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Book Review

Subproblems of Semantic Memory: A Review of "Human Associative Memory" by J. R. Anderson and G. H. Bower*,†

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In the first place, I liked the title; human conceptual memory is associative, and it is nice to see that assertion right up front in the title of this important book. I have always considered the issue of whether any memory system was associative or nonassociative to be fundamental. The first memory paper I ever wrote (Wickelgren, 1965) presented a definition of one type of associative memory and one type of nonassociative memory and asserted that the evidence favored the assumption that verbal short-term memory is associative. Since then, about half a dozen subsequent papers of mine were also concerned with this issue and related issues concerned with the associative character of verbal long-term memory (Wickelgren, 1972) and the nonassociative character of visual sensory memory (Wickelgren & Whitman, 1970).

Partly because the general notion of associative memory has been around since Aristotle, the most common reaction to my work on this topic has been largely "ho hum." Also, the decade of the 60's was not a good time for definitions, arguments, and evidence favorable to the assumption that human conceptual memory is associative. Computer models and transformational generative grammar were "in," and, for completely illogical reasons, associative memory was "out." The notion that memory is associative suffered from "guilt by association." Nearly universal acceptance of the hypothesis of associative memory throughout the early history of psychology led to the ridiculous notion during the 60's that the assumption of associative memory was directly linked to a noncognitive, operationist, crassly empirical, S–R approach to psychology. As a consequence, a lot of psycholoinguists and cognitive memory researchers threw out the baby with the bath water and went off developing theories of the human mind that either ignored memory altogether or worked with some

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primitive and incorrect nonassociative conception of it. Research of the last few years on semantic memory, particularly as exemplified by the Anderson and Bower book, has gone a long way toward rectifying this grievous error.

In the second place, I liked the overview that Anderson and Bower provided to the different aspects of understanding semantic memory. As I see it, a complete theory of semantic memory must solve seven theoretical subproblems: the structure of semantic memory, recognition, acquisition, storage, retrieval, inference, and generation. The structure of semantic memory refers to the nature of the memory code, including its associative vs. nonassociative nature, the particular types of associations and elements (nodes), how our knowledge of the world is represented in semantic memory, etc. Recognition refers to the process by which the familiar portion of new stimulus input is identified and mapped onto already existing representation in semantic memory, including its dynamics. Acquisition refers to the process by which the new (previously uncoded) portion of input is encoded into sematic memory, including its dynamics. Storage referes to the nature and dynamics of the changes that take place in semantic memory over the retention interval between acquisition and usage (retrieval).

Retrieval, inference, and generation could all be subsumed under the rubric of "usage," but the theoretical problems involved in each seem sufficiently different at the present time to warrant separate treatment. Accordingly, I use the term "retrieval" in the same way that Anderson and Bower use the term "fact retrieval" to refer to elementary question answering (which differs from Anderson and Bower's use of the term "question-answering"). Elementary question answering has two principal components: answering yes-no questions and answering wh-questions (who, what, when, where, and possibly why, and how). This subdivision corresponds approximately to the distinction in traditional memory research between recognition and recall (approximately, but not exactly). "Retrieval" will be used to refer to elementary question answering for material directly stored in semantic memory. By contrast, inference will refer to elementary question answering that requires some combination of separately stored memory traces in semantic memory (e.g., if Liebnitz was a person and people have four-chambered hearts, then Liebnitz had a four-chambered heart). Generation refers to spoken or written verbal production (principally speech production). This is distinguishable from elementary retrieval and inference by virtue of the production of long, syntactically complex utterances.

The processes are not totally independent. For example, recognition is usually involved in acquisition and necessarily in usage. The last six subproblems refer to processes for which one wants ultimately to specify both the basic nature of the process and its (temporal) dynamics. The structure of semantic memory has no dynamic aspect and is perhaps the most basic subproblem to solve, since it may be deeply involved in the solution to most, if not all, of the other theoretical subproblems. However, studying the structure of semantic memory typically requires at least some minimal assumptions concerning most of the six process. Despite the likelihood of at least a modest degree of interaction between each of these seven subproblems, some such analysis is essential to the solution of any complex scientific problem. This seems like a good one.

One of the strengths of the Anderson and Bower book is the presentation of a subproblem analysis which seems to me to be equivalent to the one just specified, or nearly so. Furthermore, Anderson and Bower present preliminary examples of a theoretical solution to each of the first five subproblems and at least discuss the problem of an adequate accounting for inference in some detail, although their theory of semantic memory has very limited inferential capacity. Anderson and Bower mention the problem of speech generation, but present no example theoretical solution. Anderson and Bower generally also discuss a number of empirical findings (their own and others) that confirm or reject various aspects of their theory. In the scope of both their theoretical approach to semantic memory and the empirical testing thereof, the Anderson and Bower theory (HAM for human associative memory) has no published rival. It should be noted, that this does not imply that Anderson and Bower's theoretical solution to any subproblem area is superior to that of Norman and Rumelhart (1975), Schank (1973), Winograd (1972), etc., to name just a few outstanding recent alternative formulations. The ultimate worth of different theories, particularly in the most basic area of the structure of semantic memory will take some time to determine. I certainly am not able to draw any definite global conclusion on this matter at the present.

Before proceeding to a critique of Anderson and Bower's theory, I wish to provide a brief overview of the book's contents and evaluate its suitability for courses. The book is divided into two parts. The first five chapters are an historical introduction to semantic memory including various versions of associationism, Gestalt and reconstructive notions of memory (such as they are), computer simulation or artificial intelligence models of semantic memory, and linguistic contributions to the understanding of syntax and semantics. This introductory review occupies the first 135 pages and substantially enhances the value of the book as a text for a semantic memory seminar or an advanced course.

The remaining three quarters of the book presents Anderson and Bower's theory with chapters having some rough correspondence to the subproblem analysis previously described, though this could have been improved to give a more exact correspondence. In addition, Anderson and Bower extend their theory to the analysis of the syntactically unstructured materials used in traditional verbal learning experiments. Finally, at various stages in the book, Anderson and Bower presented some ideas concerning the propositional representation of image memory. This is very stimulating, whether or not you agree with their point of view.

Doug Hintzman, Ray Hyman, and I used the Anderson and Bower book as the sole text for a one quarter graduate seminar on semantic memory, and in my opinion it was an unqualified success. However, many students, particularly those with little or no background in linguistics, psycholinguistics, or artificial intelligence complained that the book was too difficult to understand. Personally, I think that is a matter of expectation. Students who are familiar with courses and seminars that are focused on experiments will find a course that is primarily oriented to the understanding of a relatively complex and precisely specified theory to be conceptually difficult. If students expect such material to be difficult, to require substantial time for understanding and to require asking a lot of questions, then a course or seminar based on this book can be completely successful. Despite complaints from a number of students, the semantic memory seminar we held based on this book has had an enormous impact at the University of Oregon, certainly greater than any course or seminar I have ever been a part of before.

In my opinion, qualitative and quantitative mathematical psychology have reached the point of development where we should insist that the vast majority of all students in "experimental" psychology develop some conceptual (mathematical) sophistication to accompany their experimental and statistical sophistication. Since semantic memory is currently "hot," systematic exposure to this book provides an excellent vehicle for increasing the conceptual and theoretical training of graduate students in cognitive psychology. I do not think that the proper way to introduce the area of semantic memory is by prior study of linguistics or computer science, since these areas provide less motivation to the student in the form of the psychological relevance of the conceptual material being learned. Finally, prior study of empirical psycholinguistics is of only minor value in understanding the theoretical conceptions important in semantic memory and simply lengthens the time to acquire the necessary sophistication.

Structure of Semantic Memory

Associative Memory

As in any associative memory, Anderson and Bower's semantic memory is composed of nodes and links (associations). Anderson and Bower develop the notion that there is more than one type of link connecting the nodes of semantic memory, and they have a specific proposal regarding the different types of labeled links. However, their proposal may be somewhat open-ended in that they are concerned with only a simple subset of all English sentences. The propositions that can be represented in HAM have five principal constituents (subject, verb, object, location, and time). Each of these constituents may be modified by an adjective or a dependent proposition. Yes-no and wh-questions may be asked concerning any of the five constituents. Anderson and Bower restricted the form of the sentences that could be input to semantic memory. It was not clear to me whether Anderson and Bower thought that the set of labeled links which they employed in dealing with this subset of English sentences would be sufficient to handle the underlying semantic (propositional) structure of all sentences that can be encoded into semantic memory. As currently formulated, HAM consists of approximately 30 different types of associations organized in pairs of mutual inverses (forward and backward associations).

In my simplistic intuitive neurophysiologizing, it seems somewhat implausible to imagine that there are say 30 chemically distinct types of synapses. However, even if there were only one type of synaptic connection in the area of the brain concerned with semantic memory, for the purposes of an abstract psychological model, it might well be desirable to assume 30 different types of links, especially since we do not know whether psychological links correspond to sets of physiological synapses (though this has always been the primary hypothesis).

Propositional Nodes

Besides having a multiplicity of labeled links, Anderson and Bower have taken another important step away from traditional associative memory by assuming that learning consists not of the formation or facilitation of connections between already existing nodes (ideas, concepts), but rather "vertical" associations between existing nodes for lower-level concepts, phrases or propositions and higher-level nodes representing phrases and propositions. For example, to encode the phrase "touch debutante," Anderson and Bower do not assume the formation or facilitation of a single link between the concept "touch" and the concept "debutante." Rather, they assume that a new node is formed standing for the predicate "touch debutante" to which both "touch" and "debutante" are linked in both forward and backward directions. Similarly, the proposition "hippie touch debutante" is encoded in semantic memory, not by direct associations between each of the pairs of concepts, but rather by a hierarchy of "vertical" associations: (a) "touch" and "debutante" to the predicate nodes "touch debutante" and (b) the predicate node and the subject "hippie" to the propositional node "hippie touch debutante."

To me this assumption of the existence of phrasal and propositional nodes was the single most important idea in the book. Anderson and Bower's theory does not quite assume that phrasal and propositional nodes are equivalent to more elementary concept nodes (and I consider this to be a defect of the theory). However, Anderson and Bower's theory deviates from the traditional assumption that associations are "horizontal" (directly connecting the component ideas of a proposition) more than the theories of either Norman and Rumelhart (1975), or Schank (1974).

The assumption that associative memory requires the capability of adding new nodes by means of these vertical associations is an idea that seems very attractive and necessary to me. For example, I have argued elsewhere (Wickelgren, 1969) in favor of the assumption that associative memory can add new nodes or elements to stand for new concepts or ideas as they are learned. Horizontal associations between the attributes of a concept seem completely insufficient to explain our capacity for representation of concepts. Also, I once used a somewhat similar notion of vertical associations of items to serial position concepts to explain rehearsal grouping phenomena in short-term memory (Wickelgren, 1964, 1967). Miller's (1956) famous chunks and Estes' (1972) control elements also assume that component items can be linked together by vertical associations to a new superordinate element. Finally, as Anderson and Bower suggest, it is possible to interpret some aspects of the Gestalt and reconstructionist theories of memory as involving the assumption that nodes can be added to associative memory. So there are predecessors of this basic idea, but to my knowledge no one before ever proposed the elegant idea that new nodes might be introduced in memory to represent phrases and propositions. Although Anderson and Bower's theory does not quite propose this, it proposes something so close to it that, should this idea prove to be useful, it must rank as a major contribution by Anderson and Bower to cognitive psychology.

Actually, Anderson and Bower economize on the number of nodes in memory by representing conjunctive compounds of phrases and propositions with single nodes as often as possible in preference to unique node representation of each phrase or proposition. For example, if HAM has already stored that "John hit the ball" and later is presented with "John touched the debutante," it will link the new predicate to the old propositional node in such a way as to form a propositional node representing the compound sentence "John hit the ball and touched the debutante." Similarly, at the phrasal level, if HAM has already stored in memory that "a hippie touched a debutante" and later receives the sentence that "the same hippie kissed the same debutante," HAM will link "touched" and "kissed" to the same predicate node to form a compound predicate representing "kissed and touched the debutante."

This appears to be a mistake. Individual propositions should have separate nodal representation. One reason for this is to permit easy encoding of a subsequent contradiction to one element of the compound proposition. As I understand it, HAM's current method of representing propositional negation, in combination with single node representation of compound propositions, would not permit one to later contradict a single propositional component of the compound. HAM encodes the negation of an existing proposition by embedding the proposition into the higher order node "It is false that ..." HAM's treatment of propositional negation seems correct. The assumption of compound phrasal and propositional nodes seems incorrect.

What appears to me to be a more reasonable way to represent a compound sentence such as "the hippie touched the debutante and the policeman touched the debutante" is to assume separate propositional and subject nodes, but links to a common predicate node ("touched the debutante"). An associative semantic memory must recognize the commonality of two predicates, but not at the price of inability to later independently negate either proposition, to say nothing of the ability to independently retrieve one proposition without the other. Graphical illustration of the difference between these two modes of representing compound propositions is shown in Figure 1.

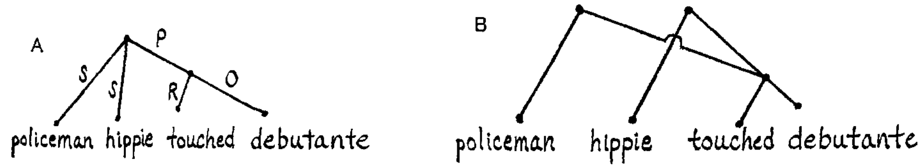

FIG. 1A. Anderson and Bower's representation of a conjunctive compound proposition. S = Subject, P = Predicate, R = Relation (verb), O = Object.

FIG. 1B. Independent propositional representation of a compound proposition.

Semantic Memory is a Network

In agreement with all psychological and computer science models of semantic memory with which I am familiar, HAM represents memory by means of a network, rather than a set of independent hierarchies such as were commonly found representing propositional material in the early days of the Chomskian revolution in linguistics. I suppose no one ever believed that semantic memory was a set of independent hierarchies, but it is worth pointing out that in "deep structure" (here interpreted to be equivalent to semantic memory), as in surface structure, one proposition can be embedded as a constituent of another proposition. The same node for a concept or phrase should be considered as linked into every propositional structure in semantic memory in which it occurs.

Between-Propositional Analysis

One of the many useful distinctions made in Anderson and Bower's book is the distinction concerning the between-propositional level of analysis and the within-propositional level of analysis. The distinction has some analogy to that between propositional and predicate calculus, though Anderson and Bower's within-propositional constituent structure is far more detailed than the constituent structure of predicate calculus.

Basically, Anderson and Bower's theory of the between-propositional level of analysis simply states that compound and complex sentences have as their constituents the propositions represented by the various component clauses of the sentence. I guess everyone in linguistics and psycholinguistics agrees with this, and, in Chapter 9, Anderson and Bower present some evidence supporting the psychological reality of this between-propositional level of analysis in the form of positive transfer for learning new sentences that contain previously learned complete subject + verb + object propositions.

Adjectives. Somewhat more debatable is the assumption made by Anderson and Bower (in agreement with Chomsky) that the semantic memory (deep structure) representation of adjectives is equivalent to that of a modifying dependent clause. That is to say, a sentence such as "John bit a red apple" would be represented by two constituent propositions: "John bit an apple" and "the apple is red." Although Anderson and Bower appear to assume this deep structure analysis of adjectives, they do not do experiments using adjectives and appear to have largely ignored the issue. I do not remember the exact experiments that have been performed on this question, but it is my impression that there is precious little psychological evidence that supports the separate propositional representation of adjectives. Anderson and Bower might handle adjective and noun phrases in a manner similar to their treatment of definite descriptions, but the success of such treatment cannot presently be evaluated.

Within-Propositional Representation

In my opinion, the heart of any theory of semantic memory is its representation of the components of a proposition. There are quite a variety of different proposals regarding within-propositional representation, including the theory of Anderson and Bower, but little empirical support for one over another and predictive inadequacies for all of them.

Although Anderson and Bower admit (p. 509) that their within-propositional representation has very little support, it is still interesting to consider it. In agreement with Chomsky, Anderson and Bower assume a predicate grammar that conjoins the verb (relation) and object together to form a predicate node and then conjoins the predicate node to the subject (or agent) to form the fact node.

Context, events, scenarios. The somewhat novel and interesting component of Anderson and Bower's within-propositional representation is the existence of a context node which is conjoined with the fact node to form the high level propositional node. The immediate constituents of the context node are location and time. Thus, instead of location and time being modifiers of the verb or constituents of the predicate, they are high level constituents of the proposition on a par with the (nuclear) fact node. In HAM all of the facts that occur in a common context are linked to the same context node, which implies that the context node might be considered to represent an event (although temporal sequences would not be represented). In HAM, such event representation is done by linking the multiple fact nodes to the same high level propositional node creating a compound propositional node. However, for the reasons stated previously, it seems superior to create new propositional nodes for each of the facts that occur in a common context, but link each to the common context node. Thus, either the highest level node in HAM or the context node in the presently proposed theory represents the event (set of facts occurring in a common context). This seems intuitively nice, though no way has been specified here to represent the sequence of facts or events (a scenario) and representation of this might introduce considerable complexity.

Experiments. The experiment in Chapter 9 that demonstrated positive transfer in the learning of new propositions containing a previously learned fact constituent (subject + verb + object proposition) also demonstrated no positive transfer in the case of previously learned subject + verb, verb + object (predicate) or subject + object constituents. Anderson and Bower's theory and any theory that asserts a reality to the predicate node would seemingly require positive transfer for the verb + object constituent in comparison to a no-repetition control condition or the subject + verb or subject + object repetition conditions. Case grammars of the type used in linguistics by Fillmore (1968) and in semantic memory by Rumelhart, Lindsay, and Norman (1972) might predict the verb to be closely related to both the subject and the object, obtaining positive transfer for both of these cases, but not for the subject + object repetition. However, no positive transfer was obtained for any of these pairs of constituents, which I suspect indicates that something is basically wrong with both of these basic conceptions of the constituent structure of propositions.

One possible way out is to assume that the fact node decomposes into subject, verb, and object constituents without any intermediate node structure. However, this suggests that the subject and object are as closely related to each other as the subject and the verb or the verb and the object. This is contradicted by everyone's structural intuition. Since positive transfer was obtained for repetition of an entire fact, positive transfer experiments of this type appear to be relevant for evaluating the nodal structure of semantic memory. Hence, we are faced with a puzzling theoretical problem, the solution to which may go a long way toward adequate within-propositional representation.

Being verbs. A minor elegant feature in the Anderson and Bower theory is the fact that verbs of being (is, are, was, were, etc.,) are not represented in the same way as other verbs, but rather are considered to be represented by an undifferentiated predicate node as shown in Figure 2. The difference in the representation of a sentence with a verb of being compared to one with a transitive verb is shown in Fig. 1. It should be noted that the representations shown in Figures 1 and 2 are simplified by deletion of terminal quantifiers from the representation assumed by HAM.

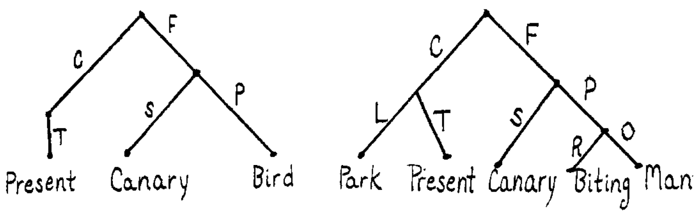

FIG. 2. Representations in HAM of "A canary is a bird" and "A canary is biting the man in the park." C = context, F = Fact, L = Location, T = Time, S = Subject, P = Predicate, R = Relation (Verb), and O = Object.

Subjects or agents. Anderson and Bower waffle considerably concerning whether they prefer to use deep subjects or agents. The distinction primarily arises concerning the question of the representation of passive sentences. The subject of a passive sentence is the object of the corresponding active sentence and vice versa. One could assume that passive sentences are represented with the subjects and objects reversed compared to the representation of the corresponding active sentences. However, it has appeared parsimonious to many people including Anderson and Bower to assume instead an underlying unitary representation for both passive and active forms of the sentence, replacing the notion of subject with the notion of agent. A similar solution might be taken for the representation of "John is taller than Bill" vs. "Bill is shorter than John," where we might consider the marked form ("Bill is shorter than John") to be represented using the unmarked relation ("John is taller than Bill").

Unfortunately, experiments performed by Anderson and Bower do not unambiguously support the notion of a common underlying form of encoding for passive and active sentences, though they do suggest that such sentences are closely related (as one feels sure must be the case). The need to explain why passive sentences exist in the language in combination with the desirability of simply representing the equivalence of active and passive forms is another important unsolved problem.

Structural vs. temporal contiguity. The sad state of affairs regarding within-propositional representation is nowhere more convincingly demonstrated than in pages 319–329 where physical (temporal) contiguity sometimes provides better prediction than HAM of what concepts are most closely associated to other concepts within propositions. Only a fool could think that the physically adjacent words in a sentence constitute the principal structure of semantic memory. Hence, I interpret the failure of HAM's propositional contiguity by comparison to temporal contiguity to reflect the miserably inadequate state of our understanding concerning within-propositional representation. This is especially so considering that, once again, the analysis of between-propositional structure was quite superior to physical contiguity in predicting what is most closely associated to what in sentence recall.

Quantifiers. Quantifiers are represented in HAM in a very interesting way. Instead of considering a quantifier (all, some, etc.,) to be a high-level constituent of a proposition which they appear to be in symbolic logic, Anderson and Bower attach quantifiers to terminal nodes of propositions. Quantifiers have always been somewhat mysterious to me and I do not pretend to understand very well the implications of Anderson and Bower's decision in favor of terminal quantification. However, the basic idea is that there is something in common between the concepts for each individual dog that we know in the world, each subset of dogs, and the concept all dogs. A given proposition refers to some particular dog or to some particular subset of dogs or to all dogs, but whichever of these particular concepts is referred to in a proposition, that concept is conceived to be associated via the appropriate quantifier link to the common concept dog. Hence, if your dog, Rover, bit a particular postman there would be a node representing Rover which was associated via the set membership link to the concept dog, and there would also be the same type of link between the node representing the particular postman that he bit and the general concept of postman. Finally, the same type of link would exist between the node representing the particular act of biting that your dog performed and the general concept of biting.

The representation of Rover bit all postmen is as shown in Figure 3, where the particular node for Rover is linked via the set membership association (∈) to the concept of dog and all postmen is linked via the "generic" association for universal quantification (∀) to postman, and the particular act of biting that Rover (or dogs ?) do (does) to postmen (or all people or no restriction ?) is linked by the generic association to a more general concept of dog-biting (?), which in turn is linked by the subset association (⊆) to the general concept of biting. Of course this sentence is a bit absurd since it asserts that Rover is currently biting or has bitten or will bite all postmen that exist. However, I wanted to represent all three types of quantifiers in HAM using a single diagram. I believe I did this.

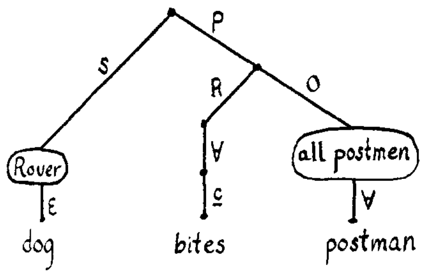

FIG. 3. Representation of the three types of quantifiers in HAM: member (∈), subset (⊆), and generic (∀ meaning "all" or "for all").

It seems like a pretty complex structure to attach to the bottom of every terminal node in a propositional structure. However, this somewhat clumsy looking structure should not be discarded without considering its desirable properties. For one thing, there are a large number of different concepts of individual dogs which are to be distinguished from the concept of all dogs and from the concepts for each subset of dogs (Terriers, Dobermans, etc.,). Yet they all have something in common. HAM represents this, and, although it complicates the structure somewhat to do so, we cannot dispense with this unless we can propose a satisfactory alternative representation. Perhaps it is unnecessary to distinguish between the particular kind of biting that a dog does and the particular kind of biting that a lion does in the manner suggested by Anderson and Bower. However, these are distinct concepts, and it is not clear one way or the other to me, intuitively, how they should be distinguished in semantic memory.

I am not fond of the procedure of labeling the links. One alternative is that "Rover is a dog" could be represented by a simple subject-predicate construction. A similar solution could be used for all subsets of dogs. However, there are important subtleties here that Anderson and Bower discuss (somewhat opaquely). For example, the Terrier subset of dogs is not itself a dog. Each member of the subset is a dog, but the subset is not a dog. The relation between individual elements and subsets of these elements must be represented. One of the major contributions of the Anderson and Bower book is to draw attention to this important problem and to suggest one possible solution.

Concepts and words. Anderson and Bower also draw explicit attention to the distinction between the concept (idea) and the word representing the concept, that is between dog and "dog." The word representing the concept is linked to the general concept node via the word-idea association. One might try to dispense with unitary word representatives and consider the representative of a word to be the set of its phonetic (segmental) constituents. However, I suspect that a unitary (chunk or concept) representation of words is also necessary.

Types and tokens. Finally, linking terminal constituents of propositional trees via quantifier associations to more general concepts, in my opinion, exhibits a superb use of the type-token distinction. Instead of pretending that we create multiple tokens willy-nilly every time the same concept appears in a new sentence, Anderson and Bower assume that tokens are introduced only to represent (sometimes subtle) differences in meaning for the same type. Hence, when the term "the dog" is used in one sentence, it may refer to Rover, and, in another sentence, it may refer to a different dog. Obviously, we should represent these by two different concepts. Anderson and Bower introduce nodes to represent these two quite properly different concepts, linking each of them via the set membership relation (quantifier) to the more general concept of dog. If both of these dogs have names, then each individual dog concept would be linked to its own word representative. However, many concepts have no name of their own and require disambiguation by an appropriate context for unique identification. The fact that these concepts do not have single words associated to them does not mean that the concepts should not have distinct nodes representing them. Anderson and Bower quite properly decide that they should. Once again, one must be impressed by the deep sophistication that Anderson and Bower demonstrate in understanding the problems of adequate representation for semantic memory.

I do not personally believe that every individual act of biting should be represented by a new node (token), and it is not clear what Anderson and Bower believe regarding such matters. It seems to me that, at some point, representation in semantic memory must ignore subtle differences in favor of completely equivalent encoding of similar concepts in different propositions, allowing the propositional context to further distinguish the concept in this context.

Verbal Learning

Anderson and Bower also assert that traditional verbal learning material is encoded by somewhat degenerate propositions. This seems like a reasonable extension of their theory to such material and recent work on the efficacy of various mnemonic devices that in most instances amount to embedding pairs of verbal items into verbal or imaginal "propositions" is certainly consistent with this general point of view. Similarly, the importance of serial position concepts and grouping concepts for the organization of linear orders, such as in serial list learning, also argues for some more abstract propositional structure underlying this type of learning as well. In the case of syntactically unstructured material, such as typically used in verbal learning experiments, it is not clear that much is added by a propositional analysis, other than the distinctly important fact that all learning is subsumed under a common rubric.

Anderson and Bower's belief that the extension of their theory to verbal learning materials was necessary to generate interest and experimental testing of their theoretical notions seems to me to be wrong. The interest in Anderson and Bower's book will surely be primarily from cognitive psychologists, psycholinguists, linguists, and computer scientists interested in theories of semantic memory, not verbal learning researchers.

Also, I fail to see how two obviously brilliant people such as John Anderson and Gordon Bower can waste their time studying a hopelessly uncontrolled procedure such as free-recall. Basic research theories of such uncontrolled and complex processes are a scientific absurdity. Since free-recall also has little practical significance, I consider FRAN a waste of time.

Recognition

The goal of a recognition procedure is to map an input sentence or some portion thereof into some or all portions of an existing node structure (network of nodes and associations) in semantic memory. Recognition is an important part of the acquisition of new knowledge in semantic memory, since new knowledge should be associated to old knowledge. Recognition is also an important part of any memory usage process, since the answering of questions requires one to recognize the question as referring to some portion of semantic memory. HAM's recognition process basically consists of two parts: the parser and the MATCH process.

HAM's parser is a top-down, left-to-right predictive parser, which works only because of the simple subset of English sentences given to it. HAM's parser is neither original nor powerful and has the common flaw of existing parsers in that it does not take semantic knowledge into account in the parsing process.

The result of the parsing process is an input tree that has the same form as trees stored in semantic memory. That is to say, HAM's parser does not produce a surface structure, but rather a deep structure (here used to be equivalent to a semantic memory). This seems nice, but my intuition says that the integration of semantic memory and the parsing aspect of sentence recognition must be much more complete than in HAM. In HAM, parsing creates a tree structure that is initially isolated from the rest of semantic memory and then MATCHed to existing semantic memory structure only after completion of parsing the entire sentence.

HAM implements Anderson and Bower's belief that syntactic knowledge should not be represented in the same way as other knowledge in semantic memory. Maybe this is so, and maybe it is not. My guess is that an adequate recognition routine will operate more from the bottom-up (starting with word nodes) and will use existing semantic memory structure from the beginning. Parsing probably proceeds in intimate combination with mapping input words, phrases, and propositions onto existing semantic memory word concept, phrase, and propositional nodes whenever possible, creating new nodes when needed. I doubt that parsing, matching, and acquisition are temporally separated at the propositional level, though they may well be somewhat separate processes that are capable of independent study.

Acquisition

Anderson and Bower have little to say concerning acquisition that was not already said in conjunction with the recognition process. This occurs for several reasons. First, Anderson and Bower have no theory of the dynamics of parsing or acquisition. They do have a theory of the dynamics of MATCHing, which will be discussed briefly in the Retrieval section.

Acquisition of new nodes and links in semantic memory is accomplished in HAM by the MATCH process which simply grafts all the unMATCHed portions of the input tree onto the MATCHed portions following the rule of achieving the highest degree of node economy.

However, as mentioned previously, HAM's MATCH process is a bit overzealous in its efforts to create higher-level node economy in that it creates compound propositional nodes. This produces the problem of independent contradiction of each proposition. Although Anderson and Bower did not acknowledge this problem, they did note that their MATCH process can lead to "multiplication of meanings" (discussed on pp. 243–246). As an example of this, consider that in HAM a propositional node may join subject-1 with predicate-1, later join subject-1 to predicate-2, and then later join subject-2 to predicate-2. When this happens, one also gets subject-2 joined to predicate-1, which is not a valid inference. To solve this problem, Anderson and Bower created another process, IDENTIFY, which inhibits the MATCH process whenever it would produce (unwanted) multiplication of meanings. Since IDENTIFY is a very ad hoc process which does not solve the problem of independent contradiction, a modification of the MATCH process to achieve structures such as shown in Figure 1b would seem to be well advised.

Avoiding multiplication of meanings raises the general principle that one good way to evaluate any theory of semantic memory is to see, not only that it produces correct inferences, but also that it does not produce incorrect inferences. As a consequence of what appears to be a clear theoretical error in representation and in the MATCH process, Anderson and Bower have generated a nice example of how this evaluation procedure might be employed in developing theories of semantic memory.

Storage

HAM has four different types of memory. First, there is the sensory buffer that contains up to seven words. Second, there is a push down store that indicates where HAM is at in the parsing process. Third, there is a working memory that holds the tree structures generated during parsing and for use during the MATCH and IDENTIFY processes. Finally, there is the long-term semantic memory. This is an excessive number of different memories for my taste. In my opinion, the reasons for this large number derive primarily from the separation of parsing, matching, and acquisition, top-down parsing, and not enough parallel processing.

Although Anderson and Bower devote an entire chapter to the topic interference and forgetting, it is clear that Anderson and Bower's primary efforts were directed to storage. Associations in HAM are "all or none," although the ordering of associations with identical link labels on the GET lists at each node does provide an unusual kind of gradation. The only storage process to be found in HAM is that new associations with the same link label at a node "bury" old associations in the recency-ordered GET list. Retrieval at a given node involves serial search in both recognition and recall, and Anderson and Bower assume that retrieval stops after some randomly determined period of time. Hence, HAM has a interference mechanism that is similarity dependent in a reasonable way.

HAM does make one unique prediction concerning storage which is that interference obtained from repeating the same word in different sentences should be obtained only if the concept denoted by that word has the same relation to the other concepts presented in the sentence. For example, HAM expects interference if the same concept is used as the subject (or the agent) in two sentences, but does not expect any interference if the same concept is used as the subject in one sentence and the object in another sentence (or the agent in one sentence and the object in the other sentence). HAM predicts both relation-specific negative transfer and retroactive interference. Anderson and Bower obtain the effect in transfer, but not in retroactive interference. The prediction is obviously "up in the air." I was no more successful than Anderson and Bower in figuring out why this should have happened.

The most obvious flaw in HAM's storage dynamics is that the ordering of the GET lists is by recency only. However, I doubt that accounting for frequency effects would pose insuperable difficulties for HAM. Overall, it appears that Anderson and Bower had no desire to devote much of their theoretical effort to precise formulation of storage processes, being content to postulate some process that was a crude first approximation which they hoped would not greatly affect their evaluation of the parts of the theory into which they put more effort. This is a reasonable and necessary way to go about attacking a complex problem.

Retrieval

I use retrival to refer to yes-no (recognition) and wh-(recall) question answering. Following Anderson and Bower, this elementary retrieval will be limited to the answering of such questions on the basis of information that was presented to a subject in a single proposition for direct encoding in semantic memory. Answering these questions requires no inference (combination of separately stored information). Besides the intrinsic interest of the problem, a precise theory of elementary retrieval is important in that it permits one to evaluate theories of the structure of semantic memory via predictions concerning the asymptotic accuracy or dynamics of such elementary question answering.

Essentially all of Anderson and Bower's theory of retrieval is contained in the recognition process which matches a probe tree to a portion of semantic memory. However, in order to predict times for recognition responses (verification times) and recall (answers to wh-questions) it was necessary to make a number of quantitative assumptions concerning the MATCH process and the decision rule concerning whether the retrieved structure matches sufficiently to make a "yes" response in the case of recognition. In recall, Anderson and Bower had to assume stimulus-input and response-output bias parameters.

Most people, myself included, feel that Anderson and Bower's chapter 10 concerned with recall (wh-question answering) after sentence learning was completely inconclusive as a means of evaluating either HAM's structural assumptions or its assumptions on wh-question answering, because of the manifold opportunities for compensating errors in the estimation of the large numbers of parameters. Some of the qualitative results concerning sentence recall are interesting, but since we already know from other data that HAM's model of within-propositional structure must be incorrect, it is not clear what comfort should be taken in partially successful predictions. It seems to me that more attention might have been paid to what Anderson and Bower refer to as "unpredicted second recalls" and "recalls to inadequate stimuli," since the nature of these unpredicted recalls might indicate some of the deficiencies of HAM's theory of sentence structure or retrieval processes.

Recognition memory dynamics (verification times) is largely discussed in Chapter 12 (fact retrieval). The first experiment discussed in this chapter obtained the result that verification time was slower for propositions whose constituents were found in other propositions in semantic memory as opposed to sentences in which the constituents were unique to that sentence. The MATCH process in HAM and in any associative theory of semantic memory will develop multiple associations to the same concept used in several propositions. This leads to the possibility of associative interference.

Anderson and Bower interpret this finding as evidence for a serial search of identically labeled links from a given node. However, in view of the fact that A-C interpolated learning produces unlearning of A-B associations (as assessed by recognition tests), it would appear to be at least as reasonable to assume a parallel search process with lower levels of strength for A-B associations that are followed by A-C interference.

Because of the enormous degree of speed-accuracy tradeoff found in recognition memory retrieval (Reed, 1973, 1974), it is not possible to draw conclusions regarding the dynamics of memory retrieval processes on the basis of reaction time data alone without also considering accuracy level (Pachella, 1974; Wickelgren, 1974, 1975), Speed-accuracy tradeoff in memory retrieval occurs over a substantial period of time on the order of 500 to 1000 msec. (Reed, 1973), and the form of the speed-accuracy tradeoff function is such that at low levels of error rate, small differences in error rate can translate into tens or hundreds of msec. of difference in reaction times. It is precisely at low error rate where the possibility is greatest for drawing erroneous conclusions on the basis of reaction time alone. Furthermore, the existence of substantial speed-accuracy tradeoff renders meaningless the quantitative prediction of reaction time as the dependent variable, without simultaneous quantitative prediction of error rates.

Anderson and Bower's attempt to fit a quantitative model for yes-no recognition memory times provides yet another illustration of the irregularities one encounters when one develops and tests quantitative theories for reaction time without consideration of speed-accuracy tradeoff. In the first place, the quantitative fit of their model is not too good. In the second place, there is substantial parameter variation. In the third place, as Anderson and Bower move from one recognition memory reaction time experiment to another, they shift their assumptions regarding whether the scan is exhaustive or self terminating. Such unsatisfactory results are precisely what one expects when a basic factor such as speed-accuracy tradeoff is being totally ignored.

Some interesting experimental results are reported in the rather curious but interesting Chapter 11. These results are supportive of both HAM's structure of semantic memory and its retrieval process. However, since HAM's theory of within-propositional structure appears to be wrong on the basis of other evidence, these results can only be taken as phenomena that any new theory must predict.

One interesting result was that the probability of recalling the object to the subject, for example, was independent of the number of sentences in which the verb was involved. So verb repetition does not produce associative interference for "irrelevant" constitutents of the proposition. Whether this is contradictory to a Gestalt theory seems to me to be undecidable, since Gestalt theory is so vague and insufficiently developed that it is not clear what predictions it makes. However, the result would seem to be contradictory to some versions of case grammar in which the verb plays the central role in linking subject and object. However, if one uses a different node for a verb in every different proposition in which it occurs, as I guess Norman and Rumelhart do, such a case theory of the structure of semantic memory would not be contradicted by this result. Nevertheless, the result seems important.

Other interesting results were those involving crossover-cues (pp. 337–341). If a subject learns two sentences such as "The child hit the landlord" and "The minister praised the landlord," HAM predicts that object recall will be slightly superior for a sentence that mixes the subject for the first sentence with the verb for the second (e.g., "The child praised the ———.") than for a sentence that takes the subject and the verb from the same sentence (e.g., "The child hit the ———."). Although the difference is not predicted to be large, it seems to me that intuition would have suggested the opposite conclusion. In fact, the experiment showed a small difference in the direction predicted by HAM. The result appears to mean that having two independent cues for eliciting recall is superior to having two dependent cues (utilizing some of the some links). This probably says more about retrieval processes involved in wh-question answering than it does about the structure of semantic memory.

One might well question the ultimate psychological validity of distinguishing fact retrieval for previously stored information from retrieval that requires inference. Anderson and Bower distinguish these two subproblems, but it may well be that precisely the same retrieval processes are involved in each case. Regardless of the ultimate outcome of this question, it seems useful at the present time to distinguish these two subproblems, keeping in mind the attractive possibility of eventually developing a unified theory for both.

Inference

Anderson and Bower admit that HAM is weak in inferential capacity. However, largely in Chapter 10, Anderson and Bower list and discuss a large number of semantic inferences that people are capable of making.

Synonyms and Definite Descriptions

Apparently, HAM is programmed to achieve the inference that "If George Washington lived at Mt. Vernon and George Washington was the first president of the United States then the first president of the United States lived at Mt. Vernon." HAM draws these inferences automatically at the time of input by virtue of having a single representation for the concept of George Washington regardless of whether he was referred to directly by name or by a description. The same holds for synonyms. It is quite desirable that HAM has this inferential capacity, but it is also clear from the results on pages 248–251 that subjects are capable of some differential encoding for sentences with names as opposed to sentences with definite descriptions. There is no elegant accounting for this difference in HAM, though Anderson and Bower often make noises to the effect that differences like this could be accounted for by means of a certain degree of auxiliary propositional encoding.

Negation

Anderson and Bower discuss the representation of negation and inferences involving negations. HAM encodes propositional negation by embedding a negated proposition P as a predicate in a superordinate proposition, "It is false that P."

This is okay for saying no to P in fact retrieval, but how, in general, does one make the inference that Q is false because it is contradictory to stored information. Perhaps this should be considered a different problem.

Another nice feature of HAM is that it includes encoding of the presuppositions of negation. Anderson and Bower provide the example of "It wasn't in the park that the hippie touched the debutante." HAM's encoding of this is equivalent to "At some place the hippie touched the debutante and it is false that the place was the park." One presupposes that the episode occurred and then denies that its location was in the park. Beside its intuitive plausibility, there is some direct psychological evidence for the distinction between given information (the presuppositions) and the new information in a variety of sentence types (Haviland and Clark, 1974).

Verification vs. recognition memory. Recognition memory experiments and verification experiments appear similar in that both involve two alternative answers that at first glance might appear to be equivalent. Anderson and Bower implicitly regard them as equivalent probably because their verification experiments were essentially recognition memory experiments. However, in general, verification (judging truth or falsity) is not equivalent to recognition (judging occurrence), though there is probably a close relation. In a verification experiment, one might present two contradictory sentences with subjects instructed to go by the more recent sentence in determining truth. In which case, the answer "true" and the answer "yes" (sentence has occurred) would have different logical determination. It is even less appropriate to identify "false" with "no," since "false" means that the probe is contradictory to stored information, while "no" means something equivalent to "not stored in memory." Consideration of this issue is the sort of thing that leads one to speculate about the utility of the three-valued logic where a proposition can be true "true," "false," or "undetermined."

Opposites

Consider opposites both on binary scales, such as "in-out," "open-closed," "same-different," etc., where one term implies the negation of the other and as ends of continua, such as "tall-short," "heavy-light," "top-bottom," etc., where the two terms are contradictory, but the negation of one end of the continuum does not imply the opposite end. HAM is not currently programmed to perform relevant inferences involving opposites, but Anderson and Bower think it could be, and their discussion is quite interesting.

Mutually exclusive concepts

Anderson and Bower refer to mutually exclusive concepts as disjoint sets. An example inference here is that if Chicago is located in Illinois, it cannot be in Florida, since being in Illinois implies not being in Florida. One might regard this as a simple extension of the inferences involving ends of a continuum and perhaps an adequate theory of mutually exclusive concepts would handle both binary and continuum opposites and negation as well.

Set Inclusion

An example of such inferences is: "All pets are bothersome, Fido is a pet, therefore Fido is bothersome." As Anderson and Bower discuss, such set inclusion inferences could be programmed into HAM, but they appear to be rather awkward to achieve. By contrast, Quillian's (1968, 1969) much more limited model of semantic memory achieves set inclusion inferences quite simply and automatically. In my opinion, this deficiency of HAM is a critical one to focus on in modifying the theory.

All Implies Some

Such inferences have the form: "If all x are P, then some x are P." It was not clear whether HAM was already programmed to draw this inference, but it was quite clear that it could be. However, while the rule is trivial for this class of inferences, the conclusion begins to dawn on one that HAM is handling a large variety of inferences by means of a large variety of rules. It would be more elegant if a relatively small number of rules handled all the different types of inferences people make.

Exemplar Implies Some

A seventh inference type which Anderson and Bower do not discuss until the epitaph chapter as a deficiency of HAM is that "If x_i is P, then some x are P. The example given was "If red headed chickens are good layers, then some chickens are good layers." HAM does not make this inference, and clearly it should.

Disjunction (Or)

For example, "If John drove Mary home, then John or Keith drove Mary home." This does not seem like a very useful example of disjunctive inference, but human beings clearly have this capability.

Expansion

These are the important class of inferences most cogently identified by Schank (1972) and perhaps best described in the paper by Schank and Rieger (1973). My favorite example of such inferences is as follows: From "John fell overboard," we are capable of inferring (perhaps incorrectly but that is no matter) that "John was in a boat; John is now in the water; John is wet; John is swimming or otherwise struggling in the water, etc."

Schank handles such inferences by means of encoding at the time of the input that expresses an extended meaning for a proposition in terms of a primitive set of atomic concepts. I think Anderson and Bower are correct to disagree with Schank's approach to this problem. Anderson and Bower claim that many of these inferences are not made at the time of input, but only at the time of retrieval. They even cite some verification latency data in support of their prediction, though I think such experiments should be done using speed-accuracy tradeoff methodology. In any event, my intuition agrees with Anderson and Bower that many inferences are made at the time of retrieval. However, HAM has no mechanism for achieving such inferences. Since human beings make these expansions (relational and predicate inferences) easily and frequently in understanding written or spoken language, an explanation for this inferential capacity is another primary unsolved problem.

Transitive Relations (Linear Spatial Orders)

These inferences are of the form: "A is greater than B and B is greater than C, therefore, A is greater than C." HAM can encode such linear orderings in an economical way by storing the propositions "A greater than B" and "B is greater than C." HAM then can use a reasonably simple, but ad hoc, inference rule for the class of transitive relations.

One of the problems of this theory is that it makes the production that verification for a proposition such as, "An elephant is bigger than a termite" would be slower than verification for a proposition such as, "An elephant is bigger than a tiger." The proposition "elephant is bigger than tiger" is presumed to be stored directly, but the proposition "elephant is bigger than a termite" must be verified by the rule applied to a chain of transitive relations. Anderson and Bower discuss some evidence collected by Potts (1972) which is basically contradictory to this prediction and attempt to explain away Potts' results. The paradigms used by Potts (1972, 1973) may not yield evidence clearly contradictory to the prediction that decisions concerning close pairs are made more quickly than decisions concerning remore pairs in a linear ordering. However, the results of Moyer (1973) suggest that there is a class of linear ordering inferences which possesses the property that decisions are faster for remote pairs than for close pairs. Such results are incompatible either with Anderson and Bower's assumptions regarding the representation of linear orderings or with their inference and retrieval assumptions.

Generation

Much of our usage of semantic memory is in generating connected speech in conversations and soliloquies (and occasionally in lectures, dictating or writing papers, etc.). Anderson and Bower specifically avoided developing any theory of written or spoken sentence generation. The question is more complex than simple yes-no or wh-questioning for at least two reasons. First, the output is more complex than a single word or phrase as in yes-no and much wh-question answering. Problems of mapping underlying semantic memory structure into surface grammatical structure using syntactic rules come into play.

Second, the input conditions for such a generation of syntactically structured utterances are not so clearly defined as they are in verification or wh-question answering. What should we assume is the goal in speech generation? One reasonable solution to this problem is to imagine that the goal is to communicate fully some subset of the semantic memory network via one or more sentences. This is probably not a totally satisfactory answer to the input question, since one probably needs to place restrictions on the types of subsets of semantic memory that can be the input to the generation process. For example, it would seem unreasonable to require an adequate theory of speech generation to be able to translate any random set of nodes and links in semantic memory into connected discourse. It must be impossible to achieve a sentence with grammatical surface structure for most randomly selected subsets of semantic memory. Hence, it is necessary to specify some sort of grammar of appropriate input subsets from semantic memory.

Then, of course, it is necessary to specify the nature of the speech generation process that maps that subset of semantic memory into one or more grammatical surface structures. Note that I am ignoring the supposed fact that most spoken speech is not grammatical. For the moment, we might consider this to be a performance, rather than a capacity, problem and ignore it. However, psychologists are property suspicious of such solutions, and it may be that we need to know more about the real grammar of spoken speech than the "ideal" grammar of surface structure as developed from linguistic intuition.[1]

The only specific suggestion that I have for solving the problem of mapping underlying semantic structure into surface structure is to use augmented transition networks. For a discussion of augmented transition networks see Kaplan (1975), Stevens and Rumelhart (1975), and the classic paper by Woods (1970). Curiously enough, augmented transition networks appear to have been used primarily for speech recognition than for speech production, where they seem less obviously suited. Of course, it

[1] Recent research by Deese (1975) indicates that most of the spoken speech of educated adults consists of grammatical sentences, contrary to earlier intuitive assertions. Thus, performance appears to be much closer to capacity than previously supposed.

has always been an attractive hypothesis that the same syntactic knowledge used in speech production is also used in speech perception. Personally, I find the control ordering characteristic of augmented transition networks to be far more natural for speech generation than for speech recognition and reading. In any event, augmented transition networks are quite elegant and basically consistent with an associative memory structure.

Imagery

Anderson and Bower use the ideas of Winston (1970) that images are represented not as analog pictures, but rather as sets of propositions that describe various aspects of the image. The propositional representation of images is a very exciting idea which currently seems open to extensive theoretical development and ultimately experimental testing. The analog picture notion has produced some interesting experiments but has so far defied precise theoretical statement (Pylyshyn, 1973).

Anderson and Bower specifically reject the dual encoding position that there is both a verbal semantic memory and a spatial image memory, and instead opt for a single unified modality of semantic memory in which the construction of images constitutes only a greater "unpacking" of visual detail from higher order nodes in semantic memory. This is an interesting hypothesis, but I do not see how it will wash with all the evidence from split brain studies, lateralized brain damage, temporary immobilization of one hemisphere, and all the other evidence indicating that verbal memory is a separate modality from spatial image memory.

There are several different issues here. First, there is the question of whether the representation of images is propositional or analog-pictoral. Second, even if image memory is propositional like semantic memory, there is the question of whether the propositional structures are equivalent in semantic and image memory. Finally, there is the issue of whether these are two anatomically and psychologically separate representation modalities in which there might be dual representation.

One possibility is to consider that image memory is propositional, but that the nature of the propositional structure for the two modalities and/or the nature of the inference processes that accompany these structures are quite different. The nature of this difference should probably be that semantic memory has greater flexibility for representation of various types of information, including spatial information, but that image memory is particularly well suited for encoding, retrieving, and deriving inferences about spatial relations.

I have a strong hypothesis concerning what the difference might be. Semantic memory has an extensive degree of hierarchical structure for the storage of propositions that are embedded in other propositions. Furthermore, within-propositional encoding probably has some hierarchical structure. In general, this sort of complex embedding capability is quite essential to representation of human knowledge.

However, perhaps image representation has no propositional embedding and uses a one-level symmetric relational grammar. Thus, in image memory a scene is encoded as a set of relations with arguments, $R_i(\cdots x_j \cdots)$, where the arguments must be atomic elements, not propositions containing relations. There is clearly a massive degree of interconnection of various elements of the scene, since each object or part of an object has multiple relationships to a variety of other elements. However, it appears to me that scene description does not require embedding. I would appreciate a clear counter example.

If no counter example is forthcoming, this is an attractive idea for the difference between semantic memory and image memory, since a representation system that avoided embedding would appear to facilitate information retrieval. Even if there is a need for a certain degree of embedding for adequate scene description, it is conceivable that such embedding is accomplished by the verbal semantic memory with the rest of the information being stored in image memory. This begins to slip into a position similar to that held by Anderson and Bower, but preserves the claim that there is something basically different about image memory from semantic memory, besides the amount of visual detail.

For the moment it seems like the propositional approach to representation of image memory is more productive than the analog-picture approach. However, Anderson and Bower admit that there are certain phenomena, such as Stromeyer's (1970) eidetiker and the Shepherd and Metzler (1971) mental rotation phenomena, that appear on the surface to be more consistent with an analog picture approach. My guess is that we will soon have a number of theories of image memory, with at least a few having some analog-picture characteristics, even if the highest level image representations are propositional.

Conclusion

I hope it is obvious that I regard Anderson and Bower's book as a monumental accomplishment. The failures of various portions of HAM are often as interesting as its successes, and perhaps even more important. ***Human Associative Memory*** is the most valuable book I have ever read in psychology. I say this despite my guess that HAM will rapidly be superseded by better theories of semantic memory. But no matter how little of HAM is found in later theories, these theories will owe an enormous debt to the intellectual work done by John Anderson and Gordon Bower. However, on a lexical-graphemic level, I must declare that Anderson and Bower's book is frequently "unprincipaled."

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