Organizational Factors in Memory

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The research reviewed illustrates how the structural organization of material influences the way in which it is learned and recalled by the person. Specific factors investigated concerned relational rules and perceptual-conceptual groupings as these appeared in various laboratory learning tasks. The influence of relational rules was illustrated in paired-associate learning in which a list rule, stipulating a particular relation between the nominal stimulus and response terms, enhanced performance and reduced interference from other learning. The apparent role of the S-R pairing rule, inferred from studies of rhyming rules, is to enable restriction of the range of response alternatives which the person needs to consider at crucial points in his recall. The role of perceptual groupings was examined in immediate recall of digit series; conceptual groupings were examined in free recall of word lists. By one or another means, the learning materials are segmented by the subject into integrated groups which become his functional recall units. Recall suffers if the subject is made to adopt new groupings of the same material. The results on digit series were interpreted by the "reallocation" hypothesis, which ties together the perceptual coding of a string and the "memory location" at which its trace is stored, with implications about recognition memory and trial-by-trial increments in recall of the same string. In free recall, the stable groupings of list words which develop are often supplemented by the subject developing a higher-order retrieval scheme to guide his reproduction of the many items on the list. The nature and influence of several retrieval schemes is reviewed, including interchunk associations, pegword mnemonics, semantic category cuing, and hierarchically embedded category systems. These basic schemes provide implicit cues to guide the person's search through memory. Hierarchical schemes, based on recursive associative decoding, are particularly effective retrieval plans. The results are discussed in terms of the advantages of common strategies preferred by human learners, viz., the tendency to subdivide and group material, and to do this recursively, producing a hierarchical organization of the information to be learned.

A modest revolution is afoot today within the field of human learning, and the rebels are marching under the banner of "cognitive organization." The clarion call to battle was sounded by Miller, Galanter, and Pribram (1960) in their book, Plans and the Structure of Behavior. The immediate

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precursors to the ideas in this book were the work by Newell, Shaw, and Simon (1958) on computer simulation of human thinking, and the work by Chomsky (1957) on syntactic structures in languages. Although there is little altogether new under this psychological sun, the newer organization man does have a different perspective and slant of attack on memory problems than do his S-R associationistic progenitors. The result has been a changing emphasis in what research gets done by the rebels and how they talk about it. The nature of this changed emphasis will be illustrated by reviewing my recent research on some very potent organizational factors in human memory.

The word "organization" has become a slogan, a rallying cry, with clearer emotional than denotative meaning, so I would prefer to substitute some less emotional terms for it. The ideas of interest to me can be formulated in terms of the notions of groups (or classes) and relations (or relational rules). Psychological elements can be grouped (classified, categorized) together on the basis of common properties, and such classes can be related to one another in multiple ways. Grouping and relating are basic cognitive processes, and I think they are inevitably involved in specifying what is learned and how it is learned by the adult human subject. The operation of these processes can be illustrated in the context of familiar, laboratory learning paradigms which my group has studied, so let us turn to a selective review of those now.

GROUPING AND RELATING IN PAIRED-ASSOCIATE LEARNING

Specification of a paired-associate procedure requires explicit use of a grouping operation, since all procedures use some means of temporal or spatial grouping to help the subject segment and differentiate one pair from another. Although items are usually grouped in pairs by temporal contiguity, Thorndike's (1935) many experiments on the principle of "belongingness" are one long demonstration of the fact that other grouping factors can override temporal contiguity. He used sentences like "John is a teacher. Bill is a doctor. Harry is a carpenter.", etc., and found no association between the last word in one sentence and the first word in the next sentence, despite their temporal contiguity. By use of syntax, stress, and pauses, subjects segment the speech flow into sentences and apparently store these as units in memory.

So, the first point is that belongingness is a result of grouping operations or programs applied to experience by the subject. A second point is that, after the pairs have been segregated, their memorability depends upon the subject relating the two members of the pair in some way. Mnemonic techniques prescribe methods for finding or generating such pair relations. If the pair consists of unrelated words, then they can be related by gen-
gerating a sensible linking sentence (Bobrow & Bower, 1969), by visualizing some "mental picture" of spatial interactions (Bower, in press; Paivio, 1969), by searching for an intermediary associate, by noting graphemic or phonological similarities (e.g., clang associates), or by any of a diverse range of categorical relations available in most adults' semantic memory. With nonsense syllables, a preferred strategy is to code them into words and associate these by some mnemonic (cf. Kiess & Montague, 1965). Rote memorization of contiguous pairs would appear to be a last-resort option taken only if other relational-search strategies fail or are never activated.

These mnemonic techniques are for relating members of a given pair, but the person also searches for common relations among several or all the pairs he is learning concurrently. That is, he looks for a rule for calculating or generating the "response" given the "stimulus" of each pair. The experimenter, of course, can build such rules into the paired-associate list. A few examples would be when (a) the response word rhymes with the stimulus, or (b) the response number is obtained by doubling the stimulus number, or (c) the response trigram is obtained by permuting the first and last letters of the stimulus trigram. The presence of such rules radically alters the speed and character of paired-associate learning. Several armchair observations can be made about such examples. First, the S-R pairing rule is a structural property of the list as a whole, and the vicissitudes of learning a particular pair will depend on this wholist property (cf. Garner & Whitman, 1965). Second, the presence of rules probably affects the degree of interference between two lists that the person learns in succession. And third—the moral—if subjects clearly discover and utilize pair-rules when we explicitly put them in the list, we can be reasonably confident that they are also searching for (and probably finding) some rules even when they are learning the lists of unrelated, arbitrary pairs that are customarily used in such experiments.

The point about rules reducing interference and forgetting can be illustrated by reviewing an experiment by Tulving (1967), using the materials exemplified in Table 1. His subjects learned two paired-associate lists in succession, the lists conforming to the conventional A-B, A-C paradigm of negative transfer. The stimuli and responses came from different classes of materials—people's names, numbers, geographical names, letters, and three-letter words. In the rule lists, the pairings were systematic with the stimulus and response members coming from the same class. In the random lists, the pairings were unsystematic and the class correlations were altered between list 1 and list 2. Learning was, of course, much faster for the rule lists than for the random lists. However, the more interesting data came from the retention test given after second-
TABLE 1

<table>
<thead>
<tr>
<th>Type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>A-B Forgetting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random pairing</td>
<td>MALTA</td>
<td>39</td>
<td>K</td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>DREISER</td>
<td>RHINE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>PIE</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Rule pairing</td>
<td>79</td>
<td>39</td>
<td>52</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>MALTA</td>
<td>FIJI</td>
<td>RHINE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>R</td>
<td>K</td>
<td></td>
</tr>
</tbody>
</table>

List learning, when subjects were asked to recall both responses learned to each cue (an MMFR test). Recall percentages are shown in Table 1, demonstrating that A-B pairs are forgotten 42% in the random lists but only 3% in the rule lists. Thus, the customary unlearning and interference produced by the A-C paradigm is practically eliminated when the pairs exemplify a simple rule such as "like goes with like." The results appear inexplicable in terms of higher pre-experimental associations for the systematic as opposed to the random pairs. Rather, the rule applied to the stimulus serves to single out the response from the undifferentiated set ordinarily involved when multiple pairs are learned. That is, the rule-plus-stimulus tells the subject the category of the response, and he merely retrieves the element of that response category which has been made available by prior presentations. This result has been replicated and modestly extended in our laboratory, without altering the overall conclusion.

Let us try to get a firmer fix on why it is that rules accelerate learning. The reasoning will be illustrated in the context of analyzing why rhymes are an aid to memory. It is well-known that rhymes are potent mnemonics exploited by most "memory systems." Surprisingly, learning theorists seem not to have concerned themselves with analyzing why this is so. Ignoring for the present the rhythmical pattern in verse (which is itself a place-keeping and segmentation mnemonic) and paring matters down to the merest bones, rhyming is a dyadic relation between phonological compounds, between words that sound alike. Specifically, a word that rhymes with hat is a word obtained by altering the first phoneme and leaving the remainder intact, as in cat, bat, and mat.

A list of rhyming pairs is surely learned much faster than a comparable list of unrelated pairs. But why? The hypothesis is simply that the
rhyming relation restricts the search for a response (to each stimulus) to just a few alternatives. That is, the rhyming relation in principle permits the subject to generate implicitly the plausible candidate-responses, and he needs only to recognize the one that has recently occurred in the list context.

This response-restriction hypothesis has been tested in two ways. One way is to show that other, nonrhyming rules which equally restrict response alternatives will produce as much facilitation of paired-associate learning as does a rhyming rule. Laura Bolton and I (Bower & Bolton, in press) have shown this for an assonance rule, where the response relates to the stimulus by a change in its last phoneme (e.g., pit-pin, hat-hag).

Figure 1 shows a comparison of the rhyming vs. assonance rules for two groups of 15 college students learning a mixed list of 36 CVC pairs by anticipation at a 2:2-sec rate. Eighteen of the pairs were unrelated nouns printed in black and 18 pairs were related nouns printed in red letters. The 18 related pairs were rhymes for the subjects in Fig. 1a; the related pairs were assonants for the subjects plotted in Fig. 1b. The related pairs are anticipated correctly significantly more often on every trial in each group; moreover, the advantage for the related pairs is about equal in the two cases. In Fig. 1a, the mean correct responses per item over the nine trials was 5.95 for rhyme pairs and 4.11 for unrelated pairs. In Fig. 1b, the means are 5.38 for assonance pairs and 3.61 for the unrelated pairs. The related-minus-unrelated differences of 1.84 and 1.77 are nearly equal. So an assonance rule, which restricts response alternatives about as much as does a rhyming rule, confers about as much advantage in correct performance as does the rhyming rule. Therefore, in terms of learning, there is nothing uniquely special about the rhyming relation.

Fig. 1. Learning curves for a mixed list of (a) rhyming vs. unrelated pairs, or (b) assonant (end-change) vs. unrelated pairs.
TABLE 2
Sample Pairs Where Cue and Correct Response Rhyme or Are Unrelated and Where Correct Response and Its Distractors Rhyme or Are Unrelated

<table>
<thead>
<tr>
<th>Type</th>
<th>Correct response</th>
<th>Distractors</th>
<th>Mean errors$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>R U</td>
<td>can</td>
<td>man</td>
<td>bay pun wig bid</td>
</tr>
<tr>
<td>R R</td>
<td>hat</td>
<td>mat</td>
<td>vat rat bat cat</td>
</tr>
<tr>
<td>U U</td>
<td>lad</td>
<td>buy</td>
<td>dig sap rug tub</td>
</tr>
<tr>
<td>U R</td>
<td>box</td>
<td>lip</td>
<td>dip hip tip rip</td>
</tr>
</tbody>
</table>

$^a$ Mean errors per item over 9 trials are listed for each type of item.

A second test of this response-restriction hypothesis is to equate response alternatives for rhyming vs. unrelated pairs by use of multiple-choice recognition tests. Examples of possible item types are shown in Table 2 where the stimulus and correct response either rhyme or not, and the correct response and its multiple-choice distractors either rhyme or not. In the experiment, subjects learned a number of such pairs for nine trials, first seeing the stimulus along with five response alternatives (from which he selected one), then the stimulus-correct response pair. The stimuli with rhyming response terms were printed in red letters, those with unrelated responses were printed in black letters. In terms of restrictions on response alternatives, the rhyming pairs tested with unrelated distractors should be most often correct, since in this case the rhyming rule uniquely specifies the correct response. But when all distractors rhyme, then the rhyme relation should be rendered totally uninformative and such pairs should be learned no faster than the unrelated pairs.

These expectations proved correct: the mean errors per item over nine trials are shown in the final column of Table 2. As expected, there were very few errors on the rhyming pairs with unrelated distractors. More importantly, performance on the other three types of items was indistinguishable. Such data confirm the hypothesis that rhymes facilitate performance because the relation permits the learner to restrict response alternatives at critical points in his recall. I would conjecture that this is probably true of most S-R rules, not only for the rhyming rule. An important qualification to this hypothesis is that the response-set defined by the stimulus-plus-rule must be readily available for generation by the subject. For example, the rule that S-R pairs composed of five-letter words have identical second and third letters does restrict word alternatives, but most adults have difficulty generating very many candidates (e.g., what words can be filled in _nt_?). Such observations tell us some-
thing about the phonemic index for words in our long-term memory (cf. Horowitz & Prytulak, in press).

In the paired-associate illustrations above, the relational rule tells the person "where" to search in memory for a single correct answer. But rules can serve as more general retrieval devices, guiding the subject's search through and generation of larger classes of responses. The best examples of these more general retrieval rules occur in free recall, where the person must generate a large set of items identified primarily by the fact that each item occurred in a particular list which is to be recalled. I will return later to retrieval rules in discussing free recall.

GROUPING FACTORS IN SERIAL LEARNING

The other notion mentioned in the introduction was that of grouping. I wish now to fill in more details concerning the role of grouping in learning and to illustrate some of these ideas with a few of our experiments, first on serial learning and then on free recall.

The elementary serial task we have studied is the digit span test, in which the person must reproduce an ordered string of digits immediately after he hears it. One of the fundamental strategies used by people in learning a long series of symbols is to segment it into several smaller chunks or groups. Even a monotonous series can be grouped by the person imposing on it his own rhythmical stress or pauses, or in terms of his naming of numerical groups. This segmentation of a string may serve several useful purposes. First, the segments are small and are themselves easily learned, so the person's job is reduced to seriating a smaller number of units than was true before groupings were imposed. Second, the size of the successive groups and their order in the string may conform to a simple, repetitive, rhythmical pattern which helps the person to plan and execute his serial reproduction (cf. Neisser, 1967). The beats of the rhythm might serve as subjective anchor points to which digits are attached, and the pauses serve as phrase-markers delineating major constituents. Using this plan, for instance, the person knows the location of some digits even though he has forgotten others, he knows when he has reached the end of his recall, but he has difficulty unwinding the temporal rhythm backwards in order to do backwards recall.

A variety of perceptual variables will influence the groupings of a string adopted by the subject, and I think it can be shown that these groupings become "perceptual units" in a certain sense (cf. Garrett, 1965; Fodor & Bever, 1965). However, my main thesis is that these perceptual groups are the units that are stored in memory and that recall is largely a matter of assembling these chunks in their correct order. We have collected evidence on various implications of this point of view, but I will present the evidence around only one of these implications.
If what is stored about a string is a sequence of groups, then one should find rather dramatic degradations of memorial performance when the group structure of the string is altered between presentations. An experiment David Winzenz and I did relevant to this prediction used a continuous recognition memory procedure with five-place numbers (Bower & Winzenz, 1969). Items were read to the subject as number groups, such as "seventeen, three hundred forty-eight" for 17-348. Each item occurred for a second time after varying numbers of intervening items, and this recurrence was grouped either the same as or different than the item's first occurrence. To each item, the subject was to indicate whether or not he thought he had heard an earlier string with the same underlying sequence of digits. The percentages of correct recognitions as a function of lag for the two cases are shown in Fig. 2. Recognition declines towards the false alarm level over the retention (lag) interval. Importantly, recognition of identity is very much poorer when the group structure of the string is altered between its first and second presentations.

A second experiment concerned the effect on immediate recall of repeating a string but altering its group structure at each repetition. If a sequence of groups is what is stored in memory, then the usual benefits of repetition should be eliminated by altering the groups of the string at each repetition. For this experiment, we used a procedure introduced by Hebb (1961) in which a particular digit series periodically recurs amongst a background of changing "noise" items. Letting a letter stand for a 12-digit series which is presented and immediately recalled, each block of eight trials conformed to the paradigm aBcBdBeB, where a, c, d, e are new "noise" strings and B is the recurrent item. There was a brief rest pause after each block of eight trials, then a new block was begun with totally different strings (i.e., the recurrent B string would be different in

![Graph](image)

**Fig. 2.** Recognition probability related to the number of intervening items for items repeated with the same or a different grouping.
In half the blocks, the group structure of the recurrent item remained constant over its four occurrences; in the other blocks, the group structure of the recurrent string was altered each time it was read to the subject. Thus, a series grouped as 17-683-9452-7-56 on its first occurrence might recur as 176-839-45-275-6, then as 1-768-3945-2-756, then as 1768-39-45-2756. The person recalled by writing successive digits in boxes on an answer sheet, so in each of these cases he would write down the same sequence of digits.

The results of this experiment are shown in Fig. 3 in terms of the mean errors in recall per 12-digit string over the four occurrences of each item type within the block. The once-presented or noise items maintain a high error rate, as they should. The recurrent string repeated with the same group structure shows a typical learning curve, with a large reduction in errors over repetitions. However, recall of the recurrent string with changing group structure shows absolutely no improvement over its four trials. It is as though each reorganization of the recurrent digit sequence is recalled as a brand-new item.

Internal analyses of the recall data serve further to bolster the hypothesis that the digit groups act as recall units. If this were so, then the association between adjacent digits falling within a group should be stronger than between those falling across group boundaries. The serial recall data were analyzed for these interitem associations by examining conditional transition probabilities (cf. Johnson, 1968). The “transition error probability” (TEP) plotted in Fig. 4 is the conditional probability of an error on item n in the string given that item n-1 was recalled correctly. The data in Fig. 4 are for all those once-presented noise items for which the se-

![Fig. 3](image-url). Mean recall errors over four trials for noise items and for items repeated with the same grouping or with different groupings.
Fig. 4. Transition error probabilities for noise items with a 23232 group structure. Over serial-position 1, the error probability of item 1. For a later position i, the bar indicates the conditional probability of an error on Element i given correct recall of Element i-1. The initial transition into each group is stippled.

The sequence of group sizes was 23232. The crosshatched bars indicate the transitions moving into a group. The pattern of TEPs indicates clearly that errors are most probable at the transitions between groups, with TEPs decreasing over successive elements within each group. Further TEP analyses on the items recurring with the same structure revealed that the main improvement with repetitions for these items was in a reduction in between-group TEPs, with relatively little change in the within-group TEPs. To use an analogy, it is as though the digit groups were acting like single words, and with repetition groups of words come to act like phrases or sentences.

One might object that these detrimental effects of altered groupings result entirely from the fact that the words the person actually hears change with this method of altering group structure (e.g., compare "seventeen, four hundred thirty-five" to "one thousand seven hundred forty-three, five"). The force of this objection is removed by later experiments in which we obtained the same effects when groups were indicated simply by the location of pauses in the sequence of digit names. In these later experiments, the sequence of phonemes heard was the same in each repetition and only the temporal location of pauses was altered. Yet there

In this and the following, the sequence of group sizes in the string will be denoted by digits. Thus, 23232 denotes any string composed of a first group of two digits, a second group of three digits, a third group of two digits, etc.
was no accumulated learning whatsoever for strings repeated with such altered structure; the results were exactly like those depicted in Fig. 4.

We may summarize our results to date with the diagram in Fig. 5 which schematizes what I will call the reallocation hypothesis. The process is conceived to operate as follows: as a grouped string arrives, the perceptual coder first decides whether it has been heard before by trying to match the first one or two groups of the string to the traces of past strings it has stored at various "locations" in memory. If this match test succeeds, then the input string is allocated or shunted to the location of the matching trace, thus to contact and strengthen the trace residing there. If the match test fails, then the incoming string is shunted to a new location and stored as a new trace. The trace is presumably a hierarchical phrase structure (i.e., a sequence of groups of groups) and we may assume that information is lost from it as other items arrive and are processed.

In these terms, memorial recognition of identity depends both upon the information remaining in the target trace and on whether the coded input gets shunted to the same storage location. A string repeated with the same group structure will often be shunted to the same storage location, is likely to signal a high matching score with respect to the trace residing there, and so it will be recognized. A string repeated with an altered group structure is likely to be shunted to a new location, will signal a low match score, and will not be recognized. To handle immediate recall, it must be assumed that recall consists in reading out the informa-

Fig. 5. Heuristic block diagram of the reallocation theory, showing a perceptual coder shunting an incoming string to a particular storage location in memory.
Improved recall of constant portion?

<table>
<thead>
<tr>
<th>Last 7 constant:</th>
<th>Improved recall of constant portion?</th>
</tr>
</thead>
<tbody>
<tr>
<td>presentation (1) 937618542</td>
<td>No</td>
</tr>
<tr>
<td>(2) 727618542</td>
<td></td>
</tr>
<tr>
<td>(3) 357618542</td>
<td></td>
</tr>
<tr>
<td>First 4 constant:</td>
<td>Yes</td>
</tr>
<tr>
<td>presentation (1) 7462 983 51</td>
<td></td>
</tr>
<tr>
<td>(2) 7462 85 913</td>
<td></td>
</tr>
<tr>
<td>(3) 7462 1953 8</td>
<td></td>
</tr>
</tbody>
</table>

tion in the trace in the most recently activated storage location, with better recall from stronger traces. Strings repeated with the same group structure are recalled progressively better because the input is being repeatedly assigned to the same storage location and trace strength for that phrase structure will accumulate there. But with altered groupings, the string is reallocated to a new storage location (precluding contact with the old trace) from which it is recalled as though it were a new item.

Although it is doubtless possible to state this theory in less metaphori*


cal terms, the present formulation is heuristic and leads to several interesting implications. First, it implies that constancy of the first group in the recurrent string is critical for getting the repetition-learning effect. This appears correct for digit-span experiments of the Hebb design, in which only a portion of the string recurs while the remainder of the string varies over recurrences of the constant portion. Two examples of these recurrent chunks are shown in Table 3. For example, if the first two elements of a nine-digit string are varied while the last seven digits remain constant over repetitions (separated by two noise strings), there is no progressive improvement in recall of the constant seven-digit ending (Schwartz & Bryden, 1966). However, we have found that if the constant portion is the first group in an otherwise variable string, then recall of this constant first group does improve with repetition.

A second implication of the theory involves the distinction between experimenter-imposed groupings (E-codes) and subject-imposed groupings (S-codes). Subjects can be trained to try to subvocally shadow and chunk the string into a standard phrase structure, such as 3333 (i.e., a sequence of triplets), even though the E-code induced by pauses might be, say, groups of sizes 24231. Such processing involves a small "cognitive fight" between E's code and the person's attempt to impose a different
FIG. 6. Mean errors over four trials for noise items and for items repeated with a constant or changing group structure. For the noise and constant items, separate curves are plotted for items with a 3333 group structure or a non-3333 structure.

S-code, but we have found that our subjects are moderately successful if the input rate is slow (1 digit per sec). Since the theory supposes that the S-code is what is stored about a string, it follows that a person's use of a standard S-code should reduce the formerly disastrous effect on recall of changing the phrase structure (E-code) of the recurrent string. To test this prediction, the Hebb design of Fig. 3 was repeated with subjects pretrained to chunk the 12-digit series as 3333 (as triplets). The results are shown in Fig. 6, giving recall errors over four trials for noise strings, for strings recurring with a changing structure, and for strings recurring with a constant structure. The latter are divided into 3333 strings (where E- and S-codes agree) versus non-3333 strings. The significant result in Fig. 6 concerns the strings recurring with changing groupings: formerly, when the E-code predominated, there was no learning whatsoever of such strings (cf. Fig. 3); now, when the S-code frequently predominates, there is very definite learning (i.e., improved recall). The learning improvements for the other conditions are ordered as one would expect from the features of the "cognitive fight": performance is best when the E-code and S-code agree (the 3333 strings), and next best when the codes differ but in a constant manner over recurrences (which yielded learning in Fig. 3).

A third implication of the theory concerns recognition of an uncoded string after experiencing two coded strings some time earlier. The question is whether recognition of the ungrouped string "98765" is about equivalent after experiencing "98-765" twice, as opposed to experienc-
ing "98-765" and "9-876-5" once each. The theory says that the former condition establishes a strong trace at one location, while the latter condition establishes equivalent but weak traces at two locations. We may suppose that the ungrouped string "98765" is recognized by the person trying out particular articulatory groupings, trying to match a trial-coding to the trace of a coding of that string he has stored in memory. The net probability of recognition of the uncoded string would then depend on the number of locations at which equivalent forms of the string have been stored and upon the strength of the trace at each location. Without further information, one cannot predict whether double strength of one code leads to the same recognition as does single strength of two equivalent codes. But a determinant prediction is that recognition of either type will exceed that of a once-presented control item, which theoretically corresponds to a single-strength trace at one location.

The experiment to test this prediction involved an input block of trials when auditorily grouped five-place numbers were heard, then a block of recognition test trials during which ungrouped strings were presented visually. The subject had to say whether or not each test string of digits corresponded to some one that he had just heard in the input block. Half the test strings were in fact Old and half were New, providing a check on false alarms. Table 4 gives the percentages of recognition responses for the various item types. Singly presented items were recognized about 17% above the false alarm rate, while doubly presented items averaged about 32% above the false alarm rate. Consonant with expectations, the repeat-same-structure items and repeat-changed-structure items are both recognized significantly more often than the once-presented items, but the two repeated types of items do not differ from one another. Combining these results with the earlier ones from Fig. 2, we may conclude that alternative coding of the same string reduces recognition that they are identical, but does not alter the net probability of recognizing the uncoded string.

<table>
<thead>
<tr>
<th>Item type</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise items (false alarms)</td>
<td>.40</td>
</tr>
<tr>
<td>Once-presented items</td>
<td>.57</td>
</tr>
<tr>
<td>Twice-presented items</td>
<td></td>
</tr>
<tr>
<td>(a) Repeated same</td>
<td>.70</td>
</tr>
<tr>
<td>(b) Repeated changed</td>
<td>.74</td>
</tr>
</tbody>
</table>
All in all, the reallocation hypothesis appears consonant with these data, saying essentially that a perceptual interpreter intervenes between input and contact of input with memory traces. Similar results presumably could be shown for other “ambiguous” stimuli, such as ambiguous outline figures or ambiguous sentences allowing different syntactic parsings or semantic readings. Presumably a person's recognition of having experienced a figure or sentence before depends on whether contextual factors lead him to interpret it the same both times (e.g., as a drinking goblet versus two faces in profile).

GROUPING FACTORS IN FREE RECALL

The experiments above concerned serial recall, where a small vocabulary of elements must be emitted in a prescribed order. In free recall, the vocabulary is much larger and there is no prescribed order for recall; the person is merely to recall in any order as many items as he can from a list of words he has studied. Experimental analyses over the past few years have brought out clearly that a basic strategy adopted by the person in free recall is the grouping or categorizing of list-words into subjective units or clusters. Experimenters studying free recall have come to realize that there is no such thing as a list of “unrelated” words: with the adult’s vast capabilities for searching out similarities and differences, almost any collection of “unrelated” words can be partitioned into subsets within which items share a number of features. These features are usually semantic; in fact, Miller (1967) has used such grouping or sorting tasks to infer the semantic-feature distinctions people commonly employ over a range of lexical items. Even if semantic similarities fail, then other similarities can be found: grouping can occur by graphemic similarity (e.g., words beginning with the same letter, or words of the same length), by phonemic similarity (e.g., rhymes or clang associates), or by syntactic categories (e.g., parts of speech). The moral is that “no word is an island, entire unto itself”; it rather occupies the intersection of a vast number of classifying features, almost any one of which can be cognitively emphasized by the person for purposes of aggregating this word with others in the list.

The importance of this fact is that these subjective groups appear to become the “recall units” for the person. Items grouped together come to be recalled together as an interassociated cluster. There are several ways of collecting evidence relevant to this thesis. First, there is the

3 The issue addressed here is quite old, starting with an early but thorough discussion by Hoeffding (1891). The issue has been reviewed recently by Rock (1962) and by Martin (1968).
category-clustering evidence in free recall reported by Bousfield, Cohen, Cofer, and many others; in these cases, the items have strong associations to taxonomic categories and it is practically guaranteed that adults will group items into these categories. Clustering in free recall is then indexed by the degree to which items in the same category are recalled adjacent to one another. This index of recall stereotypy can be very high even though the words belonging to the same taxonomic category are randomly scattered throughout the presented list. In these cases, by selection of the word list, the experimenter knows in advance which groups of items to examine for clustering. If allegedly "unrelated" words are used, then multiple bases of idiosyncratic groupings are potentially available and we must get the subject to tell us how he is grouping the items. This has been done by Dong and Kintsch (1968), Mandler (1967), and Seibel (1965), among others. And the outcome is that the person tends to cluster in recall those items which he has assigned to the same group.

In these terms, the effect of multtrial practice in recalling a particular list of words should be to increase the stability and size of the person's subjective groups or recall units. Indeed, Tulving (1962) and Bousfield, Puff, and Cowan (1964) have found that indices of consistent clustering increase over practice trials, correlating very highly with the number of words the person can recall from the list. If the cause of the improvement in words recalled is the increasing size and integration of the person's subjective groups, then one should be able to severely retard this improvement by preventing the development of stable groupings. This proposition was tested in the following experiments.

The experiments required some method for controlling the groupings the person will impose upon any arbitrary set of words. In conjunction with my students, David Tieman and Alan Lesgold, the following simple method was devised and evaluated (Bower, Lesgold, & Tieman, 1969). The subject was simply shown a group of unrelated concrete nouns, usually four at a time, and told to integrate these together by imagining (visually imaging) a scene in which these four objects were interacting in some vivid way. For example, for the quartet dog, bicycle, cigar, hat, the person might visually imagine a colorful scene in which a dog wearing a homburg hat is smoking a huge cigar while pedaling along on a bicycle. Whether due to the perceptual unity of the elements in such scenes, or to the fact that covert sentences are generated, this procedure results in very strong interassociations among the four words. If free recall is tested after the person has studied a number of such quartets, his recall is dominated by the groupings established in this way. That is, his recall consists entirely of bursts of two to four words from the various quartets.

With this method, we are in a position to test the proposition that multi-
trial free recall is retarded by preventing stable groupings. All that needs to be done is to impose new quartet groupings upon the same list of unrelated words at each study trial. This procedure may be compared to a control procedure in which the same quartet groupings are repeated over trials, which should lead to rapid improvement in recall.

The effect of these maneuvers is shown in Fig. 7 giving the percentage of words recalled out of 24 unrelated concrete nouns presented as six quartets over three trials. Recall in the two conditions begins at the same level on Trial 1 as it should, since they are identical at that point. But there is marked divergence of the conditions over Trials 2 and 3; subjects receiving the same grouping improve rapidly, while those receiving changing groupings improve hardly at all. Subjects receiving the changing groupings were less likely to recall new words and were much more likely to forget words they had previously recalled. These data support the proposed hypothesis. Improvement with practice in free recall is a concomitant of developing better integrated chunks; and if such developments are prevented, the usual benefit from repetition is markedly reduced.

Recall that the argument is that the subject develops his own recall clusters even when the words are not being grouped for him by the experimenter. These groupings are doubtless idiosyncratic but the learner could nonetheless tell us what they are. Armed with this knowledge of the person's "natural" groupings of the material, we could then predict whether a subsequent grouped input trial would increase or decrease his

![Fig. 7](image-url)
recall. Specifically, if the groupings imposed on the input trial are consistent with the groups the person uses, then his recall should be facilitated; contrariwise, if the input groupings systematically violate or conflict with the subject’s natural groupings, then the input trial should actually reduce his recall.

The experiment to test this prediction involved first training subjects on free recall of an ungrouped list of 36 unrelated nouns until they achieved a recall criterion of at least 32 of the 36 words. At this point, the subject was asked to indicate his natural groupings of the 36 words, by sorting together (in nine piles of four words) those words which he thought “went together” or those words which he noticed he had been recalling together. Following this sorting test, a final input and recall trial occurred. On the input trial, the person was presented with quartets of words with instructions to integrate together the words of each quartet by the mental imagery method. For half the subjects, the quartets presented were exactly those the person has indicated to us by his sorting; for the other subjects, the quartets were composed so as to systematically conflict with the nine quartets into which he had sorted the words. The following recall trial substantially confirmed expectations about these manipulations. Presentation of groupings consistent with the subjects’ natural groupings increased recall (by about two words); presentation of conflicting groupings decreased recall (by about two words) compared to prior recall on the criterion trial. This decrement in recall with the conflicting groupings occurred despite the intervention of the final study trial and the prolonged exposure (2 min average) to the words during the sorting test, factors which normally would have increased recall.

In our view, these last two experiments are making the same point, namely, free recall suffers if the person is forced to change his prior groupings of the material. The difference between the experiments is that in one case the prior groupings were imposed by the experimenter while in the other they were developed by the subject. By implication, the results support the view that increasing stability of subjective groups is normally a concomitant of, perhaps even a cause of, increasing free recall with practice trials.

RETRIEVAL PLANS IN FREE RECALL

Although grouping of list words is one of the common cognitive strategies appearing in free recall, it is clear that further strategies must be engaged to enable the person to retrieve most of the list words. That is, even if the person succeeds in establishing stable clusters, he still requires some method for retrieving these clusters from memory, for moving from one cluster to the next in his recall.
As this remark suggests, a major problem in free recall is that the subject usually knows much more than he can retrieve. This can be shown by comparing unaided recall either to recognition or to cued recall where the person is provided with some minimal cues referring to the list words. The responses in free recall might be described as responses in search of stimuli: what is missing in free recall are cues to remind the person of all the list words he is supposed to recall.

A retrieval plan is a rule which provides a set of retrieval cues for the various words of the list. Grouping or clustering is a low-level retrieval scheme, since in that case the retrieval cue for a word is recall of any other word in the group. Directly associating one cluster with another is a slightly higher-level retrieval scheme; it can be a slow heave, but its main advantage is that it is always applicable to any material. More powerful retrieval schemes are those which directly provide a well-known list of cues for the subject to associate with each word or subjective group in the list to be learned. The mnemonic pegword systems capitalize on this method. The person first learns a list of pegwords such as one-is-a-bun, two-is-a-shoe, three-is-a-tree, and so on. The person then associates one-bun with the first list word or group, two-shoe with the second list word or group, etc., the associations usually being established by mental imagery or by generating sentences linking the pegword and the list word to be recalled. Similar schemes are to use a list of geographic locations (Ross & Lawrence, 1968) or to use the alphabet (Earhart, 1967) whereby list words are associated with their first letter; so that for example, in a grocery shopping list, a-means-apples, b-means-bananas, c-means-cat-food, and so forth. At the test for recall, the person is to generate his well-known list of pegwords (e.g., the locations or the alphabet) and have these cue recall of the list words. Various researches by us and others indicate that these are very effective devices for boosting recall.

Semantic category labels, of course, are very effective retrieval cues. An elementary classroom demonstration of this is to read students 25 category labels, requesting for each category that the student record his first or second or third associate (instance) as required. Some time later the students are asked to free recall their recorded associates: depending on circumstances, one observes around 20–50% recall. One then reads the category labels again, and now the student can recall practically all the associates he recorded earlier, with no difference depending on whether the associate was his first, second, or third to the category (cf. Tulving & Pearlstone, 1966). We have also done this experiment in the opposite direction: instance-words are presented and the subject classifies each one; when later he fails to free recall an instance-word, he can be brought to recall it by providing him with the categorical associate he
gave to it earlier. These observations support the aforementioned distinction between availability and retrievability, and also show the effectiveness of semantic categories as retrieval cues.

The truly semantic character of these retrieval cues is brought out whenever one uses ambiguous words belonging to multiple categories. For example, if the context is such that the person classifies the word ruby as a color (rather than a gem), then the category label “color” will be an effective retrieval cue for this word while “gem” will be totally ineffective. This was brought out clearly in an experiment by Samuel Bobrow and Leah Light at Stanford. Forty-four ambiguous nouns were used, each presented with one or another adjective specifying different meanings for the noun. The adjectives on one list (Categorized List) were selected so that the 44 nouns fell neatly into eight large taxonomic categories (e.g., Birds: chirping cardinal, homing pigeon; Foods: lamb chop, roast ham). The adjectives on the other list (Decategorized List) were selected so that the nouns fell into very many unique categories (e.g., church cardinal, stool pigeon, karate chop, theatrical ham). After one presentation, half the subjects freely recalled and half were cued with the names of the eight large categories, such as Birds and Foods. The results are shown in Table 5 in terms of the average number of nouns recalled in the four conditions.

In free recall, the Categorized nouns are recalled better than the Decategorized nouns, which is to be expected from the differing numbers of categories to be remembered. More importantly, category cuing enhanced recall for the Categorized List but reduced recall for the Decategorized List. That is, Birds was a good retrieval cue for cardinal studied as chirping cardinal, but not for cardinal studied as church cardinal. Now if the subject were only storing or marking words in his long-term memory, then Birds should elicit the word cardinal and increase recall even for the person who studied church cardinal. But since this did not happen, one must conclude that the subject must be marking meanings, or semantic-feature bundles, not words. The result is consistent with the view that for a given stimulus to become an effective retrieval cue for a given to-be-

<table>
<thead>
<tr>
<th>List</th>
<th>Free</th>
<th>Cued</th>
</tr>
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<td>Categorized</td>
<td>17</td>
<td>24</td>
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<tr>
<td>Decategorized</td>
<td>12</td>
<td>9</td>
</tr>
</tbody>
</table>
remembered word, the person must have thought of the relation between
the cue and the to-be-remembered word at the time he studied the word
(a hypothesis proposed by Tulving & Osler, 1968).

Returning to the question of retrieval plans, we could say that a list of
categories or semantic features would constitute a first-order retrieval
plan, where each cue would retrieve a group of list items. If one asks how
one might learn the category labels, an obvious optimal strategy is to
categorize the category labels into broader but fewer superordinate
categories. If one were to continue this categorizing again and again
(recursively), one would generate a hierarchy of nested sets. An example
of a natural hierarchy based on class inclusion is shown in Fig. 8. Min-
erals can be classified as metals or stones, stones as precious or masonry,
and granite, slate, limestone, and marble as instances of masonry stones.
We have constructed about eight of these conceptual hierarchies which
we have used in our research.

Such hierarchical trees have a simple construction rule, namely, re-
cursive rewriting of successive nodes in terms of class-inclusion relations.
The same structural rule should also serve as an effective retrieval plan
when a person is trying to reconstruct these words from memory (cf.
Mandler, 1968). The experimental question we asked is whether subjects
would use this structural rule in generating their recall, and if so whether
it gives them any advantage over control subjects recalling the same word
lists but without knowledge of this structural rule.

In one of our experiments (Bower, Clark, Winzenz, & Lesgold, 1969),
subjects learned four of these 28-word hierarchies concurrently, amount-
ing to 112 words in total. For half the subjects, the words were presented

![Conceptual Hierarchy of Words]

**Fig. 8.** Example of a conceptual hierarchy of words.
as four complete hierarchical trees, much like the Minerals hierarchy shown in Fig. 8. For the control subjects, the same 112 words were presented in spatial trees, 28 per slide, but the words on a given slide were chosen randomly from all levels of the four conceptual hierarchies. Thus, the random lists appeared to have no obvious structural principle.

After presenting the four hierarchies (at 56 sec per slide), the subject recalled all the words he could in any order he wished. The results for mean words recalled are shown in Fig. 9. It is obvious that subjects having the organized presentation are recalling about three times as many words as are subjects in the random condition. By Trial 3 all subjects in the organized condition were recalling all 112 words, whereas recall by subjects in the random condition by Trial 4 had not yet reached the Trial-1 score of the organized subjects.

It is a simple matter to show that subjects in the organized condition were using the list-construction principle as a retrieval plan for generating their recall. First, their recall is entirely clustered by the conceptual categories. Second, all of them generate the hierarchies from top-to-bottom in their recall. In over 90% of the cases where a superordinate word and some of its subordinate words were recalled, the superordinate word came first in the recall protocol. Third, recall of a nodal word served as a cue for recall of the subordinate words under that node. That is, conditional recall of a word was much higher if its superordinate node was recalled than if this node was not recalled; often when a node was forgotten, the entire "tree" below that node was lost. Conditional relationships of this kind were totally absent in the random presentation.
The difference here is about the same sort one obtains between recall of words presented in a sentence versus recall of the same words presented in a scrambled order. In either case, structure is introduced by the arrangement of the words, by the pattern of their temporal or spatial grouping; and this structure, more than the individual words themselves, is a strong determinant of how much is recalled.

One might question how much the subject is remembering the list words as opposed to simply generating them by guessing from knowledge of the list-construction principle. To answer this we ran some control subjects who tried to generate these hierarchies simply from knowledge of the list-construction principle. These word hierarchies turn out to be very open-ended and nonexhaustive, and naive subjects in fact do very badly in trying to generate the particular trees our experimental subjects were learning. Thus, sheer guessing would appear to account for only a small part of the difference in recall between our organized versus random conditions. Rather it appears that the organized presentation gives the subject a systematic retrieval plan. This type of presentation also strengthens particular category-to-instance associations. However, the retrieval plan operates with a particular constraint, namely, that candidate words suggested by it are first checked for recognition of list membership before they are overtly recalled. It is this editing or monitoring of generated candidates by a recognition process that prevents intrusions of related words in recall. Such intrusions are very infrequent, less than 1% in such studies, whereas an unchecked guessing mechanism would spew large quantities of intrusions because of the nonexhaustive character of these hierarchies.

Such experiments as these demonstrate the benefit in free recall for a subject using a systematic retrieval plan. The plan tells him where to start, how to proceed systematically from one unit to the next in his memory. The plan also monitors the adequacy of his recall, telling him which parts he has left out and telling him when he has finished his recall. It is not so much a procedure for storing words as it is a plan for retrieving or reconstructing the words he has tagged in his long-term memory.

CONCLUDING COMMENTS

I have reviewed some of our evidence for organizational factors in learning, specifically tracing out some implications of ideas about rules and groupings for understanding paired-associate learning, serial learning, and free recall. The various pieces of evidence were examined in their local experimental context without much heed to more general
theoretical considerations. However, I would be remiss not to point out a few of the broader conclusions to which such research may lead us, though the conclusions are hardly original with me. The conclusions may be cast in terms of preferred strategies of the human learner when he is viewed as an information-processing device equipped with programs that do learning. The first general idea is that a preferred strategy of the adult human in learning a large body of material is to “divide and conquer”: that is, subdivide the material into smaller groups by some means, and then learn these parts as integrated packets of information. The bases for the groupings can be richly varied depending upon the nature of the material and the person’s mental set. With elementary visual and auditory materials, the main determinants of groupings were described long ago by Wertheimer (1923) under such names as proximity (spatial or temporal), similarity, good continuation, and so forth. With speech materials, our analyzing system has a remarkable ability for segmenting the acoustic wave form into separate phonemes, or morphemes, or into syntactical constituents depending on the stimuli and the task at hand. With word lists, the main grouping determinants are similarity of meanings or semantic categories, although other bases are available when these fail.

The level and type of the chunking are under some cognitive control. Physical variables normally determining groupings can be counteracted by utilizing our focal attention to impose different groupings: this happened when our subjects were pre-set to chunk phrased digit series into triplets, or it happens whenever a person finds an embedded figure concealed in visual noise. Similarly, the mental set established via context determines how the person will segment, code, and classify an ambiguous figure, an ambiguous word, or an ambiguous sentence. Our researches demonstrate that the subjective coding of an event determines important features of its recall, e.g., the TEP profile in recall of digit series, the effective retrieval cues in free recall, etc. We may generalize this point to encompass the results on relational mnemonics in paired associates, and say that what a person remembers are his prior cognitive acts, the constructive elaborations he employs to relate two items. That is, what we remember is our cognitive autobiography, not stimulus and response events.

The grouping strategy may be preferred by the adult learner for various reasons, but I would like to emphasize one of these in this context. The advantage of a simple grouping strategy is that the operation can be applied recursively, aggregating together chunks and then groups of chunks into an organized hierarchy. For adults, a hierarchy is an extremely familiar and efficient organizational scaffold, encountered throughout life (in books, library files, etc.) and in science (atomic structure, phylo-
genetic trees, sociopolitical structures, etc.). In fact, the occurrence of hierarchical structures in nature is so pervasive that Simon (1969) has argued that it has special natural properties enabling its stability and evolution. Alternatively, one could turn around the causal direction and claim that man's rational reconstruction of nature is predisposed towards "projecting" hierarchical structures upon the world because they are "natural" given the capabilities and limitations of his information storage and retrieval mechanisms. It is hardly arguable that an efficient way to handle large bodies of data is to divide it into groups, assign a code label to each group, and then classify the code labels. The higher-level code labels can then serve as tokens to reference and to manipulate rather large masses of data. Simon has argued further that given the known limitations on conscious attention, that we can think of only a few things at once, and that retrieval from memory operates through this focal bottleneck, then linked hierarchical list structures would be one of the better ways to organize masses of information in memory if retrieval is to be fast and efficient.

In our experiments, the notion of hierarchical organization seems most applicable to the studies of chunked digit series, of groupings in free recall, and the several retrieval strategies reviewed in free recall. To flesh out this remark with a concrete illustration, consider briefly a possible functional representation of a chunked digit list as it might be stored in a cognitive simulation program. Suppose, for instance, that the series arriving at time \( n \) is 73-42-95. The central processor would assign an internal symbol (say, \( \Sigma_n \)) to this string as it arrives, and within the available time attempt to set up the ordered list \( \Sigma_n: S_1, S_2, S_3 \) with the sublists \( (S_1: P_7, P_3), (S_2: P_4, P_2), (S_3: P_9, P_5) \), where \( PX \) is either the address of the motor program for generating the digit \( X \) or is a list of the parameters for such a generation. The convention adopted here is that the name of the list is written first followed by a colon then the names of the elements on that list. Since many such series are successively presented and immediately recalled by the subject, the control processor needs some way to keep track of the list which must be recalled. This may be represented by a push-down list named Most Recent List (MRL) to which successive list symbols are added at the top as they arrive, so that after the \( n \)th string we would have \( \text{MRL: } \Sigma_n, \Sigma_{n-1}, \Sigma_{n-2}, \ldots \). In brief, recall would proceed by the executive program taking the top symbol from MRL (\( \Sigma_n \)) and unpacking it recursively; that is, finding the list with this name, reading its first symbol (\( S_1 \)), finding this sublist, reading its first symbol (\( P_7 \)), which is an instruction to say or write the digit 7, get the next symbol on this sublist (\( P_3 \)), say the digit 3, return control up one level to get the next symbol (\( S_2 \)) of the top list, then unpack the sublist \( S_2 \), and so on. In this
context, forgetting could be represented in several ways, most of which result in the effective "fading" or "loss" of distinctive features of the various symbols attached to the list name. For example, some components of the terminal list P7 may be lost so that the digit 7 will be missing or substituted for in recall; or the link between $\Sigma_n$ and the symbol $S_n$ may be lost (or be below some threshold) so that all of the terminal symbols on that sublist would be missing in recall.

The reallocation hypothesis proposed earlier can be recast in the present terms: the first group ($S_1$) of the newly arriving list is compared with the $S_1$ sublist of recent lists attached to MRL; if a match occurs, the matching list (call it $\Sigma_k$) is updated with a new recency tag ($set \, k = n$), the information in the newly arriving list is used to make fresh copies of any missing portions of the prior list $\Sigma_k$, and the decay rates on retained pieces are altered to reflect their enhanced retention. There is no need to go further into the sticky details here, since the general point of the illustration is clear, viz., that hierarchical list-structures provide a natural language in which to represent and theorize about our results on memory for grouped digit series.

Although perhaps not so obvious, our work on pairing rules (e.g., rhyming rules) in paired-associate learning can also be related to these kinds of list structures. There is converging agreement that a good representation of a "word concept" in our semantic memory is in terms of lists of features (cf. Deese, 1965; Katz & Fodor, 1963; Miller, 1967; Minsky, 1968). That is, a word concept would be the head name of a list of features partitioned into sublists of semantic markers (usually other words), phonetic-graphemic features, syntactic features, and probably other information (e.g., sensory-object features). Words that are semantically related share many common semantic features, whereas rhyming pairs of words would share particular phonetic features. The presumption is (cf. Deese, 1965; Pollio, Deitchman, & Richards, 1969) that "word associations" are determined by the cue and response word sharing some subset of these features; which feature set is shared by the cue and its associate can be pre-set by explicit or implicit instructions (e.g., to give opposites, or clang associates, or synonyms, etc.). Within this framework, the ease of learning rhyming paired-associates is easily understood. The central processor "knows" what subset of features of the stimulus word to examine and follow out to retrieve the pool of plausible words (response terms) to that cue; then it is a matter of recognizing which of these words have been marked as occurring in this context.

A convenient property of representing word concepts by such list structures is that they enable efficient searches for verbal relationships such as those required in verbal problem solving. Word pairs can be classified
according to the set of features which they share, and this provides a way of classifying their relationship. Such semantic networks can be well organized for carrying out relational searches having the generic form "Find a word A which stands in relation R to word B," or equivalently "Find an A such that R (A,B) is satisfied." Psychologists are doing essentially this when they classify different types of word associations, and we do it simultaneously for two word pairs when we handle verbal analogies problems.

In paired-associate learning of arbitrary word-word pairs, the problem confronting the subject is the reverse of that above; here, he is given the terms A and B, and the problem is to find or construct (and then remember) a plausible relation, R, which groups them into the functional unit R (A,B). With noun-noun concepts, the most available, all-purpose relationships are those involving linguistic predication, which in essentials links A and B by means of a verb or preposition. For instance, for connecting the arbitrary terms dog and bicycle, the verbs rides or chases will do as will the prepositions on or under. Thus, Rides (dog, bicycle) is a permissible relation in the sense that no semantic selection restrictions are violated when these terms are substituted for the arguments of the function Rides (A,B). The implied assumption is that verbs are represented in our semantic memory as functors with ordered arguments, with the admissible arguments specified by a set of semantic features. Thus, the class of admissible substitutions for x and y in the functor eats (x,y) are animate nouns and "food" nouns, respectively (cf. Reichenbach, 1947, Ch. VII).

The foregoing remarks indicate a few of the general themes that I see as knitting together the various pieces of evidence reviewed earlier. The main relation is in the similarity of organization of the several cognitive representations, which structures have convenient properties allowing us to mimic or understand some of the relationships found in our behavioral records. As noted, this organization often appears to be hierarchical, representing information as a list of sublists. It is no accidental coincidence that the chief languages used to write computer programs simulating cognitive processes are "list processing" languages. Even the program of code is itself hierarchically organized, consisting of an executive routine which carries out a sequence of subroutines which may call other subroutines or call themselves recursively; and these subroutines in turn are a sequence of instructions which either decide something or which compute some function of the information provided to them. Reitman (1965) and Newell and Simon (1963) have argued convincingly that list processing languages provide a rich, "natural" language for representing cognitive processes. The research reviewed here stems from my
attempts to add more experimental evidence to these conjectures in the field of human learning.

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