Holography is more than just making pictures

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In the year 2000 we shall celebrate the centenary of Nobel-prize laureate Dennis Gabor, who is known as the father of holography, a fascinating new display technique. However, Dennis Gabor was not only an engineer and inventor, as he often spoke of himself, but also a real humanist, in the sense of the Renaissance. As one of the founding fathers of the Club of Rome, he fertilized and enriched with his method of approach not only the physical and technical, but also the economical and environmental sciences, and even philosophy. The scope of this presentation is to show in the spirit of Gabor, why the concept of holography is more than just making pictures that preserve not only form but also space impression of the environment.

Perceiving the structure of the environment

We consider our environment to be a three-dimensional space, not a formal space, though, developed by mathematicians, but rather a *physical space*, which is mostly experienced by touch, muscle tension and movement, and which manifests itself in most of us primarily by vision, as a *cortex space* in our mind where our sensations are addressed to.

The visual space, i.e., an imprint of a three-dimensional visual world, results as encoding signals carried by electromagnetic waves of a given frequency, and scattered by object points in space. The problem, however, is that these signals, originating from various 3D space coordinates and in different time, are projected on a two-dimensional surface of a square-law energy detector, the *retina*. But how can the visual system encode "depth" as a geometric quantity to time if the retina is sensitive only to the intensity (i.e., amplitude square) of the signal carrying waves, and not to their phase relations?

The answer can be given by applying the concept of the "relevant future" introduced by Gabor.

Relevant future

It is well known that signals describing changes in the environment are carried by mechanisms that can interpret energy packs as waves (by electromagnetic waves in the case of light, by mechanical waves in the case of sound, etc.). Therefore, if we want to lay claim to the *entire* information content, we have to make analysis not only with respect to temporal function or frequency, but we also need mechanism of processing patterns of signals that enable the *simultaneous* analysis of the time/space range and function range, i.e., where the *symmetry* is - not lost, but - preserved. However, as shown by Gabor (1), in the course of complete processing of the elementary signals (called *logon*s by Gabor) strictly taken *causality* is valid only in the language of time. As soon as we want to consider frequency as well, uncertainty - called the *termination of causality,* or the *uncertainty* relation of modern physics - arises. Nevertheless, according to him, this problem can be solved, but for this "*it is not enough to know the past, one has to know the future as well*", but the duration of this "*relevant* future" is not fixed. It can be limited to an amazingly short period of time, further, this relevant future can be "created" by the processor of the signal (or patterns of signal) for the period of signal processing, e.g., by delaying the processing of some of the individual signals, i.e., it is sending future back to the past. Basically this happens when a hologram is created.

For when a hologram is recorded, the so-called *reference background* constitutes the relevant future, which will enable the analysis of the light waves simultaneously in the dimensions time/space and frequency. Thus, it will not let the symmetry of time/space and frequency get lost, the only precondition that makes upon the reconstruction of the hologram the perception of the three-dimensional aspect of space via the signal carried by the light waves possible.

Perhaps the very first unexpected result of such a signal processing strategy is that it always renders a solution with two outcomes. Mathematically speaking, the two outcomes are complex conjugates. In order to make this mathematical expression clearer, one should consider that whenever a hologram is reconstructed with the help of its reference background (relevant future) the three-dimensional object will be seen in space and place where it was at the time of recording, i.e., from where the optical signal came; nevertheless, one cannot touch or grasp the object itself, because the image formed in our mind, i.e., the three-dimensional scene observed is the "*virtual* content" of this signal processing strategy, while its *complex conjugate, the real image,* – which is also three-dimensional, – can, however, be seen only when projected on a two-dimensional screen, but, in this case, the time-related information, the depth of the three-dimensional physical space, is lost

In the mid 60s I demonstrated that this spatial signal processing strategy, which preserves both amplitude and phase bound information is valid not only for signals carried by electromagnetic waves, but also for mechanical, ultrasonic waves, i.e., acoustical holography is possible (2). At that time, during a discussion with Gabor, I suggested that the relevant future concept – sometimes also called as a *two-step process* – may be used to explain some biological signal processing results which otherwise seem to be inexplicable. So, e.g., echo-locating animals, such as bats, dolphins, etc., - in spite of the fact that their signal receptors are square-law detectors - can distinguish between targets of various shapes, they know whether bars in their way are horizontal or vertical, further, they can discriminate between their own signals and those emitted at the same time by their companions, although the frequency of the pulses is the same. Further, the signals reflected by the targets are in some cases 2000 times fainter than the background noise.

According to my model based on the "relevant future" signal processing concept (3), when a bat emits an ultrasonic impulse of a certain frequency, at the same time that part of the brain which *ordered* the pulse to be emitted sends a stimulus pattern to that part of its brain from where the target reflected ultrasonic impulse pattern is received by a square-law detector and processed. This stimulus pattern acts then as relevant future, as a coherent reference background (when speaking in holographic language) and, as a result, the phase bound information necessary for 3D shape discrimination is not lost. This biological signal processing model was backed up by histological findings, and also by the fact that when the ambient noise level becomes high, bats are increasing ***only*** the intensity of their reference stimulus, and not the intensity of their emitted ultrasonic impulse, as a consequence of the two step signal processing practice. When Gabor encouraged me to refine my concept, I started to develop a more generalized biological signal processing model which could be used to explain, e.g., vision related phenomena (4)

A biological signal processing model

Starting from the reports of Sokolov, Bishop and others, that somewhere the sensory input is matched against a comparator before being relayed further in the central nervous systems (CNS), a more-or-less generalized biological signal processing model using the “relevant future” concept was developed. This model regards the incoming signal pattern, i.e., its description function, as a wavefront represented either as a Fresnel or a Fourier transform,. Both operations show self reciprocity, only in the Fresnel transformation the sum of the parameters is appearing, while in the Fourier transformation, their product. In this model, the CNS acts as a Fourier analyzer using holographically matched spatial filters for pattern recognition. It has, however, to be emphasized that this simple model (5) consists only of those function groups that are necessary to describe visual 3D pattern recognition processes, but does not claim morphological equivalents. According to this model a stimulus model is generated by the optical signal pattern acting on the visual receptor field, the retina. When passing through a function group, a matrix of neurons induces another stimulus pattern. This acts then as the “relevant future” for a group of neurons storing spatial filters (e.g., 2D Gabor filters) in a holographic form.

More or less at the same time, another matrix of neurons delivers the Fourier spectrum of the signal carrying stimulus pattern and interacts with the neuron matrix storing the spatial filters. The result of these operations is a stimulus pattern having a complex conjugate form, which shows that the visual system is concerned with extracting information jointly in the 2D space domain and in the 2D frequency domain. However, because of this incompatibility of these two domains (resulting from the uncertainty relation) the “nature” of the 2D filter strongly influences the “interpretation” of the visual encoding which, however, explains why the same 3D spatial optical signal pattern may have different “meaning”, may raise various emotions, etc. So, e.g., the optical signal pattern **BOLT** reaching the retina and processed by a “Hungarian-type” filter conveys the information “*shop*”, but when an “English-type” filter is used in processing, “*rod”* or “*pin*”. Or the optical signal pattern **FOG** in the first case means “*tooth*”, and in the second, “*haze*”.

The feasibility of such a biological signal-processing model may be backed up by paraphrasing as follows the famous Second Dogma of Barlow (6)

> “The visual system is organized to achieve as complete a representation of the visual stimulus as possible in both 2D spatial and 2D spectral terms with a minimum number of 2D filters”

and by the experimental findings of Daugman (7), who studied the properties of human spatial visual channels in two-dimensional form by a signal detection masking paradigm.

Hamlet speaking from the Fourier-plane

According to the biological signal-processing model presented, the visual system uses neural matrixes functioning as spatial filters in a holographic form, and the CNS acts as a Fourier analyzer. Thus, it can be assumed that, if this model is a functionary one indeed, *non-specific* stimuli (e.g., electric or magnetic stimulation, etc.) when acting on such a function group, may result in a *visual* pattern sensation characteristic to the filter pattern the CNS used in its signal processing. Such so-called “subjective light patterns of the second kind” are not unknown in physiology (phosphenes) and in psychiatry (hallucinations).

In my earlier investigations (8) I found that some of them might be regarded as a perceived filter pattern. I believe that we are not too far from the truth when we think that artists – without being aware of– are using such subjective light patterns of second kind when expressing themselves (9). At the Experimental Photography Exhibition of this Symposium, in my tableau entitled “*Hamlet speaking from the Fourier plane*”, (See: Fig.) I tried to show what form of stimulus pattern that we are not aware of may glide over our CNS when acting as a Fourier analyzer during reading the text “*to be or not to be*” and its Hungarian counterpart “*lenni vagy nem lenni*”. Can this tableau be regarded as an artwork?

Closing remark

The original name of the presented biological signal-pattern processing model was *bioholography*. Unfortunately, there has been some misunderstanding regarding this description, not understanding that this is a functional scheme, and not a morphological equivalent. Some people, bordering on charlatanism, already talked about the interference of waves in the brain, and even about tuned systems of resonators. Therefore, at the conference of "Building HAL" (Normal, Alabama, August 1992), H. J. Caulfield, J. Shamir, and P. Greguss suggested that it would be more useful to replace the expression *bioholography* with the etymologically equivalent *biomalehgraphy*.

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Caption of Fig.: P. Greguss: Hamlet speaking from the Fourier-plane. 1999.