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Consciousness: A Scientific Approach

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The results of recent research both in physics and in the brain sciences make it possible to attempt a scientific approach to the problem of consciousness. Two major areas are discerned: consciousness as perception of the physical and social world; and consciousness as awareness of self as distinct from those worlds. Only the former is treated in this paper. A data-based theory is documented which proposes that a domain exists both in the world and in the brain which is best described in frequency terms. In this frequency domain, events are distributed and each part represents the whole. The hologram provides a model for this form of organization. In order for the world of appearances to become manifest (in perception), a transformation from the frequency domain into the space/time domain must occur. The transfer functions that accomplish this transformation are proposed to operate hierarchically much as in a computer which provides the model for this portion of the theory. Conscious perception – the appearance of reality - is therefore conceived to be constructed by the operation of programme-like structures on a holographic-like matrix.

The face of psychology has undergone a series of changes during a century of growth as a science. Initial concerns with sensory processes, (as, for instance, in the hands of Helmholtz and Mach) and thought (as studies by Kuple, Brentano, and James) gave way to investigations of feelings (e.g., Wundt) and motivations (e. g., Freud). The introspectionism of Titchner was succeeded by the factors of Spearman, Thurstone, and Cattell and by the behaviourism of Watson; the Gestalts of Koffka, Kohler, Wertheimer and Metzger were pitted against the learning theories of Pavlov, Hilgard, Hull, Spence, Tolman and Skinner. Each of these faces has left a legacy which can be traced through its descendants and the variety of their modifications, techniques and formal statements of what constitutes psychology, and attests to the vigour of this young science.

During the past quarter century, the ferment has continued. The major influences now are seen to be existential encounter on the one hand and structural analysis based on computers and mathematics on the other. Superficially, it appears as if the earlier apposition of

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Gestalt to learning theory had gone to extremes: Wholism transcendent *vs* mechanism transitorized. But this would be superficial reading. A number of transcendentalists are beginning to be seriously concerned with physiological and social mechanisms as explanations of the philosophical teachings of Zen, Tantra and other eastern experiential systems, while, the mechanists have gone cognitive, allowing considerable fluidity and introspective latitude to the models they construct with their computers and mathematics.

The question I want to address, therefore, is whether the time is perhaps ripe for a more comprehensive view of psychological processes—a view that would encompass not only the variety that is psychology, but play a serious role in the scientific Zeitgeist as a whole. Meanwhile, because each current endeavour in psychology, as part of science, is deeply rooted in its technology, the confusion between disciplines continues to be aggravated. Loyalty is often to the discipline or subdiscipline, not to the content of psychology. Thus, several groups, though pursuing the same problems, fail to communicate because of the technical jargon developed in each group, often even to the use of identical words to convey different referents.

My concern with the problem of disparate theoretical and technical descriptions is a very practical one. I have spent this quarter century performing experiments that purport to relate brain function and behaviour to mental processes as these are expressed by verbal (and nonverbal) reports of my fellow humans (often in a clinical situation). In my attempts to communicate the specific fruits of the research results, I have related the function of the frontal cortex of primates to conditional operants; to decisional processes in ROC space; to attention as measured by eye movements, GSR, heart rate changes and reaction time in the presence of distractors; to motivation in relation to food deprivation and pharmacological manipulations; to learning as a functional change in performance; to the structure of memory using computer simulation; and to other brain processes by neuroanatomical and electrophysiological investigations. Intuitively, I feel that what I have found out about frontal lobe function (and the limbic system function, and temporal lobe function, etc.) is important not only to brain physiology, but to psychology—and this intuition is shared by most psychologists. Yet in trying to understand and communicate what I have discovered, I come up against a myriad of systems and beliefs: operant conditioners, decision theorists, attention theorists, motivation theorists, learning theorists, memory theorists and neuroscientists of various disciplinary persuasions (e. g., microelectrode artisans, evoked potential analysts, the CNV specialists or EEG computationists, let alone the neurochemists and neuropharmacologists) rarely relate their findings to one another. What is the connection between learning and memory, between attention and decision, between motivation and the various electrical manifestations of brain function? There is no universally agreed answer. It is as if in the physical sciences we did not know the relationship between the moons and their planets, between the solar system and galaxies, between atomic and molecular structure, between mechanical, gravitational and electromagnetic forces.

In short, if I am to make sense of my data, I must come to grips with the multiple framework within which these data have been gathered—the framework we call scientific psychology. This is the task I want to address. Only an outline, a proposal can be entertained in this paper. The detailed fitting of data, working the outline into a coherent body of scientific knowledge will require a more comprehensive effort over the next decades.

The proposal is contained in the holonomic theory. As the name suggests, the theory is holistic. It therefore addresses the interests of Gestalt, of existential concerns, of social encounter and transcendence. However, it is rooted in the disciplines of information, computer and systems analysis and thus aims towards expression of facts in precise mathematical form. The theory, because of its comprehensiveness, has philosophical implications (see e. g., Pribram, 1965, 1971a, 1971b); but its corpus concerns the relationship of neural, behavioural and experiential levels of inquiry. At this stage, the theory must of necessity be primarily inductive, relying on a systematization of available data and drawing upon metaphor and analogy from more advanced knowledge concerning other physical, biological and social organizations for initial model construction.

In this paper I want, in the tradition of empiricism, to discuss the holonomic theory as it concerns problems of consciousness, perception, imagining and attention, because, as will be shown in the last section of this paper, in a very real sense this area of problems is central to a scientific understanding of anything at all and especially of psychology. My point of departure is brain organization and function as it relates to observations of the behaviour (including verbal reports of experience) of the organism in which the brain is functioning. The departure proceeds from a conflict of views which opposes holistic to analytic processes. The following account hopes to show that such opposition is unwarranted, that in fact both types of processes occur in the brain and that their interaction is coordinate with perception.

The Brain and the Computer

One of the most challenging discoveries about brain organization concerns the precise connection between parts of the brain and between these parts and the topography of bodily surfaces. Localization of connections predicts a localization of function. Grossly, this prediction is often confirmed: For example, eyes, ears and nose project by way of nerve tracts to separate parts of the brain and when these parts are damaged, stimulated or electrically analyzed, a correspondence is obtained between anatomical projection and sensory function. The challenge is posed by the precision of the connections. Assignment of a precise function to a particular anatomical arrangement does not come easily. One investigator, Karl Lashley, has even despaired of ever making such assignment and suggested that the anatomy may represent a vestigial residue of some phylogenetically earlier functional organization, much as our veriform appendix represents an earlier functional digestive organ (Lashley, 1960).

The problem arises from the fact that large holes can be made in the anatomical organization of the brain without severely disturbing some functions that would be expected to depend on this precise organization. This does not mean that holes in the brain have no effect: when made in the sensory projection areas, for instance, such holes produce scotomata in the appropriate sensory receptive field. However, very little disturbance of sensory, perceptual, attentional, memory or other psychological process can be ascertained when tests are made within the remaining intact field. The remaining brain-behaviour field, the remaining neural organization appears capable of taking over, functioning in lieu of the whole—the system shows equipotentiality as Lashley put it (e.g., 1960). Currently, we would say that the sensory input becomes distributed over the reach of the projection system. The question arises, therefore, how.

An alternative to Lashley's phylogenetic argument is to look at current data-processing systems for an appropriate analogy. General purpose computers are wired with very specific connections. Yet, one day, in the early period of computer technology, I experienced the following incident: The then current Stanford machine had been sold to a nearby commercial bank to make way for a new installation. Unfortunately, I had collected a batch of irreplaceable data on patients who had received frontal lobotomies some ten years earlier (Poppen, Pribram and Robinson, 1965), in a tape format tailored to the existing computer. Learning of the replacement only at the last moment, we rushed to the computer center to process our tapes. Much was completed in the next two days and nights, but a small amount of work still needed to be done when, on the third day, dismantling for shipment was begun. We discussed our problem with the person in charge, hoping to delay things by the crucial three or four hours we needed to finish our task. Much to our surprise he said, "go ahead and keep processing your tapes, we'll begin the dismantling in such a way as not to disturb you." We were grateful and expected peripherals and cabinets to be tackled first, only to witness the removal of assemblies of switches and tubes from the innards of the machine. Our data-processing meanwhile proceeded merrily without any interruption of the cadences to which we had become accustomed. Though we expected the whole affair to come prematurely to a grinding halt at any moment, this did not happen and we gratefully acknowledged the seeming equipotentiality of the man-made brain that had given us such excellent service.

Could it be, that our biological brains, though "wired" as precisely as any computer, are organized in a similar way–i.e., to be a general-purpose instrument that, when properly interfaced and given proper bootstrap programs to get the "machine" going, can then handle more complex higher order programmes with seeming equipotentiality? Why not? The underlying principles of the operation of biological and hardware brains may be sufficiently similar to warrant such an explanation. An early book with George Miller and Eugene Galanter explored this possibility (Miller, Galanter and Pribram, 1960) and more recently I presented the neurophysiological and neurobehavioural evidence in support of this approach, pointing out as well, however, the divergences and differences between biological brains and computers (Pribram, 1971a).

One difference involves the very problem of specificity of connections which initiated the present discussion. Computers currently are primarily serial and therefore analytic processors—one event leads to another. Brains, to a much larger extent, are parallel and therefore holistic processors—many related events occur simultaneously.

In an attempt to simulate biological brains on the computer, scientists have constructed programmes utilizing highly interconnected hardware which are called random-net configurations. Though these do approximate one aspect of human perception, the constructive aspect (Neisser, 1967), they nevertheless fail when tested against the general characteristics of the human perceptual system (Minsky and Papert, 1969), and fail equally to correspond to the anatomical specificity of the human system in which sensory projections are topologically discrete.

These limitations of hardware simulations have been discouraging to those who felt that current computers were, at least in principle, models of biological brains, and have provided fuel for those who would like to reject the use of mechanistic analogies to the nervous system.

Another interpretation is possible, however. Perhaps we have gained only a partial insight into brain function by stressing essential similarities to the organization of computers. Perhaps what is needed, in principle, is a look at another type of organization conducive to parallel processing, working in conjunction with that represented by present-day computers.

The Brain and the Hologram

There is a set of physical systems that meets these requirements—i.e., they display the essentials of parallel processing. These are optical (lens, prism, diffraction, etc.) systems—often called optical information processing systems to distinguish them from the systems of digital switches comprising the computer mechanisms through which programmable information processing is conducted. In optical systems "connections" are formed by the paths which light traverses and light bears little physical resemblance to the electrochemical energy that is the currency of both brain and computer. Thus, the analogy must at once be seen as more restricted. What is to be taken seriously is the analogy between the *paths* taken by the energy; the interactions among these paths and the resulting organisations of "information" that are produced. Elsewhere, I have, with Nuwer and Baron, discussed possible (and even on the basis of current evidence some probable) physical correspondences between optical and brain systems with respect to these information processing capabilities (Pribram, Nuwer & Baron, 1974).

The essence of optical information processing systems is their image construction potential. This capacity is to be compared and contrasted with the programming potential of the computer. Neither programmes nor images reside as such in the information processing system—they are configurations made possible by the construction of the system. Both images and programmes can be captured and stored as such outside their processing systems. When this is done, there appears to be no superficial resemblance between the image or programme and the system in which processing takes place, nor even with any readily recordable event structure that occurs during processing. This is because the topography of images and the statements of programmes are re-presentations of the process and as such are subject to transformation. The job of the scientist is to specify the transformations that occur between image and optical information processing system and between programme and computer. The power of these analogies to brain function comes when the mathematical description of these transformations can be shown by experiment to be identical for information processing by the brain as for processing by optical and computer systems. When in addition, the physical components responsible for the transformations are identified, a model of brain function can be constructed and tested deductively by subsequent experiment.

Images and programmes are patently different constructions and a good deal of evidence is accumulating to show that in man the right hemisphere of the brain works predominantly in an image mode while the left hemisphere function is more compatible with programme processing (see reviews by Sperry, 1974; Milner, 1974; and Gassaniga, 1970). There is also a considerable body of evidence that this hemisphere specialization is derived from an earlier mammalian pattern of image construction by the posterior-lateral portions of the brain based on somatotopic and visual input, contrasted with a more sequential organization of the fronto-medial (limbic) systems by olfactory and auditory input (see Pribram, 1960 and 1969a for review). These dichotomies are not exclusive and hold only for overall functions—there are many sequential processes involved in image construction (as, for instance, scanning by the eye of a pictorial array) and there are parallel processes involved in programming (for example, the conducting of a symphony or even the appreciation of auditory harmonics). Yet the fact that neurobehavioural data readily distinguish image and programme processing suggests that both must be taken into account in any comprehensive understanding of psychological function.

By contrast to programmes, images can be comprehended in their totality even after brief exposures to the energy configurations they represent. They tend to be wholistic rather than analytic, e.g., they tend to completion in the absence of parts of the input ordinarily responsible for them. Also, they tend to be "good" or "bad" on the basis of the structure of the redundancy of their components (Garner 1962). (Programmes, on the other hand, have no such internal criteria for goodness. A programme is good if it works—i.e., is compatible with the computer and is better if it works faster. When, as in a musical composition, esthetic criteria can be applied, they pertain to the image-producing properties of programmes, their compatibility rather than their internal structure.) In short, imaging obeys Gestalt principles (which were first enunciated in the visual arts) as would be expected, while programming takes its kinship from linguistics. Both have gained precision and a new level of understanding by recourse to information measurement and processing concepts.

Holograms provide a powerful mechanism for storing the image construction properties of optical information processing systems. As already noted, what called attention to the distributed information state is that it makes the brain highly resistant to damage. In addition, the holographic state allows a fantastic memory storage capacity: some hundred million bits of retrievable information have been stored in a cubic centimeter of holographic memory. This is accomplished by separately storing modulations of one or another spatial or temporal frequency. It is somewhat as if there were myriads of FM (frequency modulation) radios c o m p r e s s e d into a tiny space. The short wave length of light (as compared to sound) makes such capabilities possible. In the brain, the short wave lengths characterizing a slow potential microstructure can be assumed to serve in a similar fashion (Pribram, 1971a).

There are other properties (e.g., associative recall, translational, i.e., positional and size invariance) of holograms that make the analogy with brain function in perception and memory attractive. These have been presented in another paper (Pribram, Nuwer & Baron, 1974). Here I want to emphasize that testable hypotheses can be formulated and models of actual brain function can be proposed within the domain of what can loosely be called the holographic properties of optical information processing systems. We have reviewed the evidence for image construction by the brain. What assemblies of neurons (and their processes), if any, function as true Fourier holograms? Which brain structures function more like Fresnel holograms? Which mimic a Fourier process by convolving, integrating neighbouring neural events and those at successive stages? These questions are being asked and experiments are being performed to provide answers.

As might be expected, such experiments have already encountered one serious obstacle in drawing too close a parallel between optical information processes and image construction by the brain. This obstacle concerns the size of the receptive fields recorded for cells in the primary visual projection systems. For example, the projection from the macular portion of the retina, the foveal receptive fields, is extremely small—some 3–5° of visual angle as a maximum. A hologram of this size will hardly account for the fact that information becomes distributed accross the entire visual system as indicated by the evidence from electrophysiological recordings.

A search has therefore been made for larger receptive fields that integrate the input from the smaller fields of the primary projection cortex. Such larger fields have been found in the cortex that surrounds the primary projection areas. It would be simple if one could assume that there, rather than in the primary projection cortex, the true holographic process takes place.

But this simple assumption runs contrary to other evidence. First, it would not account, by itself, for the distribution of information within the projection cortex. Second, complete resection of this *peri* projection cortex (where the larger receptive fields are found) produces no permanent damage to image construction as far as one can tell from animal experiments (Pribram, Spinelli & Reitz, 1969).

Beyond these visual areas of the brain cortex, however, there is another, lying on the inferior surface of the temporal lobe which, when it is resected, leaves monkeys markedly and permanently impaired in their ability to make visual discriminations (Pribram, 1954, 1960, 1969a). This impairment is limited to the visual mode (H. Pribram & Barry, 1956; M. Wilson, 1957). Only visual performances demanding a choice are impaired; other visual functions such as tracking a signal remain intact (Pribram, Chapter 17, 1971a). The difficulty involves the ability to selectively attend to visual input (Gerbrandt et al., 1970; Rothblat & Pribram, 1972; Gross, 1972).

Much to everyone's surprise, this visual "association" area (as the area with comparable function is known in man (Milner, 1958) appears to function remarkably well when all known visual input to it is destroyed. As already noted, removal of the perivisual cortex has little permanent effect; destruction of the thalamic input (from the pulvinar) to the inferior temporal cortex has no effect whatsoever (Mishkin, 1972;

Ungerleicter, personal communication). Even combined lesions of perivisual and thalamic inputs do not permanently disrupt visual discriminations.

These data make plausible the hypothesis that the inferior temporal cortex exerts its effect on vision via an output to the primary visual projection system (Pribram, 1958). Evidence in support of this hypothesis has accrued over the past fifteen years: the configuration and size of visual receptive fields can be altered by electrical stimulation of the inferior temporal cortex (Spinelli & Pribram, 1967); recovery cycles in the visual projection system are shortened by such stimulation (Spinelli & Pribram, 1966); the pathways from the inferior temporal cortex have been traced (Whitlock & Nauta, 1956; Reitz & Pribram, 1969).

Thus, another, more specific hypothesis can be entertained—viz., the suggestion that the inferior temporal cortex helps to programme the functions of the primary visual projection systems. Specifically, such programming, as well as programming by input from sensory receptors, could "get together" the distributed store of information from the various loci of restricted receptive field size. If the relevant loci were addressed in unison they would, in fact, function like a hologram.

The difference, therefore, between brain function and the function of optical information processing systems is the one set out at the beginning of this paper. Brain is *both* an image construction and a programming device. Optical systems construct only images.

The thesis presented here, therefore, suggests that the holographic-like store of distributed information in the primary visual projection system is akin to the distributed memory bank of a computer. The computer's memory is organized more or less randomly; the brain's memory has been stored along holographic principles. Both must be addressed by programmes which access the appropriate "bits" of information. The computer does this serially; the brain, to a large extent, simultaneously, by pathways that allow signals to be transmitted in parallel. Such simultaneity in function produces momentary brain states that are akin to the holographic patterns that can be stored on film.

Because of these differences between brain and optical systems, it may be better to talk about brain function as holonomic rather than just holographic or hologrammic. The term holonomic is used in engineering whenever the systems, in an interactive set of such systems, are reasonably linear in their function. Linearity allows the computation of the functions of each system and therefore an estimate of the amount of their interaction the "degrees of freedom" that characterize the interactive set. The interactions are known as the holonomic constraints on the system. In the context of the model of brain function in vision suggested here, the neural systems that determine any momentary visual state would have to be shown to be linear; then the amount of interaction among the systems in producing the holographic visual state would appear as the degrees of freedom characterizing that state.

Evidence is available to show that the visual system, despite local nonlinearities, acts linearly overall above threshold (e.g., Ratliff, 1965). This is the case in other neural systems, notably the motor system (Granit, 1970). It is thus reasonable to propose that the holonomic model applies to brain functions other than visual. Support for such a proposal comes from work on the auditory (von Bekesy, 1960), somatosensory (von Bekesy, 1959) and even gustatory (von Bekesy, 1967; Pfaffman, 1960) and olfactory systems (Gesteland, et al., 1968).

Briefly summarizing, the holonomic model of brain function proposes that the brain partakes of both computer and optical information processes. The brain is like a computer in that information is processed in steps by an organized and organizing set of rules. It differs from current computers in that each step is more extended in space—brain has considerably more parallel processing capability than today's computers.

This parallel processing aspect of brain function leads to another difference. The rules of parallel processing are more akin to those that apply to optical information processes than they are to those used in current serial computers. Thus the momentary states set up by the programming activity are considerably like those of image constructing devices, i.e., holographic. Thus memory storage is also holographic rather than random as in today's computers. This does not deny, however, that storage of rules also takes place—as it does in machine peripherals (e.g., DEK tapes for minicomputers). What the model requires is that the "deep structure" of the memory store is holographic.

Since the holographic state is composed by programmes and since the distributed store must be got together by the actions of and interactions among programmes, the holographic brain state can be analyzed according to the systems that produces it. Thus the holonomic constraints or degrees of freedom that characterize the holographic state can be determined. The holonomic model of brain function is therefore mathematically precise, and its assumptions (such as overall linearity of component programming systems) and consequences (the distributed nature of the deep structure of the memory store) are, at least in principle, testable.

But what relevance does the holonomic model of brain function hold for psychology? The advent of computers gave rise to a psychological science that could cope with cognitive processes. The scope of studies of memory mechanisms, attention and problem solving could now be precisely explored and models constructed "in vitro" much as the biochemist can model and explore in the laboratory the chemistry believed to be operative in organisms. Holography promises to provide similar "in vitro" possibilities for the study of consciousness. Perceptual processes, imaging and the like can now be modelled and explored in the laboratory. Let us next, therefore, take a look at the problems posed by the study of consciousness and examine the ways in which the holonomic theory can contribute to their resolution.

Achieving Consciousness

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 colouration. 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 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.

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 behaviour of the organism. Here the term "behaviour" should be understood in a larger sense then its usual English connotation. The German "Verhaltung" and the French "comportment" come closer since they connote English "bearing" as well as more active behaviour. Thus, a question we need to address is whether we can also access these manifestations of consciousness by looking at the behaviour 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 centre 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 we also 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 behaviour 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* endeavour). 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, 1971a, 1971b, 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 hierarchical structure, their arrangements. Information becomes encoded in such organizations and decoded from them. Codes are languages (Pribram, 1971a) 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 neighbouring elements mandatory? How can a pattern, the encoded information, be transmitted without transmission of the substance or medium in which the communication occurs?

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 fullblown 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 modelled 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 meta-contrast (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 neighbouring 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 let me to propose that we take seriously the analogy between neural processing and physical holography (1966, 1971 a, 1974, Pribram, Nuwer & 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 neighbouring 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 neighbouring 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 as well as self-consciousness.

Elsewhere (Pribram, 1971a) 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 micro-structure, 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."

Structure and Probability

In the concluding part of this paper, I want, therefore, to explore some questions as to the organization of this external "material" physical world. Unless we know something of consensually validatable "information" that remains invariant across transformations of the input to the brain—and, as we have seen, we cannot rely only on the directness of our perceptual experience for this knowledge—how can we think clearly about what is being perceived? Questions as to the nature of the physical universe lie in the domain of the theoretical physicist. Physics has enjoyed unprecedented success not only in this century, but in the several preceding ones. Physics ought to know something, therefore, about the universe we perceive. And, of course, it does. However, as we shall shortly see, the structure-distribution problem is as pervasive here as it is in brain function.

The special theory of relativity made it clear that physical laws as conceived in classical mechanics hold only in certain circumscribed contexts. Perceptions of the Brownian "random" movements of small suspended particles, or of the paths of light coming from distances beyond the solar system, strained the classical conceptions to the point where additional concepts applying to a wider range of contexts had to be brought in. As in the case of direct perception, the laws of physics must take into account not only what is perceived but the more extended domain in which the perception occurs. The apparent flatness of the earth we now know is an illusion.

The limitations of classical physics were underscored by research into the microcosm of the atom. The very instruments of perception and even scientific observation itself became suspect as providing only limited, situation-related information. Discrepancies appeared such as an electron being in two places (orbits) at once or at best moving from one place to another faster than the speed of light—the agreed upon maximum velocity of any event. And within the nucleus of the atom matters are worse—a nuclear particle appears to arrive in one location before it has left another. Most of these discrepancies result from the assumption that these particles occupy only a point in space—thus when the equations that relate location to mass or velocity are solved, they lead to infinities. Furthermore, in the atomic universe, happenings take place in jumps—they appear to be quantized, i.e., particulate. Yet when a small particle such as an electron, or a photon of light, passes through a grating and another particle passes through a neighbouring grating, the two particles appear to interact as if they were waves, since interference patterns can be recorded on the far side of the gratings. It all depends on the situation in which measurements are made whether the "wavicle" shows its particle or its wave characteristics.

Several approaches to this dilemma of situational specificity have been forwarded. The most popular, known as the Copenhagen solution, suggests that the wave equations (e.g., those of Schroedinger, 1935, and DeBroglie, 1964) describe the average probabilities of chance occurrences of particulate events. An earlier solution by Niels Bohr (the "father" of the Copenhagen group, 1966) suggested that particle and wave were irreconcilable complimentary aspects of the whole. Heisenberg (1959) extended this suggestion by pointing out that the whole cannot in fact be known because our knowledge is always dependent on the experimental situation in which the observations are made. Von Neumann (1932) added, that given a positivistic operational framework, the whole reality becomes therefore not only unknown but unknowable. Thus, the whole becomes indeterminable because we cannot in any specific situation be certain that what we are observing and measuring reflects "reality." In this sense, as well as from the viewpoint of brain processes, we are always constructing physical reality. The arguments of the quantum physicist and those of the neurophysiologist and psychologist of perception are in this respect identical.

But several theoretical physicists are not satisfied with these solutions or lack of solutions. Feynman (1965), for instance, notes that though we have available most precise and quantitative mathematical descriptions in quantum mechanics, we lack good images of what is taking place. (His own famous diagrams show time flowing backwards in some segments!) DeBroglie, who first proposed wavelike characteristics for the electron fails to find solace in a probabilistic explanation of the experimental results that led him to make the proposal (1964). And DeBroglie is joined by Schroedinger (1935) who formulated the wave equation in question and especially by Einstein, whose insights led him to remain unconvinced that an unknowable universe, macro- and micro-, was built on the principle of the roulette wheel or the throw of dice.

I share this discomfort with attributing too much to chance because of an experience of my own. In the Museum of Science and Industry in Chicago, there is a display which demonstrates the composition of a Gaussian probability distribution. Large lead balls are let fall from a tube into an open maze made of a lattice of shelves. The written and auditory explanations of the display emphasize the indeterminate nature of the path of each of the falling balls and provide an excellent introduction to elementary statistics. However, nowhere is mention made of the symmetrical maze through which the balls must fall in order to achieve their probabilistic ending. Having just completed *Plans and the Structure of Behavior* (Miller, Galanter & Pribram, 1960), I was struck by the omission. In fact, students of biology routinely use statistics to discover the orderliness in the processes they are studying. For example, when a measurable entity shows a Gaussian distribution in a population, we immediately look for its heritability. Perhaps the gas laws from which statistics emerged have misled us. A Gaussian distribution reflects symmetrical *structure* and not just the random banging about of particles. Again, the physical reality behind the direct perception may contain surprises.

Moreover, when we obtain a probabilistic curve, we often refer to a distribution of events across a population of such events—e.g., a Gaussian distribution. Could it be that for the physical universe, just as in the case of brain function, structure and distribution mutually interact? After all, the brain is a part of the physical universe. For brain function, we found structure to be in the form of program and distribution in the form of holograms. Is the rest of the physical universe built along these lines as well?

THE STRUCTURAL AND HOLONOMIC ASPECTS OF ORGANIZATION

David Bohm (1957), initially working with Einstein, has among others, made some substantial contributions to theoretical physics compatible with this line of reasoning. Bohm points out, as noted above, that the oddities of quantum mechanics derive almost exclusively from the assumption that the particles in question occupy only a point in space. He assumed instead that the "wavicle" occupies a finite space which is structured by subquantal forces akin to electromagnetic and gravitational interactions. These interacting forces display fluctuations—some are linear and account for the wave form characteristics of the space or field. Other interactions are nonlinear (similar to turbulence in fluid systems) and on occasion produce quantal events. In biology, Thom (1972) has developed a mathematics to deal with such occurrences in the morphogenetic field and this mathematics has been applied to perception by Bruter (1974). Thom calls the emergence of quasiquantal structures from turbulent processes "catastrophes." In physics, the quantal structures that result from such catastrophic processes may, therefore, be only partially stable. Thus, they can disappear and reappear nearby in a seemingly random fashion, which, on the average, however, are subject to the more regular oscillations of the forces. In biology, observations pertaining to the entrainment of oscillatory processes by clocks or temporary dominant foci parallel these concepts. Bohm goes on to point out where in the subquantal domain these events will become manifest: the interactions of high frequency and high energy particles in nuclear reactions, in black bodies, etc. An article in a recent issue of *Scientific American* reviews the contemporary scene in these attempts at a Unified Field Theory in the subquantal domain (Weinberg, 1974).

More recently, Bohm (1971, 1973) has reviewed the conceptual development of physics from Aristotelian through Gallilean and Newtonian times to modern developments in the Quantum Mechanics. He points out how much of our image of the physical universe results from the fact that, since Gallileo, the opening of new worlds of enquiry in Physics has depended on the use of lenses. Lenses have shaped our images and lenses objectify. Thus, we tend to assess external space in terms of objects, things and particulars.

Bohm goes on to suggest that image formation is only one result of optical information processing and proposes that we seriously consider the hologram as providing an additional model for viewing the organization of physical processes. He and his group are now engaged in detailed application of this basic insight to see whether in fact a holographic approach can be helpful in solving the problems of high energy nuclear physics. Initial developments have shown promise.

As noted above, the subquantal domain shows striking similarities to holographic organization. Just as in the case for brain processes presented here, Bohm's theoretical formulations retain classical and quantum processes as well as adding the holographic. The holographic state described by wave equations and the particle state described quantally, are part of a more encompassing whole. The parallel holds because the holographic models describe only the deeper levels of the theory which is thus holonomic, rather than holographic, as we found it to be for the special case of brain function (where the deeper level is constituted of pre- and post-synaptic and dendritic potentials and the quantal level, of the nerve impulses generated by these slow potentials).

Bohm relates structural and holographic processes by specifying the differences in their organization. He terms classical and particle organization *explicate* and holographic o r g a n i z a t i o n *implicate*. Elsewhere (Pribram, 1971a), I have made a parallel distinction for perceptual processes: following Bertrand Russell (1959), I proposed that scientific analysis as we practice it today, begets knowledge of the extrinsic properties (the rules, structures, etc.) of the physical world. My proposal departs from Russell, however, in suggesting that intrinsic properties (which he defines as the stoneness of stones, e.g.) are also knowable—that in fact they are the 'ground' in which the extrinsic properties are embedded in order to become realized. Thus artists, artisans and engineers spend most of their time realizing the extrinsic programmes, laws and rules of the arts and sciences by grounding them in an appropriate medium. For example, a Brahms symphony can be realized by an orchestra, on sheet music, on a long-playing record or on tape. Each of these realizations come about after long hours of development of the medium in which the realization occurs. R u s s e l l was almost correct in his view that the intrinsic properties of the physical world are unknowable—they have apparently little to do with the more enduring extrinsic properties, show no resemblances among themselves, and demand considerable *know-how* to replicate.

The sum of these ideas leads to the proposal that the intrinsic properties of the physical universe, their implicate o r g a n i z a t i o n, the field, ground or medium in which explicit organizations, extrinsic properties, become realised, are multiform. In the extreme, the intrinsic properties, the implicate organization, is holographic. As extrinsic properties become realized, they make the implicate organization become more explicit.

The consequence for this view is a revaluation of what we mean by probabilistic. Until now, the image, the model of statistics, has been indeterminacy. If the above line of reasoning is correct, an alternate view would hold that a random distribution is based on holographic principles and is therefore determined. The uncertainty of occurrence of events is only superficial and is the result of holographic "blurring" which reflects underlying symmetries (much as does the Gaussian distribution in our earlier example) and not just haphazard occurrences. This relation between appearance and reality in the subquantal domain of nuclear physics and its dependence on underlying symmetries (spin) is detailed in the review article in *Scientific American* already referred to (Weinberg, 1974).

A preliminary answer to the question posed at the outset of this section—what is it that we perceive—is therefore that we perceive a physical universe not much different in basic organization from that of the brain. This is comforting since the brain is part of the physical universe as well as the organ of perception. It is also comforting to find that the theoretical physicist working from his end and with his tools and data has come to the identical problem (which is, in Gibson's terms, the nature of the information which remains invariant across situations) faced by the neurophysiologist and psychologist interested in perception (Bohm, 1965, Appendix). Though surprising, the fact that at least one renowned theoretical physicist has made a proposal that addresses this common problem in terms similar to those set forth on the basis of an analysis of brain function, is most encouraging. For science is of a piece, and full understanding cannot be restricted to the developments made possible by one discipline alone. This is especially true for perception—where perceiver meets the perceived and the perceived meets the perceiver.

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, 1969b). 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 (1976) defense of panpsychism and Eccles's (1976) 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 Boolean 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's 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 enbedded. 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 imprint 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 33 1/3 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 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 D.N.A. to form now this organ, now that one. The organizations that produce voluntary behaviour 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. 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—today's psychologist can delight in the vistas that are opened by this renewed view of science.

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