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Ambiguity in 3-D patterns induced by lighting assumptions

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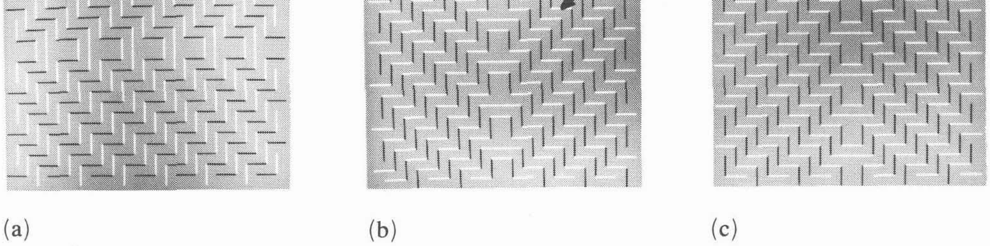
Abstract. A bistable pattern is shown with white and black bars with horizontal and vertical orientations which produce an impression of thin slabs stacked up in depth either toward or away from the observer. It is postulated that the ambiguity is induced by the observer's assumption of the direction of the light source.

In our efforts to study the roles that orientation and luminance polarity play in texture segregation (Gorea and Papathomas 1989, 1990; Papathomas and Gorea 1990; Papathomas et al 1990), we almost accidentally produced the images shown in figure 1, in which white and black bars with horizontal and vertical orientations form staircase patterns. These patterns produce vivid impressions of three-dimensional objects arranged in depth. One possible percept is that of thin slabs, stacked on top of each other. Another is that of 3-D steps or stepped rows of seats.

The arrangement of both the top and bottom halves of figure 1a seems to have two possible stable interpretations: as we traverse the path shown by the arrow, the slabs are stacked up either toward or away from us. These two stable states seem to alternate either spontaneously or at will for trained observers, as we shall discuss shortly. As a result, when one views figure 1a in its entirety, the top and bottom halves may induce either a coherent global percept or, as most of our casual observers noticed, a conflicting one; in the latter case, the observer fails to perceive figure 1a as a single, coherent, 3-D structure.

By contrast, the two halves of figures 1b and 1c, which are identical with figure 1a but merely rotated by 90° counterclockwise and clockwise, respectively, always produce a dominant stable interpretation, as the reader may verify. Figure 1b (or 1c) forms the impression of a convex (or concave) solid angle along the vertical border, in which the slabs are stacked toward the observer in the direction of the arrow.



(a) (b) (c)

Figure 1. Staircase patterns referred to in the text.

One way that figure 1b can be visualized, for example, is as an edge of an ancient pyramid when viewed from above. In addition to the dominant percept in figures 1b and 1c, there is a latent percept in each, not easily obtained, in which the angles become concave and convex, respectively.

One possible explanation, which accounts for all the percepts described above, is in terms of the assumption the observer makes on the position of the light source. The images of figure 1 can be thought of as parallel (not perspective) projections of the structure shown in figure 2a, which attempts to depict part of the top half of figure 1a. The three principal unit vectors are shown for reference, with $\hat{z}$ coming out of the page (right-handed coordinate system). If we assume that the parallel light rays (coming from a source located an infinite distance away) have a strong component in the $-\hat{x}$ direction, a weak component in the $-\hat{z}$ direction, and no component in the $\hat{y}$ direction, then the orthographic projections along lines of sight $-\hat{z}$ (front view) and $-\hat{x}$ (side view) would be as shown in figures 2b and 2c, respectively.

In this interpretation, the image-plane normal, ie the direction in which the eye is located, is along the vector $(\hat{x}, \hat{y}, \hat{z})$. The percept is that slab A is in front and occludes part of the slab B which, in turn, partially occludes slab C. The volume of each slab lies *below* the staircase contour. Parenthetically, we have assumed Lambertian surfaces, which diffuse the incident light in all directions, with the intensity of the reflected light proportional to $\cos u$, where u is the angle between the surface normal and the vector pointing to the light source (this explains the gray, black, and white intensities).

However, if we assume the light source in the opposite direction and we go through an analysis similar to that outlined by figure 2 (but with a different coordinate system), we now get the second stable percept in which slab C is in front and partially occludes slab B, which, in turn, occludes part of slab A; here, however, the volume of each slab lies *above* the staircase contour.

Our explanation of the bistable percept is that, in the case of figure 1a, both directions of the light source (from the left or from the right) are equally likely and equally easy to be adopted by the observer, either spontaneously or at will. Experienced observers can switch between the two percepts at will and all of them report that the easier way to do that is by deliberately assuming the light source in one of two opposing directions. However, most of the naive observers report their inability to perceive figure 1a as a coherent structure. In order to experience such a

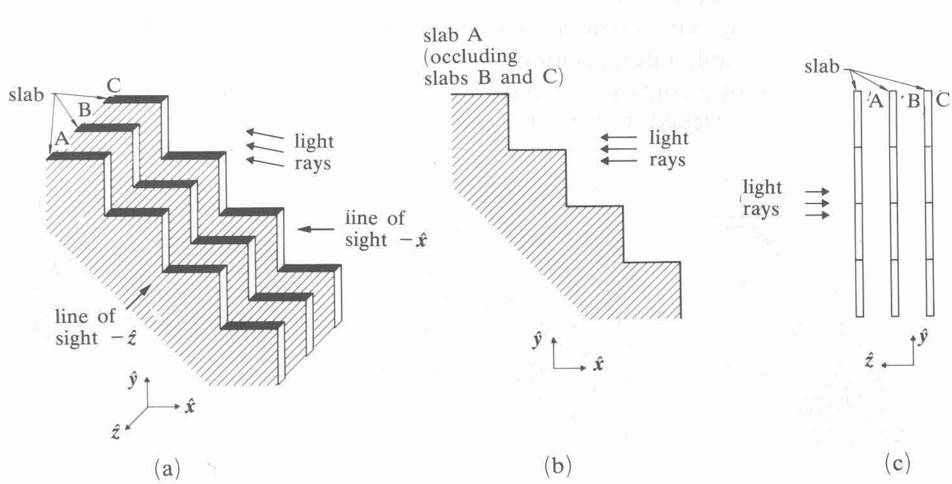


Figure 2. (a) The structure shown in top half of figure 1a, and (b) and (c) its parallel projections.

coherent whole, the observer (or his/her visual system) needs to assume the existence of two, mutually exclusive, light sources. We conjecture that this is not a natural task for the visual system.

By contrast, the inherently dominant assumption of a source shining from above, a consequence of living on Earth with the Sun overhead (Brewster 1847; Kaufman 1974; Yonas et al 1979; Ramachandran 1988a), produces the stable percept described earlier for figures 1b and 1c. In fact, the suppressed percept may be obtained in figures 1b and 1c, perhaps with difficulty, if one assumes a light source shining from below. In both cases, however, the assumption of a single light source is necessary (Ramachandran 1988b). We mention parenthetically that it is much more difficult to obtain the suppressed percept in images composed of shaded hemispherical shapes, which can be perceived either as convex or concave (see, for example, figure 2 in Ramachandran 1988a). This may be attributed to the strong impression of 3-D smooth surfaces created by such highly realistically shaded images, in which it is very difficult for the viewer to override the assumption that the light source is located overhead.

Additional evidence for the validity of our explanation is that when the gray background and the black and white lines of figure 1 are replaced by a black background and equiluminant red and green lines, respectively, the impression of a three-dimensional structure is almost entirely eliminated. Perhaps there are other factors which may help to explain the visual experience elicited by our stimuli, but we believe that our explanation of the percepts as a result of lighting assumptions adds an interesting example to that class of phenomena.

The interesting stimuli described in this paper have been used in the design of the logo of the 13th European Conference on Visual Perception (held in Paris in September 1990), reproduced in the announcement of the Conference which appeared in this journal (1989, *Perception* **18** 695).

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