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PERCEIVED ORIENTATION, SPATIAL LAYOUT AND THE GEOMETRY OF PICTURES

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The purpose of this paper is to discuss the role of geometry in determining the perception of spatial layout and perceived orientation in pictures viewed at an angle. This discussion derives from Cutting's (1988) suggestion, based on his analysis of some of my data (Goldstein, 1987), that the changes in perceived orientation that occur when pictures are viewed at an angle can be explained in terms of geometrically produced changes in the picture's virtual space. Before dealing with Cutting's idea, let's first consider the paper that stimulated it.

Goldstein (1987) distinguishes between three different perceptual attributes of pictures:

1. Perceived orientation. The direction a pictured object appears to point when extended out of a picture, into the observer's space.

2. Perceived spatial layout. The perception of the layout in three-dimensional space of objects represented in the picture.

3. Perceived projection. The perception of the projection of the picture's image on the observer's retina.

One basis for making these distinctions is that the perception of these attributes is affected differently by changes in the observer's viewing angle. Perceived orientation and perceived spatial layout, the two attributes we will focus on in this paper, differ in the following way:

1. Perceived spatial layout remains relatively constant with changes in viewing angle. This "layout constancy" is demonstrated by presenting photographs of triangular arrays of dowels like the ones in figure 1, and asking subjects to reproduce the layout this array would have if viewed from directly above. The results of these experiments, indicated by the general correspondence between the shapes of the solid triangles in figure 2, indicate that changing viewing angle causes only small changes in a subject's ability to reproduce spatial layout. This relative constancy has also been observed for other arrays and for pictures of environmental scenes (Goldstein, 1979, 1987).

2. Perceived orientation, on the other hand, undergoes large changes with changes in viewing angle. Figure 3 shows the average perceived orientations for four observers judging the orientations defined by pairs of dowels BA and BC of figure 1. When the picture is viewed at an angle of 20° (far to the right side of the picture plane), the relationship between the two orientations is different than when it is viewed at 160° (far to the left side of the picture plane). These differences are manifestations of the *differential rotation effect*—the fact that pictured objects oriented more parallel to the picture plane rotate less in response to an observer's change in viewing angle than do pictured objects that are oriented more perpendicular to the picture plane.

(See Goldstein, 1979, 1987, for a more detailed graphical presentation of similar data for a number of viewing angles).

In my paper I presented evidence that the subject's awareness of the picture plane is one of the causes of these changes in the perceived orientation of different objects relative to one another. Cutting (1988) has offered an alternate explanation–that perceived orientation is controlled by the geometrical changes associated with the affine shear that accompanies changes in viewing angle. His analysis is based on an analysis of the virtual space defined by a picture–that is, the three-dimensional space that corresponds to the picture's geometrical array. Cutting's original analysis was based on a formula developed by Rosinski et al. (1980), but it is also possible to use the graphical method illustrated in the top part of figure 4 (see Cutting, 1986, p. 36, for an illustration of the geometrical method used to construct this figure) to determine how the picture's virtual space is affected by changes in viewing angle. This figure shows the virtual space defined by the array in the center top of the figure, for viewing angles of 20°, 90°, and 160°.

After determining the virtual space defined by my triangular array at different viewing angles, Cutting used the orientations defined by this space to predict perceived orientations at each viewing angle. The resulting predictions for perceived orientations fit the data well at some viewing angles and not as well at others. Consider, for example, his prediction for a viewing angle of 160°. We can compare the predicted orientations shown at the top right of figure 4 to those determined empirically by constructing a triangle based on the empirically determined perceived orientations. Such a triangle, calculated from the data in figure 3 of Goldstein (1987)[1] and shown on the lower right of figure 4, is oriented slightly differently than Cutting's predicted triangle, but has the same general shape. The fit is not, however, as good for a viewing angle of 20°; at that angle Cutting's predicted orientations for the directions defined by B → C and C → A differ from those determined empirically.

Although these differences between geometrically predicted and empirical results suggest that geometry cannot supply the entire explanation for the changes in perceived orientation that occur with changes in viewing angle, Cutting's model does succeed in predicting the differential rotation effect. Geometry may, therefore, play at least some role in determining perceived orientation, and it is this role I wish to focus on now.

Let's assume for the moment that perceived orientations *are* linked to the changes that occur in virtual space with changes in viewing angle. This possible linkage between changes in virtual space and perceived orientation becomes particularly significant when we consider that *these same changes in virtual space* cause little change in the observer's perception of spatial layout. This constancy of spatial layout occurs not only for changes in viewing angle, as illustrated by the solid triangles in figure 2, but also for changes in viewing distance, as indicated by comparing the solid and dashed triangles in figure 2. The solid triangles were produced by subjects viewing the array in figure 1 from a distance of 8 in., whereas the dashed triangles were produced from a viewing distance of 64 in. Despite this eight-fold difference in distance, which causes a large expansion of virtual space,[2] there are only small differences between the triangles.

[1]The data on which these triangles are based were collected using a stimulus with the same layout as the stimulus shown in figure 1, but the photograph of the dowels was taken from a slightly lower angle (see Goldstein, 1987, for a picture of this stimulus).

[2]The use of the graphical method to determine how virtual space is changed by this increase in distance indicates that the expansion of the space caused by changing the viewing distance from 8 to 64 in. produces an elongated triangle in which side BA is stretched to four times the length of side BC.

What we have here, therefore, is a situation in which large changes in virtual space cause little or no change in the perception of spatial layout, but which, to the extent that the geometrical hypothesis is correct, cause large changes in perceived orientation. This situation raises the possibility that perceived orientation may result directly from stimulus geometry, whereas the perception of spatial layout may involve a processing step to compensate for the geometrical changes caused by viewing at an angle.

This idea of a compensation mechanism is not new. Pirenne (1970), Rosinski, et al. (1980) and Kubovy (1986) have linked such mechanisms to the subject's awareness of the picture plane; however, the exact operation of this compensation mechanism has never been specified. The first question that should be asked to help elucidate the nature of this hypothetical mechanism is: What stimulus manipulation will cause a subject's perception of layout to correspond to the picture's virtual space–or, put another way, What stimulus manipulation will eliminate layout constancy?

It is also possible that layout constancy is the outcome, not of a compensation mechanism, but of the subject's attention to information in the picture that remains invariant with changes in virtual space. While it is easy to talk glibly about invariant information, we need to identify this information if, in fact, it exists.

Finally, returning to perceived orientation, the suggestion that this percept may result directly from stimulus geometry cannot be the whole story. It seems clear that the observer's awareness of the angle of view is also important (Goldstein, 1987), although exactly how this factor interacts with stimulus geometry remains to be determined.

Obviously, many questions remain to be answered before we fully understand the mechanisms underlying perceived orientation and perceived spatial layout. These questions are important, not only because they suggest possibilities for future research that could yield answers that will greatly enhance our understanding of picture perception, but also because they acknowledge an important fact about picture perception: Perceived orientation and perceived spatial layout are affected differently by changes in viewing angle, are probably controlled by different mechanisms, and should, therefore, be clearly distinghished from one another in future research on picture perception.

REFERENCES

Cutting, J.E. (1986) Perception with an eye for motion. Cambridge: MIT Press.

Cutting, J.E. (1988) Affine distortions of pictorial space: Some predictions for Goldstein (1987) that LaGournerie (1859) may have made. J. Exp. Psychol.: Human Percept. Perform., in press.

Goldstein, E.B. (1979) Rotation of objects in pictures viewed at an angle: Evidence for different properties of two types of pictorial space. J. Exp. Psychol.: Human Percept. Perform. 5, 78-87.

Goldstein, E.B. (1987) Spatial layout, orientation relative to the observer, and perceived projection in pictures viewed at an angle. J. Exp. Psychol.: Human Percept. Perform. 13, 256-266.

Kubovy, M. (1986) The psychology of perspective and Renaissance art. Cambridge: Cambridge Univ. Press.

Pirenne, M.H. (1970) Optics, painting, and photography. Cambridge, Cambridge Univ. Press.

Rosinski, R.R., Mulholland, T., Degelman, D., & Farber, J. (1980) Picture perception: An analysis of visual compensation. Percept. Psychophys. 28, 521-526.

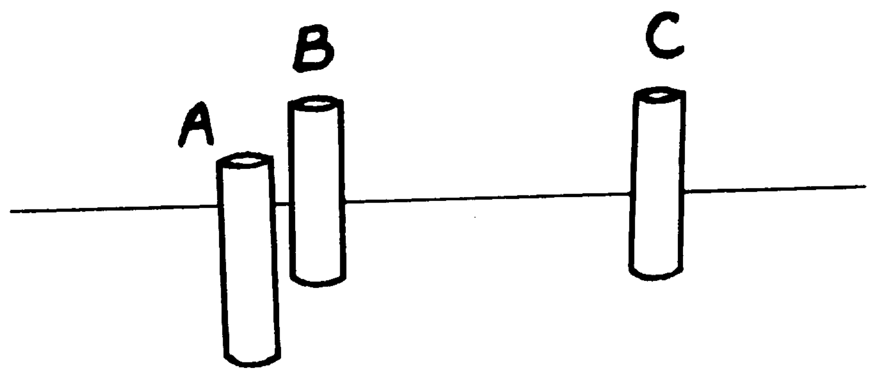

Figure 1.– Stimulus used to determine the perceived spatial layouts of figure 2 and the perceived orientations in figure 3. In the actual photographic stimuli the dowels had horizontal black and white stripes to clearly distinguish them from the background.

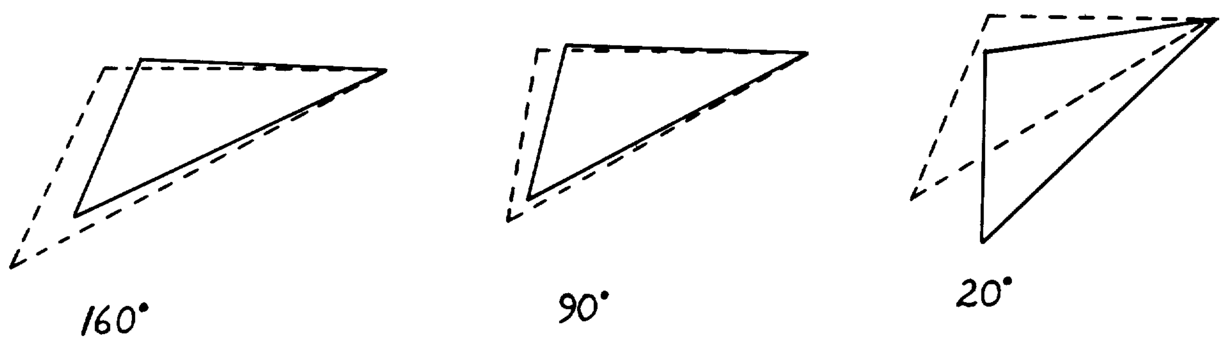

Figure 2.– Solid triangles—average spatial layouts produced by four observers viewing the array of rods in figure 1 from a distance of 8 in. at viewing angles of 20°, 90°, and 180°. Dashed triangles–average spatial layouts produced by the same observers from a viewing distance of 64 in. Viewing angle is the angle between the observer's line of sight and the picture plane, with a viewing angle of 0° occurring when the observer is looking at the right edge of the picture and a viewing angle of 180°, occurring when the observer is looking at the left edge. (See Goldstein (1987) for further details of stimulus specification and procedures.)

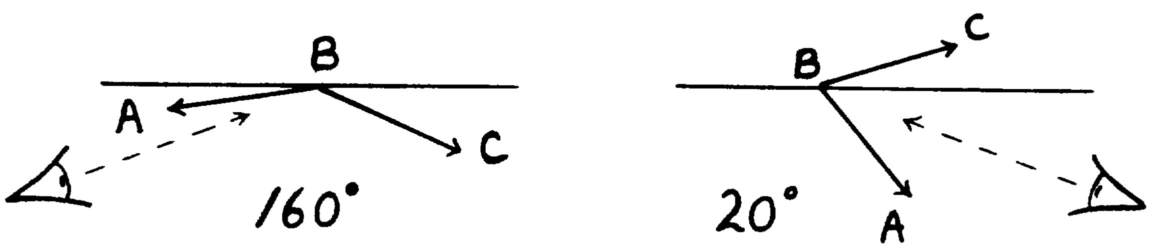

Figure 3.– Averaged perceived orientations defined by dowels BA and BC of figure 1, when viewed at viewing angles of 20° and 160°. The picture plane is indicated by the horizontal line and the observer's position is shown by the schematic eye. Perceived orientations are indicated by the direction of the arrows. Note that for a viewing angle of 20°, the orientation of BC points behind the picture plane. This is a typical result, which has been previously reported (Goldstein, 1979, 1987).

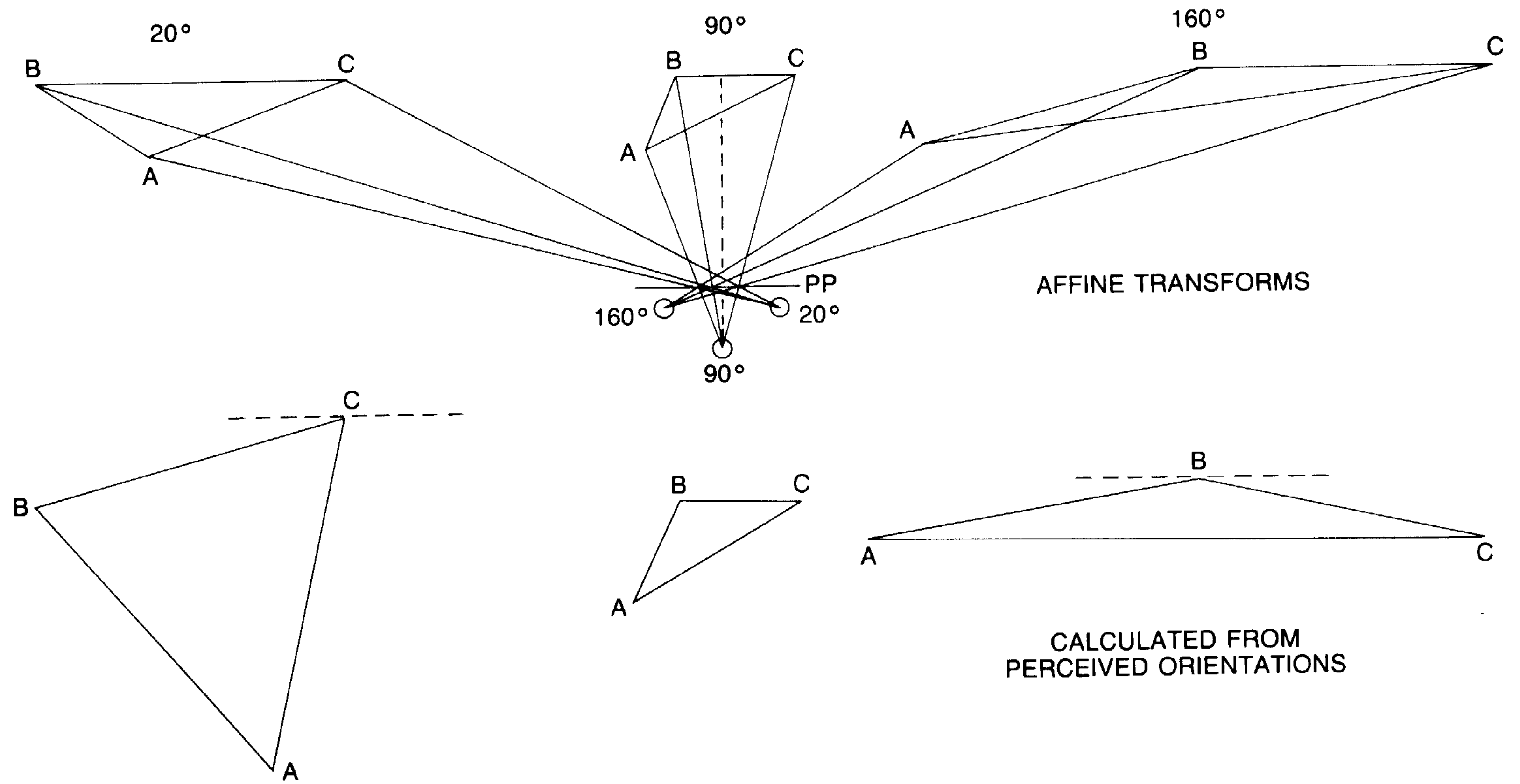

Figure 4.– Top: center–layout of the triangular array used in Goldstein (1987); left–affine transformed array for a viewing angle of 20°; right–affine transformed array for a viewing angle of 160°. PP = picture plane; open circles = positions of observers at viewing angles of 20°, 90°, and 160° relative to the PP. The dashed vertical line is the observer's line of sight for the 90° viewing angle. Bottom: layouts calculated from the empirically determined perceived orientations in figure 3 of Goldstein (1987). Since perceived orientations do not provide information regarding size, the sizes of these triangles were determined by setting the length of side BC equal to the length of side BC of the corresponding triangle above. The triangles were constructed by drawing each line so its orientation matches its empirically determined perceived orientation relative to the picture plane. The orientation of the picture planes for the lower triangles are indicated by dashed lines for the 20° and 160° viewing angles. The picture plane is omitted for the 90° viewing angle for clarity, since the angle between BC and the picture plane is 2°.