

#816

The Bottleneck of Attention: Connecting Thought with Motivation

Herbert A. Simon
Carnegie Mellon University

In W. D. Spaulding (Ed.),
Integrative views of motivation,
cognition, and emotion. Lincoln,
NE: University of Nebraska
Press, 1994.

Classical learning theory provides an interesting insight into the uneasy relation that has existed throughout the history of modern psychology between the study of thought and the study of motivation. Central to learning theory was the idea that if certain responses of the organism in the presence of a stimulus were positively reinforced (rewarded) while others were negatively reinforced (punished), the organism would learn to respond to the former rather than the latter. Motivation, in this view, was a key factor in learning.

Latent Learning

The dispute about latent learning, that is, "learning without motivation," forced a revision of classical learning theory (Hilgard & Bower, 1975, pp. 134-36). Tolman and others showed that a hungry

This research was supported by the National Science Foundation under grant no. DBS-912 1027 and by the Defense Advanced Research Projects Agency, Department of Defense, ARPA Order 3597, monitored by the Air Force Avionics Laboratory under contract F33615-81-K-1539. Reproduction in whole or in part is permitted for any purpose of the United States government. Approved for public release; distribution unlimited.

rat could learn the location of water, even though it was motivated to search for food, and a thirsty rat could learn the location of food, even though it was motivated to search for water. From these experiments one could argue that the key factor was not reward and punishment but knowledge of results—that is, feedback connecting behavior with its consequences. If the rat followed a certain path and found water, then it could remember that this path led to water even if the initial discovery was not motivated by thirst and the rat did not stop to drink the water. But knowledge of results is a cognitive rather than a motivational mechanism.

Of course, this interpretation was too simplistic. The rat, when hungry, did not *always* learn where the water was. It was more likely to learn when thirsty and least likely to learn when *very* hungry. Motivation reentered the picture, but with the help of an intermediate mechanism. The alternative explanation was that the rat learned (obtained knowledge of results) about anything it *attended to*. While searching for food, but in not too hungry a state, it might attend to other interesting characteristics of its environment, for example, the location of water. But when the rat was very hungry, its attention would not be distracted by anything but food; water would go unnoticed, and hence its location unlearned.

Attention as the Mediator

Learning, in this revised version, derives from the following sequence:

- | | |
|----------------|--|
| motivation | → search |
| (e.g., hunger) | → noticing (attention to item of interest) |
| | → knowledge of results (path to item) |
| | → storage (of path-item relation) |

Noticing, in turn, depends on the control of attention. A strong motive attracts attention to objects in the environment relevant to that motive. Under weaker motivation, attention could be distracted by other objects, that is, those relevant to motives not then active (and these motives could thereby be aroused). Hence, a theory of learning would have to encompass the laws of attention. Motivation reenters the theory in two ways. First, attention is itself a function of

motivation. Second, motivation might initiate an activity that would encounter information relevant to a different goal, sometimes causing that information to be learned or even diverting attention and search to the new goal.

Another, evolutionary, line of thought leads to the same conclusion (Simon, 1956, 1967). A system that is capable of working on only one task at a time but that must, over some period of time, satisfy many goals or needs requires a mechanism that will allocate its activity among its several goals. If some of its needs have to be satisfied in "real time"—that is, now or never—the attention-directing mechanism must have the means for interrupting ongoing activity to give priority to the urgent needs.

Further, if the system's activities in the service of particular goals bring it in contact with information useful for the attainment of other, currently latent goals, it would be advantageous to store that information. But the key phrase here is "useful for the attainment of other goals." The system would need a mechanism for discriminating, at least roughly, between potentially useful information and uninteresting information.

We should not be surprised, therefore, if natural selection (in an organism that had to satisfy some needs in serial, one-at-a-time fashion) developed motivational mechanisms for signaling current urgencies among its many needs, noticing mechanisms for detecting and learning information of future interest to goals not currently active, and an interrupt mechanism to set aside currently active goals for more urgent or advantageous ones. Precisely such mechanisms appear to have emerged in the evolution of animals, including human beings.

Seriality and Parallelism

Before we return to the mechanism of attention as the linchpin between motive and emotion on the one hand and cognition on the other, let us pursue a little further the respective roles of seriality and parallelism in human processes and behavior. While the empirical evidence, both neurological and behavioral, on these roles is still highly incomplete, perhaps some light can be cast on them from the evolutionary viewpoint above.

SERIALITY AND PARALLELISM OF "HIGHER" FUNCTIONS

From the mid-1950s until the early 1980s, the formal psychological models that accompanied the "cognitive revolution" mainly described human thinking as a collection of processes executed in a serial, one-at-a-time fashion. Of course, it was understood that the principal sensory organs were parallel in structure and function and that there was a substantial degree of parallelism in motor action. However, the models of the more central parts of the nervous system were perceived as predominately serial.

This commitment to seriality rested on the clear and massive evidence that, at the level of "higher" nonautomatic functions (e.g., solving problems, generating meaningful linguistic strings, attaining concepts), a human being can only do one or at most a few things at a time. What little parallelism is evident in such behavior (e.g., pacing up and down while lecturing) can sometimes be explained away as time-sharing—that is, alternating attention between activities. Time-sharing would be expected when one or both of the shared activities require only a little attention. In the limit, one of the activities might be automatized through extensive practice and thus places no burden on cognitive capacity. But only activities requiring no processing of sensory stimuli can be fully automatized.

The severe limits on concurrent activity have been amply demonstrated in the psychological laboratory, but they are also evident in everyday experiences. One can carry on a conversation while driving a car, but the intensity and quality of the conversation deteriorates as traffic becomes heavier and the driving demands more attention. Once, in the dead of winter in Iowa, I maneuvered a car in which I was the passenger into a large snowbank by giving the driver (who was defending the case for cognitive parallelism) a mental imagery task to perform while driving. (I kept close watch over his foot on the accelerator to make sure the car was moving very slowly, but we should not be unwilling to make sacrifices for the progress of our science.)

PARALLELISM AND AUTOMATISM

Of course, if our observations begin on the neural end of the scale, we are just as strongly impressed by the evidence of parallelism—not only in the retina and the inner ear but also in the immense neuronal structures of the central nervous system. What are all these neurons doing if there is not a great deal of parallel activity going on?

Even here we must be careful in drawing conclusions. A classical von Neumann computer, the quintessence of seriality, has large banks of memory units, all in parallel. Since these units are “passive,” that is, used only to record and retain information, we do not think of them as operating in parallel; we call the von Neumann machine a serial computer since all of its processes other than memory storage and retrieval are highly localized in a few units. It is quite possible that much of the apparent parallelism of the human brain also consists of passive memory units, with only a few units active in the processing sense at any moment. The decisive neurological evidence on this point is simply not yet available.

But the accumulated evidence of high degrees of automatism for many tasks acquired through extensive practice cannot be ignored (Shiffrin & Schneider, 1977). To the extent that such automatism is achieved, the organism’s capacity for parallelism is increased.

A plausible explanation for the parallelism associated with the automatization of processes is that the sequence of “instructions” controlling such processes is gradually *compiled*. That is, instead of depending on sensory signals to initiate each new step in the process, the system gradually learns that the next step can safely be taken on completion of the previous one without new tests of appropriateness. Removal of these frequent tests both speeds up execution of the process and releases it from using scarce short-term memory capacity at intermediate points (Hayes & Simon, 1974).

For a skilled driver, operating an automobile is an example of a process that has become partly but not wholly automated (the driver must still occasionally obtain new sensory information about the current situation and cannot drive successfully with eyes closed or while processing other mental images). But as a result of the compilation of the process, the skilled driver makes far smaller demands on the senses and on short term memory than does the novice.

PARALLELISM IN SENSATION AND PERCEPTION

The existing evidence is *consistent* with the position that somewhere between the sense organs and the central system and between the central system and peripheral motor neurons are zones within which incoming signals are converted from parallel to serial encodings, and outgoing signals from serial to parallel. We have only the vaguest indications of exactly where these zones lie, and there is a broad no-man's-land in which it is not unreasonable to model the system as either parallel or serial.

In encoding from parallel sensory stimuli to serial symbols, a considerable compression of information occurs. The organism attends to only a small part of the information received by the sensors. The nature of this "filtering," for auditory stimuli, has been studied since World War II in a long series of experiments on dichotic listening by Cherry, Broadbent, Moray, Treisman, and many others (see Treisman, 1969).

In early experiments, it appeared that, when a message in one ear was being attended to, the message in the other ear was almost completely neglected, and little or no information about it was retained. Then more and more exceptions were found to this rule, such as the "cocktail party" phenomenon: when the name of the listener was spoken in the unattended ear, it was noticed rather than filtered out. Attention could switch "automatically" from one ear to the other if a meaningful continuous message was broken off in one ear and simultaneously taken up in the other. Even more troublesome to the theory of filtering, a word sounded in the unattended ear, synonymous with one meaning of an ambiguous word presented simultaneously to the other ear, could resolve the ambiguity in favor of the "unattended" synonym.

These experiments showed that, although attention was presumably focused at a given moment on the message in one ear, the message delivered to the other ear was also being processed, at least sufficiently to detect "interesting" content, which could then sometimes either divert attention from the previously attended ear or influence the processing of the message in the attended ear. The filtering of the unattended message was much less than complete. Later, I will consider mechanisms of attention that are compatible with this evidence of parallelism.

WHY SERIALITY?

But let me return to the issue of why there should be seriality at all. Isn't this highly inconvenient for the organism, and wouldn't the forces of natural selection gradually have replaced seriality with parallelism? To answer these questions, we must examine more closely the nature of the needs of the human organism, for example for air and for food.

Air is nearly ubiquitous in the human environment, and we breathe in parallel with our other activities. When breathing is interfered with in any way, however, the need for air becomes urgent, and the autonomic nervous system sends messages that take high priority in interrupting attention from other goals to satisfying this need. The urgency is related to our small capacity, in time units, for storing air for subsequent use. This small capacity in turn reflects the usual ready availability of air and the high cost of storing an item that is used in large volumes. The respiration mechanisms, including those that implement the "drive to breathe," seem well adapted, from an evolutionary standpoint, to the economies of the situation.

Food, particularly for hunting-and-gathering creatures, is not at all ubiquitous but is only obtained by arduous search and harvest processes. Inventory capacity must be amply provided to span the intervals between successful harvests. The body must signal when the inventory shows signs of depletion, but the arousal can be more gradual than in the case of air, and, even when aroused, hunger need not interrupt ongoing activity as imperiously as does the need to breathe. Again, evolution seems to have shaped the system in such a way as to relate inventory capacity in an efficient way to the costs of replenishment and to adapt the attention-interrupting system to the urgency of competing demands.

There are, of course, a whole host of requirements for survival and procreation beyond these two. Most of them, like hunger, are handled by systems of inventories and periodic replenishment, with corresponding drives to compete for the system's attention. This scenario still does not explain why the organism does not attend to many of these needs simultaneously, but the answer should now be evident. Because of the dispersion of need-satisfying situations in the environment, most needs can be satisfied only after extensive activity involving collaboration of sense and motor organs in

pursuit of a specific goal. It is seldom either convenient or effective to make love, for example, while hunting for prey.

An effective division of labor is not achieved by segmenting the organism into components that each work toward satisfying one of these goals. It is much more efficient to divide labor by time segments—the resources of the entire organism being devoted, in turn, to satisfying successive goals, the priorities being established by the signaling and attention control mechanisms. Much more extensive parallelism and division of labor by functions reappear at the social level, at which independent, physically self-contained members of a society can be allocated temporarily, or even permanently, specialized tasks.

When we look at the organism's internal metabolic mechanisms parallelism reappears again on a large scale, and insofar as internal processes depend on neural control, they call for a corresponding measure of neurological parallelism. The regulation of the action of the heart and of breathing is the most obvious example of this internal activity that goes on in parallel with the regulation of external activities.

From all of these easily observed phenomena and the inferences we can draw from the requirements of evolutionary fitness, we conclude that there is no simple answer to the question: Is the nervous system serial or is it parallel? It is both—not haphazardly but in an organization that is responsive to the demands of survival and efficiency. The serial constriction imposed by the limits of short-term memory is itself a response to the structure of the environment and of the organs that sense and act on it. The parallel functioning that is observable in the sensory organs and in the control of internal processes is a response to the need to process information in real time, when it is presented and available, and to control processes that must operate continuously.

Unified Theories of Behavior

Currently the cognitive community is strongly interested in constructing unified theories of cognition, theories that aspire to describe and explain the whole cognitive person. For example, at Carnegie Mellon University alone there are at least four candidates for

such a unified architecture. The Act* architecture of John Anderson is designed around the structure of semantic memory and the spreading-activation processes that operate in it. The Soar architecture, developed under the leadership of Allen Newell, places problem spaces, production systems, and learning through chunking in central positions. The connectionist architecture of parallel distributed processing is championed by Jay McClelland. And the slightly more ramshackle architecture that I espouse includes among its principal components EPAM (elementary perceiver and memorizer), GPS (general problem solver), and UNDERSTAND (a program for constructing problem spaces from problem descriptions in natural language).

These architects are all aware that behavior must be motivated and, consequently, that a unified theory of cognition must include a theory of motivation. Newell, in his magisterial *Unified Theories of Cognition* (1990), is explicit on this point. In describing the ultimate scope of a unified theory (pp. 15–16), he places motivation and emotion fifth among the six areas to be covered (the ellipses at the end of his list remind us that there are others). But he then observes that this area is not yet part of any extant unified theory. Unification must proceed by stages, and in its first stages of development a unified theory must attend to problem solving, decision making, routine action, memory, learning, skill, perception, motor behavior, languages—a formidable list of topics before we arrive at motivation and emotion.

However, there is perhaps more motivation in these theories than immediately meets the eye, and we become aware of its role when we switch our own attention from the term “motivation” to the terms “attention” and “goals.”

Goals and Motivation

In the description of experiments conducted in cognitive psychology laboratories, the motivation of subjects is usually mentioned only casually and in terms that already assume a theory of human motivation. We are told that the subjects were satisfying a course requirement in Psychology 100 or that they were paid \$5.00 per hour. The assumption is that these conditions are sufficiently motivating

that the subjects will address themselves to whatever cognitive task is presented. We are supposed to know enough about college sophomores to understand that these rewards are enough to gain their attention for some length of time—an hour, perhaps.

If we were trying, say, to secure the attention of a professional chess grandmaster or a practicing architect for half a day, we might have to say more about motivation in describing our experiments. The question also arises, especially in experiments concerned with decision making under risk and uncertainty, whether modest rewards of a few dollars produce behavior that is predictive of how people behave when the stakes are larger—a million dollars, say, or potential loss of an arm or leg. And appropriate motivation cannot be presumed for tasks that are aversive for subjects: very boring tasks protracted for hours, for example.

But in more common types of experiments, when measuring problem-solving skills or the use of language or visual imagery, we usually take motivation for granted, and not without reason. We have extensive experience with the fact that, within broad limits, people are very obliging about doing what researchers ask of them. Organizations could not otherwise exist: in them we pay people to accept authority, and as long as orders remain within their "areas of acceptance," they generally obey. Of course, they may obey with greater or less enthusiasm, and their performance may vary in quality and quantity accordingly.

Laboratory subjects likewise obey authority within an area of acceptance. In the cognitive psychology laboratory, we typically ask our subjects to perform some tasks as well as they can. Provided they direct their attention to the tasks and are not distracted, added increments of effort would not greatly alter their performance. The subjects are trying about as hard as they can to apply their knowledge and skills to solve the problems posed. (We should be less confident of this, the less well structured the tasks are.) In addition to the extrinsic rewards they will receive, their self-esteem is also enlisted. Within broad limits, trying harder would not alter their performance much.

But if we can assume in most circumstances that our subjects will be motivated to do what we ask of them, we must still be clear and precise in informing them exactly what the goal of the experi-

mental task is. Explicit goals attach free-floating motives (the willingness to do what we ask) to specific tasks. They secure the subject's attention to the relevant things in the task situation.

Suppose that we present a column of numbers to a subject. If the instructions call for the sum of the column, then the subject will likely hold the running total in short-term memory and scan down the list, adding each successive number to this running total until reaching the bottom of the list. If, on the other hand, the instructions call for reporting the largest number in the list, the subject will likely hold in short-term memory the largest number noticed so far and, progressing down the list, will compare it with each new number, replacing it whenever the new number is larger. By specifying different goals, the same motive (doing what the experimenter asks) is enlisted for performing different tasks. In this example, both tasks attract attention to the same objects but extract different information from them.

In Stroop-like tasks, the conflict of attention is made explicit. One can attend to the shape of a color word or the color in which it is printed. The goal (of reporting the word or its color) attaches the motive to perform correctly one or the other of these tasks, although they are not of equal facility. It is easy to invent tasks in which different instructions cause the subject's eyes to attend to different locations in the stimulus. A chess player who is asked to describe the position around the black king will look at a different part of the board from someone asked to describe the position around the white king.

If unified theories of cognition are silent about motivations, they are quite explicit about mechanisms for controlling attention. Newell (1990, p. 257) provides an example in his discussion of how perception operates:

The attention operator is the required active process. It can be executed, as can any other operator, by central cognition. It is given a search specification [i.e., a goal], and it finds an element satisfying this specification from anywhere in [the percept]. The result of the attention operator (if successful) is that it switches cognition to be at the place of the attended element.

ATTENTION CONTROL IN PRODUCTION SYSTEMS

In Soar, in my own eclectic architecture, and in architectures based on production systems in general, goals are the essential directors of attention. The basic component in production systems (sometimes inaccurately called "rule-based systems") is the structure known as a production, which has a striking resemblance, at least superficially, to the $S \rightarrow R$ connections of our behaviorist past. If we replace S and R by C (for "conditions") and A (for "actions"), respectively, then we have the production $C \rightarrow A$, to be read, "Whenever the conditions, C , are satisfied, the actions, A , are carried out."

A production system is simply an unordered list of productions. If the conditions of more than one production are satisfied at the same time, then either some rules of priority must determine which will be executed or the system must be capable of executing them in parallel. In their pure form, production systems provide the possibility of anarchy, for every production in the entire system is potentially active at every moment: it is simply waiting, independent of the rest of the system, for the announcement that its conditions are satisfied. Indeed, production systems were first applied to cognitive simulation in reaction to the overly structured control imposed by hierarchies of routines and their subroutines. In the hierarchical schemes, a process can execute only if it is "called" by a superordinate process, and it retains control of attention until it terminates and returns control to the superordinate process. Production systems and hierarchical languages represent wholly different theories of attention, its persistence, and its shifting.

The pure production system proved to be too much of a libertarian good thing and was soon modified, in particular by the introduction of goals. Recall the example above of two arithmetic tasks performed on a column of numbers. Suppose we had two productions: If there is a column of numbers \rightarrow find its sum; and: If there is a column of numbers \rightarrow find the largest. If this system were presented with a column of numbers, even without specific instruction it would report both the sum of the column and the largest number. To limit the system's actions to the relevant goal, we create a symbol, S , for "sum" and place it in short-term memory if the task is to add the column. We create a different symbol, L , for "largest" and place it in short-term memory if the task is to find the largest number in the col-

umn. We amend the first production by adding the presence of *S* in short-term memory as another condition for its execution: "If there is a column of numbers, and if *S* is in short-term memory → . . ." Similarly, we amend the second production by adding the presence of *L* in short-term memory as another condition for its execution. Now, giving the system the appropriate goal, by placing *S* or *L* in short-term memory, will cause it to perform the desired task.

Having introduced goals, we can also easily provide for subgoals. If we have a goal, G_1 , as one of the conditions of a production, and if its achievement requires the achievement of subgoals G_2 , G_3 , and so on, then we simply include among the actions of G_1 the placing of G_2 , G_3 , and so on in short-term memory. This will arm productions, otherwise inactive, that are relevant for attaining these subgoals.

In this way, motivation to achieve goals is propagated through the cognitive system to direct attention to relevant information and actions. In simple situations, presence of a goal permits recognition of conditions that invoke, through one or more productions, an immediate response that achieves the goal. This kind of response, often called "intuitive," is common in familiar matters, whether they be everyday affairs or the routine matters that constitute so much of professional activity. Intuitive responses are acts of recognition that are conditioned by goals that bring them within the focus of attention.

When goals cannot be satisfied through immediate and unreflective recognition, then more elaborate problem-solving schemes come into play. These schemes make considerable use of means-ends analysis: that is to say, the initial goal defines a situation not yet attained, and differences between the goal situation and the present situation evoke actions that may reduce or remove the difference, creating a new situation closer to the goal. At each step in this recursive process, removal of the perceived difference constitutes a new goal to connect the action with the original motive and final goal.

The typical "rule-based" expert systems that seek to emulate professional performance are largely based on a combination of these two procedures: problem solution by recognition and by heuristic search through means-ends analysis. For example, a chess-playing program designed to emulate human chess play would have stored in memory a large number of patterns (perhaps 50,000)

that commonly appear on chess boards during games and that signal important features of the positions in which they occur. Skill in chess requires the recognition of these patterns when they occur, which in turn gives access in memory to information about their significance and the actions they call for. Every serious chess player will recognize the feature called an "open file" when it appears on the board and will be reminded to consider placing a rook on that file.

Chess players can play reasonably well using only their recognition capabilities, based on the patterns stored in memory (e.g., in speed chess, in which the time for each move is limited to a few seconds). But in more deliberate play, they also look ahead to possible sequences of moves, their own and their opponents', using means-ends analysis to guide the search. In this way they become aware of future contingencies that recognition of static features of the present position may not reveal.

Goal symbols in short-term memory create contexts within which certain actions are relevant and others irrelevant. In the absence of a particular goal symbol, productions that include that symbol among their conditions will simply not execute. Thus, despite the infrequency of mention of motivation, information-processing models of cognition are thoroughly impregnated with goals. They have motives as well as reasons for what they do.

I do not want to imply that goal symbols and recognizable stored features solve all of the problems of attention control in cognition. I have described their use in some detail to give a concrete picture of how attention control mechanisms might actually operate to connect thinking with motivation.

ATTENTION CONTROL WITH SPREADING ACTIVATION

In Act* and connectionist systems, attention control, and hence the link with motivation, is handled somewhat differently, that is, with the help of spreading activation or some nearly equivalent mechanisms. (In some versions, Act*, which is actually a whole family of related systems, uses goal symbols as well as spreading activation, but I consider here only the latter.)

In any system composed of nodes connected by links (and this

describes almost all symbolic architectures), it is possible to attach numbers that represent levels of activation to the nodes and numbers that represent the strengths of connections to the links between them. Suppose now that an increase in the activation of one node increases the activation of the other nodes to which it is connected by strong links—the strength of the effect depending on the strength of the link. (We may also postulate *negative*, inhibitory, links that transmit a *decrease* in activation of the destination node when the activation of the source node is increased.)

If we now postulate that only when activation is above some threshold level will a node be “noticeable,” we again restrict the activity of the system to interaction among nodes that lie in this focus of attention. We can think of the set of nodes that are above the threshold as constituting the system’s short-term memory and the conditions of productions as referring only to symbols in short-term memory. Arousal of a node is roughly equivalent to linking it with the current goal.

Without searching out the details, we can see that activation can play the same general role in controlling actions in node-link systems as goal symbols in systems that do not employ activation levels. In both cases, mechanisms link more or less general or specific motivation to particular tasks and thereby direct the system’s attention to the performance of these tasks rather than others.

We can also see how activation can account for some of the phenomena revealed by the dichotic listening experiments. If attention to the message in one ear largely inhibits the activation of other information, then the latter information will remain unnoticed. However, if some of the information in the unattended ear also has an additional independent source of activation, it may pass through the filter and gain attention. Consider here two phenomena mentioned previously: switching from one ear to another to preserve continuity of meaning and noticing the mention of one’s name in the unattended ear.

Attention to a particular semantic context, evoked by a continuous message dealing with that context, activates nodes in long-term memory that belong to that context. (If the text deals with “Italian operas,” activation arises in those parts of memory relevant to Italian operas, operas, or even music and Italy.) When the continuity of the message is suddenly interrupted in one ear but the same con-

text is taken up by the other ear, the activation of the message in the latter ear may now be higher than in the former, with a consequent switch in attention. The role of a synonym in the unattended ear in influencing the interpretation of a word in the attended ear may be explained in a similar way.

To explain attention to one's name, we make a new assumption and also refer for the first time to emotion, which we have neglected up to this point. We assume that emotion, in various degrees, is associated with some nodes in long-term memory. Emotion raises the activation level of these nodes, making it easier to carry them above threshold and to divert attention to them. We will return to the topic of emotion and its relation to attention after some further consideration of the nature of the contexts that influence responses to stimuli.

Contexts and Situated Action

The notion of context has been recently brought into prominence in the literature of cognition by those who argue that real-world actions are *situated* and can only be understood in relation to the context in which they are embedded. The premise that actions are situated is sometimes taken to imply that thinking is therefore not symbolic, or not planned, or not represented inside the brain—there are many flavors of situated action and no single accepted party line. But I will not take up these issues here, since Alonso Vera and I (Vera & Simon, 1993) discuss them at length elsewhere. Instead, I consider here how cognitive systems can deal, as they must, with the context of action.

The general shape of my answer should be clear from the previous discussion of goals and their relation to motives. The cognitive system stores extensive knowledge about the world in its long-term memory and can gain additional knowledge through its sensory and perceptual processes. The voluminous knowledge in long-term memory relates literally to everything under the sun, most of which is unlikely to be relevant at any given moment. Moreover, because of the limits on the system's ability to operate in parallel, it can only make use of a small amount of information during any short interval of operation.

The problem of context is therefore twofold: both to gain access

to the information that is relevant in the current context and to shield off the vast body of potentially available information that is irrelevant. In the earlier discussion of attention as the mediator, I argued that it is the structure of the real world in relation to the needs of the organism that makes it possible to meet both of these requirements. Fortunately, internal drives and external situations calling for action do not all press on the organism simultaneously. Except for those drives that are physiologically "wired" for parallel action, goals can usually be dealt with one at a time, and only knowledge and information relevant to the current goal—a tiny part of the total—need be evoked in order to deal with it. When a pressing real-time need presents itself while the system is engaged in another task, the interrupt mechanisms mentioned previously bring about the required shift of goals.

The mechanisms relating to attention that are important for creating the context of thought and action do not, of course, operate perfectly. Frequently, we are distracted by irrelevancies. Even more frequently, we fail to retrieve or perceive information that would be useful in dealing with the current situation—the well-known problem of transfer of training (or rather, failure to transfer). Thus, contexts may be defined by the cognitive system too broadly, too narrowly, or simply incorrectly. We can well apply to this system Dr. Johnson's comment on the dancing dog: "The marvel is not that it dances well—it doesn't—but that it dances at all."

Emotions

Apart from one previous mention of them, I have left emotions to the end of my discussion. My postponement reflects my feeling that I and perhaps my fellow psychologists understand emotions less well than we understand motivations or attention. In many ways, emotion seems an even less homogeneous category than motive. Motives can be connected with the goals they evoke, but they may or may not involve strong emotions.

Person A is motivated to kill B (he has been offered \$10,000 for the deed) but will do it in cold blood, that is, with little or no emotion. Subject C is motivated to kill D because C is enraged with him.

In the latter case, but not the former, motive and emotion go cheek by jowl; in fact, the emotion seems to be the source of motivation.

To simplify matters, let us focus on just four of the common emotions and/or motives: hunger, fear, hate, and pleasure. Hunger is not always classified as an emotion, but it can be associated with intense feelings, and since emotions are usually defined in terms of the feelings they evoke, it is hard to see what criterion would rule hunger out.

Fear may be evoked not only by external events (e.g., a sudden noise) but also by a verbal stimulus (e.g., the word "cancer"). It is usually accompanied by arousal of the autonomic nervous system, and this arousal is often explained in evolutionary terms as preparing the organism for a response (e.g., flight). Hunger is usually evoked by internal stimuli, but it may also be aroused by the sight of a favorite food. As we have seen, it tends to turn the attention of the organism to seeking food.

Hate, like fear, may be aroused by the appearance of hated objects, but it may also be evoked by verbal stimuli that have become associated with that emotion. Pleasure is similar to hate and fear but seems somehow more general and diffuse than they. In some philosophies, pleasure and pain are taken as the ultimate sources of the motivational chain, from which all goals or motives are derived. Pleasure sets the task of maintaining the emotional status quo; pain the task of terminating it. Fortunately, our investigation here does not require us to decide whether this view is correct or not.

What kind of mechanisms can we propose to account for such diverse emotions (to say nothing of all the others we are ignoring) and for their effects on behavior? Since the phenomena themselves appear to be rather complex, there is no reason to suppose that the mechanisms are simple or that they may not be somewhat hybrid in structure.

First, we observe that there does appear to be some connection between the emotions and attention. The negative emotions tend to direct our attention to activities that might terminate them; the positive emotions to activities that might cause them to persist. Second, we observe that emotions may be associated with topics already stored in memory, so that mention of the topic arouses the corresponding emotion.

These considerations suggest the following metaphor (which is

already part of the folk culture). Memory is not a uniform, grey network; parts of it are "colored" in varying intensities. When attention is directed to such a colored region of memory, evoking that memory activates the corresponding color—that is, the corresponding emotion. The emotion, in turn, has attention-directing and attention-interrupting capabilities, thereby modifying the organism's current motivation and actions. In the words of Robert Abelson, cognition may be color or it may be hot.

This account leaves the boundary between motivation and emotion in a rather fuzzy state, but it does provide a fairly unified account, in terms of arousal mechanisms and the focus of attention, of the nature of emotions and their operation. Items in memory with which emotion is associated are, *ceteris paribus*, more easily aroused than other items and hence more capable of directing attention or causing interruption of attention. They operate much like motives but are associated with perhaps less specific goals than motives usually are.

Conclusion

My goal in this chapter has been to look once more at the linkage between cognition on the one hand and motivation and emotion on the other. Professional specialization in the discipline of psychology has assigned responsibility for these two subsystems to two different groups of psychologists. As a consequence, the vital connection between them has sometimes been neglected.

I have argued here that the connection between motives (or emotions) and thoughts is in fact both strong and explicable. People have both motives and reasons for what they do. The motives define their goals, and the reasons connect those goals with particular courses of action for realizing them. Thinking begins with goals and cannot move without them. Emotions, when aroused from memory, interrupt action and redirect it to alternative motives that have become more pressing than the current one.

The general theory that postulates attention as the principal link between cognition and motivation is not new. Among physiological psychologists it goes back at least to the recognition of the functions of the reticular layers of the brain. If there is anything new on the

present scene it is to be found in the concrete proposals for symbol-processing mechanisms that can account for the linkage and the phenomena it produces.

I have tried to provide a rough sketch of the main mechanisms that have been proposed for regulating the focus of attention and thereby enabling mental activity to be organized, appropriately situated, and motivated. Among them are attention-interrupting mechanisms, goal symbols, spreading activation, recognition mechanisms, and processes to guide heuristic search.

1. Attention-directing mechanisms act explicitly to distract attention from its current focus and direct it to some urgent task. The new direction may be influenced from the sensory source of the interrupter or from the nature of the motives or other contexts that have been activated in long-term memory.

2. If certain sets of productions are capable of firing only when appropriate goals are in activated memory, then goal symbols, by their presence or absence, limit the range of topics to which attention can be directed.

3. Spreading activation, by defining at each moment which part of memory is activated, defines a context that can influence the control of attention and the interpretation of the things attended to.

4. Recognition mechanisms activate particular contexts in memory as a function of the stimuli that are recognized. Most often, recognition directs attention to contexts that are already active and hence is a mechanism for continuity of behavior. But attention may sometimes be directed to the unexpected instead of the expected, with resultant surprise and the redirection of attention.

We are close to the time, if it has not already arrived, when we can aspire to construct models that will encompass these linking mechanisms and thereby elucidate a wide range of phenomena regarding attention, the elusive boundary between the parallel and serial components of mental processing, and the role of motivation and emotion in regulating behavior. Unified theories will rapidly give up their exclusive (if only apparent) preoccupation with cognitive processes and embrace also these other crucial aspects of the whole person.

REFERENCES

- Hayes, J. R., & Simon, H. A. (1974). Understanding written problem instructions. In Lee W. Gregg (Ed.), *Knowledge and cognition* (pp. 167-200). Potomac, MD: Erlbaum.
- Hilgard, E. R., & Bowers, G. H. (1975). *Theories of learning* (4th ed.). Englewood Cliffs, NJ: Prentice Hall.
- Newell, A. (1990). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.
- Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review*, 84, 127-190.
- Simon, H. A. (1956). Rational choice and the structure of the environment. *Psychological Review*, 63, 129-138.
- Simon, H. A. (1967). Motivational and emotional controls of cognition. *Psychological Review*, 74, 29-39.
- Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review*, 76, 282-299.
- Vera, A. H., & Simon, H. A. (1993). *Cognitive Science*, 17, 7-48.