Appeared in Papanicolaou, A. C. and Gunter, P.A.Y. (Eds.) BERGSON AND MODERN THOUGHT: Toward a Unified Science. Chur, Switzerland: Harwood Publishers, 1987, pp. 149--174.

BERGSON AND THE BRAIN: A BIO-LOGICAL ANALYSIS OF CERTAIN INTUITIONS

Karl H. Pribram
Stanford University

> The consciousness of a living being . . . is inseparable from its brain in the sense in which a sharp knife is inseparable from its edge: The brain is the sharp edge by which consciousness cuts into the compact tissue of events, but the brain is no more coextensive with consciousness than the edge is with the knife. (Bergson, *Matter and Memory*, p. 263)

INTRODUCTION

In keeping with the Zeitgeist of the nineteenth and early twentieth centuries, Henri Bergson was convinced that understanding the mental and spiritual nature of mankind depended to a large extent on understanding the relationship between man's conscious experience and his brain. What puzzled the intellects of the nineteenth century was that experience, introspectively analyzed, had so little in common with the physical and biological processes which contemporary science was then describing. Even the behavior of organisms often appeared to be controlled by processes resistant to such analyses. Their introspective analyses were therefore reported in what appeared to be speculative, intuitive, and even mystical terms which seemed remote from the precision achieved in scientific discourse.

I believe the situation has changed, and that it is most worthwhile to return to the insights achieved by these intellects and to apply the knowledge we have gained during the twentieth century to the questions they framed so successfully. On this occasion, it is Bergson who holds center stage, and I must confess amazement at the richness and precision of thought with which this philosopher foreshadowed what current brain-behavior research has demonstrated. Let us begin with and frame other issues within the most complex of these problems, that of consciousness per se.

CONSCIOUSNESS

Bergson has clearly stated the issue that needs to be addressed if a scientific understanding of consciousness is to be achieved: Just what is the relationship between brain and consciousness? The answer to this query is not as simple as Bergson has made it appear, as we shall see. However, Bergson's intuition does prehend one important aspect of the relationship, an aspect that proves to be most innovative and exciting.

The term "consciousness," like many in the brain and behavioral sciences, is used with a variety of meanings. For this reason, among others, behaviorists suggested that we cannot study consciousness scientifically. These scientists would have us abandon the term and describe operationally just what is going on that allows the inference to be made that consciousness is involved. Thus, "verbal reports of introspection," "observing responses," and "the regulation of appetitive behaviors by deprivation schedules" are some of the phrases that have come to be used by psychologists where neurosurgeons and psychiatrists might infer "consciousness." The behaviorist has a telling point in his favor, for he is clear where, as it turns out, the neurosurgeon and psychiatrist are not: in situations where the neurosurgeon pronounces someone conscious, the psychiatrist may decide that unconscious processes are at work.

The trouble with taking the behaviorist's negative approach to this definitional problem is that people from other disciplinary backgrounds continue to use the term "consciousness" and some of us might be interested in what they have to say. When Julian Jaynes (1977) stated, in his controversial book on the bicameral mind, that an important change in consciousness had taken place between the *Iliad* and the *Odyssey*, some critics thought he was saying that humans were unconscious before that change. When a neurosurgeon finds a patient unconscious, he calls this a stupor; when the patient fails to respond at all, he is comatose. Stupor and coma are considered to be mindless states — states of unconsciousness in which the patient cannot mind, cannot attend, cannot react. The behaviorist philosopher, Gilbert Ryle (1949), pointed out that the term "mind" is derived from "minding" — thus we come to identify consciousness and mind, and as Ryle and others of behaviorist persuasion have urged, ignore these "ghosts" in the machine. But it is just these "ghosts" that constitute the most interesting problems for psychological science — negating their existence can lead only to impoverishment and sterility.

If indeed science is the search for beauty in nature, as George Wald (this volume) has suggested, how do we deal with "consciousness"? One solution is to separate the various states, operators on those states, and the resulting transformations of those operations. Thus states of consciousness can be distinguished from the processes of attention and from the contents of awareness. When the neurosurgeon makes the diagnosis of stupor, he is referring to the *state* of consciousness of his patient.

By contrast, when a psychologist is cataloging the occurrence of observing responses on reaction times, he is studying the processes initiated by or directed toward his momentary state. Attention is manifest when certain inputs are processed and others ignored. What is attended also allows psychiatrists to distinguish conscious from unconscious processes: Attending leads to conscious, nonattending to unconscious processing. Psychiatrists—and clinical psychologists note that behavior is often controlled by unattended variables. Lack of attention can result from habituation and habit, or from the fact that attentional competence is insufficiently developed. Important here is the fact that when a psychoanalyst speaks of unconscious processes he is not describing the state of his patient but the effects of processing on behavior and experience.

Finally, there are those who concern themselves with the contents of consciousness, the resultants of the attentional process. In most animals attention is ordinarily directed toward sensory input. During problem-solving, however, attention may be directed inward in an attempt to resolve "active uncertainty": a process which John Dewey (1916) has identified with thinking. As a result, humans and probably other organisms with highly complex brains become aware of the contents of their thoughts, leading to Descartes' dictum "cogito ergo sum." In the hands of Brentano (1874, 1973) and von

Üxkill (1926), the ability to discern the distinction between the contents of sensory input and of thought defines intentional beings. It was Freud (1895, 1950), a student of Brentano, who insisted that intentional beings can scientifically investigate their intentionality, their consciousness, and their unconscious processes. Equally important, though more elusive, has been Bergson's insight into a universal order that lies beyond immediate apprehension of the ordinary space/time sensory input. Let us examine each of these facets of the brain/consciousness relationship one at a time, with the aim of clarifying a set of intuitions in which many of these facets are currently confounded.

STATES OF CONSCIOUSNESS

What, then, composes states of consciousness? States are separated from one another by "phase boundaries." Ice, liquid water and steam are three states of H_2O. Sleep and wakefulness, wakefulness and an hypnotic state appear to be separated by such boundaries because what is experienced in one state is almost totally inaccessible to another. Hilgard (1977), in a set of studies using hypnotized subjects, has concluded that different states organize conscious processes in different configurations much as different languages differently organize what we mean to say. There is always some "hidden observer" who in some sense "knows" what is being configured, what is meant. The "hidden observer" is the "state space" within which the states develop.

The organization of the states that determine these configurations of conscious processes is dependent upon a class of nerve cells found in the core of the brainstem, cells which distribute their branches widely over the reach of the forebrain, including the cerebral cortex. In agreement with the conception that phase boundaries separate such states, these single-source, highly divergent systems are neurochemically differentiated from one another. As Schrödinger (1944) has observed, living tissue partakes of the characteristics of crystalline structures at absolute zero temperature in that the metabolism of life does not obey the second law of thermodynamics. Recall that the second law deals with the efficiency of a process and defines entropy as the loss of order due to inefficiency (i.e. energy becomes spent as heat). Schrödinger pointed out that in contrast to physical systems the biological processes produce order and concluded that all living systems tend to maintain structure or even enhance it. Prigogine (1980) has developed thermodynamic models which show that initially random fluctuations can become organized into structured states. These same models can be applied to describing how, when sufficient randomness remains, one organizational state can flip-flop into another much as in a kaleidoscope. An organism is deprived of food; an appetitive state of hunger becomes organized from the fluctuations of blood sugar, the rhythmic contractions of stomach and gut, etc. In this state of hunger the organism is disposed to attend stimuli which in the past have usefully matched the appetitive state: signs depicting restaurants, menus, unopened peanut shells, and the like. Once eating behavior has commenced, another state — the state of satiety — becomes organized. In this state the particular fluctuations associated with hunger are reduced and some other set of appetitive fluctuations, such as those produced by sex hormones, may take over. Now the state space is so organized that the organism is sexy rather than hungry. In the salmon, the two states are mutually exclusive — when salmon feed, they do not spawn; when they spawn, they do not feed. This exclusiveness is also seen to some extent in mammals who may eat ravenously after copulation, but exclusion is much shorter in duration.

Mutual exclusion is also characteristic of the relationship between appetite and satiety states. There is thus an opponent aspect to the relationship, (see Solomon 1980) a see-saw between a motivating appetitive condition and an emotional "I've had enough" satiety state. Each of these opponent operations has been shown to have its own neural circuitry (Pribram & McGuinness, 1975), and in addition there is yet another system which mediates between appetite and satiety in such a way as to make the transition take place in the most efficient manner — i.e., with the expenditure of least effort.

States can determine what is attended, but so can environmental variables. Sexiness is not only due to internal states but can be initiated by attractive potential mates. Appetite for food can be whetted by the smell of a roast in the oven, the taste of an appetizer, or the sight of a smorgasbord. Thus states are induced not only by the fluctuations of the neurochemical biological substrate but by events that capture attention. Such "captures" are reminiscent of the way in which eliciting stimuli initiate the expression of inherited behavior patterns, the instinctive species-specific behaviors studied so extensively by ethologists (see, e.g., Konrad Lorenz, 1969).

CONSCIOUS AND UNCONSCIOUS PROCESSES

It is especially human to attempt to distinguish between, i.e., direct their attention selectively either to the endogenous (neurochemical) or to the exogenous (sensory) variables that organize states of consciousness. Philosophers in particular are concerned with such problems, and when they speak of consciousness they mean the self-reflective consciousness that can to some extent discriminate between endogenous and exogenous factors in the organization of awareness and of behavior. Thus we can clearly distinguish at any moment between our intentions and our actions, and between what it is we sense and ourselves as sensible. As noted in the introduction, Brentano, a Viennese philosopher who greatly influenced Freud, called our sensibility "intentional inexistence" because like intentions, sensory imaging can fail to correspond to actuality. Later, von Üxkill, a German philosopher-scientist and the godfather of ethology, shortened "intentional inexistence" to "intentionality."*

Earlier, reference was made to Julian Jaynes' discourse on the change in consciousness between the *Iliad* and the *Odyssey*. Jaynes su ge s that self-reflective consciousness, as we experience it today, was lacking in the earlier period, that the variables we now regard as endogenous were at that earlier period "projected" onto a set of deities. Jaynes hints at some possible biological change to account for the initiation of self-reflectivity in this form. A more parsimonious explanation would attribute the change to the invention of writing. In an oral-aural culture, the opportunity for consensual validation provided by a more or less permanent exogenous record is absent. Thus it becomes difficult to sort our endogenous (self) and exogenous (erstwhile bearer of tales) variables in those aspects

* Intentionality with a "t" is different from intensionality with an "s" in philosophical discourse. Intentionality is related to intention; intensionality is related to the intensive dimension of experience: intension, as distinguished from extension in space and time. Neurologists use the term "local sign" for extension and Henry Head (1920), a famous British neurologist, dubbed sensations which display local sign "epicritic." As we shall see, the brain systems that deal with epicritic extension are different from those that are involved in the intensional, protocritic, aspects of experience.

of culture transmitted by speech. "Intentional inexistence" cannot be readily discerned.

In psychiatric and psychological discourse, consciousness, when the term is used at all, refers to the process of attention. The organization of attention can be determined endogenously by states or exogenously by sensory input, or by both. A distinction is made between conscious and unconscious processes (and preconscious, etc.) which refer to an ability to separate endogenous and exogenous variables that determine a particular experience and/or behavior.

It is this reflective aspect of consciousness that also motivates philosophical discourse. Nineteenth century neurologists such as Freud (see Pribram & Gill, 1976) who came under the influence of philosophers such as Brentano, held that the cerebral cortex is the locus of a match between sensory input and state-originated brain patterns. The anatomical, and to some extent physiological, insights (based largely on clinical data) of the nineteenth-century neuroscience community have been substantially supported.

In the mid-1970s some patients were thoroughly examined who had unilateral resections limited to the striate (visual) occipital cortex which receives the optic projections. As expected, these patients displayed a contralateral homonymous hemianopia, i.e., blindness in the visual hemified opposite to the side of the resection. But, on testing with large objects, these patients were shown to be able to locate those objects in space by pointing and to verbally identify correctly the shapes of the objects. Despite this performance, the patients continued to maintain that they could not "see" anything in that visual hemispace and that they were guessing in the tasks they were so proficiently performing. Weiskrantz, Warrington, Sanders and Marshall (1974), the investigators who discovered this phenomenon, have called it "blind-sight."

A similar effect is produced when other parts of the brain cortex are damaged. Sometimes an input to the contralateral hemifield remains unattended in the presence of other inputs to the ipsilateral hemifield. Sometimes the "neglect" is total, as in the blind-sight patients. Research with monkeys (Heilman & Watson, 1977; Wright, 1980) has related these neglect syndromes to systems that involve the projections to cortex from the basal ganglia and other core-brain structures.

It is discoveries such as these which more than anything else keep neuroscientists from discarding the concept of consciousness. When the results of behavioral investigations turn up disparate answers, depending on which behavior is observed, it becomes necessary to infer different states or processes to account for that disparity. When the disparate behaviors are separated in time, behaviorists are comfortable in inferring changes in dispositional states to account for the changed behaviors. Behaviorists are not so comfortable when two different behaviors (e.g., verbal report of introspection and instrumental behavior) give different results in the same task. Why? Some set of variables (e.g., dispositional, state, or operational process) must account for the disparity. Why not identify that set of variables with a name (e.g., consciousness) and its determinants (input, sensory, neural, chemcial, etc.)?

What is it about cortex that makes reflective consciousness possible? There is currently no complete answer to this question. However, Benjamin Libet (see Libet, Wright, Feinstein, & Pearl, 1979) has provided some preliminary data which indicate that reflective consciousness is just that. Libet has shown that the awareness produced by stimulation is not immediate: a minimum of a half-second and a maximum of five seconds elapses before the patient experiences anything. It appears that the electrical stimulation must set up some state in the brain tissue, and only when that state has been attained does the patient become aware. Libet has also shown that the organization of such a state must recruit systems beyond those directly stimulated, since the application of GABA (an inhibitory agent) does not abolish the sensory awareness that is produced by the stimulus. A good candidate for the additional systems that become recruited are those which, when injured, lead to neglect.

INTUITION AND INTELLECT

Bergson makes a distinction between intuition and intellect which corresponds in large measure to the psychoanalytic distinction between unconscious and conscious processes. For Bergson an intuitive formulation is one which is capable of verification through analysis, i.e., by dividing and subdividing the content intuited until a good share of it can be communicated intelligently. In a similar vein Matte Blanco (1975) has pointed out that unconscious processes can be considered to be based on "infinite sets" in which opponent properties and the paradoxes of infinities are to be found. The opponent aspects of emotional and motivational states are examples: one is hungry, becomes sated during the course of a sumptuous meal, only to have one's appetite whetted when a particularly attractive desert is brought in. When one feels deeply, love and hate may alternate. Infinities are even more paradoxical: when a line of infinite length is divided, two lines of infinite length result. Thus one equals two. Another is the puzzle of logical types which Russell (1919, 1956) and Whitehead (1948) addressed: the problem of stating that "I am a liar." Spencer Brown (1972) has tackled these paradoxes and shown that the basic problem is that such statements invoke alternations. Thus you are caught between "you can believe me" and "you cannot believe me," and in the line example, between, one equals two and one does not equal two. Brown provided a Boolean (two-valued) mathematical solution to the alternation problem which involved imaginary numbers.

Instances such as these partake of an organization markedly different from that which characterizes ordinary intelligence. Conscious intelligence is manifest when circumscribed sets can be appropriately partitioned into reasonably unambiguous categories. When behavior is guided by sets of variables which cannot be readily partitioned, variables which show opponent characteristics and/or are paradoxical we are apt to conclude that behavior is based on intuition or that unconscious processes are at work.

We are just beginning to understand these intuitive processes which enter so frequently into important decisions in our lives. But some progress has been made in determining that the parts of the brain involved in the intuitive, emotional and motivational aspects of psychological processing are essentially separate from those involved in intellectual functions, although of course there is continual interaction between the systems composing the disparate parts.

The distinction between brain systems subserving intellect and those subserving intuition can be drawn on the basis of the type of sensory input which reaches each set of systems. On the one hand, sensory nerves such as those from the receptors in the eye, ear and skin convey sensations which are clearly marked in time and space. Neurologists call such sensations epicritic and denote them as showing local sign, i.e., locality in time and space. The tracts of nerve fibers which convey such sensations terminate in the middle and posterior portion of the cortical convexity.

By contrast, there are sensations which are devoid of local sign. A large segment of the nerve fibers relaying the sensations of pain and of temperature fall into this category. These fibers course together in the spinal cord in a location separated from that in which the epicritic fibers are found. Experiments performed in my laboratory (Chin, Pribram & Drake, 1976; Pribram, 1977) have shown that these aspects of pain and temperature can be disrupted by electrical stimulations of the frontal and medial portions (called limbic, because they form the internal edge) of the cerebral hemispheres. To

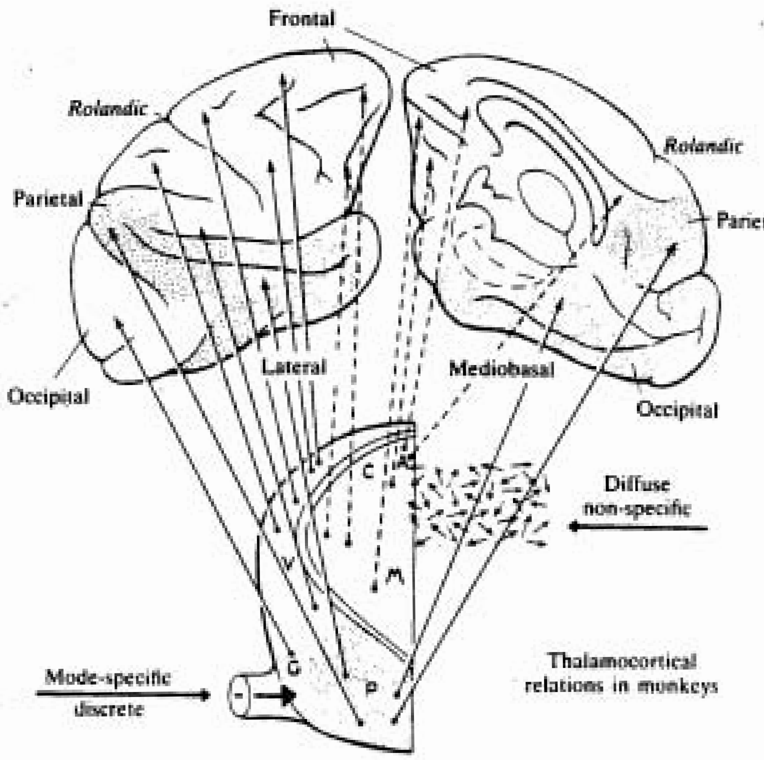

FIGURE 1. Schematic representation of the projections from the dorsal thalamus to the cerebral cortex in the monkey. The lower half of the figure diagrams the thalamus, the straight edge representing the midline; the upper half of the figure shows a lateral and mediobasal view of the cerebral hemispheres. The broad black band in the thalamic diagram indicates the division between an internal core which receives a nonspecific, diffuse input and an external portion which receives the modality-specific, discrete projection tracts. The stippled and cross-hatched portions represent the "association" systems: the medial nucleus of the internal core and its projections to the anterofrontal cortex; the posterior nuclear group of the external portion of the thalamus and its projections to the parieto-temporo-occipital cortex. (From Pribram, 1971.)

contrast such sensations from the epicritic, I have called them protocritic.

To locate an event in space and time determines the extensional aspect of categorizing. When events are perceived as non-local, the intensional dimension of experience is invoked. Categorization becomes difficult and often inappropriate. Many hours of therapy are devoted to analyzing emotional and motivational feelings, the origins of suffering, and even the roots of overeating.

A most dramatic example of protocritic processing is manifest in masochism. How is it that pain, defined by its aversive effect on behavior, should in some instances be sought? The recent discovery of a group of morphine-like substances, which are secreted internally by the pituitary gland and in various parts of the core of the brainstem, has provided a base for understanding. Just as the level of blood sugar determines whether we are hungry, so the levels of endorphins (the endogenous "morphines") determine whether an event will be felt as painful. When the endorphine level is high, the exciting event may be felt more as an appetitive itch rather than a pain, which corresponds to a sated state leading to withdrawal. The paradox has been explained, but paradox it remains nonetheless. Explanation comes at the physiological level; paradox remains at the behavioral.

Another set of experiments performed in my laboratory (Spevack & Pribram, 1973; Pribram, Spevack, Blower, & McGuinness, 1980) has shown that resections of the posterior cortical convexity bias monkeys toward risk, while resections of the frontolimbic forebrain bias them to caution. These results suggest that the epicritic systems ordinarily operate to make us somewhat more cautious when we are facing a choice; that conversely, the protocritic systems operate so as to allow us to take risks even when we are not sure that our choices are apt to be correct. In Bergson's terms we would claim that intelligent behavior is ordinarily cautious, and that intuitions can often lead to impetuosity and impulsiveness. In Freud's terms, conscious processes are intelligibly cautious; unconscious processes tend toward risky inappropriateness. But of course Freud's observations were made for the most part on a patient population where the normal balance of risk and caution had gone awry. Ordinarily some bias to risk is necessary, for action can hardly ever be predicated on complete certainty. And creativity often entails extraordinary risks based on intuitive commitment.

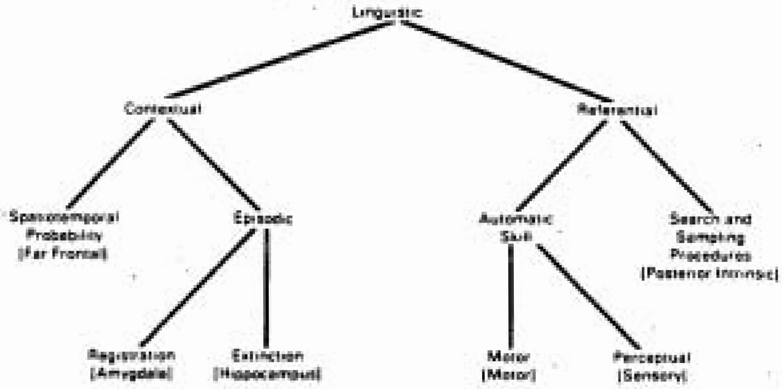

FIGURE 2. Scheme showing the functions of the frontal limbic systems of the forebrain and those of the posterior cerebrial convexity.

TIME AND THE EXPERIENCE OF DURATION

A persistent theme throughout Bergson's writings is the distinction he makes between time (as measured in physics) and experienced duration. Once again, the brain facts as well as those gathered by experimental psychology have borne out Bergson's philosophical enquiries. Much of the work of experimental psychologists was reviewed and additional experimental evidence presented in a small treatise on the experience of duration by Robert Ornstein (1975). The Penguin publication of this research unfortunately bears the title "On the Experience of Time" because the editors felt that "time" would sell better than "duration." They were probably correct: Bergson hasn't been selling all that well recently. Nonetheless, Ornstein and Bergson are correct: Experienced duration and referential time are not the same, and different brain processes are responsible.

Not surprisingly, the distinction between experienced duration and referential time is dependent on the same distinction as the one which separates intuition and intellect, i.e., the distinction between the intensive, protocritic and the extensive, epicritic dimensions of processing. Bergson's difficulty with the distinction was the fact that realization of the interdependence of time and space rested on intuition in the nineteenth century, whereas today this interdependence is an accepted aspect of relativity physics.

In the brain as well there is a continual tradeoff between time and space. Sensory perceptions are based on spatiotemporal transductions of vibratory fluctuations in the case of skin; of auditory frequencies in the case of the ear; and of the spatial and temporal frequencies of light in the case of the eye. More of this, under the heading of memory and matter below. Even the olfactory sense has been suggested to depend on a spatiotemporal analysis of infrared radiation: Faraday (see Pfaffman, 1951, pp. 1167–1168) held that a monomolecular film of the odorant absorbed on the olfactory mucosa would act as an infrared filter, while the nasal cavity performs as an infrared radiator. And more recently, Walter Freeman (1981) has shown that the spatial frequency of the patterns of neural activity in the olfactory bulb reflected the odorant being sniffed by a rabbit.

We noted above that the distinction between the systems of the frontolimbic forebrain and those of the cerebral convexity rested in part on differences in unit processing: protocritic *vs* epicritic. An additional distinction can be made. The systems of the cerebral convexity process information while those of the frontolimbic forebrain process the patterns of redundancy. Recall that the path from intuition to intellect is the path of progressive differentiation, a process of splitting up, of making distinctions among alternatives. Shannon and Weaver (1949) devised the technical definition of a measure of information on the process of choosing among alternatives. A bit of information results when uncertainty is reduced by a choice made between two alternatives. Thus information processing is dependent on making clear choices among alternatives.

By contrast, there is another aspect of information measurement theory which involves repetition rather than choice. Whenever the alternatives presented in a signal are ambiguous, repetition may help to define them. But repetition (redundancy, as it is called technically) is itself multifaceted. Simple repetition leads to habituation and boredom. When simple repetition is interrupted by change, novelty is experienced and an orienting reaction is manifest. Repetition can be complex. The amount of actual "information" in the Shannonian sense of choices among alternatives which characterizes the plot of a novel is often meager: boy meets girl, girl must choose between boy and another, etc. What makes a novel interesting is the variety of nuances, the endless repetition of the theme of the plot, with small changes of scene and timing. Interesting music depends on a similar development (see, e.g., Bernstein, 1976; Pribram, 1982).

In short, it is the patterns of redundancy which provide interest. Interest does not vary as a function of the amount of information, the number of alternative choices, which may simply lead to overwhelming uncertainty. Smets (1973) has clearly demonstrated the fact that the orienting reaction to novelty is a function of the complexity of redundancy and not the amount of information in the stimulus. And one of the most persistent findings in brain research has been the relationship between the structures of the frontolimbic forebrain and alternation behavior, and in general the structure of redundant, cyclical behavior patterns (see, e.g., reviews by Pribram, 1954, 1961, 1968, 1971, 1981). Furthermore, resections limited to the systems of the cerebral convexity do not in any way impair behavior related to redundancy while such resections drastically impair the ability of non-human and human primates to make choices among alternatives, i.e., to process information.

As Ornstein showed and as is commonly experienced, when the course of events is experienced as interesting, it is also experienced as having a short duration. However, when that course of events is viewed retrospectively by way of memory, the same course of events may be experienced as having a long duration. Once again we deal with paradox, the puzzles that occupied Bergson and kept him from acquiescence to simplistic formulations of duration in the spacetime frame. Today, it is equally important not to acquiesce to a simplistic "information processing" cognitivist approach to the experience of duration. Experienced duration is a function of interest, and is paradoxical, as when time flies when we are asleep or sunning at the beach, occupations which hardly qualify as evoking "interest." A great deal more is to be learned about the mechanisms involved in experienced duration but now that we know which parts of the brain are involved, we know where to look and how to phrase our questions intelligently, i.e., in a manner which allows confirmation or disconfirmation.

THE CONTENTS OF CONSCIOUSNESS

There is one last use of the term consciousness that does not fit either the state or the process definitions. In this use, consciousness refers to the organization of contents rather than to their state determinants or the attentional process, which includes some contents and excludes others. Used in this fashion, I can say that I am conscious of a tree or of a person's behavior. This statement is identical to one that claims that I can perceive or see a tree; that I am aware of a peson's behavior. Ordinarily, therefore, image processing would also be an analysis of how we achieve consciousness, how we perceive.

Two caveats, however: First, this ordinary use of the term, though overlapping with others, is not identical with them. This comes clear when we apply the negative unconscious — I am not necessarily unconscious of the person behind me, though I may not, at the moment, perceive her. Further, I may be conscious of wanting to perceive in the absence of the appropriate "perceptible." To repeat once more, "consciousness" is used to describe states that determine attentional process as well as sensory content. Usually we must ourselves infer which use is being made of the term. This ordinarily becomes apparent from the context in which the term "consciousness" appears.

However, even the ordinary reference to the contents of consciousness has its counterfoil. No wonder behaviorists feel urged to jettison the whole endeavor to explicate the concept. Cortical organization is composed of course- and fine-grained neural structure. Course grain reflects the topography of the senses and thus ordinary sensory awareness, ordinary consciousness. But under some circumstances, alternate states can be induced in which the description of the contents of consciousness reflects more the fine-grain structure, the dendritic receptive fields of cortical organization. A common experience of such a state is the dream state; other such states can be induced by drugs, meditational and other Buddhist techniques, mystical experiences, and religious conversions. In all these instances, what is experienced appears boundary-less, distributed, enfolded and nonlocal in time and space. Such experiences have given rise to the idea that "consciousness" is "everywhere," an idea that has gained support from the fact that similar descriptions, now stated in precise mathematical terms, also apply to the fine-grain structure of energy and matter, as studied in physics. Thus we have prominent physicists writing psychology (observations) into their equations (Wigner, 1969); speak of the flavors of quarks and their charm (Gell-Mann & Ne'mann, 1964); write books on the Tao of (modern) physics (Capra, 1975); and how the physicists are performing the *Dance of the Wu Li Masters* (Zukav, 1971). Let us explore the bases for these experiences in detail.

THE MICROSTRUCTURE OF MEMORY AND MATTER

Bergson (1911, 1959) entitled one of his books "Matter and Memory." At an intuitive level one first wonders at the title. Why memory and not mind? True, the English "mind" is derived from the same root as is "memory": "mynden." Also Bergson, whose concern was always directed at making the distinction between appearances and that which lies behind them, realized that matter as we perceive it is a form of memory which temporarily freezes a fluid motion of events. Bergson's concern was to specify the relationship between duration, the apprehension of "the purely intensive sensation of mobility" from the "extensive representation of the space transversed." Bergson did not fully integrate into his own thinking the Einsteinian concept of spacetime, but he was clear that the concept of duration to which he was referring was different from the concept of time as it was then used in physics and was later to be incorporated by Einstein into a four-dimensional concept. We now can clarify the entire issue by noting that indeed there are systems in the brain which deal with the extensive, epicritic, dimension and that local sign includes time as well as the three dimensions of space. Further, there are other brain systems which deal with the intensive, protocritic, dimension which speaks to duration and is based on cyclic alternations among event structures, i.e., among states.

But there is more. The organization of human memory is to a large extent dependent on the human brain. This is not to deny that a large part of the memory store is to be found in libraries and other cultural "cognitive commodities" (Pribram, 1983). Nor need we ignore the fact that some of the general attitudinal aspects of memory are stored in the way we posture our bodies and respond with our viscera and glands. But the regulator of all other aspects of memory is the brain and in order to regulate, the brain must remember..

The brain organization responsible for memory storage has been intensively studied over the past half-century. Two rather different views have emerged in an attempt to understand the data. One view is best labeled a "location-addressable feature correspondence" approach; the other, a "content-addressable distributed network" approach. This latter view appears to me the more comprehensive and sophisticated, but also it is more difficult to understand and is therefore currently the less popular.

The feature approach stems from the findings of Hubel and Wiesel in the late 1950s (1959) that single nerve cells in the visual cortex respond maximally when the animal is shown a line in a specific orientation. The feature selectivity, "oriented-lined," was shown to be composed of selectivities to the feature "spots" of cells earlier in the processing hierarchy. The system of Euclidean geometry was immediately invoked by most of the scientific establishment to explain how oriented lines could make up circles and planes, and proceeding further in the hierarchy to figures of any sort imaginable. At the extreme, grandfather and grandmother cells were postulated to "recognize" individuals and the search for such pontifical cells was on. And occasionally a cell would be found that responded better to a hand or to a particular bird song than to other stimuli. But in all cases the cell would also respond to other features of stimulation.

There can be no question that brain cells in the primary projection cortex are selective of certain features and relatively unresponsive to others. In several experiments I attempted to classify cells on the basis of such selectivities and found that I could no more classify the brain cells than I could classify people (Pribram, Lassonde & Ptito, 1981). Rather, it was the *properties* of a network or group of cells that permitted classification. Each brain cell had built in conjunctions of feature selectivites which made each cell, to all intents, a unique member of the population.

Thus the feature correspondence approach has to take into account networks of cells in which feature selectivity is encoded either by a spatially distributed pattern unique to that feature or by some temporal "Morse code" that signals the selected feature. Which form the code takes is under current investigation in my laboratory.

Selected responses to features by a network can take two forms. One form would be an all-or-none response: given the feature "red" one group of cells and only that group responds, and furthermore that group of cells responds to nothing else. But this sort of all or none selectivity would be indistinguishable from a pontifical cell selectivity, which the experimental results noted above have already shown to be wanting.

The alternative is that each nerve cell in the network responds more or less to the set of features to which it is selectively tuned, depending on the parameters which define the feature and the context in which it appears. In such a system the cell's response provides an adjustable weight to the total network response which defines its correspondence to a feature. Thus the perception of "red" would depend on the saturation of the wavelength of the stimulus, its luminance, and the contextual surround of wavelengths and luminances in which a particular patch of red appears.

It is this alternative which proves the most likely on the basis of currently available evidence. The advantage of such a mechanism is that it is content-addressable, i.e., an input is broadcast to the entire network and selection is based on resonances between the network properties and the features of the sensory input.

According to this approach, resonances can be tuned by prior experience with the result that a content-addressable distributed memory has been put in place. For a long time the fact that even large lesions of brain tissue fail to eliminate specific memories has troubled brain and behavioral scientists. Such lesions do interfere with coding and with retrieval of types of memory: recent, visual, verbal, etc. But details are usually retrievable via some other memory modality unless the lesion has so severely disrupted intellectual processing that memory is grossly disturbed. Such observations have indicated that specific memory traces must be somehow distributed in the brain, and direct evidence of distribution has also been obtained (Pribram, Spinelli & Kamback, 1967). The current evidence in favor of a distributed content-addressable process provides a plausible mechanism for distribution.

Another modification of the early findings of the line selectivity of cortical cells is important in relating the organization of the brain's memory mechanisms to the organization of matter. It turns out that the cortical cell is tuned not to single lines but to multiple lines making up gratings (Pollen & Ronner, 1975; Campbell & Robson, 1968). While the cell is relatively insensitive to the width of a single line, it is markedly influenced by the characteristics of the gratings: the widths of multiple lines or bars and their spacings (DeValois, Albright & Thorell, 1978). When such gratings are scanned at a uniform pace the frequency of alternation of bars and spacings can be determined. Since the frequency concerns the spatial configuration of the grating, it is called a spatial frequency. Thus we meet once more Einstein's conception of the inter- changeability of space and time. When bars and spacings are wide, the grating has a low spatial frequency; when bars and spacings are narrow, the grating displays a high spatial frequency. Each cortical cell is tuned to approximately a half to an octave of spatial frequency when addressed at threshold with ordinary light.

We might therefore liken the visual system (and this is also true of the auditory, skin, and muscular systems) to a piano. At a macro level of organization, there is a correspondence between the keyboard and the strings of the sounding board. So also in the brain there is a topographical correspondence between the receptor surfaces and the cortical network of cells. This correspondence accounts for the well known homunculus of the sensory and motor portions of the cerebral cortex, and the retinotopic and cochleotopic representations in the respective visual and auditory portions of the cerebral mantle. But when we play the piano keyboard and set the various strings of the sounding board into resonant vibration, we are addressing the built-in (and experientially tuned) micro characteristics of each of the strings, the bandwidth of their tuning curves which depend on length, tension, and material composition. In a similar fashion stimulation of the various sensory receptor surfaces addresses the built-in (and experientially tuned) micro characteristics of each of the cells of the cortical network, their feature selectivities among which is the selectivity to a bandwidth of spatial frequency.

The significance of spatial frequency encoding lies in the fact that from a two-dimensional code (the dimensions given by the orientation selectivity of the cortical neurons), image reconstruction can take place. This property of the spatial frequency domain rests on the Fourier theorem which states that any pattern, no matter how complex, can be decomposed by a mathematical transform into simple, regular (sine and cosine) waveforms of different frequencies, amplitudes, and phase relations. Further, the patterns can be resynthesized from that same set of waveforms by performing the inverse transform which is essentially identical with the original. In an imaginative experiment, DaValois et al. (1978), at the University of California at Berkeley, showed that the cells in the visual cortex respond as if they were performing such a Fourier transform on a variety of plaid patterns which he used for stimuli.

Other experiments have demonstrated that the Fourier is only an approximation to the exact transform which characterizes the operations performed by the visual microstructure. More specifically, the Fourier is an unlimited operation, while the cells of the visual cortex respond in a more limited fashion: A Gaussian probability distribution places the limits over which the transform is operating. This transform is known as the Gabor function. To return to the analogy with the piano sounding board: The theoretically unlimited bandwidth of the strings is damped by felt pads that restrict resonance within a certain range.

The image reconstruction capabilities of such systems were explored by Gabor (1949), who christened the process "holography." When the various two-dimensional waveforms produced by diffraction or reflection from objects are stored on a photographic film, the patterns they form make up an unrecognizable jumble of interfering and reinforcing wave fronts. But interestingly, images of the entire pattern of objects which reflected or diffracted the light originally can be readily constructed (by operations which perform the inverse Fourier or Gabor transforms) from any portion of the stored film. Thus the name hologram. All of the information that describes the patterns of the objects becomes distributed on the film. Each portion of the film has therefore enfolded in it all of the information characterizing those patterns.

It is no great leap to suggest that a holographic-like organization characterizes the network of cortical cells. The evidence abounds as we have seen, and readily accounts for the capability of cortex to construct perceptual images and for the distributed nature of the brain's memory mechanism. This does not mean, of course, that holographic-like processes are all that go on in the brain: Gabor transforms will not account for the spatial and temporal localizing aspects of perception, nor for the retrieval mechanisms necessary to produce the inverse transform. Nor do the data suggest that a global Fourier transform of input spreads information about input patterns across the entire extent of cortex. The microstructure of each cortical cell is separately involved in transforming the input just as each string of the sounding board of the piano is separately involved in resonating to the action of the keyboard.

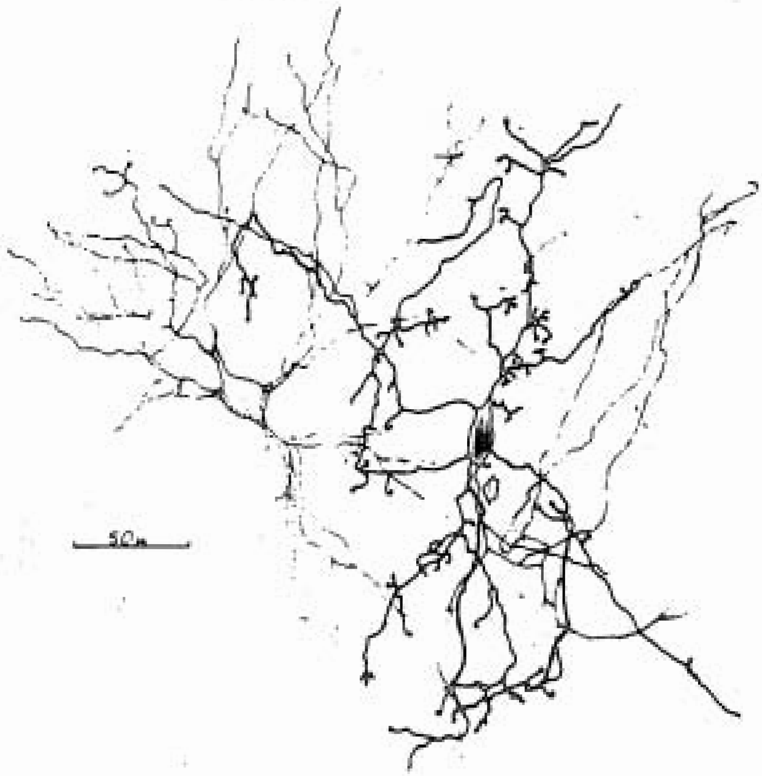

FIGURE 3. Drawing showing multiple points of contact (synaptic and ephaptic) between two neurons in brain. (From Pribram, 1971.)

But the Gabor, Fourier-like transform does have a special virtue. By way of this transform the microstructure of matter can be shown to partake of the same structural properties as the microstructure of memory. Heisenberg (1969) demonstrated that one can accurately measure the momentum of an event or its location, but not both simultaneously. This is the famous uncertainty principle. Momentum is a measure of potential energy; location places that event in spacetime. Dirac (1951) and Henry Stapp (1965) have shown that the measures of energy/momentum and of space/time are Fourier transforms of one another. We are thus faced with a four-fold relationship in which energy (E) represents flux, the potential for change; momentum (p) the inertial resistance to change; mass (x) the spatial dimension; and time (t) the time dimension. In a sense, energy thus reflects a prototemporal and momentum a protospatial dimension. Further, Einstein's relativity equation $E = mc^2$ indicates that measures on matter (i.e., mass, m) are transforms of measures on energy and the speed of light (E/c^2). Thus neither energy nor light are, in a strict sense, matter (i.e., they do not possess rest mass) although they interact with matter (see Pribram 1986).

The four-fold relationship between energy, momentum, space, and time provides some interesting insights. When one proceeds from the potential domain of energy and momentum to that of space and time, one is actualizing the potential. When one proceeds in the reverse direction, one enfolds, by virtue of the Fourier transform, space and time into the frequency domain. The enfolding process empowers: power is a measure of the energy at a given frequency.

Proceeding from the domain of energy and time to the domain of momentum and mass leads to materialization, since it is masses that display momentum and location. How then do we characterize the reverse, i.e., proceeding from the domain of momentum and space

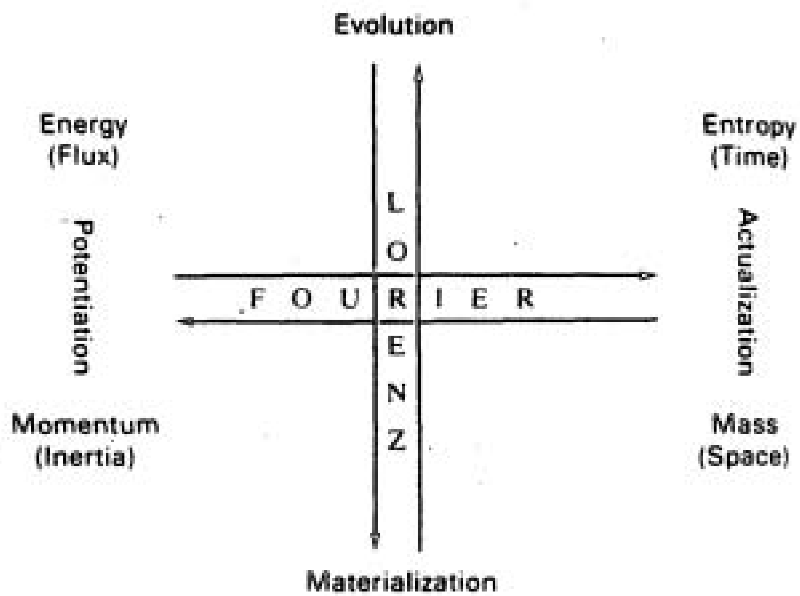

FIGURE 4. Diagram of relationships among basic universal concepts.

to that of energy and time? Change involves time and entails measures of efficiency, measures which make up the subject matter of thermodynamics. The measure of efficiency is the reciprocal of entropy. Entropy has been related to measures of information (the number of alternative events to be specified). The evolutionary processes which negate the entropic thrust of the physical universe are vital (i.e., life-giving), mental (i.e., mnemic, based on memory), and spiritual (i.e., informing).

Shades of Bergson's élan vital? Perhaps, and why not? Science is the search for beauty in nature. The relationships displayed above give precision to what appeared to be a vague mystical conception, a fantasy. But according to Bergson's own rules, a fantasy it was not. The conception of an élan vital turned out to be intuitive because by dividing and subdividing, the intuition became intelligible. And, as a personal subscript, no one can be more surprised than I.

CONCLUSION

It is an analysis of the relationship between the functional structure of the brain and experience as inferred from behavior which has led us from Bergson's philosophical intuitions to current scientific intellectual understanding. This process of analysis has provided us with the beginnings of an understanding of consciousness as state, process, and content; of the distinction between referential time and experienced duration, and even what might be meant by intuition.

Further, the similarity between the microstructure of memory and matter lead to a scientific understanding of Bergsonian concepts as vague and mystical as "élan vital." It seems reasonable, therefore to proceed with an enterprise that attempts to carefully progress from intuitive to intelligent appraisals, not only of Bergson's but of other apparently mystical conceptions such as those of Freud, Jung, and William James. These nineteenth century intellectual giants grappled with phenomena which most twentieth century scientists have chosen to ignore in an attempt to establish a positivistic, operationally verifiable body of knowledge. This enterprise has proved fruitful in providing techniques which rid us of sloppy thinking. However, as is well recognized now, there are also limitations to positivism and operationalism. Now, as we are about to emerge into a new century, it is time to transcend these limitations by applying the rigorous tools of research and logic developed during the past decades to the more difficult problems of mind and spirit which our immediate predecessors felt they had to ignore.

REFERENCES

Bergson, H.L. *Creative evolution*. Lanham, MD: University Press of America, 1983.

Bergson, H.L. *Matter and memory*. New York: Doubleday, 1911, 1959.

Bernstein, L. *The unanswered question: Six talks at Harvard*. Cambridge: Harvard Univ. Press, 1976.

Brentano, F. *Psychology from an empirical standpoint*. (A.C. Rancurello, .D. Terrell, & L. McAlister, trans.). London: 1874; London: Routledge & Kegan Paul, 1973.

Brown, G. Spencer. *Laws of form*. New York: Julian Press, 1972.

Campbell, F.W. & Robson, J.G. Application of Fourier analysis to the visibility of gratings. *J. Physiol.*, 197:551–566, 1968.

Capra, F. *The Tao of physics*. Boulder, Co.: Shambhala Press, 1975.

Chin, J.H., Pribram, K.H., Drake, K., & Greene, L.O., Jr. Disruption of temperature discrimination during limbic forebrain stimulation in monkeys. *Neuropsychologia*, 14:293–310, 1976.

DeValois, R.L., Albrecht, D.G., & Thorell, L.G. Cortical cells: Bar and edge detectors, or spatial frequency filters? In S.J. Cool & E.L. Smith (Eds.), *Frontiers in visual science*. New York: Springer-Verlag, pp. 544–556, 1978.

Dewey, J. The natural history of thinking. *Essays in experimental logic*. Chicago: Univ. of Chicago Press, 1916.

Dirac, P.A.M. Is there an AEther? *Nature*, 168:906, 1951.

Freeman, W.J. A physiological hypothesis of perception. *Perspectives in biology and medicine*, Summer, pp. 561–592, 1981.

Freud, S. Project for a scientific psychology. In J. Strachey (Ed. & trans.), *Standard edition of the complete psychological works of Sigmund Freud*. New York: Norton, 1950.

Gabor, D. Microscopy of reconstructed wave fronts. I. *Proc. Roy. Soc.* (London), pp. 454–487, 1949.

Gell-Mann, M. & Ne'emann, Y. *...e eightfold way*. Menlo Park: Benjamin Cummings, 1964.

Head, H. *Studies in neurology*. London: Oxford Univ. Press, 1920.

Heilman, K.M. & Watson, R.T. Mechanisms underlying the unilateral neglect syndrome. In E.A. Weinstein & R.P. Friedlund (Eds.), *Advances in neurology, vol. 18*. New York: Raven Press, 1977.

Heisenberg, W. *Physics and beyond*. Munich: Piper, 1969.

Hi

Hu

Jay

Lil

Lo

Ma

Or

Pf

Po

Pri

Pri

Pri

Pri

Pri

Pri

Pri

Pri

Hilgard, E.R. *Divided consciousness: Multiple controls in human thought and action*. New York: Wiley, 1977.

Hubel, D.H. & Wiesel, T.N. Receptive fields of single neurons in the cat's striate cortex. *J. Physiol.*, 148:574–591, 1959.

Jaynes, J. *The origin of consciousness in the breakdown of the bicameral mind*. Boston: Houghton-Mifflin, 1977.

Libet, B., Wright, E.W., Feinstein, B., & Pearl, D.K. Subjective referral of the timing for a conscious sensory experience. *Brain, 102*, 1979.

Lorenz, K. Innate bases of learning. In K.H. Pribram (Ed.), *On the biology of learning*. New York: Harcourt, Brace & World, pp. 13–94, 1969.

Matte-Blanco, I. *The unconscious as infinite sets: An essay in Bilogic*. London: Duckworth, 1975.

Ornstein, R.E. *On the experience of time*. New York: Pelican, 1975.

Pfaffman, C. Taste and smell. In S.S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, pp. 1143–1171, 1951.

Pollen, D.A. & Ronner, S.F. Periodic excitability changes across the receptive fields of complex cells in the striate and parastriate cortex of the cat. *J. Physiol.*, 245:667–697, 1975.

Pribram, K.H. Toward a science of neuropsychology (method and data). In R.A. Patton (Ed.), *Current trends in psychology and the behavioral sciences*. Pittsburgh: Univ. of Pittsburgh Press, pp. 115–142, 1954.

Pribram, K.H. The intrinsic systems of the forebrain. In J. Field, H.W. Magoun, & V.E. Hall (Eds.), *Behavior and evolution*. New Haven: Yale Univ. Press, pp. 1323–1324, 1960.

Pribram, K.H. The neurobehavioral analysis of limbic forebrain mechanisms: Revision and progress report. In D.S. Lehrman, R.A. Hinde, & E. Shaw (Eds.), *Advances in the study of behavior*. New York: Acdemic Press, pp. 297–332, 1969.

Pribram, K.H. *Languages of the brain: Experimental paradoxes and principles in neuropsychology*. Englewood Cliffs, N.J.: Prentice-Hall, 1971; 2nd ed., Monterey, Ca.: Brooks/Cole, 1977.

Pribram, K.H. Peptides and protocritic processes. In L.H. Miller, C.L. Sandman, & A.J. Kastin (Eds.), *Neuropeptide influences on the brain and behavior*. New York: Raven Press, pp. 213–232, 1977.

Pribram, K.H. Functional organization of the cerebral cortex. In G. Schaltenbrand & E. Walker (Eds.), *Stereotaxy of the human brain*. Stuttgart: Verlag, pp. 300–328, 1981.

Pribram, K.H. Brain mechanisms in music: Prolegomena for a theory of the meaning of meaning. In M. Clynes (Ed.), *Music, mind, and brain*. New York: Plenum, pp. 21–36, 1982.

Pribram, K.H. Brain, cognitive commodities and the enfolded order. In K.E. Boulding & L. Sevesh (Eds.), *The optimum utilization of knowledge*. Boulder, Co.: Westview Press, pp. 29–40, 1983.

Pribram, K.H. The Cognitive revolution and mind/brain issues. *American Psychologist*, 41:507–520, 1986.

Pribram, K.H., & Gill, M. *Freud's "Project" re-assessed*. New York: Basic Books, 1976.

Pribram, K.H., Lassonde, M., & Ptitto, M. Classification of receptive field properties. *Exp. Brain Res.*, 43:119–130, 1981.

Pribram, K.H., & McGuinness, D. Arousal, activation and effort in the control of attention. *Psych. Rev.*, 82:116–149, 1975.

Pribram, K.H., Spevack, A., Blower, D., & McGuinness, D. A decisional analysis of the effects of inferotemporal lesions in the rhesus monkey. *J. Comp. Physiol. Psychol.*, 94:675–690, 1980.

Pribram, K.H., Spinelli, D.N., & Kamback, M.C. Electrocortical correlates of stimulus, response and reinforcement. *Science*, 157:3784, 1967.

Prigogine, I. *From being to becoming*. San Francisco: Freeman, 1980.

Russell, B. *Introduction to mathematical philosophy*. London: G. Allen & Unwin Ltd., 1919, 1956.

Ryle, G. *The concept of mind*. New York: Barnes & Noble, 1949.

Schrödinger, E. *What is life? Mind and matter*. Cambridge: Cambridge Univ. Press, 1949.

Shannon, C.E. & Weaver, W. *The mathematical theory of communications*. Urbana: Univ. of Illinois Press, 1949.

Smets, G. *Aesthetic judgment and arousal*. Leuven, Belgium. Leuven Univ. Press, 1973.

Solomon, R.L. The opponent-process theory of acquired motivation. *American Psychologist*, [illegible]:491–712, 1980.

Spevak, A. & Pribram, K.H. A decisional analysis of the effects of limbic lesions in monkeys. *J. Comp. Physiol. Psychol.*, 82:211–226, 1973.

Stapp, H.P. Space and time in s-matrix theory. *Phys. Rev.*, 139B:257–270, 1965.

von Üxkull, J. *Theoretical biology*. London: Kegan Paul, 1926.

Weiskrantz, L., Warrington, E.K., Sanders, M.D., & Marshall, J. Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain*, 97:709–728, 1974.

Whitehead, A.N. *An introduction to mathematics*. New York: Oxford Univ. Press, 1948.

Wigner, E.P. Epistemology of quantum mechanics: Its appraisals and demands. In M. Grene (Ed.), *The anatomy of knowledge*. London: Routledge & Kegan Paul, 1969.

Wright, J.J. Intracranial self-stimulation, cortical arousal, and the sensorimotor neglect syndrome. *Exp. Neurol.* 64, 1980.

Zukav, G. *The dancing Wu Li masters*. New York: Morrow, 1971.