Processing of Optical Data by the Visual System of Insects

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The visual system of the fly performs various computations on photoreceptor outputs. The detection and measurement of movement of an object in the environment is based on nonlinear multiplication-like interactions between adjacent pairs and pairs of groups of photoreceptors. The position of a small contrasted object against a uniform background is measured, at least in part, by nonlinear flicker detectors. A fly can also detect and discriminate a figure that moves relative to a ground texture.
This computation of relative movement relies on a more complex algorithm, one which detects discontinuities in the movement field. The experiments indicate that the outputs of neighbouring movement detectors interact in a multiplication-like fashion and then in turn inhibit locally the flicker detectors.
The following main characteristic properties, partly a direct consequence of the algorithm's structure, have been established experimentally:

a) Coherent motion of figure and ground inhibit the position detectors whereas incoherent motion fails to produce inhibition near the edges of the moving figure, provided the textures of figure and ground are similar.
b) The movement detectors underlying this particular computation are direction-insensitive at input frequencies (at the photoreceptor level) above 2,3 Hz. They become increasingly direction-sensitive for lower input frequencies.
c) At higher input frequencies the fly cannot discriminate an object against a texture oxcillating at the same frequency and amplitude at 0° and 180° phase, whereas 90° and 270° phase shift between figure and ground oscillations yields maximum discrimination.
d) Under conditions of coherent movement, strong spatial incoherence is detected by the same mechanism.

The algorithm underlying the relative movement computation is an example of a coherence measuring process, operating on the outputs of an array of movement detectors. This computational process is in a sense analogous to the interference with light waves that leads to the formation of a hologram. In order to avoid misinterpretations, the analogy drawn here has to be considered with some caution. The results of the "holographic" computations, carried out by the visual system of the fly, under the conditions of relative motion, are not stored for a long time. In a typical figure-ground test, the response of a fly drops to zero in about a second after figure and ground are oscillated in synchrony. A hologram, stored on a photographic plate, practically lasts for ever.

Much more important however is the fact that the photoreceptors of the fly receive light from small solid angles that overlap only with the receptive fields of neighboring photoreceptors. A typical point on the photographic plate, where a hologram is stored, may in principle receive radiation from a solid angle of 2π. This property is a necessary requirement for the holistic feature of information storage whereas in the fly the collection of optical data is confined to rather local regions of neighboring receptive fields of photoreceptors or neuroommatidia.

The conclusion is that the evaluation of relative movement by the visual system of the fly makes use of computations analogous to those that take place during the process of hologram formation, without leading, however, to a holographic pattern of the fly's optical environment.
The point stressed here is the experimentally established fact that the fly is equipped with neuronal components whose functions could be implemented for the processing of information if the nervous system were to process and possibly store data in holographic fashion.