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Perceptual Organization in Vision

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[–] Abstract and Keywords

Perceptual organization encompasses grouping and segregating processes; grouping processes assemble visual elements into perceptual wholes, and segregating processes parse visual input into separate objects. In this chapter, we review behavioral evidence regarding both image-based (objective) and perceiver-based (subjective) factors that operate to produce grouping and segregation. We consider both how these factors combine and compete and when in the course of processing they operate. The research reviewed in this chapter shows that the traditional view of perceptual organization as an early process that provides the substrate on which high-level perceptual processes operate is oversimplified. Recent research makes a case that perceptual organization is neither a stage of processing nor a monolithic entity. Instead, perceptual organization results from interactions among multiple cues and processes at many levels; it is a form of selection, in that only one of many interpretations that could be fit to a display is perceived.

Keywords: grouping, segregation, figure-ground perception, objective factors, subjective factors, Gestalt, past experience, cue integration, selection, direct measures, indirect measures

People readily perceive and act upon objects, but perceptual processes must operate to organize the input into these coherent units. *Perceptual organization* processes can be subclassified as *grouping* and *segregating* processes. *Grouping* refers to the processes by which visual elements are "put together" into perceptual wholes. *Segregating* refers to the processes by which these wholes are parsed into separate objects. In particular, the visual system must determine which borders in the visual field are likely to be bounding edges of objects or surfaces and which are pattern borders, shadow edges, or formed by the junction of two planar surfaces. Those deemed to be bounding edges are perceived to separate entities, with one of these entities shaped, or configured, by the border (this is the near object, or *figure*), while the other is not (and thus is perceived as a surface that constitutes the local background, or *ground*, to the figure).

In the late 19th century, the prevailing theory of perception was Structuralism. Proponents of this position attributed perceptual organization to past experience, proposing that those parts of the visual field that had been grouped or segmented in past experience were grouped and segmented in current experience as well. An explanation based totally on past experience will not work, however, as the Gestalt psychologists pointed out early in the 20th century. Among other considerations, they demonstrated that segregation and grouping *can* occur without input from memory or past experience, and they argued that segregation and grouping *must* operate before memory and conceptual content are accessed. Note, however, the potential slip here, because demonstrations that perceptual organization *can* occur without input from past experience do not entail that it *always* occurs without input from experience (Peterson, 1999).

In this chapter, we take an interactive processing approach to perceptual organization, arguing that high-level and low-level representations and processes interact to produce perceptual organization. On this view, perceptual organization is neither a stage of processing nor a monolithic entity; instead it is a confluence of multiple cues and processes (Behrmann & Kimchi, 2003; Kimchi, 2003; Peterson, 1994b, 2003b). Furthermore, we consider perceptual organization to be a form of selection, in that only one of many interpretations that could be fit to a display is perceived. We review both image-based (objective) and perceiver-based (subjective) factors that operate to produce *grouping* and *segregation*; we also review behavioral evidence regarding how these factors combine and compete. We will show that behavioral research is beginning to shed light on foundational perceptual organization process. We note that computational and neuropsychological approaches have also been applied to this issue but are beyond the scope of this chapter.

Segregation

Segregating the visual field into separate objects is a multidetermined and complex process involving myriad cues. Julesz (1971) demonstrated, using random-dot stereograms, that the depth cue of binocular disparity alone can produce the perception of both depth and simple shape, and, since then, the influence of shape properties has often been overlooked. Some took Julesz's demonstrations to imply that cues that had been shown to influence figure assignment in two-dimensional displays are irrelevant in the three-dimensional world (e.g., Marr, 1982). But this conclusion is based on a reasoning error similar to that made by the Gestalt psychologists: The demonstration that binocular disparity alone *can* produce perceptual organization does not imply that other cues cannot operate singly as well; nor does it imply that other cues are irrelevant when binocular disparity is available (see Bertamini, Martinovic, & Wueger, 2008; Burge, Peterson, & Palmer, 2005; Burge et al., 2010; Peterson, 2003a; Peterson & Gibson, 1993).

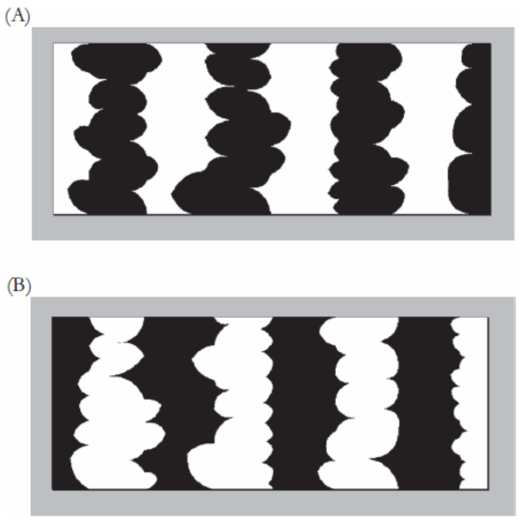

Figure 2.1 (*A* and *B*) Displays with equal-area black and white regions. Regions with convex parts alternate with regions with concave parts. For simplicity these regions are called "convex" and "concave" regions; this nomenclature dates to the Gestalt psychologists. The convex regions are black in (*A*), white in (*B*).

In this chapter, we focus our review on properties other than depth cues that affect the likelihood that a border shared by two adjacent regions will be perceived as the bounding edge of a "figure" (a shaped entity) on one side with an unshaped region (the "ground") on the other side. All borders in the visual field are ambiguous, in that shapes that might be seen on opposite sides are detected yet only one is perceived (e.g., Peterson & Enns, 2005; Peterson & Lampignano, 2003; Peterson & Skow, 2008). Hence, perceiving a figure on one side but not the other entails selection.

Image-Based Segregation Factors

"Image-based factors" refer to segregation factors that can be defined on the image. The Gestalt psychologists introduced a number of these factors and held that they were independent of the viewer's experience (i.e., "autochthonous"), although there is no evidence for this point. Additional image-based segregation factors have been identified recently.

Classic Gestalt Image-Based Segregation Factors

The Gestalt psychologists showed that the figure was more likely to be perceived on the side of a border that is *convex* rather than concave, where the convex side is that side from which the border has a positive sign of curvature. For instance, Kanizsa and Gerbino (1976) showed that with displays like Figure 2.1A and 2.1B, in which multiple convex and concave regions alternate, convexity is an effective cue: 90% of their observers reported perceiving the convex regions as figures. Strictly speaking, the “convex” and “concave” regions in Figure 2.1 are not entirely convex or concave, but Stevens and Brooks (1988; Hoffman & Singh, 1997) showed that convexity *can* operate locally; that is, when only small portions of the borders near part boundaries (minima of curvature) are convex. For brevity in what follows, therefore, we will use the terms “convex” and “concave” regions to refer to regions with convex and concave parts.

Most perception psychologists inferred that the effectiveness of convexity as a figural cue measured by Kanisza and Gerbino (1976) generalized to all types of displays. Some investigators, in fact, concluded that convexity alone could account for much of image-based segregation, and many computational models use convexity alone to account for figure assignment (e.g., Jehee, Lamme, & Roelfsema, 2007; Kogo, Strecha, Van Gool, & Wagemans, 2010).

However, Peterson and Salvagio (2008) showed that, in briefly exposed displays (100 ms, unmasked), the effectiveness of convexity as a figural cue decreases systematically as the number of alternating convex and concave regions decreases from eight to two (see Figs. 2.2A and 2.2B). In two-region displays, where one concave and one convex region lie on opposite sides of a central border, the likelihood of perceiving the figure on the convex side of the central border was 58%, which is significantly but not substantially greater than chance, and nowhere near the likelihood of perceiving the figure on the convex side of the central border in eight region displays (89%). Furthermore, Peterson and Salvagio observed these effects of region number only when the concave regions alternating with the convex regions were homogeneously colored, not when they were heterogeneously colored (Figs. 2.2C and 2.2D). Thus, much remains to be learned about how the image-based cue of convexity operates. What is certain is that it alone cannot account for figure assignment under many conditions. Peterson and Salvagio’s results also indicate that local decisions regarding individual borders are influenced by global display-wide analyses (cf. Kim & Feldman, 2009).

Other image-based shape properties identified as figural cues by the Gestalt psychologists include *symmetry*, *small area*, and *closure* (Rubin, 1915/1958; for review, see Hochberg, 1971; Peterson, 2001; Pomerantz & Kubovy, 1986). But these image-based properties can also be attributes of grounds, as shown in Figure 2.3. Therefore, these cues must be operating probabilistically rather than deterministically. Furthermore, recent research shows that, like convexity, neither symmetry (Machilsen, Pauwels, & Wagemans, 2009; Mojica & Peterson, 2012; Salvagio, Mojica, & Peterson, 2008) nor small area (Salvagio et al., 2008) is a strong figural cue in displays with only two contiguous regions. This finding is again consistent with the idea that segregation is determined by ensembles of shape properties and by scene-wide information, rather than by individual, localized properties.

New Image-Based Shape Properties

Hulleman and Humphreys (2004) introduced a new figural cue of *top/bottom polarity*, whereby regions with a wide base and a narrow top are more likely to be seen as figures than those with a narrow base and a wide top. An example is shown in Figure 2.4A. This cue, along with many of the others, may reflect a general feature of our environment: On the assumption that objects are more stable when they are wider at the base than at the top, objects with this property are probably more common in our environment than objects that are narrower at the base than at the top.

Vecera, Vogel, and Woodman (2002) systematically explored the cue of *lower region* that had been discussed but not investigated by Ehrenstein (1930; cf. Koffka, 1935; Metzger, 1953). Vecera et al. showed that, ceteris paribus, a horizontal border is more likely to be perceived as shaping the region below rather than above it (see Fig. 2.4B).

Other image-based figural cues have been introduced over the years, including *part salience* (Hoffman & Singh, 1997), whereby regions with protruding parts are more likely to be perceived as figures; *spatial frequency* (Klymenko & Weisstein, 1986), whereby regions filled with high spatial frequency gratings are more likely to be perceived as figures than regions filled with low spatial frequency gratings; *extremal edges* (Palmer & Ghose, 2008), whereby regions with shading gradients indicating a horizon of self-occlusion on a smoothly curved convex surface are more likely than abutting regons to be perceived as figures, as well as some dynamic cues (Barenholtz & Feldman, 2006). A figural property recently introduced by Palmer and Brooks (2008) integrates grouping and segregation (see section on “The Relationship Between Grouping and Segregation” for further explication).

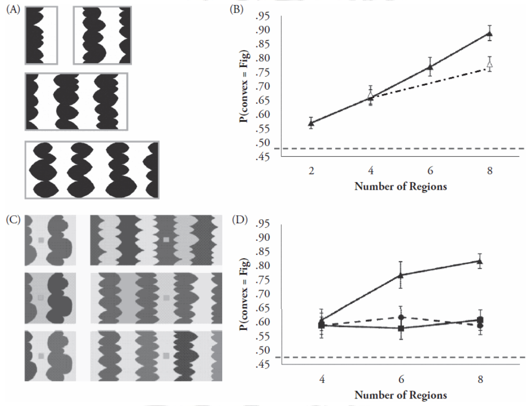

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Figure 2.2 (*A*) Displays with two-, four-, six-, and eight-region alternating equal-area black and white convex and concave regions. The convex regions are black in these displays, but they were white on half the trials in the experiments. Observers fixated the central border and reported whether the black or the white regions appeared to be figures. (Adapted from Peterson and Salvagio, 2008, *Journal of Vision*, Figure 2.) (*B*) The probability that observers perceived the convex regions as figures as a function of region number. (Region number was a between-subjects factor.) Solid black line: results obtained when all the convex regions had the same shape (as did all the concave regions); dashed black line: results obtained when each of the display regions had a different shape. The dashed red line indicates chance performance. (Adapted from Peterson and Salvagio, 2008, *Journal of Vision*, Figure 3.) (*C*) Sample four- and eight-region displays used to test whether homogeneity of color of the convex and/or the concave regions was necessary for the region number effects shown in (*B*). Top: both convex and concave regions are heterogeneously (HET) colored; no two regions of the same type are the same color (although all regions of one type are the same luminance; luminance was balanced across region type). Middle: Sample displays with homogeneously (HOM) colored convex regions and HET colored concave regions. Bottom: Sample HOM colored concave/HET colored convex displays. Note that the brightness values may not reproduce well here. Because displays were multicolored, direct report regarding the color of the figures was not possible. Accordingly on each trial a red response probe was placed on the region to the right or to the left of fixation. Observers reported whether the probe appeared to lie on or off the region they saw as figure. (Originally published as Peterson and Salvagio, 2008, *Journal of Vision*, Figure 4.) (*D*) The probability that convex regions were perceived as figure [P(convex = fig)] in multicolored displays as a function of region number. Dashed black line and disks: HET colored convex/HET colored concave displays. Solid black line and squares: HOM colored convex/HET colored concave displays; solid black line and triangles: HOM colored concave/HET colored convex displays. The dashed red line indicates chance performance. (Originally published as Peterson and Salvagio, 2008, *Journal of Vision*, Figure 5.) (See color insert.)

In summary, even when depth cues are not considered, multiple image-based properties influence figure assignment, so it is clear that multiple sources of information are used to solve the critically important task of scene segregation.

Subjective Factors

A variety of subjective factors, including past experience (learning), attention, perceptual set, and the observers’ fixation location, affect segregation.

Familiar Configuration: A Learned Geometric Shape Property

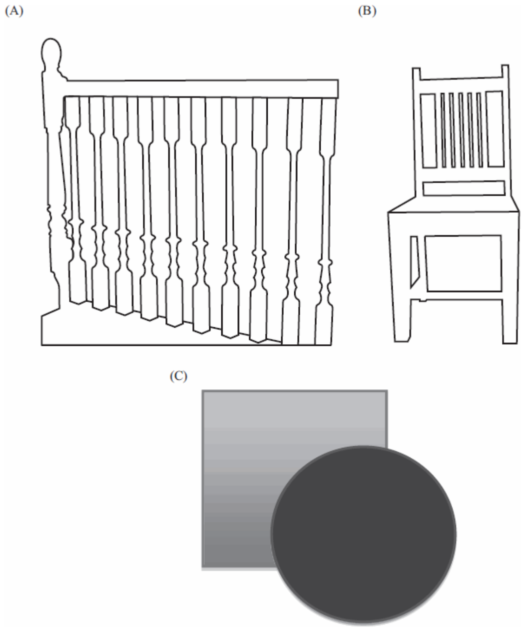

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Figure 2.3 (*A*) Bannisters: Both the turned wooden pieces (the figures) and the spaces between them are symmetric. (*B*) Chair: the small-area spaces between the slats on the back of the chair are not figures, nor are the enclosed horizontal spaces within the borders of the chair. (*C*) Both the light gray and dark gray regions are closed, yet only one is perceived as the figure at their shared border. (See color insert.)

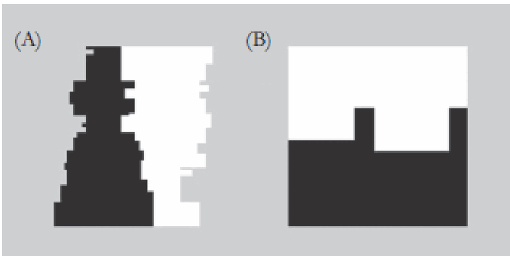

Figure 2.4 (*A*) A display illustrating the figural cue of top/bottom polarity introduced by Hulleman and Humphreys (2004). The region on the left has a wide base and a narrow top. The region on the right has a narrow base and a wide top. Hulleman and Humphreys showed that regions like those on the left are more likely than regions like those on the right to be perceived as figures. (*B*) A display illustrating the figural cue of lower region introduced by Vecera et al. (2002).

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Figure 2.5 (*A* and *B*) Sample bipartite displays in which two equal-area regions share a central border. The region on the left in black in these sample displays portrays a portion of a meaningful, familiar object, a woman. The woman is portrayed in an upright orientation in (*A*) and in an inverted orientation in (*B*). (*C*) The parts of the upright woman (delimited by successive minima of curvature along the central border) have been spatially rearranged. (*D*) A sample of a display used by Peterson and Gibson (1994) with an asymmetric region portraying a familiar configuration (a seahorse) in black on the left and a symmetric meaningless/novel region in white on the right.

Until the early 1990s the Gestalt view that past experience could not affect figure assignment dominated (see also Fodor, 1984; Pylyshyn, 1999). But, since then, carefully controlled tests have shown that past experience in the form of familiar configuration serves as a segregation cue (e.g., Peterson, Harvey, & Weidenbacher, 1991; Peterson & Gibson 1994a, b). For instance, Peterson and Gibson (1994b; Gibson & Peterson, 1994) used vertically elongated rectangular displays divided in half by a central border. The displays were designed so that no known shape properties relevant to segregation distinguished the two halves of the display, yet the central border suggested a familiar, nameable, object on one side but not the other (see Fig. 2.5A). Observers were more likely to perceive the figure on the side of the border where the familiar configuration lay when the display was presented with the familiar object in its typical upright orientation rather than in an inverted orientation (see Fig. 2.5B; for review, see Peterson, 1994). Orientation dependency was critical for attributing these effects to past experience rather than to geometric properties of the display, because past experience effects plausibly should depend on typical orientation, whereas effects due to the geometric properties of the parts alone (e.g., part saliency) should not (also see Gibson & Peterson, 1994; Peterson et al., 1991). Furthermore, when familiar parts were spatially rearranged to form a novel configuration as in Fig. 2.5C, no effects of past experience were observed. This pattern of results led Peterson et al. to conclude that familiar configurations—and not familiar parts—were the origin of the past experience effects.

In their original experiments testing effects of familiarity on segregation, Peterson and colleagues used portions of well-known familiar objects (e.g., women, seahorses, coffee pots, table lamps). Later, they found that a single experience with a novel shape was sufficient for it to exert an influence on figure assignment the next time the border of that shape was encountered (Gibson & Peterson, 1994; Peterson & Enns, 2005; Peterson & Lampignano, 2003; also Treisman & DeSchepper, 1996; Peterson, 2012). Vecera and Farah (1997) obtained similar results with alphabetic letters (see also Navon, 2011).

These results raise questions concerning how familiarity operates prior to figure assignment. Peterson and Skow (2008) proposed that objects that might be perceived on opposite sides of a border are identified in a first pass of processing; potential objects on opposite sides of a border then compete for figural status (cf. Desimone & Duncan, 1995), and the most likely percept is seen.

Fixation Location, Attention, and Perceptual Set

Subjective factors such as the location of observers' eyes or attention affect segregation as well. Observers are more likely to perceive a given region as figure when they are fixating it than when they are fixating a contiguous region (Peterson & Gibson, 1994b). Effects of spatial attention, independent of fixation location, have been demonstrated as well. Baylis and Driver (1995) showed that the voluntary allocation of attention to one of two contiguous regions boosts the likelihood of seeing that region as figure. Later, Vecera, Flevaris, and Filapek (2004) demonstrated that involuntary attention, too, can influence figure-ground assignment. Additional evidence for attention effects came from tests of unilaterally brain-damaged participants. Such participants often allocate attention to the ipsilesional side of objects, regardless of where the objects are located in space (e.g., Behrmann & Tipper, 1994; Driver & Halligan, 1991; Gainotti, Messerle, & Tissot, 1972). In bipartite displays, each region constitutes a potential object, of which only one is selected for perception (see Figs. 2.5A-C). Unilaterally brain-damaged patients are more likely to perceive figures lying on the contralesional side of the central borders of bipartite displays (Driver, Baylis, & Rafal, 1992; Marshall & Halligan, 1994; Mattingly, Price, & Driver, 1996; Peterson, Gerhardstein, Mennemeier, & Rapscak, 1998), consistent with their attention having been allocated ipsilesionally within the two bipartite display regions. These results indicate that the potential objects on opposite sides of a border can serve as substrates for attention, consistent with Peterson and Skow's (2008) view that objects that might be perceived on opposite sides of a border are identified in a fast pass of processing, followed by a competition between them for figural status.

The perceiver's *perceptual set* (or intention) to perceive the figure on one side of a border (manipulated via instructions) also exerts an influence on segregation, even when fixation location is held constant (Peterson & Gibson, 1994b; Peterson et al., 1991). Intention effects are larger for upright than inverted familiar configurations, suggesting that intention operates at least in part via representations of familiar objects (see also Strüber & Stadler, 1999).

Interactions Between Cues

There have been a few investigations exploring how different figural cues interact. Peterson and Gibson (1994b) found that effects of fixation were independent of those of past experience (i.e., the effects of fixation did not vary with the familiarity/meaningfulness of the shape depicted by a region). Fixation effects were also similar in size regardless of whether viewers had a perceptual set to try to perceive a region as figure.

Kanisza and Gerbino (1976) placed symmetry in competition with convexity, and they found that effects of convexity were undiminished by the competition. These results led some investigators to conclude that symmetry is a weak figural cue (e.g., Pomerantz & Kubovy, 1986). Inasmuch as Kanizsa and Gerbino used multiregion displays, however, their results were likely context dependent (see discussion of region number effects in section on "Classic Gestalt Image-Based Segregation Factors"). Investigations of how convexity and symmetry compete in displays with fewer regions have yet to be conducted.

Peterson and Gibson (1994a) used brief masked exposures of two-region displays to examine how symmetry and familiar configuration interact. In their displays, a region that sketched a familiar meaningful configuration shared a central border with a region that portrayed a novel, meaningless configuration[1]; the two regions were equated for area and convexity. A sample of a display, with one symmetric but novel region and one asymmetric region portraying a familiar configuration (a seahorse) is shown in Figure 2.5D (color and left/right location were counterbalanced). When these displays were viewed in an inverted orientation, the symmetric regions were perceived as figure on approximately 62% of trials (averaged over all exposure durations) and the asymmetric region was perceived as figure on 38% of trials, documenting the effect of symmetry once again. When these displays were upright, however, and effects of familiar configuration were expected, the effect of symmetry was diminished: now symmetric regions were perceived as figure on only 52% of the trials, and the asymmetric familiar configuration was perceived as figure on 48% of the trials (again, averaged over variations in exposure duration). Thus, when symmetry and familiarity were in conflict, each cue determined the figure on approximately half the trials. These results suggest familiar configuration is not a dominant figural cue; instead it is one among many shape properties relevant to figure assignment (Peterson, 1994a,b).

On a competition view, the familiar configuration should be perceived as figure more often when the region on the opposite side of the central border is asymmetric. In fact, the familiar configuration was perceived as figure on 61% of trials when both regions were asymmetric and on 84% of trials when it was symmetric and the novel meaningless configuration on the opposite side of the border was asymmetric. (For more on this competition, see Peterson & Skow, 2008; Peterson & Kim, 2001; for computational models of the competition, see Keinker, Hinton, & Sejnowski, 1986; Vecera & O'Reilly, 1998, 2000).

Figure-Ground Early or Late?

To accommodate the effects of familiarity on figure assignment, Palmer (1999) suggested that figure assignment occurs later in processing than had been proposed by the Gestalt psychologists. But this proposal seems inconsistent with the effects of exposure duration. Peterson and Gibson (1994a) exposed displays like Figure 2.5D for 14 ms, 28 ms, 57 ms, or 100 ms and followed them immediately with a mask. Effects of both familiar configuration and symmetry were evident when displays were viewed for 28 ms; effects of neither were evident in 14-ms exposures. Thus, at least via this index, figure assignment seems to occur early in processing for two region displays. Moreover, familiar configuration seems to operate as early in processing as symmetry. Other figural cues have not been tested at such short durations, either alone, in conflict, or in combination. Effects of convexity are evident in 100 ms masked exposures; shorter exposure durations were not tested. Effects of region number (i.e., context) on convexity (see section on "Classic Gestalt Image-Based Segregation Factors") are not evident in a 100-ms masked exposure; they require as long as 200 ms to emerge (Salvagio & Peterson, 2010; 2012). Thus, the processing time required for figure assignment is variable rather than fixed.

Another way to interpret the early versus late distinction is in terms of level of processing. In their interactive processing model, Vecera and O'Reilly (2000) place figure-ground perception lower than object representations in the hierarchy of visual processes. Effects of familiar configuration are therefore viewed as top-down effects on computation. Here, the Gestalt view that figure-ground perception precedes access to object memories is maintained in architectural terms, although not in temporal terms (since processing is interactive). Peterson and colleagues (Barense et al., 2012) have argued, though, that there is no single processing level at which figure assignment occurs; instead, competitions producing figure-ground perception occur at multiple levels of the visual system.

A third way to classify a process as early or late is to ask whether it can occur *preattentively*, that is, under conditions of distributed attention, before attention has been focused on a location in the input array. Although "preattentive" implies a temporal ordering, one can also interpret "pre"-attentive as "a"-attentive, that is, as occurring without attention directed to the task at hand. Kimchi and Peterson (2008) showed that by this definition, too, figure-ground perception can occur early (see section on "Methods of Assessing Segregation: Direct Versus Indirect" for further explication).

Grouping

Like segregation, grouping is a highly complex process, influenced by a variety of image-based factors as well as by past experience and attention. Researchers have investigated how multiple grouping cues combine, and they also have examined the time course of grouping and when grouping occurs in the functional hierarchy of visual processes.

Image-Based Grouping Factors

Classical Gestalt Image-Based Grouping Factors

Gestalt psychologists, most notably Max Wertheimer (1923/1938), proposed a set of grouping principles rooted in image properties. These classic factors include proximity, similarity, common fate, good continuation, and closure; they are presented in all textbooks on perception. The principle of *proximity*, perhaps the most fundamental grouping principle, states that closer elements tend to be grouped together (Fig. 2.6B). The *similarity* principle states that the most similar elements (in attributes such as color, orientation, or shape) tend to be grouped together (Fig. 2.6C-E). According to the *common fate* principle, elements tend to be grouped together if they move together (Fig. 2.6F). The principle of *good continuation* states that elements that form a smooth continuation are grouped together (Fig. 2.6G), and the principle of *closure* states that elements that form a closed figure tend to be grouped together (Fig. 2.6H).

New Image-Based Grouping Factors

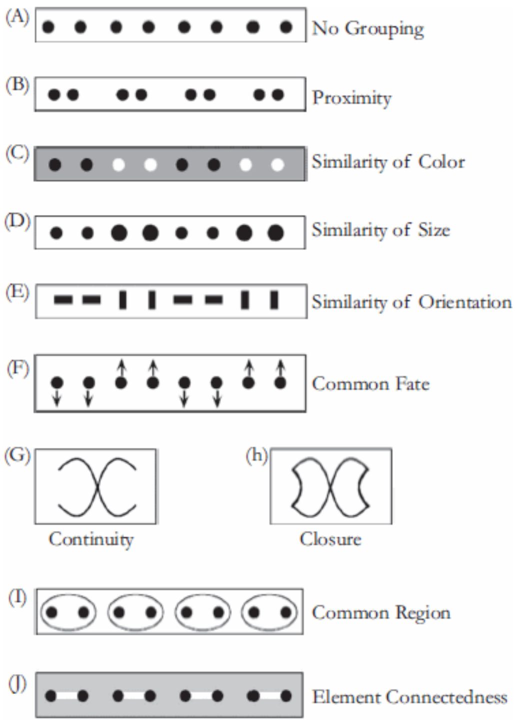

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Figure 2.6 Classical and new image-based grouping factors. (Adapted from Palmer, Brooks, & Nelson, 2003.)

In recent years new grouping principles have been added. The principle of *common region* (Palmer, 1992) states that elements that are located within the same closed region of space tend to be grouped together (Fig. 2.6I). The principle of *element connectedness* (Palmer & Rock, 1994) states that elements that are connected tend to be grouped together (Fig. 2.6J). The principle of *synchrony* (Lee & Blake, 1999; Palmer & Levitin, 1998) suggests that visual events that change at the same time tend to group. Synchrony is related to the principle of common fate, except that the simultaneous changes do not have to involve motion or to be "common" in any sense—for example, some elements can get brighter and others can get dimmer, as long as the change occurs at the same time (Palmer, 1999).

Palmer and Rock (1994) argued for an even more basic organization principle, the principle of *uniform connectedness* (UC), which precedes all forms of grouping (and parsing). According to this principle, a connected region of uniform visual property (such as luminance and color) is perceived initially as a single perceptual unit. Classical grouping principles operate only after uniformly connected units are designated as figures rather than background. However, the foundational status of UC has been challenged and several studies showed that other properties, such as collinearity and colsurer, were at least as important, if not more so, in intial organization (Kimchi, 1998, 2000; Peterson, 1994b).

Subjective Factors

Past Experience

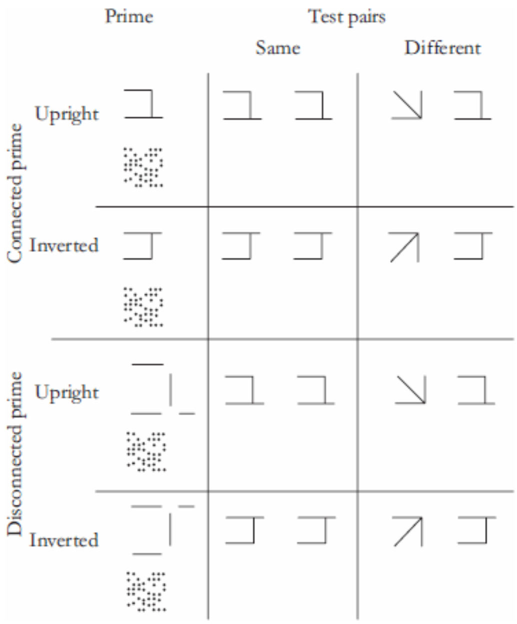

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Figure 2.7 Examples of the stimuli used by Kimchi and Hadad (2002) to show the influence of past experience on grouping. The primes and test figures were Hebrew letters. Disconnected letters were formed by introducing either small or large gaps at the interior concave discontinuities of the upright letter. The illustration depicts the letter "Bet" in the connected and the large gap conditions. The random array of dots served as a neutral prime, providing a baseline for each test pair. Connected letter prime facilitated "same" responses to the test pairs at brief exposures, regardless of orientation (upright or inverted), but when the primes were disconnected, only upright-letter primes facilitated judgments at brief exposures. (Adapted from Kimchi & Hadad, 2002.)

At the end of his seminal article on grouping, Wertheimer (1923/1938) listed "past experience" or "habit" as a *potential* grouping principle that, although championed by some had not been shown to be an independent cue. However, he made it clear that he considered habit to be dominated by other principles and secondary to them in that it probably operated only after they had produced an initial organization.

Recent studies demonstrate that past experience can influence grouping (Kimchi & Hadad, 2002; Vickery & Jiang, 2009; Zemel, Behrmann, Mozer, & Bavelier, 2002). For example, Kimchi and Hadad (2002) asked subjects to judge whether two intact letters were the same or different. The target letters were preceded by a briefly presented letter prime (Fig. 2.7) and the exposure duration of the letter prime varied (40–690 ms). They found that a connected letter prime similar to the target letters sped up "same" judgments both when the prime and targets were upright and when they were inverted. However, when the prime letters were constructed of disconnected segments, only upright-letter primes facilitated judgments at brief exposures, whereas inverted-letter primes facilitated responses only at longer exposures, suggesting that past experience with upright letters enabled the subjects to quickly group the segments into the letter configuration. Vickery and Jiang (2009) demonstrated that a short learning period (as opposed to a lifelong experience with letters as in Kimchi and Hadad's study) can also influence grouping; specifically, they showed that associative learning can induce perceptual grouping. They exposed their subjects to explicitly segmented pairs of shapes and then tested them in a transfer task that required detecting two adjacent shapes of the same color. The subjects were faster at locating the color repetition when the adjacent shapes with the same color came from the same trained groups than when they were composed of two shapes from different trained groups, indicating an effect of learning.

Attention and Expectation

Subjective factors such as attention and the observer's knowledge or expectation can also influence perceptual grouping. For example, Freeman, Sagi, and Driver (2001) provided evidence that attention can affect basic grouping. They used displays that included a central target Gabor patch with low-contrast surrounded by two pairs of high-contrast Gabor flankers (Fig. 2.8) and measured contrast thresholds for detecting the central target. One flanker pair was collinear with the target, while the other was orthogonal. Flankers collinear with the target improved target detection—but only when the flankers were attended to as part of a simultaneous task (Fig. 2.8, left panel). The same flankers, when unattended (Fig. 2.8, right panel), did not interact with the target, as if they were not physically present in the display.

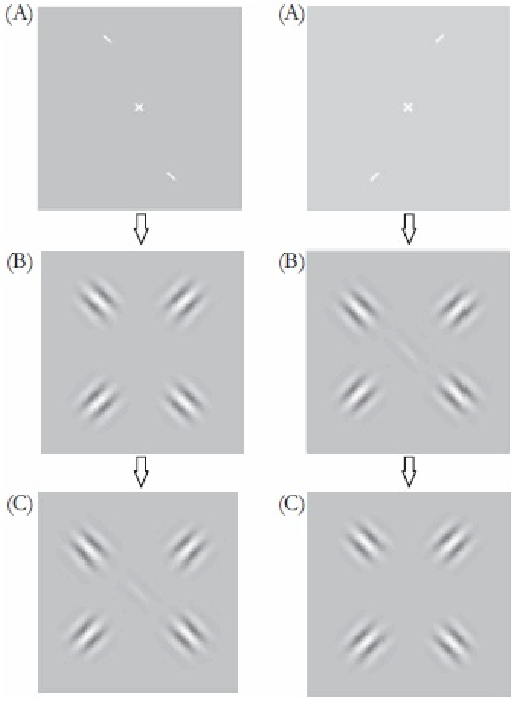

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Figure 2.8 Trial sequence and examples of the stimuli used by Freeman et al. (2001) to show the influence of attention on grouping. (*A*) Fixation display with bar markers indicating the relevant flanker pair and the direction of offset for the Vernier task. (*B* and *C*) Two successive stimulus intervals, each composed of two pairs of flanking Gabor patches, with a central target present only in one interval. One flanker pair was always collinear with the target, while the other was orthogonal. Each flanking pair had a Vernier offset. The observer made two responses, indicating first the interval in which the relevant flankers were offset in the prespecified direction, and then the interval in which the central target was present. The illustration depicts two examples. Left panel: the pre-specified Vernier offset's direction for the relevant flanker pair is in the first interval (*B*); the central target is present in the second interval (*C*); the attended flanker pair (for the Vernier task) is collinear with the target. Right panel: the prespecified Vernier offset's direction for the relevant flanker pair is in the second interval (*C*); the central target is present in the first interval (*B*); the attended flanker pair (for the Vernier task) is orthogonal to the target. The collinear flanker pair facilitated the central target detection only when attended for the Vernier task. (Adapted from Freeman, Sagi, & Driver, 2001.)

Beck and Palmer (2002) examined whether an observer's knowledge can influence grouping. They presented observers with a row of alternating circles and squares except for a single adjacent pair in which the same shape is repeated. The observers were asked to determine whether the repeated pair consisted of circles or squares. Observers were faster to find the target shapes when grouping factors (e.g., proximity, similarity, common region, connectedness) biased the pair to occur within a perceptual group. The probability of the within-group trials varied (25%, 50%, or 75%) and observers were informed about these probabilities prior to each condition. The grouping effect increased as the probability of the within-group trials increased. The influence of the probability was stronger for the grouping factors of common region and connectedness than for proximity and color similarity.

Integrating Multiple Grouping Principles

The grouping principles, as formulated by the Gestalt psychologists, hold only when everything else is equal, that is, when they are the only rule that applies and no other grouping factors are present. Perceptual organization, however, is clearly determined by the simultaneous operation of several grouping principles (e.g., Koffka, 1935). Recent developments of a quantitative approach to perceptual grouping address the issue of integration of multiple grouping factors, and studies have investigated the rules governing the combination of different principles (e.g., Claessens & Wagemans, 2005, 2008; Elder & Goldberg, 2002; Kimchi, 2000; Kubovy & van den Berg, 2008).

Kubovy and van den Berg (2008), using dot lattices, examined what happens when grouping by proximity and grouping by similarity in luminance are combined. Their strategy was to first measure grouping by proximity and then examine the relation between it and grouping by luminance similarity. Their results showed that the strength of the combined effect of these two grouping principles is equal to the sum of their separate effects. A reanalysis of Quinlan and Wilton's (1998) data by Kubovy and van den Berg showed that grouping by proximity and grouping by color similarity also combine additively. Additivity was also found for the combined effect of proximity and collinearity (Claessens & Wagemans, 2005, 2008).

Elder and Goldberg (2002; Elder, 2002) examined the principles of proximity, good continuation, and luminance similarity as they relate to contour grouping in natural images. They found that, statistically, in these real-world images, these grouping principles are approximately independent. They also found that these principles differ in their importance for contour grouping—the most powerful one is the principle of proximity. The question of whether the independence observed for these principles is true for other combinations of grouping principles awaits further research.

Ben Av and Sagi (1995) examined the interactions between grouping by proximity and grouping by similarity. They presented arrays with two principles in conflict followed by a mask and varied the array-mask interval. Grouping by proximity was perceived faster than grouping by similarity in luminance or in shape. Han (2004) examined the interaction between grouping by proximity and grouping by shape similarity in an event-related brain potential study and found both behavioral and ERP evidence for early dominance of proximity over shape similarity.

Other results suggest that collinearity can facilitate rapid grouping when proximity is relatively weak (Hadad & Kimchi, 2008; Kimchi, 2000). Interestingly, the ability to utilize collinearity to facilitate grouping of spatially distant lines into a global shape was observed in older children and adults, but not in 5-year olds (Hadad & Kimchi, 2006).

Recently, Shibata, Kawachi, and Gyoba (2010) examined the combined effects of grouping by proximity, closure, and orientation similarity, utilizing the phenomenon of motion-induced blindness (MIB), wherein salient visual stimuli alternately disappear from awareness and reappear when they are superimposed on a moving distractor pattern (Bonneh, Cooperman, & Sagi, 2001). Participants had to report whether the targets—a solid square embedded in an outline square—disappeared independently or simultaneously (Fig. 2.9A). The proportion of simultaneous versus independent disappearance was used as a measure of grouping. The combination of proximity and contour closure was examined by varying the relative separation between the inner and outer squares and the degree of closure of the outer square (Fig. 2.9B), and the combination of proximity and orientation similarity was examined by varying the relative separation and orientation difference between the two squares (Fig. 2.9C). The results showed that high proximity produced simultaneous disappearance, regardless of closure and orientation similarity. Closure produced simultaneous disappearance when the separation between the targets increased, and when the separation increased even further, the effect of orientation similarity was observed.

Thus, the findings to date regarding the integration of multiple grouping principles suggest that the different grouping principles are independent, their combined grouping effect is additive, and strong proximity appears to be the most powerful grouping cue.

Is Grouping an Early or a Late Process?

Traditional theories of perception assumed that perceptual grouping operates at an early preattentive stage, in a bottom-up fashion, in order to create the units for which attention can be allocated for further, more elaborated processing (e.g., Kahneman & Henik, 1981; Marr, 1982; Neisser, 1967). This view implies that grouping occurs before other perceptual processes, in particular before perceptual constancies are achieved (Palmer, Brooks, & Nelson, 2003). Rock, Palmer, and colleagues, however, have argued that grouping does not occur early, but instead operates on a representation available only after depth perception, lightness constancy, and perceptual completion have been achieved.

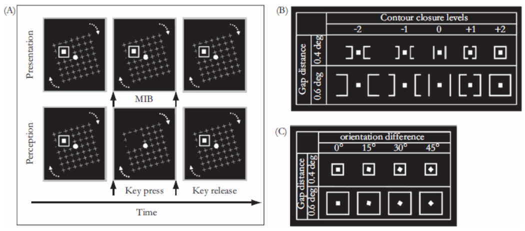

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Figure 2.9 Examples of the stimuli used by Shibata et al. (2010) to study the combined effects of grouping by proximity, closure, and orientation similarity. (*A*) Schematic representation of the MIB stimulus and the corresponding percept. The observers fixated on the center of the screen while attending to the inner and outer squares in the upper left quadrant. The background crosses rotated clockwise or counterclockwise at 180º/sec. The observers were required to press a key as soon as one of the targets (or both) disappeared and hold it down until the target(s) reappeared. The illustration depicts perceptual disappearance of both targets. (*B*) Examples of visual targets used to study the combined effect of proximity and contour closure. Proximity was manipulated by the gap distance between the inner and outer squares; for each gap distance, contour closure was manipulated by the length and direction (outward or inward) of the horizontal contour of the outer square. (*C*) Examples of the visual targets used to study the combined effect of proximity and orientation similarity. For each gap distance, the inner square was rotated. High proximity produced simultaneous disappearance, regardless of closure and orientation similarity. The closure cue produced simultaneous disappearance when the separation between the targets increased, as did the orientation similarity cue when the separation increased even further. (Adapted from Shibata, Kawachi, & Gyoba, 2010.)

For example, Rock and Brosgole (1964) presented observers with a two-dimensional array of luminous beads in a dark room either in the frontal plane or slanted in depth. The beads were closer together vertically than horizontally, so that when viewed in the frontal plane, they were always perceived as organized into columns. When the array was slanted in depth, however, the beads were retinally closer together in the horizontal direction, but observers who viewed it binocularly still reported seeing them grouped into columns. These results argue that grouping occurs after binocular depth perception.

Rock, Nijhawan, Palmer, and Tudor (1992) examined whether grouping by achromatic similarity operates on preconstancy retinal luminance or on postconstancy perceived lightness. They presented displays containing five columns of squares in which the central column was covered by a strip of translucent plastic (Fig. 2.10A) and asked observers to report whether the central column grouped with those to the left or right. The central squares were identical in reflectance to those on the left, but when seen behind the translucent strip their retinal luminance was identical to the squares on the right. The results showed that the central squares were grouped with the reflectance-matched squares on the left rather than with the luminance-matched ones on the right. Similar results were obtained when the central column was seen under shadow. These results were not due to simple luminance ratio of the squares to their background, because when the central squares were seen as in front of an opaque strip of paper (Fig. 2.10B), they were grouped with the reflectance-matched ones on the right rather than the luminance ratio–matched ones on the left. Thus, these results support the hypothesis that grouping occurs on a postconstancy representation. Using a similar method, Palmer demonstrated that perceptual grouping operates after amodal completion (Palmer, Neff, & Beck, 1996) and modal completion (Palmer & Nelson, 2000) have been achieved.

Although these findings provide evidence for the view that grouping is a functionally late process that operates after constancy has been achieved, other findings showed that grouping by color similarity was based on retinal color at short exposure durations and on surface color at long exposure durations (Schulz & Sanocki, 2003), and that grouping can influence shape and lightness constancy (see Palmer et al., 2003). In light of these findings, Palmer at al. (2003) suggested that some form of grouping occurs both functionally early and functionally late in processing.

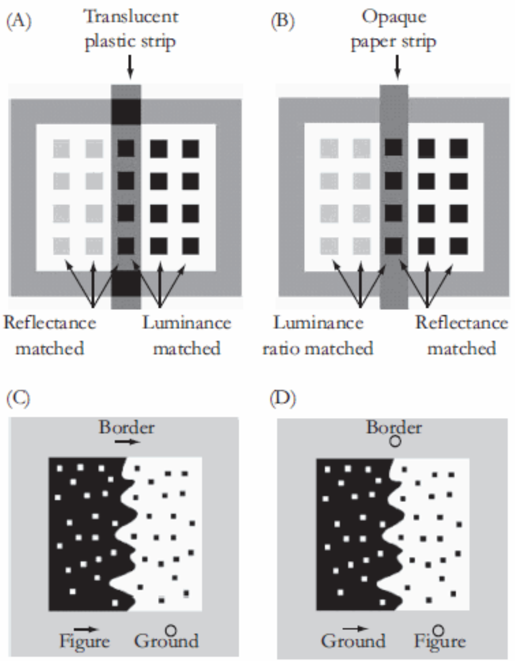

Figure 2.10 (*A* and *B*) The stimuli used by Rock et al. (1992) to show that grouping is influenced by lightness constancy. (*A*) When the central column of squares is seen behind a translucent strip of plastic, it groups with the reflectance-matched elements on the left rather than the luminance-matched ones on the right. (*B*) When the central column is seen as in front of an opaque strip of paper, they are grouped with the reflectance-matched ones on the right rather than the luminance ratio–matched ones on the left. (Reproduced from Palmer, Brooks, & Nelson, 2003.) (*C* and *D*) Stimulus displays used by Palmer and Brooks (2008) to show that grouping affects figure-ground perception. The stimuli are composed of two adjacent regions, one moving (indicated by the arrow at the bottom) and one stationary (indicated by a circle at the bottom). (*C*) When the border moves (indicated by the arrow at the top) in the same direction as the moving region—the border groups with the moving region by common fate—the moving region is seen as figural. (*D*) When the border does not move (indicated by the circle at the top)—the border groups with the stationary region—the stationary region is seen as figural. (Adapted from Palmer & Brooks, 2008.)

As noted earlier, the early versus late distinction can also be interpreted in temporal terms. Several investigators examined the time course of grouping (e.g., Ben Av & Sagi, 1995; Han, Ding, & Song, 2002; Kimchi, 1998, 2000; Kurylo, 1997; Razpurker-Apfeld & Kimchi, 2007). For example, Razpurker-Apfeld and Kimchi (2007) found that grouping into columns or rows by common lightness was evident with a 40-ms exposure duration, whereas grouping by common lightness into a shape (e.g., square or a cross) was evident only at a much longer exposure. Furthermore, the time required for grouping depends on the grouping cue. Using relatively complex displays, Kuyrlo (1997) found that grouping by proximity required a mean of 87.6 ms for processing to be completed, whereas grouping by alignment required a mean of 118.8 ms. Ben Av and Sagi (1995; see section on “Integrating Multiple Grouping Principles”) found that grouping by proximity was evident when the stimulus was available for just 60 ms, whereas grouping by similarity (in luminance or shape) was evident only when the stimulus was available for 160 ms. When cues are combined (e.g., proximity and collinearity) in relatively simple stimuli, grouping appears to emerge at shorter exposures (e.g., Hadad & Kimchi, 2008; Kimchi, 2000; see section on “Integrating Multiple Grouping Principles”). Thus, grouping is time dependent, and some forms of grouping are accomplished earlier than others.

The Relationship Between Grouping and Segregation

Recall that segregation entails determining whether borders are bounding edges of objects, and if so where the object lies with respect to the border. Palmer and Brooks (2008) showed that grouping affects segregation via an “edge-region grouping” principle: When the border groups with one of its attached regions based on the classical grouping principle of similarity (in motion, blur, color, orientation, position, or synchronous flicker), the grouped side appears figural. For example, if the border between two regions moves together with the texture on one side and the texture on the other side is stationary (Fig. 2.10C), the border groups with the moving region by common fate, and the grouped region is perceived as figural; if the border is stationary (Fig. 2.10D), it groups with the stationary region, and the stationary region appears figural.

These results provide further evidence supporting the hypothesis that perceptual grouping occurs at different levels of visual processing (Palmer et al., 2003; see section "Is Grouping an Early or a Late Process?").

Methods

We turn now to the methods that have been used to investigate segregation and grouping. The use of new methods has contributed to a rapid growth of knowledge regarding perceptual organization in recent years.

Methods of Assessing Segregation: Direct Versus Indirect

Much of the evidence regarding segregation factors was gained from experiments in which perceivers reported directly about the regions they perceived as shaped entities at critical borders. Indirect methods of assessing segregation have been employed as well. In this section, we discuss a number of indirect indices that have been developed, and the relative merits of direct and indirect methods.

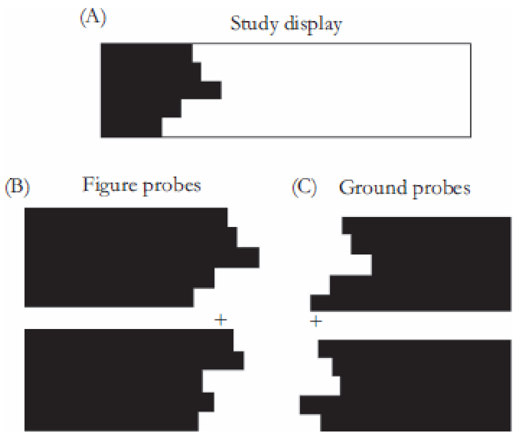

Figure 2.11 Sample trial in Driver and Baylis (1996). (*A*) Study display. (*B*) Figure probes with the boundary from the study display repeated as a boundary for a shape on the same side. (*C*) Ground probes with the boundary from the study display repeated as a boundary for a shape on the opposite side. (Originally published in Peterson and Enns, 2005, *Perception & Psychophysics*, Figure 2.)

Driver and Baylis (1996) introduced a visual short-term memory (VSTM) task as an indirect measure of segregation. Their participants viewed "study" displays in which a stepped edge divided a large rectangle into two regions, one smaller than the other (its width was 33% of that of the larger region), and higher in contrast against the overall screen backdrop (a depth cue identified by O'Shea, Blackburn, & Ono, 1994). Driver and Baylis asked their subjects to remember the shape of the stepped border in the standard display because their task was to decide which of two test shapes shown after a short delay had the same stepped border. (A sample trial is shown in Fig. 2.11.) Driver and Baylis observed that test trial performance was faster and more accurate when the border was repeated as a boundary of a figure on the same side as the small high-contrast region in the study display (see Fig. 2.11B) rather than the opposite (ground) side (see Fig. 2.11C). Because (a) responses are expected to be faster if test shapes are similar to previously seen shapes, and (b) the shape of the figure is perceived but not that of the ground, Driver and Baylis concluded that figure assignment based on small area and high contrast had occurred automatically in the standard displays, even though no mention was made of figure-ground organization.

Other investigators have used this task to infer which regions were perceived as figures in displays where top-bottom polarity (Hulleman & Humphreys, 2004), lower region (Vecera et al., 2002), and attention (Vecera et al., 2004) cued one region as figure. These investigators verified the inferences regarding figure assignment derived from the indirect measures in complementary direct-report experiments, demonstrating that certain cues determine figure assignment even when observers are not instructed on figure assignment beforehand. It should be noted, however, that inasmuch as volitional attentional allocation influences figure assignment (see section on "Fixation Location, Attention, and Perceptual Set"), performance on the VSTM task can be affected by the strategy observers adopt to solve the matching task. For instance, observers could adopt a strategy of attending to the smaller, higher contrast region of the display in order to succeed in the matching task. Consequently, the VSTM task might not index the operation of shape properties alone.

Hulleman and Humphreys (2004) introduced another indirect measure of segregation that cleverly combines a visual search task with a segregation task. Their subjects viewed single displays composed of multiple alternating black and white wide and narrow base regions like those in Figure 2.12A. They were instructed to search for a symmetric region that was present in only half the displays; no mention was made of figure-ground perception. Subjects detected symmetric targets faster and more accurately when they had a wide base and a narrow top rather than a narrow base and a wide top, as expected on the basis of the top/bottom polarity cue. The assumption underlying this measure is that observers will search for the target among the figures first before they search among the regions initially perceived as grounds.

Most recently, Kim and Feldman (2009) introduced a method that opens up exciting possibilities because it can be used to probe figure assignment along segments of a continuous border. They added a local perturbation to an otherwise smooth contour and set that perturbation in motion such that it would be perceived as a rigid part deforming at a concavity from one side and as a nonrigid part deforming at a convexity from the other side. Rather than asking subjects to report which side appeared to be figure, Kim and Feldman asked them to report which side of the boundary appeared to be moving. Based on direct reports of participants in a previous study conducted by Barenholz and Feldman (2006), Kim and Feldman assumed that the side that appeared to move was perceived as the figure.

Kim and Feldman used this dynamic indirect measure to investigate whether the figure was perceived on the same side along a continuous border, and they found that figure assignment can reverse along a continuous border, replicating previous research (Peterson, 2003b; see Figs. 2.12B and 2.12C) and demonstrations (Hochberg, 1971; see Fig. 2.12D) that had used direct reports. Kim and Feldman's dynamic indirect probe measure is valuable both because it does not require instruction regarding figure-ground perception and because it is a useful probe of local figure-ground perception.

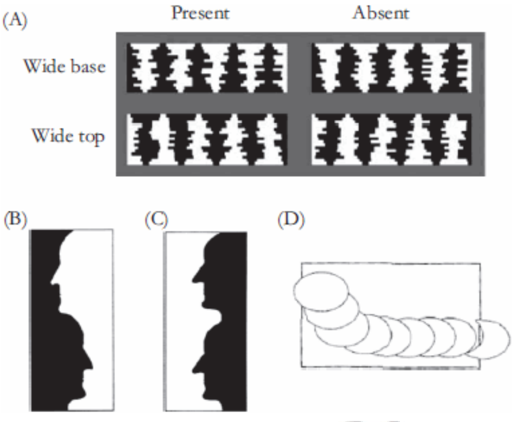

Figure 2.12 (*A*) Sample displays used in a visual search task by Hulleman and Humphreys (2004). A symmetric region was either present or absent. When present, the symmetric region could have either a wide base or a wide top. (*B* and *C*) Sample displays discussed by Peterson (2003b). (*B*) A profile of a face is suggested in white on the top of the display and in black on the bottom of the display. Observers perceived the figure on the right in the top portion of this display and on the left in the bottom portion of this display, indicating that the figural cue of familiarity/meaningfulness can operate locally. Such "cross-over" interpretations were less likely in a display like (*C*), where a face profile is suggested in black in both the top and bottom portions of the display. (*D*) A display used by Hochberg (1971) to show that figure and ground assignments are local. Observers perceive multiple oval disks occluding one another. For all but the leftmost and rightmost regions, each region is perceived as figure along one portion of its boundary and as ground along another portion.

Indirect reports and direct reports are both useful indices of figure assignment. Direct reports can provide evidence regarding the probability that the shape property under investigation determines figural status; this is an important piece of information that most indirect measures cannot provide. Among the indirect measures, only Kim and Feldman's (2008) dynamic indirect probe can assess the probability of a cue's effectiveness. On the other hand, inasmuch as perception is a private experience and subjects report what they perceive, those reports cannot be scored as correct or incorrect. Indirect reports can be scored as correct or incorrect, and response times for correct responses can provide a quantitative measure.

Indirect tasks can also be used to investigate the conditions under which figure-ground perception occurs. For instance, Kimchi and Peterson (2008) tested whether the presence of a change in the figure-ground organization of a task-irrelevant backdrop display affected participants' performance on a change detection task adapted from Russell and Driver (2005); see Figure 2.13. They observed congruency effects such that "same" judgments were faster and more accurate when the backdrop's figure-ground organization remained the same across successive exposures, whereas "different" judgments were faster and more accurate when figure-ground organization changed when the matrices differed. These effects were obtained even though, when probed with surprise questions, participants could report neither the figure-ground status of the region on which the matrix appeared nor any change in that status. Thus, the results clearly demonstrate that figure-ground segregation *can* occur without focal attention ("preattentively," in functional terms).

In addition to direct and indirect indices, implicit measures can be used to probe shape properties that are not reportable because they are properties of the regions ultimately perceived as grounds rather than as figures. Peterson and colleagues (Peterson & Enns, 2005; Peterson & Lampignano, 2003; Peterson & Skow, 2008) have shown via implicit measures that familiar configurations are accessed even when they do not win the competition for figural status. These results are consistent with the hypothesis mentioned earlier—that objects that might be perceived on opposite sides of a border are accessed in a fast pass of processing prior to figure assignment, they compete, and the loser is inhibited, accounting in part for the fact that grounds are shapeless near the borders they share with figures.

Methods of Assessing Grouping: Direct and Indirect

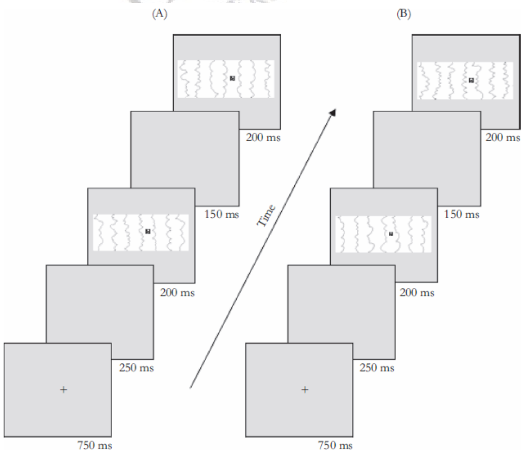

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Figure 2.13 Sequence of events in two trial types in Kimchi and Peterson (2008). (*A*) Same target (matrix is unchanged), different backdrop (target is on figure in first frame and on ground in second frame). (*B*) Different target (matrix changes), same backdrop (target is on figure in both frames).

The Gestalt psychologists used phenomenological demonstrations to investigate perceptual grouping, generating qualitative observations. Current work has used more rigorous, quantitative methods with more complex stimuli, allowing the measurement of the strength of a single grouping factor or the combined effect of multiple factors.

Direct Methods

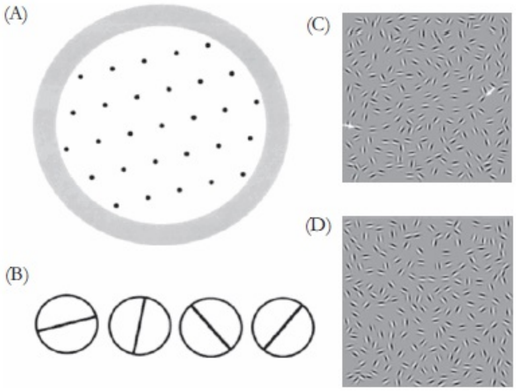

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Figure 2.14 (*A* and *B*) Examples of the stimuli used by Kubovy and Wagemans (1995) to measure proximity. (*A*) An example of stimulus display—a multistable dot lattice that can be grouped into stripes of different orientations. (*B*) A response screen—observers indicate the orientation of the dot lattice they saw by choosing the corresponding response alternative. (Adapted from Kubovy & Wagemans, 1995.) (*C* and *D*) Examples of the stimuli used in the contour detection paradigm (Field et al., 1993). (*C*) A contour (marked by white arrows) is embedded in similar background Gabor elements randomly oriented. (*D*) An otherwise similar display to the one in (*A*), except that all elements are randomly oriented. (Reproduced from Hess & Field, 1999.)

Two popular methods that evaluate grouping directly are the multistable lattice paradigm and the contour detection paradigm. The multistable lattice paradigm uses stimuli in which two or more candidate organizations are simultaneously available and measures the probability with which observers report perceiving each possible organization (e.g., Ben Av & Sagi, 1995; Kubovy & Wagemans, 1995). A prime example of the use of the multistable lattice paradigm is the extensive and elegant work by Kubovy and his colleagues on quantifying the grouping principle of proximity (Kubovy, Holcombe, & Wagemans, 1998; Kubovy & van den Berg, 2008; Kubovy & Wagemans, 1995). They briefly presented multistable dot lattices in which the distances between dots were parametrically varied (see Fig. 2.14A and 2.14B) and asked observers to indicate which organization they perceived. Their data were fit well by an exponential model: Grouping follows a decaying exponential function of the relative distance between dots. Other studies, however, suggested that the proximity cue follows a power law (e.g., Claessens & Wagemans, 2008; Elder & Goldberg, 2002). Further research is required to reconcile these differences. (For some of the rich results obtained with other uses of the multistable lattice paradigm, see Ben Av & Sagi, 1995; Claessens & Wagemans, 2005, 2008; Gepshtein & Kubovy, 2000, 2005; Kubovy & van den Berg, 2008; Palmer et al., 2003; Rock & Brosgole, 1964).

The contour detection paradigm is used mainly to study contour integration: Observers are required to detect a single contour in a background noise and the accuracy with which such detections are made is measured (e.g., Field, Hayes, & Hess, 1993; Kovacs & Julesz, 1993). In a typical experiment, observers are presented with arrays of randomly oriented Gabor elements in which a subset of the elements are locally coaligned—forming a virtual contour (see Fig. 2.14C), and an otherwise identical array where all of the elements are randomly oriented (Fig. 2.14D). Observers are asked in a two-alternative forced-choice procedure to indicate which of the stimuli contains the contour. To distinguish the contour from the background, the contour elements must be grouped, and the results show that contour detection is best for straight contours and becomes worse as the curvature of the contour increases (e.g., Field et al., 1993; Geisler, Perry, Super, & Gallogly, 2001; Hess & Dakin, 1997), and it is best when the orientations of the individual elements are aligned with the contour (Field et al., 1993). Experiments also show that smooth contours are more detectable then jagged ones (e.g., Pettet, 1999), and contour integration can occur even when elements alternate between the two eyes (e.g., Kovacs, Papathomas, Yang, & Feher, 1996), and when the polarity of contour elements alternates (Field, Hayes, & Hess, 2000; see Hess & Field, 1999; Hess, Hayes, & Field, 2003, for reviews).

Indirect Methods

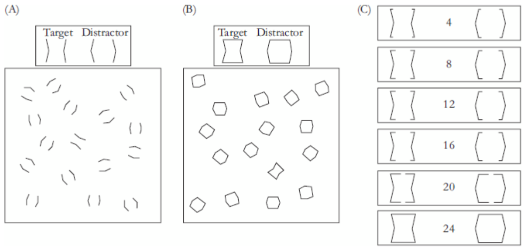

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Figure 2.15 Examples of the stimuli used by Elder and Zucker (1993) to measure perceptual closure. (*A* and *B*) Examples of search displays for the open (*A*) and the closed (*B*) outline shapes. The target and distractor for each example are indicated. The examples illustrate display size of 16. (*C*) Stimuli with different degrees of closure, created from the original open stimuli by adding pixels (the number of which is indicated in the middle) to form inward corners. (Adapted from Elder & Zucker, 1993.)

Several methods assess grouping indirectly. Some of these methods are adaptations of well-established psychophysical paradigms, such as visual search and primed matching. Elder and Zucker (1993, 1994, 1998) used visual search to measure perceptual *closure* and its utility in shape processing. Participants searched for a concave target among a variable number of convex distractors (Figs. 2.15A and 2.15B). The basic stimuli were composed of unconnected line segments, which were the same for the concave and convex stimuli, but bending inward for the concave stimuli and outward for the convex ones. Therefore, the discrimination between target and distractors required grouping of the contour segments into coherent shapes. Search efficiency, indicated by the slope of the best-fitting linear function relating response time to display size, was high (i.e., shallow slope) for closed stimuli (Fig. 2.15B), whereas search for the open stimuli (Fig. 2.15A) was inefficient (i.e., steep slope). When degree of closure of both target and distractors was manipulated (Fig. 2.15C), search speed decreased with increased degree of closure. Based on their results, Elder and Zucker (1994) proposed the notion of a closure continuum (see also, Gillam, 1975; Peterson & Lampignano, 2003) and developed a measure of closure based on a sum of squares of contour gaps; this measure emphasizes large gaps relative to small ones (for a total gap size). However, Kimchi (2000; Hadad & Kimchi, 2006, 2008) demonstrated that grouping by closure also depends on the distribution of the gaps along the contours. Apparently, large gaps hinder rapid grouping when gaps occur at point of change in contour direction but not when gaps occur at straight, collinear contour segments.

Kimchi and colleagues (e.g., Hadad & Kimchi, 2008; Kimchi, 1998, 2000; Razpurker-Apfeld & Kimchi, 2007) adapted the primed-matching paradigm (Beller, 1971) to examine the microgenesis of grouping. In this paradigm observers are presented with a prime followed immediately by a pair of test figures to be matched for identity. Responses to “same” test pairs are faster when the figures in the pairs are similar to the prime than when they are dissimilar to it. Varying the exposure duration of the prime allows the researcher to probe changes in the representation over time—in this case, tracing the time course of grouping. For example, Kimchi (1998) examined the time course of grouping multiple elements that varied in number and relative size. The primes were elements (e.g., circles) grouped into a global configuration (e.g., global diamonds). The “same”-response test pairs were either similar to the elements of the prime (and dissimilar to the global configuration) or similar to the prime’s global configuration (and dissimilar to the elements) (Fig. 2.16). The results showed priming of the global configuration of many-element stimuli at brief exposures, but priming of the local elements only at longer exposures. The converse pattern was observed for the few-element stimuli; here the relatively large elements were primed at brief exposures and the global configuration was primed at longer exposures. These results suggest rapid grouping of many small elements into configuration with elements individuation occurring later in time, whereas few, relatively large elements are individuated rapidly and their grouping into a configuration is time consuming.

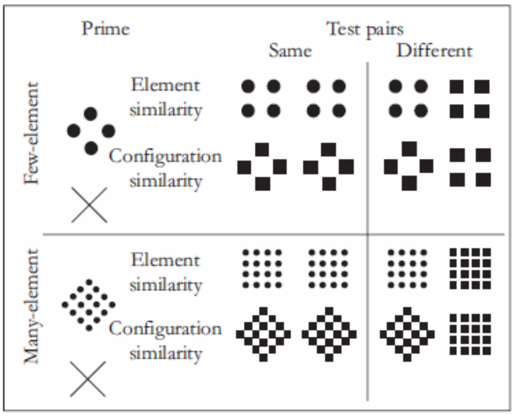


Figure 2.16 Examples of the priming stimuli and the "same"-response and "different"-response test pairs for the few-element and many-element stimuli used by Kimchi (1998) to study the time course of grouping multiple elements into a global configuration. The "same"-response test pairs were similar to the prime either in elements (element-similarity test pair) or in configuration (configuration-similarity test pair). The X served as a neutral prime, providing a baseline for each of the test-pair type. The prime was presented for various durations (40–690 ms). The global configuration of the many-element patterns was primed at brief exposures, whereas the local elements were primed at longer exposures. In contrast, the few, relatively large elements were primed at brief exposures, whereas the global configuration was primed at longer exposures. (Adapted from Kimchi, 1998.)

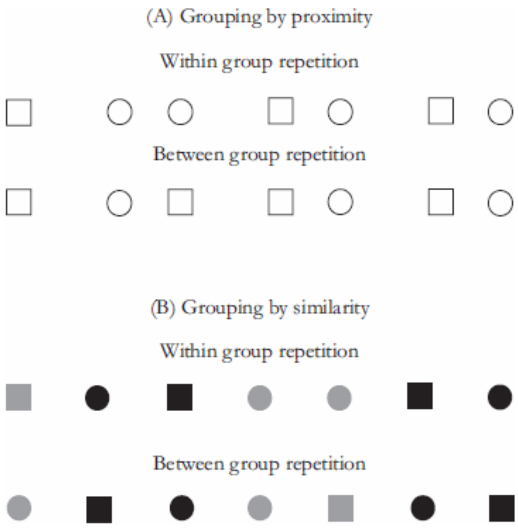
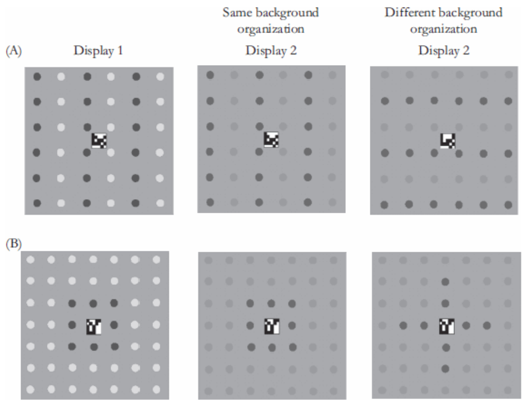


Figure 2.17 An example of the repetition discrimination task (RTD) devised by Palmer and Beck (2007). Squares and circles alternated in a row except for a single adjacent pair of repeated shapes. Because of grouping, the adjacent repeated shapes could occur within a perceptual group or across perceptual groups (between groups). The example depicts proximity grouping (*A*) and color similarity grouping (*B*). The task was to find the repetition of shape and identify it as circles or squares. Repetition discrimination was faster when the adjacent repeated shapes were located within groups than between groups. (Adapted from Palmer & Beck, 2007.)

The primed-matching paradigm was also used to study the time course of grouping by lightness similarity (Razpurker-Apfeld & Kimchi, 2007). Their primes were dot matrices grouped by lightness similarity into columns/rows or into a shape (square/cross or triangle/arrow). The results showed priming of the columns/rows under short prime durations, whereas priming of the square/cross (or triangle/arrow) was observed only under longer prime durations, indicating that grouping by lightness similarity into columns/rows was accomplished faster than grouping by lightness similarity into a shape. These results suggest that even when guided by the same principle, groupings can vary in their time course. This paradigm was also used to study the interaction between grouping by proximity, collinearity, and closure (Kimchi, 2000; Hadad & Kimchi, 2008; see section on "Integrating Multiple Grouping Principles"), and the influence of past experience on grouping (Kimchi & Hadad, 2002; see section on "Past Experience").

Another method to assess grouping indirectly is the repetition discrimination task (RDT), introduced by Palmer and

Beck (2007). Participants have to identify repeated items in an otherwise alternating row of items. The items are grouped pair-wise by a certain grouping factor. The repeated items can occur within a group or between groups (see Fig. 2.17). The difference in response time between the within-group and the between-group trials is taken as a measure of the grouping effect of the manipulated factor. Palmer and Beck found that, for grouping by proximity, color similarity, common region, and element connectedness, response times were faster in the within-group conditions (also see Beck & Palmer, 2002; Vickery & Jiang, 2009).



Click to view larger

Figure 2.18 Examples of the stimulus displays used by Kimchi and Razpurker-Apfeld (2004) to examine whether grouping can be accomplished without focal attention. Two successive displays were presented on each trial. The central target matrix in Displays 1 and 2 was either the same or different. The surrounding colored elements were grouped into (*A*) columns/rows by color similarity and (*B*) a square/cross by color similarity. The background organization either stayed the same across Displays 1 and 2 or changed, independently of whether the target matrix changed or remained the same. The colors of the background elements always changed between Displays 1 and 2. All colors were equiluminant in the experiment. Changes in the background grouping produced congruency effects on the matrix-change judgments for the grouping of columns/rows by color similarity (*A*), but not for the grouping of square/cross by color similarity (*B*). (Adapted from Kimchi & Razpurker-Apfeld, 2004.) (See color insert.)

Several investigators used indirect tasks to examine whether grouping can be accomplished without focal attention (e.g., Kimchi & Razpurker-Apfeld, 2004; Moore & Egeth, 1997; Russell & Driver, 2005). For example, Kimchi and Razpurker-Apfeld (2004) used Russell and Driver’s (2005) indirect task (see section on “Figure-Ground Early or Late?”) to investigate grouping under inattention. On each trial, two successive displays were briefly presented, each comprising a central target matrix surrounded by elements (Fig. 2.18). The task was to judge whether the targets were the same or different. The organization of the background elements stayed the same or changed, independently of the targets. In two critical conditions, the background elements were organized by color similarity into columns and rows (Fig. 2.18A), and into square and cross (Fig. 2.18B). Changes in the background grouping of columns/rows produced congruency effects on the matrix-change judgments, even though participants reported no or little awareness of the background grouping. No effect of the background was observed for grouping of shape, however. Apparently, some forms of grouping can take place without focal attention (see also Moore & Egeth, 1997; Russell & Driver, 2005; Shomstein, Kimchi, Hammer, & Behrmann, 2010), whereas other groupings cannot, suggesting a continuum of attentional demands as a function of the processes involved in the grouping (for a review, see Kimchi, 2009).

Conclusion

This chapter had reviewed behavioral evidence indicating that multiple factors act and interact to produce perceptual organization. It is clear that perceptual organization is influenced by multiple image-based factors: the classic factors introduced by the Gestalt psychologists and more recently identified factors, past experience, and various forms of attention and perceptual set. Although perceptual organization is a fundamental process, the research reviewed in this chapter has shown that the traditional view of perceptual organization as an early process that serves to provide the substrate on which high-level perceptual processes operate is highly simplified. Recent research and new methods have begun to shed light on how objective and subjective, low-level and high-level factors interact to produce the objects of perception. Although we have covered research on segregation and grouping separately, we consider them part of an integrated system of processes that accomplish the daunting task of imposing organization on the visual input. The recent research opens up the exciting prospect of elucidating this foundational process by unraveling the complex interactions among organizational cues in time and in space.

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Notes:

(1.) Pilot studies showed that no shape is completely meaningless; that is some observers usually state that any shape resembles something familiar. Accordingly, we defined regions as meaningless/unfamiliar in shape if $<$ 25% of pilot subjects agreed on a single interpretation for that region. We defined regions as meaningful/familiar in shape if $>$ 75% of pilot observers agreed on a single interpretation for that region.

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