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Abstract. A neural network model of early visual processing offers an explanation of brightness effects often associated with illusory contours. Top-down feedback from the model’s analog of visual cortical complex cells to model lateral geniculate nucleus (LGN) cells are used to enhance contrast at line ends and other areas of boundary discontinuity. The result is an increase in perceived brightness outside a dark line end, akin to what Kennedy (1979) termed "brightness buttons" in his analysis of visual illusions. When several lines form a suitable configuration, as in an Ehrenstein pattern, the perceptual effect of enhanced brightness can be quite strong. Model simulations show the generation of brightness buttons. With the LGN model circuitry embedded in a larger model of preattentive vision, simulations using complex inputs show the interaction of the brightness buttons with real and illusory contours.

Introduction. Many cases of apparent brightness enhancement are found in figures with substantial border contrast, such as the Kanizsa square in Figure 1. Border contrast refers here to enhanced brightness generated along and within the edges of relatively large regions of an image. In one class of figures, however, apparent brightness is perceived in regions demarcated by the ends of thin lines. The most famous of these figures, studied by Ehrenstein (1941), is shown in the right side of the figure below.

Figure 1: Left: Border contrast is seen in the Kanizsa square (patterned after Kanizsa, 1955). Right: An Ehrenstein disk (after Ehrenstein, 1941) is a good example of line end contrast. Note the bright central region bounded by an illusory contour in both figures.

In the Ehrenstein figure an illusory contour forms the circular border that most people see in the center of the figure. This border is a figment of your visual system; there is no continuous circular border formed by the pigments on the printed page. Likewise, the
luminance inside the circle is exactly the same luminance as the white background, yet to most people the central disk appears brighter.

Figure 2: Center-surround cells are more activated along the side of a line than the end.

Border contrast is easily explainable by center-surround mechanisms; no satisfactory mechanism for line end contrast has yet been suggested (see Figure 2). Kennedy (1979) hypothesized that line end contrast occurs even for single line ends and called the region of increased brightness outside a line end a brightness button. We propose that brightness buttons are concomitants of corticogeniculate feedback.

The Model. We simulated a model of the neural circuitry of LGN and V1 that extends a theory of preattentive vision in which image contrasts are grouped into emergent boundary segmentations by a Boundary Contour System (BCS) and generate surface properties of brightness, color, and depth using a Feature Contour System (FCS) (Grossberg & Mingolla, 1985; Grossberg, Mingolla, & Todorović, 1989; Grossberg & Todorović, 1988). The LGN stage receives input from retinal ON and OFF shunting networks that help to compensate for variable illumination, or discount the illuminant (Grossberg & Todorović, 1988). For many parts of an image, the LGN model passes these signals on to cortex unaltered. However, the LGN cells also receive feedback from model complex cells (see Figure 3), and this feedback can affect the processing of the retinal input.

Corticogeniculate feedback has been known for sometime to exist (Singer, 1977) and has been proposed as one means of stabilizing the cortical development and selection of binocularly consistent LGN signals (Grossberg, 1980). Here we suggest that these
Figure 4: Upper left: Eight line segments arranged as shown produce illusory boundary completion and enhanced brightness between their inner segments. Upper right: The LGN stage output shows the brightness buttons at line ends. Lower Left: The output of the BCS localizes the luminance boundaries and also completes illusory boundaries. Lower right: The LGN stage output (upper right) diffuses within the FCS by a process of surface filling-in until it hits the BCS boundaries (lower left). The resulting distribution of brightness simulates the pattern perceived by humans.
feedback signals may also enhance contrast at line ends and other areas of sharp boundary curvature. This can be accomplished by two distinct mechanisms. Type 1 feedback inhibits cells in the LGN whose receptive field centers are topographically aligned with corresponding cells in cortex that are characterized by strong oriented responses. This inhibition reduces the strength of signals along the sides of a line so that the signals at the line ends become relatively stronger. In type 2 feedback, a population of endstopped cells sends excitatory feedback to corresponding cells in LGN, boosting signals near line ends (see Figure 3). The result of both types of feedback is increased contrast at line ends. This increased contrast forms a brightness button, and it also allows a stronger oriented response perpendicular to the line end, which increases the strength of grouping signals that are used to segment the scene, including the formation of illusory contours (Grossberg & Mingolla, 1985).

Brightness button signals can thus be generated in two ways consistent with reported physiology (Grieve & Sillito, 1991; Weber, Kalil, & Behan, 1989): (1) Net inhibitory feedback from complex cells, modulated by LGN interneurons, can suppress activity in LGN cells coding the sides of lines, making ON/OFF contrast at line ends relatively stronger. (2) Excitatory feedback from cortical endstopped cells can enhance LGN cell activity near line ends. A combination of the two mechanisms also works. Figure 4 shows how these brightness buttons generate the percept of a bright circular disk in response to an Ehrenstein figure, as seen in Figure 1. The brightness buttons diffuse within the FCS until they hit the illusory boundaries generated by the BCS. Note that the illusory contours help to form spatially sharp discontinuities in the model output between the disk region and the background. Details of simulation methods can be found in Gove (1993).

References


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