note: because important websites are frequently "here today but gone tomorrow", the following was archived from http://www.acsa2000.net/bcngroup/jponkp on May 21, 2003. This is NOT an attempt to divert readers from the aforementioned website. Indeed, the reader should only read this back-up copy if the updated original cannot be found at the original author's site.

a comparison between
Karl Pribram's "Holographic Brain Theory"
and more conventional models of neuronal computation

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Chapter 1 - Introduction

One of the problems facing neural science is how to explain evidence that local lesions in the brain do not selectively impair one-or-another memory trace. Note that in a hologram, restrictive damage does not disrupt the stored information because it has become distributed. The information has become blurred over the entire extent of the holographic film. But in a precise fashion that it can be de-blurred by performing the inverse procedure.

This paper will discuss in detail the concept of a holograph and the evidence that Karl Pribram uses to support the idea that the brain implements holonomic transformations that distribute episodic information over regions of the brain (and later "refocuses" them into a form in which we re-member). Particular emphasis will be placed on the visual system since its the best characterized in the neurosciences. Evidence will be examined that bears on the validity of Pribram's theory and the more conventional ideas that images are directly stored in the brain in the form of points and edges (without any transformation that distributes the information over large regions). Where possible, the same evidence (for the visual system) will be used to evaluate both theories.

1. Holonomic theory where Fourier-like transformations store information of the sensory modalities in the spectral (or frequency) domain. The sensory stimulus is spread out (or distributed) over a region of the brain. A particular example (in the case of vision) would be that particular cortical cells respond to the spatial frequencies of the visual stimulus.

2. The more conventional theory that particular features of the untransformed sensory stimulus is stored in separate places in the brain. A particular example (in vision) would be that particular visual cortical cells respond to edges or bar widths in the visual stimulus.

It will be necessary in this report to first explain the concepts of a hologram and Fourier transforms before the physiological experiments can be understood. Bear in mind that the discursion into these other fields serves a purpose for later in the report.

Karl Pribram's holonomic theory reviews evidence that the dendritic processes function to take a "spectral" transformation of the "episodes of perception". This transformed "spectral" information is stored distributed over large numbers of neurons. When the episode is remembered, an inverse transformation occurs that is also a result of dendritic processes. It is the process of transformation that gives us conscious awareness.

Chapter 2 will outline the basic concept of a hologram and start to introduce Pribram's holonomic brain theory.

Chapter 3 will briefly describe the conventional accepted view of the pathway of neural processing (with particular emphasis on the visual system). The main computational event in this view is the generation of the action potential.

Chapter 4 will review the evidence for the alternative holonomic view. The holonomic theory is based on evidence that the main computational event of neurons is the polarizations and hyper polarizations at the dendritic membranes of neurons. The evidence will be reviewed that supports the notion that these dendritic processes effectively take something close to a Fourier transform.

Chapter 2 - Holograms

What is holography?

The word "holography" is derived from Greek roots meaning "complete writing". The idea is that every part of "the writing" contains information about the whole. A hologram (the material manifestation of a holograph) is a photographic emulsion in which information about a scene is recorded in a very special way. When the hologram is illuminated, you see a realistic, 3-dimensional representation of the scene. If you cut the holographic photographic plate up into small pieces, the whole image can still be extracted from any of them (although with some loss of clarity). Pribram uses the term "**holonomy**" to refer to a dynamic (or changing) hologram.

The Hologram Relationship

The basic idea of a hologram can be understood without even considering the holograms found in novelty stores. The idea is simply that each part contains some information of the whole. Or stated another way, the information (or features) are not localized but <u>distributed</u>. To clarify this concept, consider the following thought experiments (demonstrations). As will be demonstrated, light is in the holographic domain before it gets transformed (focused) by a lens.

Demonstration #1: Remove the converging lens in a slide projector that forms the image. Place a slide in the projector and project the light onto a screen. No image will form. Technically, the light incident on the screen is in a holographic form. Each point on the screen is receiving information from every point from the slide. If a converging lens is placed at a location between the screen and the slide projector, an image can be formed on the screen. The lens can now be moved to new locations in a plane cutting through the light path to the screen and in each case a complete image is formed (Taylor, 1978).

Demonstration #2: The above principle can be demonstrated with using a camera. Consider taking pictures of an object (for example, a far-away mountain). You take a picture, then move over a few feet and take another one. You move over a few more feet and take another one. Upon getting the pictures developed, they all look about the same. This demonstrates the idea that the information necessary to form the image was present at each of the locations that you took the pictures. Additionally, if you look at an object very far away, then tilt your head to the side, you can still see the object. The light incident on your eye in both positions was sufficient to form the whole image.

Demonstration #3: Take a pair of binoculars. Just look through one side focusing at a distant object. Now place your fingers in front of the lens so that only light coming from in-between your fingers enters the monocular. You will still see the whole image. If you bring your fingers together so that the light enters only through tiny slits, the whole image will still be present only dimmer (and there will be some loss of resolution). If you rotate your hand exposing the light to different parts of the lens, the whole image can still be formed. This is another representation that the light incident at the surface of the lens at any point is in a holographic form.

Demonstration #4: A pinhole camera represents a special case where an image can be formed without using a lens (without taking a transformation). Note that if the pinhole is moved over a bit, the image still forms. This demonstrates the rudimentary idea of the whole being included in a part (the part being the area of the pinhole). All of the information necessary to produce the image is contained in the area of the pinhole. A lens functions to allow the light incident on a

larger area to all be transformed (focused) to form an image. This will improve both image resolution and light gathering capability.

It is perhaps unfortunate that most physiology textbooks use a figure something like the following (**Figure 1**) to describe the operation of the eye.
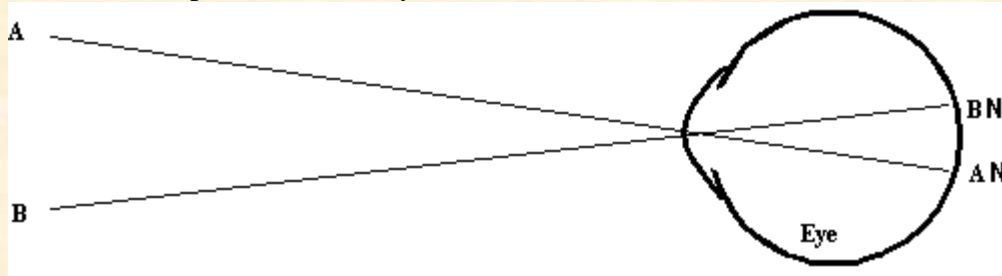

Figure 1

The above figure doesn't express the transform-taking aspect of a lens. The above figure is really more indicative of a pinhole camera. **Figure 4** (shown later in the report) gives a better depiction of what happens at the lens of the eye.

Mathematically (in one implementation), a Fourier transform converts a function of time *f(t)* into a function of frequency **F(jw)** where the **j** indicates that it is a complex function of frequency. In other words, a Fourier transform can convert a signal from the time domain to the frequency domain. A Fourier transform could also be used to convert something from a spatial locational domain (the coordinates in space) to a frequency domain (more about this later).

The idea (the mathematics) of the Fourier transform is <u>independent</u> of what the data sets represent. It will be argued that if the brain performs a Fourier transform for visual stimuli, then it is possible that it also performs a Fourier transform for the other senses also (hearing, taste, smell, touch).

The same principle can be shown with optics. Consider, for example, that a large telescope lens (or mirror) can resolve 2 distinct images (for example, 2 stars that only have a small angle separating them in respect to us). A smaller telescope lens (or mirror) will not be able to resolve (separate) those 2 stars. Likewise, small parts of a hologram -- although they have information of the whole -- will suffer some resolution deficit.
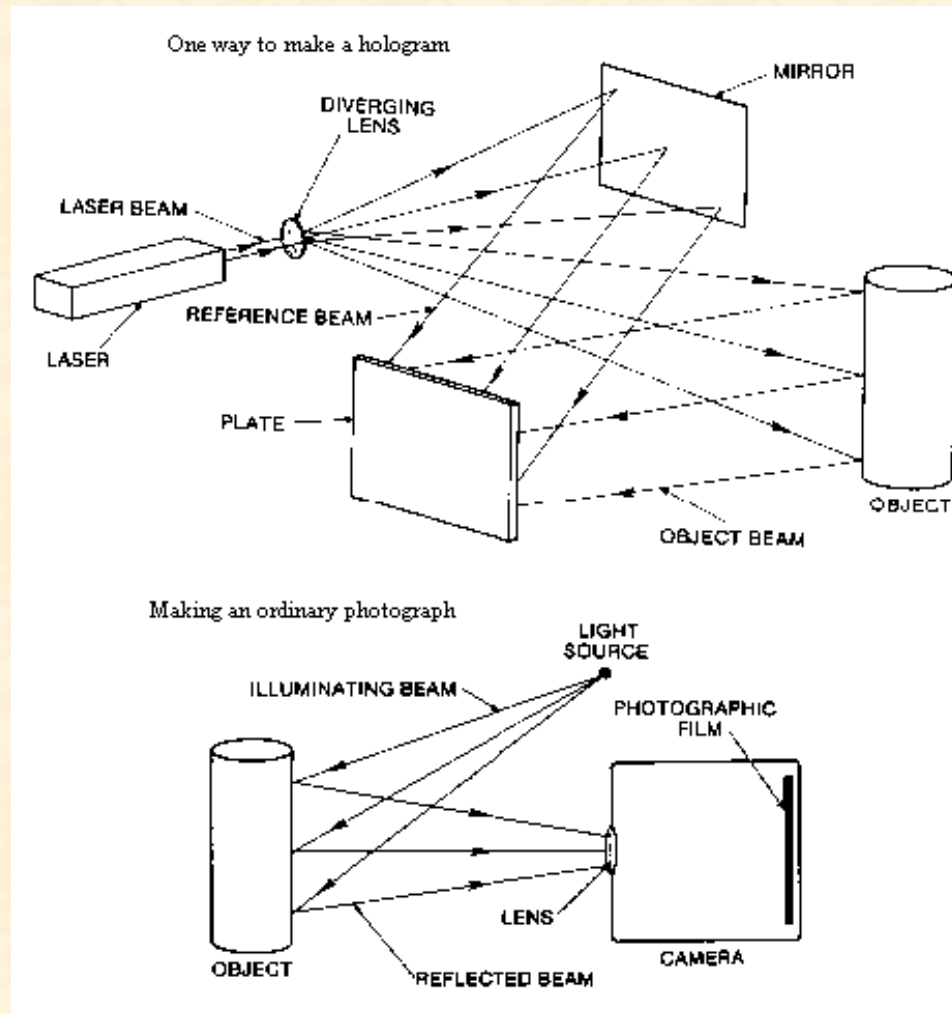
Holograms

Figure 2 Reproduced from Kasper and Feller, <u>The Complete Book of Holograms</u>, 1987, pp 4-5.

As seen above in **Figure 2**, the holographic plate records an interference pattern between the diverged laser light and the scattered laser light bouncing off the object. The pattern recorded on the holographic plate is in the holographic domain. All parts of the holographic plate contain information of the whole. Light bouncing off each point on the object is distributed (spread out) to every location on the holographic plate).

Alternatively, the pattern recorded on the photograph is an image (non-holographic). The image features are located at particular locations on the photographic plate. Light scattered off the object (now in the holographic domain) is transformed to the non-holographic (image) domain by the lens of the camera (which does an effective inverse Fourier transform) by focusing the image on the photographic film. For the photograph, there is a one-to-one mapping between the 2-dimensional projection of points on the object to locations on the photographic plate. Correspondingly, there is a one-to-all mapping for the holographic plate.
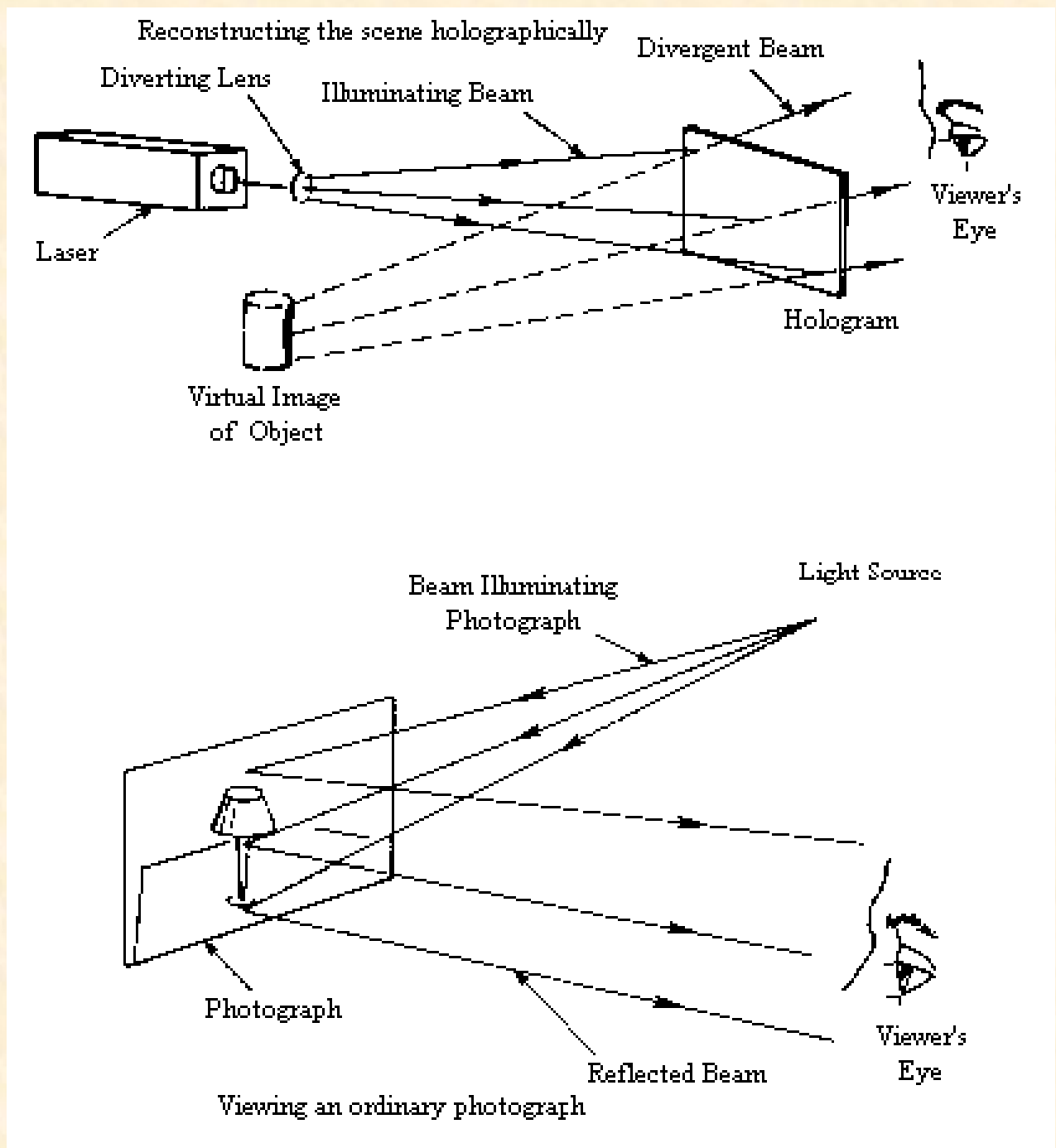
Reconstructing the scene holographically

- Diverting Lens
- Illuminating Beam
- Divergent Beam
- Laser
- Virtual Image of Object
- Hologram
- Viewer's Eye

Viewing an ordinary photograph

- Beam Illuminating Photograph
- Light Source
- Photograph
- Reflected Beam
- Viewer's Eye

<u>**Figure 3**</u> Reproduced from Kasper and Feller, <u>The Complete Book of Holograms</u>, 1987, pp 4-5.

In the case of the photograph (see **Figure 3**), light is scattered off the photograph (which is now in the holographic domain) and becomes incident on the eye which does a transformation (focuses) which forms an image on the retina. For the holograph, laser light is shined through the holographic plate (picking up the holographic information from the plate) and becomes incident on the eye which does a transformation (focuses) which forms an image on the retina. The holographic nature of the light incident on the lens is shown in **Figure 4**.
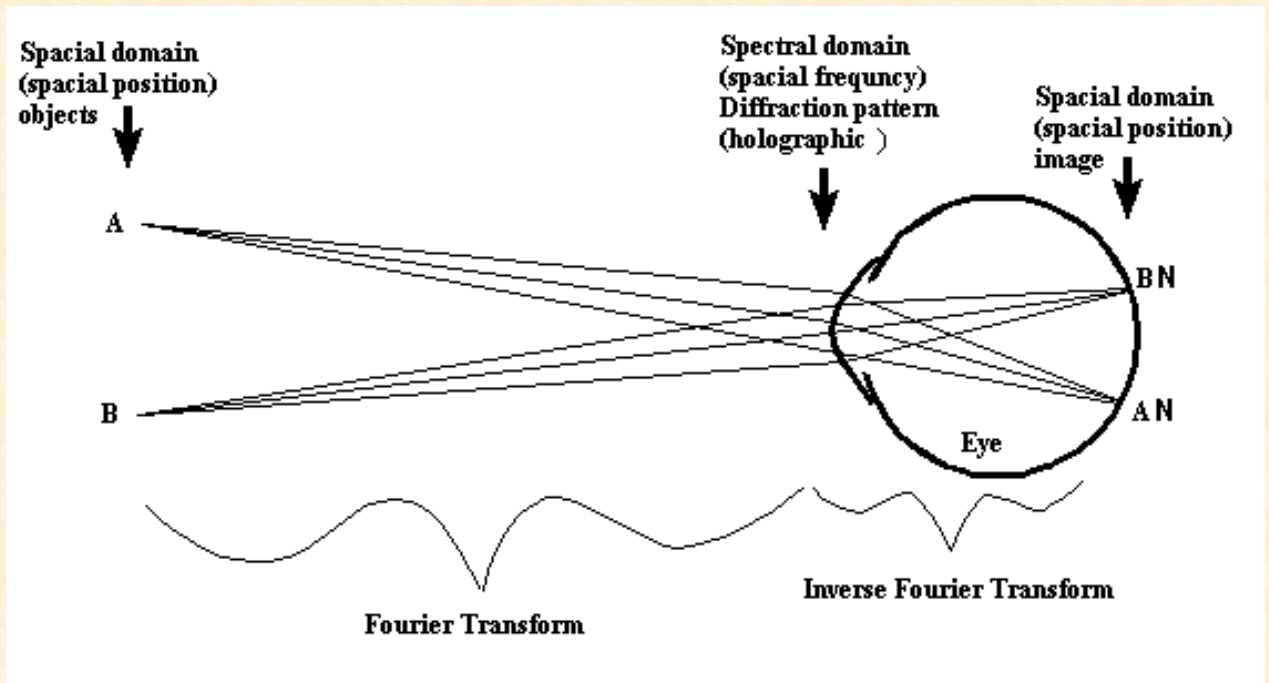
Figure 4 Diagram expressing the holographic nature of light incident on the surface of the lens of the eye.

The light scattered from point 'A' is incident at each location of the lens (likewise for the light scattered off of 'B'. The lens functions to transform this holographic domain to an image of 'A' and 'B' at the retina.

The discussion so far has just taken us to the image formed at the retina. The interesting part of the holonomic brain theory is what happens next. The focal point of the above discussion is that a lens does an effective (inverse) Fourier transform on the light incident to it. The Fourier transform (and inverse Fourier transform) consists of convolution integrals which mathematically smear or de-smear the information. For continuous functions, the Fourier transform and inverse Fourier transform are as follows (for transforms between the time and frequency domain):

$$X(F) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi Ft}\,dt$$

The Fourier transform also has meaning between a spatial domain (for instance the position in two dimensional space) and spatial frequency. Mathematically, the 2-dimensional spatial Fourier transform is

$$F(\alpha,\beta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)e^{-j2\pi(\alpha x + \beta y)}\,dx\,dy$$

and the inverse transform is

$$f(x,y) = \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} F(\alpha,\beta)\, e^{j2\pi(\alpha x + \beta y)}\, d\alpha\, d\beta$$

where **x** and **y** are spatial coordinates and **a** and **b** are horizontal and vertical frequencies.

One realization of the Fourier transform is the principle of diffraction. If you shine coherent light through one point, there will just appear a large white blob on a screen. If coherent light is shined through 2 separated points though, a diffraction pattern will appear (see **Figure 5**). The orientation of the (sine-wave) grating is caused by the relative orientation of the two points.

Figure 5

In each figure pair, coherent light shining through the point(s) on the left would create the (diffraction) pattern seen on the right. The right hand side of each figure pair represents the Fourier transform of the left-hand side of the figure pair. (Reproduced from Taylor, Images, 1978, page 27.)

Mathematically, the diffraction patterns seen are explained by taking (2-dimensional) Fourier transform of the points. The right-hand side of each figure pair is the Fourier transform of the left-hand side (and visa versa).

If coherent light (or light from a point source) is shined through 2 slits, a diffraction pattern can be demonstrated as seen in **Figure 6**. Note a large blob in the middle and smaller blobs tapering off to either side. The separation and angular position of the spectral blobs is dependent on the separation and orientation of the slits.

Figure 6

The left hand side of each pair indicates the geometry of the slits. The right-hand side of each pair shows the optical diffraction pattern. Reproduced from (Taylor, Images, 1978, pages 42-43).

Figure 7 shows the mathematical Fourier transform of 3 different patterns (square-wave grating, checkerboard, and plaid) into their respective spatial frequency domains. The spectrum of the square-wave grating has odd numbered harmonics that taper off in amplitude to each side. Note that the plaid shape is made up of the addition of vertically- and horizontally-oriented square-wave gratings.

Similarly, the spectral representation of the plaid is the superposition of the spectral representation of the vertical square-wave grating and what the spectrum would be (not shown) for a horizontal square-wave grating. Pay particular attention to the dominate 4 components to the plaid spectrum (the heaviest four dots towards the center. Now compare those dominate dots to the corresponding ones in the spectrum of the checkerboard. Note that there is a 45° rotation. This can be intuitively understood because you can perceive rows of white and black squares running at the 45° orientation for the case of the checkerboard. This fact will become very important in the physiological experiment to be described later in the report.

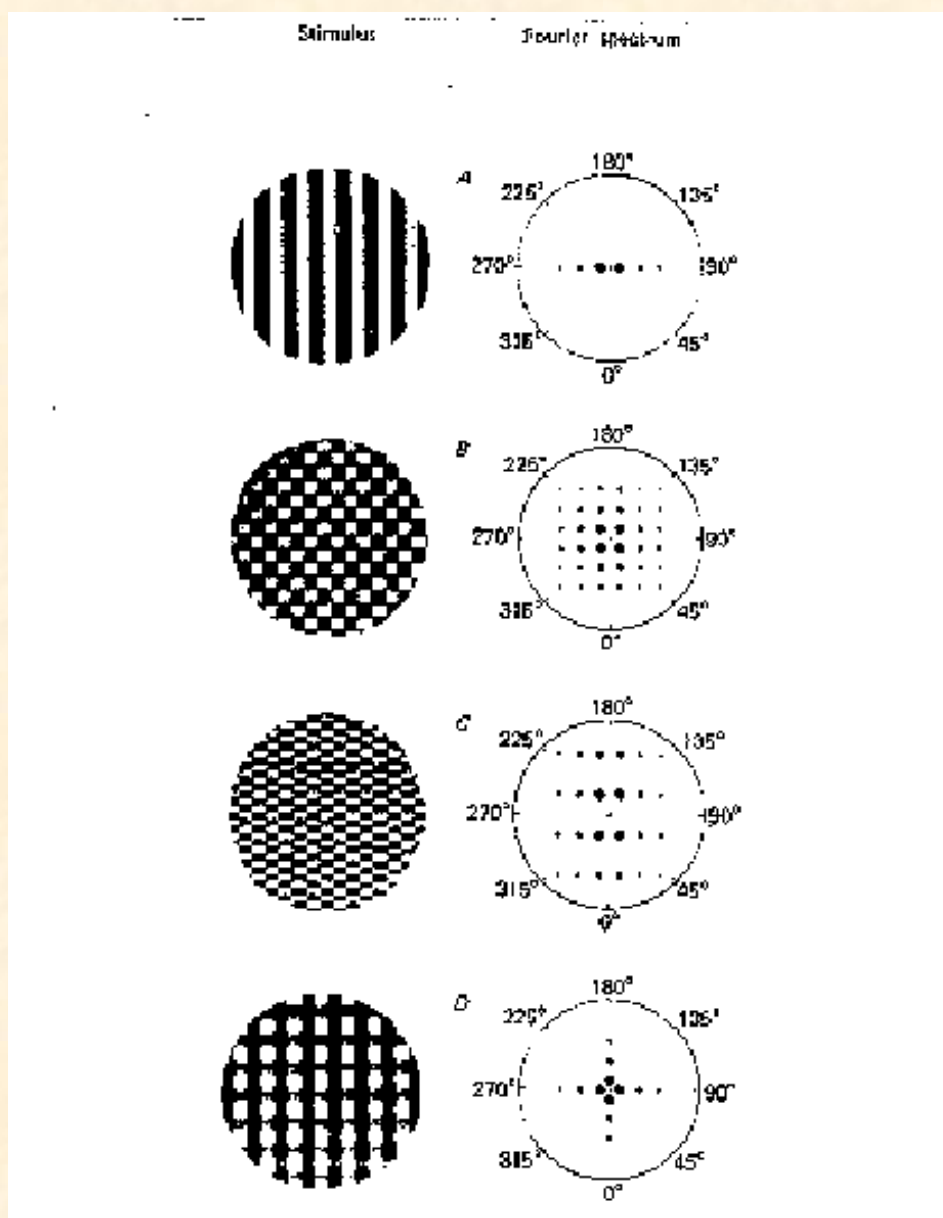**Figure 7**

Stimuli and the corresponding Fourier spectrum. **(A)** square-ware grating. **(B)** checkerboard with squares. **(C)** checkerboard with rectangles wider than tall. **(D)** plaid. Reproduced from De Valois et. al., 1979, page 485.

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Before proceeding, a couple of examples will be shown of the effect of not using the entire spectral domain in performing the inverse Fourier transform. This demonstrates the holographic idea of the "whole" being stored in all the parts. It also shows that fairly good images can be achieved without taking the full theoretical transforms. This is important because neural processing isn't infinite in extent. The brain (because of its finite nature) would only be able to take a truncated Fourier transform.

When an inverse Fourier transform is taken of smaller and smaller areas of the spectral domain, the "whole" is always captured but the resolution deteriorates. See **Figure 8**.
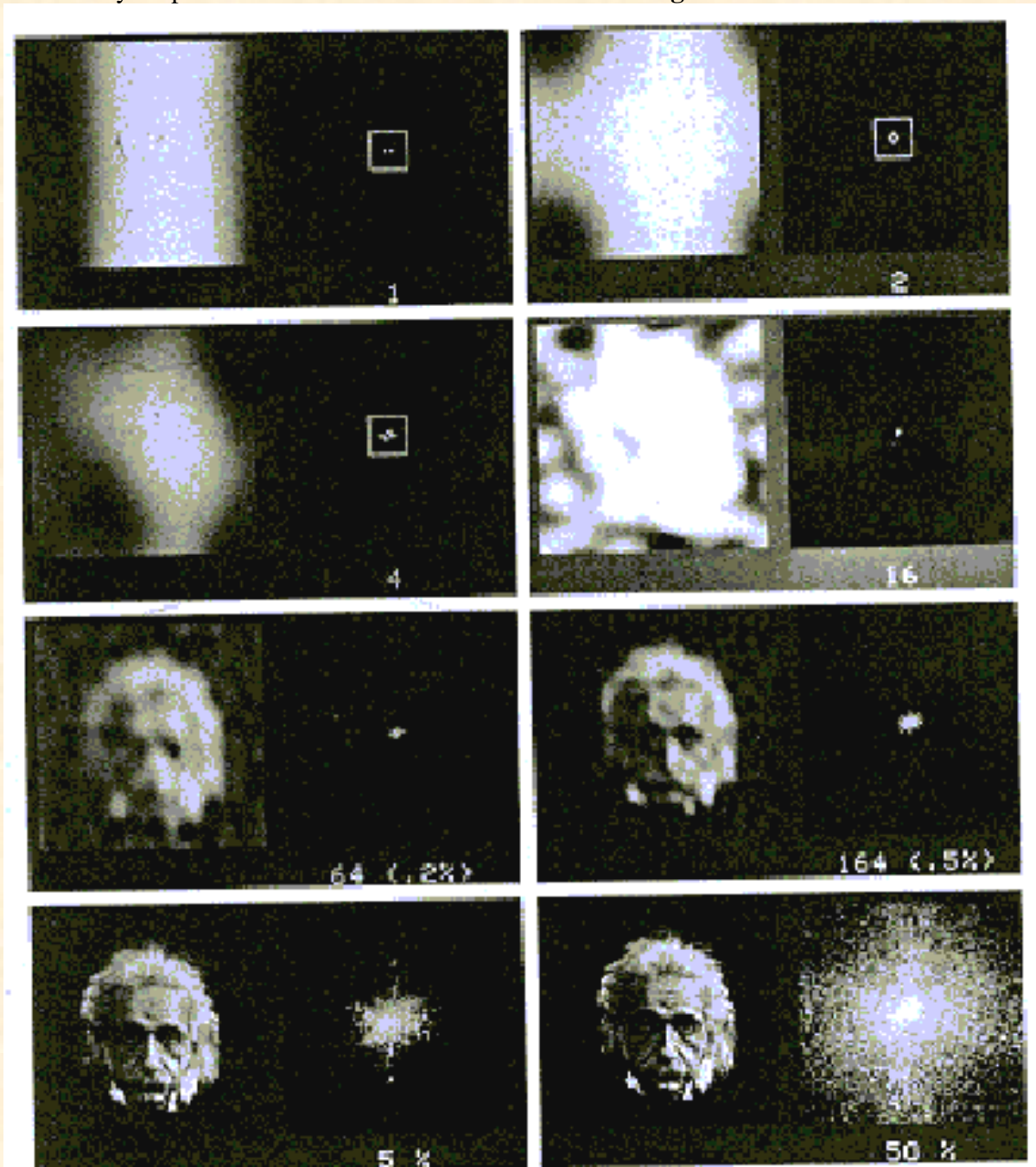

Figure 8
The right-hand side of each figure pair shows the spectrum. The left-hand side of each figure pair shows the corresponding image after the inverse transform. Reproduced from (De Valois & De Valois, Spatial vision, 1988, page 17).

Chapter 3 - Euclidean-based Geometric Model

The conventional theory is that the main computational event in neurons is the generation of the action potential. The firing of the action potential (for a single cell or a network of cells) indicates the triggering of a particular perception. In the extreme case (the "grandfather cell"), the firing of a single cell can trigger a certain memory or perception. More typically, though, it would be the near-simultaneous firing of a whole collection of cells in a network that triggers the perception. The perception would then be mediated by the action potential's propagation (through the axon) to other parts of the brain. It would be the integrative emergent response of "the other parts of the brain" (including parallel coupling to other sensory modalities) that yields the sensation of the perception.

For visual perception, there is the following information flow (Kendel, <u>Principles of Neural Science</u>, page 438)

Retina: cells respond to small circular stimuli

Lateral geniculate nucleus: cells also respond to small circular stimuli

Primary visual cortex: transforms the concentric receptive field in at least 3 ways.

1. Visual field decomposed into short line segments of different orientation, through orientation columns. Early discrimination of form and movement.

2. Information about color is processed through "blobs" which lack orientation selectivity.

3. Input from the 2 eyes is combined through the ocular dominance columns (one of the steps necessary in depth perception.

Central connections of the visual system are remarkably specific. Separate regions of the retina project to the lateral geniculate nucleus in the thalamus in such a way that a complete visual field for each eye is represented in the nucleus. Different cell types in the retina project to different targets in the brain stem. Each geniculate axon terminates in the visual cortex, primarily in layer 4. The cells in each layer have their own patterns of connections with other subcortical regions.

Cells in the visual cortex are arranged in into orientation-specific columns, ocular dominance columns, and blobs. Some of these neurons have horizontal connections. Information flows both between the layers and horizontally through each layer. The columnar units seem to function as elementary computational modules. Each group of cells acts as a dedicated circuit to process an input and send it on.

Chapter 4 - Holonomic Brain Theory

Experimental Evidence

Hubel and Wiesel (1959, 1962) described and classified simple and complex cortical cells. They concluded that both simple and complex cells responded optimally to bars and edges of a certain orientation. An alternative view was that each cortical cell might be selective for a particular portion of the 2-dimensional Fourier spectrum (a certain frequency component at a particular orientation) of the

visual stimulus (Robson, 1975; De Valois, Albrecht & Thorell, 1977). The issue was raised that a true edge detector would need nonlinear dynamics. And it was unclear whether the cortical cells exhibited the necessary nonlinear dynamics.

The 2 different views were (1) that the cortical cells function as non-linear edge detectors or (2) as linear spatial frequency filters. These 2 views each have different predictions about how the cortical cells would respond to a visual stimulus. By making use of gratings and checkerboards as the visual stimuli, De Valois et. al., 1979 were able to distinguish between these 2 possibilities.

Figure 7 (from earlier in the report) shows different patterns (that can be presented as visual stimuli) and the corresponding frequency spectrum. Each spectrum here is plotted in polar form where the distance from center represents the spatial frequency of the stimulus and the angle (from 0°) represents the phase information or the orientation of the spatial frequency of the stimulus. The size of the dots represents amplitude. In rectangular coordinates, the spectrum would be interpreted as frequency components in the vertical and horizontal directions.

For example, a square-wave grating with vertical bars (see **Figure 7**) would manifest a frequency (repeating pattern) in the horizontal direction. The spectral depiction of this image would be decomposed into various frequency components all in the horizontal direction. This would be plotted (in the representation used here) as dots along the horizontal axis. A spectral plot of a square-wave grating with horizontal bars would consist of dots along the vertical axis.

When an animal is presented with the spatial visual field (the left-hand side of each figure pair), the question can be asked "are the cortical cells responding to information in the original spatial domain or information in the frequency (spectral) domain?" In what representation is the information getting to the cortical cells? Can an experiment be devised to distinguish between these 2 possibilities? For example, is a particular cortical cell responding to the presence of a line in the visual field or to the fundamental Fourier component (at a certain orientation) of the spectrum? This issue was resolved by comparing the response of the same cortical cell to different visual fields (De Valois et. al., 1979).

A series of experiments were performed in both cats and monkeys (De Valois et. al., 1979) to see if the cortical cells responded to differences in the Fourier spectrums. The first experiment was designed around the observation that spectral Fourier fundamentals for the checkerboard were rotated at 45° relative to the Fourier fundamentals of either the square-wave grating or the plaid (see **Figure 7**). Vertical square-wave gratings, plaids, and checker-boards each have vertical edges in the same orientation. Therefore, if a cortical cell was functioning as an edge detector, the cell should respond optimally (most number of spikes or action potentials per sec) to square-wave gratings, plaids, and checkerboards all in the same orientation. If, however, the cortical cells were responding to the spectral fundamentals, the cortical cell should respond optimally to a checkerboard pattern that is rotated 45° relative to either a square-wave grating or a plaid pattern that was oriented to produce the optimal response.

In both cats and monkeys, the procedure would be as follows. A micro-electrode would be inserted into a visual cortical cell to measure the number of action potentials (spikes) per second. The optimal stimulus parameters were first determined for the cell. The receptive field was located and the animal was positioned so that the receptive field was centered on the scope display. Then by experimenting with different sine-wave gratings, the optimum orientation and the optimum spatial frequency for the cell was determined. The optimum temporal frequency was determined by drifting the best grating pattern across the respective field at different rates.

If the cortical cell was functioning as a true edge detector, one would expect the square-wave grating, the checkerboard and the plaid to all induce maximal spikes/sec in the cell at the same orientation. The cortical response to the square-wave grating was determined with various angular rotations. Then the cortical response (# spikes/sec) was determined from the checkerboard at various angular rotations. The visual cortical cells responded optimally to the checkerboard pattern which was rotated 45° relative to the square-wave grating that was rotated to produce the optimal response (see **Figure 9**). This was evidence that the visual cortical cell was responding to the Fourier fundamentals, not as an edge detector.
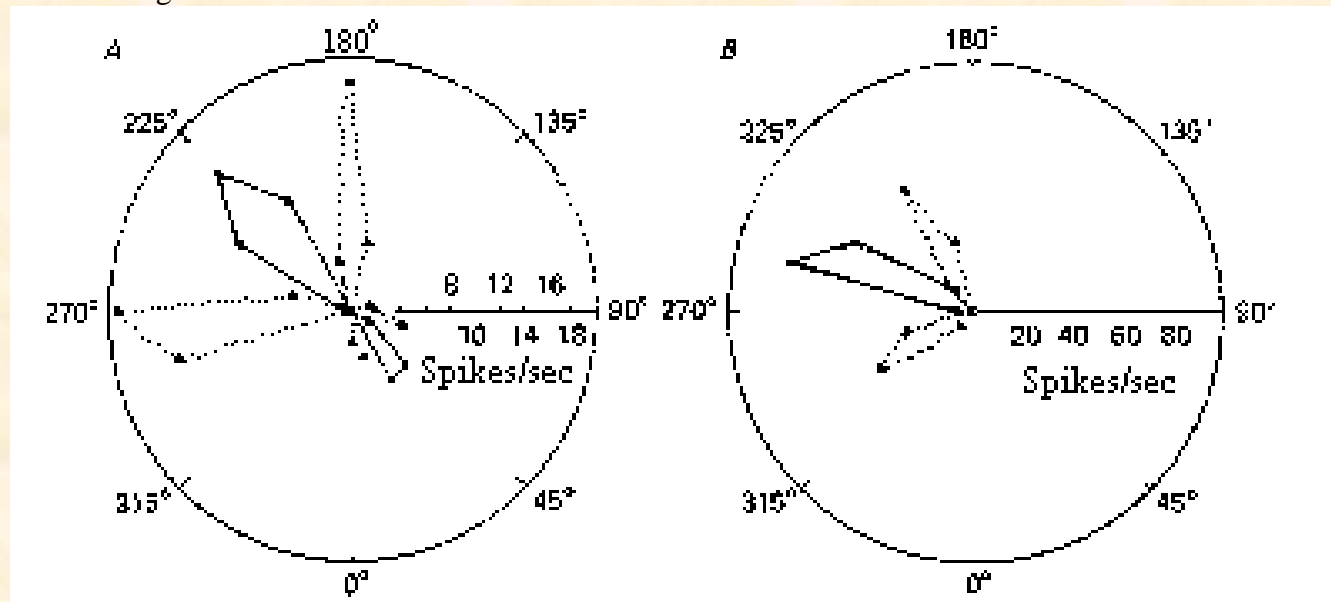

Figure 9
(Reproduced from De Valois et. al., 1979, page 489)

In another experiment, checkerboards stimuli of different check dimensions (1/1, 2/1, 0.5/1) were presented (to the animals) for comparison with the square-wave grating visual stimulus. The altered (orthogonal) dimension of the checkerboard checks should not matter if the visual cortical cells are responding to the unaltered edges. If, on the other hand, the visual cortical cells are responding to the fundamental Fourier frequency, the different checkerboard patterns would have to be rotated some to get the maximal spikes/sec from the cells.

Note how the Fourier fundamentals (the biggest dots) are at a different angle from the center in comparing figure 7B to 7C). It was indeed found that the different checkerboard patterns had to be rotated an amount that matched exactly to what would be predicted from the mathematics of the Fourier transform (the location of the Fourier fundamentals). When the data was re-plotted with the points rotated according to the mathematically predicted position of the Fourier fundamentals, it was found that a very good match existed. This was further evidence that the visual cortical cell was responding to the angular location of the Fourier fundamentals and not the edge of the squares (or grating) seen in the untransformed pattern.

In another experiment, plaid checkerboard patterns with the same dimensions were presented (with various rotations) as the visual stimulus to the experimental animals. Again, if the cortical cell was functioning as an edge detector, it would be predicted that the cell would respond optimally to the two patters at the same orientation (when the edges are at the same orientation). It was found, though, that the cortical cell responded optimally to a checkerboard pattern that was rotated 45° relative to the orientation of the plaid pattern (that had been oriented to give an optimal response).

The next batch of experiments were centered around the observation that the Fourier fundamentals for the checkerboard (with squares of the same width as the bars of the square-wave grating) were located farther out (from center) than the Fourier fundamentals for the square-wave grating. Thus, a test could be done to see whether the cortical cells were responding to the width (separation between lines) or to the spatial frequency of the optimally presented pattern. If the cortical cell was responding to the separation between edges, then the best match should be for a checkerboard with squares of the same width as the bars in the square-wave grating. If the cortical cell was responding to the Fourier fundamentals, then a checkerboard with a different sized check (or bar width) would induce the optimal response.

The "contrast sensitivity" was defined as that contrast of the pattern that was necessary to yield a particular number of spikes/sec for the cortical cell. The control was the square-wave grating with a bar width (and orientation) that produced the maximal cortical cell response. The experimental bar width (yielding the best response for the optimal orientation) for the checkerboard matched what was predicted from the Fourier mathematics (De Valois et. al., 1979). This provided more evidence that the visual cortical cell was responding to the Fourier fundamental and not the edges (or distance between the edges) of the visual stimuli.

In another experiment, the relative check dimensions were changed for the checkerboard patterns (2/1, 1.1, 0.5/1 ratios). Note from **Figure 7** that as one dimension of the check is changed, the distance (from center) of the Fourier fundamentals changes. It could then be determined what width (given a certain ratio) produced the best result (when oriented optimally). If the visual cortical cells were responding to the check width, then the different height/width ratios shouldn't influence the cell's response. If the cell was responding to the Fourier fundamentals, then it should respond optimally to different check widths when the height/width ratio changes.

It was found that the cortical cell responded optimally to checkerboard patterns of different widths and that these widths matched what was predicted from the Fourier mathematics De Valois et. al., 1979). When the data was plotted according to the theoretical prediction, the cortical cell was shown to be responding to the spatial frequency (the distance from center of the Fourier fundamental) for the various optimally oriented patterns. This was further evidence that the cortical cells were responding to the Fourier transform of the presented visual stimuli.

All of these experiments were repeated for multiple visual cortical cells in both the cat and monkey yielding similar results (data not shown in this report).

The next set of experiments examined whether cortical cells could be found that were sensitive to higher harmonic components of the Fourier spectrum. If so, then this would be powerful evidence that these cortical cells are acting like spatial-frequency filters (and not as edge and bar detectors). The higher spectral harmonics of the square-wave grating are at the same orientation as the fundamental frequency but the higher harmonics of the checkerboard are at other orientations (see **Figure 7**). If a cortical cell exhibits sufficiently narrow spatial tuning, it could potentially respond separately to the fundamental and the third harmonics of patterns.

For instance, imagine a square-wave grating with more narrow bars such that the fundamental frequency falls on what was the third harmonic for a square-wave grating with wider bars. A cortical cell sensitive to this spectral position, would respond to either stimulus (and the stimuli would be presented at the same orientation). For the checkerboard, the situation would be a little different. A smaller sized checkerboard pattern sufficient to produce a Fourier fundamental at the same frequency location as the third harmonic (that a larger sized checkerboard pattern would produce) would have to be

rotated some for the optimal response (to get the angle of the fundamental to fall on where the third harmonic would be for the other pattern).

It was demonstrated that a cortical cell (responding to a square-wave grating of a certain frequency and orientation) would also respond optimally to a square-wave grating with bar widths 3 times the size (which would be one third the spatial frequency) with the same orientation. The Fourier fundamental of the grating with the more narrow bars fell on the third harmonic of the grating with the wider bars. It was also demonstrated that the same cortical cell responding to a sine-wave grating (optimally at a certain frequency and orientation) would not respond to a sine-wave grating of 1/3 that frequency at the same orientation (remember that there are no harmonics for a sine wave).

In order for the cortical cell to optimally respond, a checkerboard pattern with check size of a certain size had to be rotated relative to the optimal rotational orientation of a checkerboard with checks that were three times larger producing the optimal response for the same cortical cell. This observed rotation matched the theoretical predicted rotation from the Fourier mathematics (De Valois et. al., 1979).

Similar experiments have been performed with the rat somatosensory system (Pribram, 1994) where the cortical cells were also found to respond to spectral information.

Other Aspects of the Holonomic Theory

Pribram says that both time and spectral information are simultaneously stored in the brain. He also draws attention to a limit with which both spectral and time values can be concurrently determined in any measurement (Pribram, 1991). This uncertainty describes a fundamental minimum defined by Gabor in 1946 (the inventor of the hologram) as a quantum of information. "Dendritic microprocessing" is conceived (by Pribram) to take advantage of this uncertainty relation to achieve optimal information processing. Pribram then says that the brain operates as a "dissipative structure" where the brain continually self-organizes to minimize this uncertainty. The next few sections will attempt to explain the concept of the Uncertainty Principle and the concept of "dissipative structures" that self-organize.

The Uncertainty Principle

Quantum **Physics**

In quantum physics, the Uncertainty Principle can be described in the following way (paraphrased from Pagels, 1982): Consider that you have a device that can simultaneously measure the position and momentum of a single electron. Every time you push a button, the device displays numerical values for the position and momentum. Although each time you press the button, you will get slightly different measurements for the momentum and position. If enough measurements are taken, then a statistical analysis can be performed.

Heisenberg defined the term Δq as indicating the "spread" or uncertainty of the position measurements around some average value and delta p as indicating the spread or uncertainty of the momentum measurements around some average value (for the series of measurements). He then found that $(\Delta q)(\Delta p) >= h$ where **h** is Plank's constant. For a series of measurements, the positions can be expressed as an average ± some uncertainty. Likewise for the momentum. No matter how good one makes a quantum measuring device, the products of the uncertainties can never be less than Planks constant.

For example, if you could build a measuring device that exactly determined the position (where $\Delta q = 0$) then you would not be able to determine anything about the momentum ($\Delta p = \infty$). There is a similar

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uncertainty relation for the energy of a particle and the elapsed time. For a series of measurements, the product of the uncertainty of the energy (ΔE) and the uncertainty of the elapsed time is always greater or equal to Planks constant [$(\Delta E)(\Delta t) >= h$].

Communication Theory

In communication theory, a variation on the Uncertainty Principle also holds (Gabor, 1946). The measurement of the frequency can be made with arbitrary precision. Likewise, the measurement of the time of occurrence can be made with arbitrary precision. But there is a <u>limit</u> to the precision when these measurements are taken simultaneously. One can exactly measure either the frequency (of for example a tone) or the time (of occurrence) -- but not both at the same time.

For instance, if the time of occurrence were known (indicating an impulse function) there would be frequency components all up and down the spectrum. If on the other hand, the frequency information was exactly known, one would not know any information about when it occurred. A single peak (or peak pair if you consider the corresponding negative frequency) in the spectrum implies that the tone has infinite extent in the time domain. Analogously to the quantum Uncertainty Principle, when frequency and temporal measurements are made simultaneously, there is a limit to the precision possible. Pribram claims that the brain functions as a dissipative structure to seek to decrease this uncertainty in the direction of its theoretical limit.

Dissipative Structures

The Second Law of Thermodynamics holds that the entropy always increases in any isolated system (**Figure 10**). This simply means that if something is left to itself, it will move towards equilibrium...it will move towards maximal disorder...its internal energy state will tend to be minimized. There has not been, to date, any confirmed observation that this law is invalid.
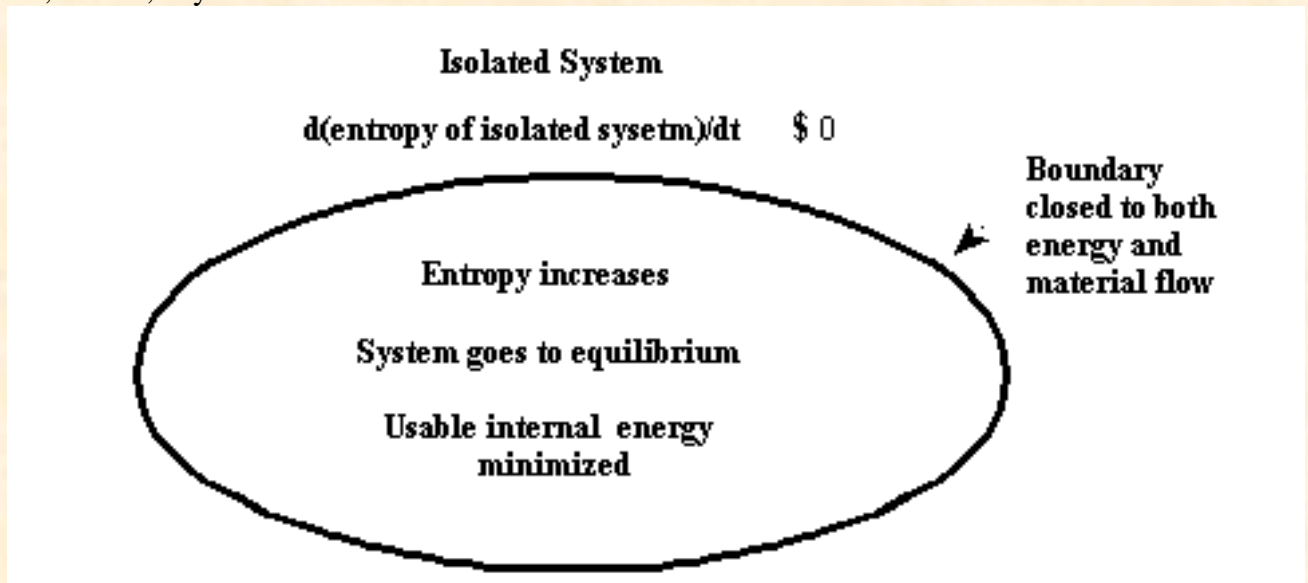
Isolated System

d(entropy of isolated sysetm)/dt $ 0

Boundary
closed to both
energy and
material flow

Entropy increases

System goes to equilibrium

Usable internal energy
minimized

Figure 10

An isolated system can itself be divided into a subsystem that is open to energy flow and the subsystem's environment (see **Figure 11**). As such, the whole combined isolated system still obeys the Second Law of Thermodynamics. But it is possible that the subsystem can experience a decrease in entropy at the expense of its environment.
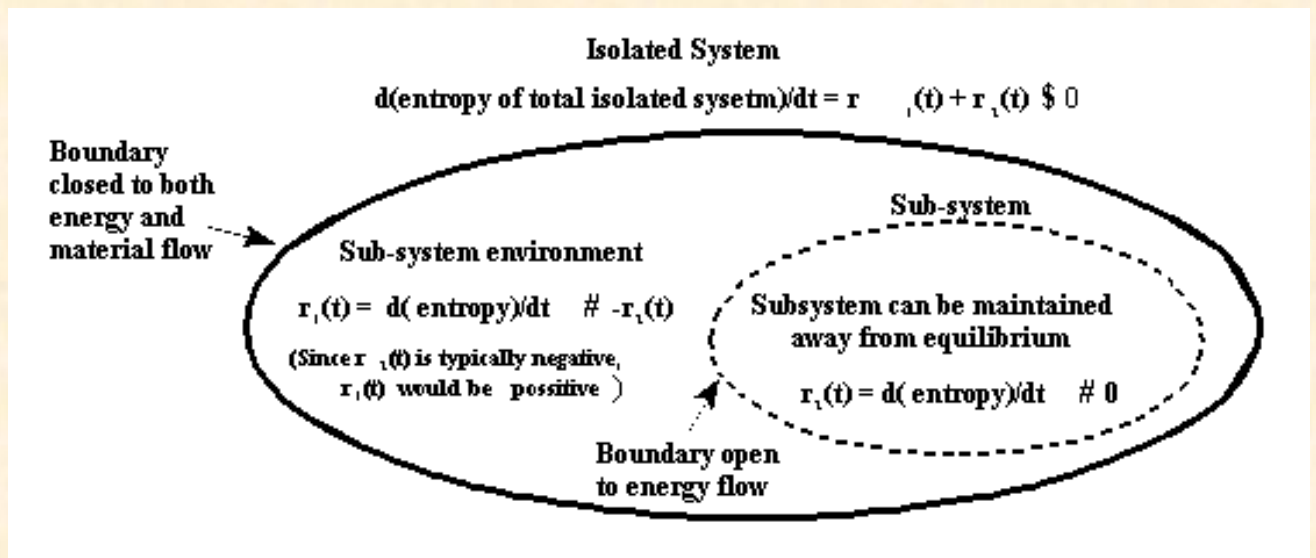
Figure 11

The entropy increase in the "sub-system environment" is guaranteed (by the second law) to more than offset the entropy decrease in the subsystem. Also note that the sub-system can only be maintained away from equilibrium as long as there is usable energy in its environment. When the environmental entropy is maximized (no usable energy), the subsystem is guaranteed to itself proceed to equilibrium.

There is a special class of such subsystems (as described above) where the subsystem's organization comes exclusively from processes that occur within the sub-system's boundaries. This class of subsystems was labeled "**dissipative structures**" by I. Prigogine, 1984 (who won the Nobel price for his work). Pribram believes the brain to be such a "dissipative structure".

One way of modeling a structure that goes to equilibrium is to minimize a mathematical expression for the internal energy (whi ch is the same as maximizing an expression for the entropy). This is called the **least action principle**. This would not be appropriate, though, for a "dissipative structure" since it is not going towards equilibrium. Dissipative structures self-organize around a different least action principle. In the holonomic brain theory, Pribram has the entropy being minimized (which maximizes the amount of information possible to store) as the "least action principle". Thus, the system (the brain) self-organizes such that more-and-more information can be stored.

In Hopfield networks and the Boltzmann engine (which are computer models of neural processing), computations proceed in terms of attaining energy minima. In the holonomic brain theory, computations proceed in terms of attaining a minimum amount of entropy and therefore a maximum amount of information. In the Boltzmann formulation, the principle of least action leads to a space-time equilibrium state of least energy. In the holonomic brain theory, Pribram describes the principle of least action as leading to maximizing the amount of information (minimizing the entropy).

Independently (in unrelated work), Schneider and Kay (1994) have proposed a variation on the Second Law of Thermodynamics which may be applicable to Pribram's holonomic theory.

> "The thermodynamic principle which governs systems is that as they are moved away from equilibrium, they will utilize all avenues available to counter the applied gradient. As the applied gradients increase, so does the system's ability to oppose movement from equilibrium".

It would be interesting to see if there is a connection between the work of Schneider and Kay and Pribram.

The holonomic brain theory maintains that the brain is continuously engaged in correlation processes. This is how we make associations (how the senses are integrated). There is an obvious computational advantage for the brain storing sensory information (and perceptions) in the spectral (or holographic) domain as opposed to the brain directly storing individual features and characteristics.

The holonomic brain theory claims that the act of "re-membering" or thinking is concurrent with the taking of the inverse of something like the Fourier transform. The action of the inverse transform (like in the laser shining on the optical hologram) allows us to re-experience to some degree a previous perception. This is what constitutes a 'memory'.

Chapter 5 - Conclusions

General Comments

The medium of the optical holography (the silver grains on the photographic film) encodes the Fourier coefficients. In the holonomic brain theory, the Fourier coefficients are stored as the micro-process of polarizations and depolarizations occurring in the dendritic networks.

Both Pribram's theory and the more conventional theory have the brain divided up into various functioning communicating modules. One main difference is in how the information is stored in these brain modules. For example, in the case of vision, the conventional theory has specific features stored in certain dedicated cells. These different sub-modules then have parallel pathways to other modules that produce the combined visual experience. This would be somewhat analogous to a computer performing signal processing directly on an image. For example, dedicated circuitry for edge detection would interface with other circuitry for other features like color. Every feature of the image gets stored (or processed) in different dedicated "circuitry". These "circuits" then have parallel pathways to other brain regions in which the collective subjective experience of the perception is formed.

The holonomic theory (for the example of vision) summarizes evidence that the image formed on the retina is transformed to a holographic (or spectral) domain. The information in this spectral "holographic" domain is distributed over an area of the brain (a certain collection of cells) by the polarization of the various synaptic junctions in the dendritic structures. At this point, there is no longer a localized image stored in the brain. Correlations and associations can then be achieved by other parts of the brain projecting to these same cells. C onscious awareness (and memory) is the byproduct of the transformation back again from the spectral holonomic domain back to the "image" domain.

Possibly the most radical part of the holonomic theory is Pribram's claim that a "receiver" is not necessary to "view" the result of the transformation (from spectral holographic to "image"). He claims that the process of transformation is what we "experience". Memory is a form of re-experiencing or re-constructing the initial sensory sensation.

Conventional neuro-physiology effectively pushes back the line between observer and what is observed (between 'subject' and 'object'). In signal processing, there always needs to be an end-user to view the processed or transformed signal. At best, conventional neuro-science leaves until later the ultimate explanation of the observer. Who would bet their grant money (career) on being able to answer this question in a couple of years? Aspects of Pribram's holonomic brain theory attempts to address this

question.

The conventional view is that the brain is a computational device. There is a growing body of literature, though, that shows that there are severe limitations to computation (Penrose, 1994; Rosen, 1991; Kampis, 1991; Pattee, 1995). For instance, Penrose uses a variation of the "halting problem" to show that the mind cannot be an algorithmic process. Rosen argues that computation (or simulation) is an inaccurate representation of the natural causes that are in place in Nature. Kampis shows that the informational content of an algorithmic process is fixed at the beginning and no "new" information can be brought forward. Pattee argues that the complete separation of initial conditions and equations of motion necessary in a computation may only be a special case in nature. Pattee argues that systems that can make their own measuring devices can affect what they see and have "semantic closure".

It is possible that the brain transcends computational behavior. If this is the case, then it will be very interesting to see what aspects of Pribram's holonomic theory are in collaboration with these non-computable ideas.

Conclusions

Karl Pribram's holonomic brain theory weaves several concepts together in forming the holonomic brain theory. A partial list is the following:

1. The apparent spectral frequency filtering aspect of cortical cells.

2. The relationship between Fourier transforms and holograms.

3. The fact that selective brain damage doesn't necessarily erase specific memories.

4. The computational advantage to performing correlations in the spectral domain.

5. His idea of conscious experience being concurrent with the brain performing these Fourier-like transformations (which simultaneously correlate a perception with other previously stored perceptions). He believes that conscious experience is the act of correlation itself and this correlation occurs in the dendritic structures by the summation of the polarizations (and depolarizations) through the processes in the dendritic networks.

6. The brain is a "dissipative structure" and self-organizes around a least-action principle of minimizing a certain uncertainty relation.

Most conventional experimental neurophysiologists are content just to gather neurological data independent from any global theory of the brain/mind and leave a theory of the brain to future generations. As such, Karl Pribram is not referenced in many of the major neuro physiology textbooks (such as Principles of Neural Science by Kandel, Schwartz, and Jessell, 1991). This is unfortunate because it helps to have a theory in asking important experimental questions. With a different theory comes different questions which can lead to new and different experiments that can bring forth novel information.

Hopefully, Pribram's ideas (or variations on them) will eventually find their way into the consciousness of the conventional neurophysiologist (and appear in most textbooks) once the current fascination with molecular biology runs its course. Then the attention of physiologists may again be directed back toward a system's organization and away from simply analyzing its parts.

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