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In this issue . . .

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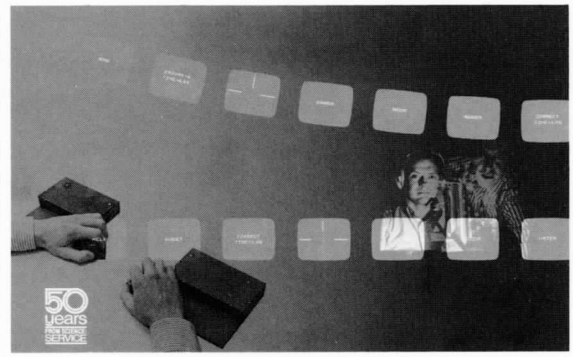

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Contents

Transferring information from one person's memory to another is what communication—and the Bell System—is all about. That's why scientists at Bell Labs do basic research on memory. The results of their studies have not only added to our understanding of mental processes, but have also shed light on what factors determine the speed with which people perform a variety of tasks related to communication.

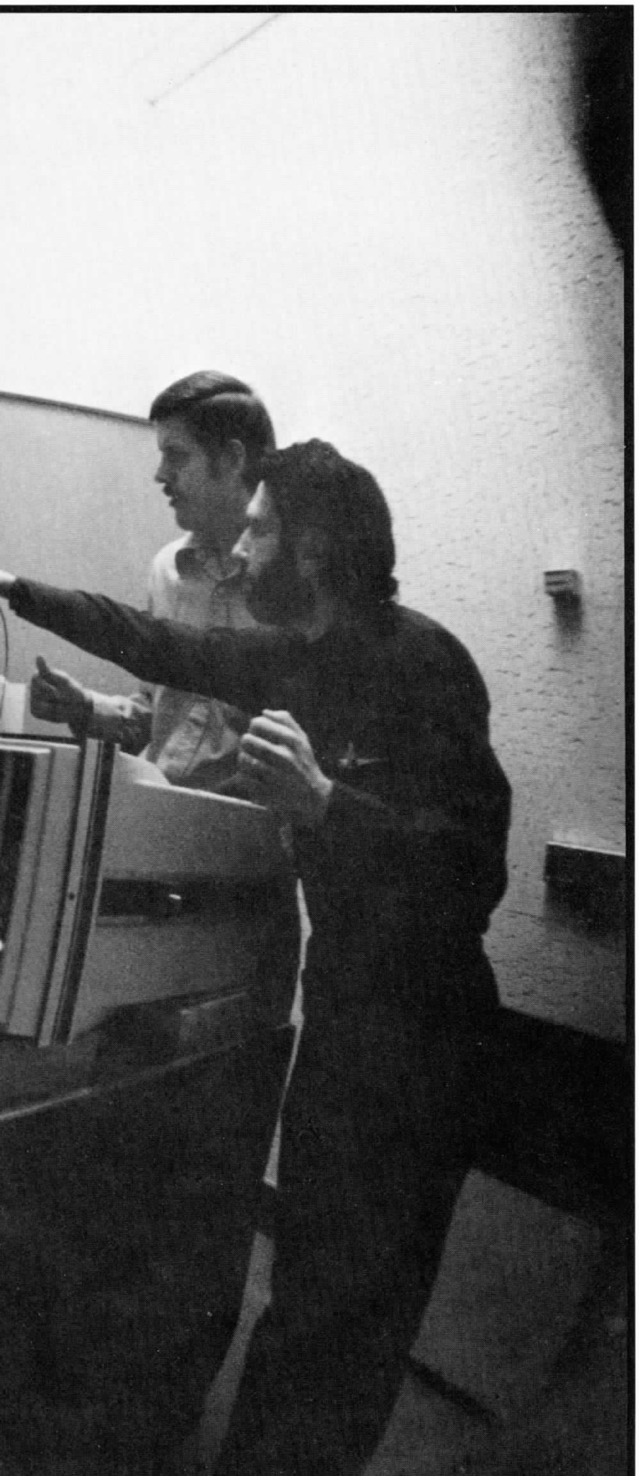
Updated reliability concepts are helping systems designers to come up with new ways to reduce downtime caused by equipment failures in electronic switching systems. These concepts have been applied initially to the Traffic Service Position System (TSPS), resulting in new maintenance facilities and procedures. Although TSPS is the first system to apply the new concepts, all electronic switching systems can benefit from their application.

About the cover—In the quiet of a test booth, a volunteer presses a key to indicate whether or not a number he has just heard belongs to a list of numbers he previously memorized. In another test, he may indicate whether or not the letters on a computer-controlled visual display spell a word. These "reaction-time" experiments, described in the article beginning on page 148, are conducted at Bell Labs to study the human memory. They will help scientists understand how communication—the transfer of information from one memory to another—takes place.

Exploring the Speed of Mental Processes

A new way to study human memory, pioneered at Bell Labs, is yielding insights about basic mental processes by measuring how much time people take to retrieve information stored in the brain.

MAX V. MATHEWS, DAVID E. MEYER, AND SAUL STERNBERG



IN ALL HUMAN COMMUNICATION, information is transferred from one person's memory to another. Regardless of how a message is sent, it must eventually arrive in a form that can be coded, preserved, and retrieved by the brain. As more ways are developed for transmitting information, the choice among alternative possibilities will depend increasingly on an understanding of mental processes. It is therefore not surprising that during the past two decades, Bell Laboratories has been building a body of knowledge and a strong tradition of basic psychological research on human memory.

Experimental psychologists have investigated two different types of human memory, one like the temporary "scratch-pad" buffers of digital computers, and the other like their more permanent "bulk-storage" devices. Human *short-term memory* can hold between five and ten pieces of information. Unless a person repeats it to himself, the information is typically forgotten in less than a minute. This temporary storage system is used, for example, when we look up and dial a new telephone number or when we recall what someone said a moment ago. It probably serves also as a small-capacity "working memory," playing a critical role in reasoning and comprehension.

In contrast, the capacity of *long-term memory* is tremendous. It normally contains records of enormous numbers of facts and experiences. Employing this essentially permanent storage system, a person can preserve information for many years without making any conscious effort to retain it. Long-term memory is used, for example, when we recall our own telephone number, recognize the meanings of words, or remember someone's face.

A technique pioneered at Bell Labs provides a new way to study both short-term and long-term memory.

Seated in a test booth, volunteer Terry Leuin of the Human Information-Processing Research department prepares to take part in a memory experiment. His fingers rest on keys used for making affirmative and negative reactions to the test items. In a typical experiment, he will press one of these keys as fast as he can, to indicate whether or not a row of letters on the screen spells a word. Coauthors David Meyer and Saul Sternberg check some of the equipment.

Most research on memory has been based on the number and pattern of errors people make when attempting to remember under conditions that produce frequent failures (see "Approaches to Human Memory from Classical Times to the Computer Era," below). Our new technique allows memory processes to be studied under conditions where people perform rapidly and make almost no errors. Instead of measuring errors, we measure how long a person takes to remember selected kinds and amounts of information correctly. This article attempts to convey the flavor of the *reaction-time method* by describing the main features of a few representative experiments.

One general aspect of our findings is that what actually happens in a person's mind when he remembers something may be very different from what he thinks is happening. Not only are people unaware of some of their mental activities, but they may actually be mistaken about others. This means that to determine the brain's capabilities and limitations we cannot rely on impressions and hunches; to find out what is really happening we need precise measurements made under controlled conditions.

Retrieval from Short-Term Memory

For example, in one of our first experiments on short-term memory, performed several years ago, we asked people to memorize a

APPROACHES TO HUMAN MEMORY FROM CLASSICAL TIMES TO THE COMPUTER ERA

Over the centuries, various methods have been used to explore both short-term and long-term memory. Aristotle and later philosophers were interested in memory, but their conclusions depended mainly on introspection, the conscious experience of their own mental activities. In studying the mind, just as in the physical sciences, the "armchair" approach may lead to incorrect conclusions.

Modern neurophysiologists have performed memory experiments that are more rigorous. For example, by electrically stimulating different points on the surface of a person's brain, Walter Penfield was able to arouse vivid recollections of forgotten events. After destroying certain parts of rats' brains and observing the effects on learned behavior, however, Karl Lashley concluded that a piece of information is stored in a large number of widely scattered nerve cells, rather than at a single place in the brain. A controversy still exists over the extent to which the functions of the human brain are spatially localized. For example, recent studies of accidental brain injury have shown that short-term and long-term memory may be independently impaired, depending on which area of the brain is damaged. This finding provides neurophysiological support for the functional differences between the two types of memory found by experimental psychologists.

Yet the physiological approach has often been frustrating and inconclusive because the nervous system is extremely complex. Even if physiologists eventually understand how individual brain cells store new information, this knowledge may reveal very little about how human memory works, just as detailed knowledge about a magnetic core helps little in understanding a large computer system.

Psychologists have therefore developed other techniques for studying memory processes. One psychological approach is to analyze the errors that people make when they try to recall or recognize various kinds and amounts of information. This *error method* was developed around the turn of the century by Hermann Ebbinghaus to study how people learn lists of nonsense syllables like ZUP or RIL. He measured how properties of the lists and learning procedures influenced the frequency of errors during later recall. His method of studying memory—by examining how and when it fails—dominated behavioral research on memory for over 50 years. Yet, like the physiological approach, it has not been entirely satisfactory. One problem is that memory failures may occur during various mental operations, including storage, retention, and retrieval of information. It is often difficult to disentangle these different sources of error. Moreover, the error method does not necessarily reveal how human memory functions under normal circumstances, when memory failures are relatively rare.

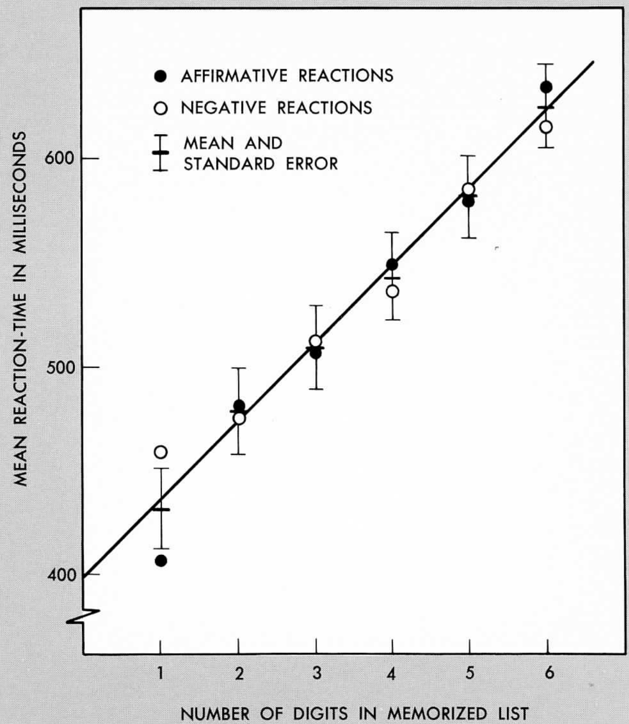
In the past two decades, however, there has been a revolution in the entire field of psychological research on mental processes, partly inspired by such technological advances as electronic signal detection, the theory of information developed by Claude Shannon at Bell Laboratories, and computer science. Information theory has led psychologists to explore more precisely the way that information is mentally coded, classified, and translated into various forms. Signal-detection devices have stimulated us to regard retrieval from memory as involving statistical decisions based on noisy signals. Computer science has raised questions about serial versus parallel processes in the brain, fostered ideas about simple search mechanisms, and encouraged a quest for basic mental operations. Memory research at Bell Laboratories has been a part of this revolution, using the *reaction-time method* to focus on the speed of mental processes under conditions in which they function with high accuracy.

EXPERIMENT 1: SEARCHING SHORT-TERM MEMORY

PURPOSE: To discover how people retrieve information that they recently memorized.
STIMULI: (1) A memory list of one to six different digits, selected randomly from the ten digits, and displayed visually one after another in a random order. (2) A test digit either contained in the list or not.
PROCEDURE: After a person had memorized a list of digits, a test digit was displayed visually. The person made an affirmative reaction as quickly as possible (by pressing a particular key) if the test digit was in the memorized list, or a negative reaction (with a different key) if the digit was not in the list. Reaction time was measured from the appearance of the test digit until a key was pressed. This procedure was repeated on several hundred trials with different memorized lists and test digits. A total of eight people participated. Affirmative and negative reactions were required equally often, regardless of the list length. Electronic apparatus gave precise control over the presentation of stimuli and the timing of reactions. Incorrect reactions were held under two percent by paying participants so as to penalize errors heavily while rewarding speed. Two sample trials:

Memorized list—2, 9, 6, 1, 7
Test digit—9
Correct reaction—affirmative

Memorized list—8, 2, 4
Test digit—5
Correct reaction—negative

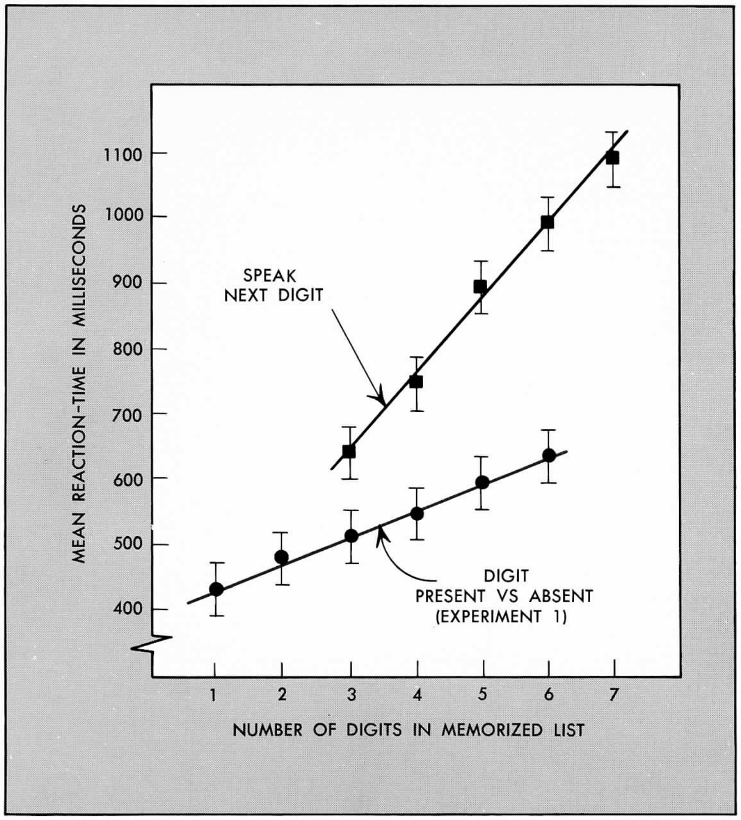


RESULTS: Reaction time increased by approximately the same amount for each digit added to the memorized list (see the diagram above). The amount of this increase (or *slope* of the line in the diagram) was about 40 milliseconds for each additional digit. The amount of increase was the same for affirmative and negative reactions.

small list of digits (say, 2, 5, 4, 8, 3) and then decide quickly whether a particular test digit (say, 8) was in the list. Some said that they made their decision immediately, without going through any special mental activity. Others reported that when the list was presented they started to repeat the digits silently; when shown the test digit they continued running through the memorized list and reacted affirmatively as soon as they encountered a number that matched the test digit.

When we examined the reaction times from our experiment, however, we found that neither of these introspections about the mental decision process is correct. (For more details about the procedure and results, see "Experiment 1: Searching Short-Term Memory," above.) The decision clearly takes a significant amount of time, and the more digits there are in the memorized list, the longer it takes—about 40 milliseconds more for each additional digit.

At first sight, this steady increase in reaction time seems to agree with the introspective report that a person checks each digit in the memorized list, one after the other, to see if it matches the test digit. But there are two remarkable differences between the actual search process and what people think they are doing. First, the search rate is at least three times as fast as a person can silently repeat digits. If you try to count silently from 1 to 10, you will come nowhere near the rate of 25 to 30 digits per second indicated by the reaction-time data. Second, it appears that the search through the memorized list does not stop as soon as it reaches a digit that matches the test digit—that is, the search is not *self-terminating*. Instead, it is apparently *exhaustive:* it continues through the entire list even if the



To determine why the memory search in Experiment 1 always continued through the entire list, people again memorized short lists of digits. But this time they did not simply decide whether each test digit was present or absent in the memorized list. Instead they had to say what digit immediately followed the test digit in the list. For example, if the list was 5, 8, 7, 1, and the test digit was 8, the correct reaction was the spoken word "seven." With this more demanding task, which required a person to ascertain where in the list a test digit was located, reaction time was longer and the search rate was considerably slower, as shown by the increased slope in the diagram (black line, as compared to colored line from Experiment 1; note that the vertical scale has been compressed relative to the scale of the graph on page 151). Other analyses of the reaction times indicated that the search process stopped when a person found the test digit, so that the search was self-terminating, rather than exhaustive. The data, from six participants, support the idea that a self-terminating search may actually be less efficient than an exhaustive search, because exhaustiveness can permit a higher search rate. They also show that information about the presence or absence of items in a memorized list can be retrieved much more rapidly than information about their arrangement.

test digit has already been found.

The reasoning behind this second conclusion is straightforward. When the test digit is not in the list, the search *must* run through the whole list before a negative decision can be reached. If the search stopped on affirmative trials as soon as the test digit was found, then adding another digit to the list would increase the average reaction-time for affirmatives by only half as much as for negatives. However, our data show that adding another digit to the list increases the times for affirmative and negative reactions by approximately the same amount. Thus, the search must be the same for affirmative decisions as for negative ones.

Many people are surprised that the mental search process always runs through the entire memorized list. Why continue searching even after a matching digit has been discovered? A possible answer is that a search through the entire list may actually go at a faster rate than a search that has to stop part way through, so that on the average an exhaustive search might be more efficient. Indeed, when we used a different experimental task that made it important to stop searching as soon as the test digit was found, the search became much slower (see diagram at left).

Evidence for a high-speed exhaustive search of short-term memory has also been obtained when other kinds of items, such as words and pictures, were memorized and searched instead of digits. And we have observed virtually identical results even when people work extensively enough with a particular list to store it in long-term memory. Thus, the search process does not seem to depend on special properties of digits, and it involves short-term memory whether or not the information is stored in long-term memory as well.

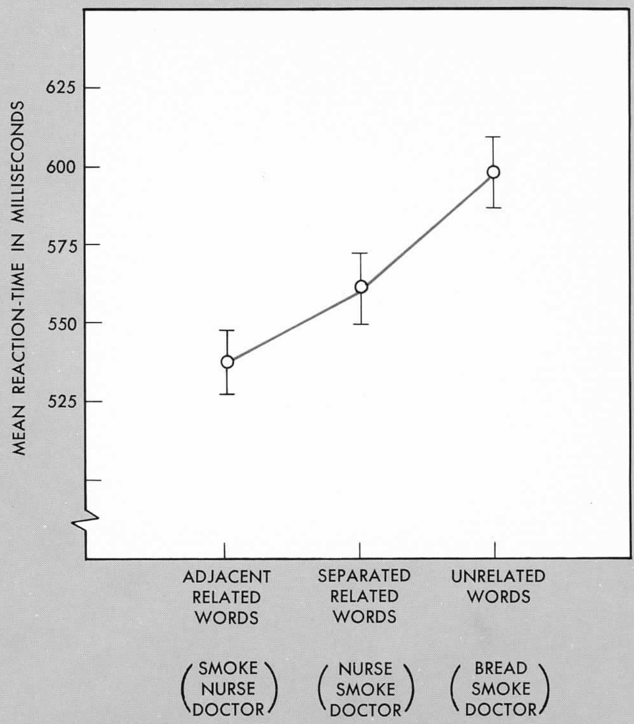
While the experiments described so far tell us primarily about short-term memory, reaction-time measurements from different experiments have permitted us to study long-term memory also. In this area we have concentrated particularly on how common words are organized in memory, and how information about words is retrieved during such activities as reading and listening.

Word Storage Arranged by Meaning

One set of findings indicates that words are arranged systematically rather than haphazardly in long-term memory. However, it appears that they are not arranged simply by spelling, as in an ordinary dictionary. Part of the evidence for a different systematic arrangement comes from measuring how quickly people can decide whether a row of letters, such as DOCTOR or PABLE, forms an English word (see "Experiment 2: Searching Long-Term Memory," page 153). Despite the large number of words stored in long-term memory, such decisions can be made in less than a

EXPERIMENT 2: SEARCHING LONG-TERM MEMORY

PURPOSE: To discover how common words are organized and retrieved in memory.
STIMULI: English words, such as NURSE, BREAD, and DOCTOR, and nonwords, such as SMUKE, PABLE, and REAB, made from words by changing a few letters.
PROCEDURE: A person was presented with three rows of letters, one after the other, with words and nonwords intermixed randomly. The person had to decide whether each row was a word or nonword, indicating affirmative and negative decisions by pressing different keys. Reaction time was measured separately for each row, and the procedure was repeated with hundreds of different words and nonwords. Twenty people participated in the experiment, which was controlled by a digital computer.



SAMPLE TEST		
EVENT	SCREEN DISPLAY	PERSON'S ACTION
Warning signal		Gives the screen his full attention.
First row of letters	CANDY	Presses right-hand key for affirmative reaction.
Second row of letters	MELP	Presses left-hand key for negative reaction.
Third row of letters	SWEET	Presses right-hand key for affirmative reaction.
Feedback	CORRECT TIME=1.28	Notes accuracy of the three reactions and how long they took overall.

RESULTS: The relevant findings (as plotted in the diagram above) come from those trials on which all three rows of letters were words rather than nonwords. Such trials included the following sequences: (1) "adjacent related" words, like SMOKE, NURSE, DOCTOR, in which the second and third words had related meanings; (2) "separated related" words, like NURSE, SMOKE, DOCTOR, in which the first and third words had related meanings; and (3) "unrelated" words, like BREAD, SMOKE, DOCTOR, in which the words all had unrelated meanings. People recognized the third word of a sequence more rapidly if it was related in meaning to one of the preceding words than if the words were unrelated. This happened whether the related words were adjacent or separated in the sequence, although the effect was larger for adjacent related words.

second. But more important for our present purpose, we found that a person can decide that a row of letters like DOCTOR is a word considerably faster when it follows a related word like NURSE than when it follows an unrelated word like BREAD. Furthermore, the increase in speed is greatest when the word follows a related word immediately, instead of after a delay; the reaction time is then shorter by as much as 50 to 100 milliseconds. This is a large percentage increase in the decision speed, since the total reaction time is usually less than a second and people use much of that time merely to see the letters and to make the physical movement indicating their decision.

Our findings support the idea that long-term memory is arranged like a thesaurus: Words with related meanings seem to be stored "near" each other in the brain (where "nearness" may correspond to either physical proximity or richness of nerve connections). The thesaurus arrangement allows a mental search to be completed more quickly for a stored word that is related in meaning to a previously seen word.

We believe that relatedness of meaning influences the speed with which people deal with words in a wide variety of situations. For example, in other experiments we found that a person can *pronounce* a printed word faster when it is related in meaning to an immediately preceding word than when it is unrelated. The increase in pronunciation speed was exactly the same as the speed increase in deciding whether a row of letters is a word. This further supports our conclusion that words in long-term memory are arranged by meaning, and it also suggests that the same search process underlies different kinds of activities involving words.

Retrieving Words from Long-Term Memory

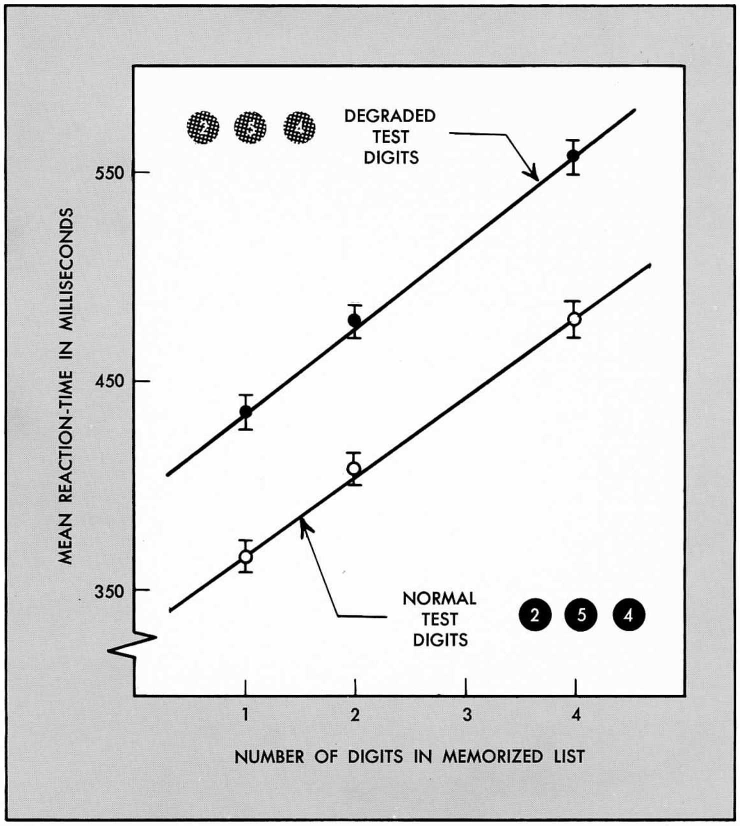
Exactly how could a thesaurus arrangement speed the memory search? It first occurred to us that a search of long-term memory might be like a computer's search for information on a magnetic tape. The computer searches sequentially, moving from one storage location to the next. The search can stop as soon as the desired location is reached, but each new search begins where the preceding search ended. Thus, the time to search both of two locations increases with the distance between them. If long-term memory worked like this, then recognizing a word would take less time when it was related in meaning to an immediately preceding word than when it was unrelated, because the search would have to cover a smaller distance.

But we found that the magnetic tape analogy does not fit with some other aspects of our data. For example, we sometimes presented people with a sequence of three words like NURSE-SMOKE-DOCTOR, in which two related words were separated by an intervening unrelated word. Despite the separation, people still recognized the third word more quickly than when the first word was unrelated to it, as in a sequence like BREAD-SMOKE-DOCTOR (see the diagram, p. 153). This would not have happened if long-term memory worked like a magnetic tape. In searching a tape, the time to find information at one location depends only on where the immediately preceding search stopped, and not on any other previous stopping points.

There is another plausible explanation, however, that is consistent with all the findings we have described: Retrieving a word from long-term memory temporarily increases neural activity at the locations of other "nearby" related words in the memory structure. This "spreading activation" reduces the amount of additional activity needed to recognize a related word, and therefore speeds the reaction, if the word is presented soon enough. While our experiments imply that the activation decays over time, they show that it persists for at least a few seconds and outlasts the decision about an intervening unrelated word.

Thus, unlike short-term memory, long-term memory seems to involve mechanisms quite different in character from those of digital computers. Of course it is not too surprising that the two memories function in essentially different ways. Even the search rate of 30 items per second that we observed for short-term memory is much too slow for finding a particular word among the thousands a person has learned. Reading, writing, or speaking a single sentence would take several minutes! So either there is some useful way to limit the number of words that are searched in long-term memory, or the search rate in long-term memory is much faster, or many words are searched at the same time. Of these alternatives, the findings about memory organization described above support the first possibility, and we are currently designing experiments to explore the second and third as well.

Indeed, another striking difference between searching short-term and long-term memory has already emerged from experiments in which we reduced the clarity of the test stimuli. In a study with lists of digits held in short-term memory (similar to Experiment 1, page 151) we compared reaction times for test digits of normal clarity with times for digits that were "degraded" by a superimposed pattern (see the diagram, at right). As before, we estimated the search rate from the increase produced in the reaction time by adding another digit to the list. We found that the rate of the memory search—about 30 digits per second—was just as high for degraded test digits as for normal ones. At the same time, however, the reactions to degraded digits were about 60 milliseconds slower.



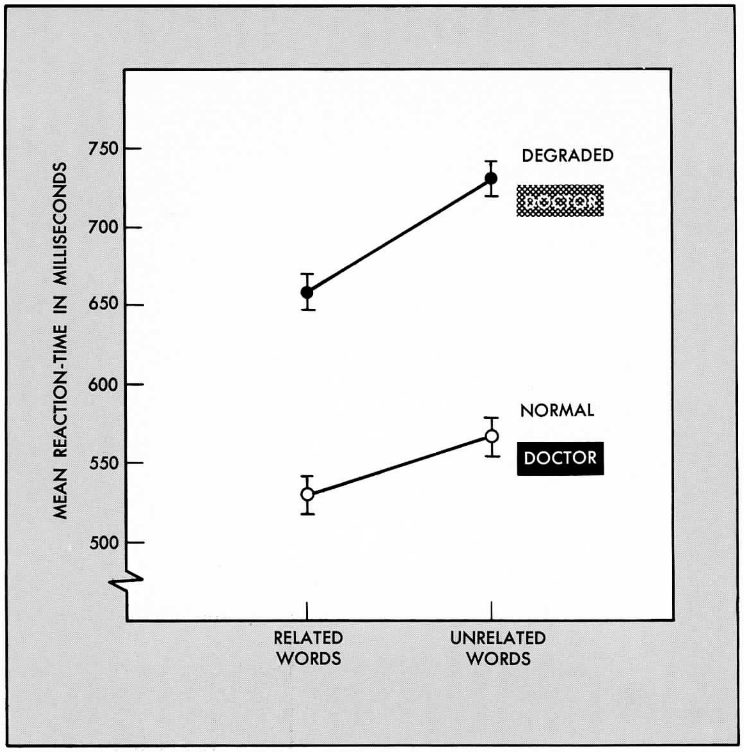
To determine what kind of "code" for the stimulus is used in searching short-term memory, a study similar to Experiment 1 (p. 151) was performed. Twelve people memorized short lists of digits and then decided whether or not particular test digits were in the lists. Some of the test digits were of normal clarity, while others were "degraded" by superimposition of a checkerboard pattern (see examples in diagram). The rate of memory search for the two kinds of test digits was measured by the slopes of the two lines in the diagram. Reducing the clarity of the test digits increased the overall reaction time by about 60 milliseconds, without markedly increasing the number of errors. But the lines are almost parallel, indicating that the two search rates were essentially the same. The data thus suggest that before the memory search starts, another mental process transforms the visual image of the stimulus into a "code" that is the same for normal and degraded test digits.

What Is The Memory "Code"?

The constancy of the search rate indicates that the degradation we used did not influence the search process itself. However, the general increase in reaction time resulting from degradation shows that there must be some other mental process that is influenced by the clarity of the stimulus. We believe that this additional process precedes the memory search, and serves to create a mental "code" for the test digit; it is this code that is then checked against information in short-term memory during the subsequent search.

There are two different types of code that might be involved. One possibility is that the initial coding process extracts just those visual features of the stimulus that are necessary for uniquely distinguishing the test digit from others. Another possibility is that the coding process converts the visual image of the stimulus into the sound of the test digit's spoken name. In either case, the code used by the memory search would be the same for normal and degraded test digits. The memory search itself would not be influenced by the clarity of the test digit, but degradation might increase the time taken by the prior coding process, thereby slowing the reaction, just as we observed. Our conclusion, then, is that by the time the search process in short-term memory begins, the brain has processed the stimulus to produce a highly refined or transformed representation of the test digit—possibly its name. This conclusion fits with a widely accepted idea, first suggested by George Sperling of Bell Labs, that short-term memory stores letters and numbers by their sounds, even when they are presented visually.

In contrast, there is evidence that the search of long-term memory may not have to wait for a coding process that significantly transforms the stimulus. Instead, the search may use a direct "visual copy" of the stimulus. Some of the support for this conclusion comes from a study (similar to Experiment 2, page 153) in which we reduced the clarity of printed words. We found that the reaction time to recognize a printed word increased by over 100 milliseconds when it was "degraded" instead of "normal." But the amount by which degradation slowed the reaction depended on whether the word was related in meaning to the



To determine what kind of "code" for the stimulus is used in searching long-term memory, a study similar to Experiment 2 (page 153) was performed. Sixteen people had to decide whether rows of letters were words or nonwords. When the stimuli were degraded (see examples in diagram), the time to make the decision increased. However, the amount of increase was substantially less for words related in meaning to the immediately preceding word. Unlike the search for a digit in short-term memory, the search for a word in long-term memory therefore appears to use a direct visual "copy" of the stimulus rather than requiring an initial mental coding process.

preceding word: The amount of slowing was less for related words (see diagram, above). If degradation in this situation had influenced only an initial mental coding process, then the amount by which the reaction was slowed would have been the same for related and unrelated words. Our findings therefore suggest that degrading a stimulus slows the rate at which long-term memory is searched. One simple explanation is that the search process starts as soon as a person has the visual image of the stimulus available, rather than requiring a higher-level code such as its spoken name, as in short-term memory.

Relevance of Reaction-Time Experiments

Like the results of other basic research, findings about short-term and long-term memory can potentially be used in many ways. Results from memory research may suggest ways to improve communication by increasing a person's rate of processing information, or by reducing errors. For example, the fact that information in short-term memory may be stored or retrieved in an acoustic form suggests that the jobs of telephone operators and craftspeople should be designed to minimize listening and talking when information is being held in short-term memory, since these activities interfere more with the memory than looking and writing do. For the same reason, the symbols in alphanumeric sequences should be selected to minimize similarities among their sounds.

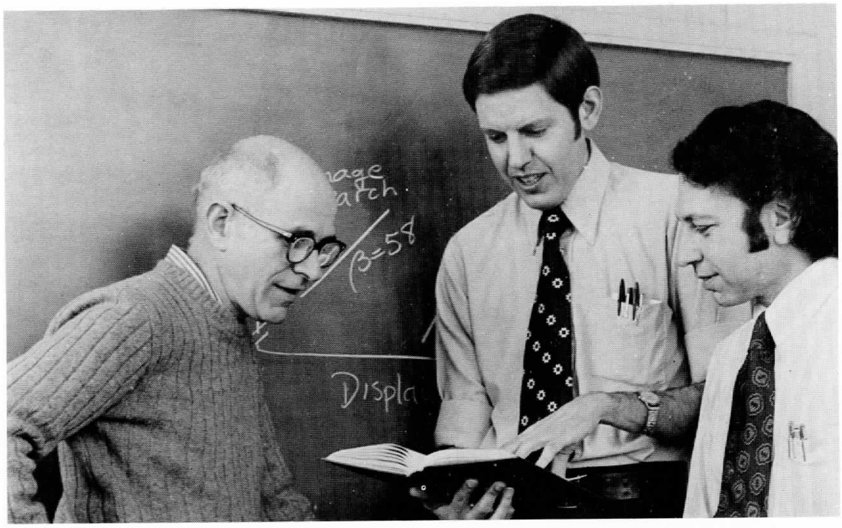
Another implication of our experiments is that sequences of numbers or letters in short-term memory can be processed faster and more accurately if the order of the symbols is unimportant. When this is not so, as with phone numbers, the seriousness of errors can still be reduced. For example, frequently called telephones can be assigned numbers that do not turn into other working numbers when adjacent digits are interchanged.

On the other hand, studies of long-term memory indicate that people see and hear verbal messages more quickly and accurately if words are ordered a certain way: Words with related meanings should be grouped as close to each other as possible, especially in the presence of visual or acoustic distortion.

Moreover, our recent discoveries about human memory have begun to influence research far removed from the topics originally investigated. Scientists outside Bell Labs are using some of the experimental procedures and theories described here to study child development and aging, the effects of acceleration in space and of hallucinogenic drugs, and the nature of aphasia, schizophrenia, and mental retardation. Reaction-time methods are being employed to attack a growing variety of other questions about mental processes, both fundamental and applied. During the past decade, the percentage of psychological studies involving reaction-time measurements has nearly tripled.

At times in the past it has seemed impossible for scientists to unravel the mysteries of the mind, since mental processes are complex and the brain's significant activities are difficult to observe directly. But despite these obstacles, a program of carefully conceived psychological experiments can add substantially to our knowledge of human memory— one of the most important components of any communications system. □

THE AUTHORS



M. V. Mathews *D. E. Meyer* *S. Sternberg*

Max V. Mathews (coauthor *Exploring the Speed of Mental Processes*) is director of the Acoustical and Behavioral Research center of Bell Labs at Murray Hill, N.J. After joining Bell Labs in 1955, he worked on speech coders and on developing digital techniques for computerized speech processing, the area in which he feels his work has had the most impact. He was also involved in studies of the perception of speech and of psychoacoustic problems related to hearing. This latter work led to his interest in experimental psychology and eventually to his present involvement in behavioral research.

A 1950 graduate of California Institute of Technology, Mr. Mathews received the M.S. degree and the Sc.D. degree from Massachusetts Institute of Technology in 1952 and 1954, respectively. He is a fellow of the Acoustical Society of America, and he is a member of the Audio Engineering Society, the Psychonomic Society, and IEEE.

David E. Meyer (coauthor *Exploring the Speed of Mental Processes*) joined Bell Labs in 1969 and began working on problems concerning information-retrieval from human short-term and long-term memory. As a member of the Human Information-Processing Research department at Murray Hill, N.J., he is currently investigating the mental operations by which people recognize and integrate words to understand messages.

Mr. Meyer completed the B.A. degree in psychology at Wittenberg University in 1964. He held Danforth Foundation, Woodrow Wilson, and National Science Foundation fellowships at the University of Michigan, where he received the M.A. degree in statistics in 1966 and the Ph.D. degree in mathematical psychology in 1969. His previous research has included work on human choice behavior and on psychological measurement.

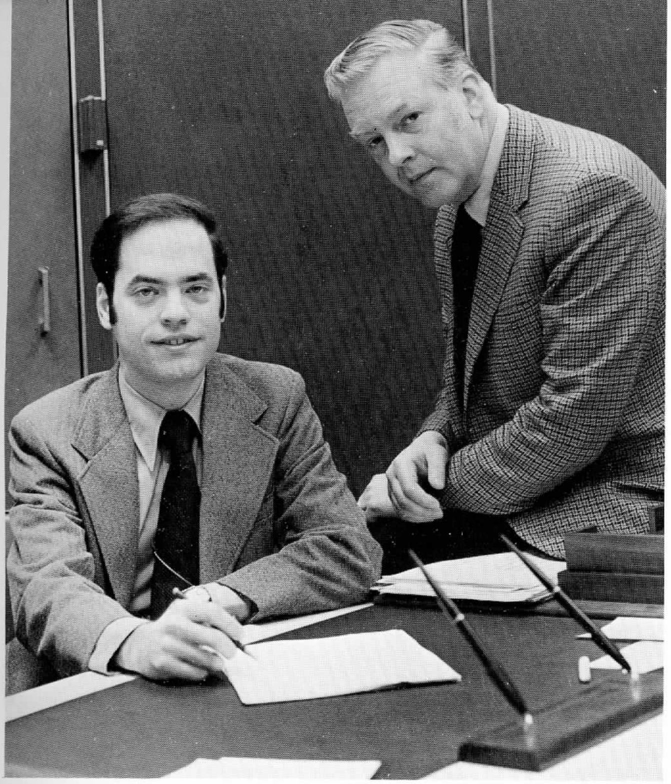
Mr. Meyer is a member of the American Psychological Association, the Psychonomic Society, and the American Association for the Advancement of Science.

Saul Sternberg (coauthor *Exploring the Speed of Mental Processes*) is head of the Human Information-Processing Research department of Bell Labs at Murray Hill, N.J. His department is responsible for investigating basic mechanisms of perception and memory that underlie our human capabilities in dealing with both visual and auditory information.

Mr. Sternberg joined Bell Labs in 1964 after teaching psychology at the University of Pennsylvania. His research has included studies of how people retrieve information from memory as well as studies of visual and auditory perception. In 1972-73, he held a Guggenheim Fellowship at University College London, for research on the temporal aspects of human information-processing.

After graduating from Swarthmore College in 1954 with the B.A. degree in mathematics, Mr. Sternberg studied at Harvard University, from which he received the M.A. and Ph.D. degrees in social psychology in 1958 and 1960, respectively. He also holds a Diploma in Mathematical Statistics awarded by the University of Cambridge in 1960.

He is on the executive committee of the International Foundation for the Study of Attention and Performance, a fellow of the Amer-



T. F. Arnold *W. B. Rohn*

H. A. Watson

ican Psychological Association, and a member of the Society of Experimental Psychologists, the Psychonomic Society, and the American Association for the Advancement of Science.

Thomas F. Arnold (coauthor *Minimizing Downtime for Electronic Switching Systems*) is head of the Remote Trunk Arrangement and Memory Development department at Bell Labs in Holmdel, N.J.

After joining Bell Laboratories in 1965, Mr. Arnold was associated for nine years with the development of the Traffic Service Position System (TSPS) No. 1. He was involved in the field testing of the first TSPS installation in Morristown, N.J., and supervised a group responsible for developing TSPS circuits and programs. Prior to assuming his present position in 1974 he headed the Stored Program Control and TSPS department.

Mr. Arnold received the S.B. and S.M. degrees in electrical engineering from the Massachusetts Institute of Technology and the D.Sc. degree in electrical engineering from Columbia University. He is a member of the honor societies Tau Beta Pi, Eta Kappa Nu, and Sigma Xi. He has been granted two patents on digital circuit design and has authored several technical articles on integrated circuits and on the design of systems with high reliability.

William B. Rohn (coauthor *Minimizing Downtime for Electronic Switching Systems*) is supervisor of the Central Office Equipment Estimating System (COEES) group at Bell Labs' Raritan River Center in N. J.

Mr. Rohn joined Bell Laboratories in 1954, initially performing operations analysis studies for the SAGE air defense system and missile projects. Later he worked on the development of a traffic simulator for the UNICOM military communications system and on the development and testing of the 4-wire No. 1 ESS for the U.S. Government. In 1965 he supervised a group involved in the initial development of the Traffic Service Position System (TSPS) No. 1. His group was responsible for several TSPS development projects, including maintenance programs for the central processor equipment, facilities for rapid system recovery from equipment failures, and an off-line computerized system for analyzing diagnostic data. He assumed his present position in 1974.

A graduate of the Polytechnic Institute of Brooklyn, Mr. Rohn received a B.S.E.E. in communications in 1951. He has authored several papers on the subject of system reliability.

Hugh A. Watson (*An Experimental Page Facsimile System*) came to Bell Laboratories in 1952 after receiving the Ph.D. degree in physics from the Massachusetts Institute of Technology. His responsibilities have included developing electron devices and digital transmission systems. Coauthor of three books on electron devices, he is now Head of the Mask Laboratory and Micrographics department of the Pattern Generation Technology laboratory, located at Murray Hill, New Jersey.

In addition to his doctoral degree in physics, Mr. Watson received the B.A.Sc. degree in engineering physics from the University of Toronto in 1948 and the M.Sc. in applied mathematics from McGill University in 1949. He is a member of IEEE and the Society for Information Display.

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