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Edited by
George Adelman
Barry H. Smith

Editorial Manager
Jennifer De Pasquale

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Holography, holonomy and brain function

Karl H. Pribram

There is considerable controversy as to whether holography can serve as a good model for certain aspects of brain function. The roots of this controversy are often to be found in misunderstandings of what holography is and what the proponents of a holographic hypothesis are claiming. Furthermore, a feature detector model is often seen as a more viable alternative.

Holography was invented in 1949 by Dennis Gabor, a mathematician. Primarily, holography is a set of mathematical propositions based on modifications of the Fourier theorem. In short, the holographic hypothesis of brain function proposes a mathematical model. Criticisms levied against the hypothesis that rely on optical holography as an analogy are misguided.

The Fourier theorem states that any pattern can be analyzed into components, each of which is represented by a regular waveform of specified amplitude and frequency. The phase relations among waveforms are also critical since both the sine and cosine properties of the wave (i.e., its quadriture) are encoded. Furthermore, in holography, the waveforms become distributed over the entire surface of the recording medium. With distribution, the information encoded in the hologram is enfolded into each portion.

An initial general criticism of the holographic hypothesis of brain function concerned the Fourier transform. Experiments in psychophysics and neurophysiology have shown that channels of limited band width encode Fourier components. However, the resultant fails to become distributed over the entire surface of the brain. Prior to his inventing holography, Gabor had developed a model of telecommunication based on what we now call a Gabor function. This function places a Gaussian envelope over the Fourier waveforms, thus constraining their otherwise infinite extent. Such constraints on computational spaces are called holonomic (Hertz, 1956; Pribram, 1991). Holograms made of patches of Gabor functions have all the essentials attributes of more globally transformed Fourier holograms (Bracewell, 1989).

A second general criticism of the holographic hypothesis of brain function devolves on the use of waveform representations in the model. Much of this criticism came from investigators in the field of artificial intelligence who use digital computers to model brain and psychological processes. In the brain, however, most computations are performed by interactions among graded fluctuating electrochemical polarizations, often with the aid of local circuit neurons, most of which do not possess the axon hillocks and axons in which digital nerve impulses are generated and propagated. Whether one wishes to model these local graded interactions in wave mechanical, statistical or vector matrix terms depends on the data being modelled. The mathematics often turns out to be equivalent with regard to the operations of the neural substrate (much as Heisenberg's matrices and Schroedinger's wave equations are equivalent in quantum physics).

The advantage of a Gabor-based approach is that it is essentially linear and invertible. Thus holonomic image processing allows easy access to the original form of the images being processed in the transform domain by simply applying the inverse transform. In brain/behavioral systems, this inverse appears to be carried out by movement (Pribram and Carlton, 1986; Pribram, 1991). The advantage of processing in the holonomic domain is computational power, especially the computation of coherence/correlation, and the enormous capacity of readily retrievable storage. Thus the hypothesis is worth pursuing. Much evidence in its support has accrued over the past three decades.

The neuroscience community has become more and more aware of the importance of local dendritic field potentials in the processing of signals in the sensory input systems through the work of George Bishop, W. Rall, Walter Freeman, Gordon Shepherd, Pasko Rakic, and Francis Schmitt. Observations that early stages of retinal processing (as well as those in most other receptor systems) are devoid of nerve impulses have provided convincing evidence that interactions among graded polarizations can play a critical role in sensory signal processing. Additionally, these observations have provided mini-models of some aspects of the functional organization of more central stations (especially of the cortical sheets that so closely resemble the layered retinal mosaic). The question that arises is whether the transfer functions that are being meticulously described by mapping receptive (i.e., dendritic) field properties for each stage of such processing can together account for neural image processing.

Two views of the neural process in vision have emerged: That pioneered by David Hubel and Torsten Wiesel emphasizes the convergence of signals onto neurons that, at successive levels of processing, progressively extract features encoded in the signals. The other, represented in the work of Fergus Cambell, Daniel Pollen, Vadim Glezer and Russell DeValois, among others, emphasizes what is called a harmonic analysis. Harmonic analysis emphasizes a parallel process that by virtue of lateral inhibition functions linearly to encode signals in the spectral domain. In the auditory mode, the idea that the sensory system may function as a harmonic analyzer goes back to the work of Ohm and Helmholtz over a century ago. In 1967 von Bekesy demonstrated with an elegant series of experiments that somatosensory experience is processed according to more or less identical rules. Experimental results in our laboratory have shown that neurons in the somatosensory and somatomotor cortex respond to limited bandwidths of the frequency of whisker stimulation and of movement of a foreleg.

More recently Daniel Pollen and S. Ronner have demonstrated the presence in the same cortical column of cells responding to complementary phases of an input, i.e., to the sine and cosine components. Vadim Glazer, Frane Marcela, John Daugman, among others, have evidence that it is the Gabor transform (or closely related Hermitians) that most accurately describes the process. Russell and Karen DeValois and their group have demonstrated the anatomical distribution of spectrally-tuned analyzers and have thoroughly and critically reviewed their own and others' psychophysical and neurophysiological investigations on the topic of spectral encoding in the visual system. They also have reported experiments that make implausible a Euclidian, hierarchical approach to image processing based on the detection of lines.

A feature analytic (as opposed to a feature detector) process is not ruled out, however. Each cortical receptive field displays selectivities to several features including a limited band of spatial frequency, orientation, direction and velocity of movement, change in luminance and color. Under current investigation is the nature of the output code that recognizes these features singly or in combination. There is already considerable evidence that ensembles of neurons are involved to form a spatial code. This would function much as the pattern formed in a classroom when all students who are wearing glasses are asked to raise their hand. When, alternatively, all students wearing grey sweatshirts are asked to raise their hand, the result would be a different pattern.

The two views of the sensory processing mechanism – that of a hierarchical nonlinear feature extraction process and that of parallel processing linear harmonic analyzer – are thus not mutually exclusive. Feature extraction can lead to information processing and harmonic analysis to image processing.

A final critique of the holographic hypothesis of brain function has been that it is counterintuitive. If, however, one imagines the sensory receptor surface to be something like a piano keyboard and the topologically corresponding cortical dendritic ensemble to function like a sounding board, a feel for the mechanism can be obtained. Input patterns to the receptors are transduced into neural patterns that are transmitted to the cortical sounding board where each receptive field resonates to a limited bandwidth of frequency. Patterns of the complexity of sonatas can be processed in this manner.

The counterintuitive aspects of holography and holonomy can also be grasped by analogy to the patterns of radio and television programs simultaneously present in the broadcast space. Each program is in fact broadcast, i.e., distributed, cast broadly over that space, and each portion of space has enfolded in it all the programs that are being transmitted at that moment. In order to make sense of any of the programs transmitted in a frequency code, we must tune in selected bandwidths that act as carriers for particular programs and re-transform them into auditory and visual images. In order to make sense of the neural holographic process, the sense organs must tune in on selected bandwidths of environmental energy patterns and re-transform them into images, probably by virtue of the motor processes of the brain (Pribram and Carlton, 1986).

The neural holographic model has become refined in its applications to understanding memory as well as perception. Here, two forms of the model were initially pitted against one another: a matrix versus a convolutional approach. In the matrix model remembering is triggered when successive inputs are related to one another by taking the outer products of vectors representing features; while in the convolutional model correlations are achieved by superposition and by taking the inner products of these vectors.

Matrix models, such as those of James Anderson have been shown to be superior in explaining categorical memory; convolutional models, such as those of Ben Murdoch, in explaining serial position memory effects. Work from our laboratory has shown that receptive fields in the lateral geniculate nucleus and the visual cortex can be altered (probably by influencing lateral inhibition) by electrical stimulations of the posterior and frontal "association" cortex (and the subjacent basal ganglia). Posterior stimulation enhances inhibitory surrounds thus producing a separation of excitatory centers. Such separate receptive fields are best represented by Gabor functions and matrix operations. Frontal stimulation disinhibits the surrounds with the result that excitatory receptive fields tend to merge into a more continuous processing mode which is best represented by a convolutional model. Further, the systems of the posterior cerebral convexity have been shown important to establishing prototypes necessary for categorizing; the frontolimbic systems, to processing serial position of events occurring in an episode.

The holographic and holonomic models of brain function in perception and memory have thus received support from neuropsychological evidence which is consonant with the evidence obtained in experimental psychology and in neurophysiology.

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See also Memory, distributed

Homeobox and nervous system development

Cahir J. O'Kane

The homeobox is a conserved DNA sequence of 180 base pairs, which codes for a protein domain of 60 amino acids, the homeodomain. It was discovered in 1984 as sequence homology between several genes that specify segment identity in the fruitfly *Drosophila*. Since then, hundreds of homeobox-containing genes have been found throughout the eukaryotic kingdom, in animals, fungi and plants.

The homeodomain is a DNA-binding domain that is part of a larger protein, or homeoprotein. Homeoproteins bind specifically to DNA sequences adjacent to other genes and thus regulate their transcription. They have evolved two distinct roles in animal development. First, they can determine the identity and biological properties of particular cells, including neural cells, by regulating which other proteins are expressed in