Physics and Mind

MINDING QUANTA AND COSMOLOGY

by Karl H. Pribram

Abstract. The revolution in science inaugurated by quantum physics has made us aware of the role of observation in the construction of data. Eugene Wigner remarked that in quantum physics we no longer have observables (invariants), only observations. Tongue in cheek, I asked him whether that meant that quantum physics is really psychology, expecting a gruff reply to my sassiness. Instead, Wigner beamed understanding and replied "Yes, yes, that's exactly correct." David Bohm pointed out that were we to look at the cosmos without the lenses of our telescopes we would see a hologram. I extend Bohm's insight to the lens in the optics of the eye. The receptor processes of the ear and skin work in a similar fashion. Without these lenses and lenslike operations all of our perceptions would be entangled as in a hologram. Furthermore, the retina absorbs quanta of radiation so that quantum physics uses the very perceptions that become formed by it. In turn, higher-order brain systems send signals to the sensory receptors so that what we perceive is often as much a result of earlier rather than just immediate experience. This influence from inside out becomes especially relevant to our interpretation of how we experience the contents and bounds of cosmology that come to us by way of radiation.

Keywords: Big Bang theory; brain systems; central control of receptors; conformal rescaling; cosmology; efficient and formal causation; Fourier transformation; holography; observation; perception; quantum physics; radiation; sensory receptors; wavelets; windowed Fourier transformations

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The revolution in science inaugurated by quantum physics made us aware, as never before, of the role of observation and measurement in the construction of data. A personal experience illuminates the extent of this revolution. Eugene Wigner remarked that in quantum physics we no longer have observables (invariants) but only observations. Tongue in cheek, I asked whether that meant that quantum physics is really psychology, expecting a gruff reply to my sassiness. Instead, Wigner beamed a happy smile of understanding and replied "Yes, yes, that's exactly correct." In a sense, therefore, if one takes the reductive path in science one ends up with psychology, not particles of matter.

Another clue to this turning of reductive science on its head is that theoretical physics is, in some nontrivial sense, a set of aesthetically beautiful mathematical formulations that are looking for confirmation (see Chapline 1999).

At a somewhat more conservative level, Henry Stapp ([1972] 1997) has eloquently reviewed the history of how the founders of quantum physics (for example, Niels Bohr, Werner Heisenberg, John von Neumann) dealt with the then newly realized importance of the "how" of our observations to an understanding of the composition of matter. Stapp has added his own views on how these innovations in thinking affect our understanding of the mind/matter interface.

Here I pursue a different take on the issue: Coming from the vantage of brain science, how can we better understand some of the puzzles that have plagued quantum theory and observation to the point of weirdness? Furthermore, how important are the prejudices of our *Zeitgeist* in interpreting our cosmological views? My hope is that by pursuing the course outlined here, weirdness and prejudice will to a large extent become resolved.

Observing Quanta

David Bohm (1973) pointed out that were we to look at the cosmos without the lenses of our telescopes, we would see a hologram. Holograms were the mathematical invention of Dennis Gabor (1948), who developed them in order to increase the resolving power of electron microscopy. Emmet Leith (Leith and Upatnicks 1965) developed the hologram for laser light photography, a development that has overshadowed in popularity the mathematical origin of the invention. Holography is based on taking a space-time image and spreading it (the transformation rule is called a spread function; the Fourier transformation is the one used by Gabor) over the extent of the recording medium. Thus, the parts of the image become wholly enfolded with each other and the whole becomes totally enfolded in each part.

I have extended Bohm's insight of the importance of lenses in creating a space-time image to the lens in the optics of the eye (Pribram 1991): The receptor mechanisms of the ear, the skin, and probably even the nose and tongue work in a similar fashion. Without these lenses and lenslike operations all of our perceptions would be enfolded as in a hologram. In optics, a very small aperture of the pupil produces the same transformation as a lens does. When the pupil is chemically dilated, as during an eye examination, focus is lost and the experienced vision becomes blurred. However, if a pinhole or slit in a piece of cardboard is placed in front of the dilated eye, ordinary vision is restored. One can accomplish an approximation of this by tightly curling one's index finger producing a slit.

In experiments during which we map the receptive fields of cells in the brain we drift dots or slitlike lines and edges in front of a stationary eye. In my laboratory we used dots, single lines, double lines, and gratings and found differences in the recorded receptive fields when more than one dot or line was used. The differences resulted from interactions produced in the visual system of the brain when the stimulating dots or lines moved together against a random background (Figure 1).

I propose that the difference in the observation of interference effects (an enfolded holographic record) in the two-slit experiment versus the observation of an object (particle) in the single-slit experiment results from the difference in the measurement apparatus. This, of course, is not a new proposal; it is the essence of the argument made initially by Bohr and accepted by quantum physicists for almost a century. What I am adding is that the measuring apparatus, the slits, are mimicking the biology of how we ordinarily observe the world we live in. There is no weird quantum effect unique to that scale of observation.

The Brain's Role in the Making of Observations. In turn, the observations made in quantum physics are relevant to how we perceive our world. The retina of the eye has been shown to absorb a single quantum of photic energy—that is, the retina has a resolving power such that it consists of pixels of single-quantum dimension. Yakir Ahranov has developed an experimental paradigm for quantum physics that he calls weak measurement (Ahranov and Rhorlick 2005). Weak measurement does not disturb what

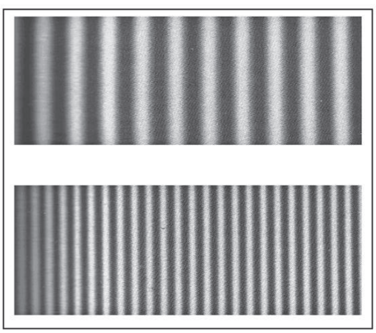

Fig. 1. Gratings.

is being observed. Essentially, the technique consists of repeated measurements composed of two vectors: a "history" vector determined by past events and a "destiny" vector determined by events that occur in the future of the time any single weak measurement is obtained. This apparently startling procedure is similar to the one used in nonlinear dynamics (complexity theory) that traces the vectors that develop what have been called attractors over repeated observations of paths *toward* stabilities far from equilibrium. Point attractors and periodic attractors are two simple examples of such stabilities.

Research in my laboratory established functional pathways that connect higher-order cortical systems to the retina. Eight percent of the fibers in the optic nerve are efferent to the retina, and these fibers are able to change retinal processing about twenty percent of the time. The control of the retina occurs within the time that retinal processing of optical input occurs. Thus, whenever there is a repetition of a sequence of optic inputs, a second vector "anticipating" that input is operative. Just as in quantum physics, attractors—contextual futures—determine our visual perceptions. What is true of vision also has been shown to be true for hearing, tactile and kinesthetic perceptions, and the perception of flavors.

Thus the laws of physics, especially of quantum physics, have their complement in the laws of human perception. The laws of quantum physics have been shown to be dependent on the constraints imposed by the instruments of observation. The laws of human perception have been shown to be dependent on the constraints imposed by processes such as attention, intention, and thought organized by the observer's brain. To complete the hermeneutic cycle, observations in physics are made by humans whose observations are dependent on their brains.

Meaning from Inside Out. Patrick Heelan (2009), in the companion essay in this issue of *Zygon*, discusses at length the transition of scientific, philosophical, and religious thought from perceiving an "out there" to an intentional view of a meaningful reality. Heelan indicates that this transition comes by way of the hermeneutic process that stems from individual encounters in the world we navigate. This view is considerably more sophisticated than the currently accepted way of describing the organization of brain function and of communication in terms of information processing.

The popularity of information-processing language has two sources. One is that when speaking of information most people mean *meaningful* information. The other comes from communication theory and its use in telephony and computer science. Claude Shannon defined information as the "reduction of uncertainty" and sharply separated this definition from the definition of meaning. The usefulness of Shannon's definition has given *information* an aura of respectability that has been assimilated by the undefined use of the term *information processing*. Actually, the more appropriate term would be the processing of meaning, but then we would need a scientifically useful, that is, testable, definition of meaning.

A good beginning can be made with Charles Sanders Peirce's definition (1974) in which he notes that what I mean by meaning is what I mean to do. Coming from one of the founders of pragmatism this is hardly surprising. But in keeping with the phenomenological approach to meaning detailed by Heelan, I would add: What I mean by meaning is what I intend to do *and what I intend to experience.*

These are good beginnings, but they do not provide us with the useful laboratory-testable procedures that make the concept of meaning as transparent as Shannon's (and Gabor's) concept of information. In order to provide such a transparent concept we need to take a detour to define a context for Shannon's definition of information and then show the shortcomings of his definition for human (and primate) communication. Finally, we need to describe an experimental result that provides at least one definition of meaning.

This detour is relevant to our interpretation of quanta and cosmology. For decades, quantum physicists were divided as to the best representation of quantum phenomena. As noted in Heelan's essay, Erwin Schrödinger, Louis DeBroglie, and Albert Einstein opted for the wave equation while Heisenberg, Bohr, and his Copenhagen adherents opted for a vector representation of quantum "reality." I recently published a paper (Pribram et al. 2004) in which the results of microelectrode analysis of brain processes was shown in terms of both wave functions and vectors. I recapitulated the quantum physicists' arguments: The wave representation is more "physical," more "*anschaulich*"; the vector representation is more abstract and therefore can be more easily applied over a range of experimental results. What both Heelan and I are proposing is a way of conceptualizing the brain/mind relationship (or, better stated, the person/experience relationship) that is derived from, and in turn motivates, our understanding of quantum physics.

The Holographic Process. The precision of our understanding is today best formulated in mathematical concepts. The root problem in coming to grips with the person/experience relationship, the brain/mind transaction, is that at first blush brain is material, matter, while what we experience is different. We can eat brains but not our experience. The current way scientists deal with experience is in terms of communication and computation, in terms of information processing. But any more human or experiential approach to the issue finds information processing barren. Additionally, as noted, the manner in which scientists use information processing is itself largely unscientific.

These limitations of understanding brain and mind, person and experience, need not be so. Careful attention to what philosophers have had to offer since René Descartes, what the science of radiation (heat and light) has shown, and what psychologists and communication sciences have developed can provide a transparent set of concepts that go a long way toward "resolving" this apparently intractable problem.

The formation of attractors during our experiencing of the world we navigate (and in performing experiments) is a complex dynamic process. In order to examine aspects of this process in detail, sections (Poincaré sections), or slices, can be taken at any "moment" to display this complexity. One such momentary display is the holographic experience. It is useful to understand at the outset that holograms are examples of the spectral domain. Spectra consist of fluctuations (flux), oscillations, and their interactions, measured as interference patterns where fluctuations intersect to reinforce or cancel.

Experiencing a holographic process at the macroscopic scale is just as weird as any observation made in quantum physics. My classroom demonstration always evokes disbelief. I take an ordinary slide projector and show a slide (a pastoral scene, for example). I then take the lens of the projector away, and, as predicted by Bohm, all one sees is a fuzzy cone of light containing no discernible image. Then I take a pair of reading glasses and hold them in front of the projector at just the right distance. Voila! Wherever and whenever the lenses focus the light, the image on the slide (the pastoral scene) appears. Taking two pairs of spectacles, I demonstrate four images—and continue to show images anywhere there is light.

In experiments performed in quantum physics, a pinhole or single slit is the equivalent of the lens in the classroom experiment. At the quantum scale, replace the pastoral scene with a particle. The particle's holographic form (its complex conjugate) becomes exposed by means of double or multiple slits (gratings). The "scenic" particle is now spread *everywhen and everywhere.*

This holographic form of holism is not to be confused with the hierarchical form in which the whole is greater than and different from the part. Hierarchical relations are found everywhere in biology and in the behavioral sciences. The holographic form of holism has come into science fairly recently. The spectral aspects of quantum physics and the procedures used in functional Magnetic Resonance Imaging (fMRI) and in digital cameras are examples. However, in optics, interference effects have been studied since Christian Huygens, though their importance to our understanding of brain and cosmos had to await the insights of the twentieth century.

The Fourier Relationship. Gabor's invention of the hologram rested on the Fourier transformation that relates space and time reciprocally to the spectral domain. I have claimed that this relationship is essential to understanding some aspects of brain function such as processing sensory input and memory. Specifically, the mathematical formulation states that any space-time pattern can be transformed into the spectral domain characterized by a set of waveforms that encode amplitude, frequency, and phase. Inverting the transform realizes the original space-time configuration. The transform domain is spectral, not just frequency, because Fourier used a trick that encodes both the cosine and sine of a waveform allowing the interference between the 90-degree phase separation of the waveforms to be encoded discretely as a coefficient.

The advantage gained by transforming into the spectral domain is that a great variety of transformed patterns can be readily convolved with each other (multiplied) so that by performing the inverse transform all the space-time patterns become correlated. This advantage is utilized in quantum holography, which I have called Holonomy. Quantum holography, originated by Gabor, is based on a windowed Fourier transformation (discussed in the next section). George Chapline in an article titled "Entangled states, holography, and quantum surfaces" argues that the simplest way to encode "objects—may be as multi-qubit entangled states" (2002, 809). Image processing as in tomography such as PET scans and fMRI as well as in digital photography are prime examples of the utility of such encoding.

The Fourier transform accomplishes the spread of space-time observables by taking the space-time image and converting it into a complex conjugate based on the interference among waveforms. The peak of each waveform is moved 90 degrees upon itself and thus treated as having both a cosine and a sine component. Fourier arrived at this analytic trick by treating a wave not as extended over space and time but as a circular recurrence much as we do when we place the extent of daily time onto an analogue clock face. Once treated as a circle, any point on that circle can be determined by triangulating its sine and cosine value. Essentially this is equivalent to determining a value for the amplitude of any point on the waveform.

The Fourier transform (and other such orthogonal functions) make it possible to reformulate any pattern observed in space and time into sets of wave forms that differ in frequency, amplitude, and phase relations among them. The utility of the Fourier transform has been noted by Richard Feynman, who declared that Fourier's theorem is probably the most far reaching principle of mathematical physics (Feynman, Leighton, and Sands 1963). The diagram on the following page (Figure 2) portrays this principle and some of the theoretical/philosophical insights it affords.

The diagram has two axes, a top-down and a left-right. The top-down axis distinguishes change from inertia. Change is defined in terms of energy and entropy. Energy is measured as the amount of work necessary to change a structured system, and entropy is a measure of how efficiently that change is brought about. Shannon (Shannon and Weaver 1949, 117), Leon Brillouin (1962), and Donald MacKay (1969) all discussed the relation between measures of efficiency (that is, entropy and negentropy) and measures of information. However, these authors came to somewhat different conclusions: Shannon equated the amount of information with the amount of entropy, Mackay and Brillouin with the amount of negentropy.

A conciliation of these views can be achieved by relating the mathematical *form* of measures of entropy to the mathematical *form* of potential information. The reasoning is similar to that which motivated Shannon. He called the structure, that is, the medium, within which information processing occurs *uncertainty*. It is this structure that allows for information to be defined as producing a reduction of uncertainty. Thus the amount of uncertainty is equivalent to the amount of potential that the information can reduce. (For elaboration see Pribram 1991, 39–43.)

Having defined *in-formation* as an *active change in form, a change within structure*, we can think of the bottom half of the Fourier relationship as follows: *moment(um)* is defined as the *unchanging velocity of an unperturbed form*. The Fourier transformation of momentum is expressed in the unchanging, inertial spatial (and temporal) location of its form, that is, in the form of matter. Matter can thus be thought of, literally, as an *ex-formation.*

We now turn to the left-right axis of the Fourier diagram that distinguishes between measurements made in the spectral domain and those made in space-time. Spectra consist of fluctuations (flux), oscillations, and their interactions, measured as interference patterns where fluctuations intersect to reinforce or cancel. Holograms are examples of the spectral domain. *Lenses* bridge the left-to-right axis of the Fourier transformation. When transformed into space-time, the spectral patterns become profiles of illuminated objects (for instance particles).

The Fourier relation provides a precise understanding of an epistemology of the mind/brain, the person/experience relationship. This is not the whole story, however.

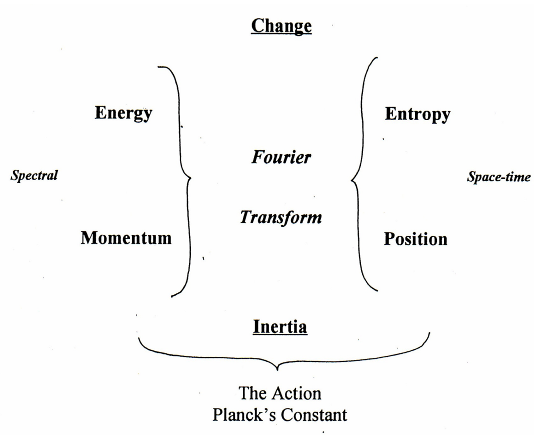

Fig. 2. The wave/particle dichotomy is orthogonal to the above distinction.

The Gabor Function. When I discussed with Gabor the idea that the brain process in (visual) perception used the Fourier transformation, his response was "Almost but not quite." Over the next decade experiments performed in many laboratories including mine showed that the receptive dendritic fields of cells in the visual cortex encoded what we now call *windowed Fourier transformations*. The Fourier process itself extends to infinity. Brain receptive fields are limited in extent, both spatially and in their processing time. It turns out that Norbert Wiener and Gabor had discussed the windowed Fourier process during the 1940s. Gabor had been interested in the efficiency with which telephone messages could be sent across the Atlantic cable, what might be the maximum compressibility that could be achieved. Using the mathematics of quantum physics (a Hilbert space), Gabor came up with a unit he called *a quantum of information*. This unit varied with the frequency voiced in the communication. Gabor noted that he had specified the limit beyond which the communication became "uncertain," much as Heisenberg had shown in quantum physics. Also, Gabor related his minimum to Shannon's measure of information as the reduction in uncertainty (Figure 3).

During the exciting period of the 1970s we had, therefore, established a convergence of precise mathematical descriptions of receptive fields in the cortex of the brain with the units of communication and with the discoveries in quantum physics. Although the Fourier diagram made possible a precise way of dealing with the relationship of thought (mind) and matter, the convergence of measures of information as they were found to apply to communication, brain organization, and quantum physics indicated that ontologically the fundamental composition of mind and matter is unitary.

Meaning Revisited. In the late 1950s I designed an experiment using monkeys to test Shannon's information-measurement theory. I planned to see which part of the brain is involved in our ability to choose among

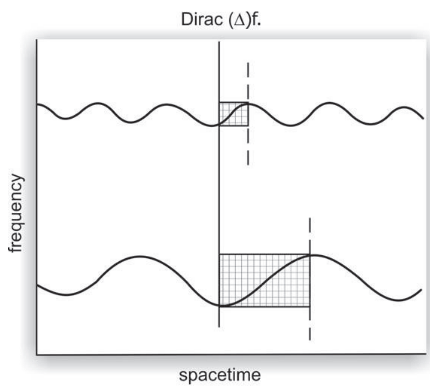

Fig. 3. Logons, Gabor Elementary Functions: Quanta of Information.

alternatives—the number of alternatives specified by the amount of "uncertainty" presented to the monkey in each choice. My plan was to set up a board that had twelve holes, each large enough to hold a peanut. I went to the dime store and picked up twelve junk objects just large enough to cover the holes. I wanted to test the monkeys' ability to find a peanut hidden under one of the objects, given a display of two, three, four, or more objects from which to choose. The idea was simple: The more objects (alternatives, uncertainty), the more trials (or the longer) it would take the monkey to find the peanut.

No one had tried to work with monkeys using a large number of simultaneously displayed choices. In preliminary tests I found that untrained monkeys simply refused to work with large displays, given so much uncertainty, such a paltry chance of finding a peanut. I had to train the monkeys by starting with a choice between two objects and working up to twelve. Two years of testing twelve monkeys, four hours each day, in what came to be called the multiple-choice experiment, provided some unexpected results: When there were fewer than four cues to choose from, the monkeys behaved differently than they did when there were more than four cues. The cutoff point at four indicates that animals (and humans) can almost immediately tell whether there are one, two, or three alternatives to be considered. This ability is called *subatizing*. With more than four alternatives, a search becomes necessary.

Rather than searching randomly—as would have been ideal for my experiment if I had been able to vary the order in which I presented different numbers of objects—the monkeys learned the sequence I used to place the peanut. Thus, for them, the choice among twelve cues was no longer quantitatively twelve times as difficult as the choice between two. For the monkeys the problem had become something very different from the one that I had set out to test.

This experiment was intended to examine the effects of restricted removals of different areas of the brain cortex on their information-processing ability. I used four monkeys for each area removed and found that removal of one specific brain area, the inferior temporal cortex, and no others, changed the way the monkeys searched for the peanut. I was puzzled by the result: The control monkeys took progressively more search trials as the experiment proceeded—but not in the way information-measurement theory had predicted. Even more puzzling, the monkeys with removals of the inferior temporal cortex actually did better than the unoperated and operated control monkeys during the early parts of the experiment, a result opposite to any that I or anyone else had found before.

As is my custom when I cannot understand an experimental result, I presented these findings (along with others that I did understand) in talks given on various occasions, and asked the audience whether anyone had an explanation. On one of these occasions, at Dartmouth, a young professor, Bert Greene, made a suggestion that could be tested by reanalyzing the data. Greene predicted that the animals with the brain operations differed in the way they sampled the displayed cues (that is, moved them to see whether there was a peanut in that well). His prediction was correct. Whereas normal monkeys tended to sample cues that had been rewarded previously, the monkeys with the brain operations sampled them randomly. The brain surgery had removed a memory process that the control monkeys used in making their choices.

I was able to show that mathematical sampling theory described quantitatively what was happening. Sampling theory predicted the change in behavior at the four-cue point in my experiment and fit the data obtained throughout. I had started to test information-measurement theory and ended up testing mathematical sampling theory instead!

From this multiple-choice experiment I learned something that other experimental psychologists were also learning at the time: If we are to measure "information" in terms of the reduction of uncertainty, we must know the subject's state of uncertainty. My monkeys responded to the alternatives, the available choices presented by the display, not as a straightforward series from two to twelve but as an array to be sampled in which previous responses were remembered. As Ross Ashby, a pioneer cybernetician, noted (in a personal communication), we learned that information-measurement theory was a superb instrument for framing issues but not helpful when the subject in an experiment was working within a context not accessible to the experimenter.

What Is Being Sampled. In another, somewhat simpler experiment, I taught two groups of monkeys, four in each group, to choose one of two objects: a tobacco tin and an ashtray. From one group of monkeys the inferior temporal cortex had been removed from both hemispheres of their brains; the other group of control subjects had not been operated on. Monkeys with the cortical removals took somewhat longer to learn to make such a choice—for example, to choose the ashtray—when compared to the number of trials it takes normal animals to learn to make that choice.

After the monkeys had learned to make the choice, I changed the situation in which the choice had to be made. Now, I placed either the ashtray or the tobacco tin in a central place between two wells covered with identical lids. The task for the monkeys was to find the peanut. The peanut was always in the well on their right in the presence of an ashtray and in the well on their left when a tobacco tin was present. This was a difficult task for the normal group of monkeys to learn—it took them about 500 trials. The monkeys who had had the cortex of the inferior temporal lobe removed failed to learn to make the correct choice in several thousand trials.

To assure myself that the monkeys who were failing were still able to tell the difference between the ashtray and the tobacco tin, from time to time

I inserted ten trials of the original task, where both ashtray and tobacco tin were present during the opportunity for choice. Invariably, all monkeys made the choice that they had learned earlier on all ten trials. The failure on the new and difficult task was not in perceiving a difference between the stimuli but in comprehending the new, more complex situation in which the choice had to be made. The lesson for me was that, in consonance with Heelan's views, it is not only specific sensory stimuli but the meaning that is given to those stimuli by the relevant context that is formed by what we experience and do while navigating our world.

The Brain's Role in the Making of Theories. Brain science can contribute even more to our understanding of quantum theory. Two observations are relevant. First, the procedure of working from theory to experiment is what minding quanta and cosmology is all about. Our brain is central to this endeavor. Rodolfo Llinas in *The I of the Vortex* (2001) develops the theme that the whole purpose of having a brain is to anticipate a useful choice on the basis of past experience—the essence of a well-developed theory. Second, brain dynamics allows conscious experiences (musings) to be momentarily superfluous to making choices; because of this delay these experiences can become aesthetically elegant. Einstein's often-quoted remark that theory must first be beautiful to be true (before its full value can be experimentally fulfilled) is a case in point.

Stapp encapsulates these two observations:

> . . . body/brain processes generate possibilities that correspond to possible experiences, and then [as we navigate our world] nature selects, in accordance with the basic quantum statistical rule, one of these possible experiences, and actualizes it, and its body/brain counterpart.—this means that our experiences are not only the basic realities of the theory and the link to science—but also [that they] play a key role in specifying the "set of allowable possibilities" that . . . [compose] mind/brain events. (1997, 181–82)

(Recall the correspondence between statistical, used by Stapp, and spectral representations to bring his comments into register with this essay.)

QUANTUM WEIRDNESS

The conceptualizations that have characterized quantum physics for almost a century have struck scientists as bizarre and weird. When taken within the framework of "minding quanta" as detailed in this essay, the weirdness can be dispelled to a large extent.

First, the hologram, embodying the spectral domain at the classical scale, is just as weird as is the entanglement observed at the quantum scale. (Probability amplitudes remain specific to the quantum scale but are currently under attack by Basil Hiley in an extension of Bohm's approach to quantum phenomena).

Second, because quantum phenomena are expressed in terms of a Hilbert space defined by both spectral and space-time coordinates, verbal interpretation often seesaws between these axes. Language has a tendency to reify, make "things" out of processes. This can be useful, as in disciplines such as biochemistry when the juice squeezed out of the pituitary gland has effects on most of the other endocrine glands: The juice is assumed to be composed of a multiplicity of substances—things—each having a specific target in one of the other glands. And indeed this is what was found.

But reification has drawbacks when the labels used to "thingify" do not properly correspond to the process being labeled. My first encounter with this issue was when we recorded a direct sensory input from the sciatic nerve to the "motor" cortex of the brain. According to the dictum of separation of input from output as in the reflex arc of the spinal cord (known as the Law of Bell and Magendie), the motor cortex should have no direct sensory input. I contacted two of the most active and respected scientists working in the field, who replied, "Yes, we've seen this strange artifact over and over." But it wasn't an artifact, as my students and I showed. I removed all possible indirect sensory inputs (post central cortex and cerebellar hemispheres) without disrupting the response evoked by the sciatic stimulation. The designation "motor" had misled, and the reification of the Law of Bell and Magendie turned out to be erroneous even at the spinal reflex level. (The nervous system works much more like a thermostat, with a control wheel to change a setting, as developed in Miller, Galanter, and Pribram 1960; Pribram 1971).

When an enfolded system with space-time constraints, a Hilbert space, is being investigated, the temptation is overwhelming to reify the process in terms of the space and time constraints within which we ordinarily navigate. Take for instance the excellent book by George Greenstein and Arthur Zajonc, *The Quantum Challenge* (1997). They describe what are considered to be bizarre quantum phenomena: (1) a particle can pass through two slits at the same time; (2) measurements can never be perfectly accurate but are beset by a fundamental uncertainty; and (3) the very concept of cause and effect must be rethought.

Their first chapter tackles the two-slit issue. The authors carefully describe matter waves and DeBroglie's description of a quantum particle in terms of wave forms. They note that the quantum treatment deals primarily with waves rather than particles. Indeed the very word *particle* plays little part in the discussion. The concept comes in only when psi is used as a measure to discern the probability of finding the particle at a given point in space. As noted above, the "wave" and statistical description are to a large extent interchangeable. Here the "particle" is not a thing, not an "it," but a statistical possibility that can occur in two spatially separated slits at the same time. Equally important, the "wave" in the above quotation is really not a wave that occurs in space-time but a spectral pattern created by interference among waves. (Bohm had to chastise me on several occasions before I stopped thinking of waves and began to think in terms of spectra in this context.)

Greenstein and Zajonc come to the conclusion that if we take quantum mechanics seriously as making statements about the real world, the demands on our conventional thinking are enormous. At this point recall my claim that conventional thinking is prejudiced by lenses and the lenslike operations of our senses. They write that hidden behind the discrete and independent objects of the sense world is an entangled realm in which the simple notions of identity and locality no longer apply.

Since the early 1960s most of us have experienced in our own sense world the value of a method for attaining correlations—the Fast Fourier Transformation—and the value of the image-storing and -restoring powers of the holographic process. Examples of the use of quantum holography in image processing, as mentioned earlier, are tomography (PET scans and fMRI) and, more recently, the operations of digital cameras. This mathematical and engineering triumph, although available to us in the world we navigate, partakes of most of the "bizarre" attributes of quantum physics. For instance, when space-time is Fourier transformed into the spectral domain, there can be no cause and effect in the usual scientific sense. The Fourier transformation is a spread function that disperses space-time events that therefore no longer exist as such.

Scientists ordinarily seek what they call efficient causation, in which effect follows cause. In the holographic, enfolded domain, space and time disappear, so it is inappropriate to inquire as to "where" or "when" an efficient causal relation exists. The transformation from space-time to spectrum (and back again to space-time) is a change in form and thus falls under Aristotle's formal causation. In this respect Greenstein and Zajonc's admonition that "the very concept of cause and effect must be rethought" is honored.

A change in form, a trans-formation, in itself suggests that some uncertainty may inhere when an attempt is made to measure both spectral and space-time forms simultaneously. The world looks different when one's pupils are dilated—a sort of neutral zone between having a good pupil-lens system and having none. A good deal of uncertainty is involved when one tries to navigate the world in this condition. Greenstein and Zajonc's second bizarre phenomenon, that measurement can never be completely accurate, actually occurs in the ordinary world of communication as well, as developed by Gabor in his (1946) "quanta of information" (Figure 3).

An argument often has been made that transformations such as the Fourier are simply conveniences to be applied as needed to describe a particular phenomenon. This is not necessarily so. The transformations describe real-world measurements that cannot be arbitrarily assigned to one or another situation. In measuring Gabor-like (Hilbert space) processes in sensory receptive fields of the primate sensory cortex, my colleagues and I showed that electrical stimulation of the posterior part of the brain would shift the receptive field toward a space-time configuration while stimulation of the frontal part of the brain shifted the configuration toward the spectral domain. These changes occurred in the experienced space-time world we navigate, not in an arbitrary application of mathematical whim.

In short, weirdness is not restricted to the quantum scale of observation. Instantiation of the Fourier relationship in holography has demonstrated practically identical bizarre characteristics. Bringing that weirdness into our everyday experience makes it seem less weird. Greenstein and Zajonc summarize the issue succinctly with their statement that hidden behind the discrete and independent objects of the sense world is an entangled realm. At the scale in which we navigate our world is hidden a holographic universe in which are embedded the objects we perceive with our senses and actions. The enfolded realm spans all scales of inquiry from cosmic through brain processing to quantum fields and accounts for much of the weirdness encountered in attempted explanations of observations.

Cosmology

I began this essay with Bohm's observation that if we did not have telescopes and other lenslike means of observation the universe would appear to us as a hologram. Thus the laws of optics such as the Fourier relationship are relevant to these observations.

Bohm's insight implemented by the Fourier relation brings clarification not only at the quantum scale but also to cosmology. The medium that allows us to observe the cosmos is radiation. Background radiation has been given several names depending on the observed database upon which the name is given. Bohm called it a quantum potential; Harold Puttoff calls it zero point energy. In conversations with each of them they agreed that the structure of this background radiation is holographic. Currently, the terms *dark energy* and *dark matter* have surfaced as having to be measured and conceived in terms other than space and time. By analogy with potential and kinetic energy, I conceive of both of these "hidden" quantum and cosmological constructs as referring to a potential reality that lies behind the space-time experienced reality within which we ordinarily navigate.

In a 2008 Smithsonian presentation Roger Penrose revealed that by using his famous techniques of "conformal rescaling" he has reformulated what occurs at the horizons of our universe, with respect to both the Big Bang and its presumed ever-accelerating expansion. Instead of a big hot bang he uses the metaphor of a gentle rain falling upon a quiet lake, each drop making ripples that spread to intersect with other ripples made by other drops. The patterns recur at the expanding future boundary of the universe. These patterns are, of course, holographic. Penrose's fertile brain has made it possible for him to reformulate widely accepted dogma with an alternative more compatible with Buddhist and Hindu teachings than with the creationism of some Judeo-Christian and Islamic traditions. Important here is not whether one or another view of the cosmos is correct but that Penrose could use an intellectual brain-formed tool, conformal rescaling, to provide a cosmology totally different from a currently mainstream scientific conception.

NOTE

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