Motion and Interaction

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1 Mechanisms of Motion Perception

Light enters the eye, is focused by the cornea, passes through the variable-diameter iris, is further focused by the lens, and strikes the light-sensitive receptors of the retina in the back of the eye. From the photoreceptors, neural responses pass through a series of linking cells, called bipolar, horizontal, and amacrine cells, which combine and compare the responses from individual photoreceptors before transmitting the signals to the retinal ganglia cells [Figure 4]. These linkages between neighboring cells provide a mechanism for lateral inhibition, whereby the response of a cell is attenuated by a large response in nearby cells. This mechanism facilitates relative, rather than absolute, judgments of intensity, emphasizing edges and other areas of change in the visual field.

In the retinal ganglia cells the visual system splits into two independent pathways [Livingtone88]. The magnocellular pathway detects objects and their boundaries, as well as providing a basis for the perception of depth and motion. This pathway begins in a subset of the retinal ganglia cells with large receptive fields and receives input from the achromatic opponent color channel. All processing along this pathway is independent of the wavelength of light received, depending only on its intensity. The parvocellular pathway is responsible for the perception of color and fine detail. This pathway receives input from all three opponent color channels. These two pathways function independently and the judgments of each are reconciled at a much later stage in visual processing.

Neural responses leave the eye via the optic nerve, passing through the optic chiasm where visual responses from each side of the visual field are sent to the opposite side of the brain, and to the lateral geniculate nucleus (LGN) located deep in that side of the brain. Each LGN (one for each side of the visual field) is structured into six layers. Two layers belong to the magnocellular pathway, each receiving input from the achromatic opponent color channel originating in one retina. The remaining four layers belong to the parvocellular pathway and receive input from all three opponent color channels. The LGN also receives a large amount of input (approximately 60 percent) from later stages of the visual pathways in the cortex. These upstream connections appear to provide a mechanism for expectations and previous perception to influence even the early stages of visual processing. From the LGN, visual signals proceed to the primary visual cortex, visual area 2, and then to various areas of higher visual processing.

The *magnocellular pathway* determines the locations and boundaries of objects in a scene. The anatomy of this pathway appears to include the achromatic opponent color channel, the magnocellular layers of the LGN, layers 4Ca and 4B of the primary visual cortex, the stripes in visual area 2 responsible for stereo and form perception, the middle temporal lobe (MT), and perhaps the parieto-occipital region responsible for tasks involving the positions of objects. The characteristics of processing done by this pathway closely match the inherent requirements of its tasks. All judgments are made without regard to difference in wavelength; only brightness differences are considered. Compared to the parvocellular pathway, receptive fields are large, responses are fast and transient, and only small contrast differences are required for discrimination.

Later stages of the magnocellular pathway, particularly MT, have a large number of cells which are selective to movement and direction, suggesting that this pathway is also responsible for motion perception. Motion sensitive cells respond most strongly to stimuli which are moving across their receptive field. Additionally, most motion sensitive cells are selective to the direction and velocity of motion. This motion perception pathway functions independently of other visual pathways, as demonstrated by a few people who have no motion perception but have otherwise normal vision. Motion plays several roles in human vision. At the most basic level, motion makes pattern vision possible by ensuring that the stimulus on an area of the retina is constantly changing. Motion gives valuable clues to our relationship with our environment: where to direct our eye movements, the time to collision with objects around us, and information about the location of parts of our body relative to other objects (exproprioceptive information). Motion also provides information about the relative depths, 3D structure, and grouping of objections that we see.

Judgments made primarily by the magnocellular pathway, those of object boundaries, stereopsis, or motion, break down under conditions with no brightness differences between objects. The term *equiluminance* is used to describe the condition where the appearance of objects in the scene differs only in hue and saturation, not in brightness. Visual relationships that break down or degrade under equiluminance include perspective depth cues, depth cues from relative motion, linking by common movement or collinearity, illusory borders, and illusions of size.

2 Roles of Motion Perception

Motion perception has a number of roles in human vision beyond the simple perception of moving objects. These include the stimulus change necessary for any pattern vision, the information used to drive eye movements, estimates of time to collision with objects in the environment, and exproprioceptive information about the relationship of the observer to the environment. At a somewhat higher level motion provides information about the relative depth of objects, the 3D structure of complex objects, and the grouping of objects in a scene. In all three of these functions, the visual system uses differential velocities across the visual field to make inferences. Deductions about relative depth can be made from assumptions of the relative size of objects and the relative magnitudes of the their velocity across the visual field. 3D shape can be inferred from relative motion of points on an object using an assumption of rigidity for the object. Discontinuities in the velocity field indicate boundaries of objects or object groups. It is these higher level roles of motion perception which are most useful as carriers of visualization freight.

3 Interactive Control

Psychological research supports the importance of interaction, as well as motion, to accurate perception. Interaction is the state of being able to change the contents of, or at least control the view of, what one is viewing. Held and Hein showed that control over visual experience, rather than just the visual experience itself, is necessary for the normal development of the visual system of cats [Held63]. Kittens who passively received visual stimulation never developed the ability to perform visually-guided behaviors.

Shneidermann [Shneiderman83] introduced the term *dynamic manipulation* to describe an interaction style involving visibility of the object of interest, rapid reversible actions, and replacement of a complex command language with physical action. A research area called *Dynamic Graphics* [Cleveland88] has grown out of the statistics field placing an emphasis on highly interactive displays for statistical information display. Arthur, Booth, and Ware [Arthur93] and Ware and Franck [Ware95] evaluated 3D task performance in the presence and absence of stereoscopic display and head-coupled view position. Van Damme [vanDamme94] compared 3D shape perception under conditions of dynamic head-coupled viewing of a stimulus with passive viewing of a moving stimulus. Smets and Overbeeke [Smets95] compared performance of a spatial assembly task under conditions of a still camera, passive camera motion, and head-coupled camera movement. All have found dynamic control to be a powerful tool in the understanding and manipulation of information. However, most of these have limited the scope of research to dynamic control over view of the scene rather than of more general representation parameters.

Rheingans [Rheingans92] investigated the role of dynamic control of the parameters of the mapping from data to display. She looked at the effects of control (none, interactive, and dynamic) and update rate on understanding of quantitative bivariate socio-economic data and found that increasing control increased subject preference, accuracy, and confidence, while update rate had little effect. That experiment showed that control increased accuracy (an average of thirty-nine percent) and confidence in tasks requiring judgements about the data value at a specified position (i.e. quantitative understanding. Rheingans [Rheingans97] also posed similar questions about a different type of task involving judgements of the distribution of values across the data domain (i.e. qualitative understanding). This experiments showed a statistically significant advantage to control in both accuracy and confidence in both shape identification and position comparison tasks.