The Microscope Metaphor in Human Memory

ROBERT G. CROWDER and IAN NEATH
Yale University, New Haven, CT, USA

Today, we shall try to weave together a pair of themes for which Bennet Murdock made early and seminal contributions. First, Murdock was among a small handful of modern pioneers in experimentation on short-term memory (Murdock, 1961). We hope to show that these discoveries were important for the light they shed on how human memory works, in general, not for uncovering a new "system" of memory. Our argument is based on a microscope metaphor—matter looks quite different under the microscope than it does to the naked eye, but it is the same matter, just seen in better detail. Secondly, we discuss new experiments on position effects in recall that we think are faithful to Murdock's Serial Position Distinctiveness Hypothesis for primacy and recency effects (Murdock, 1960). In contrast to the conventional wisdom of the day which then, as now, was highly convoluted (this is the only use we shall make of the term convolution) and controversial, he proposed a simple perceptual attitude: Performance is relatively better at the endpoints of any series than in the interior of the series because those end positions are the most distinctive in the series.

MEMORY AND MICROSCOPY

Robert Hooke (1665) startled the 17th-century world with engravings like those shown in Figure 7.1, representing his drawings of microscopic views of common objects such as a flea and a slice of cork. Although not all authorities were convinced, even as late as the 19th century, that microscopy was the Royal Road to knowing about the physical world, objections (Bichat, 1800) were all based on such recognized artifacts as the chromatic and spherical aberrations. From what we can tell (Bracegirdle, 1978; Bradbury, 1967) objections never proceeded on the suspicion that the matter seen through the eyepiece was different in kind from matter that was visible to the naked eye. No one suspected that Hooke's drawing of a flea was a different insect than the one they knew (perhaps too well).

The reason must have been that to use a microscope, one takes the target material, fully in view, and deliberately fixes it into position under the lens. Children still shaky on their Piagetian conservation skills might well deny that the cork fragment or the flea were the same before and after being brought under the microscope, but most scientists, even hundreds of years ago, were not fazed by this simple object constancy.

Human memory is also the same faculty whether examined in the context of retrieving a language-vocabulary lesson from several days earlier, a summer vacation from years ago, or a three-consonant trigram from 15 seconds earlier. Of course, we should always be open minded that it might not be the "same animal." That claim has been prominent in the last thirty years in the theory of human
memory. The impulse that animated early work: on short-term memory is nearly forgotten today, but we should be mindful of the meaning of that claim, and of where the burden of evidence lies.

Figure 1: Engraving of a flea and a slice of cork taken from Micrographia, published in 1665 by Robert Hooke.

Investigators in the early days of short-term memory research were confident that paired-associate list learning was indeed the proper way to study human learning and memory, and the distractor task, for one, was intended to show how individual items were learned and forgotten during repeated trials through the list. If you like, this was tantamount to holding the paired-associate learning process under a microscope. The dimension of magnification is temporal here, rather than spatial, but magnification is what was intended. For one reason or another our community then abandoned this basic principle of conservation that we alluded to earlier: Rather than considering these new experiments as a way of getting a closer look at how learning and memory work, the field accepted that this was a new kind of memory, with potentially different properties than those we had known before. Murdock himself does not have clean hands in this matter. He suggested tentatively (Murdock, 1961) that different principles might apply to the counting-backwards situation than accepted principles of interference in "long-term memory."

Imagine for a moment that Hooke had published his engraving of a flea to a community unaware of how the microscope works and thus perhaps vulnerable to a lack of the constancy we have described. Like psychologists with short-term memory, they also might have been disposed to regard this as a new kind of animal, a frightful one at that.

Much has been made of apparent discrepancies between short- and long-term memory systems, including specifically critical analyses of evidence thought to show the former "directly" (Crowder, 1982, 1989; Gruneberg, 1976). Rather than return to these arguments today, we shall emphasize some unexpected sources of evidence for transcendental commonalities between the two domains. First, we cite in passing two strong indications in the recent literature that theoretical structures developed for long-term memory work: elegantly for short-term memory and vice versa. Next, we describe some recent work of our own on presentation schedules for list memory which we believe illustrates process communality and confirms Murdock’s ideas about distinctiveness.

In passing we should affirm that discovering process communality does not necessarily advance the goal of parsimony, as Tulving and Schacter (1990) have claimed, in the
sense of parsimony "the easy way out." Most theoretical advances begin from empirical dissociations, such as those between short- and long-term memory, between primacy and recency, between recognition and recall, and between implicit and explicit memory. The most effortless way out of such baffling situations, in some cases, is to say "Of course, these two are different systems, and so we would expect such dissociations." The alternative we prefer is to grapple with the dissociated situations and show that each is a special case of a more general, but much more complicated principle. The cases of encoding specificity and recognition-recall differences are exactly examples of this.

Lewandowsky and Murdock (1989) have recently published a sweeping survey of classical problems in situations involving memory for serial-order information such as digit-span, serial list learning, proactive inhibition in the Brown-Peterson distractor task, and the dissociation of primacy and recency in free recall. They found that TODAM, a model originally developed for various "long-term memory" situations, was a satisfactory account of all, without the introduction of new parameters. As they moved among these well-known, and sometimes classic, paradigms, the burden of effective simulation shifted among the active parameters of TODAM, but nowhere was it necessary to introduce machinery to distinguish information being remembered over a few seconds from information being remembered longer.

Correspondingly, Nairne (1990) has reported data on an incidental serial-recall experiment in which parameters of presentation and test would surely qualify for so-called long-term memory. In analyzing the data he plotted distance gradients of exactly the sort introduced by Estes (1972) and Healy (1974) as direct evidence favoring the perturbation model of short-term memory. The latter curves came from experiments where only four single letters were exposed rapidly on a screen with a rehearsal-preventing distractor activity. In Nairne's experiment, unrelated meaningful words were presented at a 2.5 s rate with testing ten to fifteen minutes afterwards. The distance functions are shown in Figure 2, from the two situations. Clearly the principle behind these two situations. Clearly the principle behind these data extends more broadly than one would have suspected from either data set alone. Again, the amount of time over which information is being remembered makes little or no difference.

Figure 2: Distance functions generated by Nairne (1990) for incidental semantic processing of five-word lists in long-term memory (lower panels) and for single digits shadowed in lists of four tested in short-term memory (upper panels) by Healy (1974).
DISTINCTIVENESS, REGENCY, AND TEMPORAL PERSPECTIVE

In our experiments we have followed the leads of Murdock (1960) and more recently of Glenberg (1987) in accounting for the form of the serial position function by the assumption that items in a series form a unidimensional vector, among many other encoding attributes, reflecting their times of presentation in the series. By a perceptual metaphor, then, information from the extremes of this dimension would be more distinctive than those from the interior. Distinctiveness should enhance recall. By itself, this assumption will produce a curve with both primacy and recency, deriving from the same source. So did the one-process theory of Hull and Lepley (Hull, 1935). For well-understood reasons (Crowder, 1976) such models, by themselves, cannot be taken seriously today.

The agency for a recency effect based on temporal distinctiveness was implicit in the analysis by Bjork and Whitten (1974) of the long-term recency effect. They suggested that recency might be controlled by a sort of Weber fraction expressing how long the interitem intervals were relative to the retention interval before recall. In the standard free-recall situation this accounts for why the recency effect disappears with a filled retention interval after presentation (Glanzer & Cunitz, 1966). The Weber-fraction, hereafter termed the "ratio," would be diminished by this operation. The same reasoning explains why the recency effect reappears when the post-presentation retention interval is left substantial but a distractor task separates presentation of the memory items; in this case the crucial ratio increases.

Our own experimental attention was originally focused on the recency effect itself, rather than full implications of the temporal distinctiveness viewpoint, to which we shall return at the end of this chapter. Thus, our reasoning, like that of Bjork and Whitten (1974), of Baddeley and Hitch (1977), and of Glenberg and Swanson (1986) embodied a temporal perspective in which the recaller was oriented from a temporal position at the end of the presentation series. The irresistible metaphor was that the subject gazed back towards a series of telephone poles, each representing the temporal occurrence of a memory item, the whole series viewed from near or far depending on whether the retention interval had been short or long, respectively.

In a recent article (Neath & Crowder, 1990) we published results of a series of experiments on tests of the temporal-distinctiveness idea using increasing and decreasing "presentation schedules." In these experiments the control presentation schedule is conventional uniform spacing of items, including some measurable interitem interval. In the experimental schedules these interitem times were variable, going from short to long as the series progressed (increasing) or from long to short (decreasing). These arrangements allow the separation of serial order information from true temporal information. We took seriously Glenberg's suggestion that the passage of time compromises the precision of temporal codes (Glenberg, 1987). Thus in the control condition, retrieval from early positions is poorer than from the later positions because temporal codes have had time to "smear" in the former case more than in the latter. This instantiates the telephone-pole metaphor.

Conditions with increasing interitem intervals should make the situation even worse: The recency items would have been more distinctive, anyway, because of their position relative to the retrieval perspective, but now they are increasingly well separated in presentation as well. This should enhance recency and depress prerecency performance.

In the corresponding decreasing schedule, these two factors work: in opposite directions: On the one hand, the perspective at retrieval favors the most recent items, as always. On the other hand, the objectively wider spacing
of early items than of later items in the presentation sequence should partially counteract this perspective effect (One can imagine looking towards a series of telephone poles with wider and wider separations between adjacent pairs as they all recede into the distance.) Our expectation was that this decreasing schedule should produce better performance and tend to flatten the serial position curve, as it did in the data, which are shown in Figure 3.

In this experiment (Neath & Crowder, 1990, Experiment 3, visual condition) five pairs of common words were presented for 2.5 seconds per pair and subjects had to make semantic decisions about the words. Between pairs, subjects had to make true/false decisions about simple mathematics statements (2+3+1=7). Each mathematics problem was presented for two seconds.

In the control condition, four such problems (8 seconds) separated each pair of memory words. In one decreasing schedule, the four inter-pair intervals included 16, 8, 4, and 0 distractor problems, respectively, and another there were 16, 9, 5, and 3 problems, and in the third decreasing condition there were 8, 5, 3, and 2. We shall hereafter combine these three decreasing schedules for simplicity; the original report can be consulted for mere detail (Neath & Crowder, 1990). In the increasing condition, the interitem intervals included 0, 4, 8, and 16 problems. The fifth and final word pair was followed by four mathematics problems always, defining a constant 8 second retention interval. A hyphen on the CRT served as a cue for free recall of all 10 words.

The results in Figure 3 show our expectations abundantly confirmed. The largest recency effect was shown in the increasing condition, and the three decreasing conditions showed the least, with the best overall recall. (This was true for each individual decreasing condition.) These results are consistent with the idea that recall of a particular item is proportional to its temporal discriminability as defined by the ratio of its spacing from the previous item to its delay before the recall episode. Concerned with whether this was a property of the "long-term recency" effect or a more general property of human memory, we performed another version of this experiment (Neath & Crowder, 1990, Experiment 2) using Healy's (1974) technique for testing short-term memory.

In this experiment subjects were instructed to pronounce aloud letters and digits.
shown individually for 500 ms on a CRT. The letters were the memory targets and the digits were the distractors. Spacing of the five to-be-recalled letters was defined by the number of digits presented in the four interitem intervals, analogous to in the previous experiment. In the control condition, two digits separated successive letters. In the increasing schedule, there were 0, 1, 2, and 4 digits in the series and in the decreasing condition this pattern was reversed (4, 2, 1, and 0 intervening digits). In all conditions to be discussed here, a single digit served as the retention interval prior to a 20-second free recall period. Thus, in all conditions the duration of a presentation episode was four seconds or less.

The results shown in Figure 4 indicate the same pattern as we had found in the data of Figure 3, where presentation episodes lasted about 60 seconds and recall was always delayed by 8 seconds. The increasing schedule again shows the most pronounced recency effect and the decreasing condition the least, with the control condition intermediate, as expected on the basis of the temporal distinctiveness idea of Murdock as modified by Glenberg and others.

In the first of our two experiments meaningful words were being remembered with explicit semantic processing required. The distractor activity was genuine, if uncomplicated, problem solving. The total time elapsing during a trial was on the order of a minute. In our second experiment meaningless characters were presented, with barely time to read them, and "mindless" shadowing of digits was the filler activity. The total elapsed time was literally an order of magnitude shorter. In processing depth, the two tasks are vastly different, yet largely the same pattern of results emerged from them. We are reminded of the research of Glenberg and Lehmann (1980) on the repetition-test-lag interaction, showing the same pattern of findings for the continuous paired-associate task in short-term memory and for study and test lags distributed over a period of more than a week. In the manner of a microscope, the laboratory situation using STM enables us to discover and test principles that are manifest in much more cumbersome situations outside the laboratory.

Regarding these two situations as stemming from different systems of memory, short- and long-term, would dangerously have concealed the generality of what may be a general principle of how people (and others) cope with the retrieval of memories that are distributed in time. The elegance of Murdock's distinctiveness hypothesis is that it applies to an immense number of situations where other ideas on primacy and recency effects are patently helpless. For example, in free recall of the Presidents of the United States, people show a serial position curve with primacy and recency (Roediger & Crowder, 1976). Attitudes commonly accepted in free recall include extra rehearsal for the primacy items and a recency buffer 10 STM for the last few. These attitudes are of questionable value for the early part of the series (Madison might possibly be "rehearsed" more than Buchanan) but so silly as to be beneath discussion for the last few. On the other hand, if the array of presidents is to some extent held as an ordered vector in memory, then perspective from near end of the series would produce recency and a from the beginning of the list would produce primacy. Likewise, other manifestations of position effects such as the "conceptual position effect" (Crowder, 1976) are preposterous from the conventional views of primacy and recency but are easily explained by the temporal perspective point of view.

PRIMACY AND "POINT OF VIEW"

Application of the temporal perspective ideas to recency, as mentioned earlier, to the expectation that if the recaller faced a temporal array m the forward direction, from the
beginning of the list rather than from the end. The result would be primacy and not recency. This reasoning has led us to some interesting experimentally, but first let us develop the idea in simple form. If a series were evenly spaced and the individual information were still in then a shift from a backward perspective in recall to a forward perspective in recall should correspondingly be a shift from recency to primacy. The clearest of this process is found in a report by Wright, Santiago, Sands, Kendrick, and Cook (1985), and shown in Figure 5. We provide here only their data for human subjects although the data from pigeons and monkeys looked almost identical. Six people saw a series of four kaleidoscope slides exposed for 1 second apiece. Following a delay of from 0 to 100 seconds a probe slide was presented, with a lever movement indicating whether it was old or new with respect to that trial. Immediate testing showed a pure recency effect with no trace of primacy, whereas delayed testing showed more and more primacy during the first minute of retention and, finally, a pure primacy effect with no recency at a delay: As Wright et al. (1985) observed, no single-process account can explain this finding. However, a single memory representation with dual retrieval dynamics can. The former is an ordered array of evenly spaced temporal traces. A backward retrieval dynamic, like looking at telephone poles from the near direction, yields a perspective favoring distinctiveness of those at the recency end. A forward retrieval dynamic should provide perspective from the primacy end of the series. The additional assumption needs to be that immediately after presentation, retrieval orientation is based on the last part of the list and with delay this shifts to the first part of the list.

![Figure 5](image-url)

Figure 5: Percent correct performance in recognition of kaleidoscope slides from series of four, as a function of test delay in seconds. From Wright et al. (1985).
This assumption is gratuitous within the context of this single experiment of course, but it is not without independent plausibility elsewhere in the literature: The conditioning technique of experimental extinction has long been a temptation for integration with forgetting and memory theory (for example, Miller & Stevenson, 1936). A counter-conditioning theory of extinction emphasizes that the organism must learn two things in the same situation—the original response and the habit of not making that same response, during extinction. If you will, this history of training is a minimal "list" of two episodes. Immediately after extinction training, the organism does what it has just been learning to do, which is to omit the response. With delays, the observed behavior returns in a process called "spontaneous recovery." One interpretation of this last process is as a shift from a backward-looking perspective on the two-event sequence to a forward-looking perspective, in which the earlier experience is the more prominent.

We do not wish to push this extinction digression too far: In the list situation, events are almost always motivationally meaningless and more numerous than in the extinction situation. Even the Wright et al. (1985) experiment used lists of four kaleidoscope slides. It may be coincidental that the shift with delay in retrieval from recency to primacy is overtly the same as the extinction-spontaneous-recovery shift with delay. Their demonstration that species differences are immaterial to this pattern of results is, however, encouraging to the search for principles in common. (Precisely the same interpretation can be placed on the phenomenon of proactive inhibition in the distractor situation, incidentally.)

Finding both primacy and recency is expected on the assumption that some subjects, on some trials, fall into a "backward" orientation and others into a "forward orientation." In a series like the Presidents of the USA, there would be powerful reasons for embracing both recall strategies.

We recently decided to demonstrate the forward- and backward-perspective idea in the context of our experiments on increasing, decreasing, and control presentation schedules (Figures 3 & 4). Our first thought was that it would be a simple matter to ask for forward serial recall, rather than free recall which is presumably backward in orientation. Our experiment repeated the experiment of Figure 3 almost exactly (indeed we used the same presentation programs). The only difference was that subjects were to recall from the first to last item, that is, in serial order. Care was taken to ensure that this was the case. We expected the increasing schedules now to show an advantage over the decreasing schedules, with the worst performance in the latter, and the control condition intermediate. The results are shown in Figure 6, again with the two decreasing and the two increasing conditions combined.

![Figure 6: Serial recall of word pairs presented under exactly the conditions of Figure 7.3, except with forward, serial recall.](image)

Figure 6: Serial recall of word pairs presented under exactly the conditions of Figure 7.3, except with forward, serial recall.

Our findings could hardly have surprised us more. The decreasing condition, which should have been best, was almost indistinguishable from the control condition. Primacy was still very modest and the increasing schedule again provided the most recency.

As always happens with negative results,
we then had no alternative but to think more carefully about the situation. In predicting symmetrical forward and backward perspectives, producing primacy and recency, respectively, we had been forgetting about Glenberg's "other factor," apart from temporal discriminability, the automatic corruption of temporal information with time. He had termed this factor a "spread of consistency functions" with time. This over predicts recency alone, since temporal perspective by itself would favor items on the near edge of the temporal vector. But if temporal information degrades with time, our prediction of a primacy effect based on a forward recall perspective is no longer tenable because distinctiveness for these items would have been lost already by the time of the recall effort, whatever the orientation at recall.

Glenberg (1987) proposed a decay-like deterioration of temporal discriminability with the passage of time. We prefer to imagine the process of rehearsal as the agency for this deterioration. During list presentation as later items cue the implicit retrieval of earlier items, the temporal definition of the latter would gradually blur, just as the re-election of Grover Cleveland and Franklin Roosevelt blurred their times of being President. At the same time, this extra rehearsal of primacy items would tend to elevate their recall, much as Rundus (1971) claimed. So primacy through the rehearsal process would be at the expense of temporal coding. Figure 6 does exhibit more primacy than the companion Figure 3.

Whether the deterioration of temporal definition is an autonomous process of decay similar to that proposed by Glenberg (1987) or a natural consequence of rehearsal as we have been suggesting, we would be defeated in discovering the reversed pattern corresponding to Figure 3 in any situation with appreciable lapses of time during the list presentation. The evidence from Wright et al.'s (1985) kaleidoscope slides suggests that rehearsal may be the agency of loss for temporal resolution early in the list rather than straight decay, for the special feature of those stimuli is that they defy efforts at rehearsal although the 1/second presentation rate was reasonably slow.

In one of our most recent experiments we sought to neutralize both factors that could compromise temporal coding from the early list positions. We again used lists of five items, this time words, but we compressed their presentation in time drastically. The whole presentation episode lasted an average of 946 milliseconds across the control, increasing, and decreasing conditions. Indeed presentation was so rapid, we and the subjects considered this an experiment on visual perception or masking rather than on memory. In the various conditions each of the five words was visible for 50 milliseconds each with blank periods of from 40 to 400 milliseconds inserted in the four interstimulus intervals in order to realize the various schedules. These intervals were uniformly 50 milliseconds long in the control condition. In two increasing conditions, the successive four intervals were 50, 100, 200, and 400 milliseconds and 40, 72, 130, and 234 milliseconds. In the decreasing conditions these values were reversed from beginning to the end of the list. Thus the experimental design was the same as that used in the studies of Figures 3 and 4, giving, respectively, results for retention on the order of a minute and on the order of five seconds. Now this time scale is compressed by almost another order of magnitude.

The results are shown in Figure 7, arranged as before. Here, finally, we obtained the expected forward-perspective pattern we had not been able to show in the previous experiment. Now the decreasing condition was worse than the increasing condition, at least for positions 3 and 4. Primacy was everywhere larger than recency. With time (for decay) virtually equated across the list positions, and rehearsal unthinkable, subjects behave as
if performance were controlled by a "pure" serial recall perspective applied to an intact memory array.

**CONCLUDING COMMENTS**

If indeed these data show what we think, a process of retrieving information from memory arrays that reflect the coding of information across real time, not just serial order, then our theories of serial-memory tasks should reflect this process. Many of the mechanisms psychologists have devised for primacy and recency in some situations have very little to recommend them in other situations we have reviewed here. The general attitude represented by Murdock’s Distinctiveness Hypothesis does not have this parochialism.

**AUTHOR NOTE**

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