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## Some Comments on the Nature of the Perceived Universe

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### INTRODUCTION

The 1960s saw a burst of new approaches to persistent problems in psychology. For me these approaches were heralded in the concepts of Image and Plan (Pribram, 1960). In a series of papers and books, often with the help of colleagues, I attempted to portray the power of these conceptions. At the neurological level, a two-process mechanism was detailed to show how Images and Plans were, in fact, generated (Pribram, 1971). At the behavioral level the concept Plan originated early on in observed similarities in the organization of serial actions and the organization of computer programs (Pribram, 1960). The concept Image took somewhat longer to ground in a model that allowed specific hypotheses to be generated. But by the mid-1960s it became clear that optical information processing systems could provide this model, especially in the construction of holographically produced Images (Pribram, 1972). These rather sketchy proposals have gradually been filled out with the accumulation of data from several laboratories, including my own. *Languages of the Brain* (Pribram, 1971) spells out the relevance of these data to the theory and more recent additions are to be found in two papers: "The Holographic Hypothesis of Memory Structure in Brain Function and Perception" (Pribram, Nuwer, & Baron, 1974) and "How Is It that Perceiving So Much We Can Do So Little?" (Pribram, 1974a).

Rather than detail once again the supports for the concepts of Image and Plan, I want here to address a set of specific issues that derive from the theories as they have been developed and to show that the computer theory of Plans and the holographic theory of Images are not mutually exclusive but stand in relation to each other much as other fundamental scientific theories (specifically theories in theoretical physics) do today.

My interest in these issues has several roots. The tap root concerns the two-process mechanism of brain function involving discrete nerve impulses and the pre- and postsynaptic depolarizations and hyperpolarizations that constitute a dynamic slow potential microstructure best described by continuous wave equations. This led me to inquire of my son, Professor John K. Pribram, a physicist, some details on the conceptual aspects of the parallel problem in quantum physics. The results of this inquiry are described below.

A second major root stems from discussions with Professor Daniel Pollen on the nature of the Fourier or Fourier-like process in the visual system. We repeatedly puzzled on the nature of the reality imaged by the process. The cortical mechanism which we thought to be holographic stems from transformations of a series of retinal images. These images themselves were constructed by the optics of the eye. Could it be that the retinal image was a special case (similar to a photographic image) in a series of reversible transformations that include other, more holographic-like stages? Do we need a cortical imaging process at all?

It finally occurred to me that the questions critical to these issues related to the nature of the external "reality" that was being transformed by the organism's perceptual mechanisms. In this respect, therefore, I had come to the same point of inquiry as James Gibson in the formulation of his elegant program of research. And it also led directly (on recommendation from J. K. Pribram) to interaction with theoretical physics in the person of David Bohm who in his own way came to Gibson's position (Bohm, 1965, Appendix). Some of the early fruits of these inquiries and interactions are described below.

### THE HOLONOMIC THEORY

Holograms provide a powerful mechanism for storing the image construction properties of optical information processing systems. What called attention to holograms is their distributed information state which makes them like 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 compressed 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 the slow potential microstructure can be assumed to serve in a similar fashion.

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 neighboring 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 system. For example, the projection from the macular portion of the retina, the foveal receptive fields, is extremely small—some  $3-5^\circ$  of visual angle as a maximum. A hologram of this size will hardly account for the fact that information becomes distributed across the entire visual system as indicated by the evidence from resections and 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 here, 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, 1969). 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, 1971, Chapter 17). The difficulty involves the ability to selectively attend to visual input (Gerbrandt, Spinelli, & Pribram, 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; Ungerleider, 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 15 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 systems 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, namely, the suggestion that the inferior temporal cortex helps to program 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 chapter. 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 programs 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 Békésy, 1960), somatosensory (von Békésy, 1959) and even gustatory (von Békésy, 1967; Pfaffmann, 1960) and olfactory systems (Gesteland, Lettvin, Pitts, & Chung, 1968).

Briefly summarizing, the holonomic model of brain function proposed 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, that is, 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., 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 programs and since the distributed store must be got together by the actions of and interactions among programs, 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.

#### IS PERCEPTION DIRECT OR CONSTRUCTIONAL?

I want now to address some consequences to psychology (and perhaps to philosophy) of the holonomic theory of brain function. The theory, as we have seen, (1) stems from the metaphors of machine and optical information processing systems; (2) has developed by analogy to those systems, spelling out some

similarities and some differences; until (3) a testable holonomic model of brain function could be proposed. One way of understanding the model better is to compare it to another and to observe its relative explanatory power.

An apparent alternative to the "holonomic" model is presented by James Gibson's (1966) comprehensive "ecological" model of perception. Gibson's model proposes that the "information" perceived is inherent in the physical universe and that the perceiver is sensitive to whatever information remains invariant across transformations produced by changes in the environment, by organism-environment displacements, and by the organism's processing apparatus. The key concept in the ecological theory is "direct perception"—the environment as an ecological niche is directly apprehended by the perceiver.

By contrast, the holonomic theory is constructional. Images are constructed when input from inferior temporal cortex (or its analog in other perceptual systems—see Pribram, 1974) activates, organizes the distributed holographic store. Images are produced and are therefore as much a *product of* the "information residing in" the organism, as they are of "information" contained in the environment. Philosophically speaking, the holonomic model is Kantian and Piagetian; the ecological model partakes of a critical realism.

Clinical neurological experience wholly supports the holonomic view. Patients are seen who complain of macropsia and micropsia and other bizarre distortions of visual space. For instance, I once had a patient who, after a blow on the head, experienced episodes of vertigo during which the visual world went spinning. His major complaint was that every so often, when his perceptions again stabilized, they left him with the world upside down until the next vertigo which might right things once again. He had developed a sense of humor about these experiences, which were becoming less frequent and of shorter duration: his major annoyance he stated to be the fact that girls' skirts stayed up despite the upside-down position!

Further "clinical" evidence in support of the holonomic model comes from the experimental laboratory. Resections of the primate inferior temporal cortex markedly impair size constancy—the transformations across various distances over which environmental information must remain invariant in order to be "directly" perceived as of the same size.

Yet Gibson (1966, 1968) and others who share his views (e.g., Johansson, 1973; and more recently Hebb, in press), make a good case that in normal adult humans, perception is direct. A series of ingenious experiments has shown that by appropriate manipulations of "information," illusions indistinguishable from the "real" can be created on a screen. The demonstrations are convincing and make it implausible to maintain a solipsistic or purely idealistic position with respect to the physical universe—that nothing but a buzzing blooming confusion characterizes external reality. With respect to the experiments he has devised, Gibson is correct.

Furthermore, if perception is direct, a dilemma for the holonomic theory would be resolved. When an optical hologram produces an image, a human observer is there to see it. When a neural hologram constructs an image, who is the observer? Where is the "little man" who views the "little man"? Direct perception needs no little men inside the head. Gibson (1966), in fact, deplors the term image because it calls up the indirectness of the representational process. However, if what we "directly perceive" is a constructed *image* and not the true organization of the external world—and we mistake this perception as veridical—perception would be both direct and constructional.

The question to be answered therefore is by what mechanism can perception be both direct and constructional? A clue to the resolution of this dilemma comes from the Gibson (and Johansson) experiments themselves. Their displays produce the *illusion* of reality. When we know the entire experiment we can label the percept as an illusion, even though we directly experience it. In a similar fashion, the sound coming from the speakers of a stereophonic system is experienced directly. When we manipulate the dials of the system (changing the phase of the interacting, interfering sound waves) so that an equal part of the sound comes from each of the two speakers, we say that an illusion has been produced—the sound has been projected to the space between the speakers. Perception continues to be direct, but considerable computation is involved in determining the conditions over which the "information" contained in the sound remains invariant. We do not naively assume that the fireplace generates the sound. Despite the directness of the perception, it can be superficially misleading as to the actual characteristics of the physical universe.

The issues appear to be these. Gibson abhors the concept "image." As already noted, he emphasizes the "information" which the environment "affords" the organism. As an ecological theorist, however, Gibson recognizes the importance of the organism in determining what is afforded. He details especially the role of movement and the temporal organization of the organism-environment relationship that results. Still, that organization does not consist of the construction of percepts from their elements; rather the process is one of responding to the invariances in that relationship. Thus perceptual learning involves progressive differentiation of such invariances, not the association of sensory elements.

The problem for me has been that I agree with all of the positive contributions to conceptualization which Gibson has made, yet find myself in disagreement with his negative views (such as on "images") and his ultimate philosophical position. If indeed the organism plays such a major role in the theory of ecological perception, does not this entail a constructional position? Gibson's answer is no, but perhaps this is due to the fact that he (in company with so many other psychologists) is basically uninterested in what goes on inside the organism.

What then does go on in the perceptual systems that is relevant to this argument? I believe that to answer this question we need to analyze what is ordinarily meant by "image." Different disciplines have very different definitions of this term.

The situation is similar to that which obtained in neurology for almost a century with regard to the representation we call "motor." In that instance the issue was stated in terms of whether the representation in the motor cortex was punctate or whether in fact movements were represented. A great number of experiments were done. Many of them using anatomical and discrete electrical stimulation techniques showed an exquisitely detailed anatomical mapping between cortical points and muscles and even parts of muscles (Chang, Ruch, & Ward, 1947). The well-known homunculus issued from such studies on man (Penfield & Boldrey, 1937).

But other, more physiologically oriented experiments provided different results. In these it was shown that the same electrical stimulation at the same cortical locus would produce *different* movements depending on such other factors as position of the limb, the density of stimulation, the state of the organism (his respiratory rate, etc.). For the most part, one could conceptualize the results as showing that the cortical representation consisted of movements centered on one or another joint (e.g., Phillips, 1965). The controversy was thus engaged proponents of punctate muscle representation vis-à-vis the proponents of the representation of movement.

I decided to repeat some of the classical experiments in order to see for myself which view to espouse (reviewed in Pribram, 1971, Chapters 12 and 13). Among the experiments performed was one in which the motor cortex was removed (unilaterally and bilaterally) in monkeys who had been trained to open a rather complex latch box to obtain a peanut reward (Pribram, Kruger, Robinson, & Berman, 1955-1956). My results in this experiment were, as in all others, the replication of the findings of my predecessors. The latch box was opened, but with considerable clumsiness, thus prolonging the time taken some two- to threefold.

But the interesting part of the study consisted in taking cinematographic pictures of the monkeys' hands while performing the latch-box task and in their daily movements about the cage. Showing these films in slow motion we were able to establish to our satisfaction that no movement or even sequence of movements was specifically impaired by the motor cortex resections! The deficit appeared to be *task* specific, not muscle or movement specific.

My conclusion was therefore that, depending on the *level of analysis*, one could speak of the motor representation in the cortex in three ways. Anatomically, the representation was punctate and of *muscles*. Physiologically, the representation consisted of mapping the muscle representation into *movements*, most likely around joints as anchor points. But behavioral analysis showed that these views of the representation were incomplete. No muscles were paralyzed,

no movements precluded by total resection of the representation. *Action*, defined as the environmental consequence of movements, was what suffered when motor cortex was removed.

The realization that acts, not just movements or muscles, were represented in the motor systems of the brain accounted for the persistent puzzle of motor equivalences. We all know that we can, though perhaps clumsily, write with our left hands, our teeth, or, if necessary, our toes. These muscle systems may never have been exercised to perform such tasks, yet immediately and without practice can accomplish at least the rudiment required. In a similar fashion, birds will build nests from a variety of materials, and the resulting structure is always a habitable facsimile of a nest.

The problem immediately arose of course as to the precise nature of a representation of an act. Obviously there is no "image" of an action to be found in the brain if by "image" one means specific words or the recognizable configuration of nests. Yet some sort of representation appears to be engaged that allows the generation of words and nests—an image of what is to be achieved, as it were.

The precise composition of images-of-achievement remained a puzzle for many years. The resolution of the problem came from experiments by Bernstein (1967) who made cinematographic records of people hammering nails and performing similar more or less repetitive acts. The films were taken against black backgrounds with the subjects dressed in black leotards. Only joints were made visible by placing white dots over them.

The resulting record was a continuous wave form. Bernstein performed a Fourier analysis on these wave forms and was invariably able to predict within a few centimeters the amplitude of the next in the series of movements.

The suggestion from Bernstein's analysis is that a Fourier analysis of the invariant components of motor patterns (and their change over time) is computable and that an image-of-achievement may consist of such computation. Electrophysiological data from unit recordings obtained from the motor cortex have provided preliminary evidence that, in fact, such computations are performed (Evarts, 1967, 1968).

By "motor image" therefore we mean a punctate muscle-brain connectivity that is mapped into movements over joints in order to process environmental invariants generated by or resulting from those movements. This three-level definition of the motor representation can be helpful in resolving the problems that have become associated with the term "image" in perceptual systems.

In vision, audition, and somesthesia (and perhaps to some extent in the chemical senses as well) there is a punctate connectivity between receptor surface and cortical representation. This anatomical relationship serves as an *array* over which sensory signals are relayed. At a physiological level of analysis, however, a mapping of the punctate elements of the array into functions occurs. This is accomplished in part by convergences and divergences of pathways but

even more powerfully by networks of lateral interconnectivities, most of which operate by way of slow graded dendritic potentials rather than by nerve impulses propagated in long axons. Thus in the retina, for instance, no nerve impulses can be recorded from receptors, bipolar or horizontal cells. It is only in the ganglion cell layer, the last stage of retinal processing, that nerve impulses are generated to be conducted in the optic nerve to the brain (reviewed by Pribram, 1971, Chapters 1, 6, and 8). These lateral networks of neurons operating by means of slow graded potentials thus map the punctate receptor-brain connectivities into functional *ambiences*.

By analogy to the motor system, this characterization of the perceptual process is incomplete. Behavioral analysis discerns perceptual constancies just as this level had to account for motor equivalences. In short, *invariances* are processed over time and these invariances constitute the behaviorally derived aspects of the representation (e.g., Pribram, 1974b). Ordinarily, an organism's representational processes are called *images* and there is no good reason not to use this term. But it must be clearly kept in mind that the perceptual image, just as the motor image, is more akin to a computation than to a photograph.

We have already presented the evidence that for the visual system at least, this computation (just as in the motor system) is most readily accomplished in the Fourier or some similar domain. The evidence that pattern perception depends on the processing of spatial frequencies has been reviewed. It is, after all, this evidence more than any other that has suggested the holonomic hypothesis of perception.

The perceptual image, so defined, is therefore a representation, a mechanism based on the precise anatomical punctate receptor-cortical connectivity that composes an *array*. This array is operated upon by lateral interconnections that provide the *ambiences* which process the *invariances* in the organism's input. The cortical representation of the percepts go therefore beyond the anatomical representations of the receptor surfaces just as the cortical representation of actions goes beyond the mere anatomical representations of muscles.

It is, of course, a well-known tenet of Gestalt psychology that the percept is not equivalent of the retinal (or other receptor) image. This tenet is based on the facts of constancy (e.g., size) and the observations of illusions. Neurophysiologists, however, have only recently begun to seriously investigate this problem. Thus Horn (Horn, Stechler, & Hill, 1972) showed that certain cells in the brainstem (superior colliculus) maintained their firing pattern to an environmental stimulus despite changes in body orientation; and in my laboratory Spinelli (1970) and also Bridgeman (1972) using somewhat different techniques demonstrated constancy in the firing pattern of cortical neurons over a range of body and environmental manipulations. Further, neurobehavioral studies have shown that size constancy is impaired when perivisual and inferior temporal cortex is removed (Humphrey & Weiskrantz, 1969; Ungerleider, 1975).

The fact that the cortex becomes tuned to environmental invariances rather than just to the retinal image is borne out dramatically by a hitherto unex-

plained discrepancy in the results of two experiments. In both experiments a successful attempt was made to modify the orientation selectivity of the cortical neurons of cats by raising them from birth in environments restricted to either horizontal or vertical stripes. In one experiment (Blakemore, 1974) the kittens were raised in a large cylinder appropriately striped. A collar prevented the animals from seeing parts of their bodies—so they were exposed to only the stripes. However, and this turns out to be critical, the kittens could observe the stripes from a variety of head and eye positions. In contrast, in the other experiment, which was performed in my laboratory (Hirsch & Spinelli, 1970), head and eye turning was prevented from influencing the experiment by tightly fitting goggles onto which the stripes were painted. In both experiments cortical neurons were found to be predominantly tuned to the horizontal or vertical depending on the kittens' environment, although the tuning in Blakemore's experiments appeared to be somewhat more effective. The discrepancy arose when behavioral testing was instituted. Blakemore's kittens were consistently and completely deficient in their ability to follow a bar moving perpendicular to the orientation of the horizontally or vertically striped environment in which they had been raised. In our experiment Hirsch, despite years of effort using a great number of quantitative tests, could never demonstrate any change in visual behavior! The tuning of the cortical cells to the environmental situation which remained invariant across transformations of head and eye turning was behaviorally effective; the tuning of cortical cells to consistent retinal stimulation had no behavioral consequences.

These results are consonant with others obtained in other sensory modes and also help to provide some understanding of how brain processing achieves our perception of an objective world separated from the receptor surfaces which interface the organism with his environment.

Von Békésy (1967) has performed a large series of experiments on both auditory and somatosensory perceptions to clarify the conditions that produce projection and other perceptual effects. For example, he has shown that a series of vibrators placed on the forearm produce a point perception when the phases of the vibrations are appropriately adjusted. Once again, in our laboratory we found that the cortical response to the type of somatosensory stimulation used by von Békésy was consonant with the perception, not with the pattern of physical stimulation of the receptor surface (Dewson, 1964; Lynch, 1971). Further, von Békésy showed that when such vibrators are applied to both forearms, and the subject wears them for awhile, the point perception suddenly leaps into the space between the arms.

Other evidence for projection comes from the clinic. An amputated leg can still be perceived as a phantom for years after it has been severed and pickled in a pathologist's jar. A more ordinary experience comes daily to artisans and surgeons who "feel" the environment at the ends of their tools and instruments.

When validation is lacking or incomplete, we tend to call the perception an illusion and pursue a search for what physical events may be responsible for the

illusion. Gibson and his followers are correct, perception is direct. They are wrong if and when they think that this means that a constructional brain process is ruled out or that the percept invariably and directly gives evidence of the physical organization that gives rise to perception.

As noted, there is altogether too much evidence in support of a brain constructional theory of perception. The holonomic model, because of its inclusion of parallel processing and wave interference characteristics readily handles the data of projection and illusion that make up the evidence for direct perception. The holonomic model also accounts for the "directness" of the perception; holographic images are not located at the holographic plane, but in front or beyond it, away from the constructional apparatus and more into the apparently "real," consensually validatable external world.

### STRUCTURE AND PROBABILITY

In the concluding part of this chapter, I want, therefore, to explore some questions as to the organization of this external "real" 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. The science of physics has enjoyed unprecedented success not only in this century, but in the several preceding ones. Physicists ought to know something, therefore, about the universe we perceive; and, of course, they do. 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 as 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 for 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, that is, 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 neighboring 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 Schrödinger, 1935, and de Broglie, 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, Leighton, and Sands (1965), for instances, note 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!) De Broglie (1964), who first proposed wavelike characteristics for the electron fails to find solace in a probabalistic explanation of the experimental results that led him to make the proposal. And de Broglie is joined by Schrödinger (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—that is, 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 quasi-quantal 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 inquiry 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 of 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 quantumly, 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 postsynaptic 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 organization implicate. Elsewhere (Pribram, 1971), 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's, however, in suggesting that intrinsic properties (e.g., which he defines as the stoneness of stones) 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 programs, 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. Russell 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 *knowhow* to replicate.

The sum of these ideas leads to the proposal that the intrinsic properties of the physical universe, their implicate organization, the field, ground or medium in which explicit organizations, extrinsic properties, become realized, are multi-form. 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 reevaluation 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.

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