10 Problems Concerning the Structure of Consciousness

KARL H. PRIBRAM

While still in the practice of neurosurgery, I was called one day to consult on a case some 200 miles distant. A 14-year-old girl had fallen from a rapidly moving automobile when its rear door inadvertently opened. She had lacerated her scalp badly, and, when the emergency procedures to stop the bleeding were accomplished, I was called, because the family physician was afraid that the patient's head injury would become exacerbated by the additional trauma of a long trip by ambulance. I was informed that the girl's condition was critical and that everyone feared she was moribund.

When I arrived on the scene some 3 to 4 hours later, the situation had deteriorated further. The girl had not even been moved to a nearby hospital and was lying in a bed at a farmhouse near the scene of the accident. She was not expected to live.

I entered the bedroom. Blinds were drawn. Blood-soaked bandages were wrapped around the girl's head. Only a small part of her face showed, and it had a sickly coloration. She was hardly breathing.

The distressed family made room for me at the bedside. As was my custom, I said, "Hello, Cathy" (the girl's name) as I took her

KARL H. PRIBRAM · Stanford University

G. G. Globus et al. (eds.), *Consciousness and the Brain*

hand to feel her pulse. Much to my amazement, Cathy opened her eyes and said, "Hello, Doctor"! Cathy was conscious!

My whole approach to the consultation changed. I quickly looked at the girl's eyes to see if her pupils were of equal diameter, which they were, did the essentials of a neurological examination, such as lifting her head to rule out stiffness due to bleeding inside the head, and then went on to ascertain that all limbs were movable, etc. But my attention became focused, not on the neurological, but on the remainder of a thorough physical examination. I noticed that, in moving her right arm, the patient expressed considerable discomfort. And very quickly I ascertained that some ribs had been broken and had punctured the girl's right lung. She was indeed in critical condition, and I ordered an oxygen tent to be brought immediately from the hospital since our patient's trouble was not in her head but in her chest. Recovery ensued rapidly once the locus of the problem had been identified.

This case history points up the set of problems concerning the concept "consciousness" that I want to take up. (1) The concept consciousness is not just some esoteric theoretical football to be tossed to see whether interception by man-made computers can take place: my attribution of consciousness is of practical concern to those who are so graced; (2) consciousness is related primarily to brain function; and (3) consciousness sometimes involves the identification of self: Cathy responded only when I addressed her by name.

ACHIEVING CONSCIOUSNESS

My story, I believe, indicates the usefulness of the concept consciousness. I inferred that Cathy was conscious from occurrences that, in this particular circumstance, were, in fact, surprising. What then are the categories of episodes from which I infer consciousness?

The first category is that of life, based on the occurrence of growth and replication in some asymmetrical mass showing varied parts. The second category is that of movement in space. In short, I tend to view animals, especially furry animals, as conscious—not plants, not inanimate crystals, not computers. This might be termed the "cuddleness criterion" for consciousness. My reasons are practical; it makes little difference at present whether computers are conscious or not, and, in the Jamesian tradition, I hold that only a difference that makes a difference is worth pursuing.

How does consciousness make a difference? Ryle (1949, p. 136) suggests that the concept of mind in general and such concepts as perception, attention, interest, and consciousness in particular take their origin in occurrences that indicate that the conscious, interested, or attending organism minds, i.e., heeds his surroundings. Also in this view, consciousness derives from the interaction of an organism with his environment—it is therefore meaningless to ask whether consciousness "intervenes" or interacts with either the organism, his brain, or his environment. In this sense, consciousness describes a property by which organisms achieve a special relationship with their environment. We have easy access to this relationship when it becomes manifest in the behavior of the organism. Here the term "behavior" should be understood in a larger sense than its usual English connotation. The German "Verhaltung" and the French "comportment" come closer since they connote English "bearing" as well as more active behavior. Thus a question we need to address is whether we can also access these manifestations of consciousness by looking at the behavior of restricted parts of the organism such as his brain.

A useful analogy comes from mechanics: although we speak of gravity as a property of a mass, this property becomes manifest only when interactions among masses occur. So we may loosely talk of locating gravity at the center of a mass or of consciousness in the center of the head, but only in the case of consciousness do some still seriously entertain the proposition that if we go dig deeply enough, we will assuredly find "it." But neither the sophisticated earth scientist nor the brain scientist would argue against coming up with some samples that might explain specific characteristics of the "gravitational" or "conscious" process.

What are some of these specific characteristics of consciousness? We look to see, we listen to hear, we remember what we see and hear, and sometimes the looking and the listening. And sometimes also we remember that which we have forgotten. In addition, of course, we can let others know we have seen and heard and we can even talk about it. So we have a variety of characteristics to be explained. They range from asking practical questions about "seeing" (for some of us are blind), through those that deal with "looking" (since so often we see *only* what we look for), and remembering (because much of our behavior is based on *antecedent* rather than on concurrent episodes), to the more difficult problems about forgetting (it's so damned *selective*), and talking (the *sine qua non* of academic and other *human* endeavor). Finally we must face the issue of who is "we" or who am the I that manifests such conscious characteristics (the clinic is full of people in search of *their* identities). Analyzed into such components the problem of consciousness becomes somewhat less awesome and certainly amenable to scientific investigation.

BRAIN AND CONSCIOUSNESS

A second main topic was brought into focus by Cathy's case history: consciousness and brain are somehow intimately interwoven. Some would have us believe that consciousness is a brain state, but such statements are a mixture of mind talk and brain talk (Mackay, 1956) that irritate the purist. Another possibility would be that certain brain states result in consciousness, and this is what I implied in the previous section. But such statements also run into difficulties: if brain states can result in conscious experience, we should be able to replicate the brain state and thus produce a computerized robot who is conscious. My friends in computer and other physical sciences seem to welcome this as an ultimate achievement—I should like to point out to them only one among many difficulties: the emergence of an SPCC which would attempt to legislate the scientists' activities in order to prevent cruelty to computers.

Somewhat more seriously, the question entertains the possibility of consciousness and self-consciousness as emergent properties of certain kinds or amounts of neural (and therefore, perhaps of other) organizations and addresses the issue of the primacy and privacy of subjective experience. Critical philosophy has given a lead in exploring these problems in a logical fashion that allows scientific inquiry to proceed. Most of these analyses have come out on the side of a monistic and against a dualistic interpretation of the mind–brain issue, although multiple aspects of an identity are ordinarily allowed. I have elsewhere (Pribram, 1971*a*, 1971*b*, 1972) made the case that, in fact, these are not multiple aspects but multiple realizations of an ultimately understandable biological process. However, many biologists, including Sir Charles Sherrington, Wilder Penfield, Sir John Eccles, and Roger Sperry, are dissatisfied with this sort of explanation because they cannot as yet visualize a brain mechanism that readily transforms nerve impulses into subjective experience. They then come to wrestle with the converse problem that experience alters brain structure and function.

The issue can perhaps be stated somewhat more clearly by asking what sort of transformations allow spectral energies to become transformed into neural, and back again. We have little difficulty in grasping the principles of a camera which stores spectral qualities and quantities on film, which, when illuminated by other spectral energies, produces an image corresponding to the original qualities and quantities. It is but a step to store the spatial phase of the relationship between these qualities and quantities rather than the qualities and quantities themselves. And, as we know, such films (known as "holograms") are in some respects (see below) even more versatile in reproducing images corresponding to the original.

My proposal here is that there are a set of properties manifest in organized (i.e., spectral) energy that we have been slow to comprehend fully when engaged in trying to understand biological organization. Only during the past quarter century have we come to appreciate the power of the concept "information" in describing communications of any sort. Information is not the property of any single event, but the property of the relation between them, their sequence, their hierarchal structure, their arrangements. Information becomes encoded in such organizations and decoded from them. Codes are languages (Pribram, 1971*b*) and languages are the key to the structure of consciousness (Cassirer, 1966; Langer, 1951), not only in the sense ordinarily used by critical philosophers, but in a deeper sense that "the limits of my language *are* the limits of my world" (Wittgenstein, 1922, italics mine).

I believe that the particular code, the particular transformation, that makes subjective experience, conscious awareness, such a difficult topic is that biologists have yet dealt only minimally with the implications of holonomic processes. As we have seen, holographic encoding presents for study just the kind of problem that has troubled neuroscientists, biologists, psychologists, and philosophers for centuries. How are images reconstructed? Where are these images located? What is the physical property that makes superposition of the functions of neighboring elements mandatory? How can a pattern, the encoded information, be transmitted without transmission of the substance or medium in which the communication occurs?

CONSTRUCTIONAL REALISM

My proposal is therefore that the basic function of brain is to generate the codes by which information becomes communicated. Some of these codes are like those used in optical information processing—they are holographic. Thus image construction and projection occurs, and, when the system becomes sufficiently complex, it no longer functions only as a self-contained unit, but begins to act more like an open parallel processing mechanism. Characteristic of such open systems is that when they are endowed with memory they generate feed-forward processes that select, become voluntary (see below), rather than just respond to input. It is therefore readily conceivable that an open parallel processing system would generate images against which input determined images are compared. The question remains whether such images are simply epiphenomena since the encoded representations are in fact doing the work of comparison—a question couched as a dualism that may sound as strange to us some years hence as asking whether it is the gravity of one mass that is responsible for the gravity of another—when it is the interaction between the masses that allows the inference of gravity in the first place.

Thus, in philosophy I have become a constructional realist. This approach to the mind–brain problem allows me to view sympathetically the problems that have given rise to the "emergent property" theory of consciousness espoused by Sperry and the "trialist" modification of dualism used by Eccles to deal with the problem of free will—though my fundamental philosophy differs substantially from theirs. I want now, therefore, to show how this constructionalism transcends earlier formulations without denying the vitality of the issues.

For me, the problem of emergent theory revolves around the interaction between the emergent and its supposedly "material" substrate. Emergence theory, as I have heard it variously exposed, is invoked to handle those properties of a material universe that seem somehow somewhat immaterial. Thus the wetness of water, and its floatation on cooling to ice, seem less "material" than the molecules of H_2O and their constituents. But physicists have come to suspect the ultimate materiality of their observations of the universe—yet we are all agreed that a recourse to a complete subjectivism, whether cloaked in the terminology of instrumentalism or phenomenalism, leads only to a rather sterile solipsism. My response to this dilemma has been to turn the problem on its head and to suggest that we actualize a variety of experienced realities by con-struction: by composing, realizing, embodying the structures inherent in those experiences. Some of these realities may be most practically viewed as constituting a "material" level or universe; others, in practice, gain more credence when their reality is construed as subjective: that is, shown to depend more directly on individual observation and interindividual variation.

When realities are thus viewed as constructions, what does it mean to ask "do emergents interact with their substrates?" Do we worry the issue of just how "wetness" affects molecular structure or how "icing" influences the binding properties of hydrogen and oxygen? We do and we don't. We don't ask the question as it is asked of consciousness and brain by some philosophers and physiologists and thus make the mistake of crossing categories warned against by Kant (see Barrett, 1968) and by Whitehead and Russell (1927). Rather, we ask what structural combinations are involved when H_2O acts as a wetting agent and what are the differences between these structures and those that produce ice. We can then pose questions about interaction in structural terms—what is the difference in interaction among the components of the structures in the wetting and the icing realizations of the basic substructure of H_2O.

Translating this approach to the problem of brain and consciousness, we ask not how brain and consciousness interact, but how the organization of interaction of basic brain elements differs in the states characterized by automatisms and those characterized by consciousness. As noted already, this form of reduction is not a pernicious reductionism that denies reality to consciousness or "explains" all the manifestations of consciousness in brain terms. Conscious awareness is a realization as real as is brain. In understanding the origins of the organization of consciousness we employ reductive procedures leading to the structure of brain, but in understanding the organization of brain we employ procedures that are equally reductive and which lead to the structure of awareness. And who is to say that one of these reductions is more fundamental than the others? Or who would claim that these reductions provide the total panorama of the realities we call "consciousness" and "brain"?

THE DISPOSITION TOWARD SELF-CONSCIOUSNESS

The third main question raised by Cathy's case history concerns her awareness of self, identified by her name. How does self-consciousness come about?

A student enters my office, sits down in a chair opposite me and asks me to explain holography. I demonstrate how images can be reconstructed from a piece of film that itself does not look like an isomorphic representation of the object to be imaged. I point to the image, but when I try to apprehend it, touch it, the image disappears. The image is not located in the film, yet a representation of the object is located there, and from this representation the ghostlike image can be conjured by the appropriate incantations of the input. Where then is the "image" stored? Certainly not on the film, here only the representation occurs. Where is the image "located" when it does occur? Certainly not in the film itself. The image is projected beyond the film (in a transmission hologram) or inside the apparatus (in a reflection hologram).

I ask the student where she sees the book I am holding. She points to it and says, "Why there!" She is puzzled by my question.

I now say to her, "My, you look pretty today, Eva." Whereupon she changes her bearing slightly, blushes a bright crimson, smiles and acknowledges my compliment. I now ask her where she feels beautiful. The blush, which had just begun to subside, returns full-blown and she says, "All over, it's just a feeling I have inside."

Why does Eva perceive the book as out there and feel the glow of beauty as inside herself? After all, the stimulation that initiated her perception occurred at the retinal surface and the stimulation that initiated her feeling occurred in the flushing of her body surface—both in surfaces between "Eva" and her "environment."

A series of experiments by Bekesy (1967) gives at least a partial answer to this age-old philosophical puzzle. Bekesy had modeled the cochlea of the ear by making a device that placed five vibrators on the surface of the skin. The frequency and phase relationships of the vibrators could be varied. When placed on the inside of the forearm or thigh, the sensation produced was that of a point source which could be made to move along the surface by changing the relative rates of the vibrators. Then Bekesy placed two of these devices on his subjects—one on each limb. He would now play with the phase relationship between the two devices. At first the subject would feel the point source to jump from one limb to the other, but after some exposure—usually several hours—he would begin to localize the source of stimulation to a point between the limbs. In short, he now projected the somatosensory source into space much as stereophonic sound becomes projected into the space between two loudspeakers.

Bekesy's original findings of ascribing a movable point source to a set of phase related vibratory stimuli was described in terms of inhibitory interactions imposed by the receptive surface and the central processing of sensory input. Such inhibitory interactions are present in the visual as well as the auditory and somatosensory systems, and Bekesy produced some preliminary evidence which suggests that the taste mechanism may also be organized in this fashion. A great number of facts, such as the occurrence of Mach bands (Ratliff, 1965), of metacontrast (Bridgeman, 1971), and apparent motion (Cornsweet, 1970) can be explained readily by these inhibitory processes.

The mathematical equations used by Bekesy (see Ratliff, 1965) and others to quantitatively describe the inhibitory mechanisms are sets of reversible transforms that superpose the effects of neighboring stimuli. These mathematical descriptions, often called holonomic transformations (McFarland, 1971), are of the same genre as those used by Gabor (1948) when he invented holography to enhance the resolution of electronmicroscopy. In short, there is a resemblance between the equations that describe sensory processing and physical holography.

This resemblance led me to propose that we take seriously the analogy between neural processing and physical holography (1966, 1971*b*, 1974, Pribram, Nuwer, and Barron 1974). Work on the visual system has supported this proposal: the system as a whole and cortical cells in particular have been found (Campbell, 1974; Campbell *et al.*, 1968, 1969; Pollen, 1971, 1974) sensitive to spatial frequency (e.g., the distance between neighboring edges of a grating.

In view of these similarities between sensory processing and physical holography, the projection of images away from the receptor surface becomes somewhat less of a mystery. When the appropriate phase relationship between neighboring excitations occurs, the source of those stimulations becomes attributed to space between the surfaces. The mystery is not completely solved, for it was Eva and I who saw the images in my hologram demonstration. Who sees the images produced by the neural holograms occurring in the sensory systems?

INTENTIONALITY

So we turn to the enigma that is central to any discussion on consciousness: the problem of self-consciousness, the question of who am I?

There is a good deal of evidence that self-awareness is achieved gradually and that it is relatively fragile. Spitz has described the development of the smiling response (1946) and the emergence of "yes" and "no" (1957) as infants begin to differentiate themselves from their caretakers. Piaget (1960) has suggested that full awareness of a self is not attained until the age of 7 or 8. Experiments show that only the great apes and man can recognize marks placed on his body or face as identifying his image in a mirror (Gallup, 1970). Lesser apes (gibbons) and monkeys (F.P. Patterson and K. Pribram, unpublished observation) fail to have such reactions which demand a simultaneous recognition of body image and an external projection of such an image. All of this evidence, added to my simple demonstration with Eva, suggests that the disposition toward self-consciousness needs to be constructed and is not universal among organisms.

What then might be the critical aspects of the mechanism that allows the simultaneous perception of a body image and its external representation? In subtler form, this is the problem of intentionality discussed so extensively by Brentano (1960) and the postcritical realists. Intentionality is the capacity to identify the difference between agent (self) and percept (externally projected image) and to perceive both simultaneously. The concept thus involves intention or volition (see below) as well as self-consciousness.

Elsewhere (Pribram, 1971*b*) I have argued that subjective awareness is the reciprocal of smooth control of input–output relationships in the central nervous system, that only when performances become habitual and experiences become habituated does processing become automatic. Dishabituation to novelty engages the junctional and dendritic mechanisms of the brain where the slow potential microstructure, the holographic representation of input, is produced. Only with repetition do patterns of these slow potentials intercorrelate sufficiently to generate the nerve impulses necessary to action. Each slow potential pattern is assumed to leave its residue at these synaptic junctions and dendritic locations and so participate in generating the correlations. In short, to the extent that our experiences fail to correlate, to the extent that our actions are uncontrolled by habit, to that extent they are voluntary and we are conscious.

Ordinary consciousness is thus achieved by a mechanism (somewhat like a hologram) that disposes the organism to locate fresh experiences and performances at some distance from the receptive and expressive interfaces that join organism and environment. In this respect the body image is that which cannot be projected, and self-consciousness develops from the remainder of consciousness when external attributions fail to "materialize." When sufficient complexity develops in the system controlling these receptive and expressive interfaces, the distinction between those interfaces that project their image into the environment and those that do not can be processed simultaneously, i.e., they become disjoined to operate as separate channels. Ross Ashby (1960) has given a precise account of how a multiply interconnected mechanism can become disjoined when parts of it come under the control of separate environmental inputs. And I have, on the basis of experimental evidence, made a case for the specific neurological mechanisms involved in preserving and dissolving this common control apparatus (Pribram, 1969). But before we discuss this neurological mechanism, let us dispose of some of the problems that concern the "intention" part of intentionality.

VOLITION

Let me therefore apply the constructional approach to the problem of brain and free will. As Sir John Eccles (this volume) has so elegantly demonstrated, our knowledge of the functions of the motor cortex of the brain has increased tremendously over the past few decades. I want to add to his exposition some data of my own, because their import has not as yet been fully appreciated and bears directly on the problem of volition.

Man discovered about one hundred years ago (during the Franco-Prussian war) that he could electrically excite the exposed cortex of his fellows and so produce in them a variety of muscular contractions. Since that discovery, brain scientists have argued as to the nature of this relationship between brain cortex and muscular contraction. Some have shown a highly specific topological correspondence between brain and muscle locus. Others have emphasized the variability of movement that is produced by stimulation of the same cortical locus when the conditions of stimulation and of the position of the body parts are varied. This argument became encoded in the question as to whether muscles or movements were represented in the cortex. I repeated many of the earlier experiments and found the facts to be pretty much as described. In addition, however, I found (Malis, Pribram, and Kruger, 1953; Wall and Pribram, 1950) that the primate motor cortex receives a rather direct input from peripheral structures (exteroceptive, proproceptive, and interoceptive) and that it could therefore appropriately be conceived to be a sensory cortex for motor function much as the occipital cortex is the sensory cortex for optic function. The question remained as to the nature of this "motor" function.

An answer to this question came from cortical removals made in man (Bucy and Pribram, 1943) and monkey (Pribram, Kruger, Robinson, and Berman, 1955–56). Even extensive removals failed to paralyze any particular muscle or muscle groups. Nor did cinematographic analyses show any specific movement (sequence of muscular contractions) or sequence of movements to be disrupted by the ablations. Yet skill in certain tasks was impaired (latencies for completion of latch box puzzles became prolonged). I interpreted these results to mean that neither muscles nor movements were represented as such in the cortex—that instead, actions, the specific environmental outcomes of movements were represented.

It was to be many years before I would understand how an act such as writing a word or building a nest could be encoded in such a way in the brain that the resultant representations could control movements to produce a desired environmental consequence. The answer came from experiments by Bernstein (1967) and confirmation came quickly from the laboratory of Evarts (1967).

Bernstein performed a very simple experiment. He dressed subjects in black leotards, had them perform skilled actions, such as hammering a nail or running rough terrain, and took cinematographic pictures against a black background. Before taking the pictures, however, he had pinned white swatches of cloth to the leotards at the locations of major joints. The photographs therefore were running spatial displays of the perturbations in time of these white swatches. Bernstein then performed a Fourier analysis on the wave form of the photographic displays and found he could predict within a few millimeters where each next blow of the hammer would be directed or where each next step in running would land.

What Bernstein could do, his brain could do and what Bernstein's brain can do, ours can also accomplish. Again, a mathematical tool similar to that used by von Bekesy and others in the analysis of the brain's inhibitory mechanisms, and by optical-information scientists in the construction of holograms, was shown to have tremendous explanatory power. Direct evidence of this comes from experiments by Evarts, who showed that neurons in the motor cortex of monkeys do not fire proportionately to the amount of lengthening or shortening of a muscle involved in depressing a lever. Instead firing is proportional to the weight attached to the lever, i.e., the force necessary to move the lever. It is not the muscle or its contraction, it is the act, the use to which the muscle is put, the predicted end that needs to be achieved, that is reflected in the activity of the cortical cells.

The fact that actions, not just movements or muscles, are represented in the motor cortex has far reaching consequences. It means that I can with my left hand write Constantinople with muscles that have never been engaged in such a performance or anything like it. It means that chimpanzees can build nests with materials such as newspapers out of which no previous chimpanzee nests have ever been built. It means, therefore, freedom in the composition of an action—a freedom usually discussed by psychologists as response equivalence, but which is more, since pen, pencil, or typewriter can be chosen to achieve the same act.

Thus we have at hand an explanation of the origins of the brain organization that leads to acts such as moving the eyes and head about, the writing of plays and essays and the apparently self-generated variety of directions that the activities of men deploy. We even know a good deal about the machinery of accomplishing this sort of freedom. As already noted, Ashby detailed a mechanism whereby the operation of a system could come to be determined by inputs processed in parallel. Since his classic studies, it has become clear that this sort of parallel processing is constructed of a feedforward, open loop, rather than a feedback, closed loop, mechanism. Further, such parallel processing, open loop, feedforward systems display all the characteristics of voluntariness in that they run themselves off to completion in a preprogrammed fashion. Therefore, some of the mystery of volition is rapidly yielding to the precision of scientific analysis performed in the spirit of constructional realism.

TRANSCENDENTALISM AND THE LOGICAL PARADOX

But perhaps the most striking impact of a constructional approach to the problem of consciousness comes from observations of transcendental experiences. As already noted, certain brain structures have been found to control the join among the various feedback and feedforward mechanisms of the brain (Pribram, 1969). These structures (circuits centering on the amygdala) also become the site of pathological disturbance in man. Epileptogenic lesions of the medial part of the pole of the temporal lobe of the brain near the amygdala episodically disrupt self-awareness. Patients with such lesions experience inappropriate *deja vue* and *jamais vue* feelings of familiarity and unfamiliarity and fail to incorporate into memory experiences occurring during an episode of electrical seizure activity of their brains. In a sense, therefore, these clinical episodes point to a transcendence of content, a phenomenon of consciousness without content, a phenomenon also experienced in mystical states, and as a result of Yoga and Zen procedures—a transcendence of the dichotomy between "self" and "other" awareness.

As illustrated by Globus's (this volume) defense of panpsychism and Eccles's (this volume) defense of the soul, many scientists desire not to eschew the mystical and feel that certain transcendent properties of consciousness cannot be ignored: perhaps we must lapse into dualism after all, if we are to be happy ever after. The constructional realist needs no recourse to such counsels of despair. At a recent and most eventful gathering, called by Alan Watts and John Lilly at Esalen Institute, I learned of the work of G. Spencer Brown (1972), a student of Wittgenstein's and Russell's. As an engineer, Brown (and his brother) devised for British Railways a gadget that could automatically monitor the number of wheels entering and exiting their tunnels irrespective of the recursions a particular wheel of a partially halted train might perform. As a mathematician, Brown quickly realized that in devising the gadget he had performed some unorthodox arithmetical twist which, upon scrutiny, turned out to be the invention of an imaginary number in the Boolian algebra. Pursuing the problem further, he found that this invention became necessary because his system had to deal with oscillation. Oscillations occur when negative feedbacks are imperfectly timed. And oscillations may never stop—thus, when the system had to deal with an infinite calculus, the invention became necessary. As a pupil of Russell and Wittgenstein, Brown was seized by the idea that he had encountered the Whitehead–Russell dilemma of the logical paradox ("this statement is a lie") in the form of an oscillation and that his solution had transcended the paradox. Spencer Brown told us of some of the implications for philosophy of his mathematical discovery (see also Keys [alias G. Spencer Brown], 1972) and we developed others for ourselves.

In this spirit, von Foerster pointed out that the problem of the existence of a reality external to us, so persuasively discussed by Hume (1888) and Berkeley (1904), had a solution akin to that proposed by Spencer Brown. To paraphrase the ensuing discussion: If I had to choose to regard my subjective reality as purely private and you regard yours in like manner, we have a choice. We can either retreat to our own corners and deny the world, or, like oscillating wheels, shuttle our private experience between us through communication. In order to keep such communication open—infinite—we "invent," construct, a real world which includes the distinction between the "other" and the "self." In short, here again is evidence that self-consciousness is a construction, a construction as real as any other admitted by the constructional realist.

So you see, the constructional realist has a ball. His reality is not bounded by the material universe though he sees no virtue in denying its reality. Russell (1959) suggests that the structural properties of the physical world are the job of science to discover. He defines intrinsic properties as those that are undiscoverable. I prefer to think of intrinsic properties as those in which structural properties are embedded. They have a special relationship to the structural properties: they actualize, make possible the realization of the structural properties. Thus, we know a Beethoven symphony by its structure, but this structure must become realized in the notations on sheet music, the recorded inprint on a plastic disc, the arrangement of magnetized minerals on a tape, or the orchestrations at a concert. The intrinsic properties of paper making, printing, laboriously constructing 33⅓ rpm records and playback phonographs, the invention of wire recording and its gradual development into present-day tapes and cassettes, seem to have little to do with the structure of a symphony—yet they are essential to its realization. In biology, realization of genetic structures is dependent on the morphogenetic field in which the genetic material is embedded, and interestingly, early formulations of holographic-like processes were addressed to problems of morphogenesis (Pribram *et al.,* 1974). In short, I want to suggest that Russell's intrinsic properties are those in which structural properties must become embedded in order to be realized, become embodied. Further, I might point out that these intrinsic properties are the concern of and take up a considerable portion of effort expended by experimentalists, engineers, artisans, and artists who are engaged in realizing scientific and artistic structures. Yet, as Russell emphasized, these intrinsic properties are unknowable, in the sense of scientific theory, since they are subject to vagaries of the moment, are apparently unrelated to each other in any systematic fashion and can be appreciated, in the final analysis, only individually and subjectively, as in the case of the symphony, by listening. I repeat, however, constructional realism is not a reductive materialism. Though historically derived from the multiple-aspects theories of the critical philosophers, it differs sharply from them in giving primacy to realizations as embodiments of structure, not to those undefined somethings whose aspects are to be viewed. It is an understanding of structure, and of the intrinsic organizations in which structures become embedded, that is elusive and that has to be worked toward by observation and analysis. In this sense, constructional realism is more akin to William James's neutral monism and Russell's ideas on structural and intrinsic (embodied) properties and on the morphogenetic field.

Thus, the constructional realist is not afraid of spelling out the laws of transcendence—nor the brain organizations that make such laws possible. There is for him no more mystery to the mystic than to the induction process that allows selective derepression of DNA to form now this organ, now that one. The organizations that produce voluntary behavior and those that give rise to transcendence are yielding to our analyses. What we must face squarely is that such analyses do not dispel the "mystery" engendered by the operation of these processes in synthesis—that we need not polarize as opposites the hard-headed analysis and the search for structures and the wonder and awe when we view the embodiment of those structures. We have seen at the conference which gave rise to this volume that those most productive of scientific fact have maintained throughout a lifetime of contribution just these spiritual qualities—and that as scientists, they are as ready (and capable) to defend spirit as data. This is science as it was originally conceived: the pursuit of understanding. The days of the cold-hearted, hard-headed technocrat appear to be numbered—the constructional realist delights in the vistas that are opened by this renewed view of science.

REFERENCES

Ashby, W. R. (1960): *Design for a Brain: The Origin of Adaptive Behaviour.* New York: John Wiley & Sons, (2nd ed.)

Barrett, T. W. (1968): The relation between mind and brain. *Confin. Psychiatr.* **11,** 133–153.

Bekesy, G. (1967): *Sensory Inhibition.* Princeton, New Jersey: Princeton University Press.

Berkeley, G. (1904): *Three Dialogues Between Hylas and Philonous.* Chicago: Open Court.

Bernstein, N. (1967): *The Co-ordination and Regulation of Movements* New York: Pergamon Press.

Brentano, F. (1960): The Distinction between mental and physical phenomena. In: *Realism and the Background of Phenomenology.* Ed. by R. M. Chisholm. New York: The Free Press, pp. 39–61.

Bridgeman, B. (1971): Metacontrast and lateral inhibition. *Psychol. Rev.* **78,** 528–539.

Brown, G. S. (1972): *Laws of Form.* New York: The Julian Press, Inc.

Bucy, P. C. and Pribram, K. H. (1943): Localized sweating as part of a localized convulsive seizure. *Arch. Neurol. Psychiat.* **50,** 456–461.

Campbell, F. F. (1974): Transmission of spatial information through visual systems. In: *The Neurosciences: Third Study Program.* Ed. by F. O. Schmitt and F. G. Worden, Cambridge: MIT Press.

Campbell, F. W., Cooper, G. F. and Enroth-Cugell, C. (1969): The spatial selectivity of the visual cells of the cat *J. Physiol.* **203,** 223–235.

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

Cassirer, E. (1966): *The Philosophy of Symbolic Forms. Vol. 3: The Phenomenology of Knowledge.* New Haven: Yale University Press.

Cornsweet, T. N. (1970): *Visual Perception.* New York: Academic Press, Inc.

Evarts, E. V. (1967): Representation of Movements and Muscles by Pyramidal Tract Neurons of the Precentral Motor Cortex. In: *Neurophysiological Basis of Normal and Abnormal Motor Activities.* Ed. by M. D. Yahr and D. R. Purpura, Hewlett, New York: Raven Press.

Gabor, D. (1948): A new microscopic principle. *Nature* **161,** 777–778.

Gallup, Jr., G. G. (1970): Chimpanzees: self-recognition. *Science* **167,** 86–87.

Hume, D. (1888): *A Treatise of Human Nature.* Oxford: Clarendon Press.

Keys, J. (1972): *Only Two Can Play This Game.* New York: The Julian Press, Inc.

Langer, S. K. (1951): *Philosophy in a New Key: A Study in the Symbolism of Reason, Rite, and Art.* New York: Mentor Books.

McFarland, D. (1971): *Feedback Mechanisms in Animal Behaviour.* New York: Academic Press, Inc.

Mackay, D M (1956) The epistemological problem for automata. In: *Automata Studies.* Ed by C E Shannon and J. McCarthy Princeton, New Jersey: Princeton University Press, pp 235–252

Malis, L I , Pribram, K H., and Kruger, L. (1953)· Action potentials in "motor" cortex evoked by peripheral nerve stimulation *J Neurophysiol* **16,** 161–167

Piaget, J (1960) *The Child's Conception of the World.* Paterson, New Jersey· Littlefield Adams and Company

Pollen, D A (1971)· How does the striate cortex begin the reconstruction of the visual world? *Science* **173,** 74–77

Pollen, D A (1974): The striate cortex and the spatial analysis of visual space. In· *The Neurosciences Third Study Program* Ed by F. O. Schmitt and F. G. Worden, Cambridge: MIT Press

Pribram, K. H. (1966) Some Dimensions of Remembering: Steps toward a neuropsychological model of memory In. *Macromolecules and Behavior* Ed. by J. Gaito. New York: Academic Press, Inc , pp. 165–187.

Pribram, K H (1969)· The neurobehavioral analysis of limbic forebrain mechanisms: revision and progress report. In: *Advances in the Study of Behavior.* Ed. by D S. Lehrman, R. A. Hinde and E. Shaw, New York: Academic Press, Inc., pp. 297–332

Pribram, K H (1971*a*). The realization of mind. *Synthese* **22,** 313–322

Pribram, K. H (1971*b*): *Languages of the Brain· Experimental Paradoxes and Principles in Neuropsychology.* Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Pribram, K H (1972) Neurological notes on knowing. In: *The Second Banff Conference on Theoretical Psychology.* Ed by J Royce, New York: Gordon and Breach, pp. 449–480.

Pribram, K H (1974): How is it that sensing so much we can do so little? *The Neurosciences.*Cambridge· MIT Press, 249–261

Pribram, K H., Baron, R and Nuwer, M. (1974). The holographic hypothesis of memory structure in brain function and perception. In: *Contemporary Developments in Mathematical Psychology.* Ed by R. C. Atkinson, D. H. Krantz, R. C. Luce and P Suppes. San Francisco W. H Freeman

Pribram, K H., Kruger, L , Robinson, F and Berman, A. J. (1955–56): The effects of precentral lesions on the behavior or monkeys *Yale J. Biol. & Med.,* **28,** 428–443

Ratliff, F (1965)· *Mach Bands.* San Francisco· Holden Day.

Russell, B. (1959): *My Philosophical Development.* New York: Simon and Schuster.

Ryle, G (1949) *The Concept of Mind.* New York: Barnes and Noble.

Spitz, R. A. (1946)· The smiling response: a contribution to the ontogenesis of social relations. *Genet Psychol Monogr.* **34,** 57–125

Spitz, R A. (1957): *No and Yes: On the Genesis of Human Communication.* New York· International Universities Press, Inc.

Wall, P. D and Pribram, K H. (1950): Trigeminal neurotomy and blood pressure responses from stimulation of lateral cerebral cortex of Macaca mulatta. *J. Neurophysiol.* **13,** 409–412

Whitehead, A N and Russell, B. (1927): *Principia Mathematica.* Vol 1, 2nd ed., Cambridge Cambridge University Press.

Wittgenstein, L. (1922)· *Tractatus Logico-Philosophicus.* London: Routledge & Kegan Paul, Ltd.