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Meaning, Memory Structure, and Mental Processes

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People's rapid reactions to words help reveal how stored semantic information is retrieved.

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Experimental psychologists have collected a large body of data on human learning and memory. Many of their findings concern the way that new associations among words are memorized (*1*). However, there has been relatively little work on how people retrieve semantic information from memory after using it continuously for many years. Perhaps one reason for the void is that long-term memories are very difficult to study. For example, thousands of common words are normally kept in a person's vocabulary. Yet without any conscious mental activity, he or she can usually recognize a word and recall its meaning quite accurately. Little extra effort is seemingly required to comprehend the words of a whole sentence. The ease of the process, combined with the exceptionally large memory capacity, makes the underlying mechanism appear rather mysterious.

Despite the difficulty, some recent psychological research has been designed to explore more fully the memory organization and retrieval of familiar semantic information. Part of the advance is based on a change of experimental procedure. It involves measuring the speed of word recognition and sentence comprehension under precisely controlled conditions. The use of this reaction time method differs from the procedures of most previous memory experiments, which have only measured the errors that people make when trying to remember newly learned information. Unlike other procedures, the reaction time method provides a powerful tool for assessing mental processes even when memory failures are very rare (*2*). The data thus obtained have been complemented by theoretical innovations in artificial intelligence, linguistics, and other fields related to information processing. Today psychologists are rapidly modifying and extending concepts from these neighboring disciplines to characterize the nature of human memory, including both its structure and function (*3*). One benefit is an emergence of further insights about various mental processes that deal with verbal stimuli. To illustrate these developments, we will discuss some of our own work on sentence comprehension and word recognition (*4*).

Comprehension and Reaction Time

One of our first sentence comprehension experiments was conducted to study the memory retrieval of semantic information about words that denote categories of objects such as furniture, vehicles, animals, and the like (*5*). We began by selecting several dozen such categories, controlling the familiarity and length of the category names. The category names were used to construct a total collection of approximately 200 special sentences called existential affirmatives, such as the statement that SOME STONES ARE RUBIES (Table 1). Sometimes the members of the first (subject) category mentioned in a sentence formed a subset of the second (predicate) category, as in the statement that SOME PINES ARE TREES. Alternatively, the first category was a superset of the second category, as in SOME STONES ARE RUBIES; or the two categories had a partial overlap, as in SOME WRITERS ARE MOTHERS; or they were disjoint, as in SOME CLOUDS ARE WRISTS. Accompanying this variation of the set relation between the categories were changes in how much the meanings of the category names corresponded. For example, if the first category mentioned in a sentence was a subset of the second category, then the two categories had names with closely related meanings. If the two categories were disjoint, then their names had essentially unrelated meanings. We evaluated the truth of the sentences by following the formal rules of logic (*6*). A sentence was deemed true whenever, by definition and fact, the designated categories had either a subset, superset, or partial overlap relation. In the total collection of sentences, the different set relations occurred with frequencies such that 50 percent of the sentences were true and 50 percent were false.

Next we asked a group of 32 college students to verify the truth or falsehood of each existential affirmative sentence, based on their own knowledge about the set relations between the designated categories. The students participated individually during a series of test trials controlled by a digital computer. At the start of a trial, the computer presented a brief warning signal on a display screen (cathode ray tube). Then one of the printed test sentences appeared. The participants read the sentence, checked their memories for the necessary semantic information, and pressed one button to indicate that the sentence was true or another button to indicate that it was false. We instructed each individual to react quickly and accurately. The reaction time was measured from the moment when the complete sentence appeared to the moment when the button was pressed. After the trial, the computer informed the individual about whether the reaction had been correct. The same procedure was followed for all of the sentences, which were presented in a random order.

Because the category names were very familiar, the participants had little difficulty reacting to the existential affirmative sentences. Mistakes happened on less than 5 percent of the trials, and correct reactions usually took little more than 1 second to make. But the reaction times depended significantly on the set relations between the categories (Fig. 1, lower curve). This set relation effect cannot be attributed merely to a difference between true and false sentences. Reactions to true sentences considered separately were about 110 milliseconds (standard error equal to 22 milliseconds) faster on the average if the first category mentioned in a sentence had a subset relation with the second category (as in SOME PINES ARE TREES) than if the two categories overlapped partly (as in SOME WRITERS ARE MOTHERS). Similar

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Table 1. True and false existential affirmative sentences concerning categories whose set relations and sizes vary.

Set relations	Sizes of second categories	Example sentences	Values
Subset	Small	SOME PINES ARE TREES	True
	Large	SOME PINES ARE PLANTS	True
Superset	Small	SOME STONES ARE RUBIES	True
	Large	SOME STONES ARE GEMS	True
Overlap	Small	SOME WRITERS ARE MOTHERS	True
	Large	SOME WRITERS ARE FEMALES	True
Disjoint	Small	SOME CLOUDS ARE WRISTS	False
	Large	SOME CLOUDS ARE JOINTS	False

results occurred for most of the participants in the experiment (*7*). We may summarize the general outcome in terms of meaning. When the meanings of the category names were closely related to each other, reaction times tended to be shorter (*8*).

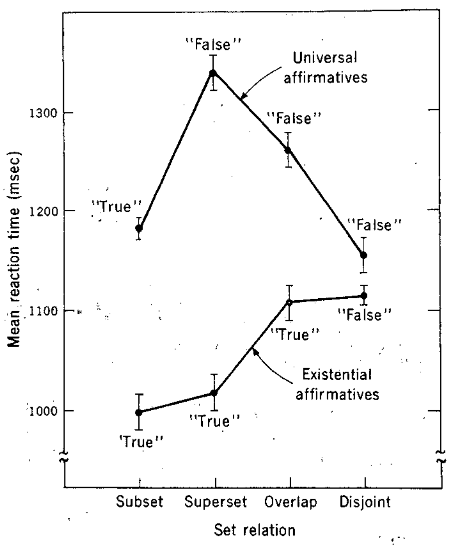
There was also another important factor that affected the reaction times. Besides manipulating the set relations, we varied the sizes of the designated categories in the existential affirmative sentences (Table 1). Some of the categories were small ones with relatively few members, whereas other categories were larger ones with many members. When the first category mentioned in a sentence was a subset or superset of the second category, reaction times increased as the sizes of the two categories became more different from each other. For example, a "true" reaction only took an average of about 887 milliseconds for a sentence like SOME PINES ARE TREES, compared with about 1085 milliseconds for one like SOME PINES ARE PLANTS (*9*). Similarly a "true" reaction only took an average of 934 milliseconds for a sentence like SOME STONES ARE GEMS, compared with 1098 milliseconds for one like SOME STONES ARE RUBIES (*10*).

While comprehension may seem easy, our overall findings reveal that people cannot recall instantaneously whether words have appropriate meanings to make a sentence true. Instead it appears that they must take time to sift their memories for stored information concerning the designated categories. The speed of retrieval varies with the similarity and specificity of the meanings involved. Several other groups of investigators have obtained results comparable to our own (*11, 12*).

A Model of Human Memory

Such reaction time data can be used to test a number of detailed models for describing human memory structure and processes (*5*). The tests have led some psychologists to adopt ideas formulated by Quillian (*13*), a pioneer in artificial intelligence and computational linguistics. Their interpretation is that human memory represents familiar categories of objects like table, chair, and furniture, or robin, canary, and bird at distinct locations of a semantic network (Fig. 2). Between these locations, the inferred network has various types of labeled links specifying relations among the categories. A subset-superset link is presumed, for example, to connect the locations of CANARY and BIRD. There are also supplementary links to connect the location of each category with attributes that define it further, such as a CANARY "is yellow" and "can sing." The arrangement of locations reflects the set relations and sizes of the categories. If two categories share few members or have very different sizes, then their assigned locations would tend to be far apart, much as the entries for words with different meanings are separated in a thesaurus (*14*).

The structure of memory may provide basic information to a "mental program" during sentence comprehension. For our existential affirmative sentences, the comprehension process requires at least four steps, which include forming visual images of the printed category names (stage 1), finding the locations of the designated categories in the semantic memory network (stage 2), checking the network about what set relation exists between the categories (stage 3), and executing a "true" or "false" reaction (stage 4). A popular idea is that stage 3 plays the most salient part (*15*). According to this view (Fig. 3), a person searches the semantic memory network systematically, starting at the locations of the two categories mentioned in a sentence. The search proceeds successively through the links to locations of other categories, with each link taking additional time (stage 3a). Tests are made along the way for whether any



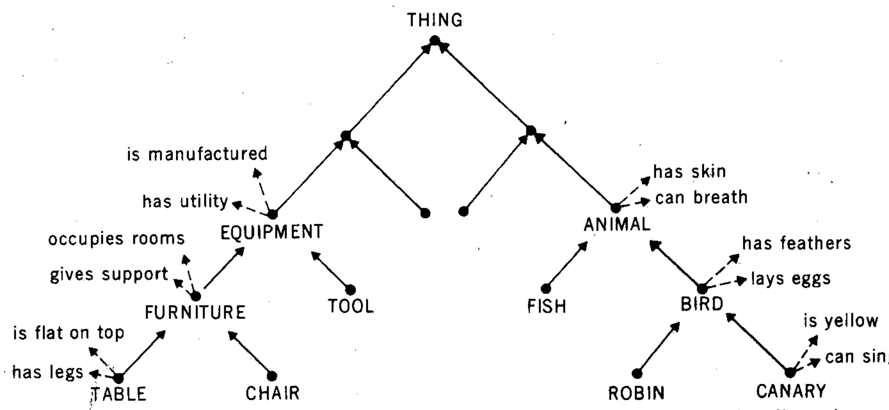


Fig. 1 (left). Mean times (±1 standard error) of "true-false" reactions to existential affirmative and universal affirmative sentences concerning familiar categories of objects with various set relations. Fig. 2 (right). Part of an inferred semantic memory network for storing information about familiar categories of objects. Solid links between category locations point from subsets to supersets, and dashed links point to other important defining attributes of each category. [Adapted from (*11*)]

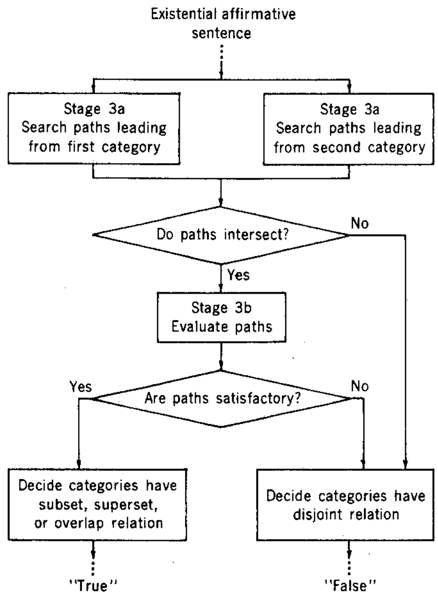


Fig. 3. A process for checking stored information in the semantic memory network to determine whether two categories mentioned in an existential affirmative sentence have any common members.

paths leading from the first category intersect the paths leading from the second category. When the search reveals an intersection, composite links that form the intersecting paths are evaluated (stage 3b). The evaluation is done to determine whether the paths satisfy a criterion sufficient for inferring that the first and second categories have at least one common member (*16*). A positive evaluation produces a decision that the intersecting paths represent a subset, superset, or partial overlap relation between the categories, and then there is a "true" reaction. "False" reactions occur either if the search reveals no path intersections within a reasonable interval, or if the later evaluation shows that the intersecting paths are not sufficient to preclude inferring a disjoint relation.

An overall model combining the inferred memory structure and processes would account for most of the effects of category size on reaction times in our first experiment with existential affirmative sentences. As an illustration, consider a group of categories like PYTHON, SNAKE, REPTILE, ANIMAL, and ORGANISM, which forms a series of nested subsets and supersets whose sizes range from relatively small to large. Their locations are presumably linked together in the memory structure. When a person must decide whether it is true that SOME PYTHONS ARE REPTILES, the model implies that he searches the paths leading from the locations of PYTHON and REPTILE. Because these locations are relatively near each other, the search should quickly reveal an intersection at the intermediate location of SNAKE; evaluating the links would show that the categories have common members and that the sentence is true. But just as we observed, a "true" reaction would be slower to make for a sentence like SOME PYTHONS ARE ORGANISMS, where the sizes of the two categories differ much more than in the preceding example. It should take longer to discover the relevant path intersection and evaluate the links because PYTHON and ORGANISM are located farther apart.

The model also accounts for the effects of set relations on reaction times for existential affirmative sentences. Categories that are disjoint or just overlap partly would tend to have locations more separated than subsets and supersets (*17*). As a result, the path searching and evaluation processes should take longer when the sentences involve partial overlap and disjoint relations than when they involve subset and superset relations, which is consistent with the observed data.

Word Recognition and Reaction Time

Nevertheless other data suggest that the preceding account requires additional elaboration. Some of our recent research on word recognition supports the hypothesis that human memory includes a semantic network, but our new experiments indicate that the memory structure may also influence mental processes that occur before people try to determine what set relation exists between the categories mentioned in a sentence. It even appears that a person's ability to see printed words may depend in some sense on how their meanings are stored.

During one of our word-recognition experiments (*18*), for example, there was a series of test trials in which 16 individuals participated. A typical trial began with the presentation of a warning signal on a display screen. Then a row of letters was presented. Each participant had to read the row of letters and decide whether or not it was an English word, indicating the decision by pressing either a "yes" or a "no" button as quickly and accurately as possible. Immediately after the initial reaction, the first row of letters disappeared, and a second row of letters was presented. The participant had to read the second row of letters, make another word or nonword decision, and press the appropriate button, thereby completing the trial. We measured the reaction times separately for the two rows of letters presented on the trial.

Table 2. Pairs of letter rows and correct reactions from various trials of the word recognition experiment

Types of pairs	Examples	Correct reactions
Related words	BREAD-BUTTER NURSE-DOCTOR	yes-yes
Unrelated words	NURSE-BUTTER BREAD-DOCTOR	yes-yes
Word-nonword	WINE-PLAME GLOVE-SOAM	yes-no
Nonword-word	VEATH-HAIR JACE-CANDY	no-yes
Nonword-nonword	NART-TRIEF PABLE-REAB	no-no

The pairs of letter rows changed from trial to trial, including a mixture of familiar words like NURSE and BUTTER together with pronounceable nonwords such as NART and TRIEF (Table 2). We also varied the legibility of the letter rows. Sometimes they consisted of normal uppercase letters, while on other trials, a pattern of dots was superimposed over them, which degraded the legibility of the letters without making their shapes impossible to discriminate (Fig. 4). More than 400 different words and nonwords were used overall.

The procedure of this new experiment had an important property. In contrast to our earlier experiment with existential affirmative sentences, the new experiment did not require the participants to determine whether the categories denoted by the words had any members in common, and they did not have to analyze the words' meanings. It might therefore be expected that relations among the meanings would not have affected the observed speed of word recognition, because the semantic structure of memo-

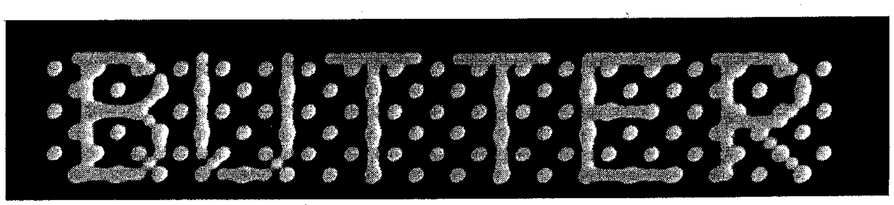


Fig. 4. Example of a word whose legibility was degraded during the recognition experiment by superimposing a pattern of dots. Words with normal legibility did not have the pattern superimposed over them. [Reprinted with permission from (*18*)]

Table 3. True and false universal affirmative sentences concerning categories whose set relations and sizes vary.

Set relations	Sizes of second categories	Example sentences	Values
Subset	Small	ALL PINES ARE TREES	True
	Large	ALL PINES ARE PLANTS	True
Superset	Small	ALL STONES ARE RUBIES	False
	Large	ALL STONES ARE GEMS	False
Overlap	Small	ALL WRITERS ARE MOTHERS	False
	Large	ALL WRITERS ARE FEMALES	False
Disjoint	Small	ALL CLOUDS ARE WRISTS	False
	Large	ALL CLOUDS ARE JOINTS	False

ry was previously suggested to influence only a high-level stage of sentence comprehension (Fig. 3).

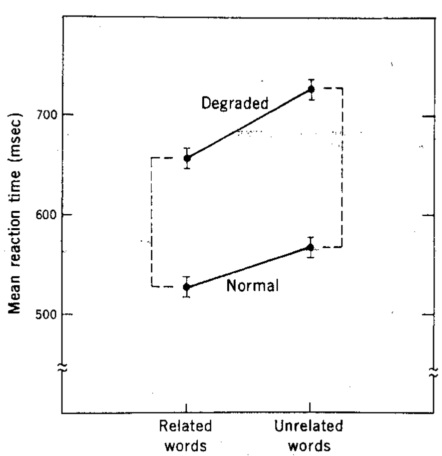
Still, we found that the meanings mattered considerably. When two words appeared one after the other on a trial of the recognition experiment, reaction time to recognize the second word depended on whether or not its meaning was closely related to the meaning of the first word (Fig. 5). People were about 55 ± 7 milliseconds faster on the average (*19*) at recognizing a word like BUTTER if it followed the related word BREAD than if it followed the unrelated word NURSE (*20*). Degrading the legibility of the words with the pattern of dots increased reaction times by more than 100 milliseconds (*21*). The harmful effect of degradation was significantly less, however, for related words than for unrelated words (*22*), suggesting that semantic relatedness helped to overcome the visual distortions produced by the degradation.

Complementing these results, some further experiments have shown that close relations of meaning also facilitate reactions in other, perhaps more realistic, situations requiring word recognition. In particular, we have found that people can pronounce a printed word faster if its meaning is related to an immediately preceding word (*18*). The decrease in the time for pronunciation approximately equals the decrease that a close semantic relation produces in deciding that a row of letters is a word. Likewise, the harmful effects of visual degradation on pronouncing words are reduced by close relations among their meanings. Although such benefits tend to disappear as the temporal interval becomes longer between one related word and another, they are not eliminated by presenting an unrelated word during the interval (*23*). The influence of meaning is remarkably robust under a variety of conditions.

Visual Analyzers and Word Detectors

One possible conclusion from our new findings is that people have a visual feature analyzer and collateral set of word detectors connected to the semantic memory network (*24*). According to this view (Fig. 6), the feature analyzer receives a row of letters and produces a code representing the letter shapes, based on their lines, curves, and angles, as well as the spatial relations among them. The code is sent simultaneously to all of the word detectors, each of which takes time to count how many visual features the letter row has in common with a particular word (*25*). Each detector has its own threshold value. If the counts by the detectors do not exceed any of their thresholds during a specified interval, then the detector system produces a negative signal that the row of letters is not a word. But if the count by a detector exceeds its threshold, then the detector produces an affirmative signal that the corresponding word has just appeared. Moreover, exceeding the threshold produces residual impulses that pass through the memory network and excite other, neighboring detectors temporarily, thus reducing the minimum number of relevant features that they must count to recognize subsequent words. For example, the appearance of the word BREAD would cause its detector to exceed threshold, thereby exciting the detectors of other words, such as BUTTER.

The spread of excitation could be what permits people to recognize words more quickly when they have related meanings rather than when they have unrelated meanings. Because of reduced thresholds, the detectors of related words may take less time to accumulate the necessary sensory information before a reaction. If visual distortions decrease the rate at which the analyzer sends features to the detectors, then just as we observed, close relations of meaning should help especially to recognize words whose legibility is degraded. The detectors would also provide a way of finding the locations for designated categories in the semantic memory network during sentence comprehension (*26*).



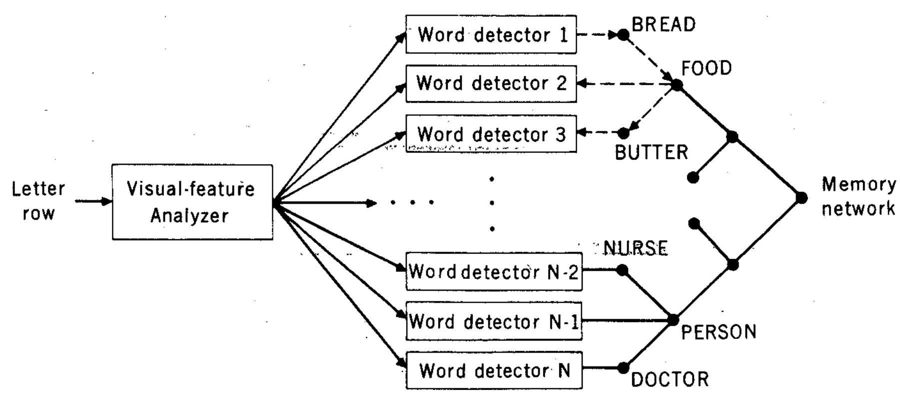


Fig. 5 (left). Mean reaction times (± 1 standard error) to recognize the second words from pairs with related or unrelated meanings and normal or degraded letters. Dashed brackets indicate the different effects of degradation as a function of the words' semantic relations. Fig. 6 (right). Outline of a model for combining sensory and semantic information to recognize printed words. Dashed lines indicate the possible spread of excitation from the detector of one word (for example, BREAD) to the detectors of other related words (for example, FOOD and BUTTER).

Inhibition of Sentence Comprehension

It is not true, however, that close relations of meaning always facilitate mental processing of words. Some processes are actually inhibited when they must deal with two words that have related meanings (*27*). The apparent inhibition raises more questions about what semantic information is stored in human memory and how the information is used.

Another one of our experiments on sentence comprehension revealed part of the additional complexities (*5*). Here again several dozen participants had to decide quickly and accurately whether visually presented sentences concerning familiar categories of objects were true or false, while we varied the sizes and set relations of the categories during a series of test trials. However, the type of sentence differed from that used before. Instead of including existential affirmative sentences such as SOME STONES ARE RUBIES and SOME PINES ARE TREES, the experiment included universal affirmative sentences such as ALL PINES ARE TREES and ALL STONES ARE RUBIES (Table 3). Unlike the former sentences, the latter were true if the first (subject) category mentioned had a subset relation with the second (predicate) category, and they were false otherwise (*28*).

We found that close relations between the designated categories sometimes slowed a person's reactions to the new sentences. For example, "false" reactions took considerably longer when the first category mentioned in a universal affirmative sentence was a superset of the second category than when the two categories were disjoint (Fig. 1, upper curve). The time it took to classify a sentence like ALL STONES ARE RUBIES as false was about 185 ± 27 milliseconds greater on the average than the time taken to classify a sentence like ALL CLOUDS ARE WRISTS as false (*29*). This result contrasts with our previous data for the existential affirmative sentences, which took longest when the categories were disjoint. The contrast was sufficiently strong that, except when the categories had a disjoint relation, mean reaction times for the universal affirmatives exceeded mean reaction times for the existential affirmatives by at least 150 milliseconds.

Another striking contrast was provided by the observed effects of category size on reaction times. For many of the universal affirmative sentences whose first categories were supersets of the second categories, we found that significantly shorter reaction times occurred when the sizes of the categories differed greatly than when their sizes were more nearly equal. A "false" reaction to a sentence like ALL STONES ARE RUBIES took about 1351 ± 37 milliseconds on the average, while a "false" reaction to one like ALL STONES ARE GEMS took about 1497 ± 37 milliseconds (*30*). This result is opposite from the one obtained in our previous experiment, where increasing the difference in the sizes of the categories significantly slowed reactions to existential affirmative sentences (*31*).

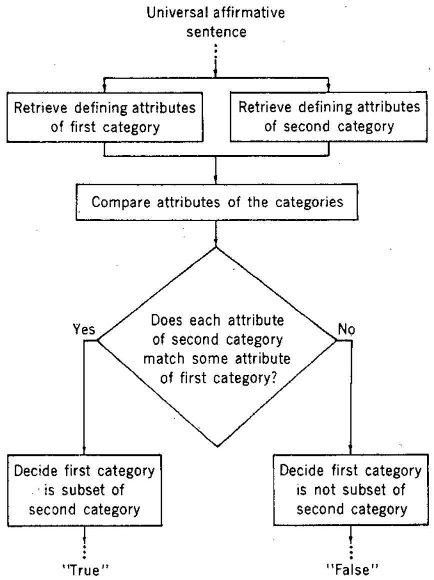


Fig. 7. A process for checking stored information about defining attributes to determine whether the first category mentioned in a universal affirmative sentence is a subset of the second category.

Comparison of Defining Attributes

Our results suggest that universal affirmative sentences sometimes require extra mental processing beyond what is used to deal with existential affirmative sentences. We do not mean to say that the comprehension of one sentence type differs completely from comprehension of the other type. Much as suggested earlier about the existential affirmatives (Fig. 3), reactions to the universal affirmatives may involve initially encoding category names, finding locations of designated categories in the semantic memory network, and searching for combinations of links (paths) that connect the locations with each other (*32*). However, we suspect there is also a subsequent check for links that connect the location of each category to a collection of basic defining attributes, which must all be possessed by members of the category (*33*). The defining attributes are probably necessary to help verify whether the first category mentioned in a universal affirmative is a subset of the second category, and it appears that a close relation between the categories can slow down the process here.

According to this view (Fig. 7), a person eventually retrieves the defining attributes of the second category in a sentence like ALL PINES ARE TREES and compares them with the defining attributes of the first category. If each attribute of the second category (for example, greenness) is found to match some attribute of the first category, then a final decision is made that the first category has a subset relation with the second category, and the comparison process produces a "true" reaction to the sentence. However, "false" reactions are produced for sentences like ALL STONES ARE RUBIES. In the latter case, the comparison process presumably encounters some defining attribute (for example, preciousness) of the second category that is not generally an attribute of the first category, thereby justifying a decision that the first category is not a subset of the second (*34*).

The attribute comparison process accounts for why close relations of meaning slow reactions to certain universal affirmative sentences. For example, consider a sentence like ALL CLOUDS ARE WRISTS, which mentions two categories that have a disjoint relation. There are few if any defining attributes that CLOUDS and WRISTS share, and so the process would not need many comparisons to obtain sufficient mismatches for a "false" reaction. However, it would have to take much longer with a false sentence like ALL STONES ARE RUBIES. Because STONES form a superset of RUBIES, they have many of the same defining attributes (for example, hardness, inanimateness), and a relatively large number of comparisons would be needed to discover some attribute (for example, preciousness) of the second category that the first category does not possess generally. The extra time requirement could outweigh the beneficial influence that close relations of meaning have on other prior processes, as indicated by our data.

At least one interesting question thus remains. If links are stored between the locations of categories in the semantic memory network, and if these links are labeled precisely to designate their set relations as proposed originally (Fig. 2), then why do people use the primitive attribute comparison process instead of checking the labels directly to determine the exact relation? Perhaps the answer is that the links actually lack precise labels. In particular, a person may know that certain semantic categories are closely related without having memorized the complete nature of their relation. Under these circumstances, comparing attributes of the categories would provide a way to compute the exact relation from other available information. The utility of the process need not be limited to comprehending universal-affirmative sentences. It is conceivably helpful whenever the various parts of any sentence are analyzed carefully (*35*).

Summary

Although people experience little difficulty in recognizing printed words and comprehending sentences, they cannot do it instantaneously. Experimental psychologists have recently measured the speed of these mental processes by applying a reaction-time method. The method provides new data concerning the organization and retrieval of familiar semantic information in human memory.

It has been found that close relations between the meanings of words help people to recognize and pronounce the words faster, especially when the words are hard to see because of visual distortions. Close relations between word meanings also facilitate the comprehension of some sentences, as indicated by how long a person takes to decide whether the sentences are true or false. The facilitation is not universal, however. When the relation between the meanings of two words must be analyzed carefully, their proximity may actually inhibit mental processing.

These results, along with additional findings, support the hypothesis that human memory includes a semantic network that represents various categories of objects at distinct locations linked to specify their relations with each other. The memory structure probably influences a number of different mental processes that use it. One possible access route to the network is through a set of detectors designed to accumulate sensory information and signal the presence of particular words. There also appear to be processes for searching and comparing pieces of knowledge after a person finds the memory locations of designated categories. Further research using the reaction-time method may provide a more detailed inventory of what facts are retrieved directly from memory and what are computed from other stored information (*36*).

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6. See I. M. Copi, *Symbolic Logic* (Macmillan, New York, 1967), who along with some other sources, for example (*5*), also refers to our sentences as "particular affirmatives."
7. Here and elsewhere our statistical inferences are based on computations of the quasi F ratio and minimum quasi F ratio discussed by H. H. Clark [*J. Verb. Learn. Verb. Behav.* **12**, 335 (1973)], which treat both the sampled participants and sentences as random variables in an analysis of variance; minimum $F(1,121) = 24.8, P < .01$.
8. Although closeness of meaning covaried with the set relations between the categories mentioned in our sentences, it is possible to separate the effects of these two factors. Closeness of meaning may be measured by asking people to rate the semantic similarity between connotations of different category names, instead of by asking them to assess the actual amounts of overlap in the category memberships [E. E. Smith, E. J. Shoben, L. J. Rips, *Psychol. Rev.* **81**, 214 (1974)]. Results of further experiments by other investigators indicate that this subjective closeness of meaning perhaps has a larger effect on reaction times than the objective set relation does.
9. Mean difference = 198 ± 30 msec; minimum $F(1,24) = 44.0, P < .01$.
10. Mean difference = 164 ± 30 msec; minimum $F(1,21) = 30.8, P < .01$. We also observed other category-size effects on reaction times for the existential-affirmative sentences. When a sentence mentioned two categories that were disjoint, for example, increasing the size of the second category slowed reactions reliably [minimum $F(1.53) = 3.7, P = .07$]. People took an average of about 37 ± 19 milliseconds longer to finish a false sentence like SOME CLOUDS ARE JOINTS than to finish one like SOME CLOUDS ARE WRISTS. The category size effects were not restricted to ones produced by varying the size of the second category in a sentence. When we held the size of the second category constant, varying the size of the first category affected reaction times as well.
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14. However, Quillian did not conceive the memory structure to be necessarily a strict hierarchy. His ideas allow for the possibility of direct links between two commonly associated categories such that one is not an immediate superset of the other (for example, HORSE and ANIMAL, even though technically MAMMAL is an intermediate category that separates them). Quillian also suggested that numerical values may be used to specify the strengths of the direct links between categories. For a full review of the Quillian model, see A. M. Collins and E. F. Loftus [*Psychol. Rev.* **82**, 407 (1975)].
15. A. M. Collins and M. R. Quillian, in *Organization of Memory*, E. Tulving and W. Donaldson, Eds. (Academic Press, New York, 1972).
16. Stage 3b is necessary because an intersection could be found between the paths leading from the locations of two disjoint categories like CANARY and ROBIN, which are both close to the location of BIRD in the memory structure. The evaluation process may apply several criteria to ascertain whether the categories have any common members. For example, suppose that the locations of two categories C_1 and C_2 are connected by a series of subset-superset links through the network. If each link along the way points from C_1 to C_2, then C_1 must be a subset of C_2. Conversely, if each link points from C_2 to C_1, then C_1 must be a superset of C_2. At least a partial overlap relation would be indicated if a third intermediate category C_3 exists such that the path from C_1 to C_2 goes through the location of C_3, but the links all point from C_3 to C_1 and C_2, implying that C_3 is a mutual subset of C_1 and C_2. In contrast, if the links all point from C_1 and C_2 to C_3, then C_3 would be a mutual superset of C_1 and C_2, which could happen even though these first two categories are disjoint.
17. The locations of two partially overlapping categories (for example, MOTHER and WRITER) in the memory structure would ordinarily have the location of at least one other category (for example, POETESS) between them. Thus a combination of two or more links would be required to connect them. However, only a single link would be required to connect the locations of two categories such as PINE and TREE, where one is an immediate superset of the other.
18. D. E. Meyer, R. W. Schvaneveldt, M. G. Ruddy, in *Attention and Performance V*, P. M. A. Rabbitt and S. Dornic, Eds. (Academic Press, London, 1975).
19. $F(1,4) = 27.1, P < .01$.
20. A variety of relations were represented among the stimuli, which included pairs of words whose second members denoted synonyms such as PAIN and HURT, antonyms such as HATE and LOVE, supersets such as APPLE and FRUIT, subsets such as FLOWER and ROSE, attributes of objects such as LEMON and SOUR, and parts of objects such as WAGON and WHEEL.
21. Mean difference = 146 ± 12 milliseconds; $F(1,4) = 98.9, P < .01$.
22. Mean difference = 33 ± 8 milliseconds; $F(1,14) = 5.2, P < .05$
23. D. E. Meyer, R. W. Schvaneveldt, M. G. Ruddy, paper presented at the meeting of the Psychonomic Society, St. Louis, Missouri, November 1972.
24. D. W. J. Corcoran, *Pattern Recognition* (Penguin, Baltimore, 1971); S. Keele, *Attention and Human Performance* (Goodyear, Pacific Palisades, Calif., 1973); J. Morton, in *Models of Human Memory*, D. A. Norman, Ed. (Academic Press, New York, 1970).
25. Although we have omitted discussing any intermediate transformations between the visual feature analyzer and word detectors, this is not a necessary restriction. There may be additional processes that convert collections of visual features to more abstract graphemic or phonemic representations (or both) before input to the word detectors, which could then count the features of these higher level codes. Some data suggest that people rely extensively on such codes under certain conditions. See, for example, D. E. Meyer, R. W. Schvaneveldt, M. G. Ruddy, *Mem. Cogn.* **2**, 309 (1974); H. Rubenstein, S. S. Lewis, M. A. Rubenstein, *J. Verb. Learn. Verb. Behav.* **10**, 645 (1971).
26. Of course, various qualitative and quantitative properties of the word detectors remain to be specified precisely. We are still uncertain how much conscious control a person could have over the thresholds of the individual detectors. Also it is unclear what would happen if a threshold is exceeded by mistake. Resolution of such details will require additional research and testing of alternative hypotheses. J. R. Tweedy and R. W. Schvaneveldt, paper presented at the Mathematical Psychology Meeting, Ann Arbor, Mich., 1974; R. W. Schvaneveldt, D. E. Meyer, C. A. Becker, *J. Exp. Psychol.*, in press.
27. A. M. Collins and M. R. Quillian, *J. Verb. Learn. Verb. Behav.* **9**, 432 (1970); L. J. Rips, E. J. Shoben, E. E. Smith, *ibid.* **12**, 1 (1973); B. Schaeffer and R. J. Wallace, *J. Exp. Psychol.* **86**, 144 (1970).
28. In constructing the universal affirmative sentences, we used the different set relations with frequencies such that 50 percent of the sentences were actually true; that is, half of the sentences mentioned categories that had a subset relation. Thus equal proportions of "true" and "false" reactions were required, just as in the experiment with existential affirmative sentences.
29. Minimum $F(1,85) = 47.6; P < .01$.
30. Mean difference = 146 ± 52 msec; minimum $F(1,13) = 7.8, P < .05$.
31. An important aspect of our procedure should be emphasized. The participants who had to comprehend the universal affirmative sentences never saw any existential affirmative sentences; likewise the participants who had to comprehend the existential affirmative sentences never saw any universal affirmative sentences. This separated presentation of the two sentence types probably contributed to the obtained differences between reaction times; L. J. Rips, *Cogn. Psychol.* **6**, 307 (1975). Some other investigators have found that the reaction time differences for the two types of sentence are not as great when mixed presentations of both universal and existential affirmatives occur during the same block

of test trials. A possible reason is that mixing the sentence types may force people to use exactly the same mental processes for comprehending each type. For example, see A. L. Glass and K. J. Holyoak, *Mem. Cogn.* **2**, 436 (1975).
32. One piece of evidence supporting the inference of shared processes is the relatively small difference in reaction times that occurred for the universal affirmatives and existential affirmatives concerning disjoint categories (Fig. 1); minimum $F < 1.0$ (*5*).
33. A similar view has also been expressed by other recent investigators. See B. Schaeffer and R. J. Wallace, *J. Exp. Psychol.* **82**, 343 (1969); E. E. Smith, E. J. Shoben, L. J. Rips, *Psychol. Rev.* **81**, 214 (1974).
34. Special provisions must be made for some idiosyncratic subsets that lack a defining attribute of their supersets, such as Japanese maples have red leaves rather than the customary green leaves of most trees. Smith *et al.* (*33*) have discussed how the attribute comparison process could be extended to handle these unusual cases.
35. E. E. Smith, L. J. Rips, E. J. Shoben, in *The Psychology of Learning and Motivation*, G. H. Bower, Ed. (Academic Press, New York, 1975). Our reasoning could also explain why participants in the experiment with existential affirmative sentences did not appear to use the attribute comparison process (*5*). When the participants had to decide whether it was true that SOME STONES ARE RUBIES, for example, they did not need to carefully analyze the relation between the designated categories. All of the false existential affirmatives involved unrelated (disjoint) categories. The presence of any close relation, that is, subset, superset, or partial overlap between the categories mentioned in a sentence sufficed for a "true" reaction. This may have allowed the participants to rely on a relatively superficial search and evaluation of paths in the semantic memory network (Fig. 3) without the later attribute comparison process.
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