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NEUROBEHAVIORAL SCIENCE, NEUROPSYCHOLOGY, AND THE PHILOSOPHY OF MIND

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INTRODUCTION

The advent of the cognitive revolution in psychology ushered in a resurgent interest in the mind/brain connection. In this essay I discuss three forms this interest has taken. Neurobehavioral science, based to a large extent on animal brain–behavioral research, has made strides in determining the nature of memory storage, and the brain systems involved in attention and in different sorts of learning. Currently the neurochemical basis of emotion and motivation is being clarified. Clinical neuropsychology has added to the neurobehavioral base, and has been supplemented by it: An examination of memory retrieval processes and the exploration of brain function in the organization of human consciousness needs a human population to study. The yield has been rewarding and has given rise to a reexamination by philosophers and others of the nature of mind and spirit as these relate to the material world.

NEUROBEHAVIORAL SCIENCE

Parts and Wholes

Three closely related issues concerning the organization of brain function have been the subject of controversy for two centuries. The first of these concerns localization versus distribution of functions within the brain. The second issue stems from the first: Does processing proceed among different localizable systems or modules in a hierarchical fashion, or is processing global and heterarchical? Finally, is processing within and between systems serial or parallel?

Toward the end of the eighteenth century, Gall brought these issues to the fore by correlating different local brain pathologies to the histories of the cadavers he autopsied. Though often wrong in detail, Gall was correct in the methods he carefully detailed (see Gall & Spurtzheim, 1809/1969). He was naive in delineating the faculties of mind for which he sought localization. But systematic classification of mental functions still eludes us despite a half-century of operational behaviorism. Today, it is popular to discuss the modularity of mind (Fodor, 1980) and component systems of the brain (Thatcher & John, 1977) and relate them both in the clinic (McCarthy & Warrington, 1990) and in the laboratory (Pribram, 1971, 1991) by crafting experimental designs and behavioral and verbal testing procedures. The use of these techniques traces its heritage directly to Gall's enterprise.

The excesses of phrenology brought reaction. First, the question was raised as to which brain system brought together the various faculties into a conscious self. The unity of being, the soul of mankind, was challenged by breaking his mentation into a mere collection of faculties (see Pribram & Robinson, 1985, for the full impact on inquiry this view had). Furthermore, experimental evidence accrued to demonstrate a relation between impairments in complex behaviors and verbally reported experiences and the amount of brain tissue destroyed irrespective of location. In the recent past, Lashley (1929) became the exponent of this mass action view.

The distributed aspect of brain function becomes most evident in memory storage. Even with large deletions of brain tissue such as those resulting from strokes or resections for tumor, specific memories, engrams, are seldom lost. When amnesias do occur they are apt to be spotty and difficult to classify. This suggests that memory is stored in a distributed and statistically more or less random fashion. The storage process dismembers the input, which is then remembered on the occasions necessitating recognition and recall. The retrieval processes, in contrast to storage, are localized, at least within systems such as those that are sensory specific. When such systems are damaged, sensory-specific (see Pribram, 1954/1969, 1960, 1969, 1974, 1991) and even category-specific agnosias (see, e.g., McCarthy & Warrington, 1990) result.

Thus with regard to memory, both distributed and localized processes can be identified depending on which property of the process is being considered. This principle of analyzing a mental process to identify specific aspects will stand us in good stead throughout this chapter as we shall see.

If one reads Lashley carefully, one finds the seeds of conciliation between the "localist" and the "distributed" approaches to brain function. In a letter to Mettler, Lashley once stated his exasperation with being misinterpreted: "Of course I know the front of the brain does something different from the back end. The visual sensory input terminates in the occipital lobes. Electrical stimulations of the pre-Rolandic areas elicit movements and the front parts are more enigmatic in their functions. But this is not the issue." Elsewhere he states the issue clearly: "...certain coordinated activities, known to be dependent upon definite cortical areas, can be carried out by any part (within undefined limits) of the whole area" (Lashley, 1960, pp. 237–240).

What Lashley emphasized was that certain psychological processes appear to be related to brain processes that are nonlocal. For instance, he pointed out that sensory and motor equivalences could not be accounted for even by a duplication of brain pathways: "Once an associated reaction has been established (e.g., a positive reaction to a visual pattern), the same reaction will be elicited by the excitation of sensory cells which were never stimulated in that way during training. Similarly, motor acts (e.g., opening a latch box) once acquired, may be executed immediately with motor organs which were not associated with the act during training" (ibid.).

An example of motor equivalence was reported by Ukhtomski (1926). A dog was conditioned to raise his right hind leg to the sound of a tone. After this conditional response was well established, his right motor cortex (which controls the left side of the body) was exposed. Then during the performance of the conditioned reaction a patty of strychninized filter paper (which chemically excited the cortical tissue) was placed on the area that controls the left forepaw. Immediately the dog switched the responding leg: He now raised his left forepaw to the conditional signal. A temporary dominant focus of excitation had been established in the cortex by the chemical stimulation. A totally different set of neural and muscular systems carries out an action "equivalent" to the one the animal has been trained to perform.

The fact that a temporary dominant focus in the cerebral cortex can take control of the expression of a learned behavior indicates that, without a doubt, hierarchical control operates in the central nervous system. Equally persuasive is the evidence for control over spinal cord activity by the brain stem and forebrain. Neuronal activity in the spinal cord displays an extremely high rate of spontaneous impulse generation. These generators are modulated by inhibitory local circuit neurons in such a way that the resultant activity can be modeled in terms of "coupled ensembles of limit cycle oscillatory processes" (Kelso & Saltzman, 1982; see also extensive reviews by Grillner, 1974, 1981, & 1985).

In turn, these ensembles of oscillators become organized by brain stem systems that consist of cholinergic and adrenergic neurons. The cholinergic set regulates the frequency of a wide range of tonic rhythmic activities such as those involved in locomotion, respiration, cardiovascular responses, and sleep. This cholinergic system is coupled to an adrenergic set of neurons that segment the rhythmic activities into episodes (Garcia-Rill & Skinner, 1988). Both systems are subject to further hierarchical control by the dopaminergic system of the basal ganglia.

Clinically, loss of this hierarchical control becomes manifest in an exaggeration of the normally present, almost subliminal tremors which under extreme conditions lead to spastic paralysis, hyperreflexia, and uncontrollable fits of oscillatory muscular spasm.

But the evidence from the experiments that demonstrated temporary dominant foci can be viewed from another perspective: The flexibility demonstrated by the shift from one controlling locus to another shows the organization of the cortical system to be heterarchical. Any locus within the system can become dominant if sufficiently excited.

Ordinarily hierarchical control is conceived to be accomplished by way of a serial process. This is because when control is direct, there is a causal connection between the controller and the controlled. Causality implies that the origination of the control signal precedes its effect on the system being controlled. Seriality remains when there are feedback loops. Heterarchical organization, by definition, involves the potentiality for parallel processing. At the same time, however, when control is exerted over other systems, a serial process becomes implemented. In general, the brain is composed of hierarchies of heterarchical systems.

Processing in the cerebral cortex is massively parallel. Simulations of these parallel cortical processes have, during the past decade, become implemented on personal computers to such an extent that the endeavors have been dubbed a cottage industry. These simulations of neural networks are capable of pattern recognition, language learning, and decision making which are remarkably true to life. Single-layered simulations have given way to three-layered computations that involve an input layer, an output layer, and a hidden layer. All the elements of the network are interconnected, each element with all the others. In several such simulations the input is fed forward through the net and the output compared with one that is desired, and the difference between the actual and the desired is fed back to the net. The process is repeated until the desired output is achieved. Variations on this theme abound, each variation being better adapted than its alternates for a particular purpose. (Several excellent texts detailing the various types of neural networks are available; see, e.g., Dayhoff, 1990; Levine, 1991. For an exposition of the utility of such networks, see, e.g., Hinton & Anderson, 1981; Rumelhart & McClelland, 1986.)

One of the most fascinating attributes of these neural networks is the fact that the information contained in the input becomes fragmented and distributed in the elements of the layers. The simulations are therefore said to be parallel distributed processes (PDP). This makes them akin to optical information processing systems such as holography and tomography, from which they were in fact derived (Bracewell, 1989; Pribram, 1971, 1991; Willshaw, 1981).

Basal Forebrain Systems, Emotion, and Motivation

Beginning with Walter Cannon's (1927) experimentally based critique of James, followed by Lashley's (1960) critique of Cannon (1929), to the anatomically based suggestions of Papez (1937) and their more current versions by MacLean (1949), brain scientists have been deeply concerned with the processes that organize emotional and motivational experience and expression. Two major discoveries have accelerated our ability to cope with the issues and placed the earlier, more speculative accounts into better perspective. One of the discoveries has been the role of the reticular formation of the brain stem (Magoun, 1950) and its chemical systems of brain amines (see, e.g., the review by Barchas, Ciaranello, Stolk, & Hamburg, 1982; and Pribram & McGuinness, 1992) that regulate states of alertness and mood. Lindsley (1951) proposed an activation mechanism of emotion and motivation on the basis of the initial discovery and has more recently (Lindsley & Wilson, 1976) detailed the pathways by which such activation can exert control over the brain processes. The other discovery is the system of brain tracts, which when electrically excited results in reinforcement (i.e., increase in probability of recurrence of the behavior that has produced the electrical brain stimulation) or deterrence (i.e., decrease in probability that such behavior will recur), by Olds and Milner (1954).

In my attempts to organize the results of these discoveries it was necessary to distinguish clearly between those data that referred to experience (feelings) and those that referred to expression (see Darwin, 1872), and further to distinguish emotion from motivation (reviewed by Pribram, 1971). Thus feelings were found to encompass both emotional and motivational experience, emotional as affective and motivation as centered on readiness processes. Not surprisingly the affective processes of emotion were found to be based on the process of arousal, the ability to make phasic responses to input that "stop" the motivational processes of activation that maintain selective readiness. Thus, feelings were found to be based on neurochemical states (dispositions or moods), which become organized by neural systems involved in appetitive (motivation, "go") and affective (emotional, "stop") processes.

The wealth of new data and these insights obtained from them made it fruitful to reexamine the Jamesian position (Pribram, 1981). James overemphasized the visceral determination of emotional experience (attitudinal factors depending on sensory feedback from the somatic musculature were included by James but not emphasized) and, more important, he failed to take into consideration the role of expectations (the representational role of the organization of familiarity and novelty) in the organization of emotional expression. On the other hand, James rightly emphasized that emotional processes take place primarily within the organism while motivations reach beyond into the organism's environment. Further, James is almost universally misinterpreted as holding a peripheral theory of emotion and mind. Throughout his writings he emphasizes the effect that peripheral stimuli (including those of visceral origin) exert on brain processes. The confusion comes about because of James's insistence that emotions concern bodily processes, that they stop short at the skin. Nowhere, however, does he identify emotions with bodily processes. Emotions are always the result of the effect of bodily processes on the brain. James is in fact explicit on this point when he discusses the nature of the input to the brain from the viscera. He points out two possibilities: Emotions are processed by a separate brain system or they are processed by the same systems as are perceptions. Today we know that both possibilities are realized: Parts of the frontolimbic forebrain (especially the amygdala and related systems) process visceroautonomic bodily inputs, and the results of processing become distributed via brain stem systems that diffusely influence the perceptual systems (Pribram, 1961, 1991).

NEUROPSYCHOLOGY

Attentive Consciousness and Unconscious Processes

Additionally, William James (1901/1950) noted that the delineation of minding, that is, consciousness, devolves on processes we usually refer to as attention and intention (volition). I would add, thought. Controls on attention determine the span of sensory processing; those on intention determine the span over which action becomes effective; and those controlling thought, the span of memories that become considered.

For over a decade and a half my laboratory investigated the neural processes involved in the control of attention. A comprehensive review of these data and those gathered elsewhere (Pribram & McGuinness, 1975, 1992) discerned three classes of such mechanisms: One deals with short phasic response to an input (arousal); a second relates to prolonged tonic readiness of the organism to respond selectively (activation); and a third (effort) acts to coordinate the phasic (arousal) and tonic (activation) processes. Separate neural and neurochemical systems (Pribram, 1977; Pribram & McGuinness, 1992) are involved in the phasic (arousal) and tonic (activation) processes: The phasic centers on the amygdala; the tonic, on the basal ganglia of the forebrain. The coordinating system (effort) critically involves the hippocampus, a phylogenetically ancient part of the neural apparatus.

Evidence (reviewed by Pribram & McGuinness, 1992) from the analysis of changes in the electrical activity of the brain evoked by brief sensory stimulation has shown that the arousal and activation systems operate on a more basic process centered on the dorsal thalamus, the way station of sensory input to the cerebral cortex. Brain electrical activity evoked by sensory stimulation can be analyzed into components. Early components reflect processing via systems that directly (via the thalamus) connect sensory surfaces with cortical surfaces. Later components reflect processes initiated in cortical and related basal ganglia systems that operate downward onto the brain stem (tectal region) which, in turn, influence a thalamic "gate" that modulates activity in the direct sensory pathways. It is the activity reflected in these later components of the brain electrical activity that constitutes "activation."

The thalamic "gate" is, however, also regulated by input from the system centered on the amygdala—the arousal system. This system, when stimulated, produces an effect on the "gate" opposite to that of the activation system.

The evidence also indicates that the coordination of phasic (arousal) and tonic (activation) attentional processes often demands "effort." When attention must be "paid," the hippocampal system becomes involved and influences the arousal system rostrally through frontal connections with the amygdala system and influences the activation system caudally via connections in the brain stem. At this juncture the relation of attention to intention, i.e., to volition (will), comes into focus. Again, William James had already pointed out that a good deal of what we call voluntary effort is the maintaining of attention or the repeated returning of attention to a problem until it yields a solution.

The distinction between the brain mechanisms of motivation and will (volition) is treated by James, but clarity did not come until the late 1960s when several theorists (e.g., MacKay, 1966; Mittlestaedt, 1968; Waddington, 1957; W. R. Ashby, personal communication, 1960; McFarland, 1971; Pribram, 1971) began to point out the difference between feedback, homeostatic processes on the one hand and programs, which are feedforward, homeorhetic processes, on the other. Feedback mechanisms depend on error processing and are therefore sensitive to perturbations. Programs, unless completely stopped, run themselves off to completion irrespective of obstacles placed in their way.

Clinical neurology had classically distinguished the mechanisms involved in voluntary from those involved in involuntary behavior. The distinction rests on the observation that lesions of the cerebellar hemispheres impair intentional (voluntary) behavior, while basal ganglia lesions result in disturbances of involuntary movements. Damage to the cerebellar circuits are involved in a feedforward rather than a feedback mechanism (as already described by Ruch in the 1951 Stevens *Handbook of Experimental Psychology*, although Ruch did not have the term feedforward available to him). I have extended this conclusion (Pribram, 1971) on the basis of more recent microelectrode analyses by Eccles, Ito, and Szentagothai (1967) to suggest that the cerebellar hemispheres perform calculations in fast-time, i.e., extrapolate where a particular movement would end were it to be continued, and send the results of such a calculation to the cerebral motor cortex where they can be compared with the target to which the movement is directed. Experimental analysis of the functions of the motor cortex had shown that such targets are composed of "images of achievement" constructed in part on the basis of past experience (Pribram, 1971, chaps. 13, 14, & 16; 1991, Lecture 6; Pribram, Kruger, Robinson, & Berman, 1955–56; Pribram, Sharafat, & Beekman, 1984).

Just as the cerebellar circuit has been shown to serve intentional behavior, the basal ganglia have been shown to be important to involuntary processes. We have already noted the involvement of these structures in the control of activation, the readiness of organisms to respond. Lesions in the basal ganglia grossly amplify tremors at rest and markedly restrict expressions of motivational feelings. Neurological theory has long held (see, e.g., Bucy, 1944) that these disturbances are due to interference by the lesion of the normal feedback relationships between basal ganglia and cerebral cortex. In fact, surgical removals of motor cortex have been performed on patients with basal ganglia lesions in order to redress the imbalance produced by the initial lesions. Such resections have proved remarkably successful in alleviating the often distressing continuing disturbances of involuntary movement that characterize these basal ganglia diseases.

The distinction between the systems that control intentional and those that control involuntary behavior extends to the control of sensory input (see Pribram, 1977, for review) and the processing of memory. With regard to sensory input, the distinction between the contents of awareness and the person who is aware was delineated by Brentano (1973) and called intentional inexistence. This dualism of a minding self and the objective material contents of perception was also present in the writings of Ernst Mach (1914) and of course, René Descartes (1927). Although Cartesian dualism is perhaps the first overt nontrivial expression of the issue, the duality between subject and object and some causal connection between them is inherent in language once it emerges from simple naming to predication. Neumann (1954) and Jaynes (1977) have suggested that a change in consciousness (i.e., in distinguishing an aware self from what the self is aware of) occurs somewhere between the time of the Iliad and the Odyssey. My interpretation of this occurrence links it to the invention and promulgation of phonemically based writing. Prehistory was transmitted orally/aurally. Written history is visual/verbal. In an oral/aural culture a greater share of reality is carried in memory and is thus personal; once writing becomes a ready means of recording events they become a part of extrapersonal objective reality. The shift described is especially manifest in a clearer externalization of the sources of conscience—the Gods no longer speak personally to guide individual man.

This process of ever clearer distinctions between personal and extrapersonal objective realities culminates in Cartesian dualism and Brentano's intentional inexistence, which was shortened by Husserl (1901/1975) to "intentionality." It is this reading of the subject–object distinction that philosophers ordinarily mean when they speak of the difference between conscious and unconscious processes.

Freud had training both in medical practice and in philosophy. When he emphasized the importance of unconscious processes, was he implying the medical definition or the philosophical? Most interpretations of Freud suggest that unconscious processes operate without awareness in the sense that they operate automatically much as do respiratory and gastrointestinal processes in someone who is stuporous or comatose. Freud himself seems to have promulgated this view by suggesting a "horizontal" split between conscious, preconscious, and unconscious processes with "repression" operating to push memory-motive structures into deeper layers where they no longer access awareness. Still, in the *Project* (Freud, 1895/1966) memory-motive structures are neural programs—located in the core portions of the brain, which access awareness by their connections to cortex that determine whether a memory-motivated wish comes to consciousness. When the neural program becomes a secondary process, it comes under voluntary control, which involves reality testing and thus consciousness. To use language as an example, one might well know two languages but at any one time "connect only one to cortex" and thus the other remains "unconscious" and voluntarily unexpressed. (See Pribram & Gill, 1976, chaps. 2 and 5 for details.)

The linking of reflective consciousness to cortex is not as naive as it first appears. As the recently reported cases of Weiskrantz et al. (1974; Weiskrantz, 1986) have shown, "blindsight" results when patients are subjected to unilateral removal of the visual cortex. As noted, these patients insist they cannot see anything in the field contralateral to their lesion but when tested they can locate and identify large objects in their blind hemifield with remarkable accuracy. Furthermore, there are patients with unilateral neglect following parietal lobe legions (see Heilman & Valenstein, 1972, for review). Neglect patients often can get around using their neglected limbs appropriately. H. M., a patient who sustained an amygdala-hippocampal resection, has been trained in operant tasks and the effects of training have persisted without decrement for years, despite protestations from the patient that he doesn't recognize the situation and that he remembers nothing of the training (Sidman et al., 1968). In monkeys with such lesions we have shown almost perfect retention of training after a two-year period, retention that is better than that shown by unoperated control subjects (Pribram, unpublished observations). These monkeys and H. M. and the blindsight patients are clearly conscious in the medical instrumental sense. What has gone wrong is their ability to reflect on their behavior and experience, an inability within the impaired sphere of clearly distinguishing personal from extrapersonal reality. This leaves them with impaired consciousness in the philosopher's sense: Behavior and experience are no longer intentional.

The thrust of most recent psychoanalytical thinking as well as that of experimentalists such as Hilgard (1977) is in the direction of interpreting the conscious–unconscious distinction in the philosophical sense. For instance, Matte Blanco (1975) proposes that consciousness be defined by the ability to make clear distinctions, to identify alternatives. Making clear distinctions would include being able to tell personal from extrapersonal reality. By contrast unconscious processes would, according to Matte Blanco, be composed of infinite sets "where paradox reigns and opposites merge into sameness." When infinities are being computed the ordinary rules of logic do not hold. Thus, dividing a line of infinite length results in two lines of infinite length, i.e., one = two. Being deeply involved allows love and ecstasy but also suffering and anger to occur. In keeping with this, Carl Jung

(1960) defined unconscious processes as those involving feelings.

My interpretation of this conscious–unconscious distinction as it relates to human behavior and experience is in line with Matte Blanco's and others which are closely related to the philosophical distinction, and not to the medical. Thus, bringing the wellsprings of behavior and experience to consciousness means the making of distinctions, to provide alternatives, to make choices, to become informed in the Shannon (Shannon & Weaver, 1949) sense of reduction of uncertainty. One of these distinctions distinguishes episodes of *feeling* states and related them to one another.

An important change in views becomes necessary when these interpretations are considered seriously: Unconscious processes as defined by psychoanalysis are not completely "submerged" and unavailable to experience. Rather, unconscious processes produce feelings that are difficult to localize in time or in space and difficult to identify correctly. The unconscious processes construct the emotional dispositions and motivational context within which extrapersonal and personal realities are constructed. As the classical experiments of Schachter and Singer (1962) have shown, feelings are to a large extent undifferentiated, and we tend to cognize and label them according to the circumstances in which the feelings become manifested. (For a recent review of other experiments that have led to such a view see Hermans, Kempen, & van Loon, 1992.)

It is in this sense that behavior comes under the control of the unconscious processes. When I have burst out in anger, I am certainly aware that I have done so and of the effects of the anger on others. I may or may not have attended the build-up of feeling prior to the blow-up. And I may have projected the build-up onto others or introjected it from them. But I could have been aware of all this (with the guidance of a friend or therapist) and still found myself in uncontrolled anger. Only when the events leading to the anger become clearly separated into alternative or harmoniously related distinctions is unconscious control converted into conscious control. It is ridiculous to think that a person with an obsession or compulsion is unaware of his experience or behavior. The patient is very aware and feels awful. But he cannot, without aid, differentiate controls on the behavior generated by his feelings.

Objective Consciousness and the Posterior Cerebral Convexity

Surrounding the major fissures of the primate cerebral cortex lie the terminations of the sensory and motor projection systems. Rose and Woolsey (1949) and Pribram (1960) have labeled these systems extrinsic because of their close ties (by way of a few synapses) with peripheral structures. The sensory surface and muscle arrangements are mapped more or less isomorphically onto the perifissural cortical surface by way of discrete, practically parallel lines of connecting fiber tracts. When a local injury occurs within these systems a sensory scotoma, or a scotoma of action, ensues. A scotoma is a spatially circumscribed hole in the "field" of interaction of organism and environment: A blind spot, a hearing defect limited to a frequency range, a location of the skin where tactile stimuli fail to be responded to. These are the systems where what Henry Head (1920) called epicritic processing takes place. These extrinsic sensory-motor projection systems are so organized that movement allows the organism to project the results of processing away from the sensory (and muscular) surfaces where the interactions take place, out into the world external to the organism (Bekesy, 1967). Thus processing within these extrinsic systems constructs an objective reality for the organism.

In between the perifissural extrinsic regions of cortex lie other regions of cortex variously named association cortex (Fleschig, 1900), uncommitted cortex (Penfield, 1969), or intrinsic cortex (Pribram, 1960). These names reflect the fact that there is no apparent direct connection between peripheral structures and these regions of cortex that make up most of the convexity of the cerebrum.

Lesions of the intrinsic cortex of the posterior cerebral convexity result in sensory-specific agnosias in both monkey and man. Research on monkeys has shown that these agnosias are not due to failure to distinguish cues from one another, but due to *making use* of those distinctions in making choices among alternatives (Pribram & Mishkin, 1955; Pribram, 1969). This ability is the essence of information processing in the sense of uncertainty reduction (Shannon & Weaver, 1949), and the posterior intrinsic cortex determines the range of alternatives, the sample size of which a particular informative element must address. A patient with agnosia can tell the difference between two objects but does not know what the difference means. As Charles Peirce (1934) once noted, what we mean by something and what we mean to do with it are synonymous. In short, alternatives, sample size, choice, cognition, information in the Shannon sense, and meaning are closely interwoven concepts. Finally, when agnosia is severe it is often accompanied by what is termed "neglect." The patient appears not only not to know that he doesn't know but to actively deny the agnosia. Typical is a patient I once had who repeatedly had difficulty in sitting up in bed. I pointed out to her that her arm had become entangled in the bedclothes — she would acknowledge this momentarily, only to "lose" that arm once more in a tangled environment. Part of the perception of her body, her corporeal consciousness, seemed to have become extinguished.

These results can be readily conceptualized in terms of extracorporeal and corporeal objective reality. For a time it was thought that corporeal (egocentric) reality ("personal body space") depended on the integrity of the frontal intrinsic cortex and that the posterior convexal cortex was critical to the construction of extracorporeal (allocentric) reality (see, e.g., Pohl, 1973). This scheme was tested in my laboratory in experiments with monkeys (Brody & Pribram, 1978) and patients (Hersh, 1980; Ruff, Hersh, & Pribram, 1981) and found wanting. In fact, the corporeal/extracorporeal distinction involves the parietal cortex. Perhaps the most clear-cut example of this comes from studies by Mountcastle and his group (Mountcastle, Lynch, Georgopoulos, Sakata, & Acuna, 1975) which show that cells in the convexal intrinsic cortex respond when an object is within view, but only when it is also within reach. In short, our studies on patients and those of others have been unable to clearly separate the brain locations that produce agnosia from those that produce neglect. Furthermore, the studies on monkeys as well as those on humans (McCarthy & Warrington, 1990, chap. 2) indicate that agnosia is related to meaning as defined by corporeal use.

In monkeys the disturbances produced by restricted lesions of the convexal intrinsic cortex are also produced by lesions of the parts of the basal ganglia (implicated in activation, selective readiness) to which those parts of the cortex project (Heilman & Valenstein, 1972). This finding takes on special meaning from the fact that lesions of the thalamus (which controls the relaying of sensory input to cortex) fail to produce such effects. Further, recent experiments have shown that the neglect syndrome can be produced in monkeys by lesions of the dopaminergic nigrostriatal system (Wright, 1980). This special connection between intrinsic (recall that this is also called association) cortex and the basal ganglia further clarifies the intentional process that these systems make possible: The distinction between an objective egocentric corporeal self (the "me") and an extracorporeal allocentric reality (the "other"). (See Pribram, 1991, Lecture 6 for detailed exposition of how this process operates.) An excellent review of the history of differentiating this corporeal objective "me" from a subjective "I" can be found in Hermans, Kempen, and van Loon (1992). The next section develops the relation between brain processing and the "I".

Narrative Consciousness and the Frontolimbic Forebrain

As is well known, frontal lesions were produced for a period of time in order to relieve intractable suffering, compulsions, obsessions and endogenous depressions. When effective in pain and depression, these psychosurgical procedures portrayed in humans the now well-established functional relationship between frontal intrinsic cortex and the limbic forebrain in nonhuman primates (Pribram, 1950, 1954/1969, 1958). Further, frontal lesions can lead either to perseverative, compulsive behavior or to distractibility in monkeys, and this is also true of humans (Pribram, Ahumada, Hartog, & Roos, 1964; Oscar-Berman, 1975). A failure to be guided by the outcomes, the consequences of their behavior can account for this effect— as well as its opposite: The alleviation of obsessive–compulsive behavior. Extreme forms of distractibility and obsession are due to a lack of "sensitivity" of the activation (readiness) process to feedback from consequences. Both the results of experiments with monkeys (Pribram, 1961) and clinical observations attest to the fact that subjects with frontal lesions, whether surgical, traumatic or neoplastic, fail to be guided by consequences (Luria, Pribram, & Homskaya, 1964; Knonow & Pribram, 1970).

Consequences are the outcomes of behavior. In the tradition of the experimental analysis of behavior, consequences are reinforcers that influence the recurrence of the behavior. Con-sequences are thus a series of events (Latin *ex-venire*, out-come), outcomes that guide action and thereby attain predictive value (as determined by confidence estimates). Such con-sequences, i.e., sequence of events form their own confidence levels to provide contexts which, in humans, become envisioned eventualities (Pribram, 1963, 1971, 1991, Lecture 10 and Appendix G).

Confidence implies familiarity. Experiments with monkeys (Pribram, Reitz, McNeil, & Spevack, 1979) and humans (Luria, Pribram, & Homskaya, 1964) have shown that repeated arousal to an orienting stimulus habituates, i.e., the orienting reaction gives way to familiarization. Familiarization is disrupted by limbic (amygdala) and frontal lesions (Pribram, Reitz, McNeil & Spevack, 1979; Luria, Pribram and Homskaya, 1964). Ordinarily familiarization allows continued activation of readiness; disruption of familiarization (orienting) leads to repeated distraction and thus a failure to allow con-sequences to form. When the process of familiarization is disrupted, the outcomes-of-behaviors, events, become inconsequential. When intact, the familiarization process is segmented by orienting reactions into episodes within which confidence values can become established.

In such an episodic process the development of confidence is a function of coherences and correlations among the events being processed. When coherence and correlation spans multiple episodes, the organism becomes *committed* to a course of action (a prior intention, a strategy), which then guides further action and is resistant to perturbation by particular orienting reactions (arousals). The organism is now *competent* to carry out the action (intention-in-action; tactic). Particular outcomes now guide competent performance, they no longer produce orienting reactions (Brooks, 1986; Pribram, 1980).

This cascade which characterizes episodic processing leads ultimately to considerable autonomy of the committed competence. Envisioned events are woven into coherent subjectivity, a story, a narrative, the myth by which "I" live. This narrative composes and is composed of an intention, a strategy that works for the individual in practice, a practical guide to action in achieving (temporary) stability in the face of a staggering range of variations of events.

Consciousness is manifest (by verbal report) when familiarization is perturbed—an episode is updated and incorporated into a larger contextual scheme (the narrative), which includes both the familiar and novel episodes (Pribram, 1991, Appendices C & D). Consciousness becomes attenuated when actions and their guides cohere —the actions become skilled, graceful, and automatic (Miller, Galanter, & Pribram, 1960; Pribram, 1971, chap. 6).

THE PHILOSOPHY OF MIND

Extremists

As in every human endeavor various shades of opinion emerge when an issue becomes "hot," fashionable and of general concern. Pronouncements regarding the nature of mind and especially of its conscious aspects are no exception. Daniel Dennett (1991) has humbly contributed a volume entitled, *Consciousness Explained.* In it he replaces the Cartesian theater (Shakespeare's "stage"?) with a tentative pluralistic set of narratives recounting our experience. Those of us who are visually and kinesthetically as well as verbally inclined might prefer to stick with Descartes and Shakespeare. Marvin Minsky (1986) has also emphasized the plurality of mental processes in his *Society of Mind.* My question is: Have these volumes made any significant change in the basic proposition forwarded by Francis Gall at the end of the eighteenth century that a variety of "faculties of mind" can be correlated with a corresponding variety of cerebral systems? The details of correspondence have, of course, been immensely enriched during the ensuing two centuries of research and observation. But, as to philosophy, what is new?

At the other extreme are those who espouse an "eliminative materialism." Folk psychology, the wisdom and folly enfolded in language and in cultural expression over the ages, is to be eliminated as scientific explanation in favor of a neural explanation. One is reminded of psychology's era of behaviorism. Stephen Stich (1986) has contributed to this endeavor a book entitled *From Folk Psychology to Cognitive Science.* Its subtitle is *The Case Against Belief.* The arguments presented in support of this extreme materialism are convoluted but seem to me to ignore the issue of scale or level. How can anyone currently ignore the fact that those who, in the former Yugoslavia, as proponents of ethnic cleansing are operating on any basis other than belief? Only differences between Orthodox, Roman Catholic, and Islamic beliefs separate the protagonists. The origins and consequences of these differences in belief can be ascertained and many of them shown to be material in nature. But, just as in the word processing performed by my computer in the writing of this essay, the material instantiations of the cultural history would be as cumbersome to communicate as would the contents of this essay in machine language. Each level of description has value determined by the use to which the description is to be put.

Scientific Dualisms: Mental and Material

Attention to the levels at which analysis is pursued helps resolve many of the hitherto untractable issues surrounding the mind/brain interface. In the ordinary world of appearances there is no question but that human mental experiencing can be distinguished sharply from the contents of the experience. As noted earlier, the issue has been labeled "intentionality" (or intentional inexistence) by Franz Clemens Brentano and has given rise to inferences about the nature of reality (Brentano, 1973; Chisholm, 1960). The question is often phrased: Are my perceptions (my phenomenal experiences) the "real," or do the contents of those perceptions make up the "real" world? My phenomenal experiences are mental; the world as it appears to me is material. I can give primacy to my experience and become a phenomenologist, or I can give primacy to the contents of the experience and become a materialist. But I can also give primacy to neither and attest to the dual nature of the reality.

Materialism and phenomenology run into difficulty only when each attempts to deny the other. As long as only primacy is at stake, either view can be made consistent. After all, our experiences are primary, and empiricism is not inimical to a real material world. And we do appear to be experiencing something(s), so our experiences may well become organized by those real (material) somethings (see Bunge, 1980, for a persuasive development of this position).

However, by accepting such a moderate position with regard to mind and matter we immediately come up against a set of dualist problems. Are the contents of perception "really" organized by the experience of the perceiver? Is that experience in turn organized by brain function, sensory input, and the energies impinging on the senses? Would a complete description of brain function of an organism also be a description of the experience of that organism? If so, are not the material descriptions of brain, senses and energies sufficient? Or at least do the descriptions of experience add anything to the material descriptions? Cannot the inverse be equally true? What do the descriptions of brain, senses, and energies materially add to what we so richly experience?

I believe that today there are answers to those questions where only a few years ago there were none. These answers come from "unpacking" conceptual confusions and demonstrating where each conceptualization captures a part of the truthful whole.

A semantic analysis shows that descriptors of brain, senses, and energy sources are derived from an analysis of experience into components. The components are organismic and environmental (biological and physical or social), and each component can be subdivided further into subcomponents until the quantum and nuclear levels of analysis are reached. This procedure of analysis downward in a hierarchy of systems is the ordinary way of descriptive science. Within systems, causes and effects are traced. When discrepancies are found, statistical principles are adduced and probabilities invoked. Scientists have become adept and comfortable with such procedures.

Mental language stems from different considerations. As in the case of descriptive science, mental terms take their origin in experience. Now, however, experience is validated consensually. Experience in one sensory mode is compared with that obtained in another. Then validation proceeds by comparison of one's experience with that of another. A little girl points to a horse. Up to now, her mother has allowed her to say "cow" whenever any animal is pointed to. But the time has come to be more precise, and the experience of horse becomes validly different from that of a cow. Mental language is derived from such upward validations in a hierarchy of systems.

Elsewhere I detail the differences in scientific approach that this upward—or outward—look entails (Pribram, 1965). It is certainly not limited to psychology. When Albert Einstein enunciated his special and general theories of relativity, he was looking upward in the set of hierarchically arranged physical systems. The resultant relativistic views are as applicable to mental conceptualizations, as they are to physical ones. It is these relativisms that existentialists and phenomenologists constantly struggle to formulate into some coherent principles. My own belief is that they will be successful only to the extent that they develop the techniques of structural analysis (deconstruction). But structured analyses often depend on enactment to clarify the complexities involved. Abhorrent as the computer and other engineering devices may be to philosophers and psychologists of the existential–phenomenal persuasion, these tools may turn out to be of great service to their mode of inquiry.

If the above analysis is correct, then a dualism of sorts can be entertained as valid. First, however, let me provide a cautionary note. This form of dualism is concerned with the everyday domain of appearances—of ordinary experiences. Commencing with such ordinary experiences, two modes of conceptualization have developed. One mode operated downward in a hierarchy of systems, analyzing experience into components and establishing hierarchical and cause-effect relationships between these components. The other operated upward toward other organisms to attain consensual validation of experiences by comparing and sharing them.

Thus two mirror images—two optical isomers, as it were—are constructed from experience. One we call material and the other mental. Just as optical isomers in chemistry have differing biological properties, although they have identical components and arrangements, so the mental and material conceptualizations have different properties even though they initially arise from the selfsame experiences.

I suggest that this is the origin of dualism and accounts for it. The duality expressed is of conceptual procedures, not of any basic duality in nature. As we will see, there are other dualities that are more basic, but these are not the ones that have become the staple of those arguing for dualism.

Thus, strictly speaking mentalism and materialism imply each other, because there would be no need for mentalism if there were no materialism. There is no up without a down. Further, Sperry (1980) and Searle (1984) attempted to limit their mentalism to those structures that are organized by and in turn organize the brain. But it is not clear whether they would be willing to go to an epistemological limit that holds that mind interacts with the elementary components making up the brain. Intuition regarding biological roots of mentality is certainly accurate. To confuse the analogy of the computer with the historically based homologies that have given rise to psychological processes is akin to calling a whale a fish. By the same token, however, Sperry and Searle are adamantly opposed to an "independent existence of conscious mind apart from the functioning brain" (Sperry, 1980, p. 195); their mentalism does not stretch to cover the very essence of what motivates mentalism in the hands of those who oppose it to materialism; that is, the *primacy and independence* of mental structures.

What Computers Can Tell Us

Within the above caveat, let us look at the usefulness for an analysis of the mind/brain connection of computers, programs, and the processing of information in some detail because in many respects these artifacts so clearly portray some of the problems involved in the mind/brain issue. As noted (see e.g., Searle, 1984), the computer is not a brain, but its programs are constructed by people who do have brains. Nonetheless, computers and their programs provide a useful metaphor in the analysis of the mind/brain issue in which the distinction between brain, mind, and spirit can be seen as similar to the distinction between machine (hardware), low-level programs (e.g., operating systems), and high-level programs (e.g., word processing packages). Low-level programs such as machine languages and assemblers are not only idiosyncratic to particular types of computer hardware, but there is also considerable similarity between the logic of these languages and the logic operations of the machines in which they operate. In a similar vein, to some extent, perceptual processes can be expected to share some similarity to brain processes. On the other hand, high-level languages such as Fortran, Algol, and Pascal are more universal in their application, and there is less obvious similarity between their implicit logic and the logic of machines. At the highest level, in languages such as English, with which I address my computer in order to use it as a word processor, the relation between the logos of English (word, concept, logic) and that of the machine is still more remote. However, English relates me to a sizable chunk of the human social order. To complete the analogy, humanity's spiritual nature strives to make contact with more encompassing orders whether they be social, physical, cosmological, or symbolic.

Understanding how computer programs are composed also helps to tease apart some of the issues involved in the "identity" approach in dealing with the mind/brain relationship.

Because our introspections provide no apparent connection to the functions of the neural tissues that comprise the brain, it has not been easy to understand what theorists are talking about when they claim that mental and brain processes are identical. Now, because of the computer/program analogy, we can suggest that what is common to a mental operation and the brain "wetware" in which the operation is realized is some order that remains invariant across transformations. The terms *information* (in the brain and cognitive sciences) and *structure* (in linguistics and in music) are most commonly used to describe such identities across transformations. Order invariance across transformations is not limited to computers and computer programming. In music we recognize a Beethoven sonata or a Berlioz symphony irrespective of whether it is presented to us as a score on sheets of paper, in a live concert, over our high fidelity music system, or even in our automobiles when distorted and muffled by noise and poor reproduction. The information (form within) and the structure (arrangement) is recognizable in many embodiments. The materials that make the embodiments possible differ considerably from each other, but these differences are not part of the essential property of the musical form. In this sense, the identity approach to the mind/brain relationship, despite the realism of its embodiments, partakes of Platonic universals, that is, ideal orderings that are liable to becoming flawed in their realization.

In the construction of computer languages (by humans) we gain insight into how information or structure is realized in a machine. The essence of biological as well as of computational hierarchies is that higher levels of organization take control over, as well as being controlled by, lower levels. Such reciprocal causation is ubiquitous in living systems: Thus, the level of tissue carbon dioxide not only controls the neural respiratory mechanism but is controlled by it. Discovered originally as a regulatory principle that maintains a constant environment, reciprocal causation is termed *homeostasis*. Research over the past few decades has established that such (negative) *feedback* mechanisms are ubiquitous, involving sensory, motor, and all sorts of central processes. When feedback organizations are hooked up into parallel arrays, they become feedforward control mechanisms that operate much as do the words (of bit and byte length) in computer languages (Miller et al., 1960; Pribram, 1971).

Equally important, programming allows an analysis to be made of the evolution of linguistic tools that relate the various levels of programming languages. Digital computers with binary logic require a low-level language (coded in the numerals 0 or 1) that sets a series of binary switches. At the next level, switch settings can be grouped so that binary digits (bits) are converted into a more complex code consisting of bytes, each of which is given an alphanumerical label. Thus, for example, the switch setting 001 becomes 1, the setting 010 becomes 2, and the setting 100 becomes 4. Given that 000 is 0, there are now eight possible combinations, each of which is an octal byte.

This process is repeated at the next level by grouping bytes into recognizable words. Thus 1734 becomes ADD; 2051 becomes SKIP, and so forth. In high-level languages, *groups* of words are integrated into whole routines that can be executed by one command.

It is likely that some type of hierarchical integration is involved in relating mental processes to the brain. Sensory mechanisms transduce patterns of physical energy into patterns of neural energy. Because sensory receptors such as the retina and the cochlea operate in an analog rather than a digital mode, the transduction is considerably more complex than the coding operations described above. Nonetheless, much of neurophysiological investigation is concerned with discovering the correspondence between the pattern of physical input and the pattern of neural response. As more complex inputs are considered, the issue becomes one of comparing the physically determined patterns with subjective experience (psychophysics) and recording the patterns of response of sensory stations in the brain.

These comparisons have shown that a number of transformations occur between sensory receptor surfaces and the brain cortex. The transformations are expressed mathematically as transfer functions. When the transfer functions reflect identical patterns at the input and output of a sensory station, the patterns are considered to be geometrically isomorphic (*iso* means same; *morph* means form), that is, of the same form. When the transfer functions are linear (i.e., superposable and invertible, reversible), the patterns are considered to be secondarily or algebraically isomorphic (Shepard & Chipman, 1970). Thus, as in the case of computer programming, levels are due to transformations that progressively alter the form of the pattern while they maintain intact some basic order, an informational structure.

What I propose, therefore, is a "monism," which states that the truly basic components of the universe are neither material nor mental, but neutral to this dichotomy. The dematerialization of energy in modern physics (which I will review in the next section), thus supports a "neutral monism" (James, 1909; Russell, 1948). Critical philosophers (e.g., Herbert Feigl, 1960), who were steeped in linguistic analysis, developed this monistic view by suggesting that the "mental" and "material" are simply different ways of talking about the same processes. Thus "mind" and "brain" come to stand for separate linguistic systems, covering different aspects of a basic commonality. The problem has been to find a neutral language to describe the commonality without being either mental or material in its connotations.

I have taken this "dual aspects" view a step further by proposing that each aspect not only is characterized linguistically but in fact is a separate "realization" or "embodiment" (Pribram, 1971). As noted, I have further proposed that what becomes embodied is informational "structure." Thus, in essence I have stood the critical philosopher's approach on its head: The enduring "neutral" component of the universe is informational structure, the negentropic organization of energy. In a sense, this structure can be characterized as linguistic—or mathematical, musical, cultural, and so on. Dual aspects become dual realizations—which in fact may be multiple—of the fundamental informational structure. Thus, a symphony can be realized in the playing at a concert, in the musical score, on a record or on a tape, and thence through a high-fidelity audio system at home.

Mind and brain stand for two such classes of realization, each achieved, as described earlier, by proceeding in a different direction in the hierarchy of conceptual and realized systems. Both mental phenomena and material objects are realizations and therefore realities. Both classes of reality are constructions from underlying "structures," which it is the task of science to specify in as neutral a language as possible (neutral, i.e., with respect to connotations that would suggest that the "structures" belong in one or the other class). I note elsewhere the relationship of such a constructional realism to critical realism, pragmatism, and neo-Kantian rationalism (Pribram, 1971).

There is thus an important difference between a constructional realism such as I propose and materialist, mentalist, dualist, and triadic interactionisms. In a constructional scheme the precise place of brain mechanisms can be specified. There is no global "mind" that has to make mysterious contact with global "brain." Many mysteries are still there—to name only one, for example, how emergents come about and why they are so utterly different from their substrate. But issues become scientific and manageable within the broader context of philosophic enquiry.

The World of Appearance and the World of Potentiality

Holding the identity "position" with regard to the mind/brain issue involves specifying what it is that remains identical. Unless something remains constant across all the coding operations that convert English to binary machine code and back to English, my word processing procedures would not work. Identity implies reciprocal stepwise causation among structural levels. Contrary to the usually held philosophical position, identity does not necessarily mean geometrical or even algebraic isomorphism. Transformations, coding operations, occur that hierarchically relate levels of complexity with one another. A level is defined by the fact that its description, that is, its code, is in some nontrivial sense more efficient (i.e., requires less work, less expenditure of energy) than use of the code of the components that compose it. In the case of the word processor, the coding is arbitrary, and the arbitrariness is stored on a diskette and copyrighted. In the case of the mind/brain relationship, the nature of the coding operations is more universal and the efforts of two centuries of psychophysical, neuropsychological, and cognitive research have provided knowledge concerning at least some of the coding operations involved.

I am belaboring these findings of scientific research to indicate that, contrary to what some philosophers hold (see, e.g., Dewan et al., 1976), they have relevance to philosophical issues. *If the mind/brain problem arises from a distinction between the mental and the material and we find that at a certain level of analysis we no longer can clearly make such a separation, then the very assumptions upon which the issue is joined may be found wanting.*

Levels of analysis thus concern the fundamental assumption that has given rise to the mind/brain problem: Mental phenomena and the material universe must in some essential fashion differ from each other. As we have seen, in the ordinary domain of appearances, at the Euclidean-Newtonian level of analysis, this view is certainly tenable. But at the levels of the macro- and microphysical universes dualism becomes awkward. Niels Bohr's complementarity and Werner Heisenberg's uncertainty principle emphasize the importance of the observer in any understanding of what presumably is observed (Bohr, 1966; Heisenberg, 1959). Eugene P. Wigner (1969) stated the issue succinctly: Modern microphysics and macrophysics no longer deal with relations among observables but only with relations among observations.

An objection can be entered that such difficulties of distinguishing observables from observations encountered today by physicists are temporary, superficial, and of no concern to philosophers interested in the eternal verities. But that is not the message these thoughtful pioneers in physics are attempting to convey. They have been exploring universes where the everyday distinction between material and mental becomes disturbingly untenable at a very fundamental level. As I proceed, I shall tender some explanations that may help account for their views.

The dematerialization of energy can be traced in some sense to earlier formulations. For instance, physics was conceptually understandable in James Clerk Maxwell's day when light waves were propagated in the "ether." But then physicists did away with the "ether." Still, they did not rid themselves of Maxwell's wave equations or the more recent ones of Erwin Schroedinger (1928) or Louis Victor Prince de Broglie (1964). One readily can conceptualize waves traveling in a medium, such as when sound waves travel in air, but what can be the meaning of light or other electromagnetic waves "traveling" in a vacuum? Currently physicists are beginning to fill that vacuum with dense concentrations of energy, potentials for doing work when interfaced with matter. It is this potential that, I propose, is neutral to the mental–material duality.

In science, such potentials are defined in terms of the actual or possible work that is necessary for realization to occur and are measured as change in terms of *energy*. Thus, multiple realization imply a neutral monism in which the neutral essence, the potential for realization, is energy. And, as stated in the second law of thermodynamics, energy is entropic, that is, it can have structure.

Energy is not material, only transformable into matter. It is measured by the amount of work that can be accomplished by using it and the efficiency of its use depends on its organization as measured by its entropy. The invention of the vacuum tube and subsequent devices have shown that properly configured minute amounts of energy can control large expenditures and that these minute organizations provide "information," that is, they inform and organize energy. Measures of information and entropy thus were seen as related (see, e.g., Brillouin, 1962; von Weizsacker, 1974). Computers were constructed to process information, and programs were written to organize the operations of computers. Is the information contained in a program "material" or "mental"? If it is either, what then of the information in a book? Or the entropy that describes the behavior of a heat engine or of a warm-blooded mammal? Clearly, we have come to the limit of usefulness of a distinction between the material and the mental.

Heisenberg (1959) developed a matrix approach to understanding the organization of energy (and momentum, i.e., inertia). Currently, this approach is used in s-matrix, bootstrap theories of quantum and nuclear physics by Henry Stapp (1965) and Geoffry Chew (1966). These investigators (among others, Dirac, 1951) have pointed out that measures of energy and momentum are related to measures of location in space-time by way of a Fourier transform. The Fourier theorem states that any pattern of organization can be analyzed into, and represented by, a series of regular waveforms of different amplitudes, frequencies, and phase relations. These regular waveforms can in turn be superimposed, convolved, with one another and, by way of the inverse Fourier procedure, can be retransformed to obtain correlations in the original space-time configuration. Thus, the Fourier transform of a set of patterns displays a spectral organization that is, of course, different from that which is displayed after the inverse Fourier transform has again converted the pattern into the space-time order.

In terms of the proposition put forward by Dirac, Stapp, and Chew, this means that the organization of energy and momentum is considerably different from the space-time organization of our ordinary perceptions that can be expressed in Euclidean, Cartesian, and Newtonian terms. David Bohm (1971, 1973, 1976) has identified these nonclassical organizations of energy potentials as "implicate," that is, enfolded, and has used the hologram as an example of such enfolded orders. Dennis Gabor (1946, 1948), the inventor of the hologram, based his discovery on the fact that one can store on a photographic film interference patterns of waveforms produced by the reflection or refraction of light from an object and reconstruct from such a film the image of the object. It is probably no accident that holograms were a mathematical invention (by Dennis Gabor) that used a form of mathematics, the integral calculus, invented by Gottfried Wilhelm Leibniz, who also came to a vision of the implicate order. Leibniz's monadology (1951) is holographic; his monads are distributed, windowless forms each of which is representative of the whole. Substitute the term *lensless* for windowless, and the description of a monad and a hologram is identical. Today the description of the enfolded organization of the stored potential for reconstruction is related to the unfolded space-time description of the object by a Fourier transform.

The Fourier theorem has also played an important role in the recent discoveries in the brain sciences. In the late 1960s, several groups of investigators found that they could explain their findings in visual research when they realized that their results indicated that encoding of spatial patterns in the visual system involved what they called *spatial frequency*. This term describes the spectral domain that results when a Fourier transform is performed on space-time. Fergus Campbell and John Robson (1968) of Cambridge University discovered unexpected regularities in their data: Responses to gratings of different widths and spacings adapted not only to the particular grating shown but also at other data points. These additional adaptations could be understood by describing the gratings as composed of regular waveforms, with a given frequency and the regularities in terms of harmonics. The spectral frequency was determined by the spacings of the grating, and thus the term spatial frequency. Spatial and temporal frequencies are related, of course: Scanning by a steadily moving beam would describe the grating's temporal frequency. Physicists therefore use the term *wave number* to denote the purely frequency, spectral form of description of patterns.

What this means is that the optical image is decomposed into its Fourier components: Regular waveforms of different frequencies and amplitudes. Cells in the visual system respond to one or another of these components and thus, in aggregate, comprise an image processing filter or resonator that has characteristics similar to the photographic filter comprising a hologram, from which images can be reconstructed by implementing the inverse transform.

There are, however, important differences between ordinary photographic holograms and the visual nervous system. Ordinary holograms are composed by a global Fourier transform that distributes the information contained in a space-time image throughout the transform domain. In the visual nervous system, distribution is limited anatomically to the input channeled to a particular cortical cell. Nonetheless, there are holographic techniques that use similar "patch" or multiplex constructions. Bracewell (1965) at Stanford University pioneered these techniques in radioastronomy by stripping together the holographic transformations of limited sectors of the heavens as viewed by radiotelescope. When the inverse transform is applied, space-time images of the whole composite can be viewed in three dimensions.

Furthermore, the transform that best describes the process in the visual system is a Gabor, not a Fourier. The Gabor transform (Gabor 1946, 1948; Daugman, 1985; Marcelja, 1980; Pribram & Carlton, 1987) is formed by placing a Gaussian envelope on the otherwise unlimited Fourier transform. This is another way of stating that the transformation is patchlike and not global, and gives mathematical precision to the limits involved.

Finally, the arrangement of the visual channels and the cortical cells is not haphazard with regard to one another. A clear retinotopic to cortical spatial arrangement is maintained. Thus the gross grain of the visual filter determines space-time coordinates, whereas its fine grain describes the Fourier components.

What advantage is gained by this fine-grain holographic-like organization? Recall that in the transform domain correlations among patterns are readily performed. This is why the fast Fourier transform (FFT) as performed by computer is such a powerful tool in statistical analysis and in computerized tomography (CT scans). The brain is an excellent correlator by virtue of its fine-grain processing potential.

The dual properties of an enfolded fine-grain (technically, the synaptodendritic receptive field organization) and a gross-grain space-time organization applies to other sense modalities as well, although the experimental evidence is not as complete. Georg von Bekesy (1967) performed critical studies in the auditory and somasthetic modalities, Walter Freeman (1960) conducted studies in the olfactory, and Pribram, Sharafat, and Beekman (1984) have shown that cells in the sensorimotor cortex are tuned to specific frequencies of movement. At the same time, in all these sensory systems the spatial organization of the receptor surface is topographically represented in the gross-grain arrangement of the cortical cells that receive the sensory input.

In summary, there is good evidence that another class of orders lies behind the ordinary classical level of organization we ordinarily perceive and which can be described in Euclidean and Newtonian terms and mapped in Cartesian space-time coordinates. The other class of orders is constituted of fine-grain distributed organizations described as potential because of the radical changes that occur in the transformational process of realization. When a potential is realized, information (the form within) becomes unfolded into its ordinary space-time appearance; in the other direction, the transformation enfolds and distributes the information as this is done by the holographic process. Because work is involved in transforming, descriptions in terms of energy are suitable, and as the structure of information is what is transformed, descriptions in terms of entropy (and negentropy) are also suitable. Thus, on the one hand, there are enfolded potential orders; on the other, there are unfolded orders manifested in space-time.

The point was made earlier in this chapter that the dualism of mental versus material holds only for the ordinary world of appearances—the world described in Euclidean geometry and Newtonian mechanics. An explanation of dualism was given in terms of procedural difference in approaching the hierarchy of systems that can be discerned in this world of appearances. This explanation was developed into a theory, a constructional realism. But it was also stated that certain questions raised by a more classical dualistic position were left unanswered by the explanations given in terms of an identity position.

Two issues can be discerned: (1) What is it that remains identical in the various levels of the hierarchy of programs or compositions? and (2) Is the correspondence between machine language (program or musical notation) and the machine or instrument's operation an identity or a duality? I believe the answer to both the questions hinges on whether one concentrates on the order (form, organization) or the embodiments in which these orders become instantiated (Pribram, 1986, 1993).

There is a difference between surface structures of different grains that become *trans*-formed and the deeper identity that *in*-forms the transformations. Transformations are necessary to material and mental "instantiations"—Plato's particular appearances—of the ideal in-forms: The instantiation of Beethoven's Ninth Symphony is transformed from composition (a mental operation) to score (a material embodiment) to performance (more mental than material) to recording on compact disc (more material than mental) to the sensory and brain processes (material) that make for appreciative listening (mental). But the symphony as symphony remains recognizably "identical" to Beethoven's creative composition over the centuries of performances, recordings, and listenings.

Instantiations depend on transformations among orders. What remains invariant across all instantiations is "in-formation," the form within. Surprisingly, according to this analysis, it is a Platonic "idealism" that motivates the information revolution ("information processing" approaches in cognitive science) and distinguishes it from the materialism of the industrial revolution. Further, as in-formation is neither material nor mental, a scientific pragmatism akin to that practised by Pythagoreans displaces mentalism and dualism as well as materialism. At least the tension between idealism (the potential) and realism (the appearance), which characterized the dialogue between Plato and Aristotle, will replace that between mentalism and materialism.

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