DOCUMENT RESUME

ED 215 308 CS 006 602

AUTHOR	Iran-Nejad, Asghar; Ortony, Andrew
TITLE	Cognition: A Functional View.
INSTITUTION	Bolt, Beranek and Newman, Inc., Cambridge, Mass.; Illinois Univ., Urbana. Center for the Study of Reading.
SPONS AGENCY	National Academy of Education, Washington, D.C.; National Inst. of Education (ED), Washington, DC.
REPORT NO	CSR-TR-231
PUB DATE	Feb 82
CONTRACT	400-76-0116
NOTE	83p.
EDRS PRICE	MF01/PC04 Plus Postage.
DESCRIPTORS	*Biological Influences; *Cognitive Processes; *Comprehension; Epistemology; Memory; Models; *Neurolinguistics; *Psycholinguistics; Reading Research; Theories
IDENTIFIERS	*Schemata

ABSTRACT

Proposing a shift in the locus of theoretical analysis of cognition, this paper argues that cognitive functioning may be more readily characterized without the mediation of long-term mental associations and structure. An account of cognition is proposed in which mental relations are transient functional relations, and in which psychological permanence is a functional characteristic of the neuronal system, making cognition a "psychobiological" phenomenon. The literature relevant to this psychobiological character of cognition is discussed, and the central concept in this approach to cognition--the schema-of-the-moment--is examined, emphasizing a functional organization created by the activity of anatomically distributed constellations of neuronal elements. Comprehension, remembering, learning, awareness, and affect also are discussed briefly in terms of this active neuronal schema-of-the-moment and the direct role of the nervous system in cognitive functioning. (Author/RL)

CENTER FOR THE STUDY OF READING

Technical Report No. 231

COGNITION: A FUNCTIONAL VIEW

Asghar Iran-Nejad and Andrew Ortony

University of Illinois at Urbana-Champaign

February 1982

University of Illinois
at Urbana-Champaign
51 Gerty Drive
Champaign, Illinois 61820

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

The research reported herein was supported in part by the National Institute of Education under Contract No. HEW-NIE-C-400-76-0116, and in part by a Spencer Fellowship awarded to the second author by the National Academy of Education.

Cognition: A Functional View

When psychological theories employ theoretical terms like _memory_, _representation_, and _structure_, they often do so because the descriptions and explanations of psychologically interesting phenomena that result are at a sufficiently abstract level to be informative and intelligible. As a first step in theory construction the use of theoretical terms at a level close to the phenomenological level of description is a very helpful, and probably indispensable strategy. However, there are good reasons to suppose that one should strive to eventually account for the phenomena of interest in terms of more concrete constructs.

One reason for attempting to employ concrete constructs in psychological explanations is that it helps to clarify the distinction between artificial intelligence (AI) and cognitive psychology as being more than simply methodological variants on one another. AI is concerned with characterizing cognition and intelligence _in abstracto_; its goal is a "machine-independent" specification of the cognitive software. Theories in cognitive psychology have to be more constrained. They need to take into account not only the constraints imposed by people's behavior, but also the sort of constraints likely to be imposed by the biological hardware, since it is these that give cognition its uniquely human quality. In fact, Eliashberg (1981), by examining the properties of hypothetical machines, has shown that ". . . the popular thesis that the problem of the algorithms performed by the brain . . . has but little to do with the problem of brain hardware" is inadequate.

Furthermore, support for this contention can be found in other domains. A striking example is provided by the recent advances (e.g. Berlin & Kay, 1969; Kay & McDaniel, 1978) in understanding the relationship between the perception of color and the meaning of color terms in different languages. It now seems that "all the basic color categories of the languages of the world are based on . . . six fundamental neural response categories, whose structures are determined by the firing patterns of . . . cells in the visual pathway" (Kay, 1981, p. 64). Thus, only after taking account of the physiology of color perception did it become possible to give a coherent explanation of the principles governing the way in which people in different cultures speaking different languages talk about the world of color.

Another more important reason for attempting to explain cognition in terms of relatively concrete constructs has to do with the ontological status of the theoretical terms employed. Terms like memory and knowledge-representation are highly complex abstractions, and it is not at all clear to what they refer. In AI this is not a problem because the functional characteristics of the hardware in which these abstract conceptions are instantiated are sufficiently well understood. However, when we turn our attention to people the indeterminate reference of theoretical terms can give rise to ambiguity, vagueness, and misleading implications. This point can be illustrated by considering the long-term memory metaphor: We talk about mental representations being stored in memory. These representations are searched for and retrieved. It is easy to see how, if taken literally, such ideas can lead to the conclusion that people's heads are populated with a huge number of pre-packaged permanent structures corresponding to everything we know. This, in turn, leads to questions about the organization of memory: what kind of search mechanisms operate on what kind of global structure to permit efficient access to encoded representations? Psychologists have from time to time objected to the heavy theoretical burden imposed upon such terms (e.g. Bartlett, 1932; Bransford, McCarrell, Franks & Nitsch, 1977; Jenkins, 1977; Palmer, 1978; Pylyshyn, 1973). Given the merits of the arguments, these objections have had disproportionately little influence, perhaps because of the absence of an alternative set of more concrete concepts in terms of which a coherent view of human cognition might be achieved.

It is our contention that more attention needs to be devoted to the functional characteristics of the physical systems that exhibit the phenomena of interest. In fact, we believe that ideally the goal of cognitive psychology ought to be the specification of those functional properties of the nervous system that make cognition possible. Such a functional account might show how mental properties are emergent properties of biological functioning. It would eschew the wholesale use of complex constructs of unclear referential status until they have themselves been characterized in terms more closely tied to the biological hardware.

Whereas it is easy to assume that the patterning aspects of cognition are based on long-term knowledge structures (schemata, frames, scripts, etc.) "stored" in memory--an approach that we shall henceforth refer to as the "structural" approach--the alternative approach need make no such assumption. It can treat cognition as a functional phenomenon involving, not permanently stored knowledge structures but only transient patterns created directly by the functioning of the biological hardware. This sort of approach can already be found in James (1890), and in Bartlett (1932) who was concerned with "a study of the conditions of organic and mental functions, rather than . . . an analysis of mental structures" (p. 304). It is also widespread in modern psychobiology.

The structural view deals with the dynamic aspects of cognition in terms of searches for and changes to permanently-stored knowledge structures. But, since we question the need to postulate such structures, we try to avoid this way of dealing with the dynamic aspects of cognition: There may not be any permanent cognitive structures to find or change. If cognition is regarded as a functional phenomenon, the solution to the static-dynamic problem resolves itself in the specification of the functioning system. Such a description will naturally, although indirectly, lead to a characterization of mental products. A direct description will be unnecessary. Cognitive patterns can be viewed as transient phenomena and meaning can be "conceptualized as a momentary . . . pattern" (Bransford, Nitsch, & Franks, 1977, p. 45). In short, along with Bartlett, Bransford and his colleagues, and Minsky (1980), we argue that people do not function by selecting templates, rather they function by creating and recreating transient cognitive patterns.

The view we are proposing is based upon one elementary construct at the level of biological hardware in terms of which another more abstract, mental, construct is characterized. The biological construct is that of a physically unitary and functionally autonomous element, which we will refer to, perhaps too loosely, as a neuronal element. The mental construct is that of the <u>schema-of-the-moment</u>, which is defined in terms of the functional properties of neuronal elements. We use the term <u>schema-of-the-moment</u> for two main reasons. First, as we will argue throughout this paper, it is in terms of this "functioning mass of the moment," as Bartlett (1932) and Head (1920) called it, that all cognitive activity (including perception, affection, learning, etc.) takes place. Second, the schema-of-the-moment is assumed to be the only structural cognitive pattern in existence in a given individual at a particular time--everything else is neuroanatomic.

Over the years a great deal of empirical data has been gathered supporting various aspects of the structural approach. The functional view is less fortunate in this respect. However, it must be emphasized that the major functional assumption that starkly contrasts the structural and the functional perspectives is unequivocally supported by neurophysiological evidence and is shared by all current neuroscientific theories (e.g., Anderson, Silverstein, Ritz, & Jones, 1977; Arbib, 1980; Edelman, 1978; John, 1967, 1972; Kachalsky, Rowland, & Blumenthal, 1974; Sperry, 1976; Uttal, 1978). This assumption is that cognition is a transient phenomenon created by the functioning of distributed components of the nervous system. The following quotation from Uttal (1978) illustrates the point:

> The major conclusion of this book (as well as what I believe will be the major guiding theme of psychobiology in the century to come) is that the essential neural aspects of mental function are to be found in the organization of the networks into which either individual neurons or

macroscopic brain nuclei are arranged. It is in the momentary states of activity within these networks that the true equivalents of mental processes are to be found. (P. 683)

Although one might think that compatibility of psychological theories with what is known about the human nervous system is an obvious minimal requirement, such compatibility is frequently conspicuously absent. For example, Schmitt (1978) complains:

> Many theories of higher brain function (learning, memory, perception, self-awareness, consciousness) have been proposed; but in general they lack cogency with respect to established anatomical and physiological facts and are without biophysical and biochemical plausibility. (p. 1)

Again Gallistel (1980) in discussing a psychological model of the control of limb movement (Adams, 1977) claims that modern neurobiological work on the mechanisms of coordination render the theory untenable. The message is clear enough: psychologists need to attend more closely to neurobiological research.

The problem as it relates to psychological research, therefore, does not seem to be the absence of biologically plausible theories. Such theories exist in the work of Arbib (e.g., 1980), Freeman (e.g., 1975), John (e.g., John, 1972; John & Schwartz, 1978), and Uttal (1978). Rather, in some subtle way, the problem seems to relate to the deep-seatedness of the influence of the structural paradigm in cognitive psychology. The structural bias, we believe, has drawn attention away from existing neuroscientific theories that are in essence functional. For instance, Jenkins (1981) noted that structural psychology frequently cites William James' treatment of habit formation and ignores his "true functionalism."

A special characteristic of our account is that it attempts to bridge the conceptual gap that results from the absence of a common language between cognitive psychology and neurophysiology. This gap cannot be filled by merely translating structural psychological concepts into neurological concepts (e.g., groups of neurons process the input information and pass it on to the next group) or vice versa (e.g., neuronal centers represent psychological units). A truly functional cognitive psychology is needed in "the style of the brain" (see Arbib, 1980) and it must be consistent with findings in neurosciences. Such a functional approach must provide the concepts and the language that would relate two phenomenal domains: The domain of the functional properties of the neuronal system and the domain of mental and behavioral structures (Maturana, 1978).

The first section of this paper discusses important aspects of the schema-of-the-moment and compares it with the notion of schema current in cognitive psychology. In the latter part of this section, we will present an overview of the neuroscientific research directly bearing on the problem. The second section discusses the creation and the development of the schema-of-the-moment in terms of the functional properties of neuronal elements. Specific and nonspecific relations and functions underlying the creation and development of the schema-of-the-moment are also discussed in this section. Finally, brief accounts of comprehension, remembering and learning, awareness, and affect are presented in an attempt to illustrate h(different psychological phenomena can be treated in term of a unified account of mental functioning.

The Schema-of-the-Moment: Some Preliminary Issues

In order to distinguish the notion of a schema as a transient functional organization from the concept of a schema as a stored mental template, we will use the term schema-of-the-moment instead of schema. The present section will describe important aspects of this central concept: What is a schema-of-the-moment? Just how is it different from more standard notions of a schema? How is schematic functioning different from information processing?

The Schema-of-the-Moment and the Input-Output Metaphor

A basic tenet of the functional view is that the dynamic aspect of mental functioning is not an information processing system in any literal sense. The neuronal system creates and recreates "knowledge," which is a transient epiphenomenon and lasts only while the underlying neuronal elements are functioning. There are no pre-functional (pre-activation) psychological entities or relations. Cognition begins with initiation of functioning, and mental relations are established only after such initiation (i.e., post-functionally).

It is our aim to demonstrate in this paper that "recreation" is a better way to conceptualize brain functioning than "processing" or "reconstruction." Recreation eliminates the need for the brain to have to deal with the difficult problems of analysis, synthesis, storage, and organization of knowledge. It allows the neuronal system to conform structurally to neuroanatomic organizational constraints rather than to the organizational constraints imposed by abstract knowledge structures.

Conceiving of cognition in terms of "creation" eliminates the need for the input-transformation-output metaphor which dominates current psychological thinking--the same type of industrial plant metaphor which haunted Galenian physiology (see Miller, 1978).[1] An analogy based on the functioning of the endocrine glandular system may serve to clarify the contrast between recreation and input-output transformation. There is a group of cells located in the cortical part of the adrenal glands. These cells, when activated, produce a hormone called cortisol. The cells themselves get activated by another hormone, called ACTH (adrenocorticotropic hormone) released in the anterior part of the pituitary gland. The crucial point is that there is absolutely no input-transformation-output relationship between the stimulator ACTH and the produced cortisol. Adrenal cortical cells, once activated, create the cortisol through, for example, biochemical operations based on substances other than those contained in ACTH. It is this dissociation between the input and the output that renders any system-independent ACTH-to-cortisol transformation rules, or any precise formal description of the product based on them, inappropriate. Similarly, neuronal mechanisms active at a given time combine functionally to create a transient cognitive system. Such a dynamic functional organization is input-independent in the sense described above--that there exists an inherent dissociation between the characteristics of the external stimulation and functional properties of the neuronal system. Neither is there any structural isomorphism between external stimulation patterns and created mental structures. There is no invariant specifiable stimulus or input pattern to correspond to the constantly developing schema-of-the-moment. There is always a great deal more going on than can be accounted for just by the contributions of the external stimulation, or input. Furthermore, contributions of external stimulation are always subordinate to the functioning of organismic mechanisms.

Function versus Structure

The essential characteristic of the schema-of-the-moment is that it is an unstable functional pattern. Its structure is analogous to that of a fountain. As used here, the word functional means "in action" and contrasts with the term at rest. The term function differs from the word process (see Iran-Nejad, 1980). The latter requires an object, something to get processed, while the former does not. Function must also be differentiated from operation (e.g., addition as in A + B = C) as used by Piaget. The verb function is an agent-specific term: "Biological function . . . implies the existence of a system" (Piaget, 1971, p. 54). It means that where there is function, or perhaps dysfunction or malfunction, one would necessarily expect an agent-system (e.g., a neuron) that would do the functioning. Conversely, operations are agent-independent and can exist in the world of abstractions. They are processes per se. They place emphasis on actions rather than on the system(s) which makes those actions possible.[2] Function must also be differentiated from transformation as used in structural psychology, which is essentially synonymous with operation even though some transformations might be readily translated into organismic functions (e.g., activation or inhibition).

From the functional perspective, a specific group of neuronal elements in action creates a unique system, an actual instance of an indefinitely large number of possible patterns. This is not simply saying that there is a specific neuroanatomic structure (consisting of elements and neural connections) which functions to create the functional pattern as has been suggested, for example, by Feldman (1979). In fact, our view is not a connectionist one at all. Theoretically, in order for two or more neuronal elements to join functionally, it is not even necessary that they be related through specific neuronanatomic connections, although normally they will be. All that is necessary for a functional pattern to form is that a group of elements be in action simultaneously. How and when each element began its activity or whether it did so independently or in relation with other elements in the pattern is beside the point. Consider another analogy. Imagine a constellation of lightbulbs each having a uni ie color: When a subset of them is on, a unique pattern is generated. It does not matter when each individual light went on or whether it did so independently of other lightbulbs. The lightbulbs need not be physically connected. The characteristics of the pattern are determined by the participating elements and not by the history of their participation. In sum, while in a structural pattern, it is the long-term "relations among elements that counts" (Piaget, 1970, p. 9), for a functional pattern what counts is the elements themselves--their characteristics, how they function, and how they functionally combine to produce an internally consistent system.

Post-Functional Mental Relations and Pre-Functional Brain Connections

Once the notion of long-term cognitive associations is disavowed, the question arises as to the relation between the neuroanatomic organization and the cognitive organization. In particular, it becomes necessary to consider the extent to which, if any, there is structural conformity between the two systems. Minsky (1980) draws attention to the problem of specifying this interrelationship and refers to it as the "crossbar" problem. According to Minsky, "this problem confronts every brain theory that tries to explain how the mind is capable of any great range of 'associations'" (p. 124).

In theory, there are at least three solutions. The first possibility is to postulate a particular (pre-existing or, rather, pre-functional) neuroanatomic pattern, partial or complete, corresponding to every cognitive pattern. This essentially amounts to mapping the structural cognitive network into an isomorphic neuroanatomic network. Strict isomorphism is often attributed to Gestalt structuralists. Their position is summarized in the following quotation from Uttal (1978):

> The Gestalt mode of description of mental activities has much to offer to those interested in global pattern effects and the action of aggregates and may be a more meaningful approach to psychobiological processes than the atomistic approach proposed by many alternative psychological theories. However, when the Gestalt psychologists proposed neurophysiological theories of perception, they turned to simplistic models that had considerably less to offer than did their descriptive statements. Their main psychobiological premise was isomorphism, the

idea that spacial neuroelectric patterns in the brain were geometrically identical to corresponding mental states. The only concession (and for isomorphism any concession may in fact be irretrievably damaging) that the strict isomorphists would make on this issue was that the neural representation might be topological, i.e., that the geometrical relationships between the parts might not be congruent to the perception although the general arrangement must still be maintained. (pp. 24-25)

While isomorphism is no longer tenable in the face of current psychophysiological evidence, "the propensity to glorify apparently isomorphic data (even though it may be illusory) is ubiquitous in modern psychobiology" (Uttal, 1978, p. 360). Isomorphism is also implicit in those structural psychological theories (e.g., Feldman, 1979) that attempt to translate directly structural constructs to neural terms and try to identify the "links between concepts with neural connections."

The second possibility is that the neuronal network is analogous to some sort of sophisticated telephone network. By allowing directional hard-wired routes between elements, the nervous system would somehow generate two-unit or multi-unit (transient) communication patterns. A telephone network is directional because the initiating unit must know the "address" (see Norman, 1980) of the target unit(s). Directional connectionist models imply "that 'remembering' requires the discharge of those particular cells which constitute the new line, and those of the cells to which the line is directed" (John, 1972). John (e.g., 1967, 1972, John & Schwartz, 1978) has discussed the connectionist models and has concluded that they are suspect "on logical, psychophysiological and neurophysiological grounds." For instance, John and his associates (see Thatcher & John 1977) reviewed numerous electrophysiological studies. All the evidence demonstrates that responses to the most elementary stimuli (e.g., a flash of light or a click) are made by cells anatomically distributed throughout the brain and that a given cell participates in many functional patterns. In order to accommodate this and similar data proponents of the connectionist view have used "the term 'connection' in a functional sense, cautiously defining it in terms of relationships while explicitly disclaiming any literal connotaion of a new anatomical junction." However, "more recently, new responses have commonly been assumed to depend upon the establishment or facilitation of a new pathway (or pathways) of synaptic connections between input and output ... " (John, 1972, p. 850).

Thus, according to the connectionist models, if mental relations are variable and plastic so must synaptic connections be. However, the large conceptual gap between synaptic plasticity (defined in terms of synaptic weights, strengths, facilitaion levels, etc.) and mental plasticity renders synaptic connectionism implausible, at least for the time being:

> Although synaptic plasticity has been the object of research attention for many years, the synaptic effects studies, without exception, are proposed as analogs of only the simpler forms of learning, such as classical conditioning, rather than of cognitive learning. This is an important constraint, for the synaptic hypothesis must transcend an enormous conceptual gap at this point to be linked to more complex mental

> processes. . . . In the absence of a specifically understood link between cellular plasticity and learning, the generalization of synaptic hypothesis must depend upon the logical assertion that any concept no matter how complicated, can be represented by a sufficiently large number of elemental and discrete processes. This assertion is a major theorem of modern mathematics, but in the brain it still represents a statement of faith that in some fundamental way runs counter to the current rejection of the idea of concatenated conditioned reflexes in atoms of learning. That a serious dilemma is thus generated is obvious. That there are, yet, no resolutions to this dilemma is also undeniable. (Uttal, 1978), p. 540-541)

The fact that neuronal elements are capable of interacting with other distant, neuronal elements suggests that there must exist within the nervous system some sort of a relational medium to make such interaction-at-a-distance possible, independently of isomorphic synaptic connections. The third possibility, therefore, and the one we find most plausible, is that in addition to a directional medium, the neuronal network also constitutes an all-spreading nondirectional relational medium. Such a medium would allow (within amplitude, etc., constraints) nondireccional conductance of electrical or chemical energy in addition to directional element-to-element interactions.

In a totally nondirectional network everything can, potentially, reach everything else and nothing is aimed at anything directly. Thus, the initiating unit does not need to know the address of the target unit. Rather, target units are specialized to get activated in response to (or "to recognize") the functioning of the initiating unit and to remain indifferent to the functioning of any other. Particularly relevant examples of specialized systems functioning in a nondirectional environment are the auditory and visual systems of animals. While both of these mechanisms function in the same environment--filled with sound and light waves--the ears respond to sound waves but are deaf to light waves while the eyes perceive light waves but are blind to sound waves. One can imagine that the same principle holds throughout the neural network. Thus, it is possible that neuronal elements are uniquely specialized to respond to some particular functional patterns while remaining indifferent to others.

Clearly, a non-directional model is by necessity localizationist; but it is also consistent with the global approach developed by John and his colleagues. It is localizationist because it must assume the existence of neuronal elements that are physically unitary, functionally autonomous, and uniquely specialized. It is consistent with John's anti-localization bias and his global approach because, having rejected, as John does, both "geometric" and "relational" isomorphism, we can no longer assume that single cells (or any other unitary local elements) represent "meaningful" (complex, molar, etc.) mental patterns such as features, concepts, or percepts.

A neuronal element must be physically unitary because it must be an internally coherent neurological system, rather than only a nerve fragment or a molecule. It must be functionally autonomous in order to participate in an indefinite number of functional combinations. And it must be uniquely specialized in order to be able to preserve its own identity while functioning in consonance with other active elements of the moment and in order to so selectively in the presence of some particular global electrical and/or chemical pattern and not in the presence of any other. While John and his colleagues have criticized current localizationist models, they have also emphasized that any solution to the problem of the interface between the mind and the brain must come from some compromise between localization and antilocalization concepts:

> Localization of function within any area of the brain must be evaluated with great caution, even when apparent physiological correlates of function have been demonstrated in as great detail as has been the case with the elegant studies of "feature extractor" cells of the visual cortex. It should go without saying, but we will nontheless state for the record, that similar caution must be exercised with respect to our own arguments in this Volume against localization. We voice a strong warning against overenthusiastic proponents of either position, localizationist or antilocalization, who ignore or shrug off the contradictions. It is precisely from the reconciliation of the apparent contradictions that we stand to learn most about how the brain processes information. (Thatcher & John, 1977; p. 211)

The evidence gathered by Hubel and Wiesel (1959, 1962, 1965) and others clearly demonstrates that the brain is not a homogeneous mass, as once was thought. However, as John and his colleagues have argued, this does not mean that single cells represent complex mental structures.

We have hypothesized an all-spreading medium in order to clarify, at least conceptually, the problem of interaction-at-a-distance. An all-spreading environment, however, does not mean that electrical or chemical conductance takes place in a vacuum, even though some sort of extracellular propagation may play an important role (see Nicholson, 1979). Neither should this mean nonspecificity or imprecision in the pattern of actual neural connections. The neural network as a whole may serve as a common network. The two types of physical relational vehicles (directional and non-directional) may be illustrated by an analogy to the functioning of exocrine and endocrine glandular systems. Exocrine glands (e.g., the salivary glands) release their products into specific ducts which direct them to target organs. These would correspond to directional element-to-element (neuroanatomic) connections. Endocrine glands, on the other hand, secrete their products into the extracellular fluid surrounding capillaries; thus, the hormones they produce enter the blood circulation system, which is itself an all-spreading environment. This would correspond to any all-spreading relational role played by the neural network.

As an example of how functional relations can be established via a common nondirectional medium, as opposed to specific and direct anatomic connections, consider the functional relation between the pituitary and the adrenal glands referred to earlier. The ACTH released in the anterior pituitary gland, located on the lower surface of the brain, serves to stimulate (activate) cortical adrenal cells located above the kidneys. It is conceivable, in principle, that a direct point-to-point duct could have been physically available to carry ACTH from the pituitary to the adrenal glands. However, if a tube were to be available from every endocrine gland to its target organ, organisms would become monstrously complex. Instead, ACTH enters the blood circulation system. This, of course, takes the hormone to other irrelevant organs as well (hence, all-spreading and nondirectional), but it is also sure to reach the adrenal cells which are specialized to get activated by it, because these cells like everything else are connected to the blood circulation network.

The possibility that the nervous system is also, in part, an all-spreading environment analogous to the blood circulation system cannot be ruled out. As early as the 1920's, Paul Weiss concluded based on existing evidence that "the central nervous system and the non-nervous periphery entertain their mutual correspondence by means of some sort of sending-receiving mechanism, specific for each individual muscle." According to this view, the central nervous system is "endowed with the capacity for discharging as many different modes or forms of impulses as there are different muscles in the limb." There is a specific impulse for every muscle receptor. Every muscle receptor, on the other hand, "would possess the power to respond selectively" to its proper impulse. Consequently, if "the central impulses for a limb muscle were circularized in the whole limb" the mechanism of selectivity of function "would ensure that every call be answered by the correct muscle, even though the latter may have been displaced, re-innervated by strange nerves, and prevented from sending informative messages back to the centers" (Weiss, 1936, pp. 511-512). Weiss's resonance principle is no longer generally accepted by developmental neuroscientists. But we believe his ideas concerning indiscriminate synaptic connectivity, successfully challenged by Sperry and his associates (see Attardi & Sperry, 1960, 1963; Meyer & Sperry, 1976), must be distinguished from his suggestive element-implulse specificity hypothesis, which has yet to be directly tested.

An all-spreading functional environment would imply that a given functional pattern could stimulate relevant neuronal elements elsewhere in the nervous system regardless of its place of origin in the neural network and regardless of any pre-established blueprints. There are definite indications that this may be the case. Consider a letter recognition (identification) task. Images ordinarily begin on the retina and presumably stimulate corresponding centers or elements somewhere in the brain. It is conceivable that specific "image-to-center" connections as well as long-term graphemic patterns could mediate recognition. However, recognition need not depend on specific connections or on pre-existing long-term patterns. Blindfolded subjects are capable of correctly identifying letters "finger-written" on their skin. White, Saunders, Scadden, Bach-Y-Rita, and Collins (1970) used a visual substitution apparatus which converted optical images into tactile displays which blind or blindfolded subjects were able to "see with their skin." It was shown that "subjects are able to perceive certain simple displays . . . almost as soon as they have been introduced" (p. 23) and that with minimal amounts of training they are able "to identify familiar objects and to describe their arrangement in depth" (p. 25).

The hypothesis of functional communication between distinctively specialized neuronal elements also finds support in the evidence that establishment of functional relations is possible even after specialized cells are surgically removed from their original site and regrown at a different part of the body. If a piece of skin is removed from the belly region of a salamander and planted on its back and if, after regeneration, this skin, now on the back, is stimulated, the animal proceeds to scratch its belly, the original site. Such seemingly maladaptive responses, extensively studied by Sperry and others, are often discussed in the light of the nature/nurture issue (see, e.g., Rose, 1976). However, more basic than whether something is innate or acquired is the problem of how it works. One may simply assume that regeneration only connects the pre-specialized skin receptor cells to an all-spreading neural network. There is no need for the establishment of particular nerve fibers to wind their path, through some mysterious innate guiding mechanism, all the way to the related central cells. Once specialized receptor cell are merely connected to the neural network (or perhaps to the particular brain region), they can activate the individual target cells through generation of unique energy patterns. The energy patterns, generated by the central cells can, in turn, activate the muscles involved in the scratching of the belly. Because the belly receptor cells function in the same unique fashion regardless of where they are located and because this functioning is recognized by the related central cells as "belly" stimulation, the animal responds maladaptively. Sperry (e.g., 1943) explained these results "in terms of reestablishment of specific anatomical associations rather than in terms of specific nerve energy and resonance phenomena." But he also emphasized that "the latter possibility is by no means excluded" (p. 47). In fact, it is still not clear that a resolution between Sperry's directional connectionism and Weiss' element-impulse specificity model has yet been achieved (see Meyer & Sperry, 1976; Sperry, 1966; Wall, 1966; Weiss, 1966). As Wall (1966) argued, "the so-called specificity of neuronal function ... may mean that specificity of function can be attained without a microscopic determination of the exact morphological structure of some parts of the nervous system" (p. 230).

Given the concept of an all-spreading relational vehicle, the most efficient way of relating the cognitive system and the neuronal system seems to be by assuming (a) that the former is comprised of transient functional relations and (b) that post-functional patterns are independent of any isomorphic pre-functional neural associations. Independence of post-functional (mental) relations also resolves Minsky's crossbar problem. As Minsky (1980) put it "if the mechanisms of thought can be divided into specialists that intercommunicate only sparsely, then the crossbar problem may need no general solution. For then, most pairs of agents will have no real need to talk to one another; indeed, since they speak . . . different languages, they could not even understand each other" (p.125). And, to continue the metaphor, if they can understand each other, they will do so regardless of where they are located or whether they are connected directly so long as they can "hear" each other (i.e., so long as they are part of the overall neural network).

Creation and Development of the Schema-of-the-Moment

This section attempts to draw a coherent picture of how the schema-of-the-moment is created based on the activity of functionally autonomous neuronal elements. A few assumptions are made concerning the functional properties of physically unitary neuronal elements and about the way they interact, and it is shown how such assumptions may make it possible to give a coherent account of the creation and the space-time development of the schema-of-the-moment. These assumptions, while speculative in detail, are generally supported by existing neurophysiological evidence bearing on localized and distributed functional properties of the nervous system. Because of the emphasis on the coherence of the functional model, we will not interrupt the discussion to substantiate every claim. The interested reader is encouraged to consult the highly readable discussions of the relevant research by Hubel and Wiesel (1980), Thatcher and John (1977), and by Uttal (1978). Hubel and Wiesel argued that "whatever any given region of the brain does, it does locally," in terms of neurons specialized to respond to highly specific stimulus characteristics. Thatcher and John, on the other hand, discussed the developmental properties of the "dynamic global representational system." Among the properties considered were expansion (i.e., inclusion of more brain structure), tuning (i.e., enhanced activity in those parts of the brain that are most concerned with the performance of the response), reorganization (i.e., turning on of certain neuronal populations and turning off of others), and coherence (i.e., synchronous activity of distributed neuronal populations). Finally, Uttal discussed the microscopic and macroscopic physiological equivalents of psychological structures.

Are Pre-Existing Long-Term Patterns Necessary?

As we have said, current approaches to cognition and comprehension presuppose the existence of long-term underlying blueprints for cognitive functioning to take place.[3] For instance, it is often claimed that in comprehension various aspects of the input are assimilated to preformed schemata. Accordingly, in a particular situation, a suitable set of schemata is found to account for the input data (e.g., Rumelhart & Ortony, 1977). It is these instantiated schemata which constitute the interpretation of the input.

One motivation for hypothesizing long-term mental structures is the fact that ideas seem to come to mind (to be recalled, etc.) together, or in relation to one another. It is then assumed that they stay together, in some cognitive warehouse, even when they are not operative. Thus, the structural approach maintains that ideas are related before they become operative. However, from the functional perspective, relations among ideas are established only after they become operative; cognitive patterns are thus transient and unstable.

The only requirement for two (or more) elements to combine functionally is that both be in a state of simultaneous functioning. The light-constellation analogy once again provides an illustration. Two or more lightbulbs in the constellation may have absolutely no connection with one another; but once they are on, they can give rise to a unique pattern of light. They need not go on in relation to one another or even at the same time. It is the elements and not the structural connections among them that count. In fact, a given (functional) pattern could result from a long series of steps in which some lights would go on, some would go off, and some would gain in brightness while others become dimmer.

The assumption of post-functional relations raises a new set of problems about the nature of psychological patterns and their formation. We now have to ask such questions as: What are the functional properties of neuronal elements? What types of functional relations exist between elements? How do neuronal elements initiate functioning? What is the role of already active elements in the initiation of functioning of other elements? What is the role of external stimulus patterns? And so on.

Some Definitions

In order to demonstrate how cognitive functioning is possible in terms of simultaneous activity of functionally independent neuronal elements, we must take a closer look at some key concepts. For the sake of clarity, we will continue to use the light-constellation analogy. Let us suppose that our array of lightbulbs contains two broad categories of lightbulbs, namely, colored and uncolored ones. We will call the colored bulbs "specialized elements." The uncolored bulbs we will call "raw elements," implying that they can become specialized by getting painted a particular color. In this array, each bulb can "perform" a few feats always in the same unique fashion: it can go on or off, it can become brighter or dimmer, and if it is not already, it can become specialized. Furthermore, combinations of specialized elements generate unique patterns of light. Similarly (and now we are out of the analogy), the neuronal network can be assumed to consist of a great number of elements, each of which can become specialized and each of which can get activated or inhibited. Each specialized element (a) produces a unique pattern of energy, (b) initiates functioning consistently in the presence of some unique pattern of internal or external energy, and (c) can generate, when functioning, a unique feeling of awareness. So, a specialized element is a discrete, functionally independent unit with quite specific but very limited properties. This assumption is consistent with the view that "neurons, in the course of differentiation and development and in processing of information over the span of the organism's lifetime, develop unique identities: genetically and experientially determined individualities" (Schmitt, 1970, p. 208).

Two or more simultaneously functioning neuronal elements may combine post-functionally to constitute a functional organization. We will refer to such a group of elements as a constellation. Constellations differ from elements in several respects. Unlike elements, they cannot be considered specialized. This is because they contain autonomous elements which can participate in other constellations. Elements are assumed to be localized and physically unitary while, given the all-spreading environment, constellations can have elements scattered throughout the nervous system. While individual elements possess <u>specific</u> functional properties that theoretically are unambiguously traceable to some unitary physical entity--the element itself--constellations have <u>nonspecific</u> properties--properties which cannot be traced to any unitary physical entity because they are different from those possessed by any one of the participating elements.

As we are using it, the word combine in the present context refers to the establishment of transient functional relations among anatomically distributed neuronal elements. It also refers to the merging of specific energy or awareness patterns resulting in novel nonspecific energy and awareness patterns. In the case of energy, pattern combinations can be conceptualized in terms of interference patterns. The existence of interference patterns in the functioning brain has been hypothesized by John Eccles and by Karl Pribram (see, e.g., Goleman, 1979). Similarly, the emergent and combinatorial nature of awareness has been hypothesized by Sperry (1969, 1976). Awareness is interpreted by Sperry "to be a dynamic emergent property of cerebral excitation. As such, conscious experience becomes inseparably tied to the material brain process" (1969, p. 533). And, finally, with respect to the functioning of individual neuronal elements, combination may be conceived as "acting in concert." Evidence gathered by John and Killam (1960) supports this notion. These authors found that as learning progressed, evoked potentials from wide areas of the brain became more similar.

It is now possible to see how cognitive functioning might be determined and constrained solely by the functional properties of independent neuronal elements without the need for postulating long-term structural relations. When a person hears, for instance, the word "cow," the unique pattern of external energy which reaches the ear activates not an isomorphic pre-existing structure but many functionally independent neuronal elements in the auditory cortex. These elements combine post-functionally into a unitary interacting constellation of neuronal elements and, consequently, a functional organization. The latter, having constituted a momentary independent pattern, will, in turn, activate (or inhibit) other (perceptual, affective, etc.) autonomous elements in various other sections of the brain. The totality of the just-activated constellation is a transient organization that constitutes the idea of a cow and, of course, a great deal more (or less) depending on the schema-of-the-moment (i.e., depending on the functional state of the system when the word "cow" was heard).

Thus comprehension need neither draw upon nor result in the construction of permanent mental representations. But, now, if no long-term representation is preserved, how are such things as recognition possible? One answer is that recognition need not be explained in terms of the relations between elements, as preservation of mental representations would imply. Recognition can be explained in terms of elements only: It can occur to the extent that the schema-of-the-moment contains the same functional elements that were involved in some previous schema-of-the-moment.[4] This gives neuronal elements functional independence--freedom to participate in other functional patterns. It further eliminates the need to claim (a) that the elements initiate functioning together, in relation to one another, or in the same original order, (b) that the mental pattern is preserved in the interim, and (c) that the underlying neuroanatomic structure somehow uniquely corresponds to the generated cognitive pattern.

Types of Functional Relations

Directional and all-spreading relational vehicles and specialized neuronal elements provide the basis for specifying the different types of functional relations that can exist among neuronal elements. An important consequence of allowing an all-spreading relational medium is that it makes it possible to see how cognitive functioning, while being a direct result of neuronal activity, can also be considered somewhat independently of the actual neural fibers. Thus, it eliminates the need to trace, in theory or in practice, neuroanatomic connections. It draws the line between psychology as a science concerned with mental functioning and neuroanatomy as a science dealing with neural architecture. A basic problem in the psychological domain is, therefore, specification of possible functional relations (as opposed to neuroanatomic connections) among neuronal elements.

Relevant to this problem is the system of relations postulated by Festinger (1957). Three types of relations are assumed to exist among cognitions (cognitive units): consonance, dissonance, and irrelevance. According to Festinger, cognitions X and Y are consonant if one follows from the other. When two cognitions have nothing to do with each other, the relation is irrelevance. And, finally, "two elements are in a dissonant relation, if considering these two alone, the obverse of one element would follow from the other" (p. 13).

Festinger's system of basic relations may be readily translated into functional terms. In fact, the notion of dissonance as an inconsistent relation between two cognitions is only meaningful if it is conceived as a functional relation. This is because no contradiction should arise when not-Y does actually follow from X. As the expression follow from suggests, the latter is a consonant relation. Contradiction should arise if the relation between not-Y and X is consonant and if, in some particular situation, X and Y compete for activation.

A functional definition of dissonance would also eliminate a potential misinterpretation of Festinger's definition. Aronson (1968), for instance, states that "dissonance is a negative drive state which occurs whenever an individual simultaneously holds two cognitions . . . which are psychologically inconsistent" (pp. 5-6). But simultaneously "holding" inconsistent beliefs need not necessarily give rise to dissonance (i.e., to experiencing contradiction or a negative drive state). An individual may truly believe that smoking is hazardous, but this does not necessarily mean that every time a cigarette is lit dissonance and/or unpleasantness is experienced. Based on the functional assumption, two or more elements give rise to dissonance only if they are competing for simultaneous functioning. In other words, dissonance is a post-functional phenomenon.

How can Festinger's system of relations be translated into long-term characteristics of neuronal elements? The basic property of neuronal elements is specialization. This concept directly implies consonance and irrelevance, and indirectly implies dissonance.

Consider three elements, A, B, and C. Suppose that element A is specialized to generate a unique energy pattern, E(A). Element B is specialized to get activated in the presence of E(A). This means that there is an A-to-B consonant functional relationship. E(A) is a sufficient condition for activation of B. On the other hand, specialization of elements other than B could be such that the presence of E(A) would have no effect on them. This would mean an A-to-NON-B irrelevant functional relationship. Similarly, a C-to-B activation-inhibition consonant relationship would imply a C-to-NON-B irrelevant functional relation: E(C) would constitute a sufficient condition for inhibition of B and no other element.

Now suppose that A and C are active at the same time. E(A) will tend to activate B while E(C) will tend to inhibit it. Such dissonance will bring about an unstable state of dissolution: it will tend to break the A-to-B activation-activation relationship and/or the C-to-B activation-inhibition relationship. Resolution can be achieved if E(A), E(C), or both are eliminated.

In theory, there can be at least three types of consonance. In the first type, activation of A always leads to activation of B. We will refer to this as logical consonance. In the second type, A does not necessarily activate B. For instance, E(A) would activate B only if B was not already in a state of inhibition. If B were in a state of inhibition, then E(A) would activate C, as an alternative to B. We will refer to this type of consonance as pragmatic consonance (cf. Brewer, 1977).

In logical and in pragmatic consonance, one element generates the conditions for the initiation and/or maintenance of functioning in another element. In the third type of consonance, while initiation cannot take place merely as a consequence of the functioning of the first element, the elements can combine once each of them is independently activated. This type of consonance may be referred to as pure consonance.

With respect to initiation of functioning, therefore, logical consonance can be referred to as single-source dependent consonance, while both pragmatic and pure consonance are multiple-source dependent. This means that in the latter cases, activation of the second element must depend on sources of initiation other than the first element. If this analysis is correct, it means that if A is related to several alternatives it does not make very much sense to characterize the situation by assigning probabilities to the alternatives. Doing so would, in effect, mean trying to explain the relational set in terms of the characteristics of A alone or in terms of some long-term relations (e.g., strength of association). In functional terms, A does all it can do by behaving always in the same fashion. While in logical consonance, this is a sufficient condition for the activation of B, in pragmatic and pure consonance, it is not. Contributions of other sources than the first element are also necessary for initiation of functioning in the second element. Assignment of probabilities makes the least sense with respect to pure consonance, because while this type of consonance seems to play a central role especially in novel situations, the probability of the first element activating the second is theoretically zero.

The concept of multiple-source dependence is consistent with the way organismic nervous systems are designed to interact with the environment. It seems as though, in order for the nervous system to function the way it does, nature has found it profitable to relate organisms to the world through more than one sense organ, each serving as an independent source of functional initiation.

Multiple-source dependence inevitably results, at some time or other, in dissonance. In general terms, dissonance can be defined as an unstable state of functioning in which elements will tend to behave in the opposite direction from their consonant functioning under the influence of independent initiation sources. For instance, under conflicting stimulation from different sources, an A-to-B activation-activation consonant relation becomes dissonant if B tends to undergo inhibition. However, conflicting situations would simply not arise in a single-source functional system.[5]

While it is presumably at the level of neuronal elements that functional relations operate, one may speak of the same relations holding among constellations. Two or more constellations may be said to relate by pure, logical, or pragmatic consonance to form more complex patterns. It must be emphasized, however, that constellations do not relate through direct constellation-to-constellation relations. Rather combining takes place at the level of individual elements. To illustrate how this might work, let us go back to the concept of interference patterns. Imagine throwing a handful of pebbles into a pond. Each individual pebble plays its role as a specific independent element in the creation of the nonspecific overall pattern. Now imagine throwing two or more handfuls at adjacent spots. While, once again, the separate wave patterns merge to constitute a more global combination, it is still at the level of individual pebbles that the nature of the interaction is determined. Similarly, the totality of all the functioning neuronal constellations forms a nonspecific unitary pattern; but it is the functioning of the autonomous individual elements which determines the interaction.

The concepts of consonance, dissonance, and irrelevance clarify how functioning neuronal elements might interact. It also becomes more evident that the development of the schema-of-the-moment is not a straightforward combination of functioning elements. Rather, since the "complexity of 'schematic' formation means that many objects, many stimuli, many reactions, get organized simultaneously into different 'schemes,' . . . they tend to set into activity various cross-streams of organized influences" (Bartlett, 1932, p. 302), many of which may be in antagonistic (dissonant) relations.

Endogenous and Exogenous Sources of Functional Initiation

The terms endogenous and exogenous have two connotations. A static connotation, meaning internal and external, and a dynamic connotation, meaning "outward" and "inward" from an internal or an external origin (source or cause), respectively. We intend to imply both of these connotations.

The schema-of-the-moment is the combined totality of the already-active relevant neuronal elements. This constellation of elements may be referred to as the endogenous constellation. It is endogenous to the unitary organization (and experience) of the moment. However, what is already occurring in the schema-of-the-moment will, of course, be affected by what happens to elements which are not yet active. For instance, when a neuronal element gets activated, it may relate, not directly and immediately to endogenous elements, but to other elements outside the schema-of-the-moment, i.e., other non-active elements or other active elements which are (by themselves) irrelevant to the endogenous organization. Consequently, a local exogenous constellation is formed, exogenous, that is, with respect to the schema-of-the-moment. Such an exogenous constellation may or may not combine with the schema-of-the-moment and must be distinguished from it. An important exogenous constellation is the just-activated constellation--one whose elements have just started functioning.

What causes initiation of functioning in inactive elements? The assumption that pre-functional blueprints do not exist, and the complementary claim that mental relations are established only post-functionally, raises a basic problem: How do neuronal elements come to be in a state of functioning to begin with? The answer to this question must be sought, not in some pre-functional arrangement of elements in a mental store, but in the fact that the neuronal system is a multiple-source dependent system with respect to functional initiation. First, there are endogenous sources. A large number of neuronal elements in the schema-of-the-moment are always in a functional state (at least during waking hours); they are specialized to maintain a particular functional rhythm or cycle. The element constellations creating the concept of self, of time, and of space are examples. Secondly, there is what might be called the <u>combinatorial source</u>. As elements combine, they set the stage for the initiation of functioning in other elements through emergent logical and pragmatic functional relations. And finally, there are the most important exogenous sources--those external energy patterns which constantly influence the neuronal system through several independent sense organs.

Some Traditional Problems Reconsidered

This section discusses, in an intentionally perfunctory fashion, how the functional view causes a reconceptualization of such traditional problems as comprehension, remembering and learning, awareness, and affect. Its aim is only to offer an impressionistic account by way of illustrating how these issues can be approached in terms of a unified, global account of cognition.

Comprehension

Given the endogenous, emergent (combinatorial), and exogenous sources of initiation and combination, what happens during comprehension is readily specifiable. Comprehension will prosper to the extent that these sources play their indispensable role and will suffer to the degree that they do not. In oral language comprehension, for instance, there are at least two independent external sources of initiation (auditory and visual), in reading comprehension there is one (visual).

In the absence of a relevant schema-of-the-moment, comprehension remains highly impoverished or does not take place at all. In other words, comprehension will suffer to the extent that the schema-of-the-moment and the just-activated constellation do not contain mutually-relevant elements. This seems to be the case, for example, when a reader goes through the motions of reading but is preoccupied with something else; there is no interaction between endogenous and exogenous functioning. Presumably, while textual stimuli do activate sensory neuronal elements, the resulting irrelevant just-activated constellations sooner or later drop out of activation since they fail to establish post-functional relations with the schema-of-the-moment.

This claim is similar to, but not the same as, the one implied by traditional theories of comprehension. It is similar insofar as it finds support in the research motivated by the influence of top-down high-level patterns on comprehension. It is different because it does not appeal to pre-functional relations; nor does it imply that comprehension takes place in some mental "location" such as a short-term memory buffer (e.g., Kintsch & van Dijk, 1978) or a message center (Rumelhart, 1977); nor does it have to face the schema-selection and other related problems. Comprehension fails to the extent that active neuronal elements consonant with the just-activated pattern are not present in the schema-of-the-moment. This can happen either because such elements are not present in the nervous system at all, or because the current endogenous, exogenous, and emergent sources of initiation cannot activate them.

That local functional patterns do, in fact, remain merely momentary to the extent that the schema-of-the-moment and the just-activated constellation do not contain mutually-relevant elements is supported by the results of an often-cited experiment by Bransford and Johnson (1972). Subjects read well-formed passages about, say, doing the laundry. However, the passages were constructed in such a way that it was impossible to figure out what they were about without being told. Those who only saw the passages found them difficult to understand and showed poor recall. Recall was also almost as poor for those who were told that the passage was about "washing clothes" <u>after</u> they had finished reading it. However, subjects who were given this topic <u>before</u> reading showed greatly facilitated comprehension and recall.

This experiment illustrates the essential role simultaneous functioning plays in the establishment of psychological relations. Only when the schema-of-the-moment contains relevant elements, can post-functional relations with elements activated by textual stimuli be established. Only then can emergent sources of initiation work properly; and only then can coherent mental patterns result, novel ideas emerge, and better comprehension take place.

Different schemata-of-the-moment can lead to different interpretations of the same text (e.g., Anderson, Reynolds, Schallert, & Goetz, 1977; Pichert & Anderson, 1977; Schallert, 1976). This is because at any given instant during comprehension, the schema-of-the-moment combines with that portion of the just-activated pattern which is relevant and "ignores" the irrelevant. In Pichert and Anderson, for instance, different groups of subjects were instructed to read the same passages while keeping in mind different perspectives. One of the passages was about two boys playing hooky from school who took a tour through the house of one of the boys. The passage was read from the perspective of a burglar, a homebuyer, or no directed perspective. Unlike previous studies, which had reported high correlations among importance ratings by different groups of subjects reading the same passage, the present study showed a mean intercorrelation of .11 among the three groups. Importance ratings for a given perspective also correlated higher with the recall from that perspective than with that of readers who had taken other perspectives.

Knowing the motive (having a relevant constellation activated) of the character of a story has also been shown to affect its comprehension. In a study by Owens, Bower, and Black reported in Bower (1978), subjects read five neutral sequences representing five scripts: making a cup of coffee, visiting a doctor, attending a lecture, going grocery shopping, and attending a party. One group of subjects read only the event sequences. A second group read the event sequences preceded by a description of the motive of the person who carried out the events. Subjects who saw the motive description recalled more scripts, remembered more of the propositions stated in the text, and made more inferences than those who read the event sequences only.

Such experiments are usually conducted to demonstrate the effects of prior knowledge on remembering and comprehension. What they actually show is that context, perspective, affective states, motives, or in short, the entire functional state of the moment must be taken into account. Some theorists (e.g., Bower, 1981) attempt to explain such findings in terms of associative connections among (tokens of) concepts stored in an associative network. Others, however, reject the theoretical underpinnings of such accounts as inadequate because they view them as being based on an incorrect characterization of human memory. For example, Norman (1980) claims that "associations among memory concepts . . . simply will not do." Bartlett (1932) believes that such approaches are "responsible for very much unnecessary difficulty in psychological discussion,'" and yet others have pointed out that such descriptions of stored products are fruitless (Bransford, McCarrell, Franks, & Nitsch, 1977; Bransford, Nitsch, & Franks, 1977). Associative theories also imply "geometric" or "relational" isomorphism, and, to the extent that they do so, they contradict the neurophysiological evidence discussed earlier. We prefer to view such results as support for the notion that comprehension, like remembering, is a constantly developing global activity. As Bartlett (1932) pointed out, "the active settings [the schemata-of-the-moment] . . . are living and developing, are a complex expression of the life of the moment . . ." (p. 214). Such an active mass of the moment does not involve one, or two, or even several local schemata (see Mandler, 1981). There is no "countable" mental entity. There are no complex building blocks (see Rumelhart, 1980). There is total continuity, not only with the immediate comprehension context, but also in time, in space, and with personal history. Bransford et al. (1977) argued that past experiences set the stage for comprehension and perception. The stage-setting metaphor was to capture this continuity. They write:

> Consider some possible understood meanings or significances of a statement like "I'm going to drive to Minneapolis tonight." If the speaker is in St. Paul, Minnesota, the statement is not surprising. If the speaker is in California, one realizes that the person is in for a long drive. And if the speaker is in Europe, the statement seems strange. Or consider reading a newspaper heading like "Peace finally comes to Europe." What is the significance of this statement? If one is reading an old newspaper, it is a historical fact. If one is reading today's paper, it is understood differently. And what is the significance of a phrase like "today's paper?" The understood significance of this utterance changes everyday. (pp. 436-437)

In spite of this total continuity, it is often readily possible to single out particular components of the schema-of-the-moment. However, even at the time of focussing on a single "distant" component, the continuity is never lost. A quick excursion to a remote childhood experience does not destroy the experience of the moment. It seems that it is always the past that "visits" the present (by getting recreated when the conditions are suitable) and not the present that searches for the past. Transitions are almost always smooth and continuous.

The structure of the just-activated constellation and the way it interacts with the schema-of-the-moment is also governed by analogous plasticity. The schema-of-the-moment does not assimilate meanings or concepts in their intact holistic form. Rather, by the very nature of its unique global functional properties, as well as that of the properties of its functioning constituents, it establishes post-functional relations with that portion of the just-activated constellation which "is most relevant to the needs of the moment." It is possible for one individual element of the just-activated constellation to get singled out, if that is the only element relevant to the schema-of-the-moment. This plasticity is absolutely essential if one is to comprehend novel or metaphoric statements. In comprehension of a simile like "A whale is like a skyscraper," there is seldom any difficulty in singling out the elements underlying "size." We believe all this is possible because active neuronal elements relate through transient, hence readily changeable, functional relations.

The assumption that the constituents of the schema-of-the-moment combine functionally, among themselves or with those contained in the just-activated constellation, to create a unique global functional system with unique properties suggests that functional conditions and relations in the schema-of-the-moment (e.g., the characteristic energy or interference patterns) constantly change and, consequently, that schema constituents must change significance accordingly. Emergent functional conditions set the stage for further new combinations, thus giving rise to new experiences (ideas, meanings, etc.). Most changes in the schema-of-the-moment do not result in disruption of its global properties. Rather, they are local changes involving the addition and deletion of active neuronal elements. The schema-of-the-moment "survives" these local changes thus maintaining its global properties. Consider for example, a person waiting in an airport for the arrival of a friend. As he waits, endogenous, exogenous, and emergent sources of (initiation of) functioning maintain continuity in space (he implicitly knows he is in the airport, in the town of . . ., the country of . . ., and so on) and in time (he knows it is about such and such hour in the afternoon of an extremely cold winter day). He looks up and sees in the cold but clear sky a distant spot. This rather impoverished external stimulation activates visual elements consonant with those already active, thus creating the idea that a plane is approaching. As the plane draws closer, there is more activity of specialized neurons in the auditory, visual, and other areas of the nervous system (he now hears and sees the plane clearly; he sees it touch the ground; he is almost certain that his friend is going to come out appropriately dressed for the weather, and so on). The passengers begin leaving the plane. He sees his friend and she sees him; and so forth. While all these are substantial changes and shifts in functioning, the overall schema-of-the-moment always maintains its continuity and its global properties. The gradual phenomenological changes are a result of merely local changes in the schema-of-the-moment. Some elements are added and some are deleted. However, the global properties of the schema-of-the-moment remain essentially unaffected by these local changes, resulting in a continuous and unitary phenomenological experience.

Changes in global characteristics also occur, as a function of the just-activated constellation. When such (dramatic) changes occur, surviving local constituents establish new functional relations and, consequently, assume a new significance relative to the new functional pattern with its unique global aspects. The following quotation from McHugh (1968) illustrates the point:

> We have all heard stories of someone who has just missed being killed in an airplane crash. Suppose the emergent item is the "airplane ride," in that it belongs to both a later and an earlier system [schema-of-the-moment]. As the person is told that the airplane is full because it is oversold, the "airplane ride" assumes the character of a missed appointment in some other city (exemplifying the influence of the future on the present thwarted airplane ride). In the later system, after being told of the crash, the significance of the ride changes, because the person is now "lucky" to have escaped disaster. The meaning of the airplane ride has changed, and it is emergent because future programs

influence the depiction of the present, just as the actual events that occur in the future (now the present) make it necessary to reconstruct the past, in this case from disappointment to relief for the passenger. (pp. 25-26)

This passage illustrates how the significance of local schema constituents (e.g., the airplane ride) changes as a result of changes in global properties and vice versa. The result: constant emergence (creation) of (new or old) ideas and meanings.[6]

Examples of dramatic global changes (reorganizations) are also abundant in literature. In a short story by Thurmond (1980), for instance, a nurse, Marilyn, leaves the hospital where she works after a late night shift. She goes to a gas station for gas, and accepting the invitation of the attendant, Gabriel, she goes inside his office. As they go inside he quickly locks the door and takes a gun out of a drawer. The story leads strongly to the expectation of rape or mugging. However, the story ends very differently. After recovery from her initial shock, she hears him say that he invited her inside in order to protect her because, while filling the tank, he had seen someone hiding on the floor in the back of her car. Comprehension of such stories involves a more or less instantaneous global reorganization. One would expect such reorganizations to be prohibited to the extent that long-term pre-functional associations connected schema constituents, and facilitated to the extent that relations between elements were temporary and post-functional. For a psychobiological discussion of how such shifts of activation might occur, see Arbib (1980).

Remembering and Learning

According to the functional view, remembering is a by-product of cognitive functioning. It is built into the properties of specialized neuronal elements and can be described only indirectly in terms of the initiation of activation in neuronal elements, for instance. The principles underlying remembering are essentially those which underlie other higher brain functions such as thinking. There is no need to postulate memory-specific mechanisms (e.g., retrieval systems) or structures (see Jenkins, 1977). In other words, the functional view makes it possible to see through the construct of "memory" and, once this is done, the components seem less memory-like, in the traditional sense of the term.

The type of problems facing different kinds of memory theories are multifarious. The "storage" metaphor gives rise to severe problems of organization and "address" (Norman, 1980), while the neural-wire theory runs into what Minsky calls the "crossbar" problem. Norman (1980) has brought such problems together in the following paragraph:

> Associations among memory concepts . . . simply will not do. That implies much too much knowledge of the wire (or its biological equivalent) that is to snake its way among the already existing stuff . . . Alternatives to wires are not easy to find, the major candidate being numbered, labeled places . . . Then, the association between two memory structures is done by giving each one the unique name of the other, trusting to the existence of some clever machinery that can get

from one place to another if only it has this name. This problem--I call it the "address problem"--is fundamental to the organization of any large scale associative memory. (p. 22)

In rejecting the notion of a long-term associative memory, the functional view seems to create a new problem. If mental structures and relations are transient, how can people remember anything? That this question appears to be so challenging seems to us to be a reflection of the deep-seatedness of the permanent-storage metaphor. However, we are not alone in calling such models into question. From time to time, others have also questioned the validity of traditional memory metaphors. For example, Bransford et al. (1977) write:

> It seems reasonable to suggest that current uses of the term memory frequently involve tacit or explicit assumptions not too different from those noted by Ebbinghaus [as unsuitable]: for example, that memory can be broken down into a set of memories, that these consist of relatively independent traces that are stored in some location, that these traces must be searched for and retrieved in order to produce remembering, and that appropriate traces must be "contrasted" in order for past experiences to have their effects on subsequent events. If memory is defined in this way, it becomes necessary to consider the possibility that the concept of memory (and memories) is simply one of many general hypotheses about the processes underlying remembering." (pp. 431-432)

Like Bartlett (1932), Bransford et al. (1977) and Jenkins (1977) also provide genuine alternatives. In fact, we believe they have essentially specified the major ingredients of a functional theory of remembering. They have argued that "memory performance is . . . not simply a function of local properties of individual traces, but is rather a function of the global characteristics of the set of acquisition experiences as a whole" (Bransford et al., 1977, p. 463). Similarly, Bartlett (1932) argued that remembering is "built out of our attitude towards a whole active mass of organized past reactions and experiences" (p. 213).

Since we have defined the global properties of the schema-of-the-moment, we can characterize remembering as the recreation of a schema-of-the-moment with global properties the same as those of a previous schema-of-the-moment, but, of course, with inevitable local differences. The coherent global totality maintains the continuity of the original experience, including its continuity in time, in space, and in personal experiences. Consider, for example, the following simple experiment from Bransford et al. (1977):

> The experimenter approached a group of people in a seminar and stated: "This is a recognition experiment. I want you to tell me whether you have heard these words before . . . That is, heard them between 1:00 and 1:15 yesterday." And the experimenter immediately began reading the words. (p. 441)

The authors report that students violently objected to this procedure, a frequent complaint being "Wait a minute, I don't know where I was." What does the recognition of the words used have to do with the place they were used? If the subjects did manage to remember where they were at the time, would that improve their performance in recalling the words they used? It seems that for these subjects the experiential continuity between the place and the words used was a requirement for proper recognition of the latter.

How is the global totality of past experiences recreated? According to the functional theory, recreation of a past schema-of-the-moment occurs to the extent that prevailing sources of initiation of functioning manage to activate the same constellations of uniquely specialized neuronal elements as were active at the time of the initial creation. These were endogenous functioning (e.g., focussing: see the section on awareness below), exogenous sources (e.g., probing, reminding), and emergent sources (i.e., consonant and dissonant functional relations).

Once the global schema-of-the-moment is recreated, recall production would require individualization (Bartlett, 1932), or unique differentiation (Bransford et al., 1977) of the components of the schema-of-the-moment. According to Bartlett (1932), this is mediated by awareness. The system somehow manages to "turn round upon itself." The global aspect manages to affect the functioning of local components. We believe this is possible because awareness enables the system to get local component constellations of neuronal elements to function independently of the overall schema-of-the-moment. That awareness can influence the activity of neuronal elements, has been postulated by Sperry (e.g., 1976).

We must also say something about what happens between the first creation of a schema-of-the-moment and its subsequent recreation. This is especially important because of the nature of functional relations we postulated among neuronal elements. In other words, in the case of pragmatic consonance, where the activation of one neuronal element can lead to the activation of one of the several equally consonant alternatives, the global schema-of-the-moment cannot provide the basis for determining which of the alternative components was actually active at the time of initial creation. Given this consideration, we are forced to speculate about what happens to neuronal elements from one activation to another; especially, since we assume that a neuronal element can participate in many combinations. It seems that the most parsimonious proposal is to assume (a) that an element can assume one of two possible functional orientations--an excitatory orientation or an inhibitary orientation--and (b) that a given element can somehow preserve the orientation of its most recent activation. This would mean that if there was an A-to-B activation-activation relation at the time of initial creation, the actual A-to-B relation at the time of recall would be the one immediately prior to recall activation. This would imply that in the case of two pragmatically consonant elements or element constellations, a person would normally have no way of determining which of the equally consonant alternatives was actually active in the initial schema-of-the-moment.

Why would an element change orientation?. The dissonance between exogenous and endogenous functioning is one reason. Under the influence of a dissonant just-activated pattern, a neuronal element may be forced to change its orientation. Shifts in orientation may simply change the functional relations within the same schema-of-the-moment. An equally consonant element may replace previously active elements which now undergo inhibition. Orientation changes may also result in dramatic shifts. Ordinarily, such shifts are only partial; there are always enough survivor elements to safeguard a "smooth" transition to the post-shift schema-of-the-moment. Among the survivors may be elements that are endogenously very resistant to change, like those involved in the concepts of self, of space, or of time. However, at times (e.g., during life-threatening circumstances) even these elements could change their orientations. When total shifts occur, a whole set of neuronal elements, which often maintain an excitatory orientation (if not a permanent functional state) to keep the individual's personal history alive, suddenly may reverse this orientation into an inhibitary state. The result would be retroactive amnesia.[7]

It must be reiterated that functional orientation merely affects initiation of functioning. Therefore, while it does affect remembering, it cannot explain it. Remembering occurs as a consequence of the post-functional activity of uniquely specialized and distributed neuronal elements. It is this uniqueness quality that determines, in combination, the remembering (or recreation) of ideas. In other words, changes in orientation may be said to influence the "episodic" relation between neuronal elements, a relation that may change from one episode to another. The permanent memorial competence, on the other hand, would depend on the unique functional properties of individual neuronal elements.

The distinction between changes in functional orientation and the post-functional qualitative properties resposible for the rec..tion of mental patterns can clarify the relative contribution of synaptic interaction as compared to that of individual neurons as physically unitary and functionally autonomous systems. In other words, synaptic interaction may be responsible for changes in functional orientation while unique fuctional characteristics of individual elements could account for remembering itself. If this hypothesis were correct, it would imply that synaptic interaction must be episodic in character while not being uniquely tied to the properties of particular mental structures. Evidence gathered by Kandel and his colleagues (see Kandel, 1979, 1980) suggests that this may indeed be the case. In what he called nonassociative learning, Kandel argued that the two antithetical mechanisms of habituation and sensitization are responsible for what might be referred to as episodic changes in synaptic interaction. Habituation seems to decrease the effectiveness of synaptic interaction while sensitization seems to increase it. Kandel (1979) writes:

> Thus, in these simple instances, learning does not involve a dramatic anatomic rearrangement in the nervous system. No nerve cells or even synapses are created or destroyed. Rather, learning of habituation and sensitization changes the functional effectiveness of previously existing chemical synaptic connections and, in these instances, does so simply by modulating calcium influx in the presynaptic terminals. Thus, a new dimension is introduced in thinking about the brain. These complex pathways, which are genetically determined, appear to be interrupted not

by disease but by experience, and they can also be restored by experience.

Finally, the present account of remembering also has implications for the problem of learning. As Bransford et al. (1977) have noted, the currently predominant "tacit assumptions [are] that learning necessarily results in memories, and that these stored memories are responsible for mediating new interactions with the world" (p. 433). If learning is not the accumulation of more knowledge or more highly structured knowledge representations, then what is it? Although we cannot offer a detailed discussion of this issue here, the functional view indicates that learning must result in (a) neuron specialization, (b) facility in simultaneous functioning of various components of the schema-of-the-moment, and (c) facility in independent functioning of individual components of the schema-of-the-moment. Thus, one outcome of learning would be the establishment of basic repertoires of specialized neuronal elements in various independent regions of the nervous system--visual, motor, and so on. This type of learning is likely to occur during initial stages and may occur slowly and incrementally. But having a basic repertoire of specialized elements does not by itself make up the difference between an expert and a novice. If the functional theory is correct, this difference must lie in the ability to use the components (elements or constellations) of the schema-of-the-moment (a) in combination and (b) independently. An expert can maintain a global pattern and at the same time use local components of the schema-of-the-moment individually. The task of the functional theory, therefore, is to specify the functional conditions that lead to the establishment of basic repertoires of specialized neuronal elements. It would also have to specify what functional conditions lead to facility in simultaneous functioning of various local regions and independent functioning of element constellations in a particular region.

Awareness and Affect

A crucial aspect of cognition is the phenomenon of awareness. The functional approach allows an explicit account of it. It was stated earlier that the neuronal system consists of an unspecified number of uniquely specialized neuronal elements. One cornerstone of such specialization was the assumption that a unique feeling of awareness would result from the functioning of each uniquely specialized neuronal element. In other words, a particular neuronal element, when in action, can generate a unique "feeling of knowing," that the given element is in a state of functioning. This is, as it were, the element's way of announcing, to the global system, that "I'm doing something." Note that this claim does not presuppose a homunculus to "perceive" the feeling of knowing and to identify it as such. It simply indicates that the active neuronal element generates a characteristic feeling which, in combination with the feelings associated with other functioning elements, creates the unitary awareness of the moment.

The characteristic feeling of knowing associated with a neuronal element would be generated only if and when that element functioned singly, i.e., independently of any other relevant neuronal element. But presumably this never happens. Rather, neuronal elements function in unison (e.g., as part of the schema-of-the-moment). To the extent that they do this, they generate nonspecific unitary patterns of awareness, patterns unlike those which would accompany independent functioning of individual components. As the number of functioning elements increases, the resulting unitary awareness pattern becomes more and more nonspecific, i.e., different from the awareness of individual components. Once again, the light constellation analogy may be helpful. When a light with a unique color is on alone, it generates precisely its characteristic pattern of light. When there is a second light with a different color, a third unitary light pattern is generated, different from that generated by either of the two individual units alone. However, the characteristic color of individual light patterns is more evident (or explicit) in a two-unit light constellation than, say, in a hundred-unit constellation. Similarly, as the extent of neuronal functioning increases the pattern becomes more diffuse (nonspecific) and awareness of individual components becomes more implicit.

One important consequence of this view of awareness is that it provides a way of conceptualizing tacit knowing (Polanyi, 1958). We may know something and constantly use it, but unless we localize or individualize it we may never become explicitly aware of it. This naturally leads us to consider a complementary function, namely, that involved in individualization (i.e., independent usage) of the components of the schema-of-the-moment.

According to Bartlett (1932), localization of schema constituents is an essential aspect of cognitive functioning and it must happen even to refined levels of differentiation though not normally to the level of atomic neuronal elements:

> If any marked further advance is to be achieved, man must learn how to resolve the 'scheme' into elements, and how to transcend the original order of occurrence of these elements. This he does, for he learns how to utilize the constituents of his own 'schemes,' instead of being determined to action by the 'schemes' themselves, functioning as unbroken units. He finds out how to "turn round upon his own schemata," as I have said--a reaction literally rendered possible by consciousness, and the one which gives to consciousness its pre-eminent function. (Bartlett, 1932, p. 301)

But if individual components seldom function singly, and if a component must function independently for its characteristic feeling of knowing to be experienced, how is explicit awareness of individual components possible? How can a component be part of the schema-of-the-moment and function independently of it at the same time? One, and perhaps the only possibility is that there occurs some change in the functioning of a component. Explicit awareness of a single component is experienced when the latter undergoes a change in relation to the global schema-of-the-moment; since this is how a component can function independently of the global functioning system, whil maintaining its continuity with it. This happens when there are increments or decrements in the level of activation of individual components (neural constellations) relative to the global level of activation of the schema-of-the-moment. In this way, a functional view of cognition attempts to explain both explicit awareness and attention at the same time. The individual becomes explicitly aware of a schema component when there occurs an independent change in that component. As this change occurs, the component becomes the focal center of the system, assuming it is the only one which is undergoing change. In other words, the individual attends to the component. Independent functioning, explicit awareness, and attention become three aspects of the same phenomenon. This can be the case, whether the source of the change is endogenous or exogenous.

An example of failure of an element to function independently is provided by the tip-of-the-tongue phenomenon. We believe this happens because, while a person is implicitly aware of a component, that component does not function independently and, consequently, it cannot be made explicit. A second example of independent functioning of a schema component was first noted by William James (1890): the phenomenon occurs when we "hear" the ticking of our clock only after it stops. Presumably, before the clock stops, there is an activation-activation irrelevant relationship in the schema-of-the-moment between neuronal elements involved in the perception of (a ticking) clock and the rest of the schema-of-the-moment. We cannot hear the clock because the auditory elements responsible for the perception of the sound are not functioning independently. However, cessation of stimulation at the time the clock stops, causes the activation-activation relationship to change suddenly to an activation-inhibition relationship. Consequently, this independent functioning makes our awareness of the functioning of the neuronal elements involved explicit.

The functional view of awareness also suggests an alternative account of affect and its relation to cognition. While from time to time, many influential psychologists have emphasized the prominent role of affect in organismic functioning (Bartlett, 1932; Berlyne, 1971, 1973; Huey, 1908; Wundt, 1874, 1907), current structural and information processing theories of cognition and comprehension have either found it difficult to incorporate or have simply ignored it (Zajonc, 1980). Empirically, this absence of a sound theory of affect has led to a great number of unrelated experiments resulting in often inconclusive and contradictory data (Athey, 1976).

Perhaps the most immediate problem facing a theory of affect is to provide a plausible account of the nature of arousal and affective valence. The functional view defines valence in terms of the awareness associated with the activity of uniquely specialized neuronal elements. We are led, therefore, to assume that the totality of all neuronal elements may divide into three broad categories: Those generating a negative valence, those generating a positive valence, and those generating a neutral valence. This would imply that the causal loci of the affective valence in the schema-of-the-moment are the participating neuronal elements. According to this view, the functioning of a given constellation of neuronal elements has two independent aspects: A domain-specific valence aspect and a domain-independent activity aspect (arousal?). While the former depends on the awareness of the particular constellation, which varies from one constellation to another, the latter has to do with the very act of functioning itself, which remains the same from one constellation to another.

This distributed account of affective functioning may be contrasted with the view that affective variables such as hedonic tone, preference, and interestingness are a function of the amount of activity in some unitary arousal system (Berlyne, 1960, 1973, Hebb, 1955). Optimal-level arousal theories essentially assume that moderate increments in arousal are pleasurable and increments beyond some optimal amount are aversive. While many authors have challenged the notion of an optimal-level function (e.g., Arkes & Garske, 1978), there exists no empirical evidence contradicting it. Arkes and Garske have pointed out that "the problem is simply that an inverted-U relation allows so many possible curves that the theory is difficult to disprove" (p. 164). The fact that the inverted-U function has drawn the attention of so many researchers in spite of the severe problems associated with it suggests that the problem may also have to do with the absence of an alternative view to conceptualize the relationship between arousal and affective variabbles. In a recent demonstration experiment Iran-Nejad and Ortony (Note 1) explored the utility of a framework which seems to make it possible to test the inverted-U function. They reasoned that if the optimal-level hypothesis is correct, then a given level of arousal should always be either pleasant or unpleasant, but could not be both. They therefore attempted to show that under different conditions the same level of arousal can be both pleasant and unpleasant. Following the notion of the independence of arousal and valence, the study involved separate manipulations of these variables. The degree of arousal was manipulated by varying the degree of unexpectedness of story endings and valence was manipulated by varying story endings so as to invoke positive or negative feelings. It was found that endings receiving identical (extreme) unexpectedness ratings were rated at opposite ends on an (un)pleanantness scale depending on the valence invoked by the events in the story. Thus, it was shown that a given level of arousal can be compatible with both positive and negative affect, a finding that is difficult to accommodate within the framework of optimal-level arousal theories.

General Summary

This paper has tried to draw an alternative picture of cognition and comprehension. Starting with only one physically unitary and functionally autonomous construct, namely, the neuronal element, we have tried to show that cognition may be more readily conceptualized as a functional phenomenon. Our account is built around a central psychological construct, the schema-of-the-moment, that is explained in terms of the functioning of neuronal elements.

Figure 1 illustrates the major causal relations characterizing the two-way interface between mental experiences and the functioning of the nervous

---

Insert Figure 1 about here

---

system. Changes in the activity of distributed neuronal elements serve as the causal basis for mental experiences of awareness and attention. Mental experiences, in turn, are assumed to have a causal effect on the activity of neuronal elements. The central cells in the model are those of independent and simultaneous functioning. The totality of active neuronal elements tend to function in concert to the extent that they are consonant. Furthermore, subgroups of neuronal elements may function independently of the background functioning in the schema-of-the-moment. Such simultaneous and independent functioning are direct causal determinants of the experiences of awareness and attention.

Even though they arise from the same causal origin, awareness and attention themselves serve as the causal basis for different mental judgements. Attention is assumed to be the basis for the subjective judgment of interestingness, while awareness seems to give rise to the judgment of valence and to judgments concerning the particular content (or meaning) of the functioning constellation. In other words, while attention seems to vary only with the degree of activity in a constellation and remains constant otherwise, awareness seems to vary from one constellation to another, depending on the specific properties of the functioning constellation.

The totality of active neuronal elements create a transient functional organization called the schema-of-the-moment. Simultaneous functioning in terms of the schema-of-the-moment is thwarted to the extent that there are active dissonant or irrelevant elements in it, and to the extent that elements that must enter the chain of combination are still inactive. These factors provide the causal basis for such subjective judgments as consistency, inconsistency, suspense, curiosity, expectation, completeness, coherence, and so on.

Throughout this paper, we have tried to specify the functional properties of the nervous system that determine the causal paths leading from the activity of neuronal elements to mental experiences and judgments. However, the present account is rather vague about the functional properties that determine the causal influence of mental states on the functioning of neuronal elements. We have assumed that the schema-of-the-moment, via the notion of <u>tuning</u>, affects the functioning of elements. As Figure 1 shows, this is accomplished by the causal influence on inactive elements of what is already active. In other words, active components of the schema-of-the-moment must be utilized as a source of initiation of functioning in inactive elements. This is possible because if a component of the schema-of-the-moment functions independently, it generates a characteristic energy pattern that can serve as a sufficient condition for activating other elements.

Two types of relational vehicles were hypothesized to provide the basis for the functioning of distributed neuronal elements: A specific, element-to-element mechanism, and a nonspecific, "all-spreading" relational environment. The relations among neuronal elements are consonance, dissonance, or irrelevance. Consonant relations are purely functional, logical, or pragmatic. Dissonant relations are either resolvable or non-resolvable.

Unlike traditional views, the present account considers affective functioning to be no different from cognitive functioning. There is explicit or implicit awareness of the functioning of (positive, negative, or neutral) element constellations, depending on whether or not there are independent changes in the level of activation of these constellations. Affective functioning often takes place to the extent that pre-existing connections are unavailable and to the extent that initiation of functioning must depend on external sources.

Learning occurs when neuronal elements get specialized, when elements or element constellations are used in new combinations, and when schema constituents are individualized, i.e., come to be used independently.

Finally, a word about the empirical consequences of the functional view: Because the functional view, as outlined in this paper, is intended to provide a coherent global perspective on cognition, we have made no effort to make specific empirical predictions. Such predictions require more detailed hypotheses concerning particular aspects of mental functioning. Nevertheless, we think that, apart from offering an account of cognition in terms of relatively concrete constructs, the functional view has one other attractive feature. It offers the promise of a rapprochment among areas of the cognitive sciences that traditionally have been not very closely related.

Reference Note

1 Iran-Nejad, A., & Ortony, A. Quantitative and qualitative sources of affect: How unexpectedness and valence relate to pleasantness and preference. Unpublished manuscript, University of Illinois, November 1979.

References

Adams, J. A. Feedback theory of how joint receptors regulate the timing and positioning of a limb. Psychological Review, 1977, 84, 504-523.

Anderson, J. A., Silverstein, J. W., Ritz, S. A., & Jones, R. S. Distinctive features, categorical perception, and probability learning: Some applications of a neural model. Psychological Review, 1977 84, 413-451.

Anderson, R. C., Reynolds, R. E., Schallert, D. L., & Goetz, E. G. Frameworks for comprehending discourse. American Educational Research Journal, 1977, 14, 367-381.

Arbib, M. A. Visuomotor coordination: From neural nets to schema theory. Cognition and Brain Theory, 1980, 4, 23-39.

Aronson, E. Dissonance theory: Progress and problems. In R. P. Abelson, E. Aronson, W. J. McGuire, T. M. Newcomb, M. J. Rosenberg, & P. H. Tannenbaum (Eds.), Theories of cognitive consistency: A sourcebook. Chicago: Rand McNally, 1968. Pp. 5-27.

Athey, I. J. Developmental processes and reading processes--invalid inferences from the former to the latter. In H. Singer & R. B. Ruddell (Eds.), Theoretical models and processes of reading. Newark, Del.: International Reading Association, 1976. Pp. 730-742.

Attardi, D. G., & Sperry, R. W. Central routes taken by regenerating optic fibers. Physiologist, 1960, 3, 12.

Attardi, D. G., & Sperry, R. W. Preferential selection of central pathways by regenerating optic fibers. Experimental Neurology, 1963, 7, 46-64.

Bartlett, F. C. Remembering: A study in experimental and social psychology. Cambridge, England: Cambridge University Press, 1932.

Beard, R. M. An outline of Piaget's developmental psychology for students and teachers. New York: Basic Books, 1969.

Berlin, B., & Kay, P. Basic color terms: Their universality and evolution. Berkeley: University of California Press, 1969.

Berlyne, D. E. Conflict, arousal, and curiosity. New York: McGraw Hill, 1960.

Berlyne, D. E. Aesthetics and psychobiology. New York: Appleton-Century-Crofts, 1971.

Berlyne, D. E. The vicissitudes of aplopathematic and thelematoscopic pneumatology (or The hydrography of hedonism). In D. E. Berlyne & K. B. Madsen (Eds.), Pleasure, reward, preference. New York: Academic Press, 1973.

Bower, G. H. Experiments on story comprehension and recall. Discourse Processes, 1978, 1, 211-231.

Bower, G. H. Mood and memory. American Psychologist, 1981, 36, 129-148.

Bransford, J. D., & Johnson, M. K. Contextual prerequisites for understanding. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 717-726.

Bransford, J. D., McCarrell, N. S., Franks, J. J., & Nitsch, K. E. Toward unexplaining memory. In R. E. Shaw & J. D. Bransford (Eds.), Perceiving, acting, and knowledge: Toward an ecological psychology. Hillsdale, N. J.: Erlbaum, 1977.

Bransford, J. D., Nitsch, K. E., & Franks, J. J. Schooling and the facilitation of knowing. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), Schooling and the acquisition of knowledge. Hillsdale, N.J.: Erlbaum, 1977.

Brewer, W. F. Memory for pragmatic implications of sentences. Memory and Cognition, 1977, 5, 673-678.

Chomsky, N. Rules and representations. The Behavioral and Brain Sciences, 1980, 3, 1-15.

Chomsky, N. A naturalistic approach to language and cognition. Cognition and Brain Theory, 1981, 4, 3-22.

Edelman, G. M. Group selection and phasic reentrant signaling: A theory of higher brain function. In G. M. Edelman & V. B. Mountcastle (Eds.), The mindful brain. Cambridge: The MIT Press, 1978.

Eliashberg, V. The concept of E-Machine: On brain hardware and the algorithms of thinking. In Proceedings of the Third Annual Conference of the Cognitive Science Society. Berkeley, California, August 1981, 289-291.

Feldman, J. A. A distributed information processing model of visual memory (Tech. Rep. No. 52). Rochester: University of Rochester, Computer Science Department, December 1979.

Festinger, L. A theory of cognitive dissonance. Stanford, Calif.: Stanford University Press, 1957.

Freeman, W. Mass action in the nervous system. New York: Academic Press, 1975.

Gallistel, C. R. The organization of action: A new synthesis. Hillsdale, N. J.: Erlbaum, 1980.

Goleman, D. Holographic memory. Psychology Today, February 1979, 71-84.

Head, H. Studies in neurology (2 vols.). London: Frowde, 1920.

Hebb, D. O. Drives and the C.N.S. (conceptual nervous system). Psychological Review, 1955, 62, 243-254.

Hubel, D. H., & Wiesel, T. N. Receptive fields of single neurons in the cat's striate cortex. Journal of Physiology (London), 1959, 148, 574-591.

Hubel, D. H., & Wiesel, T. N. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. Journal of Physiology (London), 1962, 160, 106-154.

Hubel, D. H., & Wiesel, T. N. Receptive fields and functional architecture in two non-striate visual areas (18 and 19) of the cat. Journal of Neurophysiology, 1965, 28, 229-289.

Hubel, D. H., & Wiesel, T. N. Brain mechanisms of vision. In Readings from Scientific American: Mind and behavior. San Francisco: Freeman, 1980.

Huey, E. B. The psychology and pedagogy of reading. New York: Macmillan, 1908.

Iran-Nejad, A. The schema: A structural or a functional pattern (Tech. Rep. No. 159). Urbana: University of Illinois, Center for the Study of Reading, February 1980.

James, W. Principles of psychology. New York: Holt, 1890.

Jenkins, J. J. Remember that old theory of memory? Well, forget it. In R. E. Shaw & J. D. Bransford (Eds.), Perceiving, acting, and knowledge: Toward an ecological psychology. Hillsdale, N. J.: Erlbaum, 1977.

Jenkins, J. J. Can we have a fruitful cognitive psychology? In J. H. Flowers (Ed.), Nebraska symposium on motivation, 1980. Lincoln: University of Nebraska Press, 1981.

John, E. R. Mechanisms of memory. New York: Academic Press, 1967.

John, E. R. Switchboard versus statistical theories of learning and memory. Science, 1972, 177, 850-864.

John E. R., & Killam, K. F. Electrophysiological correlates of avoidance conditioning in the cat. Journal of Nervous & Mental Disease, 1960, 131, 183.

John, E. R., & Schwartz, E. L. The neurophysiology of information processing and cognition. Annual Review of Psychology, 1978, 29, 1-29.

Kandel, E. R. Psychotherapy and the single synapse. The New England Journal of Medicine, 1979, 301, 1028-1037.

Kandel, E. R. Small systems of neurons. In Readings from Scientific American: Mind and Behavior. San Francisco: Freeman, 1980.

Katchalsky, A. K., Rowland, V., & Blumenthal, R. Dynamic patterns of brain cell assemblies. Cambridge, Mass.: The M.I.T. Press, 1974.

Kay, P. Color perception and the meaning of color words. In Proceedings of the Third Annual Conference of the Cognitive Science Society. Berkeley, California, August 1981, 289-291.

Kay, P., & McDaniel, C. K. The linguistic significance of the meanings of basic color terms. Language, 1978, 54, 610-646.

Kintsch, W. Learning from text, levels of comprehension, or: Why anyone would read a story anyway. Poetics, 1980, 9, 87-98.

Kintsch, W., & van Dijk, T. A. Toward a model of text comprehension and production. Psychological Review, 1978, 85, 363-394.

Mandler, G. The structure of value: Accounting for taste (CHIP Rep. No. 101). La Jolla: University of California, Center for Human Information Processing, May 1981.

Maturana, H. R. Biology of language: The epistemology of reality. In G. A. Miller & E. Lenneberg (Eds.), Psychology and biology of language and thought: Essays in honor of Eric Lenneberg. New York: Academic Press, 1978.

McHugh, P. Defining the situation: The organization of meaning in social interaction. New York: Bobbs-Merrill, 1968.

Meyer, R. L., & Sperry, R. W. Retinotectal specificity: Chemoaffinity theory. In Neural and behavioral specificity: Studies on the development of behavior and the nervous system, Vol. 3. New York: Academic Press, 1976.

Miller, J. The body in question. New York: Random House, 1978.

Minsky, M. K-lines: A theory of memory. Cognitive Science. 1980, 4, 117-133.

Nicholson, C. Brain-cell microenvironment as a communication channel. The Neurosciences, 1979, 457-476.

Norman, D. A. Twelve issues for cognitive science. Cognitive Science, 1980, 4, 1-32.

Palmer, E. S. Fundamental aspects of cognitive representation. In E. Rosch & B. B. Lloyd (Eds.), Cognition and categorization. New York: Wiley, 1978.

Piaget, J. Structuralism. New York: Harper & Row, 1970 (originally published 1968).

Piaget, J. Biology and knowledge. Chicago: The University of Chicago Press, 1971.

Pichert, J. W., & Anderson, R. C. Taking different perspectives on a story. Journal of Educational Psychology, 1977, 69, 309-315.

Polanyi, M. Personal knowledge: Towards a post-critical philosophy. Chicago: University of Chicago Press, 1958.

Pylyshyn, Z. W. What the mind's eye tells the mind's brain: A critique of mental imagery. Psychological Bulletin, 1973, 80, 1-24.

Rose, S. The conscious brain. New York: Vintage Books, 1976.

Rumelhart, D. E. Schemata: The building blocks of cognition. In R. J. Spiro, B. C. Bruce, & W. F. Brewer (Eds.), Theoretical issues in reading comprehension. Hillsdale, N.J.: Erlbaum, 1980.

Rumelhart, D. E. Toward an interactive model of reading. In S. Dornic (Ed.), Attention and performance, VI. Hillsdale, N.J.: Erlbaum, 1977.

Rumelhart, D. E., & Ortony, A. The representation of knowledge in memory. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), Schooling and the acquisition of knowledge. Hillsdale, N.J.: Erlbaum, 1977.

Schallert, D. L. Improving memory for prose: The relationship between depth of processing and context. Journal of Verbal Learning and Verbal Behavior, 1976, 15, 621-632.

Schank, R. C. Interestingness: Controlling inferences. Artificial Intelligence, 1979, 12, 273-297.

Schmitt, F. O. Introduction. In G. M. Edelman & V. B. Mountcastle (Eds.), The mindful brain. Cambridge: The MIT Press, 1978.

Schmitt, F. O. Brain cell membranes and their microenvironment. In F. O. Schmitt, T. Melnechuk, G. C. Quarton, & G. Adelman (Eds.), Neurosciences research symposium summaries (Vol 4). Mass.: The M.I.T. Press, 1970.

Sperry, R. W. Visuomotor coordination in the newt (triturus viridescens) after regeneration of the optic nerve. Journal of Comparative Neurology, 1943, 79, 33-55.

Sperry, R. W. Selective communication in nerve nets: Impulse specificity vs. connection specificity. In F. O. Schmitt & T. Melnechuk (Eds.), Neurosciences research symposium summaries (Vol 1). Mass.: The M.I.T. Press, 1966.

Sperry, R. W. A modified concept of consciousness. Psychological Review, 1969, 76, 532-536.

Sperry, R. W. Mental phenomena as causal determinants in brain function. In G. G. Globus, G. Maxwell, & I. Savodnik (Eds.), Consciousness and the brain. New York: Plenum Press, 1976.

Thatcher, R. W., & John, E. R. Foundations of cognitive processes. New York: Hillsdale, 1977.

Thurmond, P. J. If cornered, scream. Ellery Queen's Mystery Magazine, January, 1978, 66-68.

Uttal, W. R. The psychobiology of mind. New York: Wiley, 1978.

Wall, P. D. Functional specificity. In F. O. Schmitt & T. Melnechuk (Eds.), Neurosciences research symposium summaries (Vol 1). Mass.: The M.I.T. Press, 1966.

Weiss, P. Selectivity controlling the central-peripheral relations in the nervous system. Biological Review, 1936, 11, 494-531.

Weiss, P. A. Specificity in neurosciences. In F. O. Schmitt & T. Melnechuk (Eds.), Neurosciences research symposium summaries (Vol 1). Mass.: The M.I.T. Press, 1966.

White, B. W., Saunders, F. A., Scadden, L., Bach-Y-Rita, P., & Collins, C. C. Seeing with the skin. Perception and Psychophysics, 1970, 7, 23-27.

Wundt, W. Grundzuge der physiologischen psychologie. Leipzig: Englemann, 1874.

Wundt, W. Outlines of psychology. Leipzig: Wilhelm Englemann, 1907.

Zajonc, R. B. Feeling and thinking: Preferences need no inferences. American Psychologist, 1980, 35, 151-175.

Footnotes

The research reported herein was supported in part by the National Institute of Education under Contract No. HEW-NIE-C-400-76-0116, and in part by a Spencer Fellowship awarded to the second author by the National Academy of Education.

[1] There is a striking parallel between the approach taken by the Roman physiologist Galen (c.AD 130-201) and current information processing psychology. Galen was concerned with how inanimate matter, as the input to the body via foodstuff, is transformed to animate matter. Internal organs (e.g., the heart, the liver, the lungs) were considered relevant to the extent that they helped carry out such transformations. In Galen's physiology, as in information processing psychology, "the most notable feature of the system is the emphasis on manufacture and transformation. . . processes which convert . . . substances" (Miller, 1978, p. 187). Information processing psychology takes the input-transformation-output metaphor for granted. How do we know--what evidence is there--that there exists some sort of permanent cognitive substance and that the brain does actually perform transformations on it? And if there is no permanent object-like entity, what does the metaphor mean?

[2] It is perhaps this required dependence of the term function on an actual functioning system which renders it unpalatable to some structuralists. For instance, in the opening paragraph of a section entitled Structure and Function Piaget (1970) states that "there are thinkers who dislike 'the

subject,' and if this subject is characterized in terms of its 'lived experience' we admit to being among them" (p. 68). Viewed in the light of the structuralist's ultimate goal, the dislike for the actual subject becomes clear. The structuralist hopes to characterize all possible knowledge structures at some general level, structures which are not likely to exist in totality in any individual organism. Consequently, structuralism is forced to call "for a differentiation between the individual subject, who does not enter at all, and the epistemic subject, that cognitive nucleus which is common to all subjects at the same level" (Piaget, 1970, p. 139). Structuralists must create the epistemic subject because they assume that it is the structural knowledge patterns which constitute the common denominators (the cognitive nucleus) that the scientist must try to characterize.

[3]The notion of structural preformation has been carried to the extreme in Chomsky's modular approach to human mental capacities. According to Chomsky (e.g., 1980, 1981), there exist innately programmed "mental organs" for such human capacities as comprehending a language or doing mathematics in much the same way as there are bodily organs like the liver, the heart, or even the arm. Chomsky's major response to those who object to his strict nativism is that critics have not presented a clearer alternative. We believe the functional approach does provide a clear alternative: Innate structures may only exist at the biological and not at the mental level. For instance, the nervous system may contain highly specialized innate neuronal elements (e.g., sensory receptor cells), grossly specialized innate components (e.g., visual, auditory, motor, etc., cortexes), as well as multi-purpose highly adaptive

components. More finely articulated specialization can then come with development and learning. An organism with such innate endowment could also function "in a rich and complex world of understanding shared with others similarly endowed, extending far beyond limited and varying experience" (Chomsky, 1980, p. 4), qualities that lead Chomsky to hypothesize innate mental organs. According to the functional approach, complex capacities such as language comprehension do not depend on any unified knowledge organs, innate or acquired. Rather, mental capacities are distributed across diverse biological structures, neuroanatomic and otherwise. The fact that human beings have a highly complex language and other animals do not--if this turns out to be indeed the case--can be attributed, for instance, to such differences as the shape of their mouths and vocal organs (which are incidentally used in eating, coughing, singing, etc.) as well as to the presence or absence of multi-purpose adaptive components. What one need not hypothesize is innate knowledge structures. Biological modulation, as opposed to mental modulation, can account for both universal similarity and diversity in organismic species.

[4]Recognition has at least two aspects: Re-experiencing a past experience, and realizing that the experience has occurred in the past--that it is not a novel experience. We believe both of these aspects should and can be specified in terms of the functioning of neuronal elements rather than in terms of cognitive associations.

[5]Dissonant conditions may be resolvable or non-resolvable and resolvable dissonance may lead to precedented or to unprecedented functional

organizations. Specification of these concepts would require a more detailed analysis of the functional relations than is necessary or appropriate in the present context.

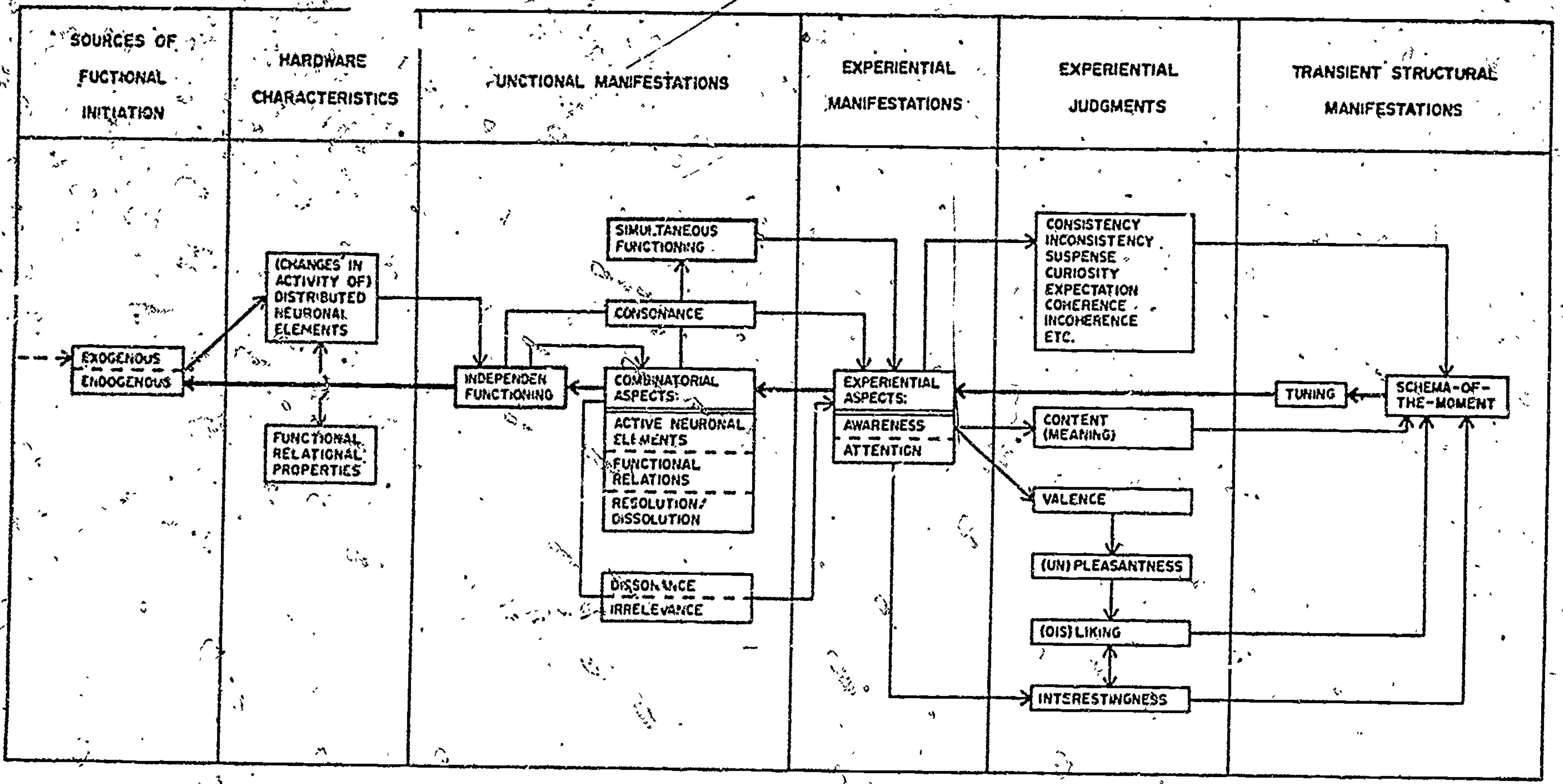
[6]How does the interaction among endogenous, exogenous, and emergent sources of initiation differ from such traditional concepts as accommodation and assimilation? As it is commonly defined, accommodation, for example, refers to gradual developmental changes in knowledge structures. It "displays itself in exploration, questioning, trial and error, making experiments or by reflection" (Beard, 1969, p. 19). Even if we extend this concept to include functional changes, it can only meaningfully describe incremental changes in the structure of the same schema-of-the-moment. It is not clear how Piagetian structural theory can explain dramatic shifts of activation which seem to occur automatically under the influence of exogenous sources. As we mentioned earlier, there are two aspects to the interaction between endogenous and exogenous functioning. First, there is the interaction between local and global aspects of the same schema-of-the-moment. The just-activated constellation is either consonant, fully or in part, with the global functioning system or it is dissonant with some local elements only. It does not disrupt the global functioning pattern. The schema-of-the-moment may accommodate and the inconsistency is resolved. The second possibility is that functional dissonance disrupts the global post-functional relations; the latter temporarily "decomposes" so the elements are free to participate in a new schema-of- e-moment. This functional condition sets the stage for a global reorgani...tion. It is this requirement of "decomposition" that

necessitates the involvement of transient functional relations, as opposed to the long-term changes implied by the concept of accommodation. In short, accommodation refers to gradual structural changes. Dramatic functional reorganizations, on the other hand, can, in principle, lead, often automatically, to new functional organizations with new global properties rather than to accommodated versions of an earlier schema.

[7]We are indebted to Richard Vondruska for bringing this point to our attention.

Figure Caption

Figure 1. Simplified Diagram of the Principle Causal Relations in the Functional Model of Cognition


SOURCES OF FUCTIONAL INITIATION
HARDWARE CHARACTERISTICS
FUNCTIONAL MANIFESTATIONS
EXPERIENTIAL MANIFESTATIONS
EXPERIENTIAL JUDGMENTS
TRANSIENT STRUCTURAL MANIFESTATIONS
EXOGENOUS
ENDOGENOUS
(CHANGES IN ACTIVITY OF) DISTRIBUTED NEURONAL ELEMENTS
FUNCTIONAL RELATIONAL PROPERTIES
INDEPENDEN FUNCTIONING
SIMULTANEOUS FUNCTIONING
CONSONANCE
COMBINATORIAL ASPECTS:
ACTIVE NEURONAL ELEMENTS
FUNCTIONAL RELATIONS
RESOLUTION/ DISSOLUTION
DISSONANCE
IRRELEVANCE
EXPERIENTIAL ASPECTS:
AWARENESS
ATTENTION
CONSISTENCY
INCONSISTENCY
SUSPENSE
CURIOSITY
EXPECTATION
COHERENCE
INCOHERENCE
ETC.
CONTENT (MEANING)
VALENCE
(UN) PLEASANTNESS
(DIS) LIKING
INTERESTINGNESS
TUNING
SCHEMA-OF-THE-MOMENT