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Structure of the Recall Process [and Discussion]

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Structure of the recall process

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It is often appropriate to analyse memory processes at a binary level corresponding to the individual item, which may be either remembered or not. But an alternative, considered here, is to study memory for material that is explicitly multicomponent in nature. This procedure is necessary in attempting to resolve some basic issues concerning memory representation. For example, the use as retrieval cues of differing combinations of components produces differing patterns of recall, in differing quantities. How may these distributions be accounted for? Similarly, what are the effects upon memory of varying the attention paid to different components, or combinations of components? In dealing with such questions, it is useful to distinguish direct and indirect retrieval routes. This distinction can be shown to be of particular service in elucidating the relation that recall bears to the other major index of memory retention, recognition.

Introduction

In the act of recollection, many different types of knowledge may be retrieved by an equally varied range of cues. In the face of such complexity, the task of attempting to understand the structure of recall is a daunting one. But recent research shows nevertheless that it is possible experimentally to dissect out situations in which the process of recall is sufficiently constrained to permit its accurate representation by parsimonious theoretical models, while still retaining sufficient complexity to display in microcosm the rich structure of everyday memory.

Attempts to elucidate the organizational structure of individual memories have a considerable history. Important early work was reported by Bartlett (1932). In one of his studies (conducted at the time of World War I) he presented people with facial sketches of different members of the army and navy, such as a colonel and a midshipman. Subsequent recall protocols showed that people's memories often centred around particular features, heads being remembered as good-humoured or stern, possessing moustaches or pipes, and with particular types of badges on their caps. Bartlett's study provided initial evidence, therefore, that the encoding and retrieval of information may usefully be assessed, not in terms of some overall criterion of success or failure, but instead in terms of the patterns that hold for individual components. Such observations, in their turn, demand explanation in terms of the processes operative at this atomistic level. They propel us toward investigation of the *structure* of the recall process.

For generality, consider now any stimulus with several different components. After the presentation of this stimulus to a person, each of its components may be used (either singly or jointly) as retrieval cues to induce recall of the missing components. The issues that then arise include the following. Do components differ in how effective they are as retrieval cues? What is the effect of directing two cues at a target, relative to the two effects in isolation? Are some components more likely to be recalled than others? Does the concurrent recall of two components represent only the chance conjunction of two separate successes?

It will be shown in succeeding sections that two different sets of answers can be given to these questions (and in particular, to the question of how the effect of two cues relates to that of one). The two sets of answers apply to direct and to indirect retrieval, and are associated with the fragment and schema theoretical models, respectively.

Attempts to determine empirical answers to the preceding questions may be illustrated first by a study that, though more recent than that of Bartlett, also examined memory for pictures.

Fragments in memory

Systematic data on recall structure were obtained by Jones (1976). In this study, unlike Bartlett's, participants were informed in advance of the salient components of the pictures to be viewed. These comprised *colour*, *object type* and *location*, for example a green comb in the top left of a photographed display. Participants were shown a series of such photographs, each depicting independently specified values on the three dimensions. Subsequently they were again provided with one or two of the components of each item (e.g. top left, or comb and top left), and attempted to recall the missing component or components.

The data of this type of experiment allow one to test possible answers to the questions about memory structure that were posed earlier. Such answers are inherent in any theory that attempts to account quantitatively for the disposition of these results, and specifically for the frequency distribution of the 18 different types of observation that arise upon categorizing the possible patterns of correct recall for each of the different types of cue (four categories for each single cue, and two for each double cue).

A successful theoretical model for these data is in fact readily described. A range of different types of memory trace can be distinguished, each corresponding to a particular stimulus fragment, or grouping of components. Recall of the information encoded within a fragment is by direct access, and is contingent only upon the presence of overlap between the fragment and the retrieval cue, and not upon the degree of overlap. Hence for a 'location and object type' fragment, the single cue colour would be unsuccessful, while the double cue colour and location would be successful in retrieving object type; whereas for a complete 'colour, location and object type' fragment, both single and double cues would be successful.

It is possible to make best-fitting empirical estimates of the frequencies of occurrence of the different types of fragment, and to use these in testing the model's predictions. For example, the proportion of occasions on which complete recall occurs should be approximately the same for the three types of single cue, corresponding in each case to the incidence of complete 'colour, location and object type' fragments. Empirically, this prediction was confirmed. In fact, the distribution of observations over the complete set of patterns of recall conformed to its predicted structure. In addition, qualitative examination of the fragment distribution itself is of interest. Of the incomplete, two-component fragments, 'colour and object type' was most frequent, followed by 'location and object type' and then 'colour and location'. Thus object type can be seen to have been overall both most effective of the components as cue and most likely to be retrieved by another component.

Limitations and extensions of the fragment model

The fragment model outlined in the preceding section has subsequently been applied successfully to the recall of several different types of material. As an example, Bruce (1980)

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investigated the recall of verbal knowledge that had been acquired in everyday life rather than in the laboratory, and found that the fragment model provided a good account of the relation of double-cued and single-cued recall. However, it is perhaps most instructive to consider next a study recently reported by Ross & Bower (1981), which demonstrated important constraints upon the generality of the direct-access model.

Ross & Bower carried out experiments in which each stimulus consisted of a number of related words, such as the four-word set (related via boxing) of *glove*, *ring*, *bruise* and *bell*. Participants viewed a series of such stimuli, and for each stimulus were subsequently provided with one or two of its words as retrieval cues for the remainder. The four components of a stimulus were interchangeable, and thus there were relatively small numbers of distinguishable types both of observations and of memory traces. Observationally, single-cued recall varied from zero to three words and double-cued recall from zero to two words. Mnemonically, we can distinguish 'four-word', 'three-word', 'two-word', 'twin two-word' and null fragments: the first four will be referred to here as *abcd*, *abc*, *ab* and *ab,cd* traces, respectively. Null fragments are those that can support no recall at all in this paradigm, and arise when only single words, at most, are encoded. Twin fragments occur when two observationally independent memory traces derive from the same stimulus. They are observationally independent in that the two traces are retrieved by non-overlapping sets of cues. Of course, multiple fragments of dimensionality greater than two can occur when the number of components increases beyond four.

The fragment model again predicts a structure for the observed patterns of recall. For example, when cued by a single word, the twin fragment should lead always to the recall of one further word; but, paradoxically, when cued by two words it should lead to no recall in one-third of instances, and to the recall of two words in the remainder. Ross & Bower found, however, that in their experiments the overall agreement between the observed and predicted structures was poor. There was relatively good agreement, on the other hand, with the alternative schema model that Ross & Bower proposed. This will be discussed in a later section. First, however, the implications of this finding for the fragment model are considered.

It may be hypothesized that the explanation for the fragment model's poor performance in the preceding paradigm resides in the nature of the stimuli. The component words of each stimulus were explicitly selected so as to each possess a pre-existing relation to a common idea. Thus recall may have proceeded indirectly via this central representation, rather than by direct access of the component representations. Recent experiments (Jones 1983) provide support for this explanation. Their method differed from that of Ross & Bower in only one important respect. The component words of each stimulus were selected independently rather than jointly: for example *boulder*, *portrait*, *elephant* and *circle*. This difference was sufficient to ensure, however, that the observed patterns of recall were now in good agreement with those predicted by the fragment model.

Figure 1 shows the percentage occurrence of each type of fragment in one such experiment (values shown are the means of those estimated separately for each participant), and illustrates two qualitative aspects of fragmentation distributions that have been consistently observed. The first finding is that a substantial proportion (in fact, the majority) of fragments are of either the complete type (in this case *abcd*), or the null type, which yield either complete success or complete failure in recall. The prevalence of these two kinds of observation in the recall of sentences has led to the proposal by R. C. Anderson and his colleagues (Anderson 1974; Goetz *et al.* 1981) that recall is in fact all-or-none at the semantic level. According to this view, apparent deviations from all-or-none recall of simple material may be attributed to the substitution, in otherwise all-correct recall, of components that are approximately synonymous with the correct ones. Little evidence of such a process, however, was found in the study under consideration, or by J. R. Anderson (1976).

A second feature of the fragment distribution in figure 1, and again a general finding, concerns the relative scarcity of the twin fragment. The generation of multiple independent memory traces is not generally possible within the framework of models that constitute theoretical alternatives (in particular, the HAM and schema models to be described later). Thus Ross & Bower (1981) claim that the very low estimates of twin-fragment occurrence obtained empirically (that shown in figure 1 is one of the highest recorded) should be taken, in the absence of an alternative explanation, as casting serious doubt upon the general validity of the fragment model. However, a simple explanation of both this and the preceding qualitative finding can be formulated.

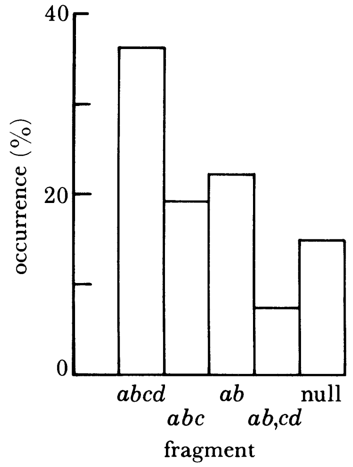

FIGURE 1. Observed distribution of memory fragments for four-word stimuli.

Consider a fragment as a set of elements corresponding to stimulus components, each of which may be linked with each other element; in the four-component case, the links could be represented as the six edges of a tetrahedron. Fragments of different types arise as the number of links encoded varies between zero and the maximum. In the simplest case, the links are encoded independently, and thus the distribution of the number of links is binomial. Any given number of links corresponds to one or more different types of fragment. In the tetrahedron case, for example, it is readily shown that an *abc* fragment should arise on average on four-fifths of occasions when two links are encoded and on one-fifth of occasions when three links are encoded. Figure 2 shows the expected overall probability of occurrence of each type of fragment as a function of the probability of encoding of a given link.

Because the link model has only one parameter, compared with the four free parameters of the general fragment model of which it is a special case, its agreement with data is expected to be less accurate. Jones (1983) found that this was so, and that the agreement was in fact significantly faulty. However, the link model nevertheless provided a surprisingly good approximation to observed patterns of recall. Certainly the approximation is sufficiently close to allow the model to be used in qualitative explanation of the two empirical findings noted earlier. Figure 2 shows that both relative commonness of all-or-none recall and relative scarcity

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of multiple fragments are the expected consequences of independent encoding of constituent links.

Although it proved possible in the preceding study to provide a higher-order theoretical account of the quantitative distribution of different types of fragment that was fairly adequate, generally this is not true. When, rather than being interchangeable, the different components of a stimulus belong to different categories (as with colour, location and object type), the formation of links in memory between their representations may be influenced by a variety of psychological factors. Prominent among the latter is the role of attention. For example, Wilhite (1982) has studied the recall of subject–verb–object sentences such as 'The farmer shot the hunter'. He found that 'subject–verb' fragments were more frequent than 'verb–object' ones, and attributed this to the effects of conceptual focus: the perceived importance of the subject is hypothesized to be greater than that of the object, as proposed for example by Tannenbaum & Williams (1968). The effects of attention upon recall have also been studied more directly.

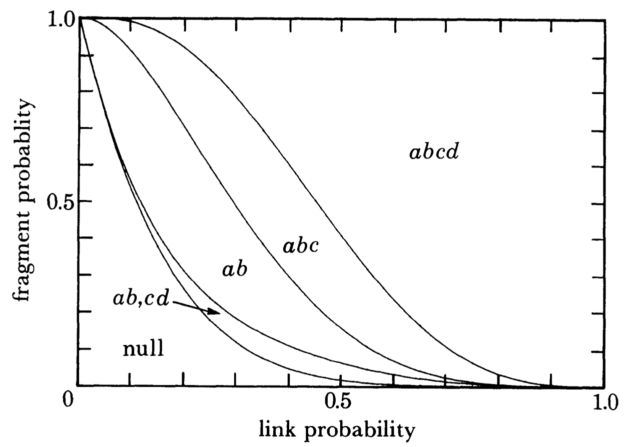

FIGURE 2. Variation in theoretical distribution of memory fragments for four-word stimuli as a function of link probability. For any link probability, the probabilities of the five types of fragment are given by the lengths of the five sections into which a vertical ordinate constructed at that point is divided by the curves shown.

Attention and recall

A sorting task that concentrated attention upon one or other of the components of each of a series of visual stimuli, such as a *red circle*, was used by Jones & Martin (1980). Subsequently, either the attended or the unattended component was used as a retrieval cue for the other. Although previous work had suggested that the attended cue might be the more effective (Spyropoulos & Ceraso 1977), such an effect was not found. According to the present view, the effects of attention upon memory are more likely to be displayed as changes in observed distributions of fragments. Evidence of such change has been obtained recently by Jones & Payne (1982).

Jones & Payne studied the recall of sentences with independently selected location, subject, verb and object, for example 'In the car the writer touched the rabbit'. The investigation and modelling of memory for sentences of this type constituted an important part of the outstanding work reported by Anderson & Bower (1973). They showed how it is possible to account simultaneously for major aspects of the psychology of both language and memory by using an extensive computer-implemented model that they termed HAM (for Human Associative

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Memory). A sentence of the form just described had attributed to it by HAM a complete propositional structure represented by 13 links between different types of conceptual node. A word was hypothesized to constitute a successful retrieval cue for another word only if an intact chain of links was encoded between the two; the probabilities of encoding individual links were not independent but were equal. The model had further parameters, but in this respect it may therefore be viewed as a partial analogue of the link model discussed earlier. Anderson & Bower carried out a series of sentence-memory experiments, and showed that the model provided an account of their results that was partly satisfactory. Subsequently, however, Jones (1978*b*) showed that the general fragment model provided a better account of almost the entire set of results (see also Anderson & Bower 1980). He suggested that attentional strategy was one possible factor within these experiments that it would be difficult to embrace quantitatively by amplifying Anderson & Bower's linguistically determined model.

In their study, Jones & Payne presented sentences under four different attentional conditions, with instructions emphasizing the first half, the second half, or the two halves of each sentence separately, or else emphasizing no particular aspect of the sentences at all (control condition). They found, as expected, that the resulting distributions of fragments (of 15 distinguishable types) were different in the four conditions. Furthermore, the changes that occurred as a consequence of the different attentional strategies appeared to be lawful.

First, though its composition varied, the observed proportion of fragments permitting some recall remained approximately constant across conditions. Second, the attentional manipulation was regular not only in this general effect but also in its specific effects. Compared with the control condition, the magnitudes of the increases in frequency of the 'location–subject' fragment in the first-half condition and of the 'verb–object' fragment in the second-half condition were approximately equal to each other, and furthermore approximately double the magnitude of the increase in frequency of the 'location–subject, verb–object' twin fragment in the both-halves condition. Hence this study confirms selective attention as a determinant of fragment frequency distributions. The outlook thus seems poor for any linguistically based attempt to predict quantitatively the distributions for sentential material, since even in a control condition it appears likely that attentional biases (e.g. the conceptual focus of Wilhite (1982)) are operative. The study also suggests that shifts in attention, though reflected qualitatively in the composition of recall, do not affect quantitatively its overall level. This finding appears highly consistent with the classic view of selective attention constraints as deriving from a finite reservoir of central general-purpose processing capacity (Broadbent 1958; Kahneman 1973).

Memory schemata

The evidence so far reviewed indicates that the direct-access fragment model provides a good account of fundamental aspects of recall in some circumstances, but not all. It needs to be supplemented by a theory that predicts the structure of recall when encoded components are *not* directly linked in memory. In this domain, the available evidence favours a form of schema model.

The notion of the schema has a considerable history within psychology, but its present use – to denote a body of extraneous knowledge that acts as a framework within which to locate new knowledge – derives principally from the work of Bartlett (1932), referred to previously. Defined in this way, the notion of the schema is a broad one, and has been applied in a correspondingly wide range of contexts (see, for example, Anderson *et al.* 1979; Abelson 1981; Rumelhart & Ortony 1977; Tversky & Kahneman 1980). The basic characteristics of the schema may, however, be captured in a simple model that is closely similar to one formulated by Ross & Bower (1981). In the model, the different components of an event give rise to a schema as a grouping node. This represents the point of intersection of memory searches that originate with the representation of each component within a memory network. Subsequently the use of one of these components as a retrieval cue can again lead to accessing of the schema. This is followed by listing of the schema's contents, with identification of those elements that correspond to target components.

The schema model can be applied to the recall of multiple-word stimuli (described previously) in the form proposed by Ross & Bower (1981). In predicting the structure of such recall, only pre-schema and post-schema retrieval need be distinguished as empirically separable. Thus (in addition to a schema-access parameter) Ross & Bower's model posits only a single response parameter, which subsumes the separate list and identification processes distinguished here. In addition, it is assumed that the probabilities of the different component words successfully accessing the schema are in each case equal and independent, as are the probabilities of subsequently responding with the different target components. Ross & Bower found that in their study with related words, the agreement between the schema model and the data was relatively good, and more satisfactory than that for the fragment model. Jones (1983), using unrelated words, found, however, that the position was reversed. The fit of the fragment model was good, while that of the schema model was very poor. In fact, the accuracy achieved by the schema model with two parameters was considerably less than that achieved by the special-case link version of the fragment model with only one parameter.

In the light of these results, it is apparent that neither the fragment nor the schema is in some way the more fundamental unit of organization. Rather, their roles are complementary. In general, independently specified components give rise to direct-access recall, while components that bear an extraneous relation to each other may be retrieved indirectly via a schema; the relation between cue and target in these two cases has been termed *intrinsic* and *extrinsic*, respectively (Jones 1980). The assignment of retrieval mechanisms on the basis of stimulus type is not a one-to-one procedure, however. In the first place, consider again extrinsically related components. It is to be expected here that although recall can occur indirectly via a schema, there is also a possibility of its occurring directly via a fragment. In the study of Ross & Bower, there appears little need empirically to entertain this more general hypothesis. But in analysing the relation between recall and recognition performance, on the other hand, the assumption that both direct and indirect routes can be operative in the recall of this type of material has been shown to be well supported (Jones 1978*a*, 1982). This work will be described in the next section, after consideration here of recall of the first category of material, for which cues and targets are not selected by virtue of their pre-existing relations.

Evidence that has been adduced so far has supported the hypothesis that independently selected contiguous components give rise to codings in memory in which their representations are connected in structures termed fragments. Within a fragment, the links are forged bidirectionally between pairs of representations; exceptionally, it is even possible to predict the approximate empirical distribution of different types of fragment on the basis of the links' theoretical distribution. It is to be expected, however, that material with independently selected components may also give rise to indirect recall to some degree. This is because of the latitude

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inherent in the notion of independent selection. The identities of components may be rendered independent according to some objective criterion operationalized as an appropriate procedure (for example, selecting words from random locations in a dictionary). But objective independence of this sort can only encourage, and not guarantee, the likelihood that a pre-existing relation between the components in memory is not used in recall. An illustration of the effect of this factor is provided by the recall of adjective–noun phrases. Lockhart (1969) showed that when appropriate adjective–noun pairs such as 'heavy cake' are selected for presentation, the noun is subsequently a much better retrieval cue for the adjective than the reverse (in fact, it was shown by Lockhart and by Peterson (1971) that the effect is associated more generally with imagery differences between words). Presumably the mediating concept ('chocolate'?) is more readily accessed by the noun than by the adjective. But Lockhart showed that even when pairings generally appeared inappropriate (e.g. 'loud cake'), and the overall level of recall was lower, a reduced asymmetry remained.

Recall and recognition

So far, the structure of recall has been examined by considering the situation in which one or more elements of a previously encoded event are used as cues for the recall of the remaining elements. Two other indices of memory retention have also been widely employed. In *free recall*, no retrieval cue as such is provided. This may be viewed as a special case of cued recall in which the functional retrieval cue (e.g. list membership) is implicit rather than explicit, and thus is not considered further here. More radically different is the case of *recognition*, in which stimulus information is re-presented to be identified, instead of being reproduced by the recaller himself.

Recognition was compared directly with cued recall in an influential article by Tulving & Thomson (1973). Participants were presented with stimuli containing two components, such as *fruit* FLOWER, with the second word weakly related to the first one. Subsequently, retention of the second word was tested both by re-presenting it for recognition and by providing the first word as a retrieval cue for its recall. After the Tulving & Thomson article, the results of a considerable number of studies within the same experimental paradigm were reported. What is of particular interest about these is that it was noticed by Tulving & Wiseman (1975) that they display considerable uniformity. In spite of many differences in method between experiments, a measure of the degree of dependence between recall and recognition varies in a lawful way with the level of recognition. Tulving & Wiseman showed that the estimated probability of successful recognition given successful recall, $P(\mathrm{Rn}|\mathrm{Rc})$, is quite well predicted over its entire range by the empirically inferred equation

$$P(\mathrm{Rn}|\mathrm{Rc}) = P(\mathrm{Rn}) + c\{P(\mathrm{Rn}) - P(\mathrm{Rn})^2\}, \tag{1}$$

where the value of c was estimated at $\frac{1}{2}$. Flexser & Tulving (1978, 1982) showed that (1) in fact holds for nearly 100 sets of results that have been reported. They also proposed a feature-based model that correctly predicts the shape of the envelope in which these data are scattered around the line of (1). Using the dual fragment and schema model outlined earlier, however, we may attempt also to predict the precise nature of the deviation from (1) for individual experiments.

According to the dual-mechanism model, recall can occur in two different ways. First, the cue may directly access the target's representation in the appropriate fragment. Second, the appropriate schema may be accessed, its contents listed, and the correct target identified. It is proposed that this final stage corresponds to the process of recognition. Further, in the present two-component context it is not necessary to distinguish the two previous stages as being pre-schema and post-schema, respectively. Thus the schema route can be described in this instance as the generation of a representation corresponding to the target, followed by its recognition. Bahrick (1970) provided some evidence that generation and recognition constitute independent processes in recall. By assuming the validity of this, and also that both processes are independent of direct-access recall, Jones (1978*a*) was able to derive a theoretical relation between recognition and overall recall.

Let D and G refer to direct-access recall and to generation, respectively. Then

$$\begin{aligned} P(\mathrm{Rc}) &= P\{\mathrm{D} \cup (\mathrm{G} \cap \mathrm{Rn})\} \\ &= P(\mathrm{D}) + P(\mathrm{G})P(\mathrm{Rn}) - P(\mathrm{D})P(\mathrm{G})P(\mathrm{Rn}). \end{aligned} \tag{2}$$

Also,

$$\begin{aligned} P(\mathrm{Rn} \cap \mathrm{Rc}) &= P[\mathrm{Rn} \cap \{\mathrm{D} \cup (\mathrm{G} \cap \mathrm{Rn})\}] \\ &= P\{\mathrm{Rn} \cap (\mathrm{D} \cup \mathrm{G})\} \\ &= P(\mathrm{Rn})\{P(\mathrm{D}) + P(\mathrm{G}) - P(\mathrm{D})P(\mathrm{G})\}, \end{aligned} \tag{3}$$

which may be rearranged to

$$P(\mathrm{Rn} \cap \mathrm{Rc}) = P(\mathrm{Rn})P(\mathrm{Rc}) + P(\mathrm{G})\{1 - P(\mathrm{D})\}\{P(\mathrm{Rn}) - P(\mathrm{Rn})^2\}$$

and hence

$$P(\mathrm{Rn}|\mathrm{Rc}) = P(\mathrm{Rn}) + [P(\mathrm{G})\{1 - P(\mathrm{D})\}\{P(\mathrm{Rn}) - P(\mathrm{Rn})^2\}]/P(\mathrm{Rc}). \tag{4}$$

Comparing (1) and (4), it can be seen that it is predicted that values of c estimated empirically from (1) should be given by

$$c = P(\mathrm{G})\{1 - P(\mathrm{D})\}/P(\mathrm{Rc}). \tag{5}$$

It was shown by Jones (1978*a*) that, over approximately 100 sets of results, there was in fact a significant inverse correlation between estimates of c and of $P(\mathrm{Rc})$.

Furthermore, the empirical values of $P(\mathrm{D})$ and $P(\mathrm{G})$ within an experiment may be estimated separately. In the dual-mechanism model, recall via the generation–recognition route is contingent upon successful recognition. Thus the probability of direct-access recall may be estimated as the probability of recall when recognition fails, or

$$P(\mathrm{D}) = P(\mathrm{Rc}|\overline{\mathrm{Rn}}), \tag{6}$$

where an overbar indicates failure. The generation probability may then be obtained as

$$P(\mathrm{G}) = \{P(\mathrm{Rc}|\mathrm{Rn}) - P(\mathrm{Rc})\}/P(\overline{\mathrm{Rn}} \cap \overline{\mathrm{Rc}}). \tag{7}$$

The results of individual experiments provide support for the appropriateness of these measures. For example, it has been shown that increases in the degree of pre-experimental relation between cue and target are reflected in several different experiments by increases in the estimated generation probabilities (Jones 1980).

A more ambitious attempt has also been made to predict absolute levels of joint recall and recognition by using parameter values estimated via separate experimental observations. Jones (1982) presented people with stimuli such as *sleep* ORANGE, and in a control condition estimated the probability of direct-access recall by the observed level of recall. In an experimental condition, people recalled not only directly but also indirectly, after being instructed to reverse the cue (e.g. *sleep* yields *peels* for ORANGE). From (3) and (2) it is readily derived that

$$P(\mathrm{Rn} \cap \mathrm{Rc}) = P(\mathrm{Rc}) - P(\mathrm{D})\{1 - P(\mathrm{Rn})\}.$$

Thus by using the estimate of $P(\mathrm{D})$ obtained in the control condition, the level of joint recognition and recall in the experimental condition could be predicted. This agreed well with the observed level in two separate experiments. However, Jones (1982) noted also a deficiency in the formal model for these experiments. In the control conditions, the absence of indirect recall should leave recall and recognition as independent processes. But in practice the two measures for each participant exhibited some positive covariation, possibly because complete elimination of indirect recall is unlikely to be achieved in practice, as noted earlier.

The componential approach

Implicit in the research discussed here has been the assumption that ostensibly unitary external events can be represented as clusters of more primitive components. An assumption of this type is almost ubiquitous in theories of cognitive representation, though the products of decomposition may be termed features, elements or nodes rather than components. Mervis & Rosch (1981) note that this unanimity is not surprising because, from the time of Plato, one of the major aspects of what is meant by an explanation has been the decomposition of the thing to be explained into its elements.

Testing of the specific models that have been discussed here provides evaluation also, *ipso facto*, of the general componential approach, of course. If the assumption of decomposition is not justified, appropriate mismatches between theory and observation should arise. However, the issue has also been addressed directly in the context of multiply cued recall.

According to both the fragment and schema models, the effect of providing two independently specified components of an event as subsequent retrieval cues should be given by concatenation of the effects of the cues in isolation. But if the event's psychological representation is in fact not decompositional but holistic in nature, access to it via a multiple cue should be better than expected on the basis of single cueings. A problem arises, however, in the translation of this statement into a testable hypothesis. The latter entails the adoption of a baseline measure of decompositional performance: a level of performance that is to be expected on the basis of a particular non-holistic theory. There is therefore some arbitrariness in the selection of a criterion for evidence of holistic processing. On the basis of a theory isomorphic with the schema model, Anderson & Bower (1973) suggested as criterion the observation of double-cued retrieval of target information occurring at a level above that to be expected if the two cues acted independently. However, the fragment model holds that, depending upon the particular distribution of fragment types, the action of two cues may exceed this level. This occurs if those fragments containing representations of the target tend to contain also representations of only one or other (and not both) of the two cues. In this case the action of the two cues will be systematically non-overlapping rather than independent, yielding as criterion the higher level that is given by simple summation of the effects of the two single cues; this level has been proposed as criterion by Foss & Harwood (1975) also. Experimental studies reviewed by Anderson (1976) and Jones (1980) suggest that there is only weak evidence for holistic transgression of the fragment bound, although transgressions of the lower, schema bound have been reliably observed.

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General implications

The research reviewed here has shown that our understanding of the basic structure of recall has advanced sufficiently to enable us to predict the quantitative disposition of experimental results in this area. This knowledge is of service also in areas other than that of memory itself. For example, analysis of the distributions of different types of memory trace formed under varying attentional conditions suggests the occurrence of perceptual processing that is limited in capacity but flexible in allocation (Jones & Payne 1982).

In order to render feasible the testing of models that would have the advantages of being parsimonious in their assumptions and unambiguous in their predictions, the instances of memory organization considered here have been relatively simple in absolute terms, though more complex than those often studied experimentally. The evidence that has been reviewed points to two different types of recall. In direct recall, subserved by fragmentary representations of previous events, retrieval of the remembered event occurs as a direct consequence of overlap between the fragment and a cue that corresponds to any of its component elements. In indirect recall, on the other hand, retrieval is mediated by a schema in which the remembered event is encoded in a form that relates it to previously acquired knowledge.

The fragments and schemata studied here are assumed to be the building blocks out of which the organization of memory as a whole is constructed. The latter has been most widely represented in terms of large networks of linked nodes that constitute assemblies of propositions (see, for example, Anderson 1976; Norman & Rumelhart 1975). An important but relatively neglected question is that of how network structures develop out of individual perceptions. Broadbent (1981) has proposed that organization in long-term memory derives from the co-occurrence of otherwise independent representations in a working memory mechanism of the type postulated by Baddeley & Hitch (1974), as a result of which a memory fragment that relates the two may be formed. In addition, the subsequent retrieval of a fragment enters its set of elements into working memory, allowing the retrieval also of all those other fragments to which any of the elements are common. Broadbent showed that a wide range of experimental results can be explained by these proposals, including the otherwise puzzling finding that the memory system appears to cope approximately equally well with information presented in the form of hierarchies and in the form of matrices (Broadbent *et al.* 1978).

A distinction close to that drawn in the present work between direct and indirect recall is that proposed previously in semantic memory research between direct-access and inferential retrieval (see, for example, Collins & Loftus 1975; Norman & Rumelhart 1975). One of the few experimental studies of the distinction has been reported by Camp *et al.* (1980). They found that people responded more rapidly to putatively direct-access probes, such as 'Who said "Dr Livingstone, I presume"?' (Stanley), than to inferential ones, such as 'How many months of the year don't share their first letter with another month?' (five), although there are obvious selection problems in studying knowledge for everyday rather than controlled materials. The distinction has some similarity also to that drawn recently by Baddeley (1982) between a relatively automatic retrieval process and a more active form of recollection that is based upon conscious awareness, which he illustrated in the context of amnesia. A variety of results suggest (Weiskrantz 1978) that amnesic patients display evidence of memory retention when this is tested by methods that do not involve the patients' awareness. Thus Baddeley makes the interesting proposal that amnesia may leave the automatic retrieval process with little or no damage, and disrupt only the process of recollection. The extent to which these two processes may be identified with the direct and indirect retrieval routes reviewed here, however, is at present unclear.

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Discussion

M. E. Le Voi (*Human Cognition Research Laboratory, The Open University, Milton Keynes, U.K.*). I should like Dr Jones to expand a little on his postulated connection between schema retrieval and recognition. Does he mean that recognition involves the access of a schema (which is required for all recall), or that activation of a schema involves a recognition process either for its own recall or for its further retrieval of items to be remembered?

G. V. Jones. It is the last of Dr Le Voi's alternatives that is being asserted. That is, the overall relation between recognition and recall appears to bear out empirically the proposal that, in schema-based recall, the activation of a schema is followed by processes that include the execution of recognition decisions upon its contents.

D. R. J. Laming (*Department of Experimental Psychology, University of Cambridge, U.K.*). I think that Dr Jones is premature to propose 'fragments' and 'schemata' as *alternative* processes in recall. In one of their experiments Ross & Bower presented a quartet of words with a common theme – for example ⟨apron, chair, brush, clip⟩ – which fit into a 'haircut' theme. This theme was announced to half of the subjects only; yet this manipulation made little difference because the other half of the subjects invariably intuited what the unannounced theme was intended to be. Model the memory traces as fragments with up to five elements. Because of the intrinsic structure of the quartets of words, the fifth element (the theme) is nearly always included in the fragment. But the experimental procedures tested only the possible inclusion of the other four elements (the quartet) in the fragment-memory because the theme went unrecorded. In this way it can be seen that a schema is simply a fragment incorporating an additional element whose existence, in this experiment, was not explicitly tested.

G. V. Jones. It was argued here that material with extraneously related components (as in the example cited by Dr Laming) can be encoded in memory in either fragment or schema form, while that with unrelated components is encoded in fragment form only. The problem with Dr Laming's proposal is that the schema model postulates not only the existence of an element corresponding to theme but also particular principles of organization and retrieval (which are reflected in the patterns of recall that the model predicts). It would indeed be straightforward to embrace the theme element within the fragment model, but to embrace the organizational principles would be difficult.

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