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ABSTRACT

Noting that the sentence memory models formulated in the 1970s need to be altered so as to be consistent with the fact that people use prior knowledge to process new information, this report discusses issues to be considered in making such an alteration. The report focuses on three questions: (1) What conditions lead people to elaborate and organize input facts? (2) What are the mechanisms behind organization? and (3) How well can these organizational mechanisms be interfaced with the original theories of sentence memory? The report reviews some basics of how current sentence memory models represent and retrieve sentences and then illustrates three conditions that lead to an elaboration of representations. It then takes up each condition in detail, reviews the experimental data showing that the condition does indeed result in an organization of the input, and delineates the theoretical mechanisms involved. (FL)

CENTER FOR THE STUDY OF READING

Technical Report No. 185

ORGANIZATION OF FACTUAL KNOWLEDGE

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Introduction

For the past decade, psychologists have been intensively studying how people represent and remember the factual knowledge they encounter in sentences. Perhaps the high water mark of this research occurred in the first half of the 1970's with the publication of large-scale models, such as Anderson and Bower (1973) and Norman and Rumelhart (1975). This work deservedly became among the best known in cognitive psychology. Unlike some of its predecessors in the field of memory, the model of Anderson and Bower (1973) was sweeping in scope yet precise in detail.

Despite their achievements, these models had a major difficulty that rapidly became apparent to many. The problem was that the models achieved their theoretical power by representing only those facts that were explicit in the input sentences, and failed to give serious attention to how people brought to bear other knowledge that elaborated the input facts. This was a serious omission, partly because such elaborations are often the hallmark of true comprehension of the input facts, and partly because these same elaborations organize the input facts and boost their memorability. To illustrate, suppose you read: "Herb needed a diversion" and

"Herb looked at the movie times." In representing this information, you would presumably depict not only the facts explicitly stated but also something about going to a movie. The latter constitutes an elaboration of the input. From the point of view of comprehension, this elaboration is crucial because it provides a basis for integrating the input facts into a coherent scenario. From the point of view of memory, it is important because the elaborated facts turn out to be more retrievable than the unelaborated ones.

Lately there has been a lot of attention given to the above problem, much of it due to the same psychologists who produced the first generation of sentence-memory models. Thus when Anderson (1976) proposed a revision of the original Anderson and Bower (1973) model, he devoted much concern to how people elaborate input propositions. Similarly, Bower (e.g., Black & Bower, 1980), Norman (e.g., Norman & Bobrow, 1976), and Rumelhart (e.g., Rumelhart & Ortony, 1977) have all begun to study how people use what they already know to organize new information. There are also many contributions from artificial intelligence dealing with the use of prior knowledge in representing and remembering new information (e.g., Adams & Collins, 1979; Minsky, 1975; Rumelhart & Ortony, 1977; Schank & Abelson, 1977; Winograd, 1972).

So everybody seems to agree that the early 1970s' approach to sentence memory needs to be altered so as to be consistent with the fact that people use prior knowledge to process new information. But in making such an alteration, certain questions arise. The first is an empirical one:

(1) Precisely what conditions lead people to elaborate and organize input facts?

The remaining questions are theoretical:

(2) What are the mechanisms behind organization? Is there one basic one, or are there many?

(3) How well can these organizational mechanisms be interfaced with the original theories of sentence memory?

These questions form the focus of this paper.

With this as background, a more exact agenda can be given. The next section reviews some basics of how current sentence-memory models represent and retrieve sentences, and then illustrates three conditions that lead to an elaboration of representations. In subsequent sections, we take up each condition in detail, review the experimental data showing the condition does indeed result in an organization of the input, and try to spell out the theoretical mechanisms involved. The final section summarizes the main conclusions.

Sentence Representations and Organizational Possibilities

Representation and Retrieval in Current Models of Sentence Memory

Representation and retrieval of single sentences. Consider first how three different models would represent and retrieve the proposition in the sentence "Woody Allen makes movies." Figure 1 contains the sample representations. In all three cases it is assumed that the representation corresponds to a network, where the concepts--"Woody Allen, "makes," and "movies"--are depicted as nodes, and the relations between concepts are given by labeled links between nodes.

Panel A of the figure is based on the ELINOR model presented in Rumelhart, Lindsay, and Norman (1972). This network is centered around the verb or action concept. The node for the action, "makes," is linked to the nodes for the other two concepts, "Woody Allen" and "movies," while the latter two have no direct connection. Each connection has a label that depicts the semantic relation operative; e.g., "Woody Allen" is the agent of "making," "movies" is the object. To see how a retrieval process might operate on this

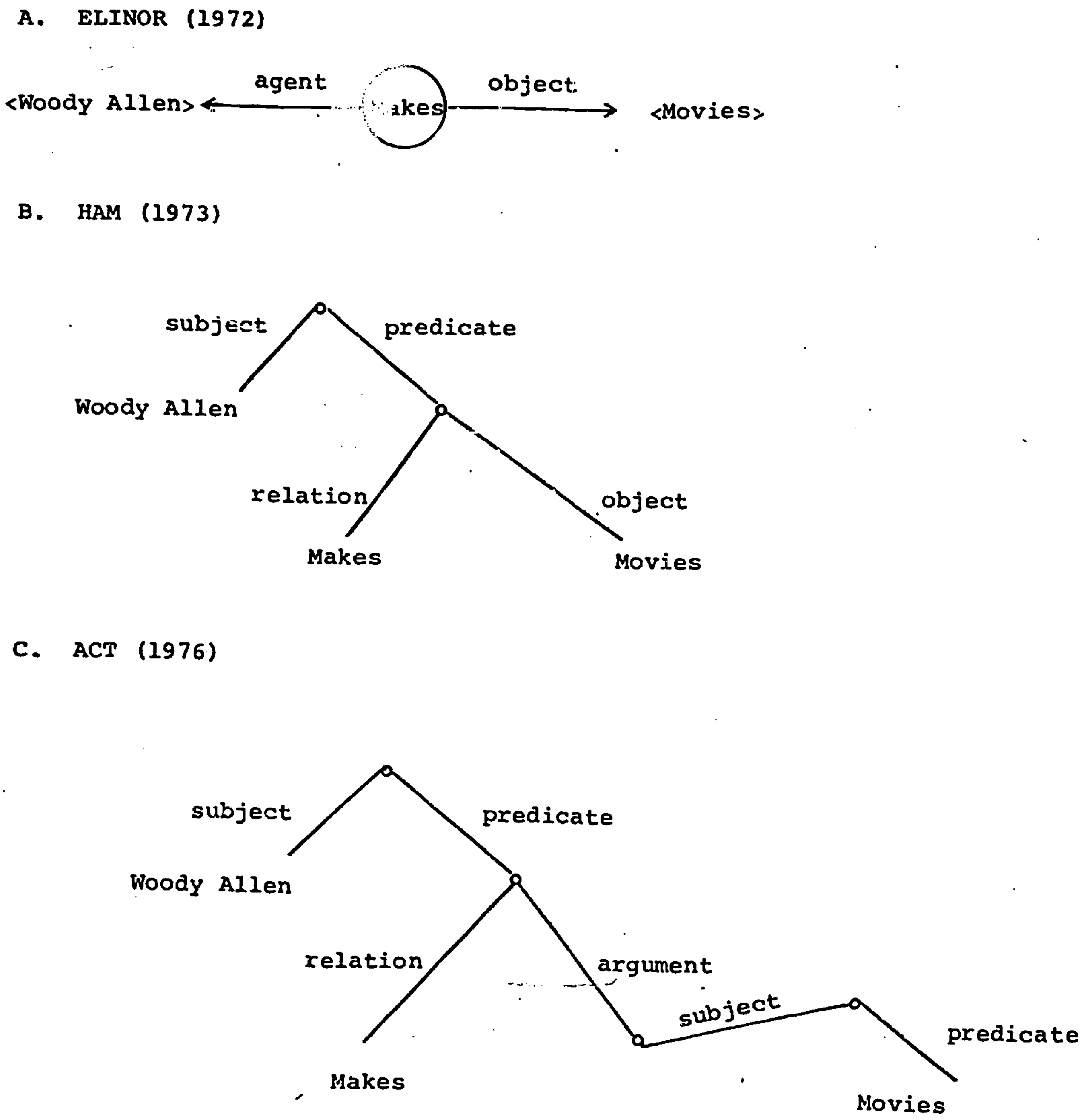


Figure 1. Propositional representations of "Woody Allen makes movies" based on: (A) Rumelhart, Lindsay, and Norman (1972), (B) Anderson and Bower (1973), and (C) Anderson (1976).

representation, suppose that you were presented the sample sentence as a probe and asked if you had seen it before. According to the general ideas in ELINOR, you would form a representation of the probe identical to that in Panel A, and then use the concepts in the probe to directly access those in the representation of the memorized sentence. From the accessed memory nodes you would search for a path, i.e., a set of labeled links, that perfectly matches the path in the probe representation. If you found such a path, you would say you recognized the sentence; if you did not, you would call it a novel sentence.

Panel B contains a representation from the HAM model of Anderson and Bower (1973). The action concept has no privileged status here. Rather, the internal structure of the proposition is closer to that of a phrase structure. There is first a distinction between subject ("Woody Allen") and predicate, and then the predicate itself is divided into a relation ("makes") and an object ("movies"). Again we have concepts connected by labeled links, but now some nodes are higher-order ones that stand for complex concepts, like that designating the entire predicate. It turns out, though, that the terminal nodes standing for specific concepts (e.g., "movies") do the bulk of the work in retrieval. And the retrieval process for HAM looks like the one described earlier. So if later asked if you have ever seen the probe "Woody Allen makes movies," you would form a representation of the probe just like that in Panel B of Figure 1, use its terminal nodes to directly access those of the memorized proposition, and search for a path connecting all nodes in the memorized proposition that matches the path in the probe representation.

Panel C of Figure 1 contains a third representation, one based on the ACT model of Anderson (1976). Its core is the subset of the network that relates "Woody Allen," "makes," and a node that eventually points to the concept of "movies." This subset is almost identical to the previously considered HAM representation, the only difference being the label _argument_ has replaced the label _object_. The rest of the present representation consists of a secondary proposition asserting that what Allen makes is a subset of the class of movies. While the latter is important for issues that Anderson (1976) was concerned with, it turns out not to be critical for the present discussion, and I will ignore it in what follows.

What cannot be ignored about ACT is its retrieval process. The discrete search process of HAM has been replaced by a continuous, spreading activation process in ACT. When the probe "Woody Allen makes movies" is presented, each word activates its corresponding concept in a long-term memory network, and activation from each of these sources spreads along the links emanating from the source. The rate of spread on a given link increases with the strength of that link (an associative-strength idea) and decreases with the number of other links emanating from that source (an associative-interference idea). When the activation from the three sources intersect, for instance, at the predicate node, the path leading to this intersection can be evaluated to see if its component links contain the same labels or relations as those specified in the probe. If the relations are the same, the probe would be recognized.

Representation and retrieval of sentence pairs. So much for single sentences. From the perspective of organization, nothing really interesting happens until we consider at least pairs of sentences. Figure 2 contains representations of two facts about Woody Allen: the old one about him making movies; and a new one about him living in New York. Panel A gives the ELINOR representation, Panel B a simplified HAM-ACT one.

In Panel A there are two propositions connected to the node for "Woody Allen." This should slow down the retrieval

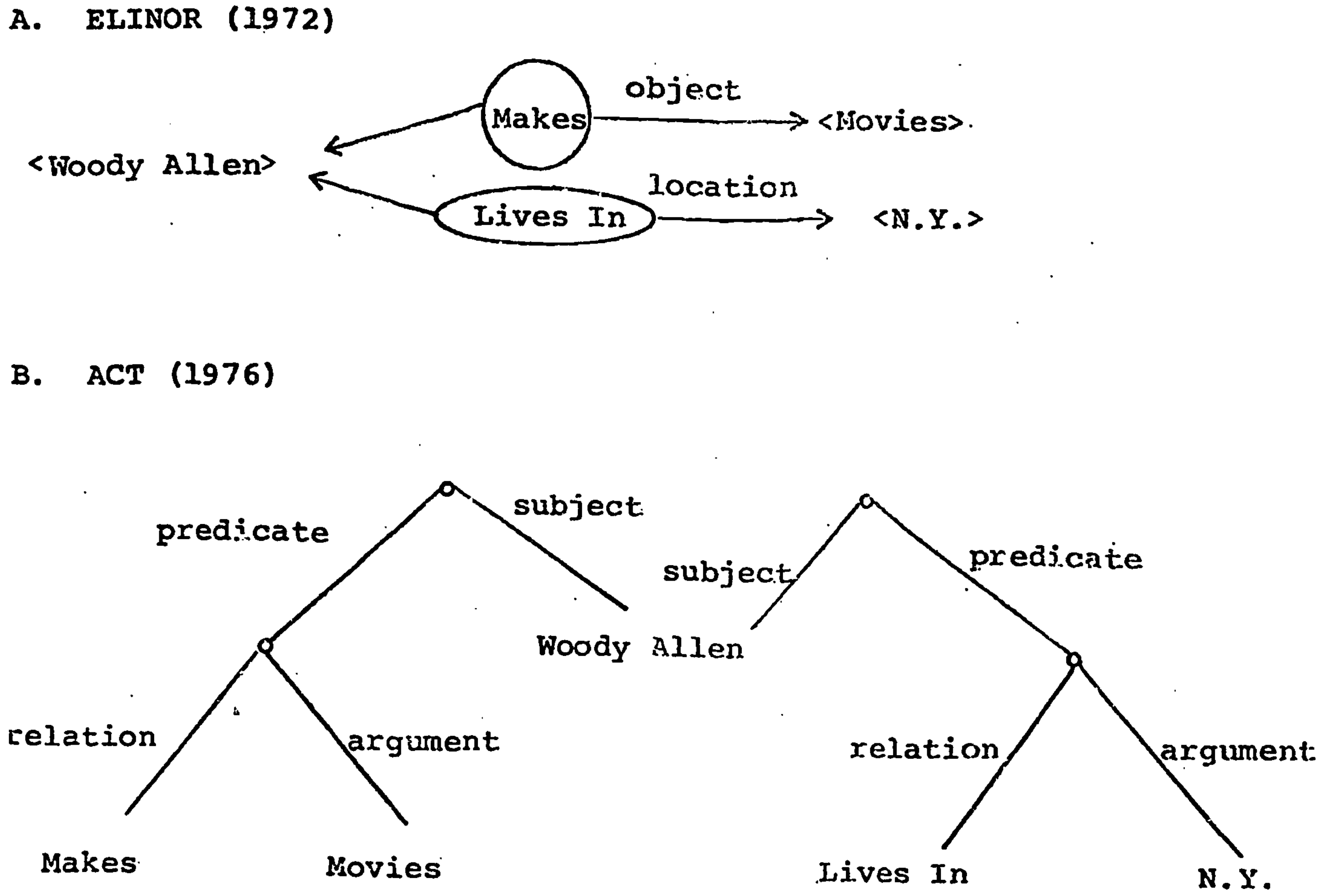


Figure 2. Propositional representations of "Woody Allen makes movies" and "Woody Allen lives in New York" based on: (A) Rumelhart, Lindsay, and Norman (1972), and (B) Anderson and Bower (1973) and Anderson (1976).

process in recognition. That is, when presented with the probe "Woody Allen makes movies," one would again use the concepts in the probe to access those in the memorized propositions; but now the search process, which is looking for a path matching that in the probe, will have to consider two links off the "Woody Allen" node. If the search process is limited in capacity, it will take longer when there are two paths from a node than when there is only one. Therefore, the time to correctly recognize a probe should increase with the number of links emanating from the relevant memory nodes.[1]

This same prediction follows from HAM and ACT. In Panel B of Figure 2 there are again two links from the "Woody Allen" node. Given the probe "Woody Allen makes movies," the three corresponding concept nodes will be activated, where the activation emanating from "Woody Allen" must be split between two links. This will slow the rate of activation on the critical link leading to "makes" and "movies." Consequently it will take longer to get an intersection that can lead to a correction recognition.

The fan effect and interference. The three models agree that as one learns more facts about a concept these facts fan out from the concept node, thereby slowing any limited-capacity retrieval process that underlies recognition.

Hence recognition time for a specific fact about a concept should slow down as we increase our knowledge about that concept. This effect, called the fan effect, has been extensively documented by recognition-memory studies showing that the time to decide whether a probe sentence is Old or New increases with the number of facts learned about each concept in the probe (Anderson, 1974, 1975, 1976; Anderson & Bower, 1973; Anderson & Paulson, 1978; Hayes-Roth, 1977; Hayes-Roth & Hayes-Roth, 1977; King & Anderson, 1976; Lewis & Anderson, 1976; Moesher, 1979; Reder & Anderson, 1980; Shoben, Wescourt, & Smith, 1978; Smith, Adams, & Schoor, 1978; Thorndyke & Bower, 1974).

One reason why fanning is important is that the fan effect on recognition latency is a common prediction of models with different representations. Another reason why fanning is important is that the basic idea behind it--that multiple facts learned about a concept interfere with one another during retrieval--may play a role in any memory task, not just speeded recognition. Thus an increase in fanning can lead to an increase in recognition or recall failures if we make the following two assumptions:

(1) People continue to search the links from a memory node until they hit a stop rule, like

"when the last n links examined have not led to a path matching the probe, call the probe a New item (if in a recognition test) or give up (if in a recall test)" (Rundus, 1973; Shiffrin, 1970); and

(2) Every time a particular link is examined it increases in strength or accessibility and is therefore more likely to be examined again (Rundus, 1973).

The more facts you learn about a concept, the more likely you are to hit the stop point before finding a target fact, and hence the more likely you are to suffer a recall or recognition failure. Moreover, this can happen even when you have learned just a few facts because if you sample the wrong link early, its accessibility will increase, and you may continue to resample it.

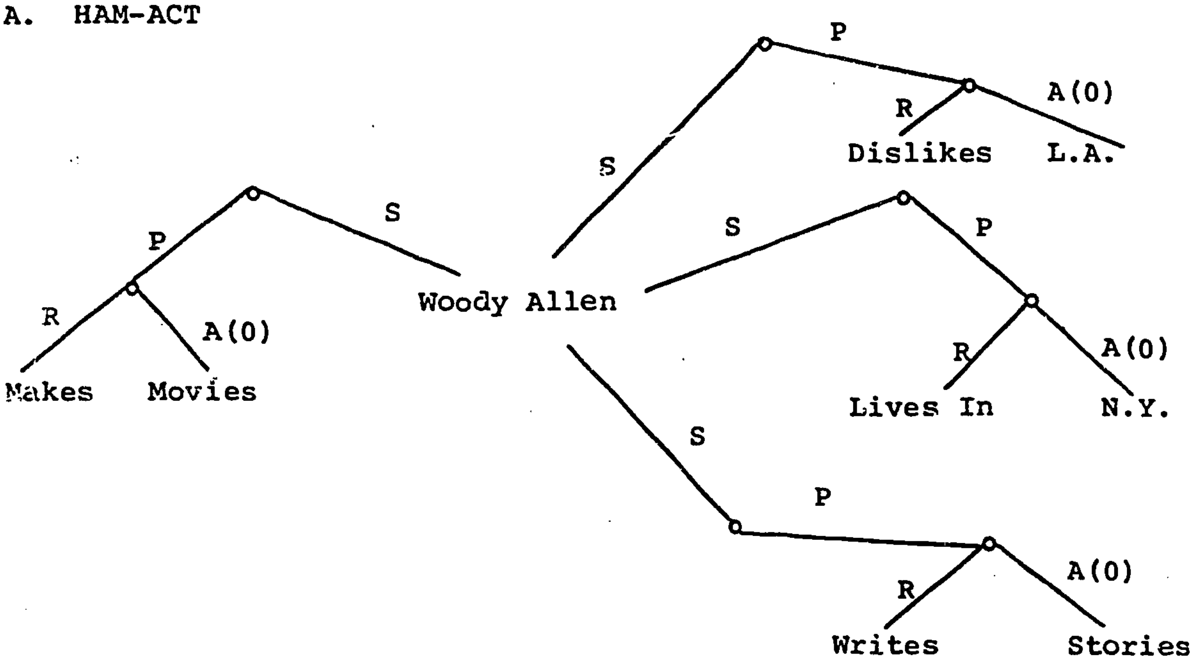
Powerful as the idea of fanning is, in its unchecked form it has a paradoxical quality (Smith et al., 1978). The idea that the more we learn about a topic the more interference we suffer seems at odds with our everyday experience that as we become increasingly knowledgeable about a topic we are often better able to answer questions about it. The way to reconcile everyday experience with the propositional representations and fan effects discussed is to invoke the organizational mechanisms alluded to earlier. That is, certain conditions lead us to alter the facts that we are explicitly given, resulting in a representation that allows us to store multiple facts about a topic without substantial increases in fanning. It is time to describe these organizational conditions.

Conditions that Foster Organization in Sentence Memory

Facts that subdivide into distinct groups. The first condition is that the facts to be learned come from distinct groups. In such a case, we may subdivide our memory representations and thereby boost retrieval. Figure 3 illustrates this.

Panel A shows a simplified HAM-ACT representation of four facts. (To expedite matters, relation names like subject and predicate have been replaced by the first letters of these names.) The facts correspond to the two sentences previously illustrated plus two additional ones: "Woody Allen writes stories" and "Woody Allen dislikes LA." There are now four links fanning off the "Woody Allen" node, and this spells trouble for the retrieval process. Panel B shows how to get

A. HAM-ACT



B. Subdivided Network

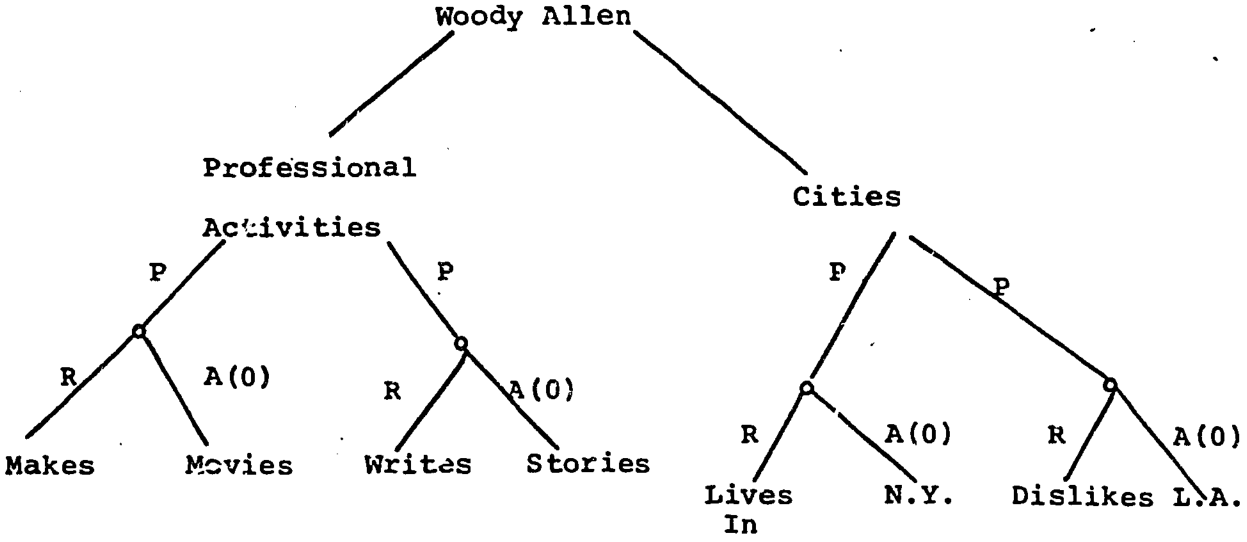
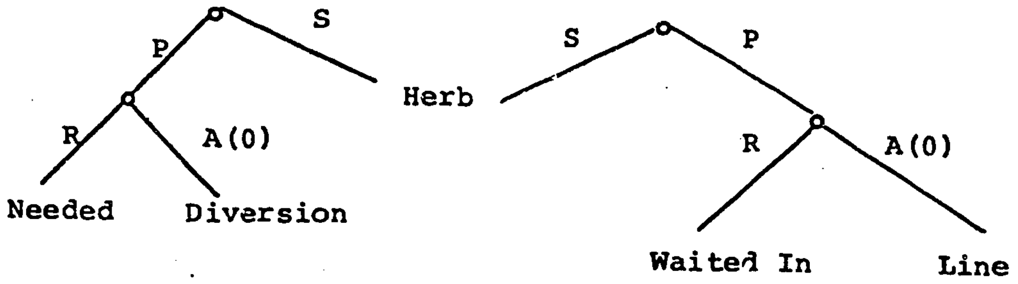


Figure 3. Propositional representations of four facts (see text) based on: (A) Anderson and Bower (1973) and Anderson (1976), and (B) a subdivided network. (Both A and O are used as labels to indicate the relation may be thought of as either argument or object.)

rid of the trouble. The representation there has been altered to take advantage of the natural division among the facts. The "Woody Allen" node now leads to two subnodes: one designating professional activities and the other, experiences with cities. These subnodes are in turn connected to their relevant predicates; e.g., the Professional subnode connects to the predicates concerned with making movies and writing stories. The major elaboration is thus to create two subnodes that were not explicit in the input facts, and to insert each subnode between the relevant subject and predicate nodes in what is called a subdivided network.

Facts that can be integrated by prior knowledge. To illustrate this condition, consider the HAM-ACT representations in Figure 4. Panel A represents two sentences: "Herb needed a diversion" and "Herb waited in line"; Panel B represents the same two sentences plus two additional ones: "Herb went to a movie" and "Herb bought popcorn." There is an increase in fanning off the "Herb" node from two to four as we move from Panel A to Panel B. This means that the models we reviewed earlier would predict it takes longer to correctly recognize "Herb waited in line" if one learned the four sentences in Panel B rather than only the two in Panel A. Intuition suggests otherwise. The four facts

A. 2 Facts



B. 4 Facts

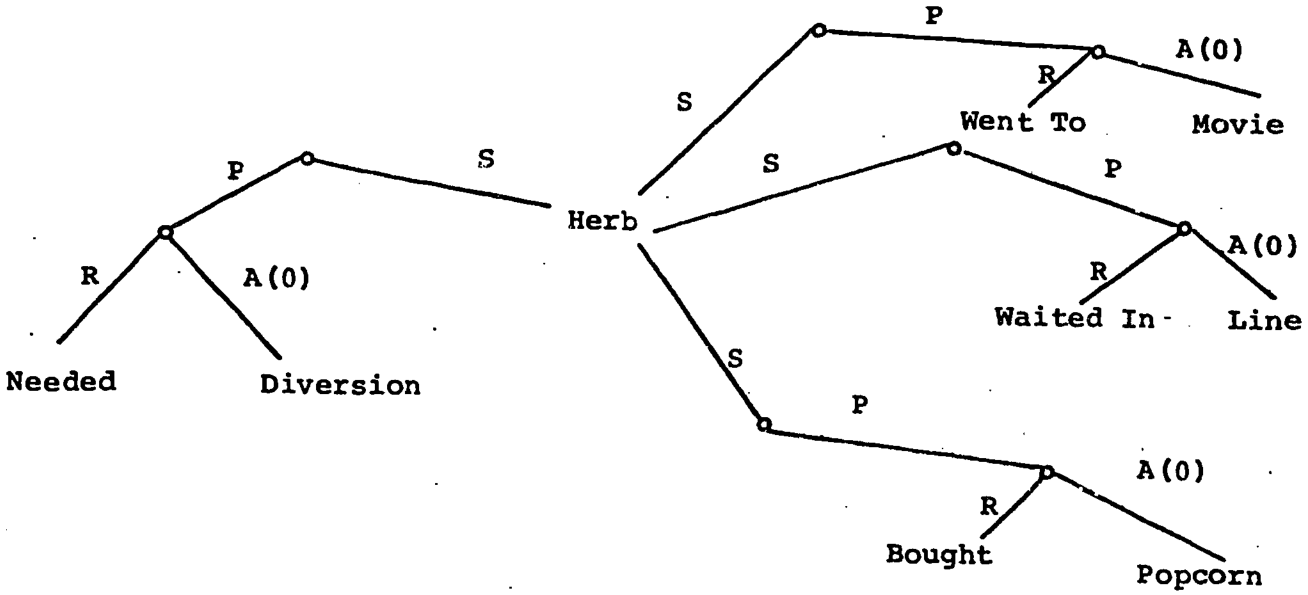


Figure 4. Propositional representations based on Anderson and Bower (1973) and Anderson (1976) for: (A) two unrelated facts and (B) four integrated facts (see text).

in Panel B seem to make up a coherent unit while the two in Panel A are more difficult to integrate. Here our sentence-memory models seem to be missing a critical point: facts integratable by some prior knowledge (like knowledge about going to a movie) may not function as independent propositions in memory.

Facts containing perfectly correlated predicates. The condition of interest is illustrated by the sentences in Table 1. On both the left- and right-hand sides, there is one fact about John, one about Ed, and three each about Woody and Mel. Furthermore, for both the sentences on the left and those on the right, each predicate is used twice, and the trio of predicates attributed to Woody or Mel are not readily integrated by any salient packet of prior knowledge. What then is the difference between the two sentence sets? The predicates on the left are perfectly correlated whereas those on the right are not. Given the facts on the left, if someone makes movies, that same someone was born in Brooklyn and went to California; or if someone visited Virginia, that is all he did. In contrast, for the facts on the right, if someone makes movies, he may have been born in Brooklyn (like Woody) or he may not have (like Mel). Perfectly correlated predicates seem to provide some structure to the input facts.

Table 1

Sentences with Predicates that Vary in Correlation

Perfectly Correlated	Less than Perfectly Correlated
John visited Virginia	John visited Virginia
Ed visited Virginia	Ed was born in Brooklyn
Woody was born in Brooklyn	Woody was born in Brooklyn
Woody makes movies	Woody makes movies
Woody went to California	Woody went to California
Mel was born in Brooklyn	Mel visited Virginia
Mel makes movies	Mel makes movies
Mel went to California	Mel went to California

And people seem to use this structure: though the variations in fanning are identical in both sets of sentences, only the sentences on the right produce a fan effect on recognition latencies (Whitlow, Medin, & Smith, Note 1).[2]

Subdividing Facts from Distinct Groups

The first task is to present empirical evidence about how facts memorized from distinct groups facilitates retrieval. We start with research on the fan effect and then move on to other empirical phenomena. After that, we will discuss theoretical mechanisms.

Empirical Evidence

Fan effects on recognition latency. A few experiments have dealt with recognition latencies for memorized facts from distinct groups. One of the simplest is by McClosky (Note 2). He first had subjects learn from one to six facts about various people identified by occupation terms, such as the tailor. For each occupation term, some facts concerned animals, the rest countries. And for each occupation term, McClosky manipulated the fan level of the animal facts independent of the fan level of the country facts. This is illustrated in Table 2. For the tailor there are five facts about animals but only one about countries, while for the chemist there is one fact about animals but five about countries. After memorizing these facts, subjects were given an Old-New recognition test. The memorized facts were intermixed with a like number of distractors, where each distractor was constructed by repairing the occupation term from one learned sentence with the predicate of another, e.g., "The tailor likes Canada" (see Table 2). The subject's task was to decide as quickly as possible whether each sentence--referred to as a probe--was Old (on the memorized list) or New (a distractor). The data of major interest were the average times needed for correct Old and New decisions.

To appreciate the results of the above experiment, note that any probe contains both an occupation and an object term from the memorized list. The occupation term is characterized by two fan levels, one designating the number of learned animal facts, the other the number of learned country facts. The object term of the probe, however, tells the subject which of these two sets of facts is relevant; e.g., if the object names an animal, only the animal facts are relevant. Thus, though a probe has two fan levels, one may be designated a <u>relevant</u> fan, the other an <u>irrelevant</u> fan. To illustrate with the items in Table 2, if the probe was "The tailor likes wolves," the relevant fan would be five and the irrelevant fan, one. If McClosky's subjects used the object term of the probe

Table 2

Example of Sentences Used in McClosky (Note 2)

Facts about Animals	The tailor likes wolves	The chemist likes wolves
	The tailor likes rabbits	
	The tailor likes bears	
	The tailor likes tigers	
	The tailor likes pigs	
Facts about Countries	The tailor likes Portugal	The chemist likes Portugal
		The chemist likes Canada
		The chemist likes England
		The chemist likes Brazil
		The chemist likes Italy

to decide which set of memorized facts was relevant, their recognition latencies should have systematically increased with the relevant fan but not with the irrelevant fan. This is roughly what McClosky found. Recognition latency increased about 370 msec as the relevant fan increased from one to five, but increased only about 100 msec as the irrelevant fan varied over this same range. While the 100 msec increase may suggest subjects were considering the irrelevant facts, two points mitigate against this: the 100 msec increase did not reach a conventional level of statistical significance; and part or all of the increase may reflect the time needed to decide whether the object term names an animal or country. All things considered, McClosky's results suggest that people can sometimes subdivide their knowledge and use information in the probe to direct their search to the relevant subgroup.

In the above study, the subdivision was based on a semantic aspect: the object term named either an animal or a country. Anderson and Paulson (1978) looked at a different basis for subdivision. Using a paradigm like that described above, they showed that if some facts about an object are presented pictorially while others are presented as verbal descriptions, subjects may use this difference in mode of presentation as a basis for subdivision. When Anderson and

Paulson's subjects were given a recognition test, if the probe was a verbal description of an object, for example, recognition latency increased substantially with the number of verbally presented facts about that object but only minimally with the number of pictorially presented facts about the object.

The above studies have two limitations. First, the only bases for subdivision that have thus far been demonstrated are simple ones--the semantic category of a probe word and the modality of presentation. If subdivision is confined to such simple aspects, it could not play much role in real-life memory situations and hence could not be the only means of organization used. Second, though the above results suggest people can restrict their search to the subgroup deemed relevant by the probe, we will soon have cause to question whether search processes in recognition are usually this selective.

Free recall of categorized lists. The previous studies make excellent contact with models of sentence memory because they focus on the fan effect. But while these studies are analytic, they provide too narrow a view of subdivision. Subdivision can have striking effects on recall, both the amount recalled and the structure of the recall. These effects have recently been demonstrated in prose recall (Black & Bower, 1980), but they have been most extensively documented in studies dealing with the free recall of word lists.

Those concerned with free recall of word lists long ago discovered that recall improves when the words are drawn from a few semantic categories. Suppose subjects are presented a list of 40 words. They will recall more if the list consists of five instances from each of eight semantic categories--just the instances, not the category names--than if all words are semantically unrelated (e.g., Cohen, 1963; Puff, 1970). This effect depends partly on subjects being aware of the categorical structure of the list at the time of input (Cofer, Bruce, & Reicher, 1966), which suggests the effect depends on setting up a certain kind of representation. The obvious possibility is a representation that is subdivided according to categories (Bousfield & Cohen, 1953). Figure 5 presents an example. Though the category terms--*animals*, *countries*, etc.--did not appear in the input list, they have been inserted in the representation as subnodes and are connected to nodes for words that did appear in the input.

This representation seems consistent with three important findings about recall from categorized lists.

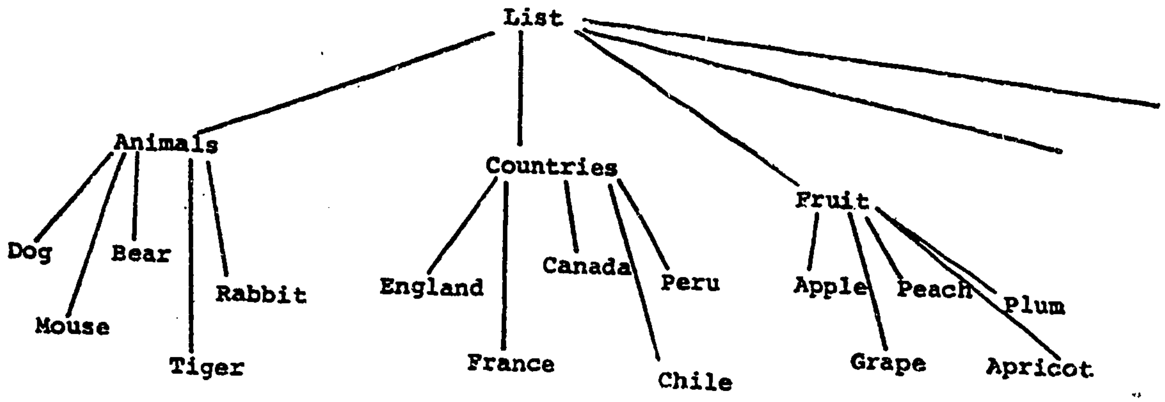


Figure 5. Example of a subdivided representation for a categorized list.

(1) Recall is clustered by categories. Subjects recall a number of instances from one category in succession, then a number of instances from another category, and so on (Bousfield, 1953). This suggests that subjects retrieve a category subnode, search its links to instances, and move on to the next subnode.

(2) Recall is "some or none." Typically either several instances of a category are recalled or none are (Cohen, 1965). This suggests that if one cannot get to a particular subnode, there is no other path to its instances.

(3) Category cueing aids recall. If recall is substantially less than perfect, giving subjects the category terms as cues will enable them to retrieve some of the missing items (Tulving & Pearlstone, 1966). The cues apparently allow subjects to retrieve subnodes they missed in their initial recall.

Theoretical Mechanisms

Retrieval processes for free recall. To illustrate the mechanisms involved, consider Figure 6. It contains some facts that a devotee of Woody Allen might have stored. The top node designates the concept "Woody Allen." Then there are two levels of subnodes. The first distinguishes "Personal" and "Professional Life," while the nature of the subnodes at the next level depend on whether they are dominated by "Professional" or "Personal-Life" subnodes. Subnodes under "Personal Life" designate periods or eras of life (Kolodner, 1978)--like "Early Childhood," "Boyhood," "Marriage," etc.--whereas subnodes under "Professional Life" designate different occupational and artistic roles--like "Gagwriter," "Storywriter," and "Filmmaker."

Consider how the information in the network might be retrieved during free recall. If the possessor of the above network were asked to say everything he knew about Woody Allen, he would presumably enter at the top node and traverse either the link to the "Professional" or "Personal-Life," with the strength or accessibility of these links determining which one is chosen (Rundus, 1973; Shiffrin, 1970). Assume he took the path to "Professional Life." Then he would traverse one of the links leading to a more specific subnode, e.g., "Filmmaker" (the choice again determined by link strength), and start searching paths from this specific subnode, emitting each fact he found, e.g., "Woody Allen's films include Annie

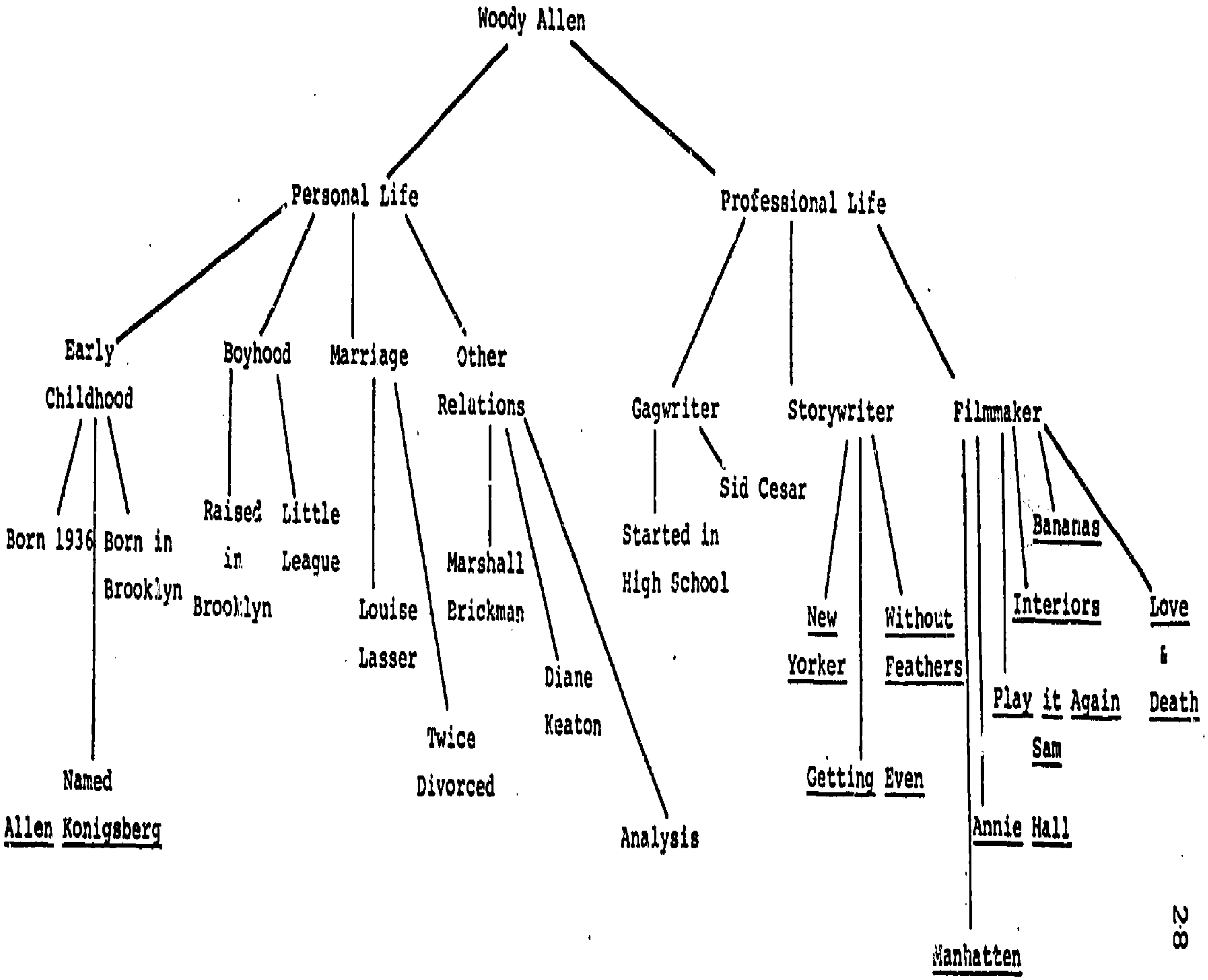


Figure 5. Example of a subdivided network for knowledge about Woody Allen.

Hall and Manhattan." Having done what he can with the facts under a specific subnode, our respondent would presumably find his way back to the higher subnode that was activated, "Professional Life," trace a path down to another specific subnode, e.g., "Gagwriter," and start searching paths from there to specific facts. Once he has done his utmost with the accessible subnodes under "Professional Life," our respondent would move on to "Personal Life" and the specific subnodes it dominates.

This scheme is consistent with the free-recall findings. Following the process just outlined, our respondent would cluster his recall by specific subnodes (e.g., he would recall Allen's movies in one group), as well as by higher-level subnodes (e.g., he would recall Allen's movies closer to Allen's published stories than to facts about Allen's boyhood). His recall should also have a some-or-none character, e.g., he would either not mention anything about Allen's marriages or mention most facts he has stored about them. And should our respondent fail to emit anything at all about a particular subnode like "Gagwriter," reminding him that Allen was once a gagwriter might bring forth the relevant facts.

Considerations of efficiency. The above retrieval scheme is extremely efficient because each node has a relatively small number of links fanning off of it. We were able to depict over 20 facts about Woody Allen while keeping the maximum fan off a node down to six. The largest number of links one would ever have to traverse is eight (for a question about films made), while the smallest is four (for a question about gagwriting). High efficiency could be maintained even with a substantial increase in the number of facts by increasing the number of subnodes at each level and/or the number of levels.

However, research on the recall of categorized lists suggests a limit to the amount of subdivision possible. Mandler's (e.g., 1967) studies indicate that recall is maximal with 5±2 categories or nodes per level; if more than this are used to divide up a fixed number of facts, recall starts to decline. Since there is no reason to think otherwise, we assume this 5±2 limit might hold at all levels. What about a limit to the number of levels? As no one seems to have worked with categorized lists using more than three levels, it is possible that this factor is also governed by some small number. If it is again about five, an optimal subdivided network, five levels with five nodes per level, could represent 3,225 facts without requiring the retrieval process to ever inspect more than 25 nodes. This remarkable efficiency may account for why hierarchical representations have been shown to be such powerful recall aids in general (Bower, Clark, Winzenz, & Lesgold, 1969; Nelson & Smith, 1972), and why they are so widely used as storage devices in computer systems (where they are referred to as _discrimination nets_).

Retrieval processes for recognition. For recognition, there is in principle no need to search the entire network. To illustrate, given the probe "Was Woody Allen ever married to Louise Lasser?", our respondent could enter at the top of the network, use the probe to get to the "Personal-Life" subnode, and then again use the probe to get to "Marriage" (Note that to use the probe to get to "Personal-Life," our respondent must know that marriage pertains to personal life). Under this view, the search process is selective, in the sense that it uses information from higher-level subnodes to select the appropriate lower-level ones.

Problems for this view arise, however, if we alter our probe slightly to, "Was Woody Allen ever involved with Louise Lasser?" Now the analysis of the probe that gets our respondent to "Personal-Life" must be quite complex. It cannot simply use "involved with" as an access condition for "Personal-Life," for the question "Was Woody Allen ever involved with Sid Caesar?" will get our respondent to the "Professional-Life" subnode. It seems that to get to the "Personal-Life" node for the Louise Lasser question but not for the Sid Caesar one, we have to consider the fact that Woody Allen is a notorious heterosexual, thereby making it plausible that "involved with" can be given a romantic reading with Louise Lasser but not with Sid Caesar. But Allen's heterosexuality is the kind of fact that is presumably represented at some lower-level subnode, so how can we have access to it while still working at a top-level subnode? More generally, selection of a higher-level subnode may sometimes rest on information at lower-level nodes, which is at odds with the idea of a selective search where one only accesses lower-level nodes by first going through higher-level ones. It seems, then, that search processes in recognition are considering lower-level nodes at the same time as higher-level ones. To illustrate with the above example, we seem to search up from the nodes for Louise Lasser or Sid Caesar at the same time we search down the nodes of the hierarchy.

Considerations like these in a different domain led Anderson (1976, Chapter 8; King & Anderson, 1976) to reject the notion of selective search altogether, and to opt for a spreading activation process that starts at the probe concepts and then searches blindly through a network. This seems to be a reasonable move, but there are two problems with it that have to be faced. First, we have to reconcile the lack of selective search in recognition with the idea that search appears directed in free recall, i.e., enter at the top of the hierarchy and search systematically through it. (Direction is a necessary component for selection.) This can be done by noting that there is typically only a single retrieval cue in free-recall--in our free-recall example, the only cue was the name "Woody Allen"--and this cue permits access to only the top of the network. In contrast, a recognition probe typically contains multiple retrieval cues--e.g., "Woody Allen," "involved with," and "Louise Lasser"--thereby permitting simultaneous access to multiple parts of the network. Under this view, which is essentially due to Tulving (1974), people use whatever retrieval cues they can and so-called directed-search is what happens when they are forced to work with a single cue.

The second problem is that the fan experiments reviewed earlier, McClosky (Note 2) and Anderson and Paulson (1978), do provide evidence for selective search in recognition, which of course contradicts the generalization that such a search is not used in recognition. A resolution here may hinge on something mentioned earlier: the fan experiments in question used very simple bases for subdivision, such as the semantic category of a probe word. Perhaps selective search is used when the basis for selection is easily computed from the probe, like determining whether the last word of the probe names an animal or country, but is not used when such computations become at all complex, like determining "involved with Louise Lasser" means something about romance.

<u>The status of subdivided networks as an organization device</u>. Let us summarize the main points made above. Free recall data provide good evidence that we can subdivide our knowledge, and that the concomitant reduction in fan-level-per-node facilitates the retrieval process. Since we can subdivide when preparing for free recall, it seems likely that we can also do so for recognition. In recognition, however, subdivision also has the potential to permit a selective search (as well as a reduction in fan-level-per-node), but such selectivity may only occur in certain simple cases.

So at this point, subdivision-without-selectivity seems a reasonable organizational device, primarily because of its reduction in fan level. There is, however, a cost to subdivision that places limits on how widespread a device it can be. Dividing our knowledge into different chunks ignores existent relations between facts stored under different subnodes. Since people know these relations and use them in answering questions, subdivided networks cannot be the only way we represent substantial bodies of knowledge.

We can again illustrate with the Woody Allen network. Under the "Personal-Life" node, we had a subnode for romantic relations that was connected to facts about Allen's relation with Diane Keaton, while under "Professional-Life" we had a "Filmmaker" subnode connected to facts about Allen's movie <u>Annie Hall</u>. But as any devotee of Allen knows, his relation with Keaton formed the basis for <u>Annie Hall</u>. So to be true to our knowledge base, we need some sort of connection between these disparate subnodes. One way to do this is to insert a link between the film <u>Annie Hall</u> and the relevant facts about Allen's relation to Keaton. But this move can substantially increases the number of facts fanning off the "Annie Hall" node, yet the whole point of subdivision is to keep the fanning down.[3] An alternative is to add a fact to the "Annie Hall" node, namely that it was based on Allen's relation to Keaton. This will increase the fanning off "Annie

Hall" by only one fact. But this move is not really faithful to the knowledge of a Woody Allen fanatic who presumably knows how various aspects of Allen's personal relations mapped onto different aspects of the film in question. That is, part of what is known here is how one structure maps onto another. More generally, part of a rich knowledge base about any topic consists of relations between seemingly disparate facts, and subdivided networks seem more disposed to keeping such facts apart than to depicting their subtle connections.

Facts Integratable by Prior Knowledge

Empirical Evidence

Again we first consider findings about fan effects, then take up results with other memory measures, and lastly consider theoretical mechanisms.

Fan effects on recognition latency. A few recent experiments demonstrate that learning new facts about a topic causes little fan effect when the propositions are integratable. In the first set of studies (Smith, Adams, & Schoor, 1978), subjects learned either two or three facts about a person designated by an occupation term, such as the banker. Some subjects learned facts that were easily integratable by prior knowledge, like those in the top of Table 3. The two facts about the banker fit with what we know about christening a ship, the three facts about the <u>accountant</u> are consistent with knowledge about playing a bagpipe. The remaining subjects learned facts that were not so integratable, as illustrated by the items in the bottom of Table 3.

For both the integrated and unrelated facts in Table 3, the fan off the "banker" node is two and that off the "accountant" is three. This means that current models of sentence memory would expect comparable fan effects on recognition latency for both kinds of facts. When subjects in the Smith et al. study were given a recognition task after learning the facts, however, there was a substantial fan effect with the unrelated items but not with the integrated ones.

Apparently subjects given the facts in the top half of Table 3 used their world knowledge about ship christenings and playing a bagpipe to integrate the facts. That world knowledge was indeed activated showed up in other findings by Smith et al., specifically, findings concerned with the distractors in the recognition task. Most distractors were formed by repairing the occupation term from one learned sentence with the predicate of another (call these <u>repaired</u> distractors); some distractors, however, were formed by

Table 3

Example of Sentences Used in Smith, Adams, and Schoor (1978)

Integrated Facts

The banker was chosen to christen the ship	The accountant played a damaged bagpipe
The banker broke the bottle	The accountant produced sour notes
	The accountant realized the seam was split

Unrelated Facts

The banker was asked to address the crowd	The accountant painted an old barn
The banker broke the bottle	The accountant produced sour notes
	The accountant realized the seam was split

changing one word in a learned sentence so that it remained consistent with the relevant world knowledge (call these related distractors). To illustrate with the distractors for "the banker" (see Table 3), a repaired distractor would be "The banker realized the seam was split," while a related one would be "The banker broke the champagne bottle." The findings of interest were that subjects who learned integrated facts responded slower and made more errors on related than repaired distractors (presumably because related distractors were consistent with the accessed world knowledge), while subjects who learned unrelated facts did just the reverse. Hence one indication of the use of world knowledge is the difficulty of rejecting distractors consistent with the knowledge.

The relative lack of a fan effect with integrated facts has been replicated by Moesher (1979) and Reder and Anderson (1980). Both studies, however, revealed constraints on the power of integration to offset the fan effect. Moesher (1979) demonstrated that integrated facts are insensitive to fanning variations only when the facts are presented close together during learning. For example, if successive facts about christening a ship are separated by five irrelevant sentences, the christening facts will behave like unrelated ones. This suggests that at least a couple of the integratable facts must be in active memory at the same time in order for the relevant world knowledge to be accessed.

Reder and Anderson (1980) showed that the fan effect is diminished with integrated facts only when the distractors are not always consistent with the world knowledge needed for integration. To illustrate, suppose subjects first learned facts about a particular person that all dealt with skiing and then were given a recognition test. If the distractors on the recognition test (a) used recombined subject and predicate terms and (b) were always consistent with skiing, there was as substantial a fan effect as occurs with unrelated facts. A plausible interpretation of this finding goes as follows. The representation that results when world knowledge is used to integrate input facts cannot adequately discriminate between the input and novel facts equally consistent with the knowledge, so when all distractors are consistent with the world knowledge, subjects are forced to use an unelaborated representation of the input.

In addition to varying the number of facts integratable by some packet of world knowledge or theme (e.g., skiing, washing clothes), Reder and Anderson also varied the number of themes learned about a particular person. Thus, subjects might have learned three skiing facts and one clothes-washing fact about a fictitious character named Arnold (i.e., two themes about Arnold), but only three skiing facts about a character named Bruce (one theme about Bruce). Even in conditions where recognition latency was unaffected by the number of facts within a theme, latency did increase with the number of themes learned about a person.

Experiments on recall and recognition accuracy. Numerous studies show that when subjects use their prior knowledge to integrate some presented facts, recall accuracy of the learned facts is increased but at the price of intrusions that are consistent with the relevant knowledge. In a similar vein, recognition studies show that integration via previous knowledge leads to better recognition accuracy of the learned items but at the cost of more false alarms to distractors consistent with the knowledge. Representative studies of each type are described below.

1. Integration and recall. Bransford and his colleagues (e.g., Bransford & Johnson, 1973; Bransford & McCarrell, 1974) have performed several experiments that take the following form:

(1) All subjects are presented some facts that appear to be unrelated;

(2) One group of subjects are also presented a clue specifying a packet of world knowledge that can be used to integrate the presented facts, while the remaining subjects receive no such clue; and

(3) Subjects given the clue rate the presented facts as more comprehensible, and recall more of them on a subsequent recall test.

We can illustrate with the Bransford and Johnson (1973) study. The seemingly unrelated facts comprised an obscure paragraph, whose first few lines were:

> The procedure is quite simple. First you arrange things into different groups. Of course, one pile may be sufficient, depending on how much there is to do. If you have to go somewhere else due to lack of facilities, that is the next step; otherwise you are pretty well set.

Subjects given the clue "washing clothes" at the time of input rated the paragraph more comprehensible and subsequently recalled more propositions from it than subjects lacking the clue. The power of the clue resides in its ability to access knowledge about the actions typically involved in washing clothes, where this knowledge can then be used to elaborate and integrate the input propositions.

The above example shows the beneficial effects of integration but says nothing about its costs. The latter has been demonstrated by Bower, Black, and Turner (1979). They had subjects read stories about recurrent, stereotyped situations, like going to a restaurant. Subjects presumably utilized their world knowledge about such situations in understanding the input stories, and in a subsequent recall test, the bulk of the intrusions were consistent with the world knowledge presumably accessed.

2. <u>Integration and recognition</u>. Some experiments on recognition have used a cueing variation similar to that employed in Bransford's studies. In Dooling and Lachman (1971), for example, all subjects were presented the following obscure paragraph:

> With hocked gems financing him our hero bravely defied all scornful laughter that tried to prevent his scheme. "Your eyes deceive," he had said, "an egg not a table correctly typifies this unexplored

planet." Now three sturdy sisters sought proof, forging along, sometimes through calm vastness, yet more often over turbulent peaks and valleys. Days became weeks as many doubters spread fearful rumors about the edge. At last from nowhere, welcome winged creatures appeared signifying momentous success.

One group of subjects was given the clue at the time of input that the paragraph was about "Christopher Columbus," while the remaining subjects made do with no clues. At some later point, all subjects were given a recognition test. It included old sentences from the above paragraph intermixed with distractors, where some distractors were related to the Columbus saga. Subjects given the clue correctly recognized more old sentences than their non-clued counterparts, but the clued subjects were also more likely to false alarm to the related distractors.

Theoretical Mechanisms

Two different kinds of mechanisms need to be considered. The first involves an extension of subdivided networks. The second focuses on some new processes, namely inferences made during comprehension.

Subdivided networks. The ideas here were developed by Reder and Anderson (1980) to account for why the fan effect on recognition latency is reduced if all facts learned about a character can be integrated by some prior knowledge. To extend an earlier example, if subjects already know that "The banker christened the ship" and "The banker broke the bottle," then learning that "The banker did not delay the trip" does not slow them down in answering questions about "the banker." According to Reder and Anderson, when learning the above facts, subjects presumably set up a subdivided network like that in Figure 7. The "banker" is the top node, "ship-christening" the only subnode, and the three specific predicates comprise the bottom nodes. This looks like the subdivided networks we considered previously. But there is something new here. In addition to the "ship-christening" subnode being attached to the three specific predicates, it is also associated with concepts relevant to ship christening, such as "bottles," "trips," and "champagne." These connections constitute the subjects' prior knowledge about ship christening, and they play a critical role in Reder and Anderson's subnode-activation hypothesis. Specifically, when a probe is presented, e.g., "The banker broke the bottle," there is activation at the "banker" node as well as at the concept nodes representing the relevant prior knowledge.

Activation from the latter nodes travels directly to the subnode along the pre-existent paths, while activation from the "banker" node goes to the subnode along the link created in the experiment. So the subnode is the first likely point of an intersection of activation, and such an intersection is assumed to be sufficient for recognition, i.e., sufficient for subjects to respond "old" to a probe.

Thus, even though search is not selective (all probe concepts are activated simultaneously), and even though there is a substantial fan off of the subnode, the subnode-activation hypothesis is consistent with organizational effects. There is no fan effect because the search process need not examine the learned predicates. Related distractors (e.g., "The banker broke the champagne bottle") are difficult to reject because they contain terms that activate the prior knowledge concepts and consequently can lead to a spurious intersection at the subnode. If all distractors are related, as in some conditions of Reder and Anderson (1980), subnode activation is no longer a useful indicator of what facts were actually presented; hence, subjects will be forced to search the specific facts, and the fan effect should reappear. Lastly, the hypothesis explains why recognition latencies increase with the number of themes

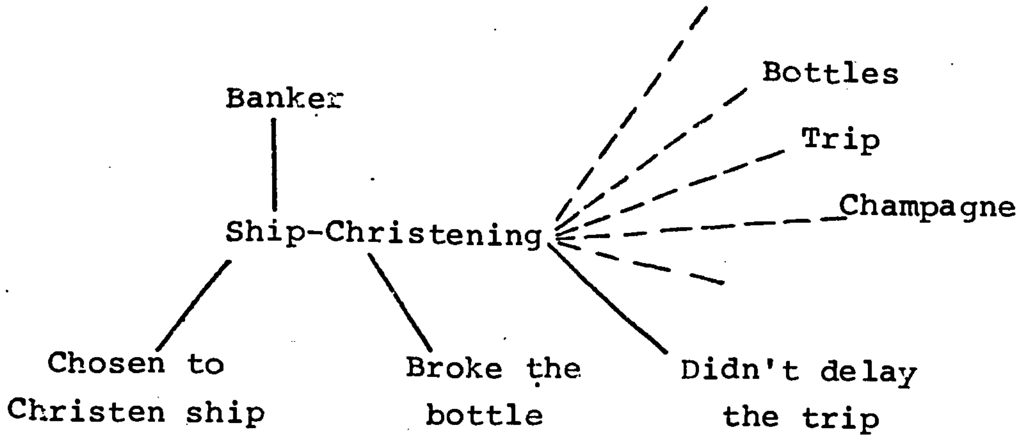


Figure 7. A subdivided network for three integrated facts. Dashed lines indicate prior associations to concepts (see text).

learned about a character. Each theme requires a different subnode (as well as different set of prior-knowledge concepts), and the more subnodes, the less activation to any one of them from the top node of the network. So the number of relevant themes slows recognition because it slows the rate of top-down activation, while the number of facts-per-theme has no effect on recognition because such facts need not be examined if the distractors are unrelated to any theme.

The virtue of the above hypothesis is that it explains the recognition results for integratable facts by the same kind of mechanism used to account for results with facts from distinct groups. Thus only one basic mechanism is needed to account for two seemingly disparate kinds of organizational effects, where this mechanism is readily interfaceable with Anderson's (1976) existent theory of sentence memory.

There are, however, two limitations to this subnode approach. The first is that while it can account for variations in recognition accuracy as well as in recognition latency, it is unclear how it would explain the comparable recall results. In the preceding accounts of fan effects, we assumed connections between a subnode and the specific concepts previously associated with it; but to account for recall, we need connections between a subnode and entire propositions, since in a recall test people emit full sentences, not single words designating specific concepts. We will not dwell on this because it is unclear whether or not the needed modification of the subnode approach can be easily made. The second difficulty with the approach is that it focuses exclusively on <u>memory</u> for integrated facts and ignores processes involved in the <u>comprehension</u> of such facts. This is problematic because it may turn out that the memory phenomena obtained with integrated facts are being mediated by comprehension effects. This leads us to a second kind of theoretical mechanism.

<u>Interconnecting inferences by schemas.</u>

1. <u>World knowledge and comprehension</u>. We can begin by expanding on the above suggestion that the effects of prior knowledge on memory may be mediated by the effects of such knowledge on comprehension. Figure 8 provides an abstract illustration of this. Suppose a reader is presented two input facts and accesses some relevant world knowledge to aid in understanding them. The world knowledge will be used to generate inferences. Some inferences will establish direct relations between the input facts, illustrated in Figure 8 by the link between Input Facts 1 and 2. Other inferences will result in inferred facts that yield a multi-link relation

between the input facts; this is illustrated by Inferred Fact 2, which creates a two-link relation between the input facts. Once a fact is inferred, it may lead to other inferences that create still other multi-link relations between the input; thus Inferred Fact 1 leads to Inferred Fact 1′, which in turn leads to Inferred Fact 2, thereby creating a four-link relation between the input facts. Lastly, there will be inferred facts that do not result in any connection between the input, as illustrated by Inferred Fact 3.

The result of all this inferencing is a representation that goes far beyond the input, one that shows enablement and causal relations between propositions and that can be used to answer all sorts of questions about the input. The construction of such a representation is what many people mean by _comprehension_. Under this account, the major purpose of contacting world knowledge during reading is to facilitate comprehension. But, and this is the critical point, note that in constructing this representation many of the inferences have interconnected the input facts, and _interconnections per se are good for memory retrieval_. For having found one fact, the retrieval process can follow the path to a second one. So a side benefit of the inference process is that it facilitates subsequent retrieval. Hence, the claim that many effects of

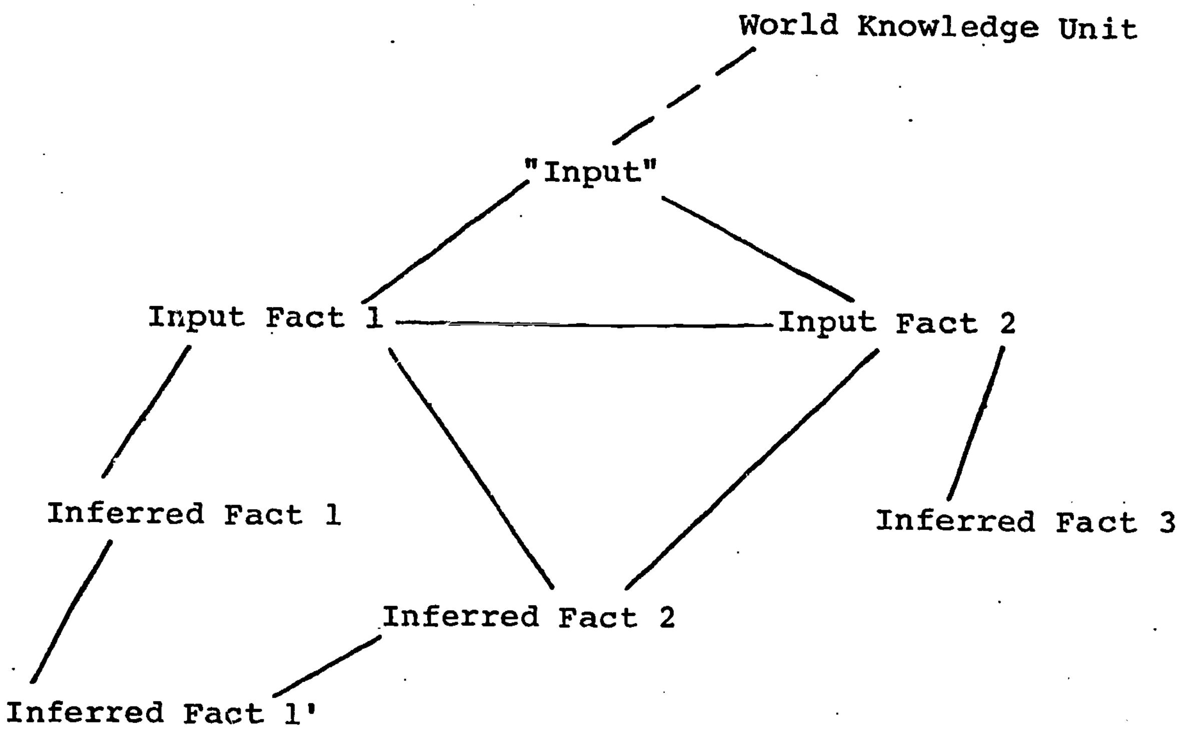


Figure 8. Abstract illustration of use of world knowledge in understanding two input facts.

world knowledge on memory are mediated by effects on comprehension.

Another consequence of accessing world knowledge is represented by the dashed line in Figure 8. This connection occurs whenever the relevant world knowledge forms a prepackaged unit of properties and actions--what Schank and Abelson (1977) call a <u>script</u>. In such cases the reader may establish a connection between some node standing for the input and the entire script. This connection can also benefit memory retrieval because it allows the reader to encode the input by constructing a single link to a pre-existent higher-unit, and to subsequently retrieve the input by tracing that link and unpacking the constituents of the unit.

The above account can be made more precise by being more specific about the world knowledge involved and how it is used to generate inferences. To aid in this, we need the notion of a <u>schema</u>, which many have taken to be the basic form of representation for units of world knowledge (e.g., Adams & Collins, 1979; Rumelhart & Ortony, 1977). Roughly, a schema is a description of a particular set of interrelated concepts that may represent a specific situation, such as going to a movie, or a general activity that can occur in many situations, such as asking someone for a favor. The components of a schema (either other schemas or primitive concepts) are often only vaguely specified; this permits them to function as variables that can be filled in or instantiated by input information with certain properties. To see what these ideas buy us, we will look at a specific schema and see how it is used in understanding and remembering.

2. Schemas for specific situations: As developed by Schank and Abelson (1977), a script represents the objects and actions that typically occur in a recurrent, stereotyped situation. Figure 9 presents a hypothetical script for going to the movies.

Our script contains several components. First, there's the header or title, "Going-to-a-Movie," whose major function is to access the script. Anytime you read something that means movie-going, you presumably retrieve the script. Second, a script contains a list of the objects, called props, and of the roles that are likely to be encountered in a situation described by the script (see Figure 9). Mention of these props or roles can also access the script. Third, a script contains pre-conditions and outcome conditions (see Figure 9), which can again access the script, and also are plausible inferences given the script has been accessed. For example, if you read "Herb went to a movie," you can infer Herb had

Header: Going to a Movie

Props: Theater, Tickets, Candycounter, Candy, Seats, Film

Roles: Customer, Cashier, Refreshment Vendor, Usher, Owner

Pre-Conditions: Goal of Seeing Movie, Money, Time

Outcome Conditions: Less Money, Knowledge of Film

Actions:

Getting Tickets

Customer stands in line
| enables
Customer Gives Cashier Money
| result
Cashier Gives Customer Tickets

Getting Refreshments

Customer Orders Candy
| result
Vendor Gives Customer Candy
| result
Customer Gives Vendor Money

Watching Film

Customer Enters Interior
| enables
Customer Finds Seat
| enables
Customer Watches Film

Leaving

Customer Leaves Interior
| enables
Customer Exits Theater

Figure 9. A sample script for moviegoing.

some money before entering the movie and less of it when he got out.

Fourth and most importantly, a script consists of the specific actions likely to occur in the situation. These actions can be grouped into chunks called <u>scenes</u> (Cullingford, 1978). The script in Figure 9 contains four scenes -- Getting Tickets, Getting Refreshments, Watching Film, and Leaving -- and under each is listed the actions that comprise it. Note that the props and roles mentioned in the actions are schema variables; e.g., Customer or Cashier name variables that can be filled in by a person playing that role in the story. Also note that successive actions are connected by labeled relations; these are critical for comprehension and retrieval processes.

The script actions make up most of the plausible inferences one can draw when reading a story based on the script. To appreciate this, consider how our script can be used to understand and subsequently retrieve the following vignette.

(1) Herb wanted to see a movie.
(2) He got a ticket.
(3) He found a seat up front.

When Sentence (1) is presented, it accesses the Movie-going script because it mentions a precondition, i.e., Herb had a goal of seeing a film. Also, Herb will be bound to the role of Customer. Once the script is accessed, the reader is expecting something from the Getting Tickets scene. This expectation is confirmed by Sentence (2), which matches the script action "Cashier Gives Customer Tickets."[4] At this point our reader can infer some of the script actions in the first scene that were not explicitly mentioned. We will assume that only those actions needed to interrelate the explicitly mentioned facts are inferred. For example, our reader might infer that Herb gave the Cashier money, for this proposition interconnects the first two explicitly mentioned ones; i.e., wanting to see a movie was the <u>reason for</u> Herb giving the Cashier money, and the latter <u>resulted</u> in Herb getting a ticket. Because Sentence (2) marks the end of the Getting Tickets scene, our reader will now be expecting something from the Getting Refreshments scene or, since the latter is optional, something from the Watching Film scene. Sentence (3) matches an action in the Watching Film Scene. Now our reader can infer some of the actions between the end of the first scene (explicitly mentioned in the preceding sentence) and the Find a Seat action of the third scene (explicitly mentioned in the current sentence). Again, she will presumably infer those actions needed to relate the explicitly mentioned sentences, e.g., she might infer that Herb entered the interior of the theater because this proposition interconnects sentences (2) and (3).

In general, then, one matches each stated fact to a script action, and one infers nonstated script actions falling between stated ones that are needed to relate input facts. The resulting representation for our vignette looks like that in Figure 10. It contains the input facts, some inferred script actions, and relations between all propositions. It also contains a pointer from the node for Herb to the movie-going script itself.

Consider now two hypotheses about how information in this representation could be retrieved. In the higher-unit hypothesis (Smith et al., 1978), our respondent would first follow the link from Herb to the script itself. If the task required recall, she could read the actions off the script. We further assume that those script actions, corresponding to (a) stated facts and (b) inferences needed to connect such facts, are explicitly tagged as such, and that these tags are used as guides to recall. If the task was one of recognition, then after accessing the script, she would match each marked script action to the probe until she found a match. This

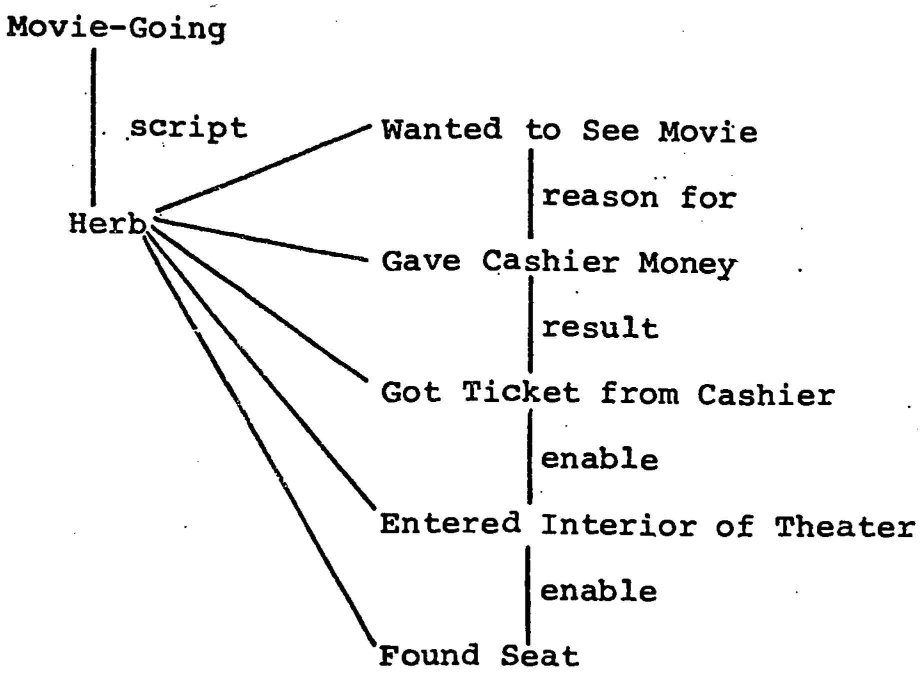


Figure 10. Example of representation for moviegoing vignette after script processing (see text).

process seems consistent with the experimental findings on recall and recognition accuracy. Thus for script-based facts, recall and recognition accuracy should be relatively high because only one new link need be examined and only one unit accessed in order to recover all presented facts. But good performance on the presented items would be purchased at the cost of an increase in memory confusions because all script actions corresponding to inferences drawn during comprehension are candidates for retrieval.

As for the results from the fan experiments, there should be little fan effect with integrated facts because the same higher unit, the script, is accessed regardless of how many facts relevant to the script have been learned. Related distractors should be difficult to reject because they often match tagged script actions that correspond to inferences drawn during comprehension. Lastly, there is the finding that latency increases with the number of themes learned about a character. If each theme corresponds to a script, an increase in the number of scripts means an increase in the number of script-links off of the node for the main character (Herb in the above example), and this fanning will slow down the search for the relevant higher unit.

Unfortunately, the higher-unit hypothesis has limited applicability. For one thing, the above process seems useless to someone who read two stories about two different people engaging in the same script, for it would confuse the facts about one person with those about the other. Another difficulty is that the hypothesis is limited to situations for which people presumably have scripts. This suggests that facts integratable by scripts will behave differently than those integratable by other kinds of schemas. The little data available on this point show no evidence for such a difference (Reder & Anderson, 1980).

The second hypothesis is the Interconnections hypothesis. (It is somewhat similar to Anderson's (1976), notion of elaboration.) It ignores the script entirely at the time of retrieval and operates instead on the interconnected propositions in the representation. If asked to recall the story about Herb, our reader would start searching links from Herb. If she can retrieve any one of the input facts, she has a direct path to the others since all were interconnected by inferences. If she cannot retrieve any input fact but can access an inference made during comprehension, this will get her to the input since all propositions are interconnected. Hence script-based facts should be well recalled because of their interconnectedness, but at the price of intrusions since all inferences drawn during comprehension are candidates for recall. For a recognition task, the process operates slightly differently. If presented the probe, "Herb found a seat up front," our reader would first access a stored fact about Herb, compare it to the probe, and respond "old" if there was a match. If no match was found, our reader would follow the connections from the accessed fact to see if any of them lead to a proposition that matches the probe. Again, recognition of facts actually presented should be relatively accurate because they are all interconnected, but at the cost of false alarms to inferences that are also part of the connected network.

The interconnections hypothesis seems to have something of a problem, though, in accounting for the results from the fan experiments. Specifically, while inferences drawn during comprehension connect input facts, they do so at the expense of increasing the fanning off of predicate nodes (i.e., the interconnections are typically relations between predicates). This caused no difficulty in explaining how integration facilitated recall or recognition _accuracy_, because every link from a predicate node _eventually_ leads to another input fact, and this could increase accuracy. But there is a difficulty in explaining how an increase in links off the predicate node can ever facilitate recognition latency. A possible solution to this problem is to note that a link between predicates essentially allows one to access an entire proposition without going through its terminal nodes. That is, given the retrieval process has failed to match the probe to Proposition A, and given an inferential link leading from Predicate A to Predicate B, one can access Proposition B without going through the terminal nodes of the probe again. This facilitation of memory access may more than compensate for the increase in comparison or search time due to the extra link off the predicate node.[5] The other findings from the fan experiments cause no further problems for the interconnections hypothesis. Related distractors are difficult to reject because they often match inferences made during comprehension. Finally, latency increases with the number of themes learned about a character because there are no inferential relations between the facts associated with one theme and those associated with another.

Note that the interconnections hypothesis avoids the problems that plagued its predecessor. Since the script itself plays no role in retrieval, the hypothesis can handle the situation where one reads and retrieves multiple stories based on the same script. Getting the script out of the retrieval process also takes care of another problem; no longer need there be any major difference between integration-via-scripts and integration-via-other-kinds-of-schemas. According to the present hypothesis, all scripts do for memory is interconnect propositions, and any kind of schema that can make comparable interconnections should lead to comparable results.[6]

3. <u>A comparison of the two kinds of mechanisms</u>. This has been a long section, and I had best summarize the major issues. To account for integration effects, we considered two kinds of theoretical mechanisms. The first assumed that subdivided networks were a sufficient representation to handle the effects of integration. The critical processing ideas were that: (a) since activation of a subnode is sufficient for recognition of a probe, the memorized fact corresponding to the probe need not be retrieved; and (b) some of the subnode activation was due to concepts that were previously connected to the subnode and that occurred in the probe. The second kind of mechanism focused on a different kind of representation, namely, a network of interrelated propositions, some corresponding to input facts and others to inferences. This led to both the higher-unit and

interconnections hypotheses, but since the former was argued to be of limited applicability, we will consider only the interconnections hypothesis in what follows.

There are obviously many differences between the two kinds of mechanisms, but at a general level the critical difference seems to be the following: the interconnections mechanism focuses on comprehension and assumes memory effects are consequences of comprehension processes; subnode activation focuses on memory per se and assumes memory for integrated facts can be accounted for without a thorough analysis of how the facts were initially comprehended. Given this general difference, specific differences fall into place. Thus in the interconnections hypothesis, we emphasized the role of world-knowledge inferences because no account of comprehension can do without them; in the subnode approach, little or nothing was said about inferences, not because Reder and Anderson (1980) do not believe inferences are needed in comprehension, but because their account of memory phenomena is not based on comprehension. Then there is the difference in parsimony. Subnode activation clearly seems the more parsimonious of the two when it comes to explaining memory data, but this may be the result of ignoring comprehension. That is, if Reder and Anderson had to stipulate what is involved in comprehending integrated facts, they might end up positing representational and processing aspects that look like those in the schema-based interconnections approach, and their edge in parsimony would be gone.

Though the key difference between the approaches is a general one, there may be a way of bringing some specific data to bear on a choice between mechanisms. In the subnode approach, it seems that activation from any concept connected to an operative subnode can contribute to recognition; in the interconnections approach, only inferences needed for comprehension can enter into the recognition process. This contrast can be illustrated by an experiment I recently performed.[7]

Subjects first read four script-based stories, each consisting of seven propositions. For example, one story was:

> Jane went to a restaurant. She went to a table and sat down. Then she drank a glass of water and ate a sandwich. Later she paid the check with cash and went to get her coat.

Later, subjects had to decide whether each of a series of probe sentences "followed" or "did not follow" from one of the stories. According to the subnode idea, a subject's representation of the stories would consist of: (a) four subnodes, one per story (e.g., Restaurants), with each being attached to the seven specific propositions in that story; and (b) connections between each subnode and all concepts previously known to be related to that subnode. Presumably, subjects would decide whether or not a probe item follows from a story partly on the basis of whether or not the concepts mentioned in the probe activate the prior-knowledge concepts connected to any subnodes. This predicts that any probe mentioning a frequent script action should be judged to follow from that script-based story. But this simply was not the case. If a probe mentioned a script action that was in no way needed to understand the original story, subjects uniformly agreed it did not follow from the story. To illustrate with the above restaurant story, the probe, "Jane ordered dessert," was judged by virtually all subjects not to follow from the story. Yet this probe corresponds to a very frequent action in the Restaurant script, more frequent than the script action corresponding to "Jane got up from the table" (as determined by the Bower et al., 1979, norms), where the latter probe was judged to follow from the story presumably because it was needed in understanding.

Having tried to make a case for favoring the comprehension approach, let us close this section on an even-handed note by pointing out that even the interconnections hypothesis must give some role to subdivided networks. For script-based stories, if a character engages in activities from two or more unrelated scripts, the final representation would likely be in the form of a subdivided network: each branch of the network would contain its own set of interrelated input facts and inferences, and the subnodes would be the relevant script headers.

Facts with Correlated Predicates

Empirical Evidence

As best we know, the organizational condition of present interest has been explicitly studied only in a series of fan experiments that we recently conducted (Whitlow, Medin, & Smith, Note 1).

Fan experiments. In our initial experiment, subjects learned either one, two, or three facts about a person designated by an occupation term. Half the subjects learned facts like those on the left side of Table 4, the other half learned facts like those on the right side. The only difference between the two sets of facts is that the predicates on the left are perfectly correlated whereas those on the right are not. For the sentences on the left, if someone "cleaned the wall," he also "pushed the truck," while if someone "moved the bucket," that's all he did; not so for the sentences on the right, where if someone "cleaned the wall," he might have "pushed the truck" or he might not have. Since all previously published studies of the fan effect used less than perfectly correlated predicates, we wanted to see if this effect held up when the predicates were perfectly correlated.

Learning was followed by the usual speeded recognition task. For correct responses to both Old and New items, we determined the fan effects separately for perfectly correlated predicates and for less than perfectly correlated ones. The results are in the first two rows of Table 5 (magnitude of the fan effect is estimated by subtracting the latency for the fan-1 condition from that for the fan-3 condition). There was a substantial fan effect when the predicates were less than perfectly correlated but not when they were perfectly correlated.

At first we thought our results could be due to the following. With less than perfectly correlated predicates, a particular predicate, e.g., "pushed the truck," sometimes

Table 4

Example of Sentences Used in Whitlow, Medin, and Smith (Note 1)

Perfectly Correlated Predicates	Less than Perfectly Correlated Predicates
The banker moved the bucket	The banker moved the bucket
The artist moved the bucket	The artist cleaned the wall
The lawyer cleaned the wall	The lawyer cleaned the wall
The lawyer pushed the truck	The lawyer pushed the truck
The farmer cleaned the wall	The farmer moved the bucket
The farmer pushed the truck	The farmer pushed the truck

Table 5

Magnitude of Fan Effects in Msec (Fan 3-Fan 1) for Whitlow, Medin, and Smith Studies

			Perfectly Correlated Predicates	Less than Perfectly Correlated Predicates
Experiment 1		Old	150	250
		New	-100	200
Experiment 2	Concrete	Old	-140	650
		New	- 10	110
	Abstract	Old	80	225
		New	- 75	125
Experiment 3		Old	-130	540
		New	- 60	100
		Mean	- 70	275

occurs in the context of one predicate, "cleaned the wall," and sometimes in the context of another, "moved the bucket" (see Table 4). If context alters meaning, then the meanings of the less than perfectly correlated predicates were more variable than those of the perfectly correlated predicates, and this might have determined whether or not a fan effect occurred. A second experiment, however, convinced us that meaning variability was not the critical factor.

Again, one group of subjects learned facts with perfectly correlated predicates, another learned facts with less than perfectly correlated predicates. In addition, each group was split into two subgroups: one worked with concrete predicates (e.g., "lifted the bucket") and was instructed to think of a particular predicate the same way when it occurred in different contexts (i.e., with different companion predicates); the other subgroup worked with abstract predicates (e.g., "moved the object") and was instructed to think of a particular predicate in different ways when it occurred in different contexts. The former subgroup should have experienced less meaning variability. Though this variation affected recognition latencies, it did not determine whether or not there was a fan effect. We again found fan effects only when predicates were less than perfectly correlated (see the middle rows of Table 5).

A last experiment sought to rule out a possible artifact (brought to our attention in a person communication by G. Bower in 1978). When subjects learn facts that always have perfectly correlated predicates, they could adopt a task-specific strategy. During learning, they could tag each occupation term and each predicate with its fan level (one, two, or three), and then during recognition, they could respond Old to any probe whose occupation term and predicate had the same fan level. A glance back at Table 4 should convince you this strategy always yields correct recognitions only for sentences with perfectly correlated predicates. Thus in our previous experiments, this strategy was available only to subjects who worked with perfectly correlated predicates and could be the reason they showed no fan effect.

To discourage this strategy, we had all subjects learn two sets of sentences, half having perfectly correlated predicates, and half less than perfectly correlated ones. With this design, subjects should be unlikely to use the above strategy since it would frequently produce incorrect decisions on facts with less than perfectly correlated predicates. The results, presented in the bottom rows of Table 5, replicated our previous findings. Apparently the power of perfectly correlated predicates to offset the fan effect is not due t the use of a specific strategy.

Implications for memory for real-world topics. In the above, we described the critical variable as perfectly correlated vs. less than perfectly correlated predicates. While literally correct, this is probably misleading. Since each predicate occurred just twice in our studies, only a limited range of correlations was possible, and our subjects may have been able to detect a correlation only among perfectly correlated predicates. The less than perfectly correlated predicates may have been perceived as uncorrelated, and a better description of our variable may be correlated vs. uncorrelated predicates. Following this line of argument, we suspect we could substantially reduce the fan effect with any set of predicates having a noticeable correlation.

If correct, the above conjecture has an important implication for fan effects. Since predicates about real-world entities or objects tend to be substantially correlated, one would expect little change in retrieval efficiency as more facts are learned about a real-world entity. To illustrate, consider classes of real-world objects, like various kinds of animals, plants, and human artifacts. As Rosch (e.g., 1978) has argued, the predicates associated with such classes tend to be highly correlated. Creatures with feathers, for example, also have wings and tend to fly; so if you already know that robins have feathers and wings, then learning that they also fly should not retard the efficiency of the retrieval process the way learning an uncorrelated predicate would. More generally, to the extent the world comes in packages of correlated predicates, there may be little retrieval interference engendered by learning multiple facts about the same topic.

Theoretical Mechanisms

In what follows, we briefly consider how well the theoretical mechanisms already discussed can be extended to account for the lack of a fan effect with perfectly correlated predicates. We can start with the subnode-activation hypothesis. When our subjects came across a set of study sentences where everyone who "cleaned the wall" also "pushed the truck," they may have assumed there was a category of people who clean walls and push trucks. Subjects might then use these categories as subnodes in a network like that in Figure 11. Here, the bottom nodes refer to the people who are members of each subnode or category. While the representation seems plausible, the subnode-activation hypothesis cannot account for the obtained lack of fan effects. Recall that this hypothesis explains the lack of fan effects as follows: a subnode can be activated before any newly learned fact because the subnode receives activation from concepts that have been previously linked to it and that also occur in the probe. In the present case, however, any subnode that corresponds to a set of predicates is novel. Therefore, there may not be any concepts previously linked to it, which means there is no way for a subnode to be activated prior to activation of the learned facts.

As for the higher-unit hypothesis, we again assume subjects treat correlated predicates as defining a category of people. They would set up a higher-unit for each category that contains the correlated predicates characterizing it. Information about an occupation term could be encoded by a single connection to the appropriate higher-unit. If later asked to recognize any proposition about a particular occupation term, subjects need consider only one link to access the higher-unit and could then unpack the unit. So this hypothesis is consistent with the lack of fan effects.

Finally, the interconnections hypothesis would assume that when presented correlated predicates, subjects infer a <u>co-occurrence</u> relation between them, thereby interconnecting the input facts. When later required to recognize a study

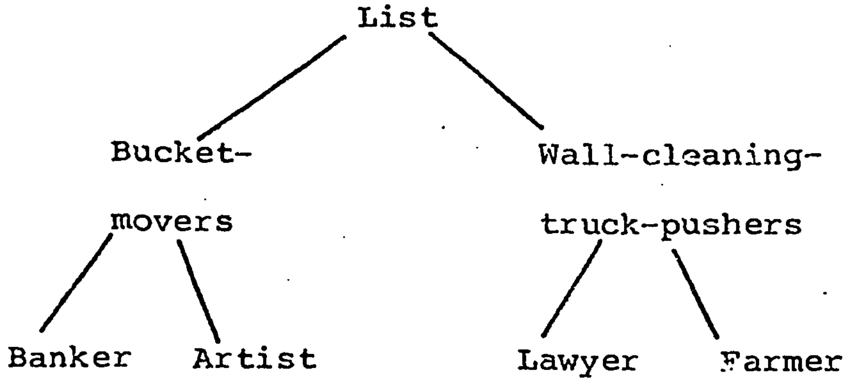


Figure 11. Segment of a possible subdivided network for correlated predicates (see text).

sentence, subjects would use these inter-predicate connections the way they presumably use interconnections established when reading integratable facts. That is, they would use the inter-predicate connections as an aid in accessing a new proposition.

Summary and Conclusions

Recapitulation of Major Points

Of one thing there is no doubt. When learning multiple facts about the same topic, various factors induce us to organize the material, and this will lead to retrieval of the input facts that is substantially better than would be predicted by current models of sentence memory. This boost in retrieval shows up in three different memory indicators -- recall accuracy, recognition accuracy, and recognition latency (i.e., reduced fan effects). More specifically: (a) Facts that subdivide into distinct groups lead to reduced fan effects and to increased recall accuracy. (b) Facts integratable by prior knowledge can result in reduced fan effects, as well as in increases in recall and recognition accuracy (though at the cost of thematically related intrusions in recall and poorer performance on related distractors in recognition). And (c) facts containing correlated predicates lead to reduced fan effects.

With regard to theoretical mechanisms, things are less clear. There is consensus on only one point -- that a subdivided network can be used to organize facts from distinct groups. More precisely: (a) if people learn facts from distinct groups; and (b) show a distinctive pattern on a speeded recognition task (increased latency with increases in the relevant fan but not with increases in the irrelevant fan), or another distinctive pattern on a recall test (some-or-none recall clusters); then (c) they have represented the input facts in terms of a subdivided network.

When we move to our second organizational condition -- facts integratable by prior knowledge -- theoretical opinions diverge. The subnode activation hypothesis holds that the facts are represented by a subdivided network with themes serving as the subnodes. As long as most distractors are unrelated to the themes, people can use activation of a subnode as a basis for recognition, part of this activation coming from concepts that were previously linked to the subnode and that now appear in the probe. Since specific facts need not be accessed, retrieval is rapid and independent of the number of facts learned about a topic. The alternative position focuses on the comprehension of integratable facts. It holds that comprehension involves using schemas to draw inferences about the input, as well as possibly establishing a link between some component of the input and the schema itself. Some inferences interconnect the input facts, thereby providing alternate access routes during recall or recognition, which boost memory in both kinds of tasks. If a connection between the input and the schema itself has been established, retrieval can be accomplished by simply accessing the schema and reading the input facts off of it. As only one link need be accessed, retrieval should be rapid and independent of the number of schema-based facts that were learned.

When we tried to extend these hypotheses to explain the lack of fan effects with correlated predicates, the clearest result was that the subnode activation hypothesis failed. Specifically, while it seemed plausible that each set of correlated predicates was dominated by a single subnode in a subdivided network, such a subnode was likely a novel concept and hence unlikely to have concepts previously linked to it that could contribute to its activation.

While the above hardly provides firm answers to the theoretical questions raised in the Introduction, it does suggest no one mechanism is going to cover all organizational conditions. Thus, subdivided networks seem our best contender for describing what goes on with facts from distinct groups, but an unlikely alternative for explaining the results for facts containing correlated predicates. Similarly, our interconnections hypothesis works best in explaining variations in memory accuracy with integratable facts, and seems beside the point when it comes to accounting for results with facts from distinct groups. So we may need all three mechanisms -- subdivided networks, higher units, and interconnections.

The Status of the Fan Effect

One strategy followed throughout is to take the fan effect as a kind of landmark, and to use reductions of this effect as indicators of organizational factors. While the theoretical importance of the fan effect seems to justify this strategy, some comment is in order about the limited generality of this effect.

We have seen that any one of three different factors can reduce the fan effect. Hence a substantial fan effect occurs only when the facts to be learned conform to the following conjunction of negative conditions: (a) the facts are not from distinct groups, (b) they are not readily integratable by prior knowledge, and (c) they do not contain correlated predicates. The work of Hayes-Roth (1977) supplies still another negative factor: (d) the facts are not well practiced. So a fan effect is obtainable in the laboratory only under a choice of parameters that captures a four-fold conjunction of negative conditions. This means the effect is not among our most robust laboratory phenomena. Furthermore, the above conjunction of negative conditions may rarely occur in real life. The vast majority of real-life learning situations involve facts that are integratable by prior knowledge and/or have correlated predicates. Most times that we read text (or listen to utterances), we are exposed to multiple facts about a topic that are integratable by prior knowledge; if this was not the case, we would probably judge the text incoherent. And when we think of real-life cases where the facts presented are not integratable by prior knowledge, the situations that come most readily to mind are where we learn a novel concept. Here, the predicates of the facts are often highly correlated.

The weak point in the preceding is that we are using laboratory experiments with a very restricted variation of fanning (generally from one to three) to draw implications about real-life situations that may have a far greater variation of fanning. Thus many real-life situations may have a fanning variation of 1 to 100 (e.g., How much do you know about the Mayor of San Francisco vs. about the President of America?), and this huge variation may result in a substantial fan effect even in situations where our conjunction of negative conditions does not hold. The only way to check this is to perform laboratory experiments with conditions known to reduce the fan effect but with huge variations in fanning. Without such experiments, we run the risk of studying a phenomenon that rarely occurs outside of the laboratory.

Even if such experiments are performed and do yield substantial fan effects, there is still a problem in focusing so much effort on laboratory situations defined by the above conjunction of negative conditions. For the representations and processes operative in situations that do not meet the conjunction of negative conditions may be qualitatively different from those operative in situations that do meet our conjunction. We saw a good example of this in the fan experiments dealing with integratable facts (at least in those using unrelated distractors). Even Reder and Anderson's (1980) account of these results introduced some new representational aspects -- namely, the subnodes -- and new processing assumptions -- namely, that activation of a subnode could trigger a recognition decision. These new aspects are qualitatively different from the entities in Anderson's (1976; Chapter 8) ACT theory of sentence memory (though readily interfaceable with that theory), and we would be unlikely to think of these new aspects unless people did research on paradigms that are not specifically configured to yield fan effects.

A Comprehension Approach to Memory Phenomena

In discussing organizational mechanisms for integrated facts, we argued that comprehension processes, like inferencing, may lie behind memory effects. Essentially, we singled out facts integratable by prior knowledge as the one condition where we need to consider comprehension in order to understand memory. This argument can readily be extended. Namely, whenever we deal with memory for facts about the same topic, we first need to understand what goes on in the comprehension of these facts.

Let us go back to the beginning. We started by considering facts from distinct groups. No mention was made there of comprehension. Instead, we noted that the memory representation for such facts often consists of a subdivided network, and traced the implications of this for retrieval. But, why is such a representation constructed? One possibility is that it facilitates retrieval. Another is that a subdivided network is the natural consequence of our comprehension processes operating on an input where the most salient relations between the facts are that some belong to one group, while others belong to different groups. That is, if the business of comprehension processes is to find relations between input facts, and the only salient relation is that some facts are members of the class of statements about countries while others are members of the class of statements about animals, then all the comprehension processes can do is construct a representation that depicts these class-membership relations. In short, subdivided networks are a kind of representation you get out of comprehension processes when your input is sparse on relations.

As for the studies involving facts with correlated predicates, we again have a case where the input is sparse on relations. The only relation the comprehension processes can pick up on here is that some predicates co-occur with others.

To sum up, we may have underestimated the extent to which memory phenomena are dependent on comprehension by consistently using materials that lack the stuff that makes comprehension go--relations. Research concerned with memory for integratable facts may be the only way to redress this imbalance.

Reference Notes

1. Whitlow, W.J., Medin, D.L., & Smith, E.E. _Retrieval of correlated predicates_. Unpublished manuscript, Rutgers University, 1980.

2. McClosky, M. _Search and comparisons processes in fact retrieval and question answering_. Unpublished manuscript, Johns Hopkins University, 1979.

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Footnotes

[1] This prediction was not explicitly made by Rumelhart, Lindsay, and Norman (1972) or in any other paper on the ELINOR model that I know of. However, I believe it follows quite directly from what has been explicitly stated about the model's representations and retrieval processes.

[2] This brief review of conditions that foster organization has omitted Hayes-Roth's (1977) work, which indicates that practice can organize the constituents of a proposition into a single unit. The reason for the omission is that Hayes-Roth focuses on the organization of a single proposition, while I am concerned with organizing a set of propositions.

[3] A substantial increase would occur if there were numerous facts stored about Diane Keaton.

[4] More precisely, the proposition in Sentence (2) matches a simple inference drawn from the script action "Cashier Gives Customer Tickets."

[5] The view of retrieval embodied in this solution makes a sharp distinction between gaining access to a memorized proposition (an <u>access</u> stage) and inspecting the contents of that proposition (a <u>comparison</u> or <u>search</u> stage). The proposed solution assumes that the speed-up in the access stage is greater than the slow-down in the comparison stage.

[6] In particular, schemata used to encode knowledge about goals and plans (e.g., Rumelhart, 1975; Schank & Abelson, 1977) should lead to the same kind of memory results as scripts do.

[7] This study was done in collaboration with Mark Chambers and John Greeno.

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