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Priming in Item Recognition: The Organization of Propositions in Memory for Text

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A priming technique is presented that allows assessment of distances between propositional (idea) units in the memory representations of texts. A representation of the meaning of a paragraph can be obtained by listing the propositions of the paragraph and then connecting those propositions that share an argument. The resulting structure defines different relative distances among propositions. These different distances were reflected in different amounts of priming between words in Experiment 1 and between sentences in Experiment 2. When a test item (word or sentence) was immediately preceded in a list of test items by an item close in meaning structure, response time was faster than when the preceding item was farther away in meaning structure. Control experiments were performed that demonstrated that the priming effect resulted from new connections in memory and not from preexisting semantic relationships. In the discussion, problems with other methods of investigating text structure are discussed.

The comprehension processes involved in reading take texts as their input and construct representations of meaning as their output. It is generally agreed that the representations of meaning are structured (Anderson, 1976; Anderson & Bower, 1973; Fillmore, 1968; Fredericksen, 1975; Grimes, 1975; Kintsch, 1974; Rumelhart, Lindsay, & Norman, 1972; van Dijk, 1977), that propositions are the units of structure, and that propositions are organized to reflect the relations among them. In this paper, we examine one aspect of organization, the relative distances among propositions.

A proposition is a unit of meaning that can take a truth value. The elements of a proposition are concepts and include a relation and its arguments (Fillmore, 1968). In most current theories (Anderson, 1976; Anderson & Bower, 1973; Kintsch, 1974; Rumelhart et al., 1972), the propositions of a text are organized by argument repetition; that is, two propositions are connected to each other if they share an argument (where the shared argument may be mentioned either explicitly or implicitly by inference or by anaphoric reference).

The representation of the meaning of a text that results when the text is divided into propositions and the propositions are connected by argument repetition is illustrated in Table 1. There are six propositions in the text; Proposition 1, for example, is the relation STEAL between the arguments YOUTH and CAR, and Proposition 2 is the relation SIDESWIPE between the arguments CAR and POLE. These two propositions are connected because they share the argument CAR. This connection is shown by the line joining P1 and P2 in the diagram. A representation of the explicit meaning of the text is shown by the six propositions and their connections. A second example is shown in Table 2.

Connecting propositions by argument

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TABLE 1
A LINEAR PARAGRAPH FROM EXPERIMENT 1

The youth stole a car.
The car sideswiped a pole.
The pole smashed a hydrant.
The hydrant sprang a leak.
The leak sprayed water.
The water flooded the flowers.

Propositions:

P1	STEAL, YOUTH, CAR
P2	SIDESWIPE, CAR, POLE
P3	SMASH, POLE, HYDRANT
P4	SPRING, HYDRANT, LEAK
P5	SPRAY, LEAK, WATER
P6	FLOOD, WATER, FLOWERS

Propositional connections:

P1——P2——P3——P4——P5——P6

Connections between nouns:

N1	N2	N3	N4	N5	N6	N7
YOUTH	CAR	POLE	HYDRANT	LEAK	WATER	FLOWERS

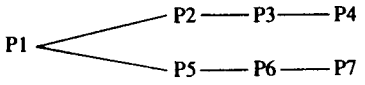
TABLE 2
A BRANCHING PARAGRAPH FROM EXPERIMENT 1

The businessman gestured to a waiter.
The waiter brought coffee.
The coffee stained the napkins.
The napkins protected the tablecloth.
The businessman flourished documents.
The documents explained a contract.
The contract satisfied the client.

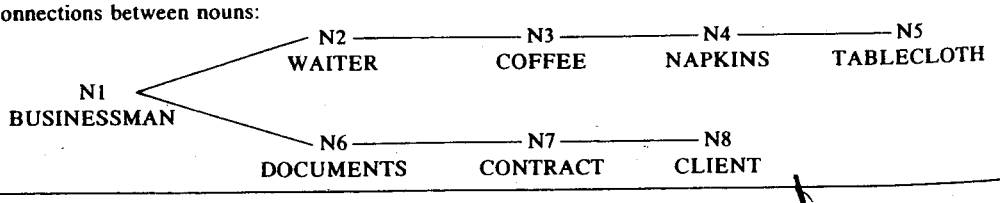
Propositions:

P1	GESTURE TO, BUSINESSMAN, WAITER
P2	BRING, WAITER, COFFEE
P3	STAIN, COFFEE, NAPKINS
P4	PROTECT, NAPKINS, TABLECLOTH
P5	FLOURISH, BUSINESSMAN, DOCUMENTS
P6	EXPLAIN, DOCUMENTS, CONTRACT
P7	SATISFY, CONTRACT, CLIENT

Propositional connections:



Connections between nouns:



repetition defines different relative distances among them. In Table 1, P6 is relatively close to P5 but relatively far from P2. In Table 2, there is one proposition, P1, between P2 and P5, but there are five propositions, P3, P2, P1, P5, and P6, between P4 and P7. Table 2 illustrates that two propositions may be relatively close together in the meaning structure of a text, even though they are relatively far apart in the surface structure (e. g., P1 and P5).

Distances among propositions can also be defined for more complex, more naturalistic texts. The structure of the paragraph in Table 3 is determined by listing the propositions of the text, choosing (by intuition) one proposition (FRENCH, SETTLEMENTS) as the topic (Kintsch, 1974; McKoon, 1977; Meyer, 1975; Rumelhart, 1975; Schank, 1976), and connecting the propositions by argument repetition. The choice of a topic and the argument repetition rule automatically order all other propositions according to their importance with respect to the topic. This ordering is shown in Table 3 by indentation; Proposition 1 is the most important proposition, Propositions 2 and 7 are less important, and so on. For brevity, only some of the propositions of the text are shown and the connections among the propositions determined by argument repetition are not shown.

The structures shown in Tables 1, 2, and 3 embody three assumptions about the representation of meaning in memory. The assumption that propositions are the units has received considerable empirical support (Anderson & Bower, 1973; Kintsch, 1974; Ratcliff & McKoon, 1978), as has the assumption that propositions are organized according to their relative importance or topicality (Kintsch, 1974; Kintsch, Kozminski, Streby, McKoon, & Keenan, 1975; McKoon, 1977; Meyer, 1975). But the assumption that propositions are connected by argument repetition has received little attention; supporting evidence is only indirect. For example, Kintsch et al. (1975; see

TABLE 3
A PARAGRAPH ABOUT A HISTORICAL TOPIC FROM EXPERIMENT 2

Early French settlements in North America were strung so thinly along the major waterways that land ownership was not a problem. The Frenchmen were fur traders, and, by necessity, the fur traders were nomads. Towns were few, forts and trading posts were many. Little wonder that the successful fur trader learned to live, act, and think like an Indian. Circulation among the Indians was vital to the economic survival of the traders.

1 = (FRENCH SETTLEMENTS)
  2 = (STRING, 1)
    3 = (SO THAT, 2, 4)
      4 = (IS PROBLEM, OWNERSHIP)
        5 = (NOT, 4)
        6 = (LAND, OWNERSHIP)
  7 = (FRENCH, MEN)
    8 = (ARE TRADERS, 7)
      9 = (FUR, TRADERS)
      10 = (ARE NOMADS, 9)
      11 = (CIRCULATE AMONG, 9, INDIANS)
        12 = (VITAL TO, 11, 13)
      13 = (HAVE, 9, SURVIVAL)
        14 = (ECONOMIC, SURVIVAL)

Test sentences close in meaning structure, far apart in surface structure:
Circulation among the Indians was vital.
The fur traders were nomads.
Test sentences close in surface structure, far apart in meaning structure:
Land ownership was not a problem.
The fur traders were nomads.

also Manelis and Yekovich, 1976) found that when subjects read paragraphs at their own pace, reading time was longer for paragraphs that required few connections (and had many arguments) than for paragraphs that required many connections (and had few arguments). When reading time was limited, the paragraphs with many connections were better recalled. In another line of research, Anderson (1976; Anderson & Bower, 1973) has demonstrated that, under some experimental conditions (see Hayes-Roth, 1977; Smith, Adams, & Schorr, 1978), a "fan" effect can be obtained in recognition of sentences: The more propositions connected to a particular argument, the longer the time to recognize that any one of the propositions was in a study list. Other researchers have presented subjects with several simple sentences that share an argument and found that the subjects falsely recognize sentences representing the single complex idea formed by the simple sentences (cf. Bransford & Franks, 1971). These studies all suggest the importance of the connections among propositions, but do not examine the connections directly. Hayes-Roth and Thorndyke (1979) carried out a more direct investigation, testing whether subjects connected certain specific propositions that shared arguments. The propositions sharing arguments were either two propositions close together in both the surface structure and the meaning structure of a story or two propositions in different stories. Hayes-Roth and Thorndyke did not investigate the organization of the propositions of a single text. That is the purpose of the experiments reported in this paper; the organization of the propositions of a text will be examined by examining the relative distances among the propositions.

The distance between two propositions or concepts of a text can be measured relative to the distance between two other propositions or concepts of the text by measuring priming effects in item recognition. The priming technique was introduced by Ratcliff and McKoon (1978), who used it to show that the structure of sentences in memory is propositional. Subjects were presented with a series of study–test trials. In the study phase of each trial, subjects read a list of four unrelated sentences. A test list immediately followed the study list and was made up of single words, presented individually. For each word, subjects had to decide whether or not it was in any of the four sentences they had just studied. As soon as a key was pressed to indicate a decision, the next test word was presented. When a test word was immediately preceded in the test list by another word from the same study sentence, the response time was faster than when it was preceded by a word from a different study sentence; that is, there was a priming effect. The priming effect was larger when a test word was preceded by another word from the same proposition than when it was preceded by a work from a different proposition in the same study sentence (with surface distance controlled). This difference in the size of the priming effect was interpreted as reflecting different relative distances between concepts in the representation of a sentence in memory: The priming effect is larger between two concepts in the same proposition because they are closer together in the representation in memory.

In the first experiment to be reported in this paper, priming in item recognition was used to examine the distances between concepts in simple paragraphs like those shown in Tables 1 and 2. If the representations in memory of the meanings of these paragraphs correspond to the structures built by the argument repetition rule, then the relative amounts of priming between the concepts should be predicted by the relative distances between the concepts in the diagrammed structures. For example, in Table 1, *flowers* (N7) should be primed most by *water* (N6), less by *hydrant* (N4), and still less by *pole* (N3). In Table 2, *waiter* (N2) should prime *documents* (N6) more than *napkins* (N4) primes *client* (N8).

In the second experiment, priming in sentence verification was used to examine the distances between propositions in more naturalistic paragraphs like that in Table 3. Subjects were asked to verify (i.e., recognize) whether the propositions of test sentences were true according to paragraphs that they had studied. The experiment is exemplified by the paragraph in Table 3. The propositions of the sentence "The fur traders were nomads" are closely connected to the propositions of "Circulation among the Indians was vital," because Proposition 9 is embedded in Proposition 11. The propositions of "The fur traders were nomads" are relatively farther away from the propositions of "Land ownership was not a problem," because Propositions 9 and 10 are connected to Propositions 4, 5, and 6 only through Propositions 8, 7, 1, 2, and 3. Thus the "fur traders" sentence should be primed more by the "Circulation" sentence than the "Land ownership" sentence.

Experiment 1

In Experiment 1, subjects were presented with a series of study–test trials. In the study phase of each trial, they read two unrelated paragraphs. Then they were tested on single words, presented one at a time. For each word, they had to decide whether or not it was in either of the paragraphs they had just read.

The connections among the propositions of the paragraphs were examined by measuring distances among concepts using the priming technique. For example, in the structure of the paragraph in Table 1, P6 is more closely connected to P5 than to P3, or, equivalently, *flowers* (N7) is closer to *water* (N6) than to *pole* (N3). Therefore, the test word *water* should prime the test word *flowers* more than *pole* does. That is, the time required for a subject to respond "yes" to *flowers* should be shorter when *flowers* is immediately preceded in the test list by *water* than when it is immediately preceded by *pole*.

Five types of paragraphs were used. Paragraphs of the first type had linear structures; Table 1 shows an example. For these paragraphs, the amount of priming between two concepts should depend on the distance between them in the linear structure. However, testing different distances (e. g., *water–flowers* vs *pole–flowers*) involves priming with different test words (*water* vs *pole*) that may have different preexperimental associations to the to-be-primed word (*flowers*). This problem was avoided with a second type of paragraph in which the second and sixth nouns could be interchanged (see Table 4). Thus the seventh noun could be primed by the same word either close in the meaning structure (as the sixth noun) or far away (as the second noun).

In paragraphs of the first and second types, the Linear order and Switching paragraphs, distance in the meaning structure exactly corresponds to distance in the surface structure. This correspondence was eliminated in paragraphs of the third type, Branching paragraphs (see Table 2). In these paragraphs, nouns equally far apart in surface structure are not equally far apart in meaning structure (e.g., N4 and N8 are farther apart in meaning structure than N2 and N6).

In the Linear, Switching, and Branching paragraphs, the meaning structure is determined by dividing the paragraphs into propositions and connecting the propositions by argument repetition. When this procedure is applied to Schema and Nonschema paragraphs, shown in Tables 5 and 6, the result for both types of paragraphs is that every proposition is connected to every other proposition (so the structures are not shown in the tables). However, for Schema paragraphs, this procedure does not capture meaning completely; the propositions in Table 5 are tied together and ordered by the reader's knowledge of the usual relations among them. There is implicit meaning that is not represented in Table 5, meaning that makes

TABLE 4
A SWITCHING PARAGRAPH FROM EXPERIMENT 1

The crops drew insects (crows).
The insects (crows) troubled the farmer.
The farmer surveyed the fields.
The fields needed pesticides.
The pesticides poisoned crows (insects).
The crows (insects) fouled the countryside.

Propositions:

P1	DRAW, CROPS, INSECTS (CROWS)
P2	TROUBLE, INSECTS (CROWS), FARMER
P3	SURVEY, FARMER, FIELDS
P4	NEED, FIELDS, PESTICIDES
P5	POISON, PESTICIDES, CROWS (INSECTS)
P6	FOUL, CROWS (INSECTS), COUNTRYSIDE

Propositional connections:
P1——P2——P3——P4——P5——P6

Connections between nouns:

N1	N2	N3	N4	N5	N6	N7
CROPS	INSECTS (CROWS)	FARMER	FIELDS	PESTICIDES	CROWS (INSECTS)	COUNTRYSIDE

TABLE 5
A SCHEMA PARAGRAPH FROM EXPERIMENT 1

The bride (N1) walked up the aisle (N2).
The bride repeated the vows (N3).
The bride kissed the groom (N4).
The bride enjoyed the reception (N5).
The bride tossed a bouquet (N6).
The bride embarked on a honeymoon (N7).

Propositions:

P1	WALK UP, BRIDE, AISLE
P2	REPEAT, BRIDE, VOWS
P3	KISS, BRIDE, GROOM
P4	ENJOY, BRIDE, RECEPTION
P5	TOSS, BRIDE, BOUQUET
P6	EMBARK ON, BRIDE, HONEYMOON

TABLE 6
A NONSCHEMA PARAGRAPH FROM EXPERIMENT 1

The explorer (N1) seduced a squaw (N2).
The explorer climbed a mountain (N3).
The explorer paddled a canoe (N4).
The explorer joined an expedition (N5).
The explorer charted a river (N6).
The explorer grew a beard (N7).

Propositions:

P1	SEDUCE, EXPLORER, SQUAW
P2	CLIMB, EXPLORER, MOUNTAIN
P3	PADDLE, EXPLORER, CANOE
P4	JOIN, EXPLORER, EXPEDITION
P5	CHART, EXPLORER, RIVER
P6	GROW, EXPLORER, BEARD

the distances among propositions in Table 5 different from those in Table 6. In the Nonschema paragraph of Table 6, all propositions may be equally distanced from each other, because they are all connected to each other, but in Table 5 the first and last propositions, for example, may be farther apart than the first and second propositions. Thus, priming effects may be different for these two types of paragraphs.

To present Experiment 1, we first describe the procedure by which the subjects were tested. Then we describe the design and results of the experiment for each type of paragraph separately.

Method

Subjects. Forty-eight right-handed Dartmouth undergraduates served as subjects for extra credit in an introductory psychology course.

Materials. There were 144 paragraphs, 48 Linear, 16 Switching, 48 Branching, 16 Schema, and 16 Nonschema, The Linear, Switching, Schema, and Nonschema paragraphs were six sentences in length and the Branching paragraphs, seven sentences. Sentences ranged from four to six words in length. All sentences were active sentences of the form (ARTICLE) SUBJECT VERB (ARTICLE) OBJECT (two-word verbs were occasionally used, e.g., bring back). The paragraphs were divided into two sets, each set to be used in one session of the two-session experiment. There were 24 Linear, 24 Branching, 8 Switching, 8 Schema, and 8 Nonschema paragraphs in each set. Within a set, no noun or verb was used in more than one paragraph. Half the subjects were tested with set 1 in the first test session and with set 2 in the second session, the other half of the subjects with the reverse.

Procedure. A study–test recognition memory procedure was employed. Subjects were tested individually for two 1-hour sessions. Study list and test item presentation were controlled by a microcomputer driven by Dartmouth's time-sharing computer system.

A study list consisted of two paragraphs displayed on a CRT screen one at a time for 12 seconds (six-sentence paragraphs) or 14 seconds (seven-sentence paragraphs) each. The two paragraphs for a particular study list were chosen randomly without replacement from the set of 72 paragraphs for that session. Thus there were 36 study lists in a session (preceded by two practice lists).

After the two paragraphs of a study list were presented, a warning signal appeared, and then the test line for those paragraphs began immediately. The test list was composed of individual words presented on the CRT screen one at a time. The subject was to respond to each word by pressing either a "yes" or a "no" key (the "/" and "z" keys, respectively, on the CRT keyboard), according to whether the word had been in either of the paragraphs just studied. A test word remained on the screen until a response was made; then the next test word appeared after a 100-millisecond pause. Accuracy and response time were recorded for each response. Subjects were instructed to respond as quickly and accurately as possible.

Each test list was composed of 36 test words, 24 positive words, nouns or verbs from the studied paragraphs, and 12 negative words, nouns or verbs not used in any paragraph. A test list was constructed in the following manner: First, words that were to be primed were placed in randomly chosen positions in the test list, but not in positions 1 or 2. Then, for each of these words, its priming word was placed in the immediately preceding test position. Second, words that were to be unprimed were placed in random positions in the test list (but not in positions 1 or 2), and then, for each of these, a randomly chosen word from the other paragraph was placed in the immediately preceding test position. Finally, the remaining positive test words (randomly chosen from the studied paragraphs) and negative test words were placed in the remaining test positions in random order. The constraints placed on

the construction of the test list were that there could not be a word from one of the studied paragraphs in the two positions preceding a priming pair of that paragraph, that there could not be a word from one of the studied paragraphs in the three positions immediately preceding an unprimed word of that paragraph, and that no word could appear in the test list more than once. Exactly which and how many words were primed and unprimed varied with type of paragraph. Order of presentation of materials was rerandomized after every second subject.

Linear Paragraphs

Design. The effect of the distance between two concepts on the amount of priming between those concepts was examined in two ways in the Linear paragraphs (Tables 1 and 7). These can best be understood with reference to the tables, where the connections between noun concepts (determined by the connections between propositions) are shown. In the first test for effects of distance, there were four priming pairs, N1–N4, N3–N4, N7–N4, and N5–N4, representing two variables: distance, close (N3–N4, N5–N4) or far (N1–N4, N7–N4), and direction, forward (N1–N4, N3–N4) or backward (N7–N4, N5–N4). These four conditions were combined with four sets of materials (12 paragraphs per set) and four groups of subjects (12 per group) in a Latin-square design. The second test for distance effects involved the priming pairs N6–N7, N5–N7, and N2–N7, and N7 unprimed (N7 preceded in the test list by a word from the other studied paragraph). These four conditions were also combined with subjects and paragraphs in a Latin-square design.

Results. For all the paragraph types, response times averaged about 100 milliseconds faster in the second session than in the first. This variable did not interact with any other variable and so data from the two sessions were combined. Response times longer than 2000 milliseconds in the first session and 1900 milliseconds in the second session were eliminated, as were response times more than 2.5 standard deviations above a subject's mean. Examination of mean response times to unprimed positive test words that were not in any of the experimental conditions showed wide variation in subjects, from a mean of 593 milliseconds up to a mean of 1097 mil-

TABLE 7
A LINEAR PARAGRAPH FROM EXPERIMENT 1

The shepherd beckoned the collie.
The collie nudged the sheep.
The sheep grazed the pasture.
The pasture delighted the goats.
The goats scaled the rocks.
The rocks dotted the hillside.

Propositions:

P1	BECKON, SHEPHERD, COLLIE
P2	NUDGE, COLLIE, SHEEP
P3	GRAZE, SHEEP, PASTURE
P4	DELIGHT, PASTURE, GOATS
P5	SCALE, GOATS, ROCKS
P6	DOT, ROCKS, HILLSIDE

Propositional connections:
P1 — P2 — P3 — P4 — P5 — P6

Connections between nouns:

N1	N2	N3	N4	N5	N6	N7
SHEPHERD	COLLIE	SHEEP	PASTURE	GOATS	ROCKS	HILLSIDE

liseconds. These means were used to adjust the response times included in all of the statistics and analyses reported here (for each subject, response times were adjusted by the difference between the subject's mean and the mean of all subjects on unprimed positive test words not in any of the experimental conditions). Only correct "yes" responses preceded by correct "yes" responses were included in the analyses and statistics in order to ensure that both the primed word and the priming word were in memory. All analyses and statistics were based on mean response times for each subject in each condition.

Linear paragraphs showed the expected effects of distance. The mean response time for N4 when it was primed by a noun close to it in the meaning structure (N3 or N5) was 634 milliseconds (3% errors); when it was primed by a noun farther away (N1 or N7), mean response time was 659 milliseconds (3% errors). This distance effect was significant with subjects as a random variable, $F(1,47) = 10.402$, $p = .002$, and with materials as a random variable, $F(1,47) = 15.106$, $p < .001$. The effect of direction of priming, forward or backward, was not significant ($F < 1$ in both subjects and materials analyses), and distance and direction did not interact ($F < 1$ in both subjects and materials analyses). The average standard error for these mean response times was 10 milliseconds.

The effects of priming on N7 also showed the expected effect of distance. Mean response time for N7 unprimed was 734 milliseconds (13% errors), N7 primed by N2, 699 milliseconds (9% errors), N7 primed by N5, 686 milliseconds (9% errors), and N7 primed by N6, 661 milliseconds (8% errors). With the unprimed condition included in the analyses, the distance effect was significant, $F(3,141) = 10.305$, $p < .001$, with subjects as the random factor, and $F(3,141) = 11.497$, $p < .001$, with materials as the random factor. Without the unprimed condition, distance was also significant, $F(2,94) = 4.676$, $p = .012$ (subjects), and $F(2,94) = 4.311$, $p = .016$ (materials). Standard error for these means was 11 milliseconds.

Switching Paragraphs

In the Linear paragraphs, priming over different distances meant priming with different words. Thus, the obtained differences in priming could have been due to differences in preexperimental associations between the priming words and the to-be-primed words. The Switching paragraphs were designed to rule out this possibility.

Each paragraph had two versions (see Table 4); the only difference between versions was that N2 and N6 were switched. There were four priming pairs of nouns, N1–N6, N1–N2, N7–N2, and N7–N6, representing two variables, distance, near or far, and direction, forward or backward. For each priming pair, half the paragraphs were presented in version 1 and half in version 2. So half the pairs involved one of the switching words and half involved the other. For example, half of the N1–N6 pairs for the paragraph shown in Table 4 were *crops–crows* and half were *crops–insects*. Similarly, half of the N1–N2 pairs were *crops–insects* and half were *crops–crows*. In this way, preexperimental association was controlled; if there is more priming with N1–N2 pairs than N1–N6 pairs, it must be due to the difference in distance in the meaning structure.

Two of the four priming pairs were tested with each paragraph (either N1–N6 and N7–N2 or N1–N2 and N7–N6). These were combined with two versions of each paragraph to give four experimental conditions. The conditions were combined with four groups of subjects (12 per group) and four sets of paragraphs (four per set) in a Latin-square design.

Results. The expected effect of distance was obtained. Priming with a noun close in meaning structure resulted in faster response times than priming with a noun farther away in meaning structure; mean response times were 630 milliseconds (3%

errors) and 649 milliseconds (2% errors), $F(1,47) = 3.806, p = .054$, with subjects as the random variable, $F(1,15) = 4.070, p = .059$, with materials as the random variable. There was also a marginally significant effect of direction; the mean response time for a noun primed in the forward direction (e.g., N1–N6) was 627 milliseconds (2% errors) and the mean response time for a noun primed in the backward direction (e.g., N7–N6) was 653 milliseconds (3% errors), $F(1,47) = 9.407, p = .004$, with subjects as the random variable, $F(1,15) = 3.676, p = .072$, with materials as the random variable. Average standard error of the means was 11 milliseconds.

It is not clear whether to attribute the effect of the second variable to a difference in direction of priming or to a difference in priming noun. In the forward direction, the priming noun is the first noun of the paragraph, which may have special status as the topic of the paragraph. The fact that there was no effect of direction of priming in the Linear paragraphs suggests that this latter interpretation may be the correct one.

Branching Paragraphs

In the Linear and Switching paragraphs, distance in meaning structure was confounded with distance in surface structure; two concepts far apart in meaning structure were also far apart in surface structure. The Branching Paragraphs (Tables 2 and 8) were constructed to allow separation of the effects of distance in surface and meaning structures.

N6, N7, and N8 were tested unprimed and three priming pairs were tested, N2–N6, N3–N7, and N4–N8. The nouns of the pairs are all equally far apart in surface structure, but N2 and N6 are close together in meaning structure, while N4 and N8 are far apart in meaning structure, and N3 and N7 are in between. If distance in meaning structure determines amount of priming, then N2 should prime N6 more than N3 primes N7, and N3 should prime N7 more than N4 primes N8.

Three of the six experimental conditions were tested with each paragraph. The two groups of experimental conditions were combined with two groups of subjects (24 per group) and two sets of paragraphs (24 per set) in a Latin-square design.

Results. Amount of priming varied with distance in meaning structure. The interaction between which noun was tested (N6, N7, or N8) and whether it was primed was significant, $F(2,94) = 7.081, p = .002$, with subjects as the random variable, and $F(2,94) = 6.206, p = .003$, with materials as the random variable. The main effect of priming was also significant, $F(1,47) = 52.647, p < .001$, with subjects as the random variable, and $F(1,47) = 66.055, p < .001$, with materials as the random variable, and so was the main effect of which noun was tested, $F(2,94) = 6.105, p = .003$, with subjects, and $F(2,94) = 3.678, p = .028$, with materials. The mean response time for N6 primed was 665 milliseconds (4% errors) and for N6 unprimed, 736 milliseconds (3% errors); for N7 primed, 672 milliseconds (3% errors), and for N7 unprimed, 719 milliseconds (4% errors); for N8 primed, 704 milliseconds (4% errors), and for N8 unprimed, 734 milliseconds (5% errors). Average standard error for these means was 8 milliseconds.

Schema and Nonschema Paragraphs

If the meaning structures of the Schema and Nonschema paragraphs (see Tables 5 and 6) are constructed by listing the explicitly stated propositions and connecting the propositions by argument repetition, then the structures for the two types of paragraphs are identical. However, for the Schema paragraphs, the reader's knowledge adds implicit information that gives order to the explicitly stated propositions, making some concepts closer together and others farther apart (cf. Bower, Black, & Turner, 1979; Schank & Abelson, 1977). The priming technique should be able to show these differences in distance.

Schema and Nonschema paragraphs

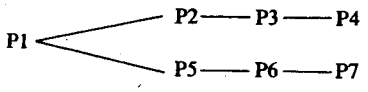
TABLE 8
A BRANCHING PARAGRAPH FROM EXPERIMENT 1

The ringmaster cracked a whip.
The whip stung a lion.
The lion frightened a toddler.
The toddler hid his eyes.
The ringmaster teased the clowns.
The clowns scattered confetti.
Confetti littered the floor.

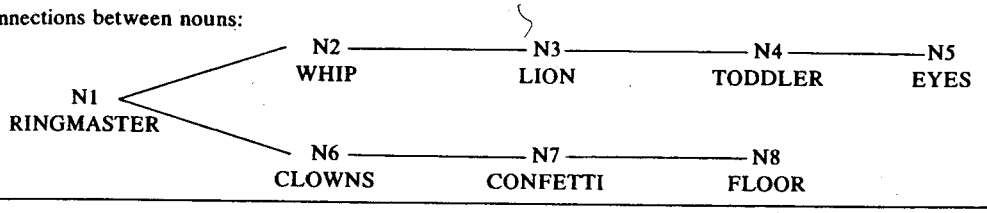
Propositions:

P1	CRACK, RINGMASTER, WHIP
P2	STING, WHIP, LION
P3	FRIGHTEN, LION, TODDLER
P4	HIDE, TODDLER, EYES
P5	TEASE, RINGMASTER, CLOWNS
P6	SCATTER, CLOWNS, CONFETTI
P7	LITTER, CONFETTI, FLOOR

Propositional connections:



Connections between nouns:



were tested in identical ways, with priming pairs N2–N5, N4–N5, N2–N7, and N6–N7. If, in the Nonschema paragraphs, every proposition is connected to every other proposition and there is no ordering of the propositions, then there should be equal amounts of priming with every test pair. In the Schema paragraphs, on the other hand, the ordering of the propositions given by implicit knowledge should lead to a larger priming effect for concepts close together (N4–N5 and N6–N7) than for concepts farther apart (N2–N5 and N2–N7). To check that there was, in fact, some priming effect for both types of paragraphs, N4 and N6 were tested unprimed for comparison with the primed nouns.

Three of the six experimental conditions were tested with each paragraph; for each type of paragraph, these two sets of experimental conditions were combined with two groups of subjects (24 per group) and two sets of paragraphs (eight per set) in a Latin-square design.

Results. For the Nonschema paragraphs, there were no significant differences in amount of priming. Nouns close together in the surface structure (N4–N5 and N6–N7) did not prime each other more than nouns far apart (N2–N5 and N2–N7); mean response times were 691 milliseconds (7% errors) and 692 milliseconds (7% errors), respectively. There was also no difference due to which noun was primed; the mean for N5 was 694 milliseconds (9% errors) and the mean for N7 was 690 milliseconds (5% errors). All F values were less than 1. The average standard error of the means was 12 milliseconds.

The average response time for the four primed nouns in the Nonschema paragraphs was 692 milliseconds, faster than the average for the unprimed N4 and N6, which was 747 milliseconds. There was also an

overall priming effect for the Schema paragraphs, 693 milliseconds for primed responses and 728 milliseconds for unprimed responses. The difference between the unprimed response times for the two types of paragraphs was not significant.

In the Schema paragraphs, if implicit knowledge orders the propositions, then there should be more priming between N4 and N5 and between N6 and N7 than between N2 and N5 and N2 and N7. This result was obtained; mean response times were 684 milliseconds (7% errors) and 702 milliseconds (9% errors), respectively, $F(1,47) = 3.249, p = .074$, with subjects as the random factor, and $F(1,15) = 3.070, p = .097$, with materials as the random factor. There was also a main effect of which noun was tested. When the primed noun was N5, mean response time was 707 milliseconds (8% errors), and when the primed noun was N7, mean response time was 679 milliseconds (8% errors); this difference was significant with subjects as the random variable, $F(1,47) = 4.765, p = .032$, but not with materials as the random variable, $F(1,15) = 1.521, p = .235$. F values for the interaction of distance and which noun was tested were less than 1. Average standard error for the Schema paragraphs was 13 milliseconds.

The contrast in the results obtained with the two types of paragraphs, although not as strongly significant as we would have liked (probably because of the small number of paragraphs), does illustrate the importance of the effect of the reader's prior knowledge on the memory representation of textual information and suggests that relations other than argument repetition can order propositions and determine the distances among propositions. The results also point to the potential usefulness of the priming technique in investigations of scripts or schema (cf. Bower et al., 1979; Schank & Abelson, 1977). Finally, it should be noted that in the Nonschema paragraphs, where there is neither prior knowledge nor semantic structure but only surface structure to provide different relative distances between propositions, priming shows no distance effects.

Experiment 2

The meaning structure of the paragraphs used in Experiment 1 were derived by connecting the explicitly stated propositions according to the argument repetition rule. The structures determined distances among the concepts of the paragraphs. These distances were clearly reflected in the patterns of priming obtained; concepts near each other in the meaning structure primed each other more than concepts farther apart, even when the concepts near each other in the meaning structure were far apart in the surface structure.

The paragraphs used in Experiment 1 were simple and so constrained in structure as to be somewhat unnatural. A clear demonstration that readers do indeed connect propositions as they would be expected to do by the argument repetition rule requires the use of naturalistic materials. This was the purpose of Experiment 2.

Paragraphs like those shown in Tables 3 and 9 were presented to subjects with a study–test procedure. On each trial, the subject read two paragraphs and then verified true–false statements about the paragraph. Verification in this experiment was essentially recognition of factual information without regard to exact wording. Verification time for a sentence preceded in the test list by a sentence close in meaning structure was expected to be faster than verification time for a sentence preceded by a sentence close only in surface structure; examples of such test sentences are shown in Tables 3 and 9.

Method

Subjects. The subjects were 16 right-handed Dartmouth undergraduates participating for extra credit in an introductory psychology course.

Materials. Twenty-eight paragraphs were

TABLE 9
A PARAGRAPH ABOUT A SCIENTIFIC TOPIC FROM EXPERIMENT 2

All scientists today agree that the universe is expanding, and they believe the universe is exploding from a very dense and hot primordial state. Historically, there were a vast number of cosmological explanations of the expansion including religious, mystical, and steady state ideas. The expansion is now generally explained by some version of the explosion or "Big Bang" cosmological theory.

1 = (IS EXPANDING, UNIVERSE)
  2 = (IS EXPLODING, UNIVERSE)
    3 = (FROM, STATE, 2)
      4 = (PRIMORDIAL, STATE)
      5 = (DENSE, STATE)
    6 = (EXPLOSION, THEORY)
  7 = (HAS, EXPLANATION, EXPANSION)
    8 = (IS, EXPLANATION, 6)
      9 = (EQUAL, 6, 10)
      10 = (BIG BANG, THEORY)
      11 = (COSMOLOGICAL, THEORY)
    12 = (INCLUDE, EXPLANATIONS, IDEAS)
      13 = (RELIGIOUS, IDEAS)

Test sentences close in meaning structure, far apart in surface structure:
The "Big Bang" is a cosmological theory.
The primordial state was dense.

Test sentences close in surface structure, far apart in meaning structure:
The explanations included religious ideas.
The primordial state was dense.

abstracted from articles in *Scientific American* (see Table 9 for an example). They varied in length from 60 to 69 words and from 28 to 33 propositions. Twenty-eight paragraphs were also abstracted from a study guide for advanced placement tests in history (see the example in Table 3); they varied in length from 71 to 79 words and from 34 to 39 propositions.

For each paragraph, a to-be-primed, target, test sentence was selected; these varied in length from one to four propositions and five to eight words. The level of the propositions in the target sentence, where level of a proposition is defined as the number of connections in a direct line between the proposition and the topic proposition of the paragraph, varied from 2 to 4. For each target test sentence, there was another, priming, test sentence selected that was far from the target sentence in the surface structure of the paragraph but for which its propositions were close to the target sentence in the meaning structure, and there was also another priming test sentence selected that was close to the target sentence in surface structure but for which its propositions were far from those of the target sentence in the meaning structure. Test sentences close to the target test sentence in meaning structure and test sentences far from the target test sentence in meaning structure both ranged from four to seven words and two to three propositions in length and from levels 3 to 5. The distance in number of words in the surface structure of the paragraphs from the target sentence to the sentence close in surface structure was 6.6 words in the science paragraphs and 5.1 words in the history paragraphs; the average distance from the target sentence to the sentence close only in meaning structure was 24.2 in the science paragraphs and 32.9 in the history paragraphs.

The correct answer for both target and priming test sentences was "true." Three filler test sentences were also constructed, one "true" and the others "false." All true test sentences were as nearly as possible verbatim copies of sentences in the paragraphs. The false sentences were direct contradictions of facts stated in the para-

graphs. No content word appeared in more than one of the test sentences for a given paragraph.

Procedure and design. A study–test procedure was employed. Subjects were tested individually for a session that lasted about 1 hour. Presentation of study and test materials was controlled by a microcomputer driven by Dartmouth's time-sharing system.

A study list consisted of two paragraphs displayed on a CRT screen one at a time for 30 seconds (science paragraphs) or 35 seconds (history paragraphs) each. The two paragraphs for a particular study list were chosen randomly from either the history paragraphs or the science paragraphs. There were 28 study lists in total, plus 2 practice lists.

The test list for each study list began immediately after the study list. Each test list consisted of 10 sentences, presented one at a time on the CRT screen. Subjects were instructed to verify as quickly and accurately as possible whether each sentence was true or false according to the information they had just read ("/" key for true, "z" key for false). Each sentence remained on the screen until a response was made; then there was a 150-millisecond pause and then the next test sentence appeared.

For each of the two paragraphs in the study list, there were five sentences in the test list. Two of these sentences were a priming pair, the target sentence and either the priming sentence close in meaning structure or the priming sentence close in surface structure. The other three sentences were the true filler and the two false fillers for the paragraph. The 10 test sentences were placed in the test list in the following manner: First, a position was chosen randomly (but not positions 1 or 2) for the two target sentences. Then their priming sentences were placed in the immediately preceding test positions. Finally, fillers were placed randomly in the remaining test positions, subject to the constraint that at least one test sentence from the other paragraph must immediately precede each priming pair.

There were two experimental conditions; the target sentence was preceded by either the sentence close to it in surface structure or the sentence close to it in meaning structure. There were also two orders of presentation of materials; either the 14 study lists of science paragraphs were presented first or the 14 lists of history paragraphs were presented first. These four conditions were combined with four groups of subjects (four subjects per group) and four sets of materials (14 per set) in a Latin-square design.

Results

Response times longer than 5 seconds and more than 2.5 standard deviations above a subject's mean were eliminated. Only correct "true" responses preceded by correct "true" responses were included in the analyses and statistics reported here. Mean response times were calculated for each subject in each condition and for each subject on filler true test sentences. The means for filler true sentences showed that subjects who had the first experimental condition (priming with sentences close in surface structure) with one half of the paragraphs were much faster than subjects who had the first experimental condition with the other half of the paragraphs (a difference of 276 milliseconds). Therefore, response times included in the analyses and statistics were adjusted by this difference.

The expected effects of distance were obtained. Test sentences primed by sentences representing propositions close in meaning structure but far away in surface structure were responded to faster than test sentences primed by sentences close in surface structure but far away in meaning structure. The respective means were 1645 milliseconds (11% errors) and 1733 milliseconds (9% errors). The response time difference was significant, $F(1,15) = 14.430$, $p = .002$, with subjects as a random factor, and $F(1,54) = 6.568$, $p = .013$, with

materials as a random factor. (The error rate difference was not significant.) The difference in response times for history and science paragraphs was not significant with subjects as the random factor, $F(1,15) = 1.306$, $p = .271$, but was significant with materials as the random factor, $F(1,54) = 7.927$, $p = .007$. F values for the interaction of type of paragraph and type of priming were less than 1. The average standard error of the means was 102 milliseconds.

Experiment 3

We would like to interpret the priming effects obtained in Experiment 2 as reflections of distances among propositions in meaning structures. However, it is also possible that the priming effects are due to preexperimental associations between the concepts or propositions of the test sentences. For example, in the test sentences of the paragraph shown in Table 9, there may be a preexperimental association between cosmological theories and primordial states that leads to more priming between their respective sentences than between the other pair of sentences. In Experiment 3, we presented the test sentences of Experiment 2 for study as single unrelated sentences without their paragraph contexts. If preexperimental association were the cause of the priming effects obtained in Experiment 2, then we should find the same priming effects in Experiment 3. If instead, as we would like to believe, the meaning structures of the paragraphs determined the priming effects in Experiment 2, then we should find no comparable priming effects in Experiment 3.

Method

Subjects. Sixteen right-handed Dartmouth undergraduates served in the experiment in return for extra credit in an introductory psychology course.

Materials. The materials were the test sentences from Experiment 2, priming pairs and fillers.

Design and procedure. A study–test recognition memory procedure was employed. Subjects were tested individually for a session that lasted about 45 minutes. Presentation of study and test materials was controlled by a microcomputer driven by Dartmouth's time-sharing system.

A study list consisted of 12 sentences displayed on a CRT screen one at a time for 5 seconds each. The test list for each study list began immediately after the study list. Each test list consisted of 20 test sentences. For each, the subject was instructed to respond "yes" or "no" according to whether or not it had appeared in the study list. Subjects were instructed and soon realized for themselves that negative sentences were different in meaning from study sentences and not simply different in surface form; thus, they were instructed to and claimed that they did respond on the basis of meaning. A test sentence remained on the screen until a response was made; then there was a 50-millisecond pause and then the next test sentence was presented.

Both the science and the history test sentences were divided into two sets. The study sentences for a particular trial were two history priming pairs (one close in meaning structure, the other close in surface structure) and two science priming pairs (one close in meaning structure, the other close in surface structure) from one of the sets of paragraphs and four filler positive sentences from the other set of paragraphs. The 20 test sentences were the 12 study sentences plus 8 negative sentences from the same set of sentences as the fillers for the study list. Sentences were placed in the study list in random order. Sentences were also placed in the test list in random order, except that the sentences of a priming pair were placed in immediate succession and not in positions 1 or 2. There were 14 study–test trials, preceded by 2 practice trials.

Order of presentation of the two sets of paragraphs mentioned above and type of priming (close in meaning or surface structure in the original paragraphs) combined to

make four experimental conditions. These were combined with four groups of subjects (four per group) and four groups of sentences (the sentences from 14 paragraphs in each group) in a Latin-square design.

Results

Response times longer than 5 seconds and more than 2.5 standard deviations above a subject's mean were eliminated from the analyses and statistics. Only correct "yes" responses preceded by correct "yes" responses were included in the analyses and statistics. Response times for filler positive items did not differ for different groups of subjects, so adjustments were not made.

Neither of the variables in the experiment significantly affected response times. The mean response times for sentences primed by sentences close in meaning structure in the original paragraphs and for sentences primed by sentences close in surface structure were 1223 and 1218 milliseconds, respectively (both 8% errors). The F values for the type of priming variable were less than 1; all the other F values were less than 1.4. Average standard error of these means was 85 milliseconds.

Discussion

We have shown that the structure in memory of the information in paragraphs can reasonably be represented by propositions connected by argument repetition. The connections among propositions define different distances among propositions. These distances were reflected in different amounts of priming between words (in the first experiment) and between sentences (in the second experiment). If two test words or sentences were far apart in the meaning structure, a small priming effect was obtained, but if the two words or sentences were close together, then a larger priming effect was obtained.

In Experiment 1, we used simple paragraphs with constrained structures. The differences in amount of priming between words were predicted by the differences in distances between the words in the theoretical meaning structures, both for paragraphs in which distance in meaning structure covaried with distance in surface structure and for paragraphs in which distance in meaning structure varied while distance in surface structure was held constant. We also found differences in priming that reflected distances among propositions ordered not by the paragraphs but by the prior knowledge of the reader. This result suggests that priming may be a way to study the structures of schema and also that relations other than argument repetition can determine distances between propositions.

In Experiment 2, we extended our results to naturalistic paragraphs, investigating priming between short sentences. When the propositions of two test sentences were close together in meaning structure but far apart in surface structure, there was a larger priming effect between them than when the propositions were close in surface structure but far apart in meaning structure. This result shows that subjects construct the meaning representations of paragraphs even in an experimental situation where they find the material boring and tedious.

It might be argued that differences in amount of priming were due not to differences in distances in meaning structure but rather were solely due to differences in preexperimental, semantic, associations between the test words or sentences. We counter this argument with two results. First, in Experiment 1, we examined the amount of priming between the same two words when they were close in meaning structure and when they were far apart in meaning structure. The priming effect was larger in the former case. Second, in Experiment 3, subjects studied the sentences that were tested in Experiment 2, but studied them as isolated sentences without their paragraph contexts. The differences in priming that were obtained in Experiment 2 were not obtained in Experiment 3, so they could not have been due to preexperimental association. This argument does not deny

the role of prior semantic association in comprehension, but instead verifies the importance of the new information provided by the semantic structure of the text.

Priming is a particularly effective procedure for investigating the structures of paragraphs in memory because it avoids the problems of free, cued, and conditionalized recall procedures, the major procedures previously used in the investigation of text structure. Recall procedures are confounded by subject selection artifacts because the subject selects which items in memory to recall. For example, suppose that the representation in memory of a paragraph were not a structure of connected propositions but were instead an exact replica of the surface structure of the paragraph. Then suppose the subject is given a cue to recall the paragraph. Being lazy, the subject does not want to write down the whole paragraph even though it is recorded verbatim in his memory, but he does want to write down something that the experimenter will think appropriate. So he searches his verbatim representation for something closely related to the cue. The information he selects is likely to be the information that is close to the cue in the experimenter's propositional representation of the text, and so the experimenter mistakenly assumes that the subject is working from a propositional representation.

Another problem with the cued recall technique is that the effectiveness of a cue in eliciting target information may not give any information about the meaning structure of the text. The cue may be effective only because of preexisting semantic associations between the cue and target information, rather than because of new associations formed at the time of encoding the text.

The priming technique avoids the subject selection artifact because the experimenter can select for testing any pair of items he or she likes and because each item selected will usually serve as its own control. Furthermore, preexisting, semantic, association can be ruled out as the sole explanation of priming effects by appropriate selection of control conditions (as in Experiment 1, Switching paragraphs) or control experiments (as in Experiment 3). The priming technique is also much easier to use than other techniques such as cued, conditionalized, or free recall because the experimenter is able to select comparisons of interest rather than wading through large amounts of recall protocols with their associated scoring problems. In conclusion, we believe that the priming technique provides an extremely powerful tool for the investigation of text structure.

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