On The Internal Consistency of Perceptual Organization

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One of the central tenets of Gestalt psychology is that configurations of stimulus elements are perceptually organized to have the lowest possible structural complexity – what is often referred to as the "minimum principle". Consider, for example, the image of a Necker cube presented in the left panel of Figure 1. It is important to keep in mind that the actual physical structure of this figure is a 2D configuration of lines, but that is not how it is perceived. It appears instead as a 3D cube, presumably because that structure is simpler than the alternative 2D interpretation.

Although the minimum principle is frequently invoked as an "explanation" of perceptual organization, a precise definition of structural complexity is seldom provided. One of the first attempts to rectify that problem was developed by Hochberg and McAlister (1953), who proposed a formal quantitative analysis for measuring the relative complexity of possible perceptual organizations based on the number of line segments in a figure and the number of distinct angles. Empirical support for this approach was later provided by Hochberg and Brooks
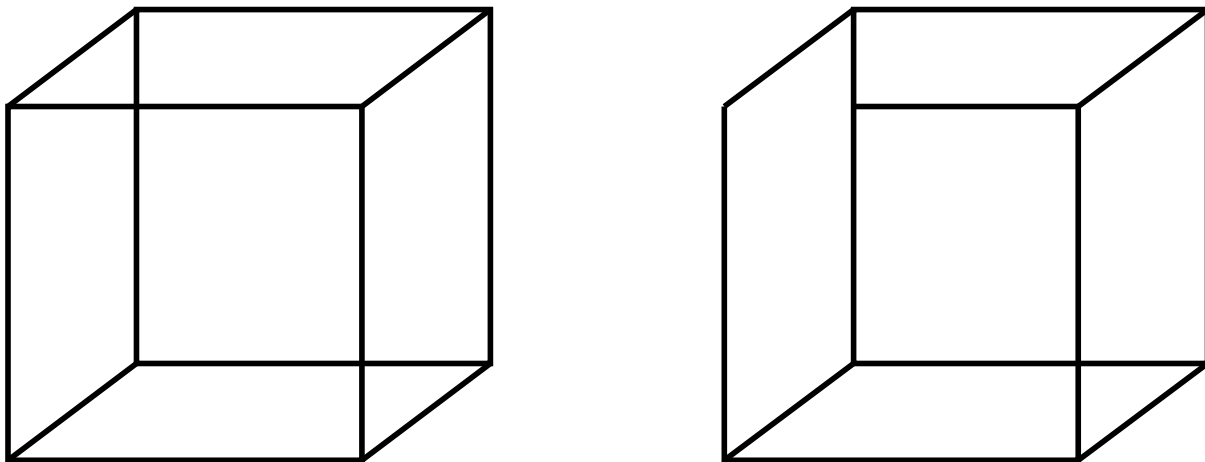

Figure 1 -- Two wire frame drawings of a cube. The one in the left panel is mathematically and perceptually ambiguous. It can appear to face upward to the right or downward to the left. The pattern in the right panel is adapted from Peterson & Hochberg (1983). Although it is mathematically unambiguous because of the occlusion information provided by the T-junction, the other ambiguous features can still undergo a piece-wise perceptual reversal, which creates the appearance of an impossible figure.

(1960). They asked subjects to rate the apparent three-dimensionality of wire-frame figures, like

Necker cubes, that were depicted from multiple vantage points. Whereas the 3D complexity of a

given object remains constant across different views, the 2D complexity of its projected image

can vary dramatically. For example, the image of a cube can appear as a square or a hexagon if

viewed from an appropriate vantage point. Hochberg and Brooks found that there was a strong

negative correlation between the apparent three-dimensionality of an object and the 2D

complexity of its optical projection. In other words, the patterns that had simple 2D

interpretations were perceived as flat rather than three-dimensional, which is consistent with the

minimum principle.

Despite these early attempts to make the intuitive notion of a minimum principle more

scientifically rigorous, Hochberg eventually concluded that it cannot be the primary underlying

mechanism for the perception of 3D shape from line drawings. His reasons for this conversion

were first laid out in an invited address to the American Psychological Association in 1966,

which was later published in Hochberg (1968). It was motivated in part by the perceptual

appearance of impossible figures (Penrose and Penrose, 1958). Because these figures have no

consistent 3D interpretation, any reasonable computational instantiation of the minimum

principle would predict that they should appear as 2D patterns. That is not what occurs,

however. Indeed, if the incompatible features are sufficiently far apart, observers may not even

notice that the depicted 3D structure is internally inconsistent. According to Hochberg (1968),

this suggests that perceived 3D structure is based on a schematic map of local depth cues

obtained over multiple eye fixations, and that the structure of this map need not be internally

consistent.

A related demonstration to support this hypothesis was first presented by Hochberg (1970), and was systematically investigated in an elegant series of experiments by Peterson and Hochberg (1983). Consider the pattern in the right panel of Figure 1, which is adapted from these studies. Unlike the ambiguous Necker cube in the left panel, this pattern has a unique 3D interpretation as a cube facing upward to the right. Based on the minimum principle, one would expect that the perceptual organization of this object should be quite stable, but a visual inspection of the figure reveals that it is easily reversed so that the cube appears facing downward to the left. When this occurs, however, the object has the appearance of an impossible figure because the inversion is incomplete. Note that the T-junction in the upper left of the pattern provides compelling information about local depth order that is not easily reversed, but this apparently does not constrain the perceived 3D structure in other regions. This can create a piece-wise inversion, in which the apparent depth order of different line segments is internally inconsistent.

Another compelling example of piece-wise inversion was discovered much later by Reichel and Todd (1990) in a study of intrinsic biases in the perception of ambiguous surfaces. The two panels labeled **A** and **B** in Figure 2 show images of a textured surface that are identical in all respects, except that they are presented in opposite orientations. Because these images were rendered under orthographic projection, the depicted sign of relief is mathematically ambiguous, but, for most observers, there is a strong perceptual bias to interpret the overall surface slant such that the apparent depth increases with height in the image plane. That is why the surface labeled **A** appears to have a small bump in its center, whereas the one labeled **B** appears to have a small dimple. If the figure is viewed upside down, however, the perceptual bias will cause the apparent sign of relief to become inverted, such that **A** will appear to have a dimple, and **B** will

appear to have a bump. In an effort to overcome this bias, Reichel and Todd also created stimuli

with visible smooth occlusion contours to provide unambiguous information about the depicted

surface depth order relations. The image labeled **C** in Figure 2 shows one example where the

occlusion information is consistent with the perceptual bias. This produces a stable perception of

the correct pattern of surface relief. The image labeled **D** shows exactly the same surface in an
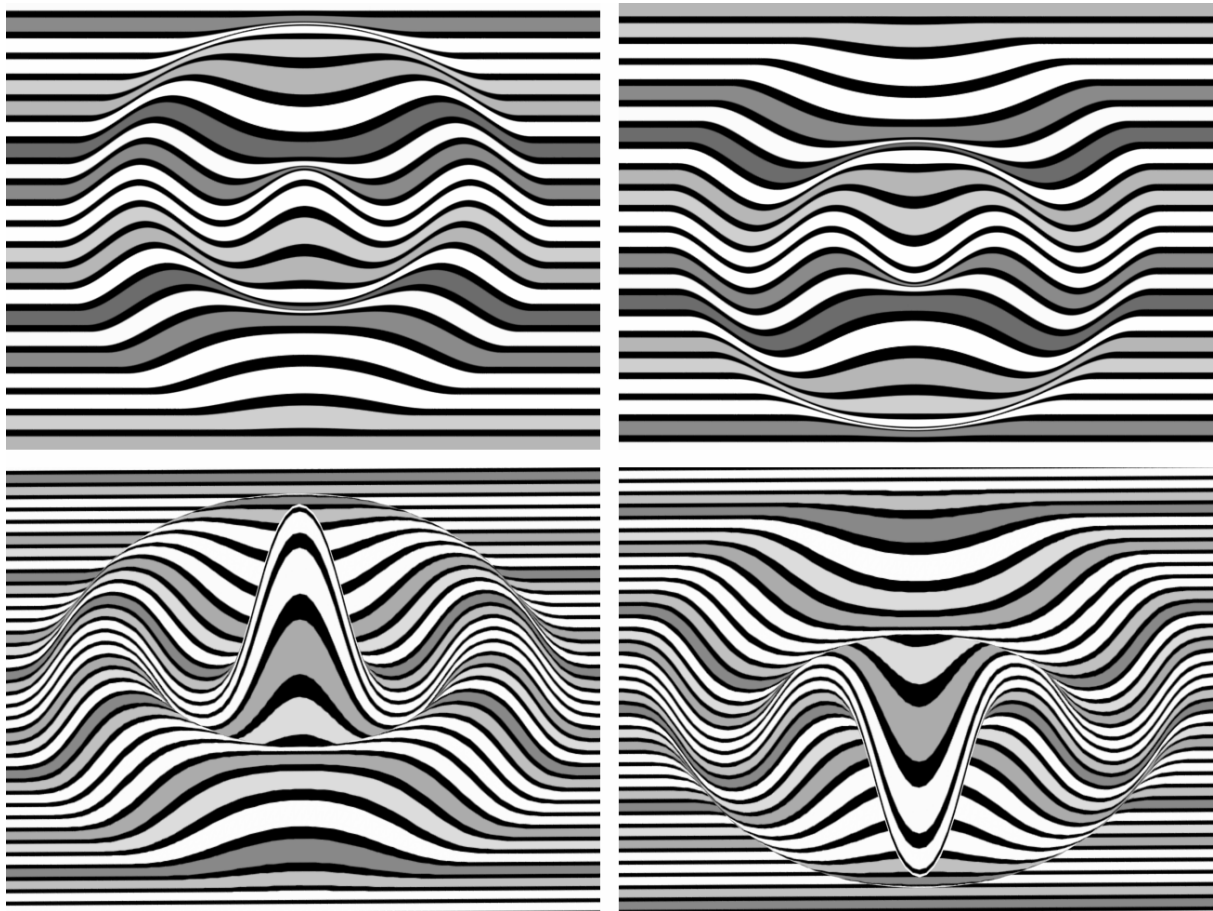

Figure 2 -- Perceptual inversion of texture surfaces. The two upper panels are identical images presented in opposite orientations. Because most observers have a perceptual bias to interpret the overall surface slant so that depth increases with height in the image plane, the apparent sign of surface relief is reversed when the image is turned upside down. The lower panels are also identical images in opposite orientations. In this case, however, they contain occlusion information to specify the correct depth order relations. When this is consistent with the perceptual bias, observers perceive the correct pattern of surface relief. When the image is turned upside down so that the occlusion information is incompatible with the bias, the surface undergoes a piece-wise perceptual reversal, which creates the appearance of an impossible figure.

inverted orientation, so that the occlusion information is in conflict with the surface orientation

bias. Note how this produces a piece-wise perceptual inversion with the disturbing appearance

of an impossible figure. Although the occlusion information determines the perceived depth

order in its immediate local neighborhood, the surface orientation bias seems to dominate the

apparent structure everywhere else. What is fascinating about this figure is that it has an

unambiguous 3D interpretation that is internally consistent, yet most observers have difficulty

perceiving it even with conscious effort. A similar effect can also be obtained in the perception

of 3D shape from shading (see Reichel & Todd, 1990).

As Hochberg first recognized over 30 years ago, the phenomenon of piece-wise inversion

has important theoretical implications, but it has not in my opinion received the attention it

deserves, and there have been few subsequent studies to investigate its generality. It is

interesting to note that in my own perception of ambiguous figures, the apparent depth order

relations among different features are not completely independent of one another – even when I

experience a piece-wise inversion. For example, when the patterns in Figure 1 switch from one

perceptual organization to another, the ambiguous features almost always switch in unison. It is

the unambiguous T-junctions that can appear inconsistent with the other features. All this raises a

number of important questions for future research. Are T-junctions special in this regard or are

there other local sources of information about depth order that are equally resistant to perceptual

inversion? The existence of piece-wise perceptual inversion is clearly inconsistent with the idea

that perceptual organization is determined exclusively by a global minimum principle, but it does

not necessarily follow from this evidence that a minimum principle has no effect whatsoever. If

so, how do we explain why the appearance of ambiguous features in Figure 1 are generally

consistent with one another, or why it is impossible to perceive the infinity of non-cubic 3D

interpretations that could also have produced the same optical projection? These are fundamental questions for the theoretical analysis of perceptual organization, but they have proven to be surprisingly elusive.

References

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