# GLOBALLY INCONSISTENT FIGURE/GROUND RELATIONS

# INDUCED BY A NEGATIVE PART

by

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ABSTRACT OF THE THESIS

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Figure/ground interpretation is a dynamic and complex process in which various factors cooperate or compete with one another. Much research has assumed that figure/ground assignment is globally consistent along the entire contour of a single figure, and has focused on global factors which affect one's perception of figure and ground. We investigated a situation where local configural cues to figure/ground conflict with global cues: a "negative part", a contour region that appears locally convex but that the global form requires be concave. To measure figure/ground assignment, we use a new task based on local contour motion attribution that allows us to measure border ownership locally at points along the contour. The results from two experiments showed that the more salient a negative part was, the more border ownership tended to locally reverse inside a negative part, creating an inconsistency of figure/ground assignment along the contour. This suggests that border ownership assignment is not an all-or-none process, but rather a locally autonomous process that is not strictly constrained by global cues.

# Table of Contents

# List of figures

## Introduction

Figure/ground organization, segmentation of an image into distinct figural and ground regions, is an important step in visual processing. Figural regions are thought to perceptually "own" the common boundary between them and ground regions, and to have well-defined shapes, while grounds are perceived as shapeless and continuing behind the figure (Rubin, 2001; Koffka, 1935). Figure/ground organization is essential in visual perception because it constrains later processing, as figures are more likely to be recognized, attended to, and acted up than background elements (e.g., Rock, 1983; Nakayama, Shimojo, & Silverman, 1989; Driver & Baylis, 1996; He & Nakayama, 1992). Figure/ground assignment is also important in shape description, as the sign of contour curvature (positive for convex, negative for concave) is defined relative to figure/ground partitioning, and this curvature sign in turn influences the shape perception of three-dimensional surfaces (Hoffman & Richards, 1984).

Figure/ground organization is a dynamic and complex process in which various factors cooperate or compete with one another. Research on figure/ground organization has focused primarily on identifying these Gestalt configural factors that influence the assignment of figure and ground. It is well known that the region that is more surrounded, smaller, more vertically oriented (Koffka, 1935; Rubin, 1921), more symmetrical (Bahnsen, 1928; Kanizsa & Gerbino, 1976), lower in the display (Vecera, Vogel, & Woodman, 2002), more convex (Kanizsa & Gerbino, 1976; Koffka, 1935), more familiar (Peterson & Gibson, 1993; 1994), and richer in high spatial frequencies (Klymenko & Weisstein, 1986) is more likely to be seen as the nearer, figural region.

In traditional approaches from the Gestaltists onwards, figure/ground organization is assumed to occur in globally consistent manner along the whole contour of a figure. Even

in reversible figures, like Rubin's (1915) famous base-face figure, it is usually thought that we cannot see both aspects of a base and two faces as figures at the same time, and at each state of reversal, the figure looks always closer than the ground. However, figure/ground assignment can be affected, not only by the combination among only global cues, but also by interaction among global and local cues.

If configural cues locally conflict with global figure/ground organization, one might expect contour ownership to locally reverse, but this possibility has rarely been tested. We investigated a situation where local cues to figure/ground organization conflict with global cues with introducing an object having a negative part. A negative part (Hoffman & Richards, 1984) is ground area mostly surrounded by an object, but which is perceived as having "shape", such as a bay, or a bite taken from an apple. Hoffman and Richards (1984) classified parts into two categories based on curvature sign on their boundaries: positive parts which are bounded by negative extrema of a principal curvature, and negative parts bounded by positive extrema. According to Hoffman and Richards' explanation, a negative part can be assumed to be a missing part of its complement, and so it receives the shape description of the interior region. If other things being equal, figure/ground assignment is preferred which leads to the most salient parts for the figural side (Hoffman and Singh, 1997), so if global configural cues, such as symmetry or convexity, locally conflict with the quasi-figural status of a negative part, contour ownership assignment could be locally reversed inside a negative part.

In this study, we investigated the interpretation of border ownership within a negative part. Most previous studies on figure/ground organization have relied on explicit verbal report or two-alternative forced choice of the global interpretation of figural assignment. Such methods make it difficult to ascertain border ownership locally at specific, isolated

points along a boundary, as we required in order to study the consistency of border ownership along the boundary. Moreover such methods are potentially susceptible to higher-level interpretations or extra-perceptual factors, and are generally not as quantitatively sensitive as we desired. Hence we sought a method that would allow us to probe contour ownership at specific boundary points in a more objective way.

In this study we introduce an indirect but robust measure of local boundary ownership. Several studies have demonstrated that contour motion is perceptually owned by the figure rather than the ground (Nakayama, Shimojo, & Silverman, 1989; Duncan, Albright, & Stoner, 2000; Barenholtz and Feldman, 2006). The study by Barenholtz and Feldman (2006) also hinged on the fact that local motion (in their case, a single articulating vertex) is owned by the figure, in their study leading to a figure/ground inversion. Hence we reasoned that we could probe figure/ground status in an otherwise static figure by introducing a small local motion signal at an isolated point along the contour, and then asking the subject which side of the boundary appeared to be moving.

In the studies below, we presented subjects computer-generated animation sequences of a circular region including a bay, where a probe point "trembles" on the boundary between the circular region and the background (see figure 1). We asked subjects which color appeared to be moving (the interior color or the exterior color), which presumably reflects the perceived ownership of the boundary. Though the motion itself is ambiguous, depending on which area owns common border, the ambiguity can be resolved and contour motion can be attributed to a certain region. Thus this indirect measure of probe motion attribution can reveal the border ownership between two regions. Experiment 1 shows that figure/ground can be inverted locally inside a negative part, and that the saliency of a negative part makes the local figure/ground inversion larger. Experiment 2

shows that if surface layer information which disambiguates depth ordering is given, the local figure/ground reversal observed in Experiment 1 disappears. Taken together, our studies suggest that many local and global cues combine and compete to produce an ultimate percept, which may not be globally consistent. Negative parts constitute a particularly acute case where local factors combine to combat the overall global preference for interior as figure, leading to a globally inconsistent figure/ground assignment.

## Experiment 1: Measuring border ownership inside and outside a negative part

Experiment 1 tested how border assignment may vary locally along the contour of an object with a negative part. We showed subjects computer-generated animation sequences of a circular region including a bay, where only a probe point trembles on the boundary between the central region and the outer area (see Figure 1). Figure 1b, which is a magnified diagram of the only varying part in animation sequences, shows two alternating frames of a probe composed of one cycle of small triangle wave. The motion perceived in alternation between two frames itself is perfectly ambiguous because in each frame white and black areas are symmetric with respect to the central point of the frame. The only property varied between frames is curvature polarity of the common contour: upper and lower halves of each frame was switched with respect to its opponent frame. The symmetry between black and white regions means that both sides have equivalent local geometry, and thus equal local figure/ground cues.

According to Hoffman and Richards' (1984) minima rule, if any two convex bodies intersect, they form negative minima of curvature at the points of contour intersection. Accordingly, the location of such minima on the occluding contour of an object may reliably correspond to the boundaries between its component parts. Figure/ground organization is critical on this contour curvature-based part structure description. Because the convexity or concavity of each segment along an edge reverses with its figure/ground organization, the description of convex parts in any given common contour is dependent on the side to which it is assigned. Thus, in Figure 1b, if an observer's figural assignment is given to the left-sided white area, the white convex angular point is perceived as a convex part segmented by the boundaries of two

neighboring white concave angular points, so the white rigid, convex part would be perceived as sliding back and forth in the animation sequences. Whereas if the black area owns the contour, black convex point would be perceived as convex rigid part bounded by two neighboring black concave angular points, so the black convex vertex would look like sliding back and forth. Thus we expect that if figure/ground organization is critical on the part structure description, it is also fundamental to the attribution of contour motion to one side or the other.

To test for the possibility of inconsistent figure/ground assignment along the length of an object's border, in this animation sequences, subjects were asked simply which color appeared to have moved, as a way of indirectly asking which region perceptually owns the probe point. What is really moving is not either area but the common border. But if the motion of the border is perceptually owned by the figure (Barenholtz and Feldman, 2006), subjects should attribute the motion more to what they perceive as figure. This allows our experiments to assess figural status at each point along the boundary independently.

## Methods

### *Subjects*

Eleven Rutgers University undergraduates participated for course credit, and they were naïve to the purpose of the experiment.

### *Stimuli*

Stimuli were computer-generated animation sequences consisting of a pair of two alternating frames of 50 ms presented consecutively 7 times, so total duration was 700

ms for the entire animation sequence. Each animation frame consisted of a black or white polygon (approximately circular) with a "bay" (Figure 1). The central shape was presented white against black background on half of the trials and black against white on the others (counterbalanced and crossed with other factors). The central polygon was originally a 24-sided polygon, measuring approximately $7.2°  × 7.2°$ in visual angle, but there introduced a bay, an arm of the background penetrating far into the polygon. A bay can be placed on the left side of the polygon or the right. There were three bay size conditions, large, medium, and small, in each of which the length between the inmost side and the entrance was $4.6°$, $3.5°$, and $2.3°$, and the area of a bay was 34.7, 12.7, and 7.1 square of degree, respectively. We also manipulated the shape of a bay by varying the ratio between the inmost side and the entrance, with keeping the area of a bay the same regardless of the shape within the same level of the bay size factor. The ratio between the inmost side and the entrance was 1:5 (large entrance), 1:1 (medium entrance), or 5:1 (small entrance), such that as the ratio is larger, entrance of a bay was more enclosed, making the bay more salient.

A moving probe was constructed by interpolating one cycle length of small triangle wave (amplitude $0.2°$, one cycle $0.8°$ in visual angle) on the contour of an otherwise smooth polygon. In two alternating frames, the probe was positioned at the same point of the contour, but only the curvature polarity of the triangle wave was reversed, so in animation sequences a probe is perceived as trembling in place. The moving probe was randomly assigned along the contour either inside or outside a bay, and in each inside and outside a bay case, there were also three possible positions according to the distance of the probe from the entrance of the bay: far away, intermediate, and near from the entrance of a bay.  The purpose of this manipulation was to allow us to probe figure/ground assignment locally at points that were either inside the negative part, or

elsewhere along the contour, and more generally track the percept as it (potentially) changed along the contour. The probe was always interpolated on locally straight contour segments between each neighboring vertex pair, but not on vertices.
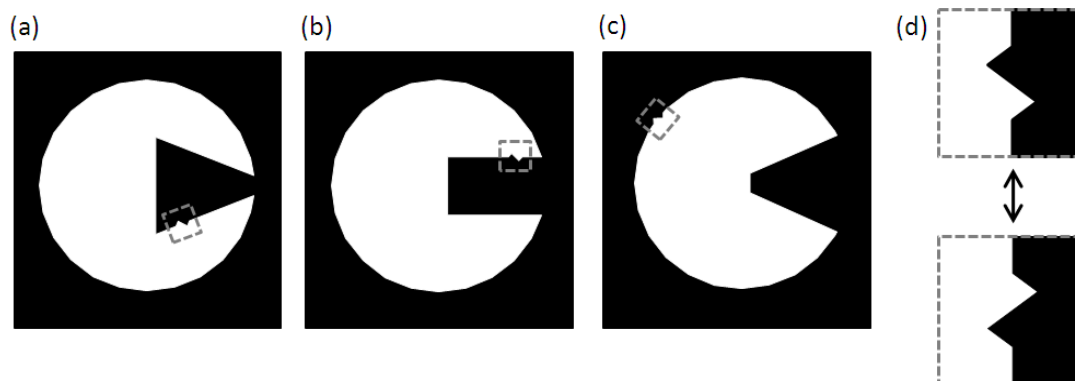


*Figure 1.* Examples of displays used in Experiment 1. The gray dotted window refers to a probe point (in real displays, gray dotted windows were not presented). Moving probes (inside gray dotted windows) were randomly assigned along the contour. (a) A medium size stimulus with small entrance. (b) A medium size stimulus with medium entrance. b) A medium size stimulus with large entrance. (d) Magnified diagrams of two alternating probe sequences.

<u>*Design and Procedure*</u>

Subjects sat in a dark room at a distance of approximately 57 cm from the monitor. The animation stimuli were generated and presented by an Apple G4 computer connected to a 17 inch monitor (1250 × 980 pixels at 75 Hz). Each subject completed 16 practice trials, followed by 432 trials divided in three blocks of 144 trials each, i.e.,2 [repetition] × 2 [color] × 2 [orientation] × 3 [bay shape] × 3 [bay size] × 6 [probe position]. All conditions were interleaved and the order of presentation of the trials was randomized for each subject. They were encouraged to take breaks if necessary at the end of each block. Each trial was initiated with presenting the plus sign (+) at the center of the screen. When subjects pressed the space bar, the plus sign disappeared and animation sequences were

presented. After the animation finished, the last frame kept still until subjects responded. They are asked to decide which color appeared to be moving between white and black. The participants were to press the key "c" when black color appeared to be moving, and the key "m" when white did.

The dependent measure to be analyzed in this and subsequent experiments was the proportion of "exterior moving" responses, that is, the proportion of responses that the color of the outside area (black in trials of white polygon stimuli, or white in trials of black polygon) appears to have moved.

## Results and discussion

The subjects' exterior moving response rate was analyzed as a function of color, orientation, and three experimental factors of bay shape, bay size, and probe position. Analysis of Variance showed no main effect between left-sided bay and right-sided bay conditions, $F(1, 10) = 1.044$, $p=0.33$. There was a significant effect of the figure/ground color, $F(1, 10) = 6.17$, $p = 0.03$, with a higher exterior moving response in the black figure/white ground (28.2%) condition than in the white figure/black ground condition (18.4%). However, color did not yield any significant interaction with any of three experimental factors, so, in analysis of three experimental factors, all color and orientation conditions are pooled.

ANOVA did not yield a significant difference among three bay size conditions, $F(2, 20) = 1.016$, $p = 0.38$, and the mean exterior moving response in each large, medium, and small size condition was 23.9%, 23.9%, and 22.0%, respectively. However, there were significant effects of the other two experimental factors. The effect of bay shape was significant, $F(2, 20) = 10.030$, $p = 0.01$. Means for a small, a medium, and a large

entrance were 28.8%, 22.2%, and 18.9%, so the narrower the entrance of a bay compared to the inmost side, the more subjects responded that the exterior color appeared to have moved. The effect of the probe position also produced a significant effect, $F(2, 20) = 10.030$, $p = 0.01$. The proportion of exterior moving response was higher when a probe was positioned inside a bay than when it was outside, and means for a far away outside, a intermediate outside, a near outside, a near inside, a intermediate inside a bay, and a inmost conditions were 15.4%, 16.4%, 15.5%, 31.2%, 31.4%, and 29.8%, respectively. Within each three outside and inside conditions, there was almost no difference, but there was a sharp increase at the transition of probe position from outside to inside of a bay, as is seen in Figure 2. Post-hoc analysis revealed that no pair-wise comparisons within each inside and outside a bay conditions was not significantly different ($p > 0.05$), but every comparison between any two, one from inside and the other from outside a bay conditions, were significant ($p < 0.03$).
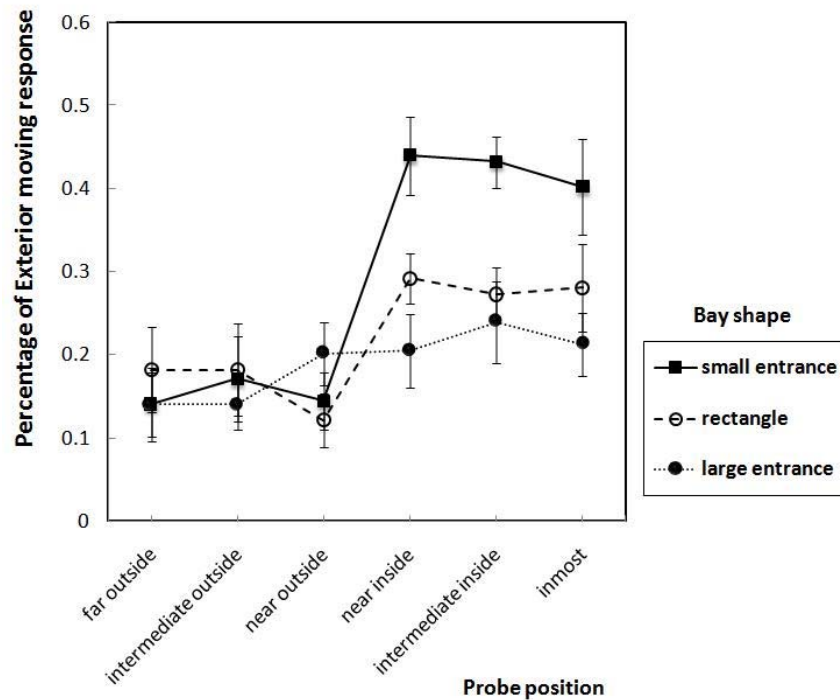


Figure 2. Results from Experiment 1. The error bars in this and all following graphs represent ± one standard error.

The interaction between bay shape and probe position was also significant, $F(10, 100) = 4.736$, $p < 0.001$. When a moving probe was positioned outside a bay, there was no difference according to the bay shape. But, when it was inside a bay, the proportion of exterior moving response was higher as a bay opening was more closed and so the saliency of a bay was increased. This demonstrated that contour ownership tends to reverse locally inside a negative part, when a negative part is salient. However, the exterior moving response did not exceed 50% in any conditions, so this tendency does not completely overturn the global preference for interior as figure. But this tendency suggests that contour ownership assignment is not necessarily globally consistent, contrary to the usual assumption. This result suggests that figure/ground organization is assigned via local mechanisms that are not constrained to yield a globally consistent result, and so contour ownership can be locally reversed inside a negative part, when a negative part is salient.

## Experiment 2: Border ownership reversal without depth reversal?

As mentioned above, in figure/ground organization depth and figural assignment are usually understood to be tightly connected so that the figural side is always perceived as both closer to the observer and shaped by the common contour. In Experiment 1, we measured border ownership inside and outside negative parts through the measurement on the probe motion attribution, and found a tendency toward border ownership reversal inside a negative part. But, what about depth assignment when border ownership is locally reversed inside a negative part? We did not measure relative depth assignment, so we cannot conclude anything about depth assignment inside negative parts. One possibility is that depth assignment and contour ownership would be tightly coupled, consistent with the traditional Gestalt assumption that the figural side and the nearer side are necessarily one and the same. Another possibility is that contour ownership and figural depth assignment might be dissociable. Unlike other forms of ground, negative parts have quasi-figural status as having shape, so it might be that negative parts are on ground depth, but own the common contour, unlike other ground area.

In Experiment 2, to test these possibilities, we added a bar occluded by the central polygon to serve as a clear cue to depth ordering. In Experiment 1, if local contour ownership reversal was accompanied by depth reversal inside negative parts, an occluded bar should suppress the possible depth reversal inside a negative part, because the occluded bar induces a strong percept that the central polygon is in front of it, so figural depth inside a negative part is incompatible to the occlusion cue of a bar. We predicted that if depth reversal had been concomitant with contour ownership reversal inside parts in Experiment 1, when an occluded bar was added, exterior moving response to a moving probe inside a bay should be decreased compared to that in Experiment 1. Conversely, if

contour ownership is dissociated from figural depth inside a negative part, an occluded bar would have no effect on local contour ownership reversal inside a bay.

## Methods

### *Subject*

Twelve new Rutgers University undergraduates participated for course credit, and they were naïve to the purpose of the experiment.

### *Stimuli and Procedure*

Stimuli and probe motion were generated as in Experiment 1, and the equipment and procedure were also identical to those in Experiment 1. The only difference in this experiment is that a gray bar (length 14.5 deg) occluded by the polygon is introduced to suppress the possible depth reversal inside a negative part. We used three occluded bar types, defined by the position of the bar relative to the moving probe: no-bar, bar far from a probe (far-bar), bar near to a probe (near-bar) types (see Figure 3). A no-bar display was the same as the display used in Experiment 1. In a far-bar display an occluded bar behind the central polygon was positioned to the remote side from a moving probe, so that when a moving probe was inside a bay an occluded bar was always outside a bay and vice versa. In a near-bar display, the bar was always near a moving probe by about 1.0˚ visual angle, from a probe to the nearest contour point of a bar, regardless of the position of a moving probe.

Three bar types were blocked and the block order was counterbalanced across subjects. Each blocked condition was composed of 216 trials, i.e., 2 [color] × 2 [orientation] × 3 [bay shape] × 3 [bay size] × 6 [probe position], and preceded by 16 practice trials. In each

block, all conditions were crossed and the order of presentation of the trials was randomized for each subject.
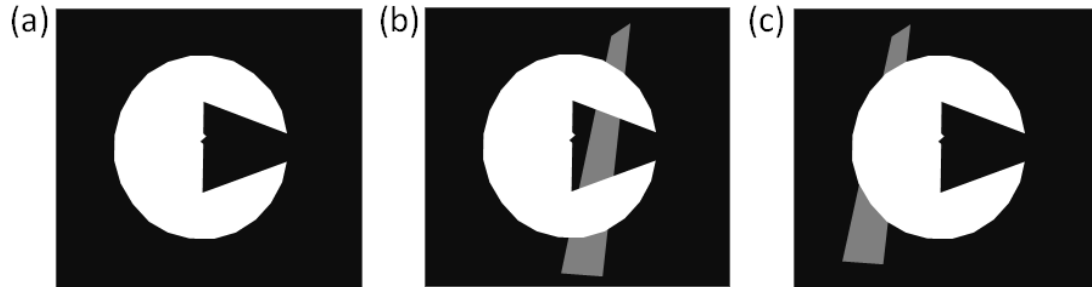


*Figure 3.* Three occluded bar displays used in Experiment 2. (a) A no-bar display which is the same as the displays used in Experiment 1. (b) A bar near probe display (near-bar) where an occluded bar behind the central polygon was positioned to the remote side from a moving probe, so that when a moving probe was inside a bay an occluded bar was always outside a bay and vice versa. (c) A bar far from probe display (far-bar) where the bar was always near a moving probe by about 1.0˚ visual angle, from a probe to the nearest contour point of a bar, regardless of the position of a moving probe.

## Result and Discussion

Data were analyzed individually for each subject as a 3-factor, repeated measures ANOVA. The factors were the bar type, the bay shape, and the probe position. As in Experiment 1, the bay shape and the probe position yield significant effect on exterior moving response, $F_{(2, 22)} = 5.520$, $p = 0.011$, and $F_{(5, 55)} = 5.007$, $p = 0.001$, respectively. There were difference in exterior moving response among three bar types, 24.6%, 21.9%, and 17.0% for each a no-bar, a far-bar, and a near-bar types, but because of large variance it did not reach significant level,  p>.05.  Interaction between the bay shape and the probe position was significant as in Experiment 1, $F_{(10, 110)} = 2.341$, $p = 0.015$.  The interaction effect

between the bar position and the bay shape was also significant, $F (4, 44) = 3.000$, $p = 0.028$ (figure 4a). When bay entrance was large or medium, there were no significant difference among the three bar positions ($p > 0.05$). But when the entrance was small, the condition in which we found the largest figure/ground reversal in Experiment 1, there was significant effect of the bar position, $F (2, 22) = 3.735$, $p = 0.04$. That is, the combination of conditions that produced the largest reversed border ownership effects in Experiment 1 was most affected by the position of the bar in Experiment 2. To confirm this interpretation, we separated out the small entrance condition, and examined the interaction between the probe position and the bar type (Figure 4b), which was significant, $F (10, 110) = 2.189$, $p = 0.023$. Summarizing, in the three conditions where the probe was outside the bay, there was no effect of the presence or position of an occluded bar, presumably because there was no tendency towards figure/ground reversal. But in conditions where we expected a tendency to reverse figure/ground, i.e. where the probe was inside a bay with a narrow entrance, then the position of the bar has a significant effect. When the bar is near the probe, suppressing the depth reversal, contour ownership (as revealed by the probe) follows suit.
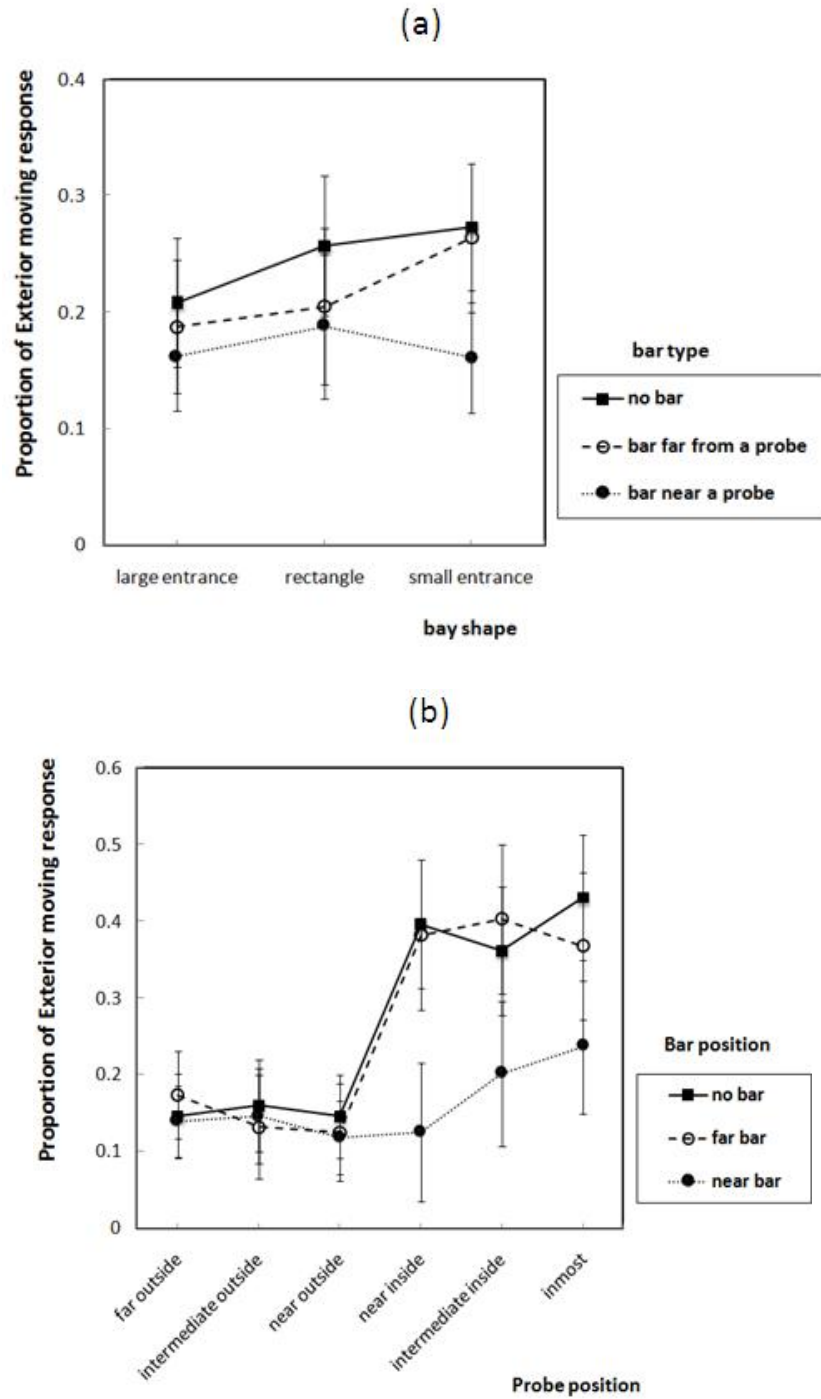
16



Figure 4. (a) Overall results from Experiment 2. (b) Results in a small entrance condition from Experiment 2.

These results show that the depth-ordering cue of an occluded bar exerted sufficient effect on figure/ground organization so that in a near bar condition participants responded more that a moving probe belonged to inner area which looked closer to them than outer area of background. That is, in a 'near-bar' display the exterior moving response was suppressed, and so the local border ownership reversal disappeared. This result suggests that the contour ownership reversal observed in experiment 1 was really accompanied by depth reversal, so when depth reversal is suppressed, contour ownership reversal is also suppressed. Whereas, in a far-bar display the result was not quite different from that in a 'no-bar' display, which means that even an occluded bar exerted no effect on relative depth inside a bay, if it positioned outside a bay. This result suggests that contour ownership reversal inside a bay was a genuinely local effect, in the sense that it is not affected by depth cues outside a bay. This suggests that global figure/ground organization is probabilistically defined by summation of local cues that are not constrained to yield a globally consistent result.

## General discussion

Figure/ground organization is a dynamic and complex process in which various factors cooperate or compete with one another. Most research on figure/ground organization has assumed that it occurs in globally consistent manner along the whole contour of a figure, and has focused on identifying these Gestalt configural factors that allow one region to appear as the figure and another to appear as the ground. However, figure/ground assignment can be affected, not only by the combination among only global cues, but also by interaction among global and local cues.

Given that most previous studies on figure/ground organization have been based on the influence of border ownership on the global interpretation of figural assignment, to understand border ownership locally at specific, isolated contour points in a more objective way, we introduced a new task based on local contour motion attribution. In this study, we investigated the interpretation of border ownership within a negative part. The results from two experiments showed that subjects' probe motion attribution was modulated by both the position of the moving probe (inside vs. outside a negative part) and the saliency of negative parts. We found that the tendency towards border ownership reversal, locally inside a negative part, which suggests that border ownership assignment is not an all-or-none process, but rather locally autonomous and graded process which is not strictly constrained by global configural cues.

Gestalt factors affecting on border ownership assignment of negative parts

Contour closure allows the closed region to be perceived as a figure surrounded by ground and in turn plays a crucial role in determining the shape of an object (Koffka, 1935; Kaniza & Gerbino, 1976). Gestalt psychologists took special notice of the fact that a

line forming a closed or almost closed figure is not simply perceived as a line on a homogeneous background, but a bounded surface region (Koffka, 1935). A closed contour divides an image into an inside (figure) and an outside (ground), and two-dimensional shape properties, which constrains the shape perception of three-dimensional surfaces, such as curvature sign, convexity, and concavity are defined based on this figure/ground partitioning (Driver & Baylis, 1995). Thus contour closure should mediate shape perception. Studies on contour integration showed that contour closure enhances the perception of global shape and makes the shape pop out among noise pattern or distracters (e.g., Kovacs and Julesz, 1993; Elder and Zucker, 1993; Elder and Zucker 1994; Mathes & Fahle, 2007). Elder and Zucker (1993; 1994) in particular showed that the concept of contour closure in shape perception is not an all-or-none property, but defined in graded manner as "continuum of contour closure". They reported that global shape perception was enhanced by degree of closure and even when contour is not perfectly closed, but almost closed, target detectability was enhanced by the global shape. Gillam (1975) also provided supportive evidence for a continuum of contour closure, showing that under ambiguous motion of line segments in depth, subjects' percept of common motion among line segments monotonically increases as the gap between them is decreased.  Once contour closure exceeds some threshold, a partially closed contour produces almost the same degree of perceived common motion of as a completely closed contour. Thus, the "degree of figurehood" of a negative part could be determined by the degree of local contour enclosure inside a negative part. The more a negative part was enclosed by outer circular area, the more likely it was to be interpreted figually, and so the more border ownership reversal tended to be reversed. Thus contour closure would be an important factor for a certain region to be a figure, not only for a global shape but also for a local negative part.

Relation between border ownership and figural depth and Neurophysiological evidence

As discussed earlier, border ownership is closely connected with figural depth in figure/ground organization. Experiment 2 indirectly suggested, by showing disappearance of border ownership reversal induced by a depth-ordering cue of an occlusion bar, that even if border ownership might not be globally consistently assigned between inside and outside negative parts, the coupled relation between figural depth and figural border assignment is consistently conserved in each local point along the contour.

Recent neurophysiological findings (Zhou, Friedman, & von der Heydt, 2000; von der Heydt, Qiu, & He, 2003; Qiu & von der Heydt, 2005) showed that cells sensitive to border ownership can be found in visual cortex of early visual processing such as V1, V2 and V4, suggesting a local neural representation of figure/ground assignment broadly consistent with the local (rather than global) determination we found in Experiment 1. Zhou et al. (2000) showed that some orientation selective neurons in V2 responded with different strength to the same edge of a square figure defined by luminance contrast, depending on the side of the figure to which the edge belonged, suggesting neural encoding of unilateral border ownership. In addition, many of these cells combine side-of-figure selectivity with selectivity for the depth order of surfaces, defined by binocular disparity cues (Von der Heydt et al., 2000; Qiu and von der Heydt, 2005) or by dynamic occlusion cues(von der Heydt et al. 2003), in a manner that is consistent with three-dimensional object perception. This observation suggests that neuronal side-of-figure selectivity to two-dimensional images is tightly connected to three-dimensional surface interpretation of the given images, consistent with psychophysical observations that border ownership assignment is modulated by three-dimensional depth order (e.g., Nakayama, Shimojo, & Silverman, 1989) ), and broadly consistent with the  tight coupling between depth and figural assignment we found in Experiment 2.

What do those neurophysiological studies suggest on the inconsistent border ownership assignment we observed using objects with negative parts in the current study? Of course, neural responses to border ownership in V2 cells may not correspond closely to the phenomenal percept of figure/ground. Nevertheless, the links between our results and these studies of neural coding are suggestive and consistent. Zhou, Friedman, and von der Heydt (2000) used a C-shaped figure, roughly comparable to the medium-entrance bay in our studies, to investigate border ownership coding under conflicting cues such as convexity, L junction, and closure. A reversed side preference was not observed in any cells for the inner contour of the "C" (inside negative parts in our terminology). But more than half of the cells with significant side-of-figure preference for simple convex (square) figures did not exhibit any side preference (to either side) for the inner contour of the "C". This weakening of side preference along the inner contour of the "C" is broadly consistent with our psychophysical finding that the default assignment of interior as figure significantly weakens inside a negative part.

Further studies are required to understand the neural processes underling inconsistent border ownership assignment inside negative parts in two-dimensional display without any depth cues. Negative parts which are almost enclosed like those in our small entrance condition are an extreme case of conflict between multiple global and local cues like convexity, L junction, and closure. Closure in particular is doubly related among global and local cues: contour closure of the whole objects with negative parts conflicts with partial closure cue of negative parts in figure/ground organization. We expect that neural border ownership assignment is determined not by a single all-or-none process but combination of multiple mechanisms employing various available cues, so neuronal

response to negative parts could be different even from the C-shaped figure, and reversed side .

A continuum of negative parts

The primary goal of our study was to investigate border ownership inside negative parts. We observed the tendency of border ownership reversal inside negative parts in Experiment 1. However, suppression of this border ownership reversal by addition of a depth-ordering cue in Experiment 2 suggests that this tendency is not purely the effect of border ownership *per se*, but rather accompanied by figural depth reversal. These results showed that when border ownership was reversed, the only possible interpretation of subjects' percept of a negative part was no more as an empty bay, but surface of an arm of the background in figural depth occluding the circular objects (Figure 5a), which is inconsistent to the global interpretation of surface structure between figure and ground.
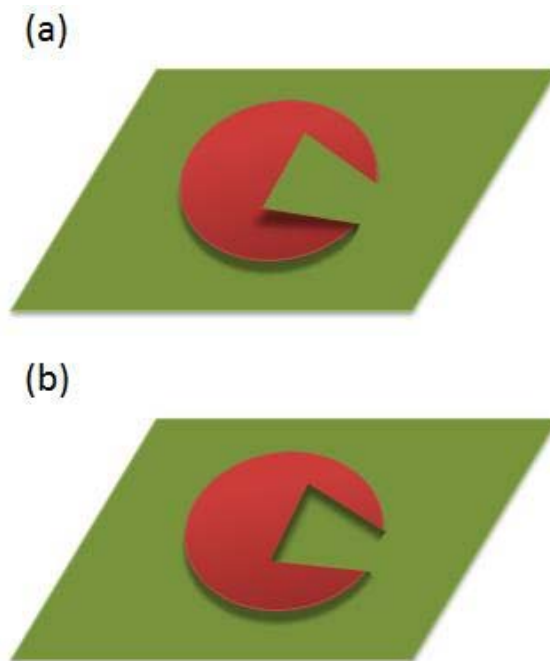


*Figure 5*. Two competing percepts of a bay. (a) A bay as a positive part of background (an arm of the background) in figural depth occluding a circular object. (b) An empty bay as a negative part.

The proportion of subjects' exterior moving responses to the moving probe inside negative parts with small entrance in Experiment 1 (over 40%) implies the presence of competition between the two percepts of a negative part of the otherwise circular region (figure 5b) in case of exterior moving response, and a positive part of the background occluding a circular region (figure 5a) in case of interior moving response. When there were no detectable depth-ordering cues, two percepts were competing as in Experiment 1. To disambiguate those competitive precepts, depth-ordering cues such as binocular disparity (Nakayama et al., 1995), "accretion-deletion" defined by motion (Kaplan, 1969), or occlusion are needed, as shown in Experiment 2. But, if the contour of a negative part is owned by the surrounding area, but not by the negative part itself, given sufficient depth-ordering cues, how can the shape of it be perceived as quasi-triangular or trapezoidal? Here a negative part would be in the same situation as a hole (see Bertamini (2006) for a review of issues relating to holes). Regions perfectly enclosed by surrounding area have two ambiguous interpretations: as a convex object or as an empty hole. The present study implies that even an almost but not completely enclosed area in a two dimensional display can have two competing percepts. Thus, it can be thought that there is a continuum of negative parts with holes at one extreme, as the concept of closure is defined in graded manner with perfectly closed contour at one end (Elder and Zucker, 1994).

## Conclusion

Our study suggests that in figure/ground organization many local and global cues combine and compete to produce an ultimate percept, which may not be globally consistent even if it favors one side as a figure. Negative parts provide a simple context in which such inconsistent border assignment manifests itself, as readily measured by our motion probe ownership task. Negative parts in effect constitute a "battleground" between competing local and global figural cues. As such they may provide an excellent opportunity to study the neural and computational processes involved in figure/ground assignment, and more broadly to understand cooperation and competition between local and global perceptual cues more generally.

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