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Contour curvature polarity and surface interpolation

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Abstract

Contour curvature polarity (i.e., concavity/convexity) is recognized as an important factor in shape perception. However, current interpolation models do not consider it among the factors that modulate the trajectory of amodally-completed contours. Two hypotheses generate opposite predictions about the effect of contour polarity on surface interpolation. *Convexity advantage*: if convexities are preferred over concavities, contours of convex portions should be more extrapolated than those of concave portions. *Minimal area:* if the area of amodally-completed surfaces tends to be minimized, contours of convex portions should be less extrapolated than contours of concave portions. We ran three experiments using two methods, simultaneous length comparison and probe localization, and different displays (pictures vs. random dot stereograms). Results indicate that contour polarity affects the amodally-completed angles of regular and irregular surfaces. As predicted by the minimal area hypothesis, image contours are less extrapolated when the amodal portion is convex rather than concave. The field model of interpolation [Fantoni, C., & Gerbino, W. (2003). Contour interpolation by vector-field combination. *Journal of Vision, 3*, 281–303. Available from http://journalofvision.org/3/4/4/] has been revised to take into account surface-level factors and to explain area minimization as an effect of surface support ratio.

Keywords: Amodal completion; Interpolation; Convexity; Good continuation; Random dot stereograms

Both local and global factors are known to affect amodal completion (Boselie & Leeuwenberg, 1986; Kanizsa, 1979; Kellman & Loukides, 1987; Kellman & Shipley, 1991; Leeuwenberg, 1982; Sekuler, 1994). In this paper we analyze contour curvature polarity (CCP), which is the spatial property of a surface boundary of being either convex or concave, and show its effect on amodally-completed portions of partially-occluded surfaces. This is a surface-level factor, more global than contour-level factors like good continuation, but less global than factors like symmetry that has been shown to affect amodal completion (Gerbino, Sgorbissa, & Fantoni, 2000; van Lier, van der Helm, & Leeuwenberg, 1994; van Lier & Wagemans, 1999). The CCP effects reported here suggest that visual interpolation is sensitive to the minimization of surface area, independent of its specific shape.

1. What is contour curvature polarity?

There has been great interest in CCP recently (Barenholtz, Cohen, Feldman, & Singh, 2003; Bertamini, 2001; Bertamini & Croucher, 2003; Hulleman, te Winkel, & Boselie, 2000; Singh & Hoffman, 2001; Xu & Singh, 2002), also because this image feature is informative

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about solid shape (Hoffman & Richards, 1984; Koenderink, 1984). To achieve a formal definition of CCP we should consider together the notions of curvature polarity and contour ownership.

As depicted in Fig. 1, *curvature polarity* is defined here with reference to a smooth 2D line containing an inflection point. The line acts as a bilateral contour for two adjacent portions of the plane. The region that includes all chords connecting any pair of points on the contour is locally convex (+); while the complementary region is concave (−). Within the same portion of the plane, a concave region blends into a convex region in the neighborhood of the inflection point.

This paper is concerned with curvature polarity; i.e., with the sign of curvature. However, let us mention some related concepts. Another local measure is the *magnitude of curvature*, conveniently described by the change of orientation of a tangent sliding along the contour (Feldman & Singh, 2005). Minima and maxima of curvature (Attneave, 1954; Norman, Phillips, & Ross, 2001) as well as inflections (i.e., inversions of curvature polarity) provide the building blocks of the *curvature primal sketch*, the early representation proposed by Asada and Brady (1984). More global measures of *shape convexity* apply to closed contours (i.e., generic polygons). Different synthetic measures of closed-contour curvature can be considered. A perimeter-based measure of shape convexity can be derived from curvature polarity, by computing the proportion of locally-convex contour lengths over the total contour length. A surface-based measure of shape convexity is the proportion of the area of the polygon, over its convex hull (Preparata & Shamos, 1985; Zunic & Rosin, 2002). Both measures range between an asymptotic 0 and 1; where values close to 0 represent star figures with long figural rays and large concavities, while 1 stands for strictly convex surfaces like a circle. According to this approach closed contours define shapes that can be either totally or partially convex.

Curvature polarity is conveniently labeled by marking the convex region with a plus sign and the concave region with a minus sign. The +/− labeling for convex/concave seems appropriate because, other things being equal, the convex region tends to be perceived as the figure and the concave region as the ground (Koffka, 1935 [p. 192]; Rubin, 1921).

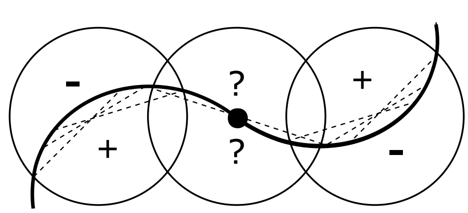

Fig. 1. Change of curvature polarity along a smooth contour with an inflection (black dot). Dashed lines are chords. The contour segment within an aperture (circle) locally defines two regions. If the contour within the aperture has no inflections, the region including all chords between any pair of points on the contour is convex (+) and the other concave (−). If the contour within the aperture brackets an inflection, chords intersect the contour and curvature polarity is locally ambiguous.

The assignment of figure/ground (F/G) roles to adjacent regions bounded by closed contours depends on various factors. Following Arnheim (1954), Kanizsa and Gerbino (1976) put convexity against symmetry and relative area, and demonstrated the strength of convexity as a disambiguating factor in F/G assignment. Recent computer vision research (Baek & Sajda, 2003; Pao, Geiger, & Rubin, 1999) provided consistent conclusions. However, convexity can be overcome and ground regions bounded by (totally or partially) convex contours can be perceived, like in holes.

The perceptual process of F/G assignment defines *contour ownership* (Koffka, 1935). The contour that geometrically separates two adjacent regions perceptually belongs to the figure only; that is, the contour tends to be perceived as an occluding edge which bounds a surface but not the ground behind it. Contour ownership plays a crucial role in various psychophysical tasks (Baylis & Driver, 2001; Bertamini, Friedenberg, & Argyle, 2002; Nakayama, Shimojo, & Silverman, 1989).

The combination of curvature polarity and contour ownership generates the notion of contour curvature polarity (CCP). Following Feldman and Singh (2005) among others, we will label figural contours as *positive* when convex and *negative* when concave. Wholly-convex surfaces (triangles, squares, disks) are bounded by positive contours only. Partially-convex surfaces are bounded by both positive and negative contours. Note that partially-convex surfaces are often called concave, just because they are not wholly convex (Massironi, 2002).

Apparently contrasting CCP effects have been reported. A peculiar visual search asymmetry involves the concavity/convexity dichotomy; a target with a concavity among convex distractors is more easily detected than a convex target among distractors with concavities (Hulleman et al., 2000; Humphreys & Müller, 2000). A similar effect was found by Barenholtz et al. (2003) in change detection; observers are more accurate when the shape change consists in the introduction or removal of a concavity, compared to a convexity. Different CCP effects support the notion of a convexity advantage for the discrimination of the relative position of two angles (Bertamini, 2001; Bertamini & Croucher, 2003; Bertamini & Mosca, 2004; Gibson, 1994).

As suggested by Bertamini (2001) a common explanation for such effects could be grounded on the minima rule (Hoffman & Richards, 1984; Xu & Singh, 2002); i.e., on the assumption that concavities mark the articulation of a whole into parts, while convexities belong to component parts. This would explain why observers are