

7

The Brain as the Locus of Cognitive Controls on Action

Karl H. Pribram
Stanford University

INTRODUCTION

Psychology has made great strides over the past century and a half in providing experimental observations in an area of inquiry that hitherto had been the exclusive domain of philosophical analysis. However, the science of psychology is now beset with the difficulty of organizing its data into a coherent body of knowledge. This lack of organization becomes a critical factor when the results of neurobehavioral experiments are reported: The relationship of brain organization to mind as adduced from the effects of brain recordings, lesions, and excitations must be framed coherently to be communicated. Yet, in my own work for example, I have completed some 30 experiments on the functions of the frontal cortex in as many years in order to obtain some idea of what might have been the effects of the human lobotomy procedures—only to find that these effects can be couched in the language of motivation and emotion, decision theory, operant reinforcement theory, or the paradigms used by experimentalists interested in attention, cognitive learning, memory, or even perception. Now it is certainly possible that perhaps all psychological processes are influenced by the frontal lobe of the brain, but if this is so, there should still be a way of systematically reporting how. For an understanding of mechanism one must at least have some rudimentary idea of what one is searching a mechanism for—in short, what is the relationship among emotion, motivation, decision, reinforcement, attention, cognitive learning, memory, and perception?

The fact that the various approaches to psychology have produced a variety of conceptual and experimental frames of psychological inquiry is obvious.

Each "school" of psychology is concerned mainly with its own body of evidence and only dimly aware that alternate schools exist. Such dim awareness can take the form of complete dissociation and denial, of a more or less mild "put down," or of active conflict. Only rarely (Estes, 1970; Pribram, 1970a) is any effort made to examine the relationship of the alternate conceptual-evidential frames to one another. What appears to be lacking is some set of operational definitions that lead from one conceptual domain to another. Only when such definitions become available will there be a nontrivial *modus operandi* for coming to grips with the Tower of Babel that now constitutes scientific psychology.

BEHAVIORAL ACTS

Central to this confusion in which psychology finds itself is the topic of this chapter: the relationship of cognition to behavior. At the root of the difficulty is a failure to define what is meant by *behavior* and an often overgenerous interpretation of what is encompassed by *cognition*. For example, experimentalists dealing with human behavior would readily acknowledge cognitive factors in motivation. Experimentalists concerned with animal behavior would have difficulty in understanding the issue: For them, motivation deals largely with the physiological mechanisms comprising hypothalamic and perhaps limbic brain function. And, even more devastating, the animal behaviorist understands by motivated behavior a particular sequence of muscle contractions such as those that produce a sexual display or birdsong, whereas the observer of the human scene is interested in describing the factors responsible for the success or failure of sexual encounters, the production of a musical symphony, or linguistic communication.

As noted, the root of the difficulty lies with the definition of behavior. Ethologists and physiological psychologists ordinarily use the terms *movement* and *behavior* synonymously. Movement is a sequence of muscular contractions. Behavior is therefore identified with series of muscular contractions. By contrast, most experimental and social psychologists use the term *behavior* to denote an action (i.e., an environmental consequence of a series of muscular contractions). Thus the particulars of the muscular sequence or even of which muscles are used become irrelevant. It matters little as to whether writing is accomplished with the left or right hand or even with toes: It is the writing as behavior that is the object of investigation. Skinner, when asked for a definition of behavior, once remarked that the behavior of his pigeons and people was the cumulative record that he took home with him each night to study.

The problem for the physiologically oriented psychologist has been to discern a brain mechanism that can organize actions and not just movement. Such a mechanism, by definition, must account for the potential equivalence among series of muscular contractions, the potential equivalence of movements in the production of an act. In a series of experiments (reviewed in Pribram, 1971) this problem was investigated and evidence was obtained to show that the cerebral motor cortex was involved in action rather than just in the control of muscles or movement. The mechanism appears to be that individual cells in the motor cortex respond to the forces exerted on muscles and sensed by the muscle receptors rather than to the lengthening, shortening, or tonicity of the muscles *per-se*.

The question remained as to how these forces on muscles could become complimented by neural mechanisms in such a way that actions become organized. Experiments by Bernstein (1967) and his successors, Gel'fand, Gurfinkel, Tsetlin, and Shik (1971), and by Turvey and his group (1973) have shown that there is a hierarchy of systems of "coordinate structures" that control muscular sensitivity, movement, and action. Our own work and that of many other neurophysiologists (Granit, 1975; Miller, Galanter, & Pribram, 1960; Pribram, 1971) has suggested that these coordinate structures are composed of feedback servo-loops (Test-Operate-Test-Exit [i.e., TOTE] sequences) that, when arranged in parallel, become feedforward predictive mechanisms.

Neural Holograms

In addition, Bernstein's (1967) work and our own leads to the formulation that the cortical representation of the forces exerted on muscles depends on the fluctuations of such forces. Fluctuations, whether of the vocal apparatus, of gravitational influences in walking, or of the repetitious swinging of a hammer, can be analyzed into their regular sine-wave components according to Fourier's theorem. In fact, Bernstein performed a Fourier analysis of acts and showed that such an analysis provided him with remarkable predictive power.

I have reviewed elsewhere (Pribram, 1971, 1974, 1977, 1978a) the evidence that the cerebral cortex operates as an analyzer of the frequencies of fluctuation, of vibration, and of the sensory input. Over a century ago Ohm (of Ohm's law of electricity) suggested that the auditory nervous system operates as a frequency analyzer, and Helmholtz provided much experimentally obtained support for Ohm's thesis. Bekesy then refined Helmholtz's work and showed that the same principles operated for tactile sensation. Finally, over the past 10 years, largely through the work of Fergus Campbell and John Robson at Cambridge University but supported by

experiments performed in Piza, Leningrad, and at Harvard, MIT, Berkeley, and Stanford (Pribram, 1978a; Pribram, Nuwer, & Baron, 1974), it has been shown that the visual system performs an analysis of the frequency of alternations of light and dark in spatial patterns. It has become clear that sensory and motor mechanisms of the brain depend on such frequency analyses for operation.

This formulation of the brain mechanisms involved in sensory and motor processes has had important consequences for understanding perception and action. These consequences derive from utilizing holograms as analogues to these mechanisms. Holograms are technical instantiations of mechanisms that utilize frequency analysis: image processors (also called optical information processors). Initially, holography was a mathematical invention (Gabor, 1969). Its realization in hardware has been accomplished by storing (on film) the interference patterns of waveforms produced by reflection and diffraction from and through objects. Illumination of the stored interference patterns recreates an image of the objects in a plane removed from the stored patterns. The mathematical descriptions of this holographic process and the brain process delineated previously are identical. A model of holographic brain processes has been developed (Pribram, 1971; Pribram, Nuwer, & Baron, 1974). This model accounts for many hitherto difficult to explain brain-behavior relationships such as the failure of even very large brain lesions to eradicate specific memory traces (engrams) and the facts of equivalence in both sensory and motor function that were noted earlier.

Equivalence and memory sparing come about in holography by the same mechanism. Both are due to the fact that Fourier and similar procedures, called "spread functions," distribute information over wide areas. In short, they blur a point source of light. Many such blurs, which can be likened to ripples emanating from point sources of pebbles thrown into a quiet pool, form interfering wave fronts. When frozen onto a film, a hologram results. An inverse transform (simply performing the Fourier operation a second time) reconstructs the point sources (i.e., the image, much as would showing a film of the ripples on the pond in reverse).

The spread of information over the surface of the encoding medium assures that damage to any one portion of the medium does not delete the information. At the same time, reconstruction of image (and act) can proceed from any location within the hologram (this is called *translation invariance*). Thus equivalence can be accounted for.

To summarize the preceding sections: Our understanding of the relationship between cognition and behavior depends on our definitions and understanding of the concepts involved. We have reviewed the confusions attendant to the term *behavior*, which sometimes refers to movements and at other times to actions. We have developed in some considerable length the concept of behavioral "act" because it is the root concept in experimental and

social psychology. Not only can act be defined as the environmental consequence of movement but the neural mechanism that is responsible for the organization of action can be detailed.

This root definition in hand, let us turn to the problem of specifying what we mean and don't mean by *cognition*. Here, no hard and fast boundaries can be established without consensual consent. For instance, even the limits of what is a language must be agreed upon socially. Purists identify language and speech because the term *language* is derived from *lingua*, Latin for tongue. But in everyday usage we talk about sign language, pictorial language, etc. The problem is not a trivial one but one that must await consensus for solution (Pribram, 1978b).

With this caveat in mind I first attempt some definitions of subject-matters that are often included in cognitive psychology but are not perhaps "cognition" in any strict sense. These definitions form the context for what might then become a more restricted pursuit of what cognitive processes are all about.

Consciousness as Attentional Control

The separateness of various conceptual frames in the study of psychology depends to a large extent on overall organization, not on elements of content (Pribram, 1970a). This is reminiscent of actual psychological experience that is characterized as taking place in a variety of states of consciousness. The same elements can be identified in a dream as in an ensuing hypnogogic period and in ordinary awareness. A bilingual person (Kolars, 1966, 1968) refers to the same content in both languages, just not at the same time nor according to the same rules of reference (or perhaps even grammar). What is composed during a creative period of authorship is recognized later in ordinary perception—it only seems strange that authorship should have occurred at all. Even extraordinary states share considerable content with ordinary ones (Barron, 1965). Thus psychological processes appear to operate within one or another frame or state that excludes for the time being other states. There is evidence, some of which is presently reviewed here, to the effect that a good deal of behavior, behavior modification (learning), verbal communication, verbal report of awareness, and feeling is state dependent. We therefore proceed to explore the assumption that psychological inquiry mirrors the fact that psychological processes are organized into states.

The determination of these brain states can be defined in terms of *attention*. Attention is also central to our understanding of the variety of conceptual frames that characterize current experimental psychology. Attention (from the Latin *hold to*) can be defined as *holding* to one rather than another program. Holding implies span, competency, and effort, all topics of

considerable interest and the focus of much experimental activity in contemporary attention theory (Kahneman, 1973; Pribram & McGuinness, 1975). Holding also implies that certain consistency over time that characterizes a state. Different conscious states are therefore due to the maintenance in operation (i.e., the holding or attending) of different neural programs that structure mnemonic events, sensory, and physiological invariants in different ways. William James (1890), in fact, suggested that all problems of consciousness are reducible to problems of attention.

At least three sources can be identified as giving rise to the events operated upon by attention: sensory input, physiological stimuli arising within the body to which the central nervous system is directly sensitive, and mnemonic stimuli stored within the brain tissue. The fact that a diversity of states shares, to some considerable extent, the content given by these sources suggests that the separateness of these states cannot be attributed per se to sensory processes, to mechanisms arising in body physiology, nor to the way in which memory storage occurs. This does not mean that such stimuli cannot serve as triggers that initiate one or another of the states—in fact there is good evidence (Ornstein, 1972, 1973; Tart, 1971) that triggering stimuli of all three sorts occur in abundance. However, the organization of a particular state cannot be coordinate with stimulus content but must reflect some particular attentional control process.

What, then, characterizes a particular attentional organization in one or another psychological state? We have already ruled out the structure of the sensory input, of physiological stimuli, or of the memory store as critical. There must therefore be involved some organizing process akin to that responsible for retrieval. Such processes are usually referred to as *programs* or as *control functions* (Miller, Galanter, & Pribram, 1960). These map the array of anatomical receptor-brain connectivities into physiological ambiances, ambiances that process invariances in the stimulus configuration into more or less coherent and identifiable structures. In short, the conclusion to be drawn is that differences in psychological states (i.e., states of consciousness) are due to differences between control processes exercised by the brain on sensory and physiological stimulus invariants and on the memory store, not on differences in stimuli or the memory store per se. Let us now take up in detail the varieties of controls as they operate on sensory input, physiological stimuli, and the memory store.

Perception as Feedback Control of Sensory Input

Even before the heyday of classical behaviorism, it was considered a truism that the brain controlled motor function as expressed in behavior. This control was conceived to take place by way of abstractive and associative mechanisms that progressively recoded the input into adaptive motor organizations, the hierarchy of coordinate structures described in the section

on behavioral acts. Today there is a considerable body of evidence that supports the conception that neural systems provide "feature analyses" and that an "association by contiguity" takes place in the brain. However, additional insights have been achieved into feature organization and what is meant by "contiguity" (Pribram, 1971, Chapter 14).

The best known of these insights is the fact that everywhere in the central nervous system closed loops are formed by neural connections. These closed-loop circuits feed part of the output signal back to their input source. Thus subsequent input comes under the influence of previous input. A good deal of neurophysiology of the 1950s and early 1960s, some in my own laboratory, was addressed to discerning the feedback characteristics of such circuits (Pribram, 1974; Pribram & McGuinness, 1975).

Neural control circuits were well-known before the last 25 years, of course. Walter Cannon's laboratory (Cannon, 1929) established the concept of homeostasis to describe the finding that physiological stimulation from an organism's body was under feedback control. What was new was the discovery that feedback control existed everywhere in the central nervous system and regulated sensory as well as physiological input to the brain (Dowling, 1967).

The ubiquity of feedback control made it necessary to alter our conception of what constitutes "association" (Pribram, 1971, Chapter 14). Contiguity no longer refers to just an accidental coincidence in time and place but to a controlled influence of temporally and spatially connected feedback units. Homeostats were found (Ashby, 1960; Pribram, 1969) to be multilinked to produce stable systems that could be perturbed only by gradually establishing new and independent input circuits (habituation). Such systems have the characteristic of matching input to the stable current organization—perturbations indicated novelty; their absence, familiarity. The stable system provides the context in which the input or content is processed. "Association by contiguity" therefore turns out to refer to a context-content matching procedure, not just a simple, haphazard conjoint happening.

In addition, it was possible to establish which parts of the brain accounted for the maintenance of a stable context and which were directly involved in habituation to novelty. A feedback control model of the perceptual functions of the brain thus emerged from a variety of neurophysiological and neurobehavioral studies (Pribram, 1971, Chapter 11).

Emotion and Motivation as Feedback Controls of Physiological (Internal) Stimuli

The actualization of the operation of one or another of these feedback controls constitutes a motivational or emotional process. Emotions and motivations occur where the operation of a feedback is stopped or initiated. The neural substrates of "stop" and "go" mechanisms have been thoroughly

investigated (Pribram, 1971; Pribram & McGuinness, 1975). The stop signals appear to be the more primitive and homeostatic whereas go involves the entire intentional system of neural programs that is discussed more fully in the next section.

The identification of stop and go mechanisms has eased difficulties of definition that have beset the concepts *emotion* and *motivation* (Pribram, 1971, Chapters 9, 10). The difficulties disappear in part by initially correlating emotion with stop mechanisms and motivations with go mechanisms. More complete resolution comes when the more subtle distinction is made between feeling and expression (Pribram, 1970a, 1970b). Feelings, both emotional and motivational, are found to be homeostatically controlled. Thus the stop mechanisms (that process input from both physiological drive and from sensory stimuli and are located in the diencephalic and limbic basal ganglia regions of the brain) sense that equilibrium has been achieved. This corresponds to the emotional feelings of satiety that stop behavior. These same mechanisms sense the perturbation and mismatch that correspond to affect produced by interruption of ongoing behavior.

Expression or intended expression (i.e., motivation), on the other hand, involves still an additional mechanism that entails the cerebellar circuit and cerebral cortex. The problem is that of distinguishing between motivational feelings and motivational intent. Thus, a person is declared guilty of a crime on the basis of his intentions, not his (emotional or) motivational feelings, though these may be taken into account in assigning the penalty. A crime may be undertaken for love or for need—both eminently respectable motivational feelings in our society. It is the intended or actual expression of these motives in behavior that is judged (Miller, Galanter, & Pribram, 1960).

Intention and Decision as Feedforward Controls

Beginning in the mid-1960s concerted effort was directed to the study of these intentional go mechanisms *per se*. A new theoretical distinction was achieved when it was realized that open-loop, helical organizations characterized certain brain organizations, making intentional, voluntary, and other forms of preprogrammed behavior possible (MacKay, 1969; McFarland, 1971; Mittelstaedt, 1968; Pribram, 1971; Teuber, 1972). Such behavior runs its course insensitive to the effects it is producing. Of course, most behavioral processes combine feedback and feedforward operations, but there are a sufficient number of relatively pure cases of each to make the analysis possible.

The classical example of feedforward behavior is eye movement. Once initiated, an eye movement is insensitive to feedback from that movement. Corrective influence must await its completion (McFarland, 1971; Pribram,

1971). The problem of control is limited to initiation and cessation, although of course a program must have been constituted either genetically or through previous learning for the behavior to be carried through. Feedforward control is therefore programmed control and shows considerable similarity to the operations performed in today's serial computers.

The distinction between closed-loop feedback associative control and open-loop helical feedforward control is not a new one in science. Feedback control is error-sensitive control. It is therefore sensitive to the situation, the context in which the operation takes place. By contrast, feedforward control operates by virtue of preconstituted programs that process signals automatically and essentially free from interference from the situation in which the program is running. Interference can only stop the program. As already noted, homeostatic mechanisms are error processing—every action begets an equal and opposite reaction when the feedback is inhibitory, leaving the system essentially unchanged. Feedforward control, on the other hand, proceeds to change the basic operating characteristics of the system. This change can be quantitatively represented as a change in efficiency of operation.

These concepts were initially embodied in the first and second laws of thermodynamics. The first law deals with the inertia or stability of systems—their resistance to change. The second law provides a measure (entropy) of the efficiency of operation of the system—the amount of work (i.e., organization)—the system can accomplish per unit time. More recently the second law was shown to apply not only to engines but to communications systems where the term *information* is used to indicate the reciprocal of entropy. Feedforward systems that exercise control through programs are therefore properly called *information-processing systems* (Brillouin, 1962).

The distinction between error-processing feedback organizations and programmed information-processing feedforward control is a useful one. Elsewhere (Pribram & Gill, 1976) I have detailed the suggestion that this distinction brings into sharp focus an earlier one made by Sigmund Freud. Psychoanalytic metapsychology, which concerns the mechanisms that underlie psychological processes, distinguishes between primary and secondary processes. Primary processes are composed of homeostatic feedback associative mechanisms; secondary processes are cognitive, volitional, and programmed, under the control of an executive (the ego) much as in today's time-sharing information-processing computer systems. The terminology *primary* and *secondary processes*, however, is not unique to psychoanalysis. Other biologically oriented disciplines have expressed similar insights. Thus, at a recent meeting of experimentalists working on hypothalamic function, it was proposed and agreed to that primary, diencephalic, homeostatic regulations were influenced by secondary, higher-order programs originating in the forebrain.

The primary-secondary process distinction, which was originally based on clinical observation, has thus been given a more substantive theoretical foundation based on a variety of experimental and analytic techniques. Clinically based concepts by necessity are often plagued by considerable vagueness that gives rise to unresolvable conflict of opinion. The sharpening that occurs when data from other disciplines become available to support and clarify a distinction is therefore a necessary preliminary if the conceptions are to be more generally useful in scientific explanation.

Cognition as Mnemonic Control

This distinction between primary processes that are organized according to feedback and associative principles and secondary processes that are organized in a feedforward manner leads us to a precise definition of cognitive processes: We subsume under cognition those intentional and decisional processes that operate on experience and behavior by virtue of feedforward mechanisms (i.e., stored programs acquired or of genetic origin).

Thus the memory store must be composed in part of items representing events and in part of programs that organize the items into usable information. In the section on the Neural Hologram, I detail the evidence that items of information become distributed in the brain and stored in holographic fashion. Of course, item storage also occurs in the environment—in our homes and other familiar places, in libraries, etc.

The problem for the brain sciences has been to discover the rules of interaction among neurons that constitute program storage. A good deal of this work is proceeding in invertebrates (Teyler, 1978) but a few impressive advances are being accomplished in mammals as well (Mountcastle, Lynch, Georgopoulos, Sakata, & Acuna, 1975).

Cognition and The Linguistic Act

Perhaps the most profound insights into the relationship between cognition and behavior have come from studies of language. Language has been, in fact, identified by some (Pattee, 1971) as *the* behavioral manifestation of cognition although others (Chomsky, 1979) see language as only one form of cognitive expression. My own view (Pribram, 1979b) is that audio-vocal communication and writing are two forms of cognitive ability that share with others such as mathematics, logics, and music certain complex structures that are akin to each other and to still other forms of cultural activity. These structures are often labeled *linguistic* or *linguistic-like* because of their commonality, and it is a matter of a convention as yet to be developed as to whether we call mathematics, music, etc., "languages" or whether we restrict the term to its root meaning (derived from *lingua*, the tongue). The facts are

that speech (audio-vocal communication) can be relatively highly developed in persons who are otherwise cognitively deficient (with intelligences rated in the IQ 40 range). Similarly, there are "idiot savants" who can accomplish remarkable arithmetic calculations whereas other cognitive competencies are normal or below normal. In addition, brain lesions in different locations produce cognitive deficits (agnosias) related to different sensory modalities although the aphasias (brain lesion-produced disturbances of speech) follow damage restricted to a still different part of the cerebral hemisphere (around the sylvian fissure). These "experiments of nature" clearly indicate that cognitive competencies are several of which the speech competency is but one.

The relationship between cognitive competencies and their linguistic-like structures is reasonably clear (Pribram, 1971a). Each sensory mode is embedded in neural systems that are concerned with *iconicity*—the initial step in image processing (Paivio, 1971). Simultaneously, most likely by way of preprocessing initiated in other neural systems (Pribram, 1971, 1974), categorical perceptions arise that distinguish features of that icon. Using Charles Peirce's (1934) terminology, such categorizing of features "*index*" an icon. Indicators have deictic functions.

Iconic and indicial processing is further embedded in neural systems that allow arbitrary representations to be made. Thus *signs* develop when iconicity is being communicated and *information*, considered as alternatives (Miller, 1953), results when the communication concerns indicators. In most right-handed persons, the right hemisphere of the brain has become specialized for image processing and significant communication whereas the left hemisphere is especially efficient in information processing.

Note the dependence of the development of arbitrary representations (tokens) on communication. I mean by communication some organism—environmental interaction that allows the consequences of that interaction (i.e., the *interact*) to become "presented" (i.e., present) in the brain of the organism or in an artifact in the environment. For example, in music such communication may lead to the development of a symphonic form or to the construction of a musical instrument. Of course, once such presentations have been developed, brain re-presentations of the instrument and environmental re-presentations of the symphony (in score, performance, tape, or disc) are readily achieved (Pribram, 1979c).

This development of a hierarchy of presentation — representation and by repetition of the process, re-representation, can be illustrated by drawing a plausible scenario of the beginnings of audio-vocal linguistic communication by man. There is considerable evidence that, initially, primate communication proceeded by establishing a reciprocal relationship between icon and index using visual-gestural mechanisms. Thus, apes have been taught to indicate their communications by American sign language (Gardner & Gardner, 1969) and the cave paintings of early man suggest considerable

skill at iconic representation. Perhaps due to darkness in caves, distance, or other awkward circumstances, initial iconic gestural representations became expressed in vocalizations that then became differentiated and used as tokens even when the gestures were no longer visible. After awhile, the more universally usable audio-vocal expressions supplanted the now redundant gestures as the primary medium for communication.

Syntax, Semantics, and Pragmatics

The rules by which communicative action, the hierarchy of presentations—representations and rerepresentations, etc., take form are known as the *syntax* or *grammar* of the interactions. Grammatical rules apply not only to audio-vocal interactions but also to play, as shown in our laboratory (Reynolds, 1968), and to music (Bernstein, 1976); and may in fact be the rules by which the coordinate structures of all action are organized (Pribram, 1971; Turvey, 1973).

The content of communication—what the communication is about—is ordinarily subsumed in linguistics under the heading *semantics*. Semantics purports to deal with the meanings of communicative acts. However, philosophers have sharply distinguished between meaning and reference. Reference refers to the environmental events that form the content of the communication: the information about those events. Meaning is more elusive: Meanings are defined as intending, as conveying, as the instrumental vehicles of the communication. The term *mean* is derived from the middle English “mene” and “menen,” tend where the tending is toward a common (i.e., average) understanding. Thus the various meanings of mean: to be common, penurious; the statistical average; the intension (with an *s*) of an expression (Searle, 1969).

Ordinarily, semantics is especially concerned with the referential (i.e., the extensive) aspects of linguistic communications. The examples of the development of hierarchically ordered re-presentations described previously give a fair view of how the referential process becomes organized. In philosophy such referential processes are defined as “extensional” and in neurology they are said to exhibit “local sign” (i.e., they refer to “locations” in space and time). Such referential organizations are disrupted by lesions of brain systems that involve the posterior cortical convexity.

What about the “intensive” aspects of communication? In part they are of course derived from the intensity with which the communication takes place. But this is only a part of the meaning of intension. As noted earlier, intension also indicates a tendency towards some norm, some commonly accepted, normative standard. How do such intensive meanings come about?

Take once again the example of how speech might have arisen. Originally, vocal expressions would have been manifestations of affective intensity—

expressions of feelings—as they are in all primates. Gestural communications would then take place within the context of these intensive expressions as a *means* for achieving a particular purpose. Thus the gestural content becomes meaningful within a pragmatic context. As the hierarchical organization of re-representation develops, vocalizations per se become indicative of content and the intensive aspects of the expressions refer as much to prior stages in hierarchical development (mnemonics of re-representation) as to the affect that initially provided the contextual frame for the communication.

The parts of the brain responsible for the organization of contextual frames are the frontal cortex and related limbic formations (Pribram, 1958, 1960, 1971, 1973). These brain systems are intimately involved not only in regulating the physiological states of the organism but also in relating external stimuli to these states. Excitation whether originating within the body or from sense organs is ordinarily processed by an organization (a representation) of prior similar excitations. Any mismatch between representation and current input is appreciated as “novel” and accompanied by an orienting reaction. Repetition of the excitation produces habituation of the orienting reaction and the excitation now becomes “familiar.” Any change in the patterns of repetition or other parameter of the excitation produces dishabituation (i.e., another orienting reaction).

Note that a representation of the excitation is formed by repetition. Irregularities—either temporal or spatial—of repetition produce an orienting reaction. Thus patterns of repetition (i.e., patterns of redundancy, Garner, 1962, 1970; Pribram & McGuinness, 1975) become the essential context in which representations of excitation form. The limbic (Pribram, Lim, Poppen, & Bagshaw, 1966) and frontal (Pribram & Tubbs, 1967; Pribram, Plotkin, Anderson, & Leong, 1977) parts of the brain (and not others) have been shown to be critical to such structuring of redundancy. In audio-vocal communication the structure of redundancy is given by pauses, inflection, and by parsing. Thus INPINETARISINOAKNONEIS makes little sense unless the appropriate pauses are inserted between *in* and *pine* and *tar* and *is* and between *in* and *oak* and *none* and *is*. The pauses and other structuring markers provide the context within which the intended meanings are conveyed. Organization is here achieved through interrupting a continuous string of redundant alphabetical items. Interruptions are produced by placing pauses and by eliminating or delaying what might otherwise have been there. Interruptions are akin to the hole in the doughnut that gives it form; the zero standing for no-thing that nonetheless can become a powerful organizer of magnitudes when properly employed. The syntactic rules of such pragmatic orderings that center on *use* are just coming to be studied by cognitive scientists: the programming of clusters of procedures that can be flexibly switched into ongoing routines in order to handle recurring episodes of experience (Miller & Johnson-Laird, 1976; Schank & Abelson, 1977; Winograd, 1977).

CONCLUSION

Psychological science has come a long way since the early cognitive explorations of the Würzburgers that came aground on the problem of the *act* of thinking. Brentano's (1874) contribution in making explicit the intentional aspects of experience as well as of action were implemented by his pupil Freud in the procedure of "free association." Freud, however, continued to focus on language as the major if not only indicator of cognitive processing. With the rise of Watson's behaviorism, the spectrum of actions investigated was broadened. At the same time however, the intentional and intensional aspects of cognitive processing were not only ignored but considered inappropriate for scientific analysis. Today, as I have outlined previously the breach has been healed: Behavior can be recognized as act with all its intentional and intensional aspects. Not only is it once more respectable to investigate cognition, but a great deal is known about how the brain processes cognitions into perceptions and actions. If this last statement sounds Kantian, it is meant to. More and more evidence accrues to the effect that sensory input becomes processed into its component waveforms by a mechanism in which individual neurons or groups of neurons resonate to specific bandwidths of the frequency of the sensory input. Such resonators, as well as the transducer capacities of the sense organs, place limits on what is sensed as stimulus. At the same time other brain processes operate on the input, often preprocessing it prior to its organization into the mechanisms coordinate with conscious perception. Similar brain processes operate on mnemonic organizations in which are encoded waveforms generated by prior sensory input (the neural hologram). Such operations on the memory store are coordinate with the cognitions. A hierarchy of these brain processes produce the syntactic structures that program behavioral acts. When the programs are organized around sensory stimuli (or their mnemonic derivatives) they provide a referential semantics that can be consensually validated. When the programs are organized around internal physiological stimuli (or their mnemonic derivatives), they provide the pragmatic meaning that forms the context within which the action proceeds. Semantic organizations tend to have a branching structure; pragmatic organizations are more apt to cluster events by interrupting or otherwise bounding and separating them from others. Semantic organizations are formed by neural systems reaching the posterior convexity of the brain; pragmatic organizations devolve from the operation of more medially placed limbic and frontal brain systems. This, I believe is how the relationship between cognition and behavior can be charted today. The chart should prove familiar to philosophers: What is new is the wealth of detailed observation of behavior and of brain function that enriches the hitherto sketchy portions of that chart.

REFERENCES

- Ashby, W. R. *Design for a brain*. New York: Wiley, 1960.
- Barron, F. The psychology of creativity. In *New directions in psychology* (Vol. II). New York: Holt, 1965.
- Bernstein, L. *The unanswered question: Six talks at Harvard*. Cambridge, Mass.: Harvard University Press, 1976.
- Bernstein, N. *The co-ordination and regulation of movements*. New York: Pergamon Press, 1967.
- Brentano, F. *Psychologie vom empirischen Standpunkt*. Leipzig: Meiner, 1874.
- Brillouin, L. *Science and information theory*. New York: Academic Press, 1962.
- Cannon, W. B. *Bodily changes in pain, hunger, fear and rage*. New York: Appleton, 1929.
- Chomsky, N. *Kant lectures*. Stanford, Calif.: Stanford University Press, 1979.
- Dowling, J. E. The site of visual adaptation. *Science*, 1967, *155*, 273-279.
- Estes, W. K. Theoretical trends and points of controversy. In J. Linhart (Ed.), *Proceedings of the International Conference on Psychology of Human Learning* (Vol. II). Prague: Czech Academy of Sciences, 1970.
- Gabor, D. Information processing with coherent light. *Optica Acta*, 1969, *16*, 519-533.
- Gardner, R. A., & Gardner, B. T. Teaching sign language to a chimpanzee. *Science*, 1969, *165*, 664-672.
- Garner, W. R. *Uncertainty and structure as psychological concepts*. New York: Wiley, 1962.
- Garner, W. R. The stimulus in information processing. *American Psychologist*, 1970, *25*, 350-358.
- Gelfand, I. M., Gurfinkel, V. S., Tsetlin, H. L., & Shik, M. L. Some problems in the analysis of movements. In I. M. Gelfand, V. S. Fomin, & M. T. Tsetlin (Eds.), *Models of the structural-functional organization of certain biological systems*. Cambridge, Mass: MIT press, 1971.
- Granit, R. The functional role of the muscle-spindles: Facts and hypotheses. *Brain*, 1975, *98*, 531-556.
- James, W. *Principles of psychology*. New York: Holt, 1890.
- Kahneman, D. *Attention and effort*. Englewood Cliffs, N.J.: Prentice-Hall, 1973.
- Kolers, P. A. Reading and talking bilingually. *American Journal of Psychology*, 1966, *79*, 357-376.
- Kolers, P. A. Bilingualism and information processing. *Scientific American*, 1968, *218*, 78-86.
- MacKay, D. M. *Information mechanisms and meaning*. Cambridge, Mass.: MIT press, 1969.
- McFarland, D. J. *Feedback mechanisms in animal behavior*. New York: Academic Press, 1971.
- Miller, G. A. What is information measurement? *American Psychologist*, 1953, *8*, 3-11.
- Miller, G. A., Galanter, E., & Pribram, K. H. *Plans and the structure of behavior*. New York: Holt, 1960.
- Miller, G. A., & Johnson-Laird, P. *Language and perception*. Cambridge, Mass.: Harvard Press, 1976.
- Mittelstaedt, H. Discussion. In D. P. Kimble (Ed.), *Experience and capacity*. New York: New York Academy of Sciences, 1968.
- Mountcastle, V. B., Lynch, J. C., Georgopoulos, A., Sakata, H., & Acuna, C. Posterior parietal association cortex of the monkey: Command functions for operations within extrapersonal space. *Journal of Neurophysiology*, 1975, *38*, 871-908.
- Ornstein, R. E. *The psychology of consciousness*. San Francisco: Freeman, 1972.
- Ornstein, R. E. *The nature of human consciousness: A book of readings*. San Francisco: Freeman, 1973.
- Paivio, A. *Imagery and verbal processes*. San Francisco: Holt, 1971.

- Pattee, H. H. Physical theories of biological coordination. *Quarterly Reviews of biophysics*, 1971, 3, 255-276.
- Peirce, C. S. *Collected papers*. Cambridge, Mass.: Harvard University Press, 1934.
- Pribram, K. H. Comparative neurology and the evolution of behavior. In G. G. Simpson (Ed.), *Evolution and behavior*. New Haven, Conn.: Yale University Press, 1958.
- Pribram, K. H. A review theory in psychological psychology. *Annual Review of Psychology* (Vol. II), 1960.
- Pribram, K. H. The neurobehavioral analysis of limbic forebrain mechanisms: Revision and progress report. In D. S. Lehrman, R. A. Hinde, & E. Shaw (Eds.), *Advances in the study of behavior* (Vol. II). New York: Academic Press, 1969.
- Pribram, K. H. The biology of mind: Neurobehavioral foundations. In A. R. Gilgen (Ed.), *Scientific psychology: some perspectives*. New York: Academic Press, 1970. (a)
- Pribram, K. H. Feelings as monitors. In M. B. Arnold (Ed.), *Feelings and emotions*. New York: Academic Press, 1970. (b)
- Pribram, K. H. *Languages of the brain: Experimental paradoxes and principles in neuropsychology*. Englewood Cliffs, N.J.: Prentice-Hall, 1971.
- Pribram, K. H. The primate frontal-cortex executive of the brain. In K. H. Pribram & A. R. Luria (Eds.), *Psychophysiology of the frontal lobes*. New York: Academic Press, 1973.
- Pribram, K. H. How is it that sensing so much we can do so little? *The Neurosciences Study Program* (Vol. III). Cambridge, Mass.: MIT Press, 1974.
- Pribram, K. H. Holonomy and structure in the organization of perception. In J. M. Nicholas (Ed.), *Images, perception, and knowledge*. Dordrecht, Holland: Reidel, 1977.
- Pribram, K. H. Consciousness and neurophysiology. *Federation Proceedings*, 1978, 37, 2271-2274. (a)
- Pribram, K. H. The linguistic act. In J. H. Smith (Ed.), *Psychiatry and the humanities* (Vol. III): Psychoanalysis and language. New Haven, Conn.: Yale University Press, 1978. (b)
- Pribram, K. H. The place of pragmatics in the syntactic and semantic organization of language. *Temporal variables in speech. Studies in honour of Frieda Goldman-Eisler*. Janua Linguarum, The Hague: Mouton, 1979. (a)
- Pribram, K. H. Representations. In T. W. Simon (Ed.), *Proceedings of the symposium of language, mind, and brain*. New York: Academic Press, 1979. (b)
- Pribram, K. H. Brain mechanisms in music: prolegomena for a theory of the meaning of meaning. *Proceedings of research symposium on the psychology and acoustics of music*. Lawrence, Kans.: University of Kansas press, 1979. (c)
- Pribram, K. H., & Gill, M. M. Freud's "project" reassessed: preface to contemporary cognitive theory and neuropsychology. New York: Basic Books, 1976.
- Pribram, K. H., Lim, H., Poppen, R., & Bagshaw, M. H. Limbic lesions and the temporal structure of redundancy. *Journal of Comparative and Physiological Psychology*, 1966, 61, 365-373.
- Pribram, K. H., & McGuinness, D. Arousal, activation, and effort in the control of attention. *Psychological Review*, 1975, 82, 116-149.
- Pribram, K. H., Nuwer, M., & Baron, R. The holographic hypothesis of memory structure in brain function and perception. In R. C. Atkinson, D. H. Krantz, R. C. Luce, & P. Suppes (Eds.), *Contemporary developments in mathematical psychology*. San Francisco: Freeman, 1974.
- Pribram, K. H., Plotkin, H. C., Anderson, R. M., & Leong, D. Information sources in the delayed alternation task for normal and "frontal" monkeys. *Neuropsychologia*, 1977, 15, 329-340.
- Pribram, K. H., & Tubbs, W. E. Short-term memory, sparsing, and the primate frontal cortex. *Science*, 1967, 156, 1765-1767.
- Reynolds, P. C. Evolution of primate vocal-auditory communication systems. *American Anthropologist*, 1968, 70, 300-308.

- Schank, R. C., & Abelson, R. P. *Scripts, plans, goals, and understanding*. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1977.
- Searle, J. R. *Speech acts*. Cambridge, U.K.: Cambridge University Press, 1969.
- Tart, C. T. *On being stoned*. Palo Alto, Calif.: Science and Behavior Books, 1971.
- Teuber, H. L. Unity and diversity of frontal-lobe functions. In J. Konorski, H. L. Teuber & B. Zerniki (Eds.), *Acta Neurologiae Experimentalis: The Frontal Granular Cortex and Behavior*, 1972, 32, 615-656.
- Teyler, T. *Brain and learning*. Stanford, Conn.: Greylock, 1978.
- Turvey, M. T. Periphery and central processes in vision: inferences from an information processing analysis of masking with pattern stimuli. *Psychological Review*, 1973, 80, 1-52.
- Winograd, T. Framework for understanding discourse. *Stanford University Intelligence Monograph*, June, 1977.