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The Holographic Hypothesis of Brain Function: A Meeting of Minds

The holographic principles which have emerged from science in the last twenty years, represent the first instance since the time of Galileo that a scientific discovery, in and of itself, has led to a closer relationship with man's spiritual nature. In the past, science was seen as something entirely separate from the spiritual nature of man, which was taken care of by the esoteric traditions—by religion and not science. Now, with a paradigm shift in our understanding, scientists are face to face with the same traditions that have motivated the peoples of the East, and that have influenced Western philosophy as well. As Fritjof Capra has pointed out, in the last fifty years many scientists, especially physical scientists, have become aware of a convergence between these theories and ideas expressed in the Vedas, and other Eastern sources.

Consciousness

What do we mean by consciousness? There are three rather different interpretations of the concept. The first refers to *states* of consciousness. If suddenly a cat walked in front of you, and I asked you, "Is the cat conscious?" you would say, "Of course, why do you ask?" Or if a surgeon comes into an examining room, finds a patient lying down, and pokes that person, who says, "Look, I am trying to get a little bit of sleep here. I have been up all night," you do not say that person is unconscious. You know he has been in a state of consciousness which we call an ordinary state of sleep. If, however, the doctor pokes and the patient just groans a few times and turns over, or if he pokes harder and nothing happens, the patient is in a stupor. If he does not respond at all, he is in a coma. The cat's awareness, or sleep, coma, or stupor are among the states of consciousness.

A second definition, in the Eastern tradition, is that mind and consciousness are extended. Consciousness is everywhere, and we happen to be particular instantiations, or precipitations out of this consciousness.

A third definition refers to the difference there may be between what people do or how they behave, and what they are aware, or conscious of doing. Someone who is hypnotized, for example, may be conscious of doing one thing while he or she is actually doing something else. This way of understanding consciousness is used in Western philosophy almost exclusively to mean a reflexive sort of consciousness, self consciousness, or the distinction between self and other. This distinction is called "intentionality" in philosophy and is based on the idea that we can tell our own awareness from that which we are aware of. It reflects the fact that we can know the difference between our intentions and our actions. In *The Origin of Consciousness in the Breakdown of the Bicameral Mind*, when author Julian Jaynes describes the change in consciousness which presumably took place between the *Iliad* and the *Odyssey*, he is referring to this kind of self-reflective consciousness. It is what we mean when we say we want to widen our consciousness, and include within our field of attention things that we have not been attending to.

These three ways of understanding consciousness are related. The first definition essentially determines what state we are in; the concept of extended consciousness found in Eastern philosophy involves the content of consciousness, or that which we are conscious of; and a third meaning, called attention or what we pay attention to, relates state to content. Attention is the process of consciousness which gives rise to self-reflection.

Holonomy

From these three definitions, I will turn to the notion of extended consciousness, the content of that consciousness which is not the ordinary one. This is related to our perception of reality—what is real, how we go about finding out what is real, and how we construct our realities in general. As you all know, we construct not one, but several realities for ourselves. Our perceptions may differ from our cognitions. For example, when the Copernican revolution took place, many people wondered if they had to hang on because the earth was round. They had, up to that time, perceived the earth as flat. Suddenly it was round and spinning, posing to people a danger of falling off. Christopher Columbus faced this problem with his crew, who were afraid that over the horizon, somewhere, they might drop off. One of my colleagues, James Gibson, who died last year, used to say, "You know, I really do not believe the world is round because I see it is flat." He was joking but, in a way, it is true that what we see and know can be quite different.

In the last twenty years we have discovered another reality, which is as slippery and strange as the idea that the earth is round, but which will eventually prove to be just as important. Mystics have been telling us we can experience from time to time a reality that has strange properties we do not appreciate in our ordinary, everyday perceptual state. I call this strange reality a *holonomic state*, a concept based on the invention of holography.

Implemented in the early 1960's, the hologram is an engineering device based on a mathematical invention by Dennis Gabor, who wanted to improve the resolution of electron microscopy. For this purpose, he developed a new technique of storing on film what was not the intensity of reflected light or transmitted light, but actually the square of the intensity and the relationship of a particular beam with its neighbors. It is called the complex conjugate of the intensity. If I drop a pebble into a pond, ripples emanate out from the place where the pebble was dropped. If I drop two pebbles, two sets of ripples form and these ripples interfere with each other. If I throw in a whole handful, there are many such ripples, and the pond is perturbed in a complex way that appears quite irregular. If I take a movie of someone throwing pebbles into a pond, and then play the movie backwards, I would find that I could reconstruct from this set of ripples the location and the actual image of the pebbles as they entered the water.

Gabor's invention, for which he received the Nobel prize, was to show mathematically how such a movie could be made. If I take a mathematical transform, and play it forward, I get the ripples in the pond. If I store these, I can, by doing the inverse of exactly the same transform, play it all backwards and the image reappears. That discovery was based on a theorem formulated by Fourier, a Frenchman who lived from the end of the 18th century to the beginning of the 19th century. Fourier's theorem states that any pattern, no matter how complex, can be analyzed into regular wave forms which are called sine-waves. A pattern that has been decomposed can be recomposed when sine-waves are synthesized or "convolved" with each other: this is the act of superpositioning, or essentially adding them, one on top of the other. To Fourier's theorem Gabor added the ripple phenomenon, that each pebble in the pond leaves its own signature in the wave form.

Holograms were developed from Gabor's original work with light photography. His technique never worked very well in electron-microscopy, the purpose for which it was built, but led to optical holography, three-dimensional photography without the use of a camera.

Holonomic Brain Functions

A major problem in the brain sciences until about the mid-1960's was how it is that we can see and feel away from our own body surfaces, away from our eyes. If I see this young lady who just walked in, I do not feel her walking across my retina. Basically it is at the sensory surface that I am being tickled, as it were, by the stimulus, but I project out into the world that which is stimulating my senses. With this is the related problem of where vision occurs. Do I see Al Huang, who is sitting over there in my cortex? Vision cannot occur only in the eye, because if someone took out my occipital lobes I would not see Al. Does that mean I see *in* my senses and brain? When you sit on a tack, where do you feel it? You think you feel it in the buttocks. But if I cut out the correct portion of your brain you would not be feeling it.

Another problem that was even more severe for brain scientists was that people who have strokes or head injuries of any kind never lose a particular memory trace. Memory is all of a piece; it seems to be distributed in the brain so that even huge destructions do not remove a particular piece of a memory.

This is where holography is of great interest. If I cover up half of a hologram, the whole image is still there. At the same time (around 1964) that I suggested holography might provide a useful way of looking at brain physiology, Fergus Campbell and John Robson at Cambridge University discovered, while investigating visual resolution, what is called hyperactivity, a phenomenon in which one can see detail that is finer than the grain of the retina.

They also discovered that seeing the same thing repeatedly causes habituation or adaptation to it. It is the same with your clothes. You know that you have got clothes on, you wiggle a little bit and you realize that you have got clothes on, but most of the time you do not notice them at all. The way scientists study this process is by presenting the same stimulus over and over again and calling that the adapting stimulus or background stimulus; then, they present a new stimulus which is different. Fergus Campbell was very surprised to find that his background stimulus influenced the test stimulus in a very peculiar but regular way. The adapting stimulus also influenced the test stimuli that were *harmonics*, or simple ratios, of the number of stripes in the pattern. This suggested that the eye responds to patterns in very much the same way that the ear responds to patterns, in terms of frequencies. Essentially, Fergus Campbell's work, conducted about 1967 and first published around 1968, provided the first evidence that the brain might indeed function very much like a hologram.

Campbell's work was largely on humans, and it involved inserting very fine wires into the brains of people during surgery, or in animals. In Figure 15-1, the wire is represented by line "a" going into the computer. The computer moves a white spot on a black background to a monkey, in this case—and since the computer knows where the spot is, it can record what the response of a neuron in the brain is doing. It is as if I could ask you, "Do you see my hand

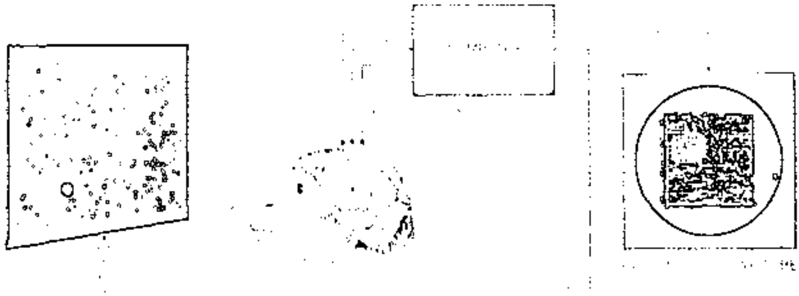

FIGURE 15–1

wiggling?" and you would say without moving your eyes, "yes" or "no," depending on where my hand is. Similarly, a cell in the visual system responds yes or no when it sees my hand waving, or the spot moving about. An electrode attached to a loud speaker allows us to hear the cell going along at a resting level emitting sounds at a slow frequency. When it sees something that it is responsive to, the cell develops a much faster rate of response. Since the computer knows where the spot is, it can correlate very simply what the spot is doing with what the cell is doing. In this way, it is possible to plot the receptive field.

When a spot is in one location, the cell responds a great deal: when the spot is in another place, the cell does not respond so much. This, as illustrated in Figure 15-2 is called a Mexican hat function: When we cut the Mexican hat function across, parallel to the brim, we get this picture on its side. You see here what is called a "center-surround field."

In the late 1950's, Hubel and Wiesel discovered that these receptive fields (which in the retina and halfway to the cortex were round) became elongated in the visual cortex. This discovery suggested that we perceive things because cells in the brain actually make stick figures. Obviously, the stick figures have to be embellished, and texture has to be added, but basically the idea was that each cell responds to lines of a certain orientation which the brain adds together.

But in 1966, we mapped receptive fields like this and found (Figure 15-3) that the receptive field is more complex than just a simple line. It has an inhibitory flank and then another excitatory flank be-

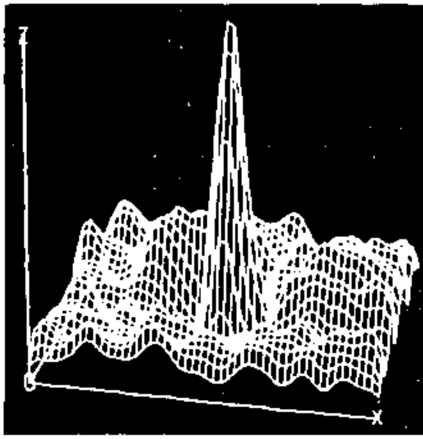

FIGURE 15–2

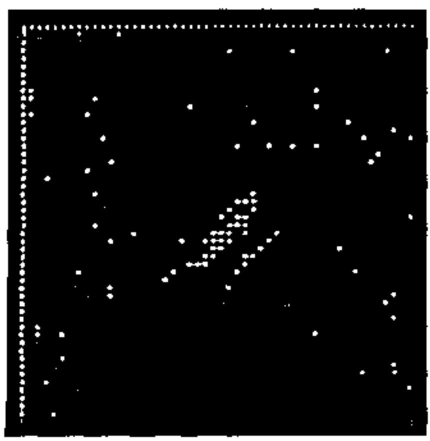

FIGURE 15–3

yond that. A group in Leningrad found several such "side bands," as they are called, and Dan Pollen at Harvard University showed that every cell had at least three or four such side bands.

Finally the idea penetrated in the early 1970's that maybe these were not line detectors as they had originally been called, but that they were like Fergus Campbell's spatial-frequency sensitive cells. They were sensitive to several lines or *stripes*, lines with certain frequencies across space. I can illustrate this by walking in front of what is called a low spatial frequency system of vertical black and white bars projected on the screen behind me. (Figure 15-4) You see me flickering. Figure 15-5 shows a set of lines that is finer, a high spatial frequency. Each of these tuning curves represents one cell;

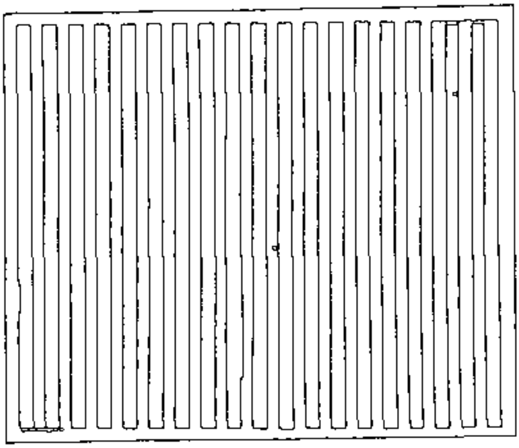

FIGURE 15–4

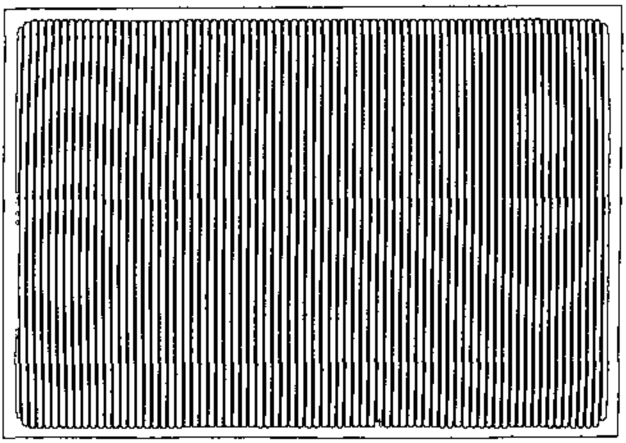

FIGURE 15–5

they illustrate that individual cells are tuned to approximately an octave of spatial frequency. It is possible to think of the brain cortex as being like a piano sounding board where each cell, when stimulated, resonates maximally to a particular frequency with its broad band tuning at approximately one octave as can be seen in Figure 15-6.

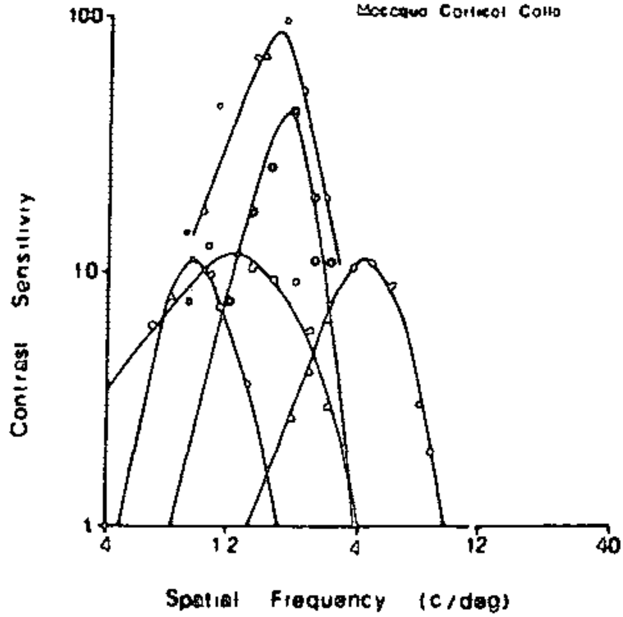

FIGURE 15–6

The only difference is that in vision the frequencies are spatial. This is a very important discovery. If the brain is made not to construct stick figures, but to resonate with particular frequencies there is a much richer perception that is like the richness of sound a pianist can produce from a piano.

These ideas, of course, are not new. Around the turn of the century, Jacques Loeb and others were thinking of the brain as resonating to an input and Helmholtz performed experiments to show that the ear worked this way. But excepting its implications for the auditory domain the general theory got lost during the 20th century and we forgot that the brain does in fact resonate. We do respond to vibrations in our environment, whether these vibrations are the "vibes" of other people or the vibrations that are set up by electric lights.

More recently, Russell and Karen de Valois have greatly refined our understanding of how brain cells function. Figure 15-7 shows the tuning curve of the cells suggesting that a cell cannot tell the difference between a very fine line and a rectangle; it is not very sensitive to the width of a single line. However, the tuning curve for spatial frequency is *very* highly specific. In another experiment

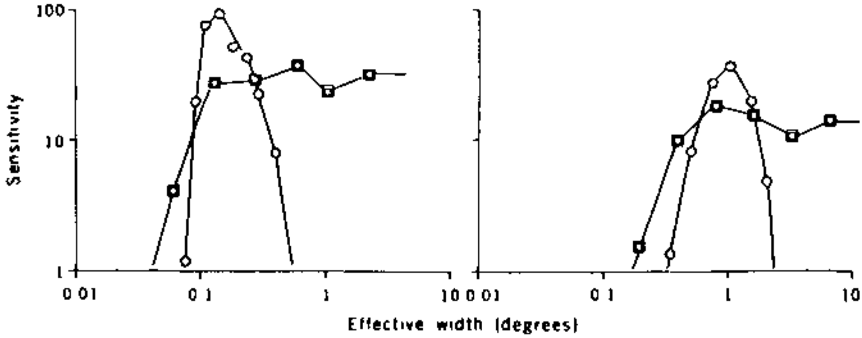

FIGURE 15–7

de Valois showed that the cell is responsive to the orientation of pattern as in a shirt plaid, for instance. De Valois scanned a plaid with a computer, did a Fourier transform on it, and showed how the axes of the transform were oriented. Then she measured whether the cell responded to the pattern as a whole or to the single lines in the pattern.

Figure 15-8 shows various patterns and their Fourier transforms. By testing, it was possible to discover that each cell was responding not to a set of lines but to their Fourier transform. De Valois found that every one of 224 cells was responding to the exact degree and minute of visual arc predicted by the Fourier transform—a convincing proof.

Holonomic Reality

In another experiment, instead of taking a spot and moving it about on an oscilloscope screen or television screen—as in all of the previous kinds of experiments—we took a television set displaying a lot of spots appearing simultaneously. This snow or "noise" on the television screen is called visual white noise. From the noise, which contains all possible patterns, the cell should pick out that which it is responsive to.

Figures 15-9 and 15-10 show how one cell responds to visual white noise, when its responses for about 30 milliseconds are added together. When the cell was responding to a dot in a particular place on the television screen we intensified dots in that area. When the

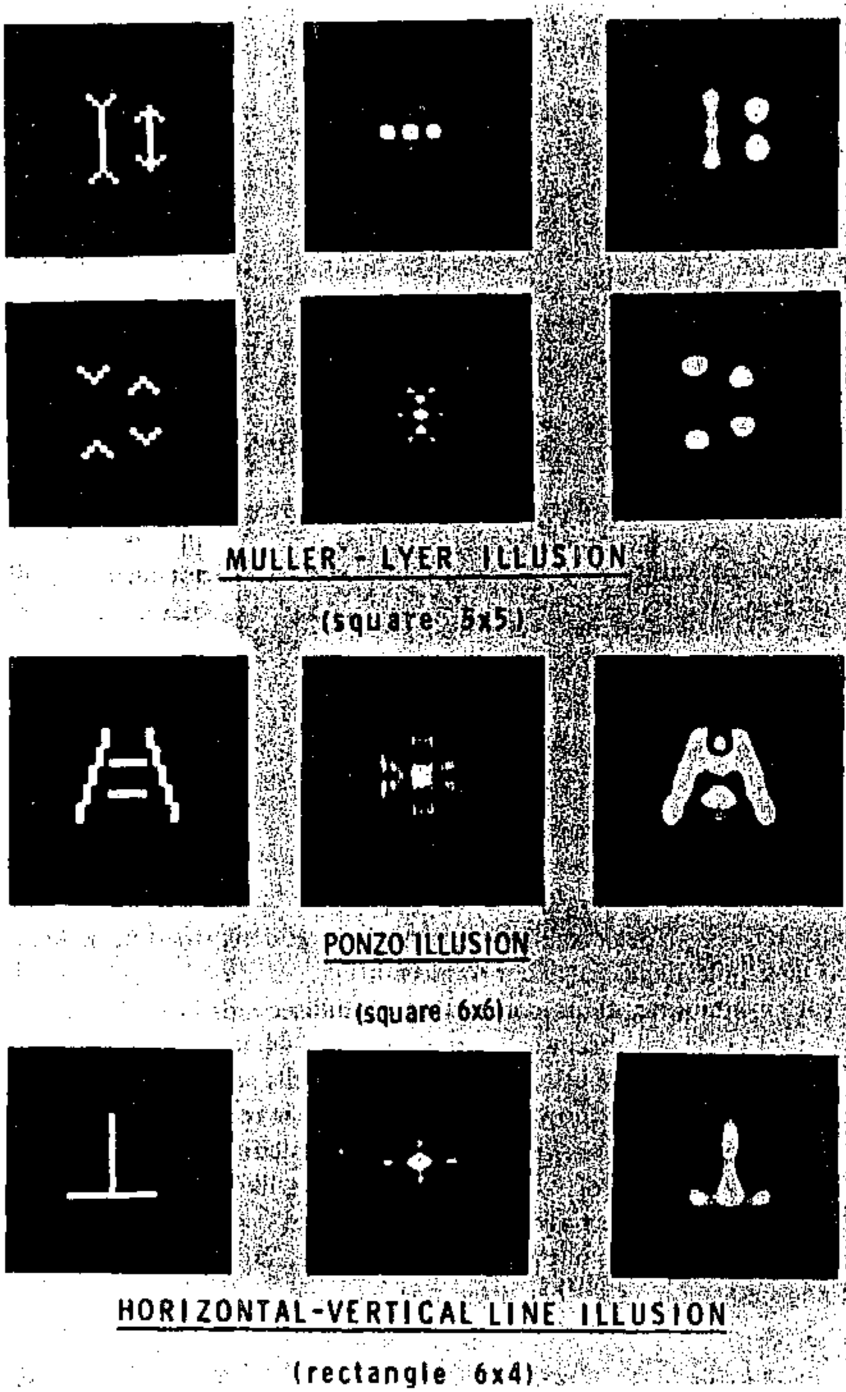
MULLER - LYER ILLUSION
(square 5x5)
PONZO ILLUSION
(square 6x6)
HORIZONTAL-VERTICAL LINE ILLUSION
(rectangle 6x4)

FIGURE 15–8

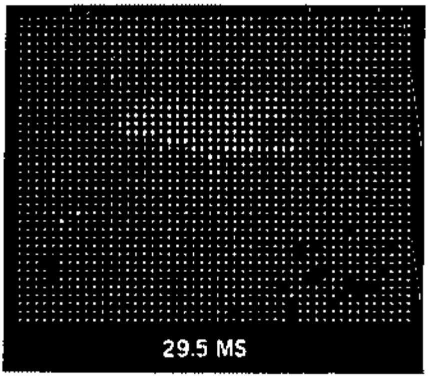

FIGURE 15–9

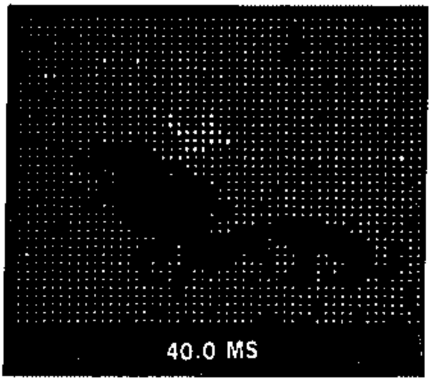

FIGURE 15–10

cell fired less than normal, we removed it and detensified it, making a black hole. This pattern produces a cigar-shaped receptive field with an inhibitory flank coming on 10 milliseconds later. If, out of random noise, our brain cells are picking up what they are sensitive to, what is it that we are perceiving? If our cells are set to create this pattern out of noise, how do we know what is really out there? We do not know because we are always constructing our own reality out of a great deal of what ordinarily seems like noise. But it is a structured noise: We have ears like radio tuners, and eyes like television tuners that pick out particular programs. With other tuners, we could be listening to other programs.

Conclusion

The importance of holonomic reality is that it constitutes what David Bohm calls an "enfolded" or "implicate order," which, as we have seen, is also a distributed order. Everything is enfolded into everything else and distributed all over the system. What we do with our sense organs and telescopes—lenses in general—is to explicate, to unfold that enfolded order. Our telescopes and microscopes are even called "objectives." That is how we explicate things: we make objects out of them with the lenses in our senses. Not only the eye, but also the skin and the ear are lens-like structures. We owe to David Bohm the conceptualization that there is an order in the universe—the enfolded order—which is spaceless and timeless in the sense that both space and time are enfolded in it. We now find that an important aspect of brain function is also accomplished in the holonomic domain. This aspect of brain function operates much as do those who perform statistical operations using the FFT—fast Fourier transform—in order to speed the computation of correlations. In medicine, computerized tomography uses a similar operation for image processing and image reconstruction.

Critical to such operations is the fact that the ordinary Euclidean and Newtonian dimensions of space and time become enfolded. Synchronicities and correlations characterize the operations occurring in this domain. There is no here, no there. There is no-thing. But this holonomic order is not empty; it is a boundariless plenum filling and flowing. Discovery of these characteristics of the holonomic order in physics and in the brain sciences has intrigued mystics and scholars steeped in the esoteric traditions of East and West: for is not this just what they have been experiencing all along?