.e. at the top of a PDS) can become permanently forgotten. SAL III can simulate the difference usually found between two methods of measuring retention: recall and recognition. That is, the model presents a mechanism which produces higher recognition scores than recall scores. Also, the model can simulate proactive inhibition and can explain some of the empirical research in this area.

As an overall assessment, SAL and EPAM models,

> account for oscillation, stimulus generalization, retroactive interference, and the effects of stimulus similarity on list difficulty. EPAM contains assumptions not present in SAL, which make it applicable to problems of serial learning, response integration, and presentation rate, and which allow it to predict negative transfer. At the same time, SAL is able to simulate some phenomena that present versions of EPAM cannot, mainly through the use of overlearning assumptions (SAL II) and the storage of multiple associations (SAL III). Although all subprocesses in SAL are all-or-none, it is consistent with a number of facts (such as the effects of overlearning on retention) which have always seemed to prove that an incremental habit strength notion was needed. (Hintzman, 1968, p. 157)

Summary:

In this section of chapter 2, five IPMs were presented. All of these models simulate a subject (or group of subjects) and the experimental conditions in a verbal learning situation. EPAM I consists of four macroprocesses. It simulates the serial position effect and the von Restorff effect (i.e. changes in serial position curve due to unusual items in the list) by hypothesizing that the list item learned on a trial is chosen from a subset of items located at anchor points. EPAM II adds one plausible set of microprocesses to the above structure. EPAM II (and the EPAM III, WEPAM, and SAL models) uses as its main structure the discrimination net. Coded input stimulus items are sorted through the net until a terminal is reached. The terminal may be empty (and no response is made) or it may contain an image. The stored image is matched against the input stimulus. If they match the stimulus is said to be recognized. Once recognized an associated cue to the correct response (if one exists) is sorted through the net to find and produce a coded response. Whenever an error occurs and processing time remains, learning processes are brought in to change the structure and/or content of the net.

EPAM III extends EPAM II by including within the net nodes for letters and stimulus-response pairs as well as for syllables. WEPAM is an EPAM III-like structure which builds multiple representations of objects in nets and multiple retrieval pathways to these objects. None of the EPAM models permits this. SAL is an EPAM II-like structure. It is concerned solely with stimulus learning. SAL is the only one of these models which incorporates stochastic processes to a major extent.

While the models differ from one another in their specific set of microprocesses, they all use the discrimination net as the primary form of memory organization. Taken together, the number of phenomena "explained" by these models is extraordinary. This in itself, supports the position that further examination of this type of model is warranted. There is a second reason for developing an EPAM-like model of free-association behavior. Namely, the simplest most straightforward position to take is that all verbal behavior phenomena can ultimately be explained with one theory or one IPM. And so, first models of free association behavior ought to try to fit into existing models of verbal behavior. Finally, it should be noted that EPAM can simulate internal mediated responses (q.v. Feigenbaum & Simon, 1963b) and both WEPAM and SAL III incorporate the use of multiple responses associated with a stimulus item. These processes may turn out to be necessary in models of free association behavior. Such models are presented in the next chapter.

CHAPTER III

In this chapter a family of related information processing models (IPMs) is described. These IPMs offer an approach to the cognitive processes within a respondant engaged in a typical continuous free association (C-F-A) task. There are two subdivisions to this chapter. In the first, the scope of the problem is discussed. This includes major assumptions characteristics of C-F-A behavior, and requirements of the models. The second division describes the models -- their structure and operation.

Scope of the Problem

As described in chapter 1 a C-F-A task requires that a subject (*S*) give a series of responses to a specified stimulus item. The stimulus item can be a word, nonsense syllable, dysyllable, etc. The usual requirements governing the responses are that the stimulus item cannot be given and no item can be given more than once. The task is completed when either a given number of responses is given or a set amount of time has elapsed. *E* usually records the actual responses and the number of responses given. He may also record the time intervals between all responses.

A final IPM of C-F-A behavior should produce associates to a stimulus item from a cognitive memory structure. To account for the response learning phase, the association phase, and the response giving phase a model must specify the operations which build and modify a memory, and identify procedures for the association and retrieval of responses from the memory.

In addition, the model should include deterministic procedures which hypothesize the mechanisms accounting for those variables found to be viable to an understanding of C-F-A behavior. The main variables to be included in a final model are those underlying response strength, response integration, response availability and response elicitation. For reasons given earlier, this first model is mainly concerned with item availability (I-AV).

The last part of chapter 2 describes the EPAM, WEPAM, and SAL models of verbal learning. Upon examination these models were found to be very general and highly heuristic. The discrimination net underlying the models and the procedures described for the modification of the net can be applied to a C-F-A model. To review briefly, these models posit operations which, at face value, seem to simulate or account for mediation and association of verbal units (through response cue codes); hierarchical associations (by means of the letters'-syllables'-pairs' portion of the EPAM III and WEPAM nets); and multiple responses associated with stimulus items (in WEPAM and SAL III). These operations are needed in a C-F-A model. It is therefore reasonable to base a first C-F-A model on the EPAM-type discrimination net memory.

There are two reasons why the EPAM-WEPAM-SAL models should not be directly employed as a complete C-F-A model. A major weakness in the verbal learning models is the lack of parallel processing. It is difficult to clearly define and separate serial and parallel operations (q.v. Minsky & Papert, 1969). The notion of parallel operations may seem to be in conflict with the character of general purpose machines which operate sequentially. The conflict is due to an erroneous identification of a machine

with its physical properties. Rather machines must be considered as a combination of hard and software. Though a machine moves through a program (IPM) sequentially, it is possible to simulate parallel operations by means of a hierarchical program structure (e.g. at a given time to process A then B then C, but treat that block of operations as if they occurred simultaneously).

Wynn's (1966) review of the area indicates that humans operate in a parallel mode for at least some of the cognitive processes -- including sensation, perception, attention and association. Of course the hierarchical organization of these processes may operate serially. While some IPMs attempt to include parallel processing (e.g. Reitman, Grove, & Shoup, 1964; Selfridge & Neisser, 1963) none of the IPMs previously described include them. This, "failure to provide for parallel processing in any respects is probably [their] most serious weakness" (Wynn, 1966, p. 210).

The second reason for not using the EPAM-type models as complete IPMs of C-F-A has to do with some important differences between verbal learning experiments and association experiments: (1) In verbal learning tasks the stimulus and responses must be learned and integrated as part of the task. An association experiment deals with the elicitation of previously learned and integrated verbal units. Thus, E can treat the S in a learning experiment as if he had a limited known memory; in C-F-A the S's memory is not limited as all his past learning can be used. Related to this is E's attempt to control the learning environment and stimuli in the former case while he is unable to control or even guess them in the latter case. (2) In verbal learning situations it is important to differentiate between correct and incorrect responses; while in free association the distinction is not applicable. (3) In the typical verbal learning study the S must give

one response to each stimulus. In C-F-A many responses are called for. (4) The time limit for responding is relatively short in a learning paradigm, while it is absent or much longer in the association paradigm.

A central assumption underlying any theory is consistency. This model of C-F-A behavior is no exception. For this model it is necessary to assume that the procedures which generate free associates for one individual are identical with the procedures operating within another individual. For this model this means that all individuals have a similar memory structure -- that of a generalized discrimination net. Observed differences between individuals engaged in C-F-A behavior must be attributed to differences in the content of the net, relationships among the components of the net, and different values of the various parameters or property sets attached to parts of the net. Once these idiosyncrasies have been determined for an individual it should be possible to treat his C-F-A behavior the same as that of other individuals. The corollary to this assumption is that the model is consistent within an individual over time. These assumptions are not particularly unreasonable and there should be little surprise that there is some related evidence supporting them (e.g. Jenkins, 1960; Cofer, 1958).

In sum there is a series of EPAM-type IPMs which can account for encoding-decoding behaviors; memory structure and growth; and those operations which associate stimulus and response items in a simulated learning experiment. This type of model must be modified to account for parallel processing, the essential characteristics of a C-F-A experiment, and the stable cognitive functions within a S engaged in a C-F-A experiment.

The next section of this chapter presents such a model. Because this model is a first attempt and because parts of the model will be simulated

by hand rather than by machine, certain simplifications are needed. Specifically, the model will be solely concerned with the retrieval of stored words from a generalized discrimination net. For the most part an EPAM-WEPAM-SAL type of model will be used to handle all parts of C-F-A other than response retrievals. The model can be thought of as being similar to a counterpart of the SAL IPMs which specify stimulus and association learning and assume response learning and integration. That is, the C-F-A model will be concerned with response retrieval while the earlier models will assume responsibility for stimulus and response learning, their association and basic net structure.

The adoption of the earlier models to handle these chores is not totally applicable. It is assumed (and not documented below) that they can be simply modified to (1) deal with natural language rather than nonsense syllables, and (2) generate values for variables -- such as I-AV -- needed by the model. Correspondingly, the model will have parallel operations described for the response retrieval phase only.

An IPM of C-F-A Behavior

The C-F-A model described in this section is exclusively concerned with the retrieval and evocation of responses to a stimulus object from a verbal memory. The model does not describe specifically how such a memory is built. It does, however, require that the memory be of a certain form. The organization of the discrimination net (memory) will be discussed first, and then the routines which control retrieval and evocation will be described. Table 4 lists the more frequent abbreviations used in the ensuing description.

Table 4. Summary of Abbreviations Used to Describe the C-F-A Model

Abbreviation	Description
CDT	Current Date-Time. Number of simulated time units from beginning of processing.
DT	Date-Time. Any specified simulated time period.
EN	Exit Number of responses. A parameter. If NR exceeds EN processing stops.
ET	Exit Time units. A parameter. If CDT exceeds ET processing stops.
IRT	InterResponse Time. One IRT is attached to each active list of responses. IRT counts elapsed DTS between responses from the same list (cf. Y).
MS	Memory Size. A parameter which specifies how many items can be put into short term memory.
NM	Number of Markers. NM equals the number of SMs plus the number of RMs active during the CDT.
NMM	Number of Markers Maximum. A parameter. If NM equals NMM no additional markers can be initiated.
NR	Number of Responses evoked.
PDS	Push Down Stack.
RM	Response Marker.
SM	Stimulus Marker.
STM	Short Term Memory. STM can only hold MS items. If additional item is added to the top of STM an item is dropped ("forgotten") from the bottom.
TM	Time Marker. TM tracks the processing in the Time Executive Routine.
V_i	A series of 3 parameters. They specify the increase in an item's I-AV due to different types of processing.
Y	A parameter. Whenever any IRT equals Y time units another response from the list associated with the IRT starts its processing.
θ_i	A series of 2 parameters. The θ's are thresholds against which the I-AV of responses are compared.

The discrimination net is quite similar to the nets presented in chapter 2. There are two divisions to the net: the letters' portion and the units' portion. The pairs' portion of the net is omitted because the C-F-A model represents S-R associations in the units' portion. The letters' portion is identical to that part of the EPAM III net -- consisting of attribute testing nodes, empty and filled terminals, and branches (including K8 and K9). The units' portion consists of attribute testing nodes, subobject nodes, and terminals. To that extent it is similar to the other nets. The major difference occurs at the terminals. If the only type of verbal unit stored in memory is an English word, then each word may occur many times throughout the net (as in WEPAM) but only once as a first item in a terminal. Terminals may contain (and usually will contain) more than one word. The first word in a terminal can be considered loosely as a stimulus word. All other words in the terminal may be thought of as cue codes for potential responses to the first word.

Words are stored in a terminal in a push down stack (PDS) similar to those in SAL. Most recent associates to the first word are higher in the stack than less recent associates. An example of a terminal in the units' portion of the net is given in Table 5. That terminal is described in an annotated form of IPL-V (Newell, et al., 1964) -- a programming language particularly suited for this type of model. The middle portion of table 5 contains the attached property set for the first object. The values in the property set are tested when the first object, DOG, is sorted through the net or is being used as a possible response. The response list in Table 5 indicates that DOG is associated with five possible responses. The responses are stored in a PDS of finite size. That is, the PDS simulates forgetting of an association from a long term memory. Whenever a more recent associate

Table 5. A Terminal in the Units' Part of the Discrimination Net-- An Example of Coding in IPL-V.

27		(name of terminal)	90	(attached property set)
	S15	(stimulus object DOG)		
	91	(attached response list)		
90		(property set)	0	
	D13	(what is mode of first object?)		
	V22	(it is printed.)		
	D63	(what is DT of first object?)		
	V69	(83 time units.)		
	D79	(what is I-AV of first object?)		
	V84	(22)		
	D91	(how many time units are in IRT for response list associated with first object?)		
	V92	(IRT has not yet been set for this response list.)		
91		(response list)	92	(attached use list)
	R13	(cue code of most recent response, CAT)		
	R17	(cue code of next most recent response, PUPPY)		
	R13	(cue code of next response, CAT)		
	R94	(cue code of next response, ANIMAL)		
	R29	(cue code of least recent response, HORSE)		
92		(use list)	0	
	U13	(has R13 been used as a response?)		
	D2	(no.)		
	U17	(has R17 been used as a response?)		
	D2	(no.)		
	U13	(has R13 been used as a response?)		
	D2	(no.)		
	U94	(has R94 been used as a response?)		
	D2	(no.)		
	U29	(has R29 been used as a response?)		
	D2	(no.)		

to the first object is learned and added to the top of the response list (i.e. where CAT is now) all lower items are pushed down one space, and if all spaces were taken in the PDS, the lease recent response would be pushed off of the bottom and lost.

In order for a word to be recognized in the memory its coded form must be sorted through the net until it reaches a terminal with a first object. (It is plausible to assume that sorting occurs with few errors because responses given in C-F-A experiments are highly learned and well integrated). If the word being sorted is a stimulus word then the terminal reached may contain cue codes for possible responses to that stimulus. In Table 5 R13 represents a cue code for a possible response to stimulus word DOG. In order for the cue code to be recognized, it is sorted through the net until it reaches a terminal containing CAT as the first object. The use of cue codes in C-F-A is much closer to the cue codes of EPAM II than the cue tokens of EPAM III because they do not name a terminal -- rather they must be sorted through the net.

Thus, every word is stored in a terminal as a first object. A stimulus word and a response word must find their first objects if they are to be recognized. If a stimulus is sorted to the proper terminal, then the cue codes stored at that terminal become available as possible responses. Many words are also stored in the response lists of different terminals in the form of cue codes.

When sorting an object through the net it is necessary to distinguish between potential stimuli and potential responses. Both are being sorted to a terminal whose first image (hopefully) matches the coded object. Once recognized, however, the two kinds of objects are treated differently. Potential stimuli will not have the opportunity of being evoked as responses;

they initiate their response list as a time-ordered set of potential responses. Potential responses, when recognized, are immediately processed in the response giving phase of C-F-A. In order to identify objects being sorted through the net, an SM is used to mark the position of a potential stimulus and an RM is used to mark the position of a potential response.

At this time, the processing of the C-F-A model is controlled by six routines. Figure 19 shows the relationships among these routines. It may be helpful to consider the C-F-A model as a type of board game with three different kinds of markers ("men") moving around the board. There is one TM which keeps track of the Time Executive Routine. The TM only moves within this routine. There are zero or more SMs and RMs subject to the constraint that the number of SMs plus the number of RMs cannot be greater than NMM. SMs keep track of potential stimuli and RMs follow the processing of potential responses. SMs and RMs move about through all six routines.

Generally speaking, the C-F-A model takes an encoded stimulus object and sorts it to a terminal where it is compared with the first object for recognition. Upon recognition, the associated words in that terminal are all popped out -- most recent first. A specific number of time units, Y, must elapse between the emission of consecutive potential responses from each response list. Each potential response emitted is a cue code which must be sorted through the net until recognized. When it is recognized the property set attached to that terminal is examined to see if the response's I-AV is sufficient for a response to be evoked. Evocation depends upon I-AV elapsed time, the contents of STM, the values of the thresholds (θ_i), and other factors. Some potential responses which cannot be evoked are "strong"

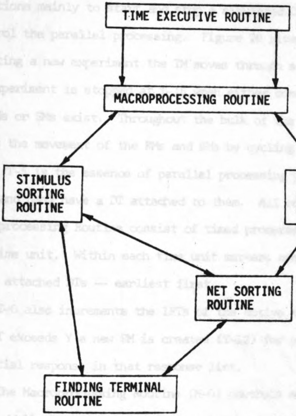


Figure 19. Interrelations Among Routines in C-F-A.

enough to be treated as mediated stimuli starting the entire process over again. That is, while there is only one nominal stimulus in an experiment, it is likely that there will be several functional stimuli.

The Time Executive Routine (T-0) controls all other routines and functions mainly to start and stop a simulated C-F-A experiment and control the parallel processing. Figure 20 gives the flowchart of T-0. Starting a new experiment the TM moves through steps T-1, T-2, and T-3. An experiment is stopped at T-16 when either condition in T-7 is met or no RMs or SMs exist. Throughout the bulk of the experiment, the TM controls the movement of the RMs and SMs by cycling through T-4, T-5 and T-6. T-5 is the essence of parallel processing in C-F-A. All markers (RMs and SMs) have a DT attached to them. All routines except T-0 and the Macroprocessing Routine consist of timed processes. T-5 moves all markers one time unit. Within each time unit markers are moved in the order of their attached DTs -- earliest first.

T-0 also increments the IRTs of the active response lists. Whenever an IRT exceeds Y a new RM is created (T-12) for processing the next unused potential response in that response list.

The Macroprocessing Routine (M-0) controls all other routines (except T-0). While both M-0 and T-0 control all of the timed routines it was desirable and necessary to separate this control into two routines. It was desirable to have one routine dealing solely with parallel processing. It was necessary to separate the routines as they are hierarchically organized: no marker leaving T-0 (at T-3 and T-13) ever returns to T-0. This makes it impossible to construct T-0 and M-0 as one routine.

M-0 links the Stimulus Sorting Routine and the Response Giving Routine It also counts the number of responses given in the experiment. Figure 21 gives a flowchart of M-0.

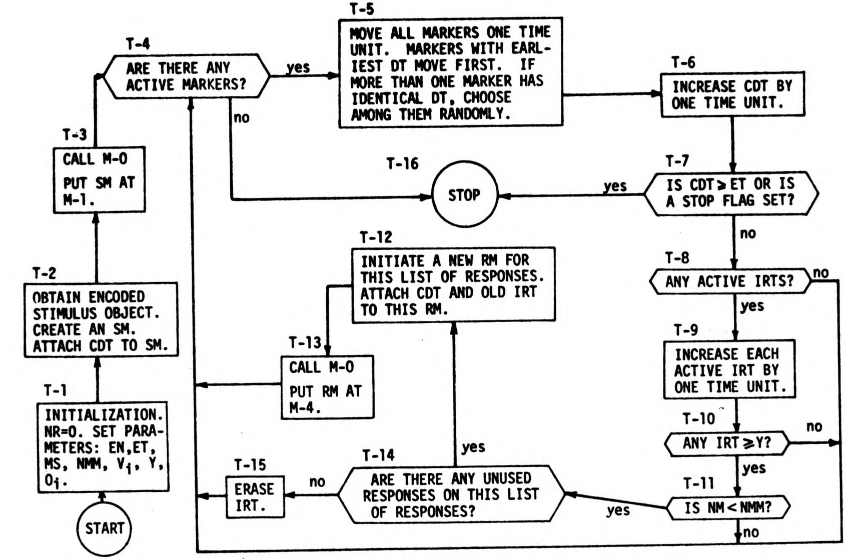


Figure 20. Flowchart of Time Executive Routine of C-F-A.

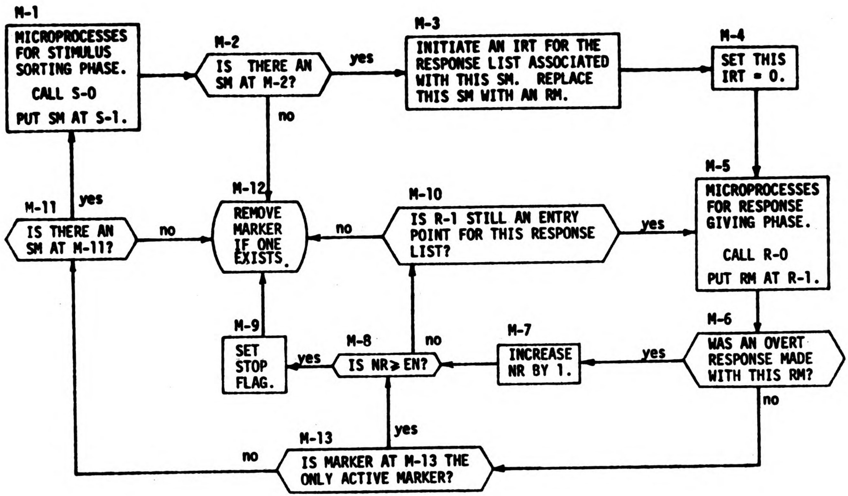


Figure 21. Flowchart of Macroprocessing Routine of C-F-A.

The other four routines of C-F-A contain timed processes. In constructing the model it was necessary to decide upon the number of time units each process should take. The following arbitrary, but reasonable rules were followed. (1) Exits from routines and calls to other routines take no time as they serve as links between processes. (2) Decisions, in general, take more time than simple processes. (3) Highly practiced processing should occur faster than less frequently practiced processing. Net sorting should be a major component of all uses of a verbal memory while giving free associates is only one use of this memory. Therefore, the Net Sorting Routine should process markers much faster than the other timed routines. Figures 22-25 outline the timed processes. The number of time units required for processing is indicated at the lower right corner of each component in those Figures. In order for a particular component to be processed, all time units for that component must be completed.

Figure 22 gives the flowchart of the Stimulus Sorting Routine (S-O). It is a simple routine designed to find the terminal whose first image matches the encoded stimulus object provided that the terminal contains at least one item in its response list. Since the goal of a C-F-A experiment is to give responses to stimuli, it is of little use to recognize a stimulus object which has no associated responses. Exactly how a terminal could be constructed which contains a first image but no associated response list is beyond this model. One possibility is that processing time "ran out" when the terminal was constructed.

The Response Giving Routine (R-O) is outlined in Figure 23. When an RM is sorted to a terminal (i.e. a response is recognized) the I-AV of the response (first image) found in the property set attached to the terminal

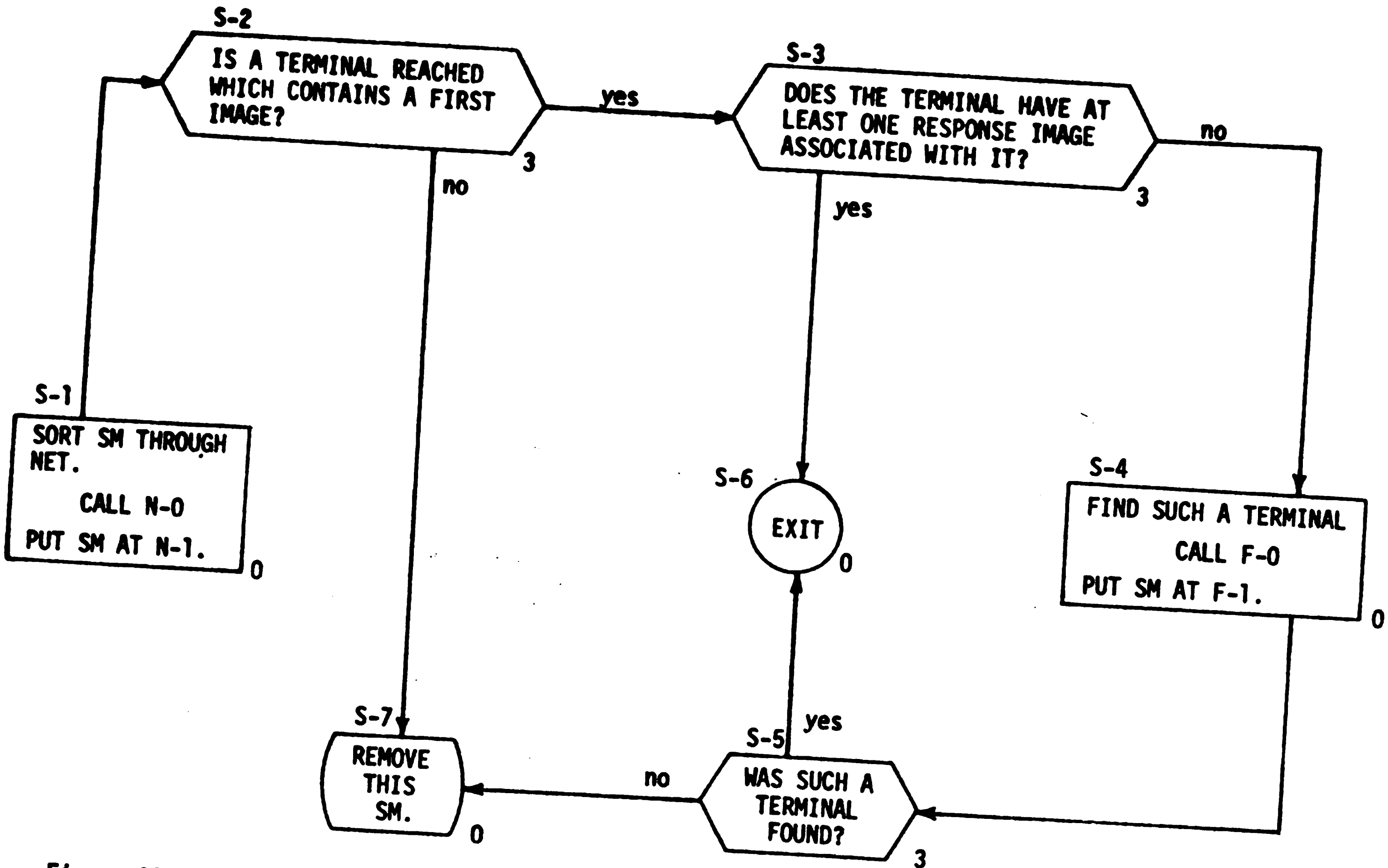


Figure 22. Flowchart of Stimulus Sorting Routine of C-F-A.

is decreased (q.v. R-8). In actuality it makes sense to consider the I-AVs of all first items decreasing at each new CDT. In practice it is easier to remember when the value of I-AV for a particular first item was last changed (its DT -- see Table 5), and decrease the I-AV according to the ratio DT/CDT. This is the procedure used in the ARGUS model of thinking (Reitman, 1965; Reitman, Grove & Shoup, 1964).

Once computed the new I-AV is compared against a series of thresholds, θ_i. While there does not seem to be any direct evidence about this, it seems reasonable that a greater I-AV is needed for an overt response than for an internal ("unconscious") mediated response. θ_1 is the threshold parameter of I-AV which must be at least equalled if an overt response is to be given. Similarly, this model assumes that an internal response will occur only with an I-AV of sufficient strength (at least equal to θ_2). Responses greater than or equal to θ_1 will be evoked if the response is neither identical with the stimulus word nor given earlier as a response. Both of these requirements are conditions of a typical C-F-A experiment. A person, however, does not always remember the words he has already given as response. In the C-F-A model the STM which holds the responses given is a PDS of finite length. Thus, it is possible for the same response to be given more than once.

Before continuing the description of the C-F-A model it is interesting to compare the methods used in WEPAM and C-F-A for choosing among possible responses in a response list. Both models have an ordered list of possible response. They are ordered so that items at the top of the list are examined first. In WEPAM associated with each item in the list is an error marker indicating whether or not that particular response had been given in error previously. WEPAM produces as a response the first item

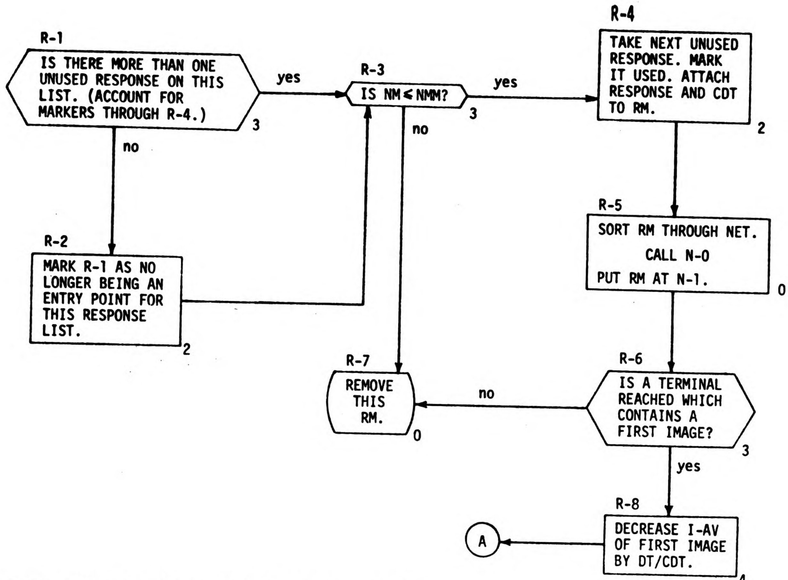


Figure 23. Flowchart of Response Giving Routine of C-F-A.

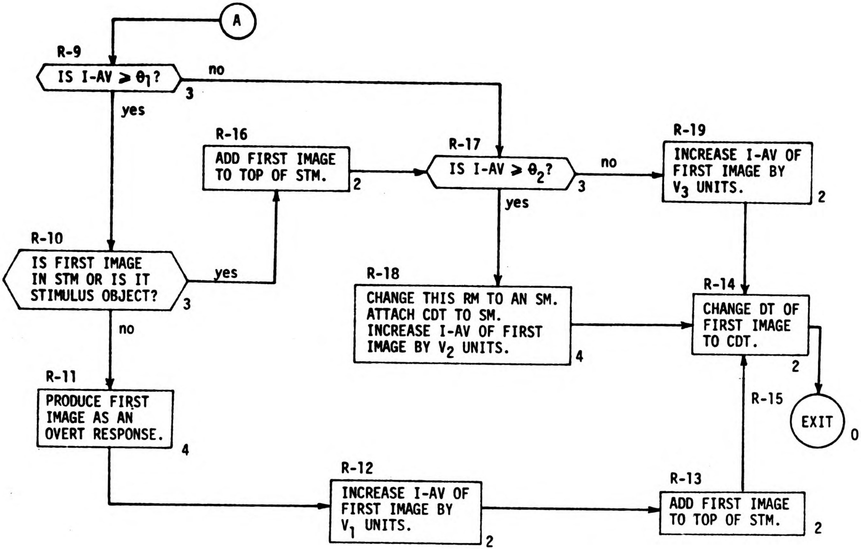


Figure 23. Flowchart of Response Giving Routine of C-F-A (continued).

in the list not previously given in error. In C-F-A all items in the response list are first of all discriminated (since criteria for evaluating them as possible responses cannot be considered until the responses are recognized) and then the corresponding RMs are moved through R-0 to see if they meet the necessary requirements for evocation. Responses are popped up from a response list under the control of its IRT (q.v. T-12). Exactly which response in the list should be popped up is controlled by marking those responses already used (R-4). This mark is stored in the terminal in the use list. This marking of used responses corresponds directly with WEPAM's error marks.

Potential responses can be either candidates for evocation, mediated response, or merely processed responses (whenever I-AV is less than θ_2). The I-AV of each of these potential responses is raised according to V_i before the RM leaves R-0 (see R-12, R-18, R-19). The I-AVs of responses which are candidates for evocation are raised more than the I-AVs of mediated responses, which, in turn, are raised more than the I-AVs of processed responses. The work of Horowitz and his associates (1964, 1966) strongly supports this ordered raising of the I-AVs.

The Net Sorting Routine (N-0) is presented in Figure 24. Understanding N-0 is rather straightforward. First of all, it identifies the location of a marker and then it takes appropriate action. The recursive nature of this routine is evident at N-16 where the routine uses itself to discriminate the letters of a word. It should be noted that the time units needed for processing in N-0 are given in tenths of time units.

Figure 25 outlines the Finding Terminal Routine (F-0). F-0 is called on two occasions: when N-0 sorts a marker to an empty terminal and when S-0 finds a terminal with no associated response list. In a C-F-A experiment

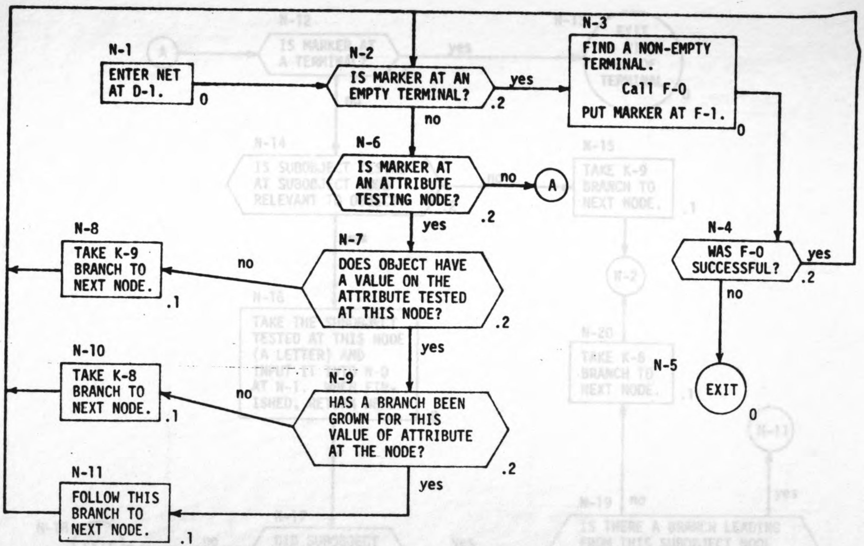


Figure 24. Flowchart of Net Sorting Routine of C-F-A.

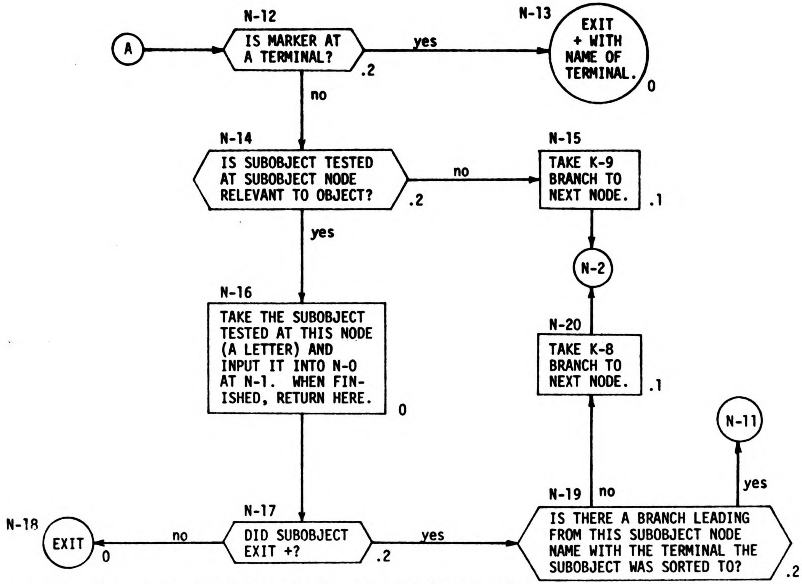


Figure 24. Flowchart of Net Sorting Routine of C-F-A (continued).

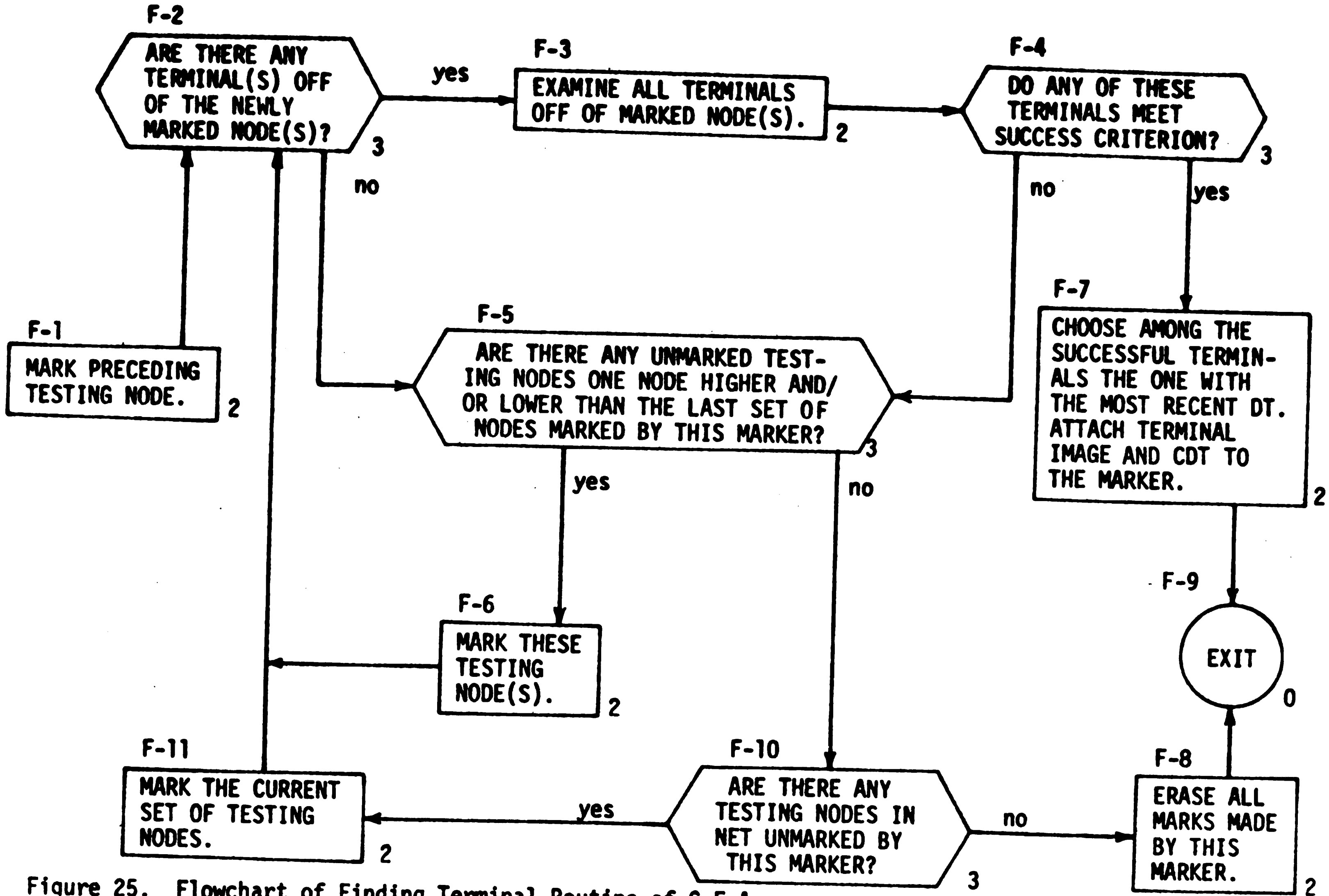


Figure 25. Flowchart of Finding Terminal Routine of C-F-A.

empty terminals do not make sense as they do in a verbal learning study. In learning studies an empty terminal (due to inadequate learning) produces no response on a given trial. In a C-F-A situation the notion of trials is irrelevant and responses are usually given (perhaps because there is not a short time limit on response giving). Secondly, stimulus items with no associated responses are of little use in C-F-A. In these two circumstances F-0 attempts to find a successful terminal by choosing among terminals close to the non-successful terminal.

This then is the basic C-F-A model. It consists of six related routines: time executive, macroprocessing, stimulus sorting, response giving, net sorting, and terminal finding. For reasons noted in the previous chapter a family of related IPMs is desirable. Major extensions of the C-F-A model are described in chapter 5. Outlined below are possible minor extensions of the basic model -- all of which constitute the family of IPMs.

Obviously, the first route to be taken is to change the values of the various parameters. It seems reasonable that various judicious choices of the parameters will cause the model to behave differently: perhaps to such an extreme difference that the model could be considered to have changed in kind. Sensitivity testing as described in chapter 2 is the method to be taken to explore these models.

Other models in the family could include one or more of the following: (1) Include with each letter terminal in the discrimination net some measure of its I-AV and use these values to adjust the recognition of letters. This alternative, however, does not seem to be too worthwhile since the high frequency of exposure to letters (as compared with words) should tend to raise their I-AV over any reasonable thresholds

(q.v. Cofer, 1961). (2) Have the response list PDS function similar to those in SAL III wherein over time the items in the stacks rise, losing newer items because of short term memory. (3) Have the net built on pronunciation rather than printing. Use of the oral-Aural mode implies a phoneme-units division of the net. In this case, I-AV for each phoneme might be useful. (4) Change R-O eliminating the need for θ_2. This means that all RMs marking responses whose I-AVs are not greater than or equal to θ_1 will be converted to SMs. This should greatly increase the activity of markers throughout the experiment.

Summary

This chapter specified some of the requirements of a general C-F-A model. Some of these requirements stemmed from basic needs of most IPMs of cognitive processes -- such a parallel processing, and some requirements arose from the differences between verbal learning and C-F-A experimental situations. The model described takes as input a coded stimulus word and sorts it through a completed discrimination net to a terminal. Associated responses in that terminal are popped-up one at a time, sorted through the net for recognition and then tested for possible evocation. Recognized responses can be treated in one of three ways: (1) they can be evoked; (2) they can be treated as internal stimulus objects; or (3) they can be considered for either of the above -- but neither occurs. The choice among these possibilities depends in the main on the relative location of a response in its response list, its DT, and its I-AV. The last two of these are values attached to each first item in a terminal. Other characteristics of the model include a parallel processing routine

(T-O) and an error correcting routine (F-O) which finds "successful" terminals. The chapter also briefly mentions some possible other members of the family of C-F-A models.

Before the model can be critically appraised its functioning needs to be tested. Chapter 4 gives it one of the necessary tests.

CHAPTER IV

This chapter describes a contrived experimental situation including a simplified simulated S who operates according to the rules of the C-F-A model presented in the previous chapter. In actuality the C-F-A model operates on a hypothetical verbal memory under set parametric conditions. The states of the system at various times (DTs) throughout the simulation are outlined. The first part of this chapter discusses the problems involved in simulating the experiment with the C-F-A model. The remainder of the chapter describes the simulation itself.

Problems of the Simulation

Two problems with this simulation make its value less than what could be theoretically desired. First there is the problem of the verbal memory. The C-F-A model does not, at this time, build one. Since one is needed to test the model it must be obtained from other sources. A primary alternative would normally be either tabled listing of stimulus words and their response lists (such as Deese, 1965), or the responses given by real Ss in a real C-F-A experiment.

Both of these procedures, however, implicitly assume that the responses evoked by Ss in a C-F-A experiment are identical with the internal response lists -- not in format or coding, but in terms of the actual words and their order in the response list. There are several reasons to

believe the assumption to be false. For example, the directions given the S may stipulate that no response may be given more than once. If the assumption were true then the internal response lists in the S's verbal memory would not contain any word more than once. Also, the work on item availability (I-AV) and response strength indicates that only highly available and strongly associated items in a response list will be evoked rather than all of the items. Thirdly, Jung (1966) declares that the actual responses given in word association tests depend to a large extent upon non-associative factors such as subject set.

Since the C-F-A model does not build a verbal memory and since little faith can be placed in the results of C-F-A experiments, this simulation will use an *ad hoc* hypothetical memory. This should cause little concern as the purpose of this simulation is not to test all levels of validity (q.v. Hermann, 1967) but to test the lowest levels. The primary object here is to see if the model evokes any responses.

The second problem with this simulation is the fact that hand rather than computer techniques will be used. Simulating even a simple model by hand is arduous, and the difficulty is greatly increased when the model functions in a parallel mode. With a computer, many simulations can be easily run with different initial conditions of the memory and of the parameters. This would allow for a fuller range of validity testing. For this reason, the simulation should not be considered to be a formal test of the C-F-A model (cf. Feigenbaum, 1959, p. 85).

A proper question at this time would ask what the results of a "good" or "validating" simulation should look like. For all of the reasons noted earlier, this simulation can be judged a success if paramountly (1) nontrivial responses are evoked from the model after being presented with a

stimulus word, and, to a lesser extent, (2) if the model and the responses manifest face validity in terms of the theories and research known in this area. The second of these conditions will be taken up in the next chapter. The first of the conditions is considered below.

A Simulation of the C-F-A Model

The hypothetical discrimination net is shown in Figure 26 and the identification of the attribute testing nodes in the letters' part of the net is given in Table 6. The net is similar to those generated by EPAM III (with the exception of the pairs' portion). For simplicity, attribute testing nodes in the units' portion are minimal; limited here to D-2. Also, it should be clear that empty terminals and branches not relevant to this simulation have been omitted from Figure 26. The K8 and K9 branches are used here in the same manner as in EPAM III and WEPAM: K8 is taken when the value found does not as yet have a branch grown from the node, K9 is taken when the dimension tested at the node is irrelevant to the object.

The terminals in the units' part of the net only show their first objects. The sixteen first objects and their associated response lists are shown in Table 7. Again it must be remembered that this organization of words is not claimed to be necessarily realistic. All simulations of cognitive processing of verbal materials have physical limitations on the size of their memories. These sizes, though they differ, are all considerably smaller than the most conservative estimates of the size of the human verbal memory. If a small subset of a human memory were obtainable, it is reasonable to expect to find some words appearing as both first objects

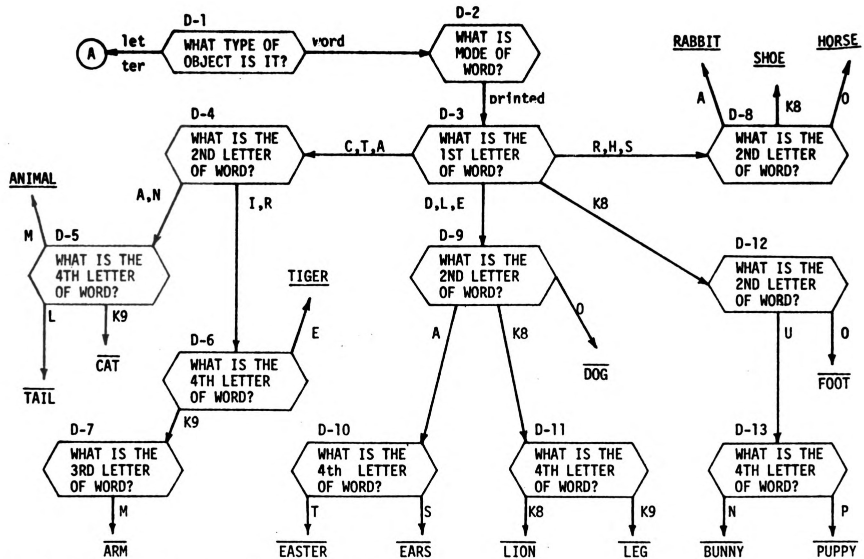


Figure 26. Discrimination Net Used in Example.

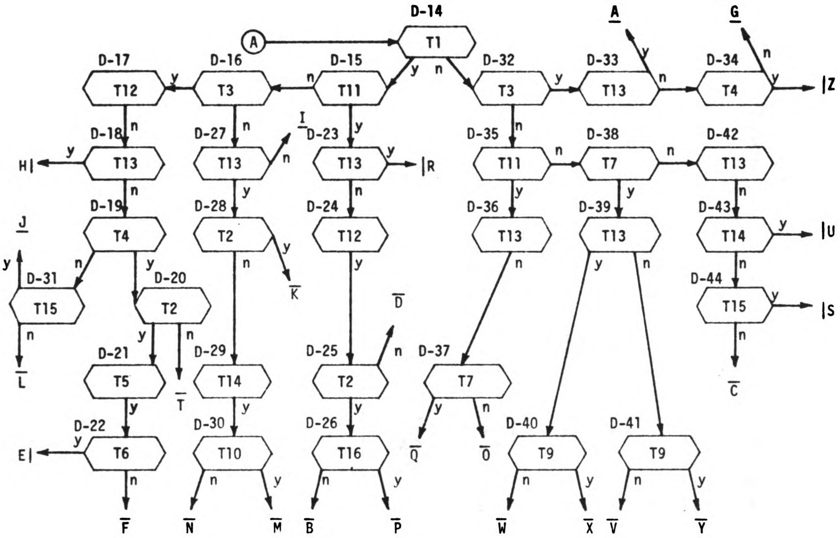


Figure 26. Discrimination Net Used in Example (continued).

Table 6. Identification of Attribute Testing Nodes in Letters' Part of Net.

Node Type	Test
T1	Vertical Line?
T2	Vertical midpoint?
T3	Horizontal line?
T4	Horizontal top?
T5	Horizontal middle?
T6	Horizontal bottom?
T7	Straight line?
T8	Diagonal line?
T9	Diagonal midpoint?
T10	Diagonal down from right?
T11	Enclosed space?
T12	Curved line?
T13	Concavity below?
T14	Concavity above?
T15	Open to the left?
T16	Open below?

Table 7. Organization of Hypothetical Memory.

ANIMAL

dog
cat
horse
rabbit
lion

ARM

BUNNY

rabbit

CAT

tiger
dog
animal

DOG

cat
puppy
cat
animal
horse

EARS

rabbit

EASTER

FOOT

leg
arm
shoe

HORSE

animal

LEG

LION

tiger
tiger
animal

PUPPY

dog
dog
dog

RABBIT

bunny
easter
tail
ears
foot

SHOE

TAIL

dog
tiger
animal
animal

TIGER

lion
animal
lion
cat

and in response lists. Also some words would be found which appear in either the first position or in the response list. In the sense of preceeding lines, the hypothetical memory used in this simulation does not seem to be troublesome. Parenthetically, it should be pointed out that the associative principle of frequency is represented directly in this verbal memory (e.g. see PUPPY).

Throughout the simulation, words will have to be frequently recognized by sorting them (in actuality, their markers) through the discrimination net under the control of the Net Sorting Routine, N-0. This is a complex operation to follow, and as it is serially connected to the other aspects of the simulation it would be helpful to run this sub-simulation separately. The results of this sub-simulation will be directly incorporated into the full simulation.

Table 8 outlines the sub-simulation for the discrimination of the word LEG. It starts with a marker at D-1 and a marker (RM or SM) at N-1. Under the control of N-0, the marker in the net is sorted to the L and E terminals in the letters' portion and ultimately to the LEG terminal in the units' portion. The number of time units needed to recognize LEG is 23.3 time units. In terms of the rest of the C-F-A routines 24 time units will elapse from the calling of N-0 to the exit from N-0. Table 9 gives the results of discriminating the other 15 first objects in memory.

The other initial conditions which must be specified are the values of the parameters and the values of the dimensions stored in the property set attached to each terminal (q.v. Table 5). Table 10 gives the values of the parameters. According to these values the simulation will end when either five responses are given or 1000 time units have elapsed. The capacity of the short term memory is seven words. This effectively prevents

Table 8. An Example of C-F-A Item Recognition for LEG

Movement of Marker in Net Sorting Routine	Position of Marker in Discrimination Net at End of Time Period	Elapsed Time (in tenths of time units)	Notes
	D-1	0	
N-1, N-2, N-6, N-7 N-9, N-11.	D-2	9	
N-2, N-6, N-7, N-9 N-11.	D-3	18	
N-2, N-6, N-12, N-14, N-16.	D-3	26	Begin discrimination of first letter of item.
N-1, N-2, N-6, N-7, N-9, N-11.	D-14	35	All testing nodes in Letters' part of net are attribute testing nodes.
N-2, N-6, N-7, N-9 N-11. (repeated 7 times)	D-15, D-16, D-17, D-18, D-19, D-31, "L"	98	
N-2, N-6, N-12, N-13	D-3	104	
N-17, N-19, N-11, N-2, N-6, N-12, N-14, N-16.	D-9	117	Begin discrimination of second letter of item.
N-1, N-2, N-6, N-7, N-9, N-11.	D-14	126	
N-2, N-6, N-7, N-9, N-11. (repeated 9 times)	D-15, D-16, D-17, D-18, D-19, D-20, D-21, D-22, "E"	207	
N-2, N-6, N-12, N-13.	D-9	213	
N-17, N-19, N-20.	D-11	218	Since there is no branch for an "E" K8 is taken.
N-2, N-6, N-12, N-14, N-15.	"LEG"	227	Since there is no fourth letter in "LEG", K9 is taken.
N-2, N-6, N-12, N-13.	------	233	

Table 9. Time Units Required to Recognize All Items in Hypothetical Memory

Items	Time Units
ANIMAL	27
ARM	24
BUNNY	28
CAT	18
DOG	18
EARS	28
EASTER	28
FOOT	21
HORSE	17
LEG	24
LION	27
PUPPY	27
RABBIT	14
SHOE	19
TAIL	27
TIGER	29

Table 10. Value of Parameters for Simulation

Parameters	Value
EN	5
ET	1000
MS	7
NMM	7
V_1	I-AV + .5(100-I-AV)
V_2	I-AV + .25(100-I-AV)
V_3	I-AV + .1(100-I-AV)
Y	25
θ_1	25
θ_2	10

STM from playing any major role in this simulation as EN is less than MS (see Table 4 for a list of abbreviations). The maximum total number of markers (SMs plus RMs) which can be active at any DT is seven.

The possible values of I-AV range from 0-100. The I-AV of a word is raised during processing to V_i where the value of $\underline{i}$ depends upon what happened to the RM. The most a word's I-AV can be raised is to decrease its difference from 100 by 50%. The least it can be raised is by 10% of its distance from the maximum.

The value of Y specifies that an IRT equal to 25 will cause a new RM to be initiated for the next unused response on that response list. This occurs, of course, when contraindications are not present.

Finally, the chosen values of theta mean that a word will be considered as a possible candidate for evocation if its I-AV is greater than or equal to 25. If a word's I-AV is less than that but at least 10 its RM will be changed to an SM.

Because the C-F-A models does not produce a memory, it does not build up values for each word's I-AV and DT (last date-time the I-AV was changed). This simulation starts at CDT equal to 201. The first 200 time units were required to actually build the verbal memory. It is not known at this time if that amount of time is reasonable. The first two columns of Table 11 give the initial values of each word's I-AV and DT. They were chosen randomly as no other information is available.

Table 12 presents the simulation. It traces all major CDTs from 201 to 541 when the simulation ends because five responses were given to the stimulus word ANIMAL. The Table is set up so the movement of the markers can be followed. It would be impossible to describe what happened in the simulation with a non-tabular format. As an overview of the simulation,

Table 11. I-AV and DT of First Items in Memory.

Item	At the Beginning of the Simulation.		At the End of the Simulation.	
	I-AV*	DT**	I-AV	DT
ANIMAL	13	134	14	500
ARM	76	1	76	1
BUNNY	46	77	17	417
CAT	53	173	66	306
DOG	22	83	16	274
EARS	4	138	11	493
EASTER	68	118	39	445
FOOT	88	187	66	519
HORSE	94	170	75	331
LEG	38	105	38	105
LION	52	82	44	538
PUPPY	83	131	83	131
RABBIT	77	73	62	539
SHOE	3	83	3	83
TAIL	5	140	12	467
TIGER	53	182	70	481

*Choosen randomly with replacement from 1-100.
**Choosen randomly with replacement from 1-200.

Table 12. An Outline of C-F-A Response Giving

End of CDT	Marker	Position of Marker*	Notes**
201		T-1	Initialization completed.
		T-2	Stimulus object ANIMAL obtained.
202	M1		M1 created. CDT attached to M1. M1 is
		N-2#1	an SM. Looking for ANIMAL terminal.
228	M1	S-2#1	ANIMAL recognized.
234	M1	R-1#1	Change M1 to an RM. Initialize IRT=0 for response list associated with ANIMAL
241	M1	R-4#2	M1 marks DOG. Mark DOG under ANIMAL as used. Update M1.
242	M1	N-2#1	Looking for DOG terminal.
259	M1	R-6#1	DOG recognized.
	M2	M-4	IRT for ANIMAL met. Initiate a new RM. Set IRT=0. Attach CDT to RM.
264	M1	R-8#4	I-AV for DOG = 22 (83/264)=7.
	M2	R-3#3	
266	M1	R-9#2	
	M2	R-4#2	Mark CAT under ANIMAL as used. Update M2. M2 marks CAT.
267	M1	R-9#3	I-AV of DOG = 7 is not $\geq \theta_1$.
	M2	N-2#1	Looking for CAT terminal.
270	M1	R-17#3	I-AV of DOG = 7 is not $\geq \theta_2$.
272	M1	R-19#2	I-AV of DOG increased by V_3 = 16.
274	M1	R-14#2	DT of DOG updated.
275	M1	M-12	M1 removed.
284	M2	R-6#1	CAT recognized.
	M3	M-4	IRT for ANIMAL met. Initiate a new RM. Set IRT=0. Attach CDT to RM.
290	M2	R-8#4	I-AV for CAT = 53 (173/290) = 32.
	M3	R-3#3	
292	M2	R-9#2	
	M3	R-4#2	Mark HORSE under ANIMAL as used. Update M3. M3 marks HORSE.
293	M2	R-9#3	I-AV of CAT = 32 is $\geq \theta_1$.
	M3	N-2#1	Looking for HORSE terminal.
300	M2	R-11#4	CAT evoked as a response.
302	M2	R-12#2	I-AV of CAT increased by V_1 = 66.
304	M2	R-13#2	CAT added to top of STM.
306	M2	R-14#2	DT of CAT updated.

*The first letter indicates the routine; the second item marks the subcomponent of that routine; the third item, if it exists, specifies the number of time units the marker has been in that subcomponent.

**Notes are only given when interesting. Whenever a marker enters the NET Sorting Routine, its position is not followed until it exists.

Table 12. (continued)

End of CDT	Marker	Position of Marker	Notes
307	M2	M-7	NR=1
		R-1#1	Since R-1 is still an entry point for ANIMAL stimulus.
309	M2	R-1#3	
	M3	R-6#1	HORSE recognized.
	M4	M-4	IRT for ANIMAL met. Initiate a new RM. Set IRT=0. Attach CDT to RM.
314	M2	R-4#2	Mark RABBIT under ANIMAL as used. Update M2. M2 marks RABBIT.
	M3	R-8#3	
	M4	R-2#2	Mark R-1 as no longer an entry point for ANIMAL stimulus.
315	M2	N-2#1	Looking for RABBIT terminal.
	M3	R-8#4	I-AV for HORSE = 94 (170/315) = 51.
	M4	R-3#1	
318	M3	R-9#3	I-AV of HORSE = 51 is $\geq \theta_1$.
	M4	R-4#1	
319	M3	R-10#1	
	M4	R-4#2	Mark LION under ANIMAL as used. Update M4. M4 marks LION.
320	M3	R-10#2	
	M4	N-2#1	Looking for LION terminal.
325	M3	R-11#4	HORSE evoked as a response.
327	M3	R-12#2	I-AV of HORSE increased by V_1 = 75
328	M2	R-6#1	RABBIT recognized.
	M3	R-13#1	
329	M2	R-6#2	
	M3	R-13#2	HORSE added to top of STM.
331	M2	R-8#1	
	M3	R-14#2	DT of HORSE updated.
332	M2	R-8#2	
	M3	M-7	NR=2.
		M-12	M3 removed as R-1 is not an entry point for ANIMAL stimulus.
334	M2	R-8#4	I-AV for RABBIT = 77 (73/334) = 17.
	—	T-12	IRT for ANIMAL met. No unused responses. IRT dropped.
337	M2	R-9#3	I-AV of RABBIT = 17 is not $\geq \theta_1$.
340	M2	R-17#3	I-AV of RABBIT = 17 is $\geq \theta_2$.
344	M2	R-18#4	M2 is changed to an SM. M2 is updated. I-AV of RABBIT increased by V_2 = 38.
346	M2	R-14#2	DT of RABBIT updated.
	M4	R-6#1	LION recognized.

Table 12. (continued)

End of CDT	Marker	Position of Marker	Notes
347	M2	N-2#1	Looking for RABBIT terminal.
	M4	R-6#2	
352	M4	R-8#4	I-AV for LION = 52 (82/352) = 12.
355	M4	R-9#3	I-AV of LION = 12 is not $\geq \theta_1$.
358	M4	R-17#3	I-AV of LION = 12 is $\geq \theta_2$.
360	M2	S-2#1	RABBIT recognized.
	M4	R-18#2	
362	M2	S-2#3	
	M4	R-18#4	M4 is changed to an SM. M4 is updated. I-AV of LION increased by V_2 = 34.
364	M2	S-3#2	
	M4	R-14#2	DT of LION updated.
365	M2	S-3#3	RABBIT as a stimulus has responses.
	M4	N-2#1	Looking for LION terminal.
366	M2	R-1#1	M2 is changed to an RM. Initiate IRT=0 for response list associated with RABBIT.
373	M2	R-4#2	Mark BUNNY under RABBIT as used. Update M2. M2 marks BUNNY.
374	M2	N-2#1	Looking for BUNNY terminal.
391	M4	S-2#1	LION recognized.
	M5	M-4	IRT for RABBIT met. Initiate a new RM. Set IRT = 0. Attach CDT to RM.
396	M4	S-3#3	LION as a stimulus has responses.
	M5	R-3#2	
397	M4	R-1#1	M4 is changed to an RM. Initiate IRT=0 for response list associated with LION.
399	M4	R-1#3	
	M5	R-4#2	Mark EASTER under RABBIT as used. Update M5. M5 marks EASTER.
400	M4	R-3#1	
	M5	N-2#1	Looking for EASTER terminal.
401	M2	R-6#1	BUNNY recognized.
	M4	R-3#2	
404	M2	R-8#1	
	M4	R-4#2	Mark TIGER under LION as used. Update M4. M4 marks TIGER.
405	M2	R-8#2	
	M4	N-2#1	Looking for TIGER terminal.
407	M2	R-8#4	I-AV for BUNNY = 46(77/407) = 8.
415	M2	R-19#2	I-AV of BUNNY increased by V_3 = 17.
416	M2	R-14#1	
	M6	M-4	IRT for RABBIT met. Initiate a new RM. Set IRT = 0. Attach CDT to RM.
417	M2	R-14#2	DT of BUNNY updated.
	M6	R-1#1	

Table 12. (continued)

End of CDT	Marker	Position of Marker	Notes
418	M2	M-12	M2 removed.
	M6	R-1#2	
422	M6	R-3#3	
	M7	M-4	IRT for LION met. Initiate a new RM. Set IRT = 0. Attach CDT to RM.
424	M6	R-4#2	Mark TAIL under RABBIT as used. Update M6. M6 marks TAIL.
	M7	R-1#2	
425	M6	N-2#1	Looking for TAIL terminal.
	M7	R-1#2	
427	M5	R-6#1	EASTER recognized.
	M7	R-3#2	
430	M5	R-8#1	
	M7	R-4#2	Mark TIGER under LION as used. Update M7. M7 marks TIGER.
431	M5	R-8#2	
	M7	N-2#1	Looking for TIGER terminal.
433	M4	R-6#1	TIGER recognized.
	M5	R-8#4	I-AV for EASTER = 68(118/433) = 19.
436	M4	R-8#1	
	M5	R-9#3	I-AV of EASTER = 19 is not $\geq \theta_1$.
439	M4	R-8#4	I-AV for TIGER = 53(182/439) = 22.
	M5	R-17#3	I-AV of EASTER = 19 is $> \theta_2$.
441	M1	M-4	IRT for RABBIT met. Initiate an RM. Set IRT = 0. Attach CDT to RM.
	M4	R-9#2	
	M5	R-18#1	
442	M1	R-1#1	
	M4	R-9#3	I-AV of TIGER = 22 is not $\geq \theta_1$.
	M5	R-18#3	
443	M1	R-1#2	
	M4	R-17#1	
	M5	R-18#4	M5 is changed to an SM. M5 is updated. I-AV of EASTER is increased by V_2 = 39.
445	M1	R-3#1	
	M4	R-17#3	I-AV of TIGER = 22 is $\geq \theta_2$.
	M5	R-14#2	DT of EASTER updated.
446	M1	R-3#2	
	M4	R-18#1	
	M5	N-2#1	Looking for EASTER terminal.
447	M1	R-3#3	
	M2	M-4	IRT for LION met. Initiate an RM. Set IRT = 0. Attach CDT to RM.
	M4	R-18#2	
449	M1	R-4#2	Mark EARS under RABBIT as used. Update M1. M1 marks EARS.

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Table 12. (continued)

End of CDT	Marker	Position of Marker	Notes
	M2	R-1#2	
	M4	R-18#4	M4 is changed to an SM. M4 is updated. I-AV of TIGER is increased by V_2 = 41.
450	M1	N-2#1	Looking for EARS terminal.
	M2	R-1#3	
	M4	R-14#1	
451	M2	R-2#1	
	M4	R-14#2	DT of TIGER updated.
	M6	R-6#1	TAIL recognized.
452	M2	R-2#2	Mark R-1 as no longer an entry point for LION stimulus.
	M4	N-2#1	Looking for TIGER terminal.
	M6	R-6#3	
457	M2	R-4#2	Mark ANIMAL under LION as used. Update M2. M2 marks ANIMAL.
	M6	R-8#4	I-AV for TAIL = 5(140/457) = 2.
458	M2	N-2#1	Looking for ANIMAL terminal.
	M6	R-9#1	
459	M6	R-9#2	
	M7	R-6#1	TIGER recognized.
460	M6	R-9#3	I-AV of TAIL = 2 is not $\geqslant \theta_1$.
	M7	R-6#2	
463	M6	R-17#3	I-AV of TAIL = 2 is not $\geqslant \theta_2$.
	M7	R-8#2	
465	M6	R-19#2	I-AV of TAIL increased by V_3 = 12.
	M7	R-8#4	I-AV for TIGER = 41(451/465) = 40.
466	M3	M-4	IRT for RABBIT met. Initiate an RM. Set IRT = 0. Attach CDT to RM.
	M6	R-14#1	
	M7	R-9#1	
467	M3	R-1#1	
	M6	R-14#2	DT of TAIL updated.
	M7	R-9#2	
468	M3	R-1#2	
	M6	M-12	Marker removed.
	M7	R-9#3	I-AV of TIGER = 40 is $\geqslant \theta_1$.
471	M3	R-2#2	Mark R-1 as no longer an entry point for RABBIT stimulus.
	M7	R-10#3	TIGER is neither the stimulus object nor in STM.
472	M3	R-3#1	
	M7	R-11#1	
	—	T-12	IRT for LION met. No unused responses. IRT dropped.
473	M3	R-3#2	
	M5	S-2#1	EASTER recognized.
	M7	R-11#2	

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Table 12. (continued)

End of CDT	Marker	Position of Marker	Notes
475	M3	R-4#1	
	M5	S-2#3	
	M7	R-11#4	TIGER evoked as a response.
476	M3	R-4#2	Mark FOOT under RABBIT as used. Update M3. M3 marks FOOT.
	M5	S-3#1	
	M7	R-12#1	
477	M1	R-6#1	EARS recognized.
	M3	N-2#1	Looking for FOOT terminal.
	M5	S-3#2	
	M7	R-12#2	I-AV of TIGER increased by V_1 = 70.
478	M1	R-6#2	
	M5	S-3#3	EASTER as a stimulus does not have any responses associated with it.
	M7	R-13#1	
479	M1	R-6#3	
	M5	F-1#1	
	M7	R-13#2	TIGER added to top of STM.
480	M1	R-8#1	
	M4	S-2#1	TIGER recognized.
	M5	F-1#2	
	M7	R-14#1	
481	M1	R-8#2	
	M4	S-2#2	
	M5	F-2#1	
	M7	R-14#2	DT of TIGER updated
482	M1	R-8#3	
	M4	S-2#3	
	M5	F-2#2	
	M7	M-7	NR = 3.
		M-12	M7 removed as R-1 is not an entry point for LION stimulus.
483	M1	R-8#4	I-AV for EARS = 4(138/483) = 1.
	M4	S-3#1	
	M5	F-2#3	Yes. EARS terminal is off of marked terminal.
484	M1	R-9#1	
	M2	R-6#1	ANIMAL recognized.
	M4	S-3#2	
	M5	F-3#1	
486	M1	R-9#3	I-AV of EARS = 1 is not $\geqslant \theta_1$.
	M2	R-6#3	
	M4	R-1#1	Change M4 to an RM. Initiate IRT = 0 for response list associated with TIGER.
	M5	F-4#1	

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Table 12. (continued)

End of CDT	Marker	Position of Marker	Notes
488	M1	R-17#2	
	M2	R-8#2	
	M4	R-1#3	
	M5	F-4#2	Yes. EARS is successful as a stimulus since it has responses associated with it.
489	M1	R-17#3	I-AV of EARS = 1 is not $\geq \theta_2$.
	M2	R-8#3	
	M4	R-3#1	
	M5	F-7#1	
490	M1	R-19#1	
	M2	R-8#4	I-AV for ANIMAL = 13(134/490) = 4.
	M4	R-3#2	
	M5	F-7#2	Terminal EARS is chosen as stimulus. Attach M5 to EARS. Attach CDT to M5.
491	M1	R-19#2	I-AV of EARS is increased by V_3 = 11.
	M2	R-9#1	
	M4	R-3#3	
	M5	S-5#1	
	--	T-12	IRT for RABBIT met. No unused responses. IRT dropped.
493	M1	R-14#2	DT of EARS updated.
	M2	R-9#3	I-AV of ANIMAL = 4 is not $\geq \theta_1$.
	M4	R-4#2	Mark LION under TIGER used. Update M4.
	M5	S-5#3	M4 marks LION.
494	M1	M-12	Marker removed.
	M2	R-17#1	
	M4	N-2#1	Looking for LION terminal.
	M5	R-1#1	Change M5 to an RM. Initiate IRT = 0 for response list associated with EARS.
496	M2	R-17#3	I-AV of ANIMAL = 4 is not $\geq \theta_2$.
	M5	R-1#3	
497	M2	R-19#1	
	M3	R-6#1	FOOT recognized.
	M5	R-2#1	
498	M2	R-19#2	I-AV of ANIMAL increased by V_3 = 14.
	M3	R-6#2	
	M5	R-2#2	Mark R-1 as no longer an entry point for EARS stimulus.
500	M2	R-14#2	DT of ANIMAL updated.
	M3	R-8#1	
	M5	R-3#2	
501	M2	M-12	Marker removed.
	M3	R-8#2	
	M5	R-3#3	

Table 12. (continued)

End of CDT	Marker	Position of Marker	Notes
503	M3	R-8#4	I-AV for FOOT = 88(187/503) = 33.
	M5	R-4#2	Mark RABBIT under EARS used. Update M5. M5 marks RABBIT.
504	M3	R-9#1	
	M5	N-2#1	Looking for RABBIT terminal.
506	M3	R-9#3	I-AV of FOOT is $\geqslant \theta_1$.
511	M1	M-4	Set IRT = 0. Attach CDT to RM.
	M3	R-11#2	
513	M1	R-1#2	
	M3	R-11#4	FOOT evoked as a response.
515	M1	R-3#1	
	M3	R-12#2	I-AV of FOOT is increased by V_1 = 66.
517	M1	R-3#3	
	M3	R-13#2	FOOT added to top of STM.
	M5	R-6#1	RABBIT recognized.
519	M1	R-4#2	Mark ANIMAL under TIGER used. Update M1. M1 marks ANIMAL.
	M3	R-14#2	DT of FOOT updated.
	M5	R-6#3	
	--	T-12	IRT for EARS met. No unused responses. IRT dropped.
520	M1	N-2#1	Looking for ANIMAL terminal.
	M3	M-7	NR = 4
	M4	R-6#1	LION recognized.
	M5	R-8#1	
523	M4	R-8#1	
	M5	R-8#4	I-AV for RABBIT = 38(346/523) = 25.
526	M4	R-8#3	I-AV for LION = 34(364/526) = 24.
	M5	R-9#3	I-AV of RABBIT = 25 is $\geqslant \theta_1$.
529	M4	R-9#3	I-AV of LION = 24 is not $\geqslant \theta_1$.
532	M4	R-17#3	I-AV of LION = 24 is $\geqslant \theta_2$.
	M5	R-11#3	
533	M4	R-18#1	
	M5	R-11#4	RABBIT evoked as a response.
535	M4	R-18#3	
	M5	R-12#2	I-AV of RABBIT is increased by V_1 = 62.
536	M2	M4	IRT for TIGER met. Initiate a new RM. Set IRT = 0. Attach CDT to RM.
	M4	R-18#4	M4 is changed to an SM. M4 is updated. I-AV of LION increased by V_2 = 44.
	M5	R-13#1	
538	M2	R-1#2	
	M4	R-14#2	DT of LION updated.
	M5	R-14#1	

Table 12. (continued)

End of CDT	Marker	Position of Marker	Notes
539	M2	R-1#3	
	M4	N-2#1	Looking for LION terminal.
	M5	R-14#2	DT of RABBIT is updated.
540	M2	R-3#2	
	M5	M-7	NR = 5. Set stop flag. M5 removed.
541	--	------	STOP.

Table 13 lists the five responses given to ANIMAL, the DT it was given, and the first object in the memory it was associated with.

Table 13. Responses Evoked During Simulation.

DT	Response	Stimulus
300	CAT	ANIMAL
325	HORSE	ANIMAL
475	TIGER	LION
513	FOOT	RABBIT
533	RABBIT	EARS

Summary

In this chapter the C-F-A model was tested by means of a hand simulation. Since the model does not include a net building routine a hypothetical memory was constructed. The memory contains 16 first objects each of which has up to five associated responses. The simulation was to stop when either five overt responses were made or 1000 time units had elapsed. The simulation took 341 time units before the five responses were evoked. This met the major criterion set for the model -- that responses are evoked. The next chapter evaluates the simulation more closely.

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CHAPTER V

This chapter is organized into three parts. In the first the C-F-A model and the execution of the hand simulation is evaluated. Major strengths and weaknesses of the model are identified along with an assessment of different dimensions of the model's validity. The second section contains approaches to needed extensions of the model if it is to be more completely tested. Mainly this section is concerned with the problems of a net building routine. The last section is more speculative as it deals with more distant future explorations with the model.

An Evaluation of the C-F-A Model

Before examining the C-F-A model in detail, it would be wise to review some of the methods and criteria for assessing its validity. Kaplan (1964), Hermann (1967) and others do not consider validity to have only two values: valid and invalid. Rather validity is a matter of degree, depending in part upon the goals of the model and the state of its development. The C-F-A model has as its primary goals understanding of the relationships among its components (q.v. Dubin, 1969) and insight into free association behavior. In this early stage of its development prediction is not of major concern.

> The pattern model [understanding] may more easily fit explanations in early stages of inquiry, and the deductive model [prediction] explanations in later stages (Kaplan, 1964, p. 332).

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Hermann's (1967) five levels of validation were discussed in chapter two. His lowest level is an assessment of test-retest reliability. Since the simulation of the C-F-A model was run only once, there is no measure of this reliability. However, the C-F-A model is almost purely deterministic in nature. The sole exception is the random process which may occur in the Time Executive Routine at T-5. In the actual simulation it was never necessary to execute this random part of T-5. Thus, there is no reason to believe that it will be utilized by all or most future simulations. Furthermore, the mere execution of that random component does not guarantee that the outcomes of the simulation will be altered in any important way. While never tested, it is reasonable to expect the test-retest reliability of the C-F-A model to be high. That is, it should exhibit very similar behaviors and outputs when it operates under identical initial conditions (memory and parameters).

Hermann's fourth and fifth levels are more appropriate for deductive-predictive models than for the C-F-A model. One aspect of his third level is sensitivity testing. Such testing requires multiple executions of the simulation with different initial conditions. Unlike the discussion above about the lowest validity level, it is much more difficult here to estimate the results of multiple runs. Some of these considerations will be included in the ensuing, more general evaluation of the model.

The other part of his third level requires a comparison of the model and the modeled. This plus his second level, face validity, are similar to Kaplan's (1964) norm of correspondance. Before applying this type of criterion to the C-F-A model several other criteria should be discussed briefly.

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Kaplan's second norm is that of coherence. Coherent models are internally consistent. They fit existing theories, are simple, and possibly, are esthetically pleasing. One sensible way to test a simulation for internal consistency is to see if it executes without a terminal error in any one run. The one simulation executed did not terminate with an error. To test for contradictory outcomes requires the sort of sensitivity testing mentioned previously. Simplicity may mean one of two things. A simple theory may be one which is not structurally complex, or it may be one that is parsimoneous in terms of its free parameters. Models attempting to explain cognitive processes must be structurally complex. EPAM I appears to be an exception to this, but that may be a function of the scope of the phenomenon it is explaining. The C-F-A model has ten free parameters. Without further simulation there is no way to tell whether or not there are too many free parameters.

The pragmatic norm is Kaplan's third criterion. Valid models need not be practical in an everyday sense. Rather they should be useful to science itself. They must generate interesting questions as well as supply some answers. The C-F-A model is proposed as a means of obtaining insight into the relationship between free association behavior and, (when a more advanced version is completed) meaning. How well C-F-A meets the pragmatic norm remains to be seen.

Finally, it is instructive to review the criteria proposed to evaluate IPMs specifically. The C-F-A model simulates a general individual. This rules out protocol matching. Statistical and empirical comparisons between the model's output and an average person's output is also ruled out due to the impossibility of having the model and the average person star

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start with identical conditions. The only procedure that seems workable is a loose version of Turing's test, which is similar to face validity.

> Detailed process simulation does not usually lend itself to significance tests. Common sense impression of similarity seems the only basis for judgment. There is nothing wrong with this use of common sense. (Frijda, 1967, p. 65)

In sum, the major criterion applicable for evaluation is face validity--or equivalently the norm of correspondance or Turing's test. This criterion is not applicable to the possible full range of comparisons. Mainly, this is because the model uses a hypothetical memory. Since the characteristics of associates given in a C-F-A task depend upon the structure and content of the verbal memory, it is not sensible to compare the model's output with that of an individual (or generalized individual) rigorously. (Notive that the EPAM-type models are not so limited as the verbal learning experiment defines the verbal memory of interest.)

The remainder of this section presents an evaluation of the model in terms of a gross examination of its output and a more detailed look at the principles and phenomena "represented" or possibly "accounted for" in some way within the model's processes. What follows is organized around four related topics: (1) the output of the simulation outlined in the last chapter, (2) the structure of the C-F-A memory, (3) the functioning of the C-F-A model especially in terms of some principles of verbal behavior, and (4) the major strengths and weaknesses of the model.

<u>Simulation Output</u>

The single most significant result of the simulation is the fact that responses were evoked. The fact that parts of the C-F-A model were designed to evoke responses (q.v. R-11 in Figure 23) in no way diminishes the importance of this result. The model as described is too complex for

one to ascertain before execution whether or not responses will be evoked under a given set of conditions. True, one successful execution does not guarantee others, with different initial conditions, but it does lend weight, ipso facto, to an optimistic expectation of future runs. In addition, when the execution ceased five unpredictable responses were evoked.

A model which evoked predictable associates might upon presentation of the stimulus word ANIMAL, respond with DOG, CAT, HORSE, RABBIT, and LION (q.v. Table 7). This type of model places the burden of free-association behavior upon the processes which build the memory net, instead of the processes which retrieve responses from the net. As stated in chapter four there are reasons to believe that humans do not evoke all responses directly associated in memory with a stimulus object. Therefore, models based upon retrieval of items from memory are to be preferred. The C-F-A model is of this type. Also, when the simulation stopped at DT=541, there were two active markers being processed. Without further processing there is no way to tell which additional responses (if any) would have been evoked.

A second interesting characteristic of the execution is the time each response was evoked. Table 13 summarizes those times. What is apparent is from an inspection of these DTs, is the fact that they are not regular and that inter-response intervals vary greatly. There are two groups of responses (1) CAT, HORSE, and (2) TIGER, FOOT, RABBIT. The inter-response interval between these groups is 150 time units while the interval within the groups never greater than 40 time units. This temporal grouping of free associates has been studied by Pollio (1966) who found that humans temporally group their associates, and the average semantic distance between groups was greater than the distance within groups. In the C-F-A

model the temporal clustering seems to be due primarily to an internal mediation of stimulus objects. Another contributer to the inter-response latency is the additional processing required whenever an unsuccessful terminal is reached. At DT=478, the potential stimulus EASTER was eliminated because it did not have responses associated with it. Routine F-0 was called and EARS was substituted for EASTER. The processing of F-0 possibly increased the number of time units between evoked responses four and five.

While ANIMAL was the only nominal stimulus in the simulation, there were four functional stimuli (q.v. Underwood, 1963) which mediated overt responses. In addition other items in the memory effected the processing of possible candidates for evocation (e.g. EASTER) and in some sense served as internal mediators.

Mediation in the C-F-A model is more complex than that in the EPAM-type models. Those models and the C-F-A model mediate responses by discriminating some coded representation (e.g. cue codes) of the response through the net. Thus, every response has been mediated. In addition to this response mediation, only the C-F-A model includes a form of stimulus mediation. Stimulus mediation occurs whenever a word's I-AV is less than θ_1 but greater than θ_2. Response mediation is similar to Osgood's r_m's (see chapter one), in the sense that they both function for all inputs. Stimulus mediation in the C-F-A model does not always occur and is closer in its operation to the three stage simple chain mediation paradigm (q.v. Jenkins, 1963).

A fourth major result of the simulation is the permanent alternation of parts of the memory as a function of processing. Newell, Shaw and Simon (1958) call this type of alteration a form of learning. Table 11

presents the I-AV and DT of all first items in the memory before and after the simulation. There was only one nominal stimulus and five evoked responses, but the I-AV and DT of 12 of the 16 items in memory were changed.

This type of learning by the model helps produce more successful mediated reactions. Two examples of this occurred in the simulation. The first example concerns TIGER which was evoked as a response at DT=475. The TIGER that was evoked was the second TIGER under LION, not the first (see Table 7). At DT=404 the first TIGER started being processed. Its I-AV was too small for it to be evoked. At DT=449 its I-AV was raised by V_2 to 41. The second TIGER was started into processing at DT=430. Its I-AV was compared with θ_1 at DT=468 which was after the I-AV was raised to 41. Hence, TIGER became a candidate for evocation on its second attempt. The other example is similar to the first. RABBIT as a response to ANIMAL did not have an I-AV sufficient for evocation. But in its processing the I-AV was raised above the threshold (at DT=344). When RABBIT as a response to EARS was processed it could be evoked as a response because of its raised I-AV.

A fifth attribute of the simulation which ought to be pointed out is that parallel processing actually occurred. The existence of T-5 in the Time Executive Routine does not guarantee parallel processing. It merely stipulates that if there is more than one marker active at a CDT, then they shall be processed in a parallel mode. The simulation starts with only one active marker, the SM for ANIMAL. The entire simulation could have occurred with only one marker active at each CDT. That wasn't the case. The actual amount of time different numbers of markers were ac

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active is given in Table 14. The Table shows that in the simulation from one through seven markers were active. There was no instance in which more than seven markers were active in any CDT. If a situation occurred in which an eighth marker were needed, the model would have prevented its initiation at T-11 because the parameter NMM was set equal to seven. NMM serves to limit the amount of parallel processing and is in line with evidence reviewed by Miller (1956) and others on the limitation of human information processing.

Table 14

Time Units Different Numbers of Markers Were Active

Number of Markers	Time Units
1	65
2	100
3	76
4	44
5	18
6	34
7	2

Finally, it is interesting to notice that all six C-F-A routines were used in the simulation, and that the inter-relations among the routines functioned as expected. In real C-F-A situations Ss rarely fail to give responses or stop responding in the middle of an experiment. They operate as if under pressure to give a response. The F-0 Routine in the C-F-A model operates to simulate this behavior. F-0 was used only once during execution which was unexpected. There was no reason to believe before beginning the simulation that F-0 would be called at all. At DT=479 the routine was called when stimulus EASTER was discriminated to a terminal w

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which contained no associated responses. What a human S does when confronted with a stimulus word for which he has no real (as opposed to overt) associates is unknown. But the human does give associates. So does the C-F-A model. F-0 operates by finding a terminal close to the unsatisfactory one which has associated responses. In the simulation that terminal was headed by the stimulus word EARS.

Considering the structure of the discrimination net, F-0 operates a forced stimulus generalization. In the EPAM-type of models stimulus generalization occurs because of incomplete previous learning. In the C-F-A model stimulus generalization operates because of F-0. EASTER is the stimulus, but a response to EARS is given. The model can be thought of as being "under pressure" to respond when no response is available. This pressure makes the difference between the "T" in EASTER and the "S" in EARS unimportant (see Figure 26, D-10). A form of stimulus generalization follows.

In most instances of C-F-A or pooled discrete free association experiments there are items in the list of associates that seem completely out of context. For example, Deese (1965) notes that an associate of BUTTERFLY is WINTER. In the simulation, the fourth associate to ANIMAL is FOOT which, in turn, precedes RABBIT. In the C-F-A model it is the F-0 Routine and the mediation of stimulus items which produce these difficult to explain responses.

<u>Memory Structure</u>

Because the C-F-A model is heavily based upon the EPAM-type of model little needs to be said about the structure of the memory net. Most of the previously described strengths and weaknesses of those models are applicable

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to C-F-A. A few variations need to be pointed to. None of the earlier models need to allow for a complex hierarchy of connections within the memory. Models of verbal learning do not require it. But because, "the associations a subject forms are probably numerous and hierarchically organized" (G.A. Miller, 1963, p. 328), the C-F-A model requires a more complex memory structure. A cursory examination of the hypothetical memory presented in Table 7 reveals such a hierarchical memory. Whenever net building is added to this model it must be able to produce an arrangement of memory items similar to that in the ad hoc memory.

WEPAM, SAL III and C-F-A all associate more than one response with a stimulus item. There are some differences however. In SAL III only the top (most recent) response is available as a possible response. The response list also functions as a stochastic short term memory -- there is a probability that the topmost response on any list will be pushed up and "forgotten". The C-F-A model operates with a central short term memory. It retains all associates, though they may not be available enough to be evoked. Whereas, SAL III activates one response, C-F-A activates an entire response list.

In WEPAM, the topmost response not previously given in error becomes the candidate for evocation. The error indicator is stored with the response list. If this form of marker were used in a free association model it would be very inefficient. All of the numerous instances of a response throughout the memory would have to be similarly marked and simultaneously updated whenever necessary. In the C-F-A model the I-AV of a word is stored only once throughout the memory at the terminal in which the word is the first item. WEPAM functions as if the responses in a response list are

known since the error indicators are checked without discriminating the response. In the C-F-A model it is impossible to make any inspection of a response or its associated property set until it has been recognized by means of discrimination.

Functioning of Model

For reasons given in the first chapter, I-AV is the variable of major interest in this model. It differs from associative strength in three ways. First, I-AV is more directly applicable to the response learning-giving phase, while associative strength is also relevant to the associative phase of verbal learning. Second, I-AV is considered to be more sensitive to change, while associative strength is more stable. And, third, I-AV is determined mainly by frequency of experience, recency of experience and mode of experience of the verbal unit. On the other hand associative strength may depend upon the reinforcement history of an S-R pair as well as the simpler principles of association.

The C-F-A model does not specify how each item's I-AV should be originally estimated. That would be a proper function of a net building routine. However, it is instructive to examine how I-AV is handled in the current model. An assumption implied within the model is that the major factors which affect I-AV do not become operative during the building of the verbal memory, but, rather during the response giving phase. That is, the value of an item's I-AV is manipulated during response processing rather than during item learning.

Recency, frequency, and mode of experience are the major factors which affect an item's I-AV (Rosenzweig & Postman, 1957; Horowitz, Norman, & Day, 1966). Figure 23 outlines the response giving phase of C-F-A. Recency affects I-AV in two ways. Most directly, recently processed items

in memory are not as affected by the effects of the passage of time on I-AV as older items are. R-8 in Figure 23 stipulates that all items' I-AVs decrease as a function of elapsed time. Items with higher DTs (more recent) have their I-AVs decreased least. The second way recency affects I-AV is less direct. The most recently acquired item in a response list is always the item at the top. A PDS operates by "popping-up" the topmost item first. It is the recent items from each response list which become the first candidates for evocation. Since association experiments end before a S's entire verbal memory is depleted, potential responses left unprocessed are those further down on the response lists. Therefore, more recent items are more likely to have their I-AVs examined (q.v. R-9 or R-17), decreased (R-8) or raised (R-12, R-18, R-19).

Frequency is represented in the verbal memory directly, by allowing the same item to appear in the same (or different) response lists as often as needed. (Again, exactly what procedure is followed depends upon the unspecified net building routine). Frequency affects I-AV by means of successive processing of the same item. The two examples described earlier in this chapter illustrates this point: The first TIGER in the response list of LION did not have an I-AV sufficiently high for it to be evoked as an overt response. But the processing of the first TIGER raised its I-AV permitting the second TIGER to be evoked. The second example is similar to this dealing with RABBIT (under ANIMAL and later under EARS) instead of TIGER.

Horowitz, Norman and Day (1966) experimentally manipulated I-AV. They found than an item's I-AV is raised most when the item is overtly produced from memory. The I-AV is also raised when the item is seen, but the increase is not as great as when it is produced from memory. The C-F-A model raises

the I-AV of item's in a manner consonant with these findings. The model of the item serves to raise its I-AV at least a little (see Figure 23, R-19). This internal processing corresponds to the "seen" condition of the experiment. The model raises an item's I-AV the greatest amount when the item is evoked from memory (R-12). And, in a condition not paralleled by the experiment, the model can raise an item's I-AV an intermediate amount whenever the I-AV is less than θ_1 but greater than θ_2 (R-18). This middle condition seems reasonable as items meeting this condition are treated as mediating stimuli: mediating stimuli are additionally processed but not evoked, while items whose I-AV are not greater than θ_2 are not additionally processed.

In sum, I-AV is quite specifically treated in the C-F-A model. Each first item in the memory has a numeric value of I-AV assigned to it. In the response giving phase, the I-AV functions in a manner which is consistent with existing theory and experimentation: I-AV is a major factor in determining which of the potential responses will be evoked, and the value of an item's I-AV depends upon recency, frequency and mode of processing. The EPAM-WEPAM-SAL models, on the other hand, do not represent or treat I-AV in any manner whatsoever.

The variable employed by these earlier models to govern response giving is relative (or absolute) associative strength. In theory, the strength of association depends upon the frequency of association and the number of associates of the stimulus word. In addition, each succeeding presentation of the S-R pair contributes less to the strength of the bond between them (Deese, 1965). This is true under the classical conditioning paradigm in which contiguity of the S-R pair is so important, nnd it is true in the operant conditioning paradigm in which reinforcement strength and schedule is important.

In EPAM II associative strength is represented indirectly by the degree of completeness of a response cue code. Cue codes which are well learning (i.e. complete) function as if the response they seek is strongly associated with the stimulus. Complete cue codes always retrieve the correct response. The degree of completeness of a cue code depends upon the nature of the discrimination net, not the number of trials. If the net is built in a manner which forces a cue code to pass numerous tests then that cue code will be complete before other cue codes. Since the cue tokens of EPAM III name a terminal and do not have to be sorted through the net, associative strength is not represented in that model in a manner which permits variation in the level of the variable. Rather the value of associative strength is either zero (before the cue token is added) or at a maximum (at the trial the cue token is added to the terminal).

Wynn's (1966) model is similar to EPAM III in accounting for absolute associative strength. It does a better job with relative associative strength since more than one response is stored at a terminal. The order of responses in the response list and the presence or absence of the error mark (see chapter 2) determines the relative strength of responses to a stimulus.

SAL III also reflects relative associative strength because of the possible multiple responses. However, the concept of absolute strength is irrelevant to the SAL model as response learning is assumed to be complete and perfect.

In the C-F-A model a precise interpretation of associative strength depends upon the, as yet unspecified, net building routine. That routine will be discussed in greater length later in this chapter. It is appropriate to speculate about its effects on associative strength at this time.

In building his memory for a future free association task a S is not confronted with repeated pairs or lists of the same objects. It is this repetition in the verbal learning studies which allows associative strength to be built up by reinforcement and/or contiguity. In free association it does not seem likely that a person will experience the pairs of words often enough to permit an incremental theory of associative strength to function faster than the negative effects of time. An incremental theory specifies that each succeeding occurrence of a S-R pair contributes (less) to the strength of their association. Elapsed time between successive pairings operates to decrease the strength of association. One possible way a person can build up a memory of associates is by means of one-trial learning and contiguity. That is, whenever a pair of words is experienced together it is associated completely (if it is associated) and symmetrically. This approach eliminates the need for several presentations of S-R pairs and for reinforcement. It places a great deal of reliance on one-trial learning (e.g. Rock & Heimer, 1959; Estes, 1964) and associative symmetry (Asch & Ebenholtz, 1967; Horowitz, Norman & Day, 1966). This approach would also reverse the order of the two stages of verbal learnings (Underwood & Schulz, 1960) described in chapter one.

Thus, the net building routine would operate by finding contiguous pairs of words. If they meet some criterion they are associated completely (associative strength is at a maximum) and summetrically (each word is both a stimulus to and a response of the other member of the pair). It is during processing in the response giving phase that availability becomes important. Availability is part of the second stage of verbal

learning (after the stages are reversed). Asch & Lindner (1963) found some support for this reversal of the two stages of learning.

Strengths and Weaknesses

The C-F-A model succeeds in that it is the first IPM of free association behavior. It posits specific deterministic processes which operate on the principles of association. The model operates in a parallel mode to evoke a string of response to a stimulus word. Some of the internal processing depends upon a word's I-AV. The C-F-A model is the first of the related IPMs to do this. Neither EPAM, WEPAM, nor SAL incorporated I-AV or parallel processing in any direct fashion. Nor do the earlier models employ a type of mediation found in this model.

What are the major limitations of the model? There are two important limitations which serve to prevent an adequate assessment of the validity of the model. The first is the lack of a net building routine. Without such a routine the model must work on an *ad hoc* memory which (though satisfactory for testing the operation of the model) makes any direct comparisons between model and human output specious. If the verbal memory were created by an adequate net building routine, it would be possible to assign to each word in the memory some measure of its connotative meaning. (One type of routine could build up such values as the net was constructed. Another version of the routine would not include these values, but if the memory were reasonable, the values could be obtained from normative data.) With such a routine it would be possible to attempt to replicate by simulation some of the experiments described in the first chapter. A net building routine is essential if the model is to be tested in terms of event validity (q.v. Hermann, 1967). The next sections of this chapter contain approaches toward the solution of these problems.

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The other limitation related to validity assessment has less to do with the model per se. For practical reasons it was impossible to run more than one simulation of the model. That one simulation was a success insofar as the operation of the model is concerned. From the simulation it was possible to see the effects of the interactions of the components of the various routines. It could be determined that responses were evoked, parallel processing occurred and a form of mediation took place. On the other hand, one simulation is not sufficient to permit an adequate testing of the model's sensitivity to different initial conditions. It is important to know the effect upon output of different memory content and structure and of different values of the parameters.

In addition to these major limitations, several lesser difficulties are apparent from an examination of the simulation. When the memory was constructed it was assumed that 200 simulated time units would be sufficient for the task. Since it took over 300 time units to evoke five responses, it now appears that 200 time units is far too few for net building -- especially if a net of reasonable size is constructed.

Given a large memory and the additional number of time units needed to construct it, then the formula given in R-8 (Figure 23) for reducing an item's I-AV as a function of elapsed time needs to be changed. It is possible with a large enough memory that many time units will elapse between successive uses of one item. If that is so, then the denominator increases much more rapidly than the numerator in the formula given in R-8. It will be possible, under such conditions, for an item's I-AV to be always reduced to a level below any of the thresholds -- leading to a model which does not evoke any responses.

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This problem is a weakness of the particular formula used in R-8. But other formulae are possible and reasonable. All should, however, decrease I-AV as a function of elapsed time. This is important if recency is to play a role in the determination of the value of I-AV.

A definitive evaluation of the C-F-A model at this time is not possible. What is possible is to begin to assess the validity of the model at different levels. This section of the chapter offered such an assessment. The model is at a level of development common to IPMs.

> For a simulation of even moderate complexity, it is such a considerable achievement to get a 'dry run' version working that investigators often do not pitch their levels of aspiration much beyond that point. That a model may work well on simple illustrative data carried through a few representative steps, however, does not at all guarantee that it will behave properly when run full-scale with a large body of data. (Abelson, 1968, p. 307).

Nothing has been proven by the model or the simulation, but the model does exist at some higher level of credibility. Some insight has been gained and now some patience is needed to continue the investigation with different versions of the model and with additional simulations. Some extensions of the model are described in the next section.

Extensions of the C-F-A Model

While there are many possible extensions to this model, obviously all of them cannot be discussed here. The most appropriate extensions to explore are those which are needed immediately if the model is to be developed further. In this case, a net building routine is central to a better C-F-A model.

An initial net building routine should be limited to assign learning. At this time it looks as if it would be easier to construct a memory from wo

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word pairs or sentences than from word-object pairs. Sign learning (word-object) is very important to a realistic C-F-A model. Probably TABLE is associated with CHAIR because of non-verbal co-occurrences of the objects themselves instead of verbal co-occurrences in the spoken or written language. Some important preliminary work has been done (e.g. Minsky, 1963; Evans, 1968) which points the way toward a sign learning net building routine. The complexity of these approaches is beyond the scope of the current model.

Consequently, let the input to the model be a series of word pairs. If a word pair is perceived then each item will be learned completely and each word will be associated symmetrically. Thus, when a word pair is perceived each word would be compared with existing first items in the memory. If the word did not exist it would be discriminated through the net and added. In addition each word would be added to the top of the other word's response list -- associating them. Since the response giving routine effectively manipulates the value of a word's I-AV, it is not necessary for the net building routine to treat I-AV in any complicated fashion. One possibility would have an item's I-AV raised by one (up to some limit) each time that item is processed.

Suppose the input to the net building routine were English sentences. A simple expedient would be to treat the sentence as a collection of all possible word pairs. Irrespective of their sequential order, all words would be associated with each other. It would be desirable to include some effect of contiguity in this by forming better (stronger, more likely) associations between words closer together in the sentence, but the model as currently envisaged has no way to do this.

If the sentence were to be treated as an entirety rather than a collection of word pairs then parts of a vast body of knowledge about modern linguistics, psycholinguistics, and computer understanding of natural language becomes pertinent. Some of this literature is applicable if it sheds light on the problem of selecting and associating words from a sentence. To critically review or summarize these areas here is impossible. However, one interesting contribution will be discussed. It was chosen not only because it contributes to the theory of a net building routine, but also because it is a relatively modern, working IPM.

The model is Raphael's (1968) SIR -- Semanitc Information Retrieval. SIR's memory is basically unstructured, consisting of words with associated property lists (much like the C-F-A model). Property lists contain other words and the relationship between the first word and each of the others. The SIR model attempts to "understand" natural English. Given some input sentences the model determines the relationships between the words. At present the relationships it can process are set-inclusion, part-whole, numeric quantity, set membership, ownership, and spatial arrangements.

With a developed memory, SIR answers some questions posed to it, demonstrating its "understanding" of English. Suppose SIR were given as input four sentences: (1) Every boy is a person. (2) There are two hands on each person. (3) John is a boy. And, (4) each hand has five fingers. Through a limited analysis of syntax the model finds subset-superset relations (e.g. boy-person), subpart relations (e.g. hand-finger) and other relations among the content words of each sentence. When queried, "How many fingers does John have?", SIR responds, "The answer is 10". (q.v. Raphael, 1968, pp. 65-66)

To employ some of SIR's principles in a C-F-A model would require an analysis of the input sentence into the syntactical or logical relations among the words. A small number of important dyadic relations (or a hierarchy of relations coupled with a limited amount of processing time) would be used. The C-F-A model could then associate word pairs found to be related. Still later, the model could store the type of the relationship between members of a word pair and use this information during the response giving phase. Responses given in a C-F-A task differ in their relationship to the stimulus word. It is known that these relationships differ as to their relative frequency of occurrence and their associated response latencies (e.g. Karwoski & Schachter, 1948). By comparing the performances of versions of the extended C-F-A model it might be possible to determine if the empirical findings were due to an input-storage process, an output routine, or some other situation.

Procedures for net building and handling sentences as input are the most important of possible future extensions to C-F-A. Other weaknesses of the current model need to be corrected. The model as now described is very inefficient in net organization and discrimination learning. The model must learn how to learn. Certain rearrangements in the net structure ought to occur as a function of processing. The restructuring would make later retrievals more efficient than earlier ones. Wynn (1966) implements several of these efficiences in his model. WEPAM permits different paths through the net to the same terminal. It also builds loops to bypass earlier nodes in the discrimination net when those nodes are redundant or "get in the way." For example, the letters' portion of the C-F-A model's hypothetical memory (Figure 26) is constructed by discriminating attributes of letters as they appear temporally at the beginning

of the experiment. If a letter occurred late in the temporal sequence, its terminal would be deep in the net. In Figure 26 the terminal for "E" is none testing nodes into the net. Since "E" appears frequently in English it is very inefficient for all processing to pass through the preceding nodes. Wynn's methods would allow for a more direct access to "E" as testing nodes and paths are changed as a function of processing.

Another need for the model is for it to handle context. It is known (q.v. Howes & Osgood, 1954) that different free associates are given when the stimulus word is preceded by other words (verbal context). Also it is common for people to modify their verbal behavior depending upon where they are (e.g. in a church or a locker room) or who they are with (ones parents or ones peers). The current C-F-A model is theoretically equipped to deal with the problem of context. Whenever a response is associated with a stimulus item, its property set could be augmented to contain some coding of the context. Appropriate attribute testing nodes included in the memory net would test for the presence of desired or undesired contexts and thereby, modify the output.

This section dealt mainly with those few major additions needed if the C-F-A model were to build its own memory as a function of its verbal experience. Especially difficult will be handling sentences in a manner which utilizes the syntactic relations among the words. The problem of making verbal associations from the physical world is very important but not considered. The ability to abstract verbal relationships from the physical world is a major need for any comprehensive model of net building for free association. These problems of net building would completely overwhelm any first attempt at a C-F-A model and therefore, the omission of a net building routine was deliberate.

Some Future Explorations with the C-F-A Model

If work with the C-F-A model is to be continued, then initial efforts need to deal with sensitivity-parameter testing and net building. Also, it appears that it is necessary to code the IPM so it can be processed by machine rather than by hand. These types of things are reasonably straightforward in concept, if not in practice, and some of them have been discussed earlier. This section of the chapter is concerned with more distant explorations of an extended C-F-A model. A caution here seems necessary. There is no a priori reason to believe that the best way to proceed with future study of C-F-A behavior is by studying a model rather than the subject matter per se (q.v. Kaplan, 1964, p. 279).

The phenomena of one-trial learning has been discussed earlier. It was relevant to the presentation of the EPAM-WEPAM-SAL models and the extended C-F-A model. Both verbal (e.g. Rock & Heimer, 1959) and mathematical (e.g. Estes, 1964) arguments have been used to present and defend the one-trial position. A critique of one-trial learning showed that both approaches were either non-supportable or indistinguishable from an incremental theory position of learning (Postman, 1963). What can be concluded? The IPMs treat one-trial learning as a useful or needed concept, while a critical review concludes otherwise. Part of the problem might be due to the different types of models. The incremental theory is verbal and it does not contain explicit internal processes (though it does contain explicit internal variables such as habit strength). Consequently, Postman must base his tests of the one-trial theory on overt responses made to specified stimuli. It is particularly difficult to separate acquisition from response giving since there is no way to ascertain acquisition without studying the responses made.

An IPM is not so limited. This type of model can separate acquisition from output mechanisms. Thus, an IPM (such as C-F-A) can employ one-trial learning but have a response pattern identical with those produced by an incremental theory. It is the processes between the acquisition and response giving phases which permit this.

This illustrates the difficulty encountered whenever an IPM and another type of model are compared. It also illustrates some of the value if IPMs. In terms of one-trial learning researchers can build various processors which operate between acquisition and response giving (the C-F-A model is one possibility). Through testing it may be possible to settle some of the differences between a one-trial and incremental position. It is also likely, that work with an IPM may offer another possibility, viz, that differences between the two theories reflect two different abstractions from a more complex model.

Similarly, the C-F-A model and the EPAM-WEPAM-SAL models contribute to a more complex version of the contiguity versus reinforcement controversy (q.v. McGeoch & Irion, 1952, p. 46f.). The IPMs require only temporal or spatial contiguity for acquisition, but need some effects of frequency (including reinforcement in the learning models) before the changes in the memory net are developed sufficiently for further processing -- such as response giving. In the C-F-A model the further processing raises an item's I-AV above the minimal threshold. In the verbal models of learning (e.g. Guthrie, 1952) or in the more formalized theories (e.g. Hull, 1943) it is difficult to separate the internal

processes and the temporal sequence of these processes (q.v. Jenkins, 1965, p. 27). IPMs clearly outline such processes and, thereby, offer approaches toward a more general formulation of the problem.

There are several areas into which a more general C-F-A model could explore. One possibility is verbal satiation. Verbal satiation names the phenomenon of a loss or change in meaning of a word as a result of its continued repetition. In the C-F-A model, the experimental situation would consist of a word associated with itself several times. This results in the most recent responses to the word being the word itself.

Without simulating this condition it is impossible to specify exactly what would occur. However, two possibilities seem likely. First of all, there should be an increase in elapsed time between the presentation of the word as a stimulus and the first evoked response. In the Response Giving Routine (Figure 23) potential responses are examined serially from the most recent to the least recent. The recent potential responses are identical with the stimulus word. Verbal satiation studies do not allow the stimulus word to be given as a response. In C-F-A, R-10 prevents the stimulus word from being given as a response. Thus, all of the responses which are identical with the stimulus word must be processed before any other word becomes a candidate for evocation.

The second possibility derives from the first. Suppose the first response to CAT is DOG. In the satiation condition, many copies of CAT are placed before DOG on the response list. As noted above, there should be some elapsed time before DOG is the current candidate for evocation. The more time elapsed, the greater DOG's I-AV will be reduced (q.v. R-8). In such a situation it is possible that DOG is no longer available as a response and may serve at most as an internally mediated stimulus word. The expectation then would be for an idiosyncratic response to CAT.

The literature of verbal satiation is not in agreement (cf. Lambert & Jakobovits, 1960; Jakobovits & Lambert, 1961). In fact Yelen and Schulz (1963) could not find much support for the existence of verbal satiation. The C-F-A model is not equipped to deal with a word's loss in meaning measured by semantic differential rating scales (as in the above three studies). If loss in meaning is measured by increased latency of response and lack of commonality of response, then studies by Wertheimer and Gillis (1958), and Smith and Raygor (1956) are applicable. These studies show that when satiation occurs less common associates are given. One hypothesis derived from the predicted behavior of the C-F-A model is that more internal processing (caused by storing many stimulus words as potential responses) produces a greater chance for idiosyncratic overt responses. Fillenbaum (1963) found that when Ss repeated the stimulus word for four seconds they had less loss of meaning (measured by commonality of response) than words repeated for one or three minutes. It should be noted, however, that the difference between the one and three minute conditions was small and not in the direction predicted.

Another area in which the model ought to explore more fully is meaning. Initially it was hoped that this model could relate C-F-A behavior with a mediational approach to word meaning. It turned out that the scope of this problem was greater than expected and could not be dealt with before a model which produced free associates was developed. The current model employs mediation in its processing. It also gives the meaning of a word -- either defined interverbally or relationally. The model does

not combine these approaches in order to permit a mediational measure of a word's meaning. In terms of initial plans, this is a serious failing of this study.

It is still not clear how the C-F-A model could be modified to incorporate such a measure. Suppose, for example, the approach chosen was that of Osgood, Suci and Tannenbaum (1957) as presented in chapter one. In their theory the mediators are not letters of a word (as in EPAM and C-F-A), nor are they indicators of a semantic or linguistic relationship (as in Reitman's Argus (1965) or SIR), nor are they words used to translate between languages (as in EPAM III). Rather they are "light-weight" components of the response to a word. In assign learning with C-F-A this would entail part of the response to one word mediating the response to the second word. A variant of this procedure may occur in the current model. Suppose R_i are the ordered set of potential response to a stimulus word S_1. If an unknown word S_2 is paired with S_1 then each word will be the topmost potential response for the other word. If an interverbal meaning for S_2 is asked for, it is likely that S_1 and its responses will be used. The C-F-A model does not employ components of the response to S_1; it uses S_1 in full. Consequently, it appears that the principle of internal mediation is incorporated directly in the C-F-A model. What is still missing is a method for obtaining a quantitative measure of a word's meaning as a function of the mediation.

Two alternative methods for obtaining these measures seem worth developing. In one case, an internal semantic space is hypothesized. For each dimension of the space the net building routine determines a word's location relative to that dimension. This is the heart of Osgood's theory. The input would be definitional or descriptive messages about an unknown word in terms of words already in the memory. The known words are located in semantic space. By means of an as yet undefined processor each dimension of each old word in the definitional input would contribute to the location of the new word. (Parenthetically, it should be noted that "location" is used here figuratively. The structure of the discrimination net need not be changed from that of the current model. All that is needed is for the relative locations on each dimension to be added to the property set for a terminal.) Once this difficult part is completed it is conceptually easy to include in a net, attribute nodes which test for values of these locations. In addition, the routines which retrieve response could have a series of thresholds testing the positional indicators. Only those words "near" another word could serve as a mediator for that word. Thus, I-AV would determine whether or not a response will be evoked, and relative location in semantic space would be the new method (cf. Figure 23, R-17) for controlling mediation.

The other alternative takes a different tack. It does not assume internal processing (at the time assign learning occurs) produces the measures of location. Instead, it assumes that the measures are a function of the measuring instrument. In this situation, the C-F-A model would require a routine to respond to a semantic differential rating scale. Suppose DOG were being rated on a "good-bad" scale. Using Quillian's (1967, 1968) procedure, markers would start at the three terminals: DOG, GOOD, and BAD. Each response to each stimulus, each response to each response, etc. would be examined until the markers crossed paths. Some weighting scheme would determine where DOG ought to be rated on the scale as a function of elapsed time to intersection or number of terminals examined before the two paths met.

If these two alternatives could be developed it would be very interesting to explore their consequences. Osgood and his associates (1957) do not distinguish between these two possible ways of obtaining measures of meaning. (This distinction is similar to the one made previously about one-trial and incremental theories of learning.) The first method operationalizes meaning as a representational mediated reaction. The second method does not require mediation of that sort at acquisition time. The measures of meaning and a chaining type of mediation occurs in the response giving or test taking phases.

There are other topics deserving exploration with the C-F-A model. Adults in a C-F-A experiment do not usually give obscene words as response. Often they give rhyming responses and opposites. Processes within the current model may contribute to an understanding of these phenomena. Obscene words could be handled in two ways; either by treating them similar to stimulus words (q.v. Figure 23, R-10) or by adding to each word's property set a role marker indicating the situations in which the word is permitted to be spoken. Rhyming responses of the CAT-HAT sort may be due to an error in decoding the stimulus word. CAT could be sorted to the HAT terminal. The C-F-A model (and EPAM and WEPAM) does not check to see if the terminal reached matches the input stimulus. A procedure could be included in the Stimulus Sorting Routine which only treats an object as a stimulus if the terminal sorted to has a first image identical with the object. If this condition is not met, the terminal must be a response terminal. This type of procedure will produce a form of response generalization. When the error in discrimination occurs at the first letter of the word, rhyming responses are possible.

Finally there is the problem of opposites: since they do not often occur contiguously it is difficult to explain how one can evoke the other. If responses are mediated by words with low I-AV (as in the current model) opposites will occur. For example, if in building the net HOT and WATER are associated together and COLD and WATER are similarly associated, then over time it is possible that the two adjectives will have a higher I-AV than WATER because they are experienced more frequently. When presented with HOT, the model's most recent associate might be WATER which is not strong enough to be evoked. Acting as a stimulus, WATER, evokes COLD as a response. This is the position taken by Horowitz, Brown and Weissbluth (1964) who showed that this interpretation based upon I-AV is not equivalent with a simple chaining paradigm.

Summary

This last part of chapter five pointed the way for some future explorations with the current and extended C-F-A models. One value of the C-F-A model (and other IPMs of cognitive processes) is its capability to temporally separate internal processes. This viewpoint may contribute to a more fundamental understanding of the phenomena of verbal behavior. Some of the phenomena discussed in this section are satiation, meaning, and evocation of opposites.

The purpose of this chapter was to evaluate the model and its simulation in terms of strengths and weaknesses. There are several major weaknesses of the model. Of considerable importance is the lack of any net building routine. This forced the use of an *ad hoc* memory and made it impossible to test several aspects of the model's validity. In addition,

because the model was not coded for computer processing, it was only possible to execute one hand simulation. Several executions are needed, however, if sensitivity and parameter testing is to be conducted. The last major weakness of the model is its inability to produce measures of a word's meaning based upon a representational mediation paradigm.

On the positive side, C-F-A is the first working model of free association behavior. Lending weight to its face validity are the facts that (1) it operates upon a hierarchically organized verbal memory, (2) in a parallel mode, and (3) evokes unpredictable responses. (4) Item availability is treated directly in this model (but not in the earlier ones). The treatment of I-AV corresponds closely with what is known about the variable. In addition the model (5) employs a form of stimulus mediation which is important to its processing. Finally, (6) the model learns. The contents of the net are changed as a function of earlier processing and these changes affect later outcomes.

Later in the chapter possible net building routines were considered briefly along with the problems of handling sentence input for assign learning. It was noted that one of the advantages of an IPM of cognitive behavior is its ability to temporally separate different processes. A possibly important role for these IPMs is to make these explorations in order to shed light on existing theoretical controversies -- such as one-trial learning. More specific directions for future exploration were also mentioned.

Finally, it must be stressed that the C-F-A model is a first try, a partially justified guess. As Popper (1962) emphasizes scientific knowledge progresses by these conjectures and by criticisms of them.

Science gains if the model is refuted and it also gains if it can not, as yet, be refuted. Both conjectures and refutations are central to the undertaking. At the conclusion of this study there is, at best, an interim model of C-F-A behavior, and a preliminary evaluation of it. That is a reasonable beginning.

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