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Approximation, torsion, and amodally-completed surfaces

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Abstract

Consider a stereoscopic display simulating two rectangular patches, the lower frontoparallel and the upper slanted around the vertical axis. When the two patches are amodally-completed and appear as the unoccluded parts of a smooth surface partially hidden by a foreground frontoparallel surface, either real or illusory, their relative slant is underestimated with respect to a baseline condition in which they are perceived as separate rectangles. Slant assimilation was studied in three experiments using with- vs. without-occluder displays and two methods, slant matching and speeded classification of twist direction. In Experiments 1 and 2 we found slant assimilation in with-occluder displays and slant contrast in without-occluder displays. In Experiment 3 we isolated a component of slant assimilation attributable to the mere presence of the occluder. Twist classification performance was impaired even when edge geometry hindered amodal completion, but the performance loss was larger when surface patches were amodally completed. To minimize the required amount of torsion, input fragments are misperceived, indicating that in limiting conditions amodal completion is mediated by approximation rather than interpolation. Slant assimilation decreases as twist angle increases, up to a limit above which the visual system does not support the formation of a smooth amodal surface with torsion.

Keywords: Amodal completion; Visual interpolation; Visual approximation; Torsion; Good continuation; 3D shape

1. Introduction

Fig. 1 illustrates an effect of amodal completion on perceived slant specified by horizontal scale disparity of untextured patches, as originally discussed by Fantoni, Gerbino, and Kellman (2004, 2005). The perceived twist is *smaller* in the left stereogram (where the gray patches are amodally completed into a unitary surface with torsion) than in the right stereogram (where they are perceived as separated surfaces). Liu and Schor (2005) discussed our effect, labeled it *slant assimilation*, and conducted three experiments using other displays. Their stereograms simulated three vertically-aligned planar patches specified by random dots and slanted about the vertical axis, including two semi-circular patches (equally slanted about the vertical) and a central elliptical test patch of variable slant. In the with-occluder condition observers underestimated the stereoscopic slant difference between the central test (visible in an aperture of the occluder) and the reference patches, relative to the without-occluder condition.

The slant assimilation effect observed in Fig. 1 cannot be attributed to the occluder as a proximal frame of reference for the horizontal scale disparity of the upper patch, since the superiority of relative over absolute disparity runs in the opposite direction (Gillam & Blackburn, 1998; Gillam, Flagg, & Finlay, 1984; Gillam & Pianta, 2005; Van Ee & Erkelens, 1995; Wallach & Lindauer, 1962). Nor can it be attributed to the conflict between disparity (indicating slant) and the lack of perspective (indicating no slant), since the latter is more evident in without-occluder than with-occluder displays (Clark, Smith, & Rabe, 1956; Cutting & Millard, 1984; Freeman, 1966; Gillam, 1968; Stevens & Brookes, 1988; van Ee, van Dam, & Erkelens, 2002).

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Fig. 1. Amodal completion modulates the amount of perceived slant from horizontal scale disparity (Fantoni et al., 2004). As shown in the upper diagrams, divergers should free-fuse the leftmost stereogram pair and cross fusers the rightmost pair in each triplet. The perceived slant is *smaller* on the left than on the right.

Here we report three experiments on untextured patches like those in Fig. 1. Such experiments complement the work by Liu and Schor (2005) and address further issues, for the following reasons. First, the amodal completion of two patches into a surface with a single twist is more elementary than the amodal completion of three patches into a surface with two twists. Second, our rectangular patches provide less slant-from-shape information than Liu and Schor's circular patches. Third, Da Vinci stereopsis is not involved in our displays (no vertical occluding contours), while it is present in Liu and Schor's with-occluder displays. Fourth, the comparison of with- vs. without-occluder conditions is balanced in our displays (where Da Vinci stereopsis is never involved), while it is unbalanced in Liu and Schor's displays (where Da Vinci stereopsis is involved only in the with-occluder condition).

We found slant assimilation in displays with an occluder specified by either luminance borders (Experiment 1) or illusory borders (Experiment 2), as well as a consistent loss of slant discrimination in an objective classification task (Experiment 3). Such findings do not fit the hypothesis that amodal completion is mediated by the *visual interpolation* of literally-represented fragments; i.e., contour segments and surface patches whose perceived positions and orientations match those locally specified in the input. Rather, they fit the hypothesis that amodal completion is mediated by *visual approximation*, a process that minimizes the required amount of surface torsion and generates a smooth surface including modal parts that do *not* match input patches, when they approach the geometric limits embodied in visual completion models. The next two sections describe how an approximation-based approach to amodal completion can provide a functional account of slant assimilation compatible with neural mechanisms evoked by Liu and Schor (2005) to explain the top–down influence of perceptual grouping.

2. Conditions for 2D and 3D completion

Visual completion captures the idea that perception goes beyond point-by-point correspondences with local stimulus information (Kanizsa & Gerbino, 1982; Kellman & Shipley, 1991; Koffka, 1935; Marr, 1982; Metzger, 1954; Michotte, Thinès, & Crabbé, 1964). We utilize it to label a set of perceptual phenomena, while "interpolation" and "approximation" indicate alternative processes underlying the formation of a unitary representation of input fragments.

The typical stimulus for contour completion is a pair of T-junctions with *tangent discontinuities* between top and stem contours (Shipley & Kellman, 1990). The geometric constraints describing the set of spatial relations required for the perception of a single contour from a pair of separated junction stems are formalized by *contour relatability* (Kellman & Shipley, 1991). In 2D conditions two junction stems are relatable when their connection bends in only one direction (monotonicity constraint) through an obtuse angle (90-deg constraint). Physiological and psychophysical studies favor a graded relatability notion, involving the fast continuous decay of completion strength beyond relatability limits, rather than an all-or-none notion (Kellman & Shipley, 1991). Suboptimal relatability affects both salience (Kellman & Shipley, 1991; Sha'shua and Ullman, 1988; Singh & Hoffman, 1999) and shape of perceptually completed contours (Fantoni, Bertamini, & Gerbino, 2005; Fantoni & Gerbino, 2003; Gerbino & Fantoni, 2006). As regards the monotonicity constraint, subjective estimates (Shipley & Kellman, 1992; Tse, 1999a), objective performance measures (Kellman, Yin, & Shipley, 1998; Mussap & Levi, 1995; Takeichi, Nakazawa, Murakami, & Shimojo, 1995), and physiological evidence (Fiorani, Rosa, Gattas, & Rocha-Miranda, 1992; Li & Li, 1994) confirmed that visual completion tolerates misalignments of parallel junction stems less than 15–20 min of arc (Hilger & Kellman, 2005; Roncato & Casco, 2003; Shipley & Kellman, 1992). As regards the 90-deg constraint, visual completion has been studied in patterns including partially occluded angles smaller than 90 deg (Fantoni & Gerbino, 2001; Guttman, Sekuler, & Kellman, 2004).

A general theory of completion should also cover the 3D domain (Kellman, 2003; Saidpour, Braunstein, & Hoffman, 1994; Yin, Kellman, & Shipley, 1997, 2000), as demonstrated by effects on 3D positions and orientations of edges. Kellman, Garrigan, Yin, Shipley, and Machado (2005b) tested different amounts of misalignment of 3D-relatable surface patches and found that even small misalignments substantially weakened completion effects. Recent work indicates that similar effects occur also in the absence of explicit edge information and depends on geometric con-