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Mind, Brain, and Consciousness: The Organization of Competence and Conduct

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The history of psychology in this century can be charted in terms of the issue that dominated each decade of exploration. Early studies on classical conditioning and Gestalt principles of perception were followed subsequently by two decades of behaviorism. In the 1950s information measurement took the stage to be supplanted in the 1960s by an almost frenetic endeavor to catalogue memory processes, an endeavor which culminated in the new concepts of a *cognitive* psychology. Currently, the study of *consciousness* as central to the mind-brain problem has emerged from the explorations of altered and alternative states produced by drugs, meditation, and a variety of other techniques designed to promote psychological growth.

Each of these new departures built upon old foundations but at the same time challenged and changed the dogma that had solidified to identify those foundations. The environmentalism of conditioning was countered by the nativism of Gestalt. The holism of Gestalt was leavened by the operationism of behavior. The peripheralism of S–R behavior theory gave way to the feedbacks of cybernetics and the correlational descriptive functionalism of both became quickly obsolete in the face of the new process oriented structuralism of cognitive psychology.

The purpose of this chapter is to examine the impact that the study of consciousness must make on the conceptions of current structuralism. True to tradition this impact ought to derive from an examination of the structure of consciousness, while at the same time challenging the dogma that has developed to characterize current thought.

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1. Consciousness and Information Processing

At any period in history, the characteristic dogma is ordinarily implicit and therefore must be made explicit if a challenge is to succeed in making modifications. Originally, structuralism took as its model the digital computer and the programs that make it operational (Miller, Galanter, & Pribram, 1960; Pribram, 1960). As such, it is rooted in both the earlier functionalism of behavioral psychology and in information processing. Information is conceived in terms of features or alternatives that describe a situation, and processing proceeds by associations or list structure hierarchies among alternative features. The operations involved in processing are digital. In the computer, they result from switch settings; in the biological brain from convergences of nerve impulses onto a neuronal switching mechanism (e.g., Pitts & McCulloch, 1947; Pribram, 1971, Chap. 4). The refreshing power of this model in the development of a cognitive psychology and of an information processing approach to brain function cannot be denied.

But certain inadequacies remain. The information processing approach cannot account for the richness and immediacy of imaging. Nor does it by itself, handle the problem of meaning, of the semantic deep structure of language. Current cognitive structuralism also does not satisfactorily address itself to the nature of feelings, the emotions and motivations that are the substance of clinical psychology—though a classical cognitive clinical psychology (which takes into account the issues delineated below) exists in the form of the psychoanalytic metapsychology (Pribram & Gill, 1976).

One of the central problems is that an information processing approach based on nerve impulse transmission ignores the vast number of neurons that do not generate nerve impulses (Pribram, 1971, Chap. 1). Such neurons are often without axons but display widespreading dendritic arborizations. They function by hyperpolarization and depolarization to produce graded inhibition or excitation in their immediate surroundings. The retina is made up exclusively of such neurons until the ganglion cell layer is reached. Only here is the digital nerve impuse produced which allows signals to be transmitted over the distance traversed by the optic nerve and tract. The computations that give rise to these digital signals (and, therefore, vision) all occur in the analogue domain via graded interactions in receptor networks of horizontal, bipolar, and amacrine cells. Studies of the analogue interactions occurring in other neural networks (e.g., the olfactory bulb, Rall, 1970, pp. 552–565; Shepherd, 1974; the pyriform cortex, Freeman, 1960) are in the forefront of neuroscience research.

However, the most incisive challenge to current structural cognitive psychology comes from observations on consciousness. The variety of conscious perceptions and feelings are varieties of *states*. Such states are produced by the operation of processes, but operational and process analyses do not reveal much about the states produced. It is this deficiency in structural cognitive psychology that needs redressing and studies of consciousness provide the tools for meeting that need.

This chapter will therefore focus on the problems raised by studies of consciousness with special emphasis on brain mechanisms that can account for its phenomena. As this is not the first time I have written on these topics, the issues are covered here in nature of review and the reader is referred to their more extensive treatment in the original manuscripts. It should be helpful, however, to gather in one presentation the range of profound problems that must be faced in a scientific attempt at understanding what surely is central to any study of *human* psychology.

2. CONSCIOUSNESS AND SELF-CONSCIOUSNESS

The first question that must be posed is whether the concept "consciousness" is necessary at all for a scientific understanding of man's psychological processes. My answer (Pribram, 1976a) is a definite "yes." Neurosurgeons are constantly faced with making diagnoses of the amount of brain injury based on the patient's ability to make verbal and gestural responses to inquiries. These inquiries mobilize the patient's attention and a second question therefore arises: Are the concepts "consciousness" and "attention" both necessary? James (1901) raised this question and emphasized the relationship between the two concepts almost to the exclusion of the study of "consciousness" from being a fruitful endeavor. He did in the end retain the term in his own deliberations, however. I will here do likewise because, as we shall see, we need to make a distinction between state and process. "Consciousness" refers to states which have contents; "attention" refers to processes which organize these contents into one or another conscious state.

The problem is not a simple one. Consider recent reports of patients who exhibit "blind sight" (Weiskrantz, Warrington, Sanders, & Marshall, 1974). Carefully performed resections of occipital cortex (for hemangioma or aneurism) restricted to the projections from the retina, produce the expected contralateral homonymous hemianopsia. Despite this inability to see, the patients are able to point with a high degree of accuracy to objects located within the blind visual field and often are able to identify the shapes of such objects. When questioned, they stoutly maintain that they are merely "guessing," that they are completely unaware of any basis for making the responses. Yet their "guesses" come to 80% or even 90% correct answers.

Patients with "blind sight" are not the only ones who show this disassociation between instrumental performance and verbal report of introspection. When surgical severance of the cerebral hemispheres is made by cutting the extent of the major intrahemispheric connections (the corpus callosum and anterior commissure), and visual input is restricted to the right hemisphere, right-handed patients can identify objects gesturally and by matching, but verbal report indicates that the left hemisphere has not "seen" the object that has been gesturally identified.

This dissociation between instrumental and subjective report is not limited to instances where lesions separate the functions of one hemisphere from the other. Patients with bilateral resections of limbic structures—the amygdala, hippocampus, or both—demonstrate a similar syndrome (Milner, 1971; Pribram, 1965, pp. 426–459). While completely unable to "recognize" what ought to have become familiar, they nonetheless are able to learn and retain instrumental skills (Sidman, Stoddard, & Mohr, 1968).

Nor is the dissociation shown by the patients merely between verbal and nonverbal report. The difficulty is more profound, although the critical evidence for this is not easily obtained. Nonetheless, in patients with limbic lesions, it has been shown that performance in both verbal and nonverbal (geometric figure completion) recognition tasks can be substantially improved by providing contextual clues (parts of the word or geometric figures) at the time recognition is requested (Warrington & Weiskrantz, 1971).

My interpretation of these observations is that we need to distinguish between levels or at least between alternate states of consciousness. Closely tied in with verbal report, but not completely interdependent with it, is the state of subjective awareness, the state of self-consciousness. Self-consciousness is what we ordinarily refer to as "consciousness" in human discourse but it is not what is of concern in the neurosurgical clinic nor ordinarily in observations of animal behavior. Here instrumental responses are deemed adequate to define awareness.

Philosophers since James (1901) and Brentano (1960, pp. 39–61) have discussed self-consciousness as *the* essential characteristic that "makes man human" (Pribram, 1970). The term Brentano coined was "intentional inexistence" which von Uexkull (1960) shortened to "intentionality." Intentionality is to perception what intention is to action. Intentions and intentionalities may or may not be realized in the objective world. They thus define subjectivity and self-consciousness. I have elsewhere detailed the brain mechanism whereby self-consciousness can be achieved (Pribram, 1976b) and we shall return to this topic shortly. Here the important point is that self-consciousness can be identified and that on the basis of clinical neuropsychological observations self-consciousness is dissociated from other forms of consciousness which do not involve intentions and intentionalities.

3. CONSCIOUSNESS AND FEELINGS

This distinction between ordinary perceptual consciousness and self-consciousness is paralleled by a similar distinction between forms of attention. James discussed the difference between reflex or primary attention and higher order processes (James, 1901). Freud made the process of attention and its neural mechanism central to the development of (self-) consciousness from perception (Freud, 1954; Pribram & Gill, 1976). And I have reviewed the contributions of recent neuropsychological research including those from my own laboratory to the understanding of the brain mechanisms involved in attention (Pribram, 1977; Pribram & McGuinness, 1975). Three major control processes were identified. One, centered on the amygdala, regulates arousal, a phasic response to input. A second, based on the basal ganglia, activates tonic states of readiness to respond. The third, termed the "effort" process, critically involves the hippocampus and coordinates arousal and readiness.

Both phasic arousal (the orienting reaction, distraction), and tonic readiness to respond were shown to be organized as feedback mechanisms. The operation of the hippocampus links these two feedbacks into a parallel process (Isaacson & Pribram, 1976) which feeds forward thus constituting an open (helical) loop rather than a homeostatic feedback mechanism. The resultant "effort" is a "voluntary" control over arousal and readiness that shows many of the characteristics of the cerebellar mechanism which organizes voluntary acts (Pribram, 1971).

The operation of these three brain systems is predicated on neurochemical differences that are currently the center of concerted research endeavor (see review by Pribram, 1977). Best known is the dopaminergic property of the readiness mechanism. Less well understood are the norepinephrinergic and serotonergic interactions involved in phasic arousal. But striking advances are being made in delineating a series of hormonally sensitive receptor brain sites regulated by peptides secreted from the pituitary gland. Among other things, these peptides control the range of comfort tolerated by the organism and the effort he is able to exert in any specific activity. The peptides have been shown to have morphinelike qualities and the brain sites involved in the regulation of comfort and effort are those known to be specifically sensitive to morphine. The pituitary peptides controlling comfort and effort are closely related to or identical with the hormone that controls the adrenal cortex. Thus a dual mechanism operates in the regulation, one peripheral and one central. This dual mechanism most likely takes the form of a homeostat; a quantitative central representation of peripheral hormonal activities is set up. Changes in the representation are effected directly via the connections from sensory input to the brain structures in which the representations occur. These alterations in representation then elicit changes in the amount of neuropeptides secreted by the pituitary, changes which also influence the peripheral hormonal mechanisms.

Note that two of the control mechanisms outlined above delineate what are ordinarily called emotional (arousal) and motivational (readiness) processes. They thus define the organism's feelings as well as regulating his perceptions and actions. Note also that when the automatic feedback mechanisms of control become organized into feedforward operations that a feeling of "effort" based on very real physiological changes occurs (Pribram & McGuinness, 1975). Thus the organism "pays" attention and "exerts" his will in the control of his behavior.

This distinction between feedback and feedforward processing is considered to be the critical one underlying the difference between ordinary perceptual consciousness and self-consciousness (Pribram, 1976b). The contents of ordinary consciousness involve interests in occurrences and objects, interests that were described by William James (1901) as either "terminating within the subject's own body" (emotions) or "going farther and entering into practical relations with the exciting occurrence or object" (motivations). The contents of self-consciousness involve intentions and intentionalities, cognitive thought processes that can be readily distinguished from emotional or motivational feelings, from perceptions of occurrences of objects, and from the behavioral actions that constitute James' "practical relations" with them.

4. Consciousness and Information Measurement

This distinction between feedback (emotional/motivational) and feedforward (cognitive) processing was anticipated by Freud's *Project for a Scientific Psychology* (1954) and in the distinction between primary and secondary processes (Pribram & Gill, 1976). Not only was the distinction carefully drawn, but the specific neural mechanisms upon which the distinction was based were so clearly enunciated that a hitherto murky aspect of information measurement theory became clarified in the course of studying *The Project*. The term "information" is commonly used in several ways. In ordinary language, information conveys meaning. But in information measurement theory this usage was eschewed in favor of a simple measure of the *number* of alternatives described by the information—thus, the amount of information could be manipulated as a function of the initial uncertainty (also measured as information) reduced by a communication (more information). As the theory of communication developed, it became enmeshed in the theory of control—cybernetics, the study of steering mechanisms based on the operation of feedback processes. Feedback sense error or discrepancy between a setpoint (readiness) and the results of behavioral operations. Feedback mechanisms control these behavioral operations so as to reduce the discrepancy. The term "information" was used to define both the alternatives operating in a communication and the error sensing of control mechanisms.

However, the structure of feedback controls and that of a communication are different. Communications are feedforward operations. Thus, a distinction ought to be made on the basis of whether the term "information" is applied to feedback or feedforward processes. Shannon in his original treatise (Shannon & Weaver, 1949) did in fact make such a distinction. He called the errors processed by feedbacks "bad information" and the alternatives processed by a communication "good information." Later Brillouin (1962) identified the "good information" of alternatives with novelty and thermodynamic measures on the organization of energy called entropy, while Ashby (1960) pointed out that the sensing of error in feedback organizations involves the enhancement of redundancy rather than its reduction. Thus feedback operations maintain alternatives rather than specify or reduce them. These insights were not commonly recognized, with resulting confusion and degradation of the precise meaning of the term "information" as it had originally been set out in information measurement theory.

To summarize the preceding three sections of this chapter, the distinction between feedback and feedforward organization of control mechanisms is critical to an understanding of the distinction between ordinary perceptual consciousness and self-consciousness. Recall that feedforward organizations are constituted of feedbacks joined into parallel processes. Feedforwards thus mesh simultaneous and sequential operations (as, for instance, in list structure processing). Information processing in communication and computer networks is a feedforward process in which alternatives are specified by feedbacks which reduce redundancy, eliminating error and discrepancy. In biological organisms, redundancy reduction by feedback mechanisms is automatic while feedforward mechanisms apparently entail effort as when an action is voluntarily "undertaken" or attention is "payed." I have suggested elsewhere (Pribram, 1976b) that these communications take effort because they involve the reorganization of the constraints (redundancies) that define the system thus altering its processing capacity. These reorganizations of the structure of neural information processing systems are also the basis for experiencing alternate states of consciousness.

5. Consciousness and Competency

Recently experimental psychologists have been especially concerned with the issue of cognitive capacity—the limits on central processing of information (for review, see Broadbent, 1974; Pribram, 1974, pp. 249–261; 1976b). William James (1901) had already suggested that an understanding of the limitations of attention and thus of consciousness would provide the key to intellectual accomplishment. George Miller in a classical paper (1956) made the point that information processing capacity was not fixed but depended on how the information had become organized. Grouping or "chunking" allowed a great increment in the amount of information that could be handled. When this concept is extended to the organization of the neural system that processes information, a new view (Pribram, 1976b) of the limitations on processing capacity becomes evident. Ordinarily the brain's capacity is compared to that of other communication devices, such as telephone systems, in which channels are fixed. But as George Miller, Eugene Galanter, and I (1960) pointed out some time ago, this view of the brain is incorrect. Information processing by the brain is more like that which takes place in a computer where efficient programming can influence to a remarkable degree the amount of processing that can take place. I have, therefore, suggested (Pribram, 1976b; Pribram & McGuiness, 1975) that we approach the problem of limits on processing in terms of competence (or efficiency) rather than in terms of a limit due to a fixed capacity. There is much evidence that there is enough brain to go around to solve most problems and experience the world in new ways, provided we are sufficiently competent in efficiently deploying our attentional and intentional controls to organize the processing capacity. This competency need not necessarily reside entirely in the attentional process itself. Just as in computer processing much of the organization of the central processor is derived from the input to the computer—the program being processed. But there must be sufficient central organization to allow the program to work. It is this central competency or bootstrap organization which is the analogue to the attentional and intentional mechanism we have been discussing.

In more biological terms, one can conceive of the limitations on information processing either as due to a fixed and limited capacity or due to a limited but flexible competency which, by reorganization, can overcome the limitations. A fixed capacity is like a crustacean exoskeleton while a flexible competency is more like a vertebrate endoskeleton which can adjust more readily to the demands of the input. Competency may not be limitless, but its limits are continuously challenged by renewed attentional and intentional effort (remember when the four-minute mile was a record?). Competence, not capacity, characterizes human consciousness as the recent "greening" of American consciousness has indicated. Alternate states are characterized not only by changes in what is perceived but also in the amount of information that is processed.

6. CONSCIOUSNESS AND PERCEPTION

Up to now this chapter has focused on the attentional and intentional control processes that make consciousness possible. Current advances in neuroscience also contribute to our understanding of the nature of the contents of consciousness. What we are aware of, what we feel and perceive, derives only in part from the organization of the input to our senses. Brain organization, as we have already touched on with respect to how much we can be aware of, is also critically involved.

The physical dimensions of what we are aware of are usually reduced to differences in spatial and temporal configurations. We are, therefore, inclined to look at brain organization in similar terms. To some considerable extent this approach is successful. The input from the eyes reaches one part of the brain, the input from the ears, another. The timing of nerve impulses (as, for instance, measured by interresponse intervals) is considered to be an important mechanism in the coding of neural information. But recently, both in physics and in brain physiology (Bohm, 1971, 1973; Pribram, 1966, pp. 165–187; 1971; 1976c; Pribram, Nuwer, & Barron, 1974, pp. 416–467) the limitations of explanations in the space/time domain have been faced. In physics, with respect to levels of organization other than those covered by classical mechanics (e.g., the levels of nuclear and quantum physics and also the macro universes to which the special theory of relativity is addressed) paradoxes appear when explanations are formulated in the space/time domain. These paradoxes are described in terms of the principles of complimentarity (Bohr, 1966) and uncertainty (Heisenberg, 1959). In brain physiology, paradox also appears. Despite the exquisitely detailed organization of neuroanatomical structures and exquisitely sensitive neurophysiological timing arrangements, large lesions of brain tissue which disrupt spatial continuity and grossly disturb brain electrical activity, often fail to have any demonstrable effect on awareness and behavioral performance.

In brain science, therefore, it has become accepted that information becomes distributed over a reach of tissue and that replication accounts for the protection against damage. What remains at issue is the extent of brain over which the spread of information occurs and the mechanism of spread. Elsewhere (Pribram 1966, 1971, 1974, 1976c; Pribram, Nuwer, & Baron, 1974) I have argued that optical information or image processing is as potent a model in accounting for the distribution of information as is digital computer processing for the operations of control mechanisms. Here, a brief review of the main points at issue can be helpful in providing an opportunity for presenting some recently acquired data and discussing their relevance to the problem of conscious awareness.

There are basically only two ways by which information could be distributed in the brain. One way would be by virtue of more or less random interconnections. Most computer models of neural nets are predicated on such connectivity. However, as noted earlier, brain organization is highly structured, not random. The structure is one of essentially parallel pathways from receptor surface to cortex which characteristically converge to some extent onto a one-way station, only to diverge in reaching the next. These parallel pathways are crossed at each level (from receptor through way stations to cortex) by networks of neurons whose connectivity is primarily perpendicular to the pathways, neurons which often have no, or only very short and highly arborized, axons. The work of such horizontal networks is therefore, as noted earlier, accomplished by graded local potential changes (Freeman, 1975; Rall, 1970; Shepherd, 1974) rather than by action potentials.

As the ubiquitous horizontal networks of primarily dendritic connectivities operate in the analog mode, it seems plausible to compare their function to that of *lenses* in optical information processing systems. This comparison suggests that the parallel nerve impulse transmitting pathways from receptor to cortex are organized as are the *light paths* in the optical system. Just as in the use of the digital computer model, the *organization* of the information processing mechanism is being modeled—not its realization in the hardware of computers and lens systems or the wetware of the brain.

Optical information processing technology has developed several methods for producing and storing distributed information which are called holography. These methods were originally devised (Gabor, 1948) in mathematical form in order to enhance the resolution of electron microscopy. They have since been found to be useful tools whenever high resolution of images, especially in depth (i.e., in three dimensions) is called for.

The distribution of information in optical systems is delineated mathematically by a spread function which describes what actually happens to the information in the image being processed. The image becomes blurred. However, the blurring is an orderly process which takes each point of information and distributes it in successive arcs much as ripples in a pond are formed by the impact of a pebble. Since there are many points of information in an image, the arcs intersect forming interference patterns. These patterns can be stored and with the appropriate method (the inverse of the transform that had originally been used to distribute the information) the image can be reconstructed. The stored distributed representation is called a hologram, and the process holography, because from each part of the representation the whole can be reconstructed.

The hypothesis that information is distributed in the brain by a process whose organization is like that of holography comes readily from the foregoing considerations. If the horizontal networks of neural interconnections function somewhat as do the lenses of optical information processing systems, then the possibility exists that the distribution of information in the brain is accomplished by virtue of holographic principles (Pribram, Nuwer, & Baron, 1974).

The evidence to date supports this hypothesis, but in a very special sense only. As noted in the earlier publication, two mechanisms at least can be formulated to accomplish the necessary transformation. One involves the storage of information and this possibility has as yet not been put to test. The other depends on the successive transformations of input by the functions of the horizontal networks of neurons we have been discussing. Recordings from single cells in the input systems can be used to analyze those transformations that have occurred in the network by the time that particular cell is reached. In the visual system such analyses have shown that the mathematical formulations which define holography, usefully, describe the transformations occurring in the visual mechanism.

But one major restriction must be recognized in this use of the holographic model. Each cell in the system, by virtue of the size of its receptive field, is tuned to a limited bandwidth of the spectrum of spatial frequencies (the frequency of occurrence of relative light and dark over space which is analogous to the frequency of occurrence of waves of sound in time in audition). Thus, within each receptive field information becomes distributed by the holographic transformation (which is described by spatial frequency). However, each receptive field subtends only a few degrees of visual angle and our initial purpose in using the model was to explain the distribution of information over considerably greater reaches of brain tissue.

The resolution of this dilemma which has been faced by neural holographic theory since its inception (Pribram, 1974) comes from the development of a special type of optical hologram called the composite or multiplex hologram (for a description see Leith, 1976). This holographic process was derived from work in radioastronomy (Bracewell, 1965) where information is gathered in the holographic (spatial frequency) domain in segments or strips and then integrated into a highly detailed three-dimensional whole during image reconstruction.

The composite or multiplex hologram is in many ways simpler than the original more global form. The earlier version necessitated coherent light (produced by a laser beam or monochromatic light source) for its formation and for image reconstruction. This constraint does not apply to multiplex holography which can be performed with ordinary white light. The composite hologram has the additional advantage that three-dimensional *movement* can be captured and reconstructed.

Many of the receptive fields of the cells of the visual cortex have the shape of strips, elongated ovals or rectangles (Spinelli, Pribram, & Bridgeman, 1970). The discovery that such cells were tuned to specific orientations (Hubel & Wiesel, 1962) has ordinarily been interpreted as an indication that the cells were "detecting" the orientation of lines as features of the input. However, the output of each cell is, as we have seen, sensitive to spatial frequency (and often also to movement and direction of movement). It is, therefore, more appropriate to view the output of the cell as representing an integral of spatial frequency, orientation of a strip, movement and direction—an integral mathematically and functionally similar to that produced when a multiplex hologram is illuminated.

The question immediately arises as to what brain process corresponds to the illumination of the composite optical hologram. Much of the work of my laboratory over the past fifteen years has been devoted to delineating the control over input processing which is exercized by remote brain structures such as the association cortex (see review by Pribram, 1974). Changes in receptive field properties and recovery functions have been demonstrated and the anatomical pathways by which these effects are mediated have been traced. Behavioral experiments have linked these control processes to selective attention, intentional behavior, and the ability to make discriminative and delayed responses. Either through such control operations or by way of abstraction (or both) the integrative, imaging properties of the multiplex neural hologram can become realized.

Mathematically the multiplex neural hologram can be thought of as a matrix of cells whose sensitivities, spatial frequency, orientation, color, movement, and direction are represented by vectors. Multivariate matrices have the advantage that they represent occurrences rather than space/time organizations whose limitations were noted earlier and have been extensively discussed by Whitehead (1958), although space/time dimensions can be derived from them. Each vector relationship can in theory be abstracted from them and realized separately (e.g., the derivation of size constancy from spatial frequency (Campbell & Robson, 1968) or the integration into an image can be performed by the neural control operations. In a very real sense the separate derivations are complementary as they are in quantum mechanics where frequency (i.e., momentum) and orientation (location) are never completely specified in one and the same analysis. Research is now being addressed to specifying the conditions under which, and the neural mechanisms by which, various abstractions can occur or image integration takes place.

One of the properties of image processing by holography is that the image which is reconstructed is projected into space away from the holographic storage medium. A series of elegant experiments by von Bekesy (1967) has demonstrated that biological sensory processes behave in a similar fashion by virtue of the horizontal networks of interconnections described earlier in this presentation. Von Bekesy showed both mathematically and by experimental demonstration that projection results from inhibitory interactions within the horizontal network to produce an effect similar to that produced by stereophonic audio systems. The source of the sound is projected away from the speakers when the phase relationships between the frequencies emitted is properly adjusted. Von Bekesy worked with spatial frequency and showed, for instance, that the perception of tactile stimulation would be projected into the space between when two arms or fingers were stimulated.

These experiments and the holographic model (mathematical and optical) help to explain how a brain process can give rise to an image which is experienced as remote from the representational mechanism and even the receptor surface which is involved in the construction of the image. The contents of consciousness (what we are aware of) are thus experienced apart from the brain apparatus (holographic and control) that organizes those contents from its inputs. Mind and brain are separate except in this special relation to each other.

7. Consciousness and Mind

Gilbert Ryle (1949) has pointed out that the term "mind" is derived from minding, attending. The analysis presented in this essay supports Ryle's derivation: minding, attending is a control operation that organizes the holographic process of image construction, the content of mind. Images can be experienced when the process is engaged by sensory input or from memory. We have focused on visual imagery but auditory imagery, which constitutes verbal thought, and haptic or kinesthetic imagery, which enhances mechanical "know how" and even gustatory images are formed in a similar fashion (von Bekesy, 1967). Mind is the sum of the content of psychological perceptual processes such as vision, audition, etc. Mind, so defined, is an emergent property of information processing by the brain much as wetness is an emergent property of the appropriate organization of hydrogen and oxygen into water, and gravity is an emergent property of the organization of matter into interacting masses. Strictly speaking, in all these instances it is inappropriate to locate the emergent in any constituent part of the organized whole, although colloquially we are apt to talk about the earth's gravitational force without referring to other masses on which such a force might be exerted. It is this mode of speaking which identifies consciousness with brain processes without specifying the contribution of sensory input. As Whitehead (1958) suggested, mind is more appropriately conceived of as a property extending throughout the natural universe—with this important caveat, however, that a brain, perhaps a human brain, must be minding. There cannot be mind without minding.

Recently (for review see Dimond & Beaumont, 1974) a good deal of interest has been aroused by the finding that when the cerebral hemispheres are separated by surgical severance of the commissures that ordinarily connect them, that information processing occurring in one hemisphere appears to be inaccessible to the other. When such surgery is performed in man, two separate minds seem to coexist, one verbal—the other instrumental in its operations. Only the verbal hemisphere has so far been shown to produce intention and intentionality and, thus, self-consciousness. This suggests that meta operations of feedforward mechanisms such as those of transformational grammar must be critical in organizing linguistic competence.

These, and some of the observations detailed earlier in this paper, have raised once more other philosophical issues of the relationship between brain and mind. Most physiologists such as Sherrington (1941), Penfield (1975), Eccles (1970), and Sperry (1976, pp. 163–179) have opted for a cleancut dualism. Sherrington, Eccles, and Sperry have proceeded further in stating that mind can act on brain directly. They have not specified, however, what they mean by mind, nor by what mechanism mental organization can influence brain function.

Behavioral psychologists and biologists when they have not entirely eschewed mental operations, have by and large used the information measurement and information processing approach to the brain-mind problem used in this essay. The brain's wetware is akin to the hardware of computers and optical systems. Mental operations are akin to programs and image constructions. A systems approach distinguishes between hardware and software—between reductive analysis on the one hand and conventional construction on the other (Pribram, 1965). Dualism is thus affirmed but in a practical, pragmatic fashion rather than as an epistemological impasse. Furthermore, the mechanisms of interaction between brain and mind are being clearly specified in terms of information measurement and processing operations, mechanisms which do not belie the distinction between subjectivity and objectivity, but rather enhance it. As we have seen, subjectivity is a function of self-consciousness whose structural organization is feedforward rather than feedback.

Science pursues knowledge by observation and experimentation. As such it addresses problems that have been posed and clarified by philosophical analysis. The most recent surge of basic scientific activity in what were heretofore philosophical pastures has been in the behavioral, brain, and information sciences. In this essay we have been grazing, munching, and processing the results of these activities especially as they relate to the problem of consciousness. I believe the evidence attests to the fact that science can address the problem successfully and that we do indeed know a great deal that we did not know only a few decades ago. What is accomplished by such knowing is that a new set of questions at a much more precise (sometimes microstructural, often mathematical) level of inquiry can now be asked. In short our consciousness has been expanded both in breadth and in depth—spatial terms that do injustice to our enhanced feeling for the occurrences which are composed by and compose consciousness.

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