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Boundary extension: Findings and theories

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A view of a scene is often remembered as containing information that might have been present just beyond the actual boundaries of that view, and this is referred to as *boundary extension*. Characteristics of the view (e.g., scene or nonscene; close-up or wide-angle; whether objects are cropped, static, or in motion, emotionally neutral or emotionally charged), display (e.g., aperture shape and size; target duration; retention interval; whether probes of memory involve magnification/minification or change in physical distance), and observer (e.g., allocation of attention; age; planned fixation, gaze direction, and eye movements; monocular or binocular viewing; prior exposure; neurological correlates) that influence boundary extension are reviewed. Proposed mechanisms of boundary extension (perceptual, memory, or motion schema; extension–normalization; attentional selection; errors in source monitoring) are discussed, and possible relationships of boundary extension to other cognitive processes (e.g., representational momentum; remembered distance and remembered size; amodal completion; transsaccadic memory) are briefly addressed.

Keywords: Boundary extension; Scene perception; Spatial memory; Perceptual schema; Picture perception.

When observers view a close-up picture of a scene, and their memory for that scene is later tested, those observers usually remember the scene as containing more information than was actually viewed. Information (objects, background, etc.) that might have been present just beyond the boundaries of the view but that was not actually visible is often incorporated into memory for the scene. It is as if the boundaries of the remembered scene were extended outward, and so this has been referred to as *boundary extension* (Intraub & Richardson, 1989). The only previous review of the boundary extension literature focused primarily on comparison of the characteristics of boundary extension with the characteristics of representational momentum (Intraub, 2002); in contrast, the current review focuses primarily on boundary extension and (a) offers a comprehensive discussion of variables known or proposed to influence boundary extension, (b) draws conclusions regarding properties of boundary extension, and (c) describes mechanisms proposed to account for

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boundary extension. Following a brief introduction, variables influencing boundary extension are reviewed in Part I. Some conclusions regarding general properties of boundary extension are drawn in Part II, and potential mechanisms of boundary extension are briefly discussed in Part III. Finally, a summary is provided in Part IV.

Studies of boundary extension present participants with a target stimulus such as the example shown in the top panel of Figure 1. The target is usually a photograph or drawing of a scene containing an object or small number of objects within a larger background or context (e.g., Intraub, Bender, & Mangels, 1992; Intraub, Gottesman,

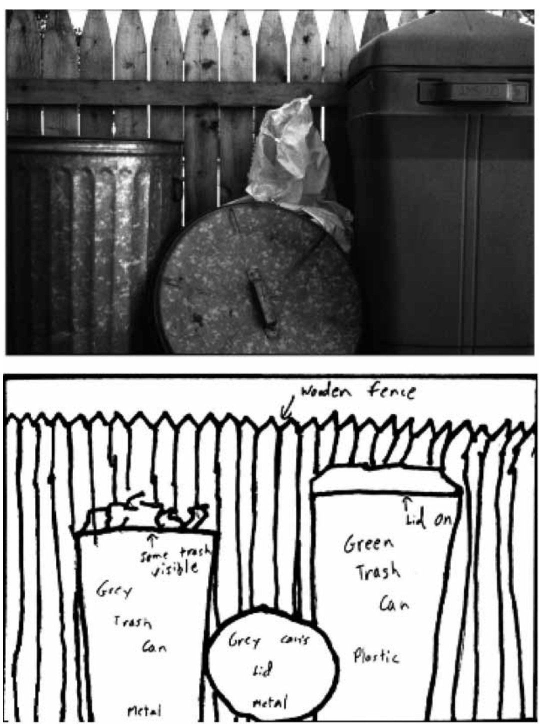

Figure 1. *An illustration of boundary extension. A participant who viewed the target photograph shown in the top panel produced a drawing of the remembered target shown in the bottom panel. Boundary extension is illustrated in the additions of the bottom of the waste containers, fence to the left and right, and sky above the fence. From "Wide-Angle Memories of Close-Up Scenes", by H. Intraub and M. Richardson, 1989,* Journal of Experimental Psychology: Learning, Memory, and Cognition, 15, *pp. 179–187. Copyright 1989 by the American Psychological Association. Adapted with permission.*

& Bills, 1998; Intraub, Gottesman, Willey, & Zuk, 1996). After viewing the target, participants' memory for the target is measured. Two commonly used response measures involve participants (a) drawing the target from memory or (b) rating whether the viewpoint in a probe (second) photograph or drawing of the same scene is closer, the same as, or more distant than the viewpoint in the remembered target. As shown in the bottom panel of Figure 1, when participants draw the remembered target, they usually include information not present in the target but that might have been present just beyond the visible edges of the target. When participants rate the viewpoint in a probe photograph or drawing, they are more likely to rate probes with a slightly more wide-angle view as the same as the target than to rate probes with a slightly more close-up view as the same as the target. Inclusion of additional information in drawings—and judgement that a wider angle probe is more similar to the target—is consistent with outward extension of the boundaries of the remembered target (i.e., the remembered target contains more information than did the actual target).

PART I: VARIABLES THAT INFLUENCE BOUNDARY EXTENSION

There are several variables that influence boundary extension, and these variables can be classified as reflecting characteristics of the stimulus, display, or observer. The listing of variables in this section reflects variables that have been investigated and does not rule out the possibility that additional variables (or categories of variables) that influence boundary extension might be subsequently documented.

Characteristics of the stimulus

Characteristics of the stimulus, including setting (i.e., whether the target and probe depict a scene or a nonscene), viewing angle (i.e., whether the target or probe depict a close-up view or a wide-angle view), object size, cropping of objects in the scene (i.e., whether objects are partially occluded by the boundary), actual or implied movement within the scene, and emotional content of the scene, can potentially influence boundary extension. Additionally, whether boundary extension can be obtained with nonvisual scenes is considered in this section.

Setting

Although not explicitly defined within the boundary extension literature, a scene usually involves a continuous spatial layout or context within which a stimulus object or objects is embedded and that extends beyond the edges of the available view; in contrast, a nonscene usually involves an isolated object that is not embedded within a larger surrounding spatial layout or context (e.g., Gottesman & Intraub, 2002). Intraub et al. (1998) presented photographs of scenes, line drawings of those scenes, or line drawings of the central objects (on blank backgrounds) of those scenes. When participants viewed a target picture and a probe picture and then rated the probe picture on a 5-point scale from −2 (much closer up, object much bigger) to +2 (more much wide angle, object much smaller), ratings suggested that boundary extension occurred for photographs and for line drawings of scenes but not for line drawings of central objects. When participants viewed a target picture and then drew the target picture from memory, drawings revealed a relatively smaller area for central objects and inclusion of peripheral material when participants viewed photographs or line drawings of scenes but not when participants viewed line drawings of central objects. When participants viewed line drawings of central objects, boundary extension occurred when participants were instructed to "project an image" of a described scene around the object, but boundary extension did not occur when participants did not receive such instructions.

Although interpretation of a view as a scene might be necessary for boundary extension, it is not sufficient, as having a target view interpreted as a scene does not guarantee that boundary extension will occur. Bertamini, Jones, Spooner, and Hecht (2005) compared boundary extension for computer-generated views of rooms that contained (a) several pieces of furniture or decorations appropriate to the room type in addition to a main object or (b) just a main object. In both conditions, a main object was clearly located within a scene, but amount of context within the scene varied (e.g., the presence of other pieces of furniture in the room varied). When there was less context (i.e., fewer objects in the scene), there was a greater trend toward normalization (i.e., regression to the mean of the stimulus set, e.g., closer objects remembered as more distant, more distant objects remembered as closer). Bertamini et al. suggested that removing context made the memory task more difficult, and that a shift toward the mean distance of the stimulus set was more likely to occur under conditions of higher uncertainty, even when the stimulus was interpreted as a scene. Also, Legault and Standing (1992) did not find boundary extension for line drawings of scenes (cf. Intraub et al., 1992), and Hutchison et al. (2009) did not find boundary extension for auditory scenes consisting of piano performance or spoken prose.

Viewing angle

The target or the probe can each depict a close-up view of a scene or a wide-angle view of a scene. Presentation of a close-up target usually results in larger boundary extension than does presentation of a wide-angle target, and in many cases, memory for a wide-angle target does not exhibit boundary extension (e.g., Bertamini et al., 2005; Intraub et al., 1992; Intraub et al., 1998; Intraub et al., 1996). Indeed, the finding that boundary extension is larger when the target is a close-up view is one of the most replicated findings in the boundary extension literature. Intraub (2002) suggested that a close-up view of a scene imparted a greater sense of expectation, as the surroundings (i.e., context) just outside the boundaries of a close-up view are more predictable than are the surroundings just outside the boundaries of a wide-angle view. Thus, larger boundary extension with close-up views might be related to greater predictability and increased extrapolation beyond the edges of a close-up view. Additionally, Intraub noted that extreme close-ups are often used in television and film productions as a way to induce or heighten tension in viewers and suggested that this might be related to increased extrapolation of close-up views.

Intraub et al. (1992) presented pictures of target scenes that had close-up, wide-angle, or medium-angle views. In the first experiment, participants were presented with close-up views and medium-angle views. After a retention interval of 48 hours, close-up views resulted in boundary extension, but medium-angle views did not result in boundary extension. In a second experiment, participants were presented with medium-angle views and wide-angle views. In an immediate memory condition, medium-angle views resulted in boundary extension, but wide-angle views did not result in boundary extension. After a retention interval of 48 hours, medium-angle views resulted in boundary extension, and wide-angle views resulted in boundary restriction. A comparison of these two experiments suggests that whether memory for medium-angle views exhibited boundary extension after a retention interval of 48 hours depended upon whether medium-angle views were initially perceived to be relatively close up (i.e., when paired with wide-angle views) or relatively more wide angle (i.e., when paired with close-up views). In a third experiment, participants were presented with close-up, medium-angle, and wide-angle views; boundary extension occurred for all views in an immediate test, and boundary extension occurred for close-up views and medium-angle views after a retention interval of 48 hours, with no change in memory for wide-angle views.

A wide-angle probe is rated as more similar in remembered viewpoint to a close-up target than is a close-up probe to a wide-angle target (e.g., Intraub et al., 1992; Intraub et al., 1998). Although this asymmetry is consistent with the notion that boundary extension is more likely with close-up views than with wide-angle views, it also underscores the importance of the probe view on estimates of boundary extension. Along these lines, Chapman, Ropar, Mitchell, and Ackroyd (2005) presented probe pictures that were initially very wide angle or very close up, and participants adjusted the boundaries of those probes (by magnification or minification, i.e., zooming in or out) until the viewpoint in the probe matched the viewpoint in the remembered target. Close-up targets resulted in larger boundary extension than did wide-angle targets, but of greater interest, whether the probe was initially very wide angle or very close up influenced participants' adjustments. Adjustment of a probe that initially exhibited a very-wide-angle view suggested larger boundary extension than did adjustment of a probe that initially exhibited a very-close-up view, even when target view was held constant (cf. effects of aperture size, Dickinson & Intraub, 2009; Intraub, Hoffman, Wetherhold, & Stoehs, 2006). Such data also highlight a potential role of adjustment and anchoring (Kahneman, Slovic, & Tversky, 1982) in boundary extension (for discussion, Chapman et al., 2005).

Object size

Gottesman and Intraub (2003) examined whether boundary extension resulted from extension of object boundaries or from extension of view boundaries. Participants were presented with target views of natural scenes that contained a smaller object within the boundaries of a larger object (e.g., a cap on a larger folded shirt). Participants were provided with rectangular cards that depicted each background (e.g., grass, asphalt, carpet) but did not depict any objects and were also provided with five cut-out copies of the smaller object and five cut-out copies of the larger object. Of the five cut-outs for each object, one cut-out subsumed the same portion of the area of the background card as the object subsumed in the target and the other cut-outs were 8% or 16% smaller or larger. Participants placed cut-outs that they believed accurately reflected the previously viewed target on the appropriate background card, and they usually chose smaller cut-outs. In a second experiment, participants drew the target from memory, and the proportion drawn (i.e., the ratio between percentage of the areas occupied by the object in the drawing and in the target, Intraub & Berkowits, 1996) for the smaller object and for the larger object were similar. In scene reconstruction and in proportion drawn, decreases in remembered size of the smaller object and the larger object did not differ, and Gottesman and Intraub argued that this pattern demonstrated that boundary extension involves extrapolation of view boundaries rather than extrapolation of object boundaries.

If boundary extension only involves the periphery of a scene (i.e., only involves the view boundary), then distal size of the central objects in a scene should not influence boundary extension. Bertamini et al. (2005) examined boundary extension when retinal size of the central object was constant but distance and distal size of the object varied (e.g., a taller object at a distance of 500 cm from the depicted viewpoint occupied the same percentage of the retinal image as did a shorter object 200 cm from the depicted viewpoint). Boundary extension occurred for small objects and when those small objects were scaled up in retinal size to match the retinal size of a larger object farther away, but boundary extension did not occur for a larger object that matched the retinal size of a smaller and closer object. In a complementary experiment, larger objects were scaled down in retinal size to match the retinal size of closer and smaller objects. Boundary extension occurred for normally small objects, but boundary extension did not occur for scaled-down objects that matched the retinal size of a smaller object that was closer. In general, boundary extension occurred for scenes containing an object of one distal size and did not occur for scenes containing an object of a different distal size, even though the two objects were the same retinal size. Bertamini et al. concluded that the distal size of an object in a scene could influence boundary extension, and this questioned the notion that boundary extension only involves the periphery of a view.

Cropped objects

In many studies of boundary extension, objects in a target picture of a scene might have been cropped by an edge of the picture (e.g., the waste containers in the top panel of Figure 1). Intraub et al. (1992) and Intraub and Bodamer (1993) examined the hypothesis that boundary extension resulted from completion of cropped objects by comparing boundary extension for target pictures in which the main object was cropped and boundary extension for target pictures in which the main object was not cropped. Boundary extension occurred with both types of pictures. Furthermore, boundary extension occurred for cropped versions and for noncropped versions of the same scenes (Intraub & Richardson, 1989). Chapman et al. (2005) had participants zoom in or zoom out on a probe picture to match the remembered view of a target picture, and even though zooming in or zooming out produced different degrees of cropping (or even appearance or disappearance) of peripheral elements of the scene, whether the target contained a cropped object or did not contain a cropped object had no effect on boundary extension. Consistent with the idea that cropping does not influence boundary extension, Gottesman and Intraub (2003) demonstrated boundary extension of a scene does not result from extension of boundaries of objects within that scene.

Movement

The majority of studies of boundary extension presented views of static stimuli, and no motion of those stimuli was implied (e.g., a traffic cone on asphalt pavement, a row of waste containers against a fence). However, if one purpose of boundary extension is to facilitate subsequent recognition of what might be encountered in the next fixation (e.g., Dickinson & Intraub, 2008; Intraub, 2002; Intraub & Dickinson, 2008), then boundary extension should be increased in the direction in which participants expect a fixated object within a scene to move. Courtney and Hubbard (2004) tested this hypothesis by presenting target pictures containing a single object in motion (e.g., a still photograph of a galloping horse). After viewing stimuli, participants drew their recollections of the target pictures. The distance between the leading edge of the object and the nearest boundary in the drawing and between the trailing edge of the object and the nearest boundary in the drawing were measured and were compared to the analogous distances in the target. Boundary extension was larger in the direction of implied motion than in the direction opposite to implied motion. Interestingly, the asymmetry in boundary extension was larger for objects that typically move at a faster velocity (e.g., airplane) than for objects that typically move at a slower velocity (e.g., automobile).

Addition of actual movement to a target view allows examination of how additional characteristics of motion representation interact with or influence boundary extension. One such characteristic is representational momentum, in which memory for the final location of a moving target is displaced forward in the direction of motion (for review, Hubbard, 2005). Hubbard (1996) presented a series of computer-animated concentric square stimuli that increased or decreased in size and then a probe for the final size, and participants were instructed that stimuli represented targets moving toward or away from them, respectively. Representational momentum was larger for receding motion than for approaching motion (see also Nagai, Kazai, & Yagi, 2002). Hubbard noted that typical patterns in boundary extension (i.e., the central object in the scene was remembered as smaller, more background was remembered) were equivalent to displacement of the target away from the participant. According to such a notion, larger displacement in depth for receding targets is consistent with a combination of boundary extension and representational momentum: When boundary extension and representational momentum were in the same direction (receding motion), they summed, and displacement of the target in depth was larger, but when boundary extension and representational momentum were in opposite directions (approaching motion), they partially cancelled, and displacement of the target in depth was smaller.

Munger, Owens, and Conway (2005) examined the relationship between boundary extension and representational momentum, and they presented three blocks of trials. In Block 1, the target was a single picture. In Blocks 2 and 3, the target was a series of pictures depicting movement, and the final picture was the same as that in Block 1. In Blocks 1 and 2, boundary extension was measured using a −2 (much closer) to +2 (much farther away) rating scale for probe pictures. In Block 3, representational momentum (for the location of the viewpoint) was measured by examining the probability of a *same* response to probe pictures behind, the same as, or in front of the actual final location of the viewpoint. The direction of motion in Blocks 2 and 3 was toward the scene, and so boundary extension should lead to an increased probability of accepting probes in which objects in the scene were remembered as smaller, whereas representational momentum should lead to an increased probability of accepting probes in which objects in the scene were remembered as larger (because the viewpoint was displaced forward toward the scene). Boundary extension occurred for most participants in Blocks 1 and 2, and the majority of participants who exhibited boundary extension in Block 1 exhibited less boundary extension in Block 2. All participants exhibited representational momentum in Block 3, and representational momentum in Block 3 did not correlate with boundary extension in Block 1 or Block 2.

DeLucia and Maldia (2006) presented targets composed of a series of pictures depicting movement of a participant's viewpoint relative to a scene. The first picture of the series was always a medium-angle view of the scene, and motion of the viewpoint was toward or away from the scene (ending in a close-up view or in a wide-angle view, respectively, of the scene). Given that representational momentum of the self (e.g., as in Thornton & Hayes, 2004) could potentially influence boundary extension for the scene, DeLucia and Maldia also measured boundary extension for the final picture of the target sequence when that picture was not preceded by other pictures suggesting motion (and the probe was the close-up view or wide-angle view from the motion conditions). In all conditions, the scene was visible for 3 s. Boundary extension occurred in all conditions. In a second experiment, DeLucia and Maldia measured representational momentum for the viewpoint during motion toward a scene. Representational momentum occurred with a 250-ms retention interval but not with a 2-s retention interval, and this is consistent with studies on the time course of representational momentum (e.g., Freyd & Johnson, 1987).

Emotional content

Candel, Merckelbach, and Zandbergen (2003) presented participants with target pictures containing emotionally neutral content selected from Intraub (2002) or emotionally charged content (a decomposed dog, wounded hand, injured face, gun) selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1995). Boundary extension occurred for neutral targets and for emotionally charged targets, but the magnitude of boundary extension was not influenced by the emotional content of the target. Mathews (1996) presented participants with target pictures containing news photographs that varied in emotionality. Participants rated the emotionality of each target on a 1 (very unpleasant) to 5 (very pleasant) scale. Participants were then shown two probe pictures; one probe was a slightly more close-up view of the scene in the target, and the other probe was a slightly more wide-angle view of the scene in the target. When asked which probe was more similar to the photograph they had previously seen, the majority of responses (72%) involved the wide-angle version, and this is consistent with boundary extension. There was no correlation between ratings of emotional content and boundary extension. A similar pattern of boundary extension for emotional pictures and for neutral pictures viewed by children 10 to 12 years old was reported by Candel, Merckelbach, Houben, and Vandyck (2004).

Safer, Christianson, Autry, and Osterland (1998) presented participants with one of two sets of slides, and the sets differed only in two target slides in the middle of each set: In the neutral set, a man hands a woman a set of keys, and the woman then picks flowers, whereas in the traumatic set, the man holds a bloody knife, and the woman's throat is slit. Participants viewed the slides, and after a 10-min retention interval, participants were asked to select each of the two targets from two groups of four probes, and the four probes for each target differed only in terms of boundary location. For the first target, there was no effect of set on memory for boundaries, but for the second target, participants who viewed the neutral target exhibited boundary extension, whereas participants who viewed the traumatic target exhibited boundary restriction. Curiously, when the response measure was changed, and participants rated on a 5-point scale from −2 (much closer) to +2 (much farther) whether an identical probe was the same as the target, neither group exhibited boundary extension or boundary restriction for the first target, and both groups exhibited boundary extension for the second target. However, when the probe varied, participants who viewed neutral targets were more likely to exhibit boundary extension, whereas participants who viewed traumatic targets were more likely to exhibit boundary restriction.

Mathews and Mackintosh (2004) presented participants with positive, negative, and neutral target pictures from the IAPS. Positive pictures were separated into high-arousal, low-arousal, and high-pleasantness targets; negative pictures were separated into high-arousal, low-arousal, and high-unpleasantness targets; and neutral pictures were separated into high-arousal and low-arousal targets. Participants were classified as high-anxious or low-anxious on the basis of the trait scale of the State–Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants first rated each target on a 1 (very unpleasant) to 5 (very pleasant) scale and then received a recognition test for the targets. In the recognition test, four probes that differed only in terms of boundary location were presented, and participants were asked to select the probe most similar to the remembered target. Boundary extension was reduced for negative scenes in high-anxious individuals, especially for highly arousing scenes. High arousal was associated with less boundary extension for negative scenes, but arousal level did not influence boundary extension for positive scenes. Ratings of high arousal were associated with decreased boundary extension for negatively valenced targets, but were unrelated to boundary extension for neutral targets or for positively valenced targets.

Nonvisual scenes

The majority of experiments on boundary extension presented visual pictorial scene stimuli. Hutchison et al. (2009) presented participants with auditory scenes in which target and probe stimuli consisted of excerpts of piano performance or excerpts of spoken prose. It was hypothesized that boundary extension would occur (especially for shorter excerpts that presented less "periphery" and that might accordingly be analogous to close-up views; cf. Intraub et al., 1992), but boundary restriction consistent with memory averaging was observed in several experiments. Intraub (2002; Intraub et al., 1992) hypothesized that boundary extension reflected continuity of spatial layout of scenes, and so it is possible that boundary extension did not occur in Hutchison et al. because spatial continuity was not a salient aspect of the auditory scenes (indeed, spatial layout is not a salient aspect of many examples of auditory scenes, cf. Bregman, 1990). It might be that spatial continuity is a necessary criterion for visual scenes but is not a necessary criterion for auditory scenes, and, if so, then boundary extension would not be expected in memory for nonspatial auditory scenes. Such an interpretation suggests that a lack of boundary extension for auditory scenes in Hutchison et al. is consistent with a lack of boundary extension for visual stimuli not embedded within scenes (e.g., as in Gottesman & Intraub, 2002, 2003; Intraub et al., 1998).

Intraub (2004) examined boundary extension for haptic stimuli in a congenitally deaf-and-blind participant (diagnosed with Leber's syndrome) and in control participants who had normal vision occluded. Several objects were placed in floor or tabletop settings to create scenes. A truncated region of each scene was produced by using a movable wooden frame to provide boundaries, and this produced a partial view of each scene analogous to that in photographs of visual scenes. Participants haptically explored each scene for 30 s. After presentation of the scenes, there was a retention interval of 5 min during which the wooden frames were removed, and participants were then escorted back to the scenes. Participants indicated where boundaries around each scene should be located by placing a fingertip in the correct location and then adjusting a marker that the experimenter placed in the indicated location. Similar levels of boundary extension were exhibited by the deaf-and-blind participant and by control participants with normal vision occluded. Even so, boundary extension following haptic exploration of the scene was less than boundary extension following visual exploration of the scene by other control participants. However, a baseline condition consisting of a haptic nonscene was not reported, and so it is not clear whether Intraub's results reflect boundary extension or a more general expansion in haptic memory.

Characteristics of the display

Characteristics of the display, including shape and size of the viewing aperture, target duration, retention interval, and viewpoint production (i.e., whether probe stimuli were created by magnification/minification from a single viewpoint or by changes in camera/viewing distance), can potentially influence boundary extension. These characteristics are considered in this section.

Aperture shape

The majority of experiments on boundary extension presented target pictures with rectangular borders. However, the shape of the human visual field is not rectangular, nor do occluding boundaries in the natural world necessarily conform to straight lines or have sharp and distinct edges. Daniels and Intraub (2006) examined effects of aperture shape (i.e., boundary shape) on boundary extension. They presented target pictures, and boundaries of those pictures afforded a rectangular, oval, irregular linear, or irregular curved view of the target scenes. Different aperture shapes were equated so that locations of the outermost points of each aperture shape for each target were the same. In the first experiment, participants rated on a −2 (much closer up) to +2 (much more wide-angle) scale whether the probe was the same as the target. Boundary extension occurred with all apertures, and there was no effect of aperture shape. In additional experiments, Daniels and Intraub presented rectangular apertures or oval apertures for targets, and probes presented the same view as the targets. Boundary extension was assessed by having participants adjust the boundaries of probes by pressing keys marked " + " or "−" to increase or decrease, respectively, the size of the surrounding rectangular aperture or oval aperture. Boundary extension occurred with both aperture shapes, and there was no effect of aperture shape.

Aperture size

Intraub et al. (2006; Dickinson & Intraub, 2009) presented probes with a small aperture or a large aperture and that were smaller or larger, respectively, than apertures of target pictures. Thus, when adjusting boundaries of a probe to match boundaries of a remembered target, participants moved boundaries outward when a small aperture probe was presented and inward when a large aperture probe was presented. Boundary extension occurred with small aperture probes and with large aperture probes, but boundary extension was consistently larger with large aperture probes (cf. judgements of wide-angle probes in Chapman et al., 2005). Intraub et al. suggested that large aperture probes led to larger boundary extension because large apertures provided additional activation to information already extrapolated by boundary extension. This allowed weaker traces from peripheral regions to more easily reach threshold in a subsequent recognition test, thereby increasing boundary extension. Intraub et al. suggest that the region immediately beyond a boundary is such an integral part of a participant's representation of the scene that attempts to provide participants with knowledge about boundary extension and asking those participants to overcome boundary extension are not successful (Intraub & Bodamer, 1993; but see Intraub et al., 2006, for evidence that boundary extension can be inhibited by participants). However, effects of aperture size may also be consistent with an adjustment and anchoring heuristic (e.g., Chapman et al., 2005).

Target duration

Boundary extension has been observed with a wide range of target durations. Intraub et al. (1996) presented targets for 250 ms (see also Intraub & Dickinson, 2008; Munger et al., 2005) or for 4 s. With drawings, and with both target durations, close-up views yielded boundary extension, and wide-angle views did not yield a consistent directional displacement. With ratings of whether the viewpoint in probes was the same as the viewpoint in targets, there was a trend for the 250-ms target duration to result in greater boundary extension than the 4-s target duration. In a second experiment, Intraub et al. (1996) presented targets for 333 ms each and found robust boundary extension. Boundary extension has also been found with target durations of 325 ms (Dickinson & Intraub, 2008), 500 ms (Dickinson & Intraub, 2009; Intraub et al., 2006), 3 s (DeLucia & Maldia, 2006), 5 s (Chapman et al., 2005), and 15 s (Intraub et al., 1992; Intraub et al., 1998; Gottesman & Intraub, 2002). In an exception to the general finding that target duration does not significantly influence boundary extension, Dickinson and Intraub (2009) reported larger boundary extension for the right side of targets than for the left side of targets with target durations of 500 ms but not with target durations of 10 s.

Retention interval

Boundary extension has been observed with a wide range of retention intervals. Dickinson and Intraub (2008) obtained boundary extension with retention intervals of 100, 250, 625, or 1,000 ms. In additional experiments, retention intervals of 42, 100, and 250 ms were used; boundary extension occurred at each retention interval, and boundary extension for the 250-ms retention interval was larger than boundary extension for the 42-ms retention interval (see also Intraub & Dickinson, 2008). Such a rapid onset and increase in boundary extension are consistent with Munger et al.'s (2005) suggestion that boundary extension for a scene precedes representational momentum for an object in that scene, as representational momentum increases during the first few hundred milliseconds after a target has vanished (e.g., Freyd & Johnson, 1987). Intraub et al. (1996) and Bertamini et al. (2005) obtained boundary extension with a retention interval of 1,000 ms, and Dickinson and Intraub (2009) obtained boundary extension with a retention interval of 2,500 ms. Intraub (2004) obtained boundary extension for haptic stimuli with a retention interval of approximately 5 min. Intraub et al. (1992), Intraub and Berkowits (1996), and Intraub and Richardson (1989) obtained boundary extension after a retention interval of 48 hours. Safer et al. (1998) obtained boundary extension when retention interval ranged from 6 to 13 (mean of 8) days.

Viewpoint production

Rather than moving the physical location of the camera, Intraub et al. (1992) used a zoom manipulation to prepare probes that portrayed viewpoints closer or farther away than the viewpoint in the target. However, there are differences between an actual change in distance involving camera location and an apparent change in distance involving magnification/minification with a zoom manipulation (e.g., multiple changes in camera location preserve differences in parallax that are not preserved in multiple zooms; see discussion in DeLucia & Maldia, 2006). Bertamini et al. (2005) presented participants with targets and probes in which probes were the same perimeter size as targets but varied in magnification/minification (scaling the image up or down by 3%) or in camera distance (15 cm shift in "virtual viewpoint"). Participants rated on a −2 (much closer) to +2 (much farther) scale whether probes depicted the same distances as targets. Boundary extension was obtained for close-up views but was unrelated to whether probes varied camera distance or magnification/minification; Bertamini et al. concluded that boundary extension is not an artifact linked to magnification or minification of probes. In a follow-up experiment in which magnification and camera distance were manipulated within subjects, boundary extension was obtained in both conditions, but boundary extension was smaller with changes in magnification than with changes in camera distance.

Characteristics of the observer

Characteristics of the observer, including allocation of attention, age, expectations and strategy, planned eye fixations, gaze direction and eye movements, whether targets are viewed monocularly or binocularly, and prior exposure to a layout, can potentially influence boundary extension. Additionally, potential neurological correlates of boundary extension are considered in this section.

Allocation of attention

Intraub's (2002) hypothesis that boundary extension results from activation of a perceptual schema suggests that manipulation of such a perceptual schema should influence boundary extension. One way to manipulate activation of a perceptual schema is to vary perceptual and cognitive processing demands of the target. Intraub and Berkowits (1996) presented target stimuli in a normal upright orientation or in an inverted orientation. They suggested that participants would allocate greater attention to processing inverted scenes than to processing upright scenes. Therefore, for inverted scenes participants might be less likely to confuse externally presented pictorial information with internally generated information from a perceptual schema, and this would reduce boundary extension for inverted scenes. Alternatively, if boundary extension is a fundamental aspect of picture perception or of picture comprehension, then inversion of a scene should have no effect on boundary extension. In two experiments, memory for inverted scenes exhibited significant boundary extension, but boundary extension for inverted scenes did not differ from boundary extension for upright scenes. Intraub and Berkowits suggested that a lack of an effect of inversion was consistent with the notion that boundary extension is caused by activation of expectancies during perception of a scene.

A more convincing way to manipulate activation of a perceptual schema would be to present a concurrent task that requires allocation of attention away from the target. A perceptual schema might be more useful when less attention is allocated to the target, and such a schema should have larger effects if participants allocate less attention to the target. With less attention allocated to the target, there would be more potential gaps in perceived information and more activation of a perceptual schema to fill those gaps. Thus, boundary extension during divided attention (i.e., when participants perform a concurrent attention-demanding task) should be larger than boundary extension during selective attention (when participants focus solely on the target). Courtney and Hubbard (2004) placed participants in a dual-task (divided attention) or single-task (selective attention) condition. In the dual-task condition, participants were presented with target pictures while simultaneously counting (by 3s) along with the beats of an auditory metronome; in the single-task condition, participants were presented with target pictures in the absence of the metronome. With drawing, there was no effect of allocation of attention, but with the rating scale, participants in the dual-task condition exhibited larger boundary extension than did participants in the single-task condition.

Intraub, Daniels, Horowitz, and Wolfe (2008) presented target pictures of scenes in which different sets of numerals consisting of several 2s and 5s were superimposed upon each target picture. Memory for each target view was tested by presenting a probe view, and participants rated on a −2 (much too close-up) to +2 (much too wide-angle) scale whether the probe was the same as the target. In the dual-task condition, participants additionally had to report the number of 5s (0, 1, or 2) superimposed on the target picture, and in the memory-only condition, participants were instructed to study the target picture and not let the numerals distract them. In the baseline-search condition, participants were instructed to count the number of 5s and not let the underlying picture distract them. Boundary extension occurred for close-up views, and, consistent with Courtney and Hubbard (2004), boundary extension was larger in the dual-task condition than in the memory-only (i.e., a single-task) condition. There was no difference in hit rates for the dual-task condition and baseline-search condition, and so participants in the dual-task condition were allocating attention to the search task. The increase in boundary extension in the dual-task condition occurred when target pictures and probe pictures were presented in separate blocks and when probes were presented after each target, but a comparison of boundary extension from each of these conditions was not reported.

Dickinson and Intraub (2009) suggested that the larger boundary extension on the right side of a target that they obtained when target duration was 500 ms was due to a larger initial allocation of attention to the left side of a target: If initial fixation was on the left side of the target, and if an increase in attention decreased boundary extension (cf. Intraub et al., 2008), then initial boundary extension would be decreased for the left side of a target. Consistent with this, Dickinson and Intraub found that participants exhibited a leftward bias in the direction of their initial saccade and that recognition of objects on the left side of a scene was slightly greater than recognition of objects on the right side of a scene. Dickinson and Intraub did not obtain a difference in boundary extension for the left side and right side when target duration was 10 s, and they suggested this was due to subsequent saccades to other regions of the target. It is possible that similar effects existed in other studies with short target durations, but most of those studies used measures of boundary extension that were not sensitive to directional asymmetries. However, Dickinson and Intraub's finding of an initially larger boundary extension on the side opposite to fixation is not consistent with Intraub et al.'s (2006) finding that boundary extension did not occur on the uncued side of the target following an eye movement.

Age

Quinn and Intraub (2007) used preferential looking methodology to examine whether boundary extension occurred in 3- to 7-month old infants. Infants viewed a target picture, and then a wide-angle probe and a close-up probe were simultaneously presented. Both 3- to 4-month-old infants and 6- to 7-month-old infants looked at the close-up probe at higher than chance levels, and this is consistent with boundary extension. However, it is not clear that gaze direction and fixation are related to boundary extension in adults (see Dickinson & Intraub, 2008), and so it is not clear that gaze direction and fixation should be taken as indices of boundary extension in infants. Chapman et al. (2005) examined boundary extension in adolescent males 9 to 16 years old with Asperger's syndrome, a control group of adolescent males matched in age and intelligence, and a control group of adult males and females 18 to 53 years old. After targets were presented, participants magnified or minified probes to match their memories for the corresponding targets. Boundary extension occurred in Asperger's patients and in both control conditions, and there were no differences in boundary extension across conditions. Even so, high performance IQ and high full-scale IQ in adolescent males with Asperger's syndrome was linked with increased boundary extension, whereas high performance IQ and high full-scale IQ in aged-matched controls was linked with decreased boundary extension.

Seamon, Schlegel, Hiester, Landau, and Blumenthal (2002) examined boundary extension in first graders (5–7 years old), fifth graders (10–12 years old), college students (18–21 years old), and older adults (58–84 years old). Participants viewed target pictures of scenes containing one or two objects. Immediately after each target was shown, participants drew the remembered target within a rectangular outline (the same size as the target) on a response sheet. Boundary extension occurred in all age groups, and boundary extension exhibited by children and by older adults was larger than boundary extension exhibited by college students. Additionally, boundary extension was slightly larger for older adults when two objects were included within the target than when only a single object was included. Candel et al. (2004) presented children 10 to 12 years old with target pictures of emotionally charged scenes (e.g., an attacking shark, a snake) selected from the IAPS or with target pictures of emotionally neutral scenes (e.g., bananas, a stuffed toy bear). After viewing the targets, participants drew the remembered targets within rectangular outlines (the same size as the targets) on response sheets. Boundary extension occurred for emotionally neutral targets and for emotionally charged targets and was not influenced by whether the target was emotionally charged or emotionally neutral.

Expectations and strategy

Intraub and Bodamer (1993) examined whether participants' expectations and encoding strategy influenced boundary extension. In the test-informed condition, participants were informed, prior to viewing target pictures, that they would be asked to draw the pictures from memory afterwards, and they were also given a detailed description of the recognition test (a −2 to +2 rating scale), which would be given after their drawings were completed. In the demo condition, participants took part in a demonstration of boundary extension and were explicitly instructed to avoid boundary extension when studying the target pictures and in their subsequent responses. In the control condition, standard task instructions (that made no reference to boundary extension) were given. With drawing, boundary extension occurred in all conditions, and boundary extension was reduced but still significant in the test-informed and demo conditions. With the rating scale, boundary extension occurred in all conditions, and boundary extension was reduced but still significant in the test-informed condition but not reduced in the demo condition. Also, with neither response measure was boundary extension influenced by whether the main object in the target picture was cropped by a boundary of the picture.

Planned eye fixations

Intraub et al. (2006) examined whether planned eye fixation influenced boundary extension. Target pictures were presented for 500 ms while participants maintained central fixation, and then a visual cue instructed participants to fixate an object near the left boundary or right boundary of the target. The target was replaced with a mask before the eyes reached the new fixation point. A probe picture appeared 2 s later, and participants used a computer mouse to adjust the locations of each of the four boundaries (left, right, top, bottom) of the probe. Boundary extension occurred on the cued side (closest to the new fixation), but boundary extension did not occur on the uncued side (opposite to the new fixation). Boundary extension on the cued side did not differ from boundary extension on that same side when a single fixation side was not cued, and so it is not the case that a "window of boundary extension" shifted in the direction of the cue. When the cue indicated no eye movement to the left or right side, boundary extension did not occur on the left or right side. Regardless of whether left, right, or neither left nor right was cued, boundary extension occurred for the top and bottom of the target. Intraub et al. suggested that elimination of boundary extension on the side opposite planned fixation, and elimination of boundary extension on both left and right sides when the cue indicated no change in fixation, reflected active inhibition of boundary extension (but see Intraub & Bodamer, 1993, for evidence that explicit attempts at inhibition cannot eliminate boundary extension).

Gaze direction and eye movements

Dickinson and Intraub (2008) suggest that if boundary extension contributes to integration of information across successive eye fixations, then boundary extension should not be decreased if there is a shift in gaze direction or fixation (but see Dickinson & Intraub, 2009). To test this hypothesis, they varied whether a probe was presented (a) at the same display coordinates at which the target was presented (gaze direction and fixation did not change) or (b) to the left or right of the display coordinates at which the target was presented (gaze direction and fixation did change). Boundary extension occurred in both conditions, and changes in gaze direction and fixation did not influence boundary extension. In a follow-up study, Intraub and Dickinson presented (a) a target on the left side of the display and a probe on the right side of the display or (b) a target on the right side of the display and a probe on the left side of the display. After presentation of the target, a cue indicating where the probe would appear was presented, and participants made an eye movement to the cue. The probe appeared as soon as the eye moved into the cued region (i.e., the probe was not visible at the beginning of an eye movement but was visible at the end of an eye movement). A robust boundary extension occurred.

Monocular/binocular view

In one experiment of Bertamini et al. (2005), participants viewed targets and probes with both eyes in half of the trials, but participants viewed targets and probes with their dominant eye and wore an eye patch to occlude vision with their nondominant eye in the other half of the trials. Close-up views and wide-angle views were presented. Boundary extension occurred for close-up targets viewed with binocular vision, but did not occur in other conditions. In a follow-up experiment, target views were presented as stereograms (which induced binocular disparity) or as pictures (which did not induce binocular disparity). Stereograms were generated by taking "virtual pictures" of computer-generated scenes from two vantage points that differed by 6.5 cm (i.e., by the average human interocular distance) along a horizontal line on the plane orthogonal to the line of sight. Close-up views and wide-angle views were presented. Boundary extension occurred for stereograms or pictures of close-up views, but boundary extension did not occur for stereograms or pictures of wide-angle views. Bertamini et al. suggested that binocular information was not necessary for boundary extension and that boundary extension was not related to perceived depth.

Prior exposure to spatial layout

As noted earlier, the majority of participants in Munger et al. (2005) exhibited boundary extension to static views (Block 1) and decreased boundary extension to motion sequences (Block 2). However, a few participants did not exhibit boundary extension or exhibited boundary restriction to static views. Participants who did not exhibit boundary extension to static views exhibited boundary extension to motion sequences, and participants who exhibited boundary restriction to static views exhibited a trend of nonsignificant boundary extension to motion sequences. In the latter groups, responses more similar to boundary extension occurred when stimuli depicted movement of the participant's viewpoint through the spatial layout, and Munger et al. speculated that some participants required greater exposure to a surrounding scene before those participants were able to include additional scene layout information in their representation of a partial view of the scene. If such participants were shown such information (as was provided in the motion sequences), they were more likely to extend the boundaries of the scene. It might be that the threshold for activating a perceptual or scene schema was higher in such participants, and so they did not activate such a schema in response to static views but did activate such a schema in response to motion sequences (cf. DeLucia & Maldia, 2006).

Neurological correlates

Park, Intraub, Yi, Widders, and Chun (2007) obtained functional magnetic resonance imaging (fMRI) from participants who viewed targets and probes of scenes. Attenuation of fMRI signals occurred when participants viewed close-up targets and wide-angle probes but not when participants viewed wide-angle targets and close-up probes; this suggests that participants were more likely to interpret probes as similar to targets in the former condition (i.e., they habituated to it) and is consistent with boundary extension. A smaller attenuation occurred when participants viewed targets and probes that were both close-up views or both wide-angle views. Brain areas implicated in boundary extension included the parahippocampal place area, a region active when participants view scenes such as landscapes, rooms, or buildings (Epstein & Kanwisher, 1998), and the retrosplenal cortex, a region important in processing of spatial layout and navigation (Epstein, Higgins, & Thompson-Schill, 2005). Interestingly, brain regions previously implicated in processing object location information but not scene or layout information (e.g., lateral occipital cortex, Grill-Spector et al., 1999) were not implicated in boundary extension, thus underscoring the importance of spatial layout and continuity in boundary extension. Also, early visual processing areas were not implicated in boundary extension, thus suggesting that boundary extension involves high-level processes rather than low-level perceptual filling-in.

PART II: THEORETICAL EVALUATION OF EMPIRICAL FINDINGS

As shown in Part I, boundary extension can be obtained with multiple methods of stimulus presentation and multiple response measures. These methods and measures are summarized in Tables 1 and 2, respectively. As also shown in Part I, a wide range of variables influences boundary extension. A typology of these variables is presented in Figure 2. In addition to the specific questions asked and conclusions drawn in the individual studies discussed in Part I, general questions regarding boundary extension and addressed by comparisons across the individual studies discussed in Part I can be asked.

Does boundary extension occur for all pictures?

Boundary extension in memory for a picture occurs when that picture's edges are understood as limiting or truncating a continuous view that would otherwise extend beyond the edges of the picture (Gottesman & Intraub, 2002, 2003). Line drawings of an object on a simple texture background (e.g., asphalt pavement, brick wall) elicit boundary extension if that background is understood as continuing (i.e., extending) beyond the picture's edge, but if the same object is presented on a blank background, boundary extension is not elicited (Intraub et al., 1998) unless participants imagine an extended background while they study the picture (Gottesman & Intraub, 2002). Boundary extension can even be observed for a smaller picture within a larger picture (e.g., a framed photo of a scene on a desktop within a larger scene of a room) if boundaries of the smaller picture are understood as continuing beyond the edges of that picture (Gottesman & Intraub, 2003). Boundary extension for pictures

Table 1. *Stimulus presentation in studies of boundary extension*

Method	*Description*
Photographs	Participants view a photograph of a scene or of a isolated object for a brief duration, and then the photograph is removed from view (e.g., Intraub et al., 1992; Intraub et al., 2006). Photographs can have either emotionally charged (e.g., Candel et al., 2003; Mathews & Mackintosh, 2004) or emotionally neutral content (e.g., Intraub et al., 1996) and portray either static (e.g., Intraub et al., 1998) or implied motion (e.g., Courtney & Hubbard, 2004).
Line drawings	Participants view a line drawing of a scene or of an isolated object for a brief duration, and then the line drawing is removed from view (e.g., Intraub et al., 1998; Legault & Standing, 1992). In a variation of this, computer-generated images approximating photographs can be presented (e.g., Bertamini et al., 2005).
Sequence	Participants view a series of photographs, line drawings, or computer-generated images depicting motion of the viewpoint toward or away from the scene (e.g., DeLucia & Maldia, 2006; Munger et al., 2005).
Blocking	Participants view a block of targets that is followed by a block containing response measures (e.g., Chapman et al., 2005; Intraub et al., 1998) or the response measure for each target can be presented immediately after that target (and before the next target; Intraub et al., 2006). Blocking can also separate different types of targets (e.g., Munger et al., 2005).
Attention	Participants focus on the target or focus on the target and a concurrent distractor (Courtney & Hubbard, 2004; Intraub et al., 2008).
Dimensionality	Participants view two-dimensional or three-dimensional scenes. Two-dimensional scenes are often photographs or line drawings that depict or imply a three-dimensional scene (e.g., Intraub et al., 1998). Actual three-dimensional scenes have involved displays on a floor or tabletop (Intraub, 2004) or within a room or corridor (Courtney & Hubbard, 2008a).
Restricted vision	Participants view a scene monocularly (Bertamini et al., 2005) or through goggles containing a narrow aperture (Courtney & Hubbard, 2008a; Intraub, 2004).
Music or prose	Participants listen to auditory recording of piano music or spoken prose presented via headphones (Hutchison et al., 2009).

of inverted scenes does not differ from boundary extension for pictures of upright scenes (Intraub & Berkowits, 1996), but simultaneous performance of another attention-demanding task increases boundary extension (Courtney & Hubbard, 2004; Intraub et al., 2008). However, increases in uncertainty regarding the location of the main object within a scene decreases boundary extension (Bertamini et al., 2005). Also, differences in emotional content of pictures can influence boundary extension (Mathews & Mackintosh, 2004; Safer et al., 1998; but see Candel et al., 2004; Candel et al., 2003).

Is boundary extension related to object completion?

The hypothesis that boundary extension results from object completion has been rejected in many papers (e.g., Chapman et al., 2005; Gottesman & Intraub, 2003; Intraub et al., 1992; Intraub & Bodamer, 1993; Intraub & Richardson, 1989). However, even if object completion is not a cause of boundary extension, object completion might be an effect of boundary extension. Boundary extension might induce amodal continuation/completion of a cropped object in a target view, and this would be similar to amodal continuation/completion of an object that is partially occluded (e.g., Yantis, 1995). As discussed by Gottesman and Intraub (2003), boundaries of a target could be considered a partial occluder of a larger scene that extended behind that occluder, and the picture could be considered a "window" showing a partial view of a larger scene (see also Intraub, 2002). Although boundary extension allows amodal continuation/completion of a cropped object, the occurrence of boundary

Table 2. *Response measures in studies of boundary extension*

Method	*Description*
Rating scales	Participants rate (typically on a −2 to +2 scale) whether the viewpoint in a probe photograph or line drawing is closer (objects are larger) than, the same as, or farther away (objects are smaller) than the viewpoint in the remembered target (e.g., Intraub et al., 1992, 1998).
Drawing	Participants draw the remembered scene. Such a drawing can be constrained by a frame in the same aspect ratio as the original picture and in which the edges of the frame reflect the edges of the target (e.g., Intraub & Berkowits, 1996; Seamon et al., 2002) or by presenting a picture of the central object and letting participants draw the background (e.g., Courtney & Hubbard, 2008a). A "proportion drawn" measure reflecting the percentage of an object's area (relative to the background) in the drawing and in the target can be calculated (Gottesman & Intraub, 1999).
Boundary adjustment	Participants adjust the boundaries on a probe to match the boundaries on the remembered target. Size of objects is constant, and perimeter size of the boundary varies as a function of participants' responses (e.g., Daniels & Intraub, 2006; Intraub, 2004; Intraub et al., 2006).
Magnification adjustment	Participants magnify or minify (i.e., zoom in or zoom out) a probe to match the remembered viewpoint of the target. The perimeter size of the probe is constant, but the size of objects varies as a function of the level of magnification/minification (Chapman et al., 2005).
Forced choice	Participants choose which of several simultaneously presented probes most closely matches the remembered target (Candel et al., 2003; Mathews & Mackintosh, 2004; Safer et al., 1998).
Reconstruction	Participants are given paper cut-outs of objects in a target view, and the cut-outs vary in size. Participants are also given a blank card and choose the appropriate sizes of paper cut-outs to reconstruct the scene on the blank card (Gottesman & Intraub, 2002, 2003).
Stepping	Participants are placed before a previously viewed scene and are asked to step forward or backward so that they are at the viewpoint from which they previously viewed the scene (Courtney & Hubbard, 2008a).
Preferential looking	Participants view a target scene and then view simultaneous presentations of close-up and wide-angle probe views of the target scene (Quinn & Intraub, 2007).

extension when scenes do not contain a cropped object underscores that object completion is not the sole cause of boundary extension. Alternatively, amodal continuation/completion and boundary extension might both result from a more general spatial continuity that extends beyond an occluder for figures (amodal continuation/completion) and backgrounds (boundary extension).

Does boundary extension reflect remembered size or remembered distance?

Many studies intended to assess boundary location actually assessed remembered distance or remembered size of objects. Findings in the memory psychophysics literature suggest that remembered distance and remembered size are underestimated (for review, Algom, 1992; Hubbard, 1994), and so it is possible that apparent changes in remembered boundary location do not result from boundary extension per se, but rather result from underestimation of remembered distance or remembered size of objects within the target—for example, choice of a smaller cut-out in scene reconstruction and decrease in proportion drawn are both consistent with a decrease in remembered (retinal) size of an object. However, it is not clear how a purely psychophysical account would distinguish between objects in scenes and objects not in scenes. When participants presented with a probe view of a three-dimensional scene indicated differences from the remembered target view of that scene by stepping toward or away from the scene, their responses were consistent with literature on remembered distance but

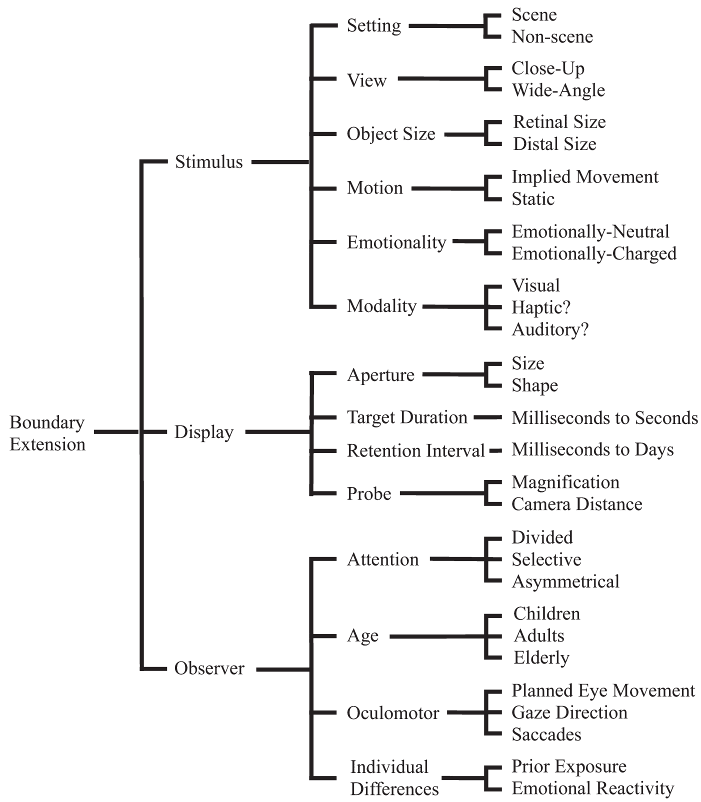

Figure 2. *A typology of influences on boundary extension. Variables are first categorized as characteristics of the stimulus, display, or observer, and variables in each category are listed. The divisions follow those in the text. Given that the typology focuses on variables that influence boundary extension, variables that are reviewed in the text but that do not have an effect on boundary extension (e.g., whether an object is cropped) are not included.*

inconsistent with boundary extension; however, when participants compared a probe view with a target view of the same three-dimensional scene on a −2 (much too close) to +2 (much farther away) rating scale, their responses were consistent with boundary extension but inconsistent with literature on remembered distance (Courtney & Hubbard, 2008a).

The most common response measure in the boundary extension literature—a −2 to +2 rating scale with which participants indicate whether the probe is closer (or objects larger), the same as, or farther away (or objects smaller) than in the remembered target—explicitly involves judgements of the distances or sizes of objects in the target view and in the probe view and does not explicitly involve judgements of boundary location. It is not obvious that viewpoint distance and boundary location must necessarily be highly correlated (as boundaries of a scene could in principle be relatively independent of the size of objects in that scene or the distance of those objects from an observer), and so it is not clear that viewpoint distance offers a reliable index of boundary location. Although not explicitly discussed in the boundary extension literature, this issue appears to have been tacitly dealt with by constraining the perimeter sizes of probes (when rating scales are used) and drawing areas (when participants draw the target). When the perimeter size of a probe or drawing area is the same as the perimeter size of the target, then incorporation of additional information at the periphery of the probe or drawing area would require that objects in the probe or drawing area subsume a smaller visual angle than that subsumed by the corresponding objects in the target. Even so, differences in distance or size provide only an indirect measure of boundary location.

Is there a preferred method for measuring boundary extension?

Given that some response measures used in studies of boundary extension only indirectly address memory for boundaries (e.g., ratings of distance, using different sizes of paper cut-outs to reconstruct the scene), whereas other response measures more directly address memory for boundaries (e.g., adjusting magnification, adjusting placement of boundaries), it is not obvious that all response measures necessarily provide equally valid or equally accurate assessments of remembered boundary location. Although conclusions regarding boundary extension that are based on different response measures generally converge (e.g., Gottesman & Intraub, 2003; Intraub & Berkowits, 1996), there are exceptions (e.g., Courtney & Hubbard, 2008a; Intraub et al., 1996; Safer et al., 1998). Until the relationship between viewpoint distance and boundary location is more clearly known, and given the greater face validity of response measures that provide more direct measures of boundary location and do not involve explicit judgements of distance or size, use of response measures such as boundary adjustment and magnification adjustment should be preferred when a single response measure is used. Even so, different response measures might exhibit different biases or confounds (e.g., drawings might also reflect artistic or motor skill), and so use of multiple converging response measures should be more preferred.

Is boundary extension robust?

Intraub and Richardson (1989) speculated that differences in findings related to differences in response measures in studies of boundary extension might reflect use of different processing or different memory modules. A related possibility is that different response measures provide different information (e.g., as noted earlier, rating scales provide indirect measurement of boundaries based on distances of objects in the scene from the viewpoint, whereas drawings and boundary adjustments provide direct measurement of boundaries). However, despite substantial differences in potential mechanisms and response measures, evidence consistent with boundary extension is often obtained; this suggests that boundary extension is a robust phenomenon and not an artifact of a single type of response measure. Indeed, the percentage of participants who exhibit boundary extension is often very high (e.g., 100% in the immediate condition in Intraub et al., 1992). The robustness of boundary extension is also underscored by findings that boundary extension is not eliminated by explicit instructions intended to counteract the effect (Intraub & Bodamer, 1993). Robustness is related to effect size, but thus far only one investigation reported an effect size for boundary extension: Chapman et al. (2005) reported an extremely large effect size ($d = 1.86$) for boundary extension in a normal adult population, and effect sizes that are large are easily observable in even casual inspection of the data (e.g., compare the top and bottom panels in Figure 1).

Does boundary extension reflect prototypical viewing distance?

As acknowledged by Intraub and Richardson (1989), viewpoints in target scenes often tend to be closer to the main objects of those scenes than might occur in everyday experience with such scenes. Thus, what appears as boundary extension for a close-up view might actually be a more general shift toward a prototypical viewing distance (see also Intraub et al., 1992). However, an explanation based on regression toward a prototypical viewing distance predicts that boundary extension should occur for close-up views, and boundary restriction should occur for wide-angle views. Such a pattern can be found in memory for an object in the absence of a scene, but addition of a scene surrounding the object usually changes this pattern such that a smaller boundary extension or neither boundary extension nor boundary restriction is found for wide-angle views (e.g., Bertamini et al., 2005; Gottesman & Intraub, 2002; Intraub et al., 1998). More tellingly, medium-angle views exhibited boundary extension when paired with wide-angle views but not when paired with close-up views (Intraub et al., 1992), even though medium-angle views were similar to prototypical viewing angles. This suggests that whether an observer interprets a picture as a close-up view or a wide-angle view, rather than the prototypical viewing distance, is more important in determining whether boundary extension occurs. Such a suggestion is consistent with effects of object size reported by Bertamini et al. (2005).

Is boundary extension automatic?

Boundary extension is not eliminated when participants are explicitly instructed about boundary extension prior to experimental trials and are asked to compensate for boundary extension in their responses (Intraub & Bodamer, 1993), and this suggests that boundary extension is automatic. Similarly, boundary extension exhibits a rapid onset (with retention intervals as brief as 42 ms; Dickinson & Intraub, 2008), and this suggests that boundary extension is automatic. However, boundary extension is modulated by anticipated movement of an object (Courtney & Hubbard, 2004), or by expectations that an eye movement will not occur (Intraub et al., 2006), and this suggests that boundary extension is not automatic. Therefore, boundary extension might not be a unitary process, but rather might be composed of at least two processes: one of which is automatic (i.e., is cognitively impenetrable, modular) and is not influenced by expectations or strategies, and one of which is not automatic (i.e., is cognitively penetrable, nonmodular) and is influenced by expectations or strategies. Operation of two such processes could account for the reduction but not elimination of boundary extension reported by Intraub and Bodamer: Explicit knowledge of boundary extension might decrease a nonautomatic and cognitively penetrable component of boundary extension, but would have no effect on an automatic and cognitively impenetrable component of boundary extension.

Is boundary extension symmetrical?

Previc and Intraub (1997) reexamined data from Intraub and Richardson (1989), and they found that central objects in participants' drawings of scenes were displaced downward (i.e., central objects were drawn relatively closer to the bottom boundary than to the top boundary). Courtney and Hubbard (2004) found that boundary extension was larger on the side of the target closest to anticipated motion of an object in that scene than on the side of the target opposite to anticipated motion of an object in that scene. Intraub et al. (2006) found that boundary extension was decreased on the side of the target opposite to a cued saccade but unchanged on the side of the target in the direction of the cued saccade. In the first example, displacement is larger in the direction in which an object might fall if its support were removed. In the latter two examples, boundary extension is larger in the direction of anticipated object movement or eye movement than in the opposite direction. The presence of asymmetries when object movement or eye movement is anticipated, and the absence of asymmetries when object movement or eye movement is not anticipated, is consistent with the hypothesis that boundary extension results from anticipatory extrapolation of what might be encountered in the next fixation or in the next moment of time. Dickinson and Intraub (2009) found that boundary extension was larger on the right side of the scene than on the left side of the scene with a short target duration but not with a long target duration, but the initial asymmetry was attributed to a bias for an initial leftward saccade rather than to a fundamental property of boundary extension per se.

Does boundary extension reflect dynamic properties of representation?

Previc and Intraub (1997) suggested that downward displacement of central objects in participants' drawings of scenes might reflect (a) expansion of the upper visual field (consistent with the viewpoint being farther away) or (b) an elevated head view (of objects resting on the ground). Alternatively, downward displacement might reflect the direction of implied gravitational attraction within the scene. Implied gravitational attraction has been shown to influence memory for location; this has been referred to as *representational gravity* (Hubbard, 1997), and memory for location of a stationary object depicted in computer-animated displays is usually displaced in the direction of implied gravitational attraction (e.g., Freyd, Pantzer, & Cheng, 1988; Hubbard & Ruppel, 2000). Representational gravity is similar to representational momentum in that both types of displacement appear to result from dynamic properties of mental representation that reflect invariant physical principles that bias memory for location. Furthermore, just as findings of Previc and Intraub suggest that representational gravity might influence boundary extension, findings of Courtney and Hubbard (2008a) that boundary extension was greater in the direction of implied motion of the object in the scene suggest that representational momentum might influence boundary extension. Thus, boundary extension reflects dynamic properties of mental representation and can be influenced by information regarding physical principles relevant within the scene.

Is boundary extension related to representational momentum?

Hubbard (1995, 1996, 2006a) suggested that boundary extension and representational momentum reflected a common or more general mechanism. Although acknowledging that both boundary extension and representational momentum are anticipatory dynamic processes, Intraub (2002) suggested that it was unlikely that boundary extension and representational momentum shared a common mechanism.[1] Existence of separate mechanisms is consistent with Munger et al.'s (2005) suggestion that boundary extension occurred prior to representational momentum and with DeLucia and Maldia's (2006) distinction of scene schema and motion schema. However, larger boundary extension in the direction of anticipated motion within a scene reported by Courtney and Hubbard (2004) questions such a sequence and separation. It is not clear how representational momentum might influence boundary extension if representational momentum occurs after boundary extension and if representational momentum and boundary extension are processed by separate mechanisms. Such an influence might be accounted for if information related to motion and the scene in which motion occurred were processed by the same mechanism, and this possibility is consistent with Whitney and Cavanagh's (2000) proposal that location and motion are processed by the same neural mechanisms. Also, Intraub's (2002) suggestion that boundary extension results from continuity of spatial layout is consistent with Freyd's (1987, 1992) suggestion that representational momentum is more likely when the underlying stimulus dimension is continuous.

Several pairs of convergent findings are consistent with the hypothesis that boundary extension and representational momentum are related and might share a common or more general mechanism. Boundary extension (Seamon et al., 2002) and representational momentum (Hubbard, Matzenbacher, & Davis, 1999) are larger in 5- to 7-year-olds than in young adults. Boundary extension (Courtney & Hubbard, 2004; Intraub et al., 2008) and representational momentum (Hayes &

[1] One of the most obvious differences between boundary extension and representational momentum discussed in Intraub (2002) and that led to a rejection of the notion that boundary extension and representational momentum might be related was in the apparent time course of each type of displacement; at that time, representational momentum had been shown to increase in magnitude rapidly during the first few hundred milliseconds after a stimulus vanished (for review, Hubbard, 2005), but there was no evidence that boundary extension exhibited such a rapid time course. However, Dickinson and Intraub (2008) subsequently reported that boundary extension exists after just 42 ms and was larger after 250 ms, and this is much more compatible with the time course of representational momentum. Such a rapid time course for boundary extension is also essential if boundary extension precedes representational momentum (as suggested by Munger et al., 2005).

Freyd, 2002; Hubbard, Kumar, & Carp, 2009) are decreased when more attention is allocated to the target (or final target location) during target presentation. Boundary extension (Intraub & Dickinson, 2008) and representational momentum (Freyd & Johnson, 1987) occur within tens of milliseconds after a target vanishes. Boundary extension (Intraub et al., 2006) and representational momentum (Jordan, Stork, Knuf, Kerzel, & Müsseler, 2002) are influenced by action plans regarding eye movements. Boundary extension (Intraub & Bodamer, 1993) and representational momentum (Courtney & Hubbard, 2008b) are decreased but not eliminated if participants receive explicit information regarding the effect and are instructed to counteract the effect. As suggested earlier, boundary extension might involve modular and nonmodular components, and representational momentum has similarly been suggested to involve modular and nonmodular components (Courtney & Hubbard, 2008b; Hubbard, 2005). Also, boundary extension and representational momentum both reflect answers to problems in spatial localization.[2]

Does boundary extension reflect continuity?

Gottesman and Intraub (2003), Intraub (2002), and Intraub et al. (1998) suggest that boundary extension reflects an anticipatory representation of spatial layout that supports scene comprehension by providing a spatial framework or context for interpreting truncated views and facilitating integration of successive views. This spatial framework or context has an adaptive function and is enabled by the continuity of spatial layout inherent in a scene (Intraub, 2002; Intraub et al., 1992). In the absence of a scene, such continuity (and resultant boundary extension) would not occur. Scenes that result in boundary extension are continuous in time as well as in space, and a subsequent fixation will differ from a previous fixation in time as well as in space. An influence of both temporal continuity and spatial continuity is consistent with Dickinson and Intraub's (2008; Intraub & Dickinson, 2008) suggestion that boundary extension contributes to transsaccadic memory and Freyd's (1987) suggestion that data interpreted as reflecting properties of spatial representation (e.g., mental rotation) can be interpreted as reflecting properties of temporal representation. Just as representational momentum might reflect a spatiotemporal coherence between physical and mental domains (Freyd, 1987), boundary extension might reflect a similar spatiotemporal coherence (cf. Intraub, 2002). The lack of boundary extension for auditory scenes in Hutchison et al. (2009) could challenge this notion, but given the discrete notes and words presented in those scenes, it is not clear whether participants interpreted those scenes as exhibiting temporal continuity.

Is boundary extension a general or domain-specific phenomenon?

Intraub (2004) suggested that boundary extension for haptic scenes in a congenitally deaf-and-blind participant (a "haptic expert"), in conjunction with a similar magnitude of boundary extension for haptic scenes in normally sighted participants who had vision occluded and haptically explored the same scenes, was evidence that boundary

[2] Hubbard (2005, 2006b, 2009) suggested that any account of representational momentum should begin with consideration of the underlying computational theory. Following Marr (1982), such a computational theory would focus on initially defining a problem that an organism needed to solve; in the case of representational momentum, the problem involves locating objects in and navigating through the environment. Interestingly, boundary extension could be considered a different solution to this same general problem. Thus, it is possible that ideas regarding a computational theory of representational momentum could be extended to include boundary extension in a broader computational theory of displacement in spatial representation. This would be consistent with Hubbard's (2006a) suggestion that boundary extension and representational momentum (a) reflect operation of a more general mechanism that biases representation in ways consistent with past experience, and (b) help bridge the gap between perception and action (and compensate for delays in perception due to neural processing times) by allowing observers to anticipate what would be likely to be seen in the next fixation or moment of time. It would not be surprising to find that boundary extension and representational momentum use different implementations or algorithms to implement their respective displacements, but such considerations are independent of a more general computational level theory that unites these two types of displacement as solutions to the same more general problem.

extension was a fundamental aspect of spatial cognition. Such a claim is consistent with the idea that boundary extension is a general phenomenon (a) involving representation of spatial properties rather than visual properties of a stimulus, and (b) not limited to the subset of processes unique to picture perception (but see Bertamini et al., 2005). As noted earlier, Intraub (2002; Intraub et al., 1992; also Gottesman & Intraub, 2003) proposed that boundary extension arises from spatial continuity. Although spatial continuity might be critical to the specific domain of visual scenes (and haptic scenes in Intraub, 2004), it is not clear that spatial continuity is critical to the more general domain of all nonvisual scenes (e.g., auditory scenes in Hutchison et al., 2009). Along these lines, neither Intraub nor Hutchison et al. definitively answered questions regarding the possibility of haptic or auditory boundary extension, respectively. Questions regarding boundary extension in memory for nonvisual modalities, and whether boundary extension is a general or domain-specific phenomenon limited by spatial continuity, remain open.

PART III: THEORETICAL MECHANISMS OF BOUNDARY EXTENSION

There are several models and theories proposed to account for boundary extension, and these models and theories involve perceptual schema, memory schema, extension–normalization, scene schema, attentional selection and focus, and failure of source monitoring. The listing of models and theories in this section reflects mechanisms that have been proposed and does not rule out the possibility of additional mechanisms. Although presented separately, models and theories listed here need not be mutually exclusive in operation.

Perceptual schema

According to the perceptual schema account, when an observer sees a partial view of a scene (e.g., when viewing a photograph), expectations regarding the spatial layout of the scene are activated, and the observer understands this partial view within the context of these larger expectations (Intraub & Richardson, 1989). Comprehension of the scene involves activation of a perceptual schema, and when the information is encoded into memory, both perceptually sampled information and information from a perceptual schema are encoded into the memory representation (cf. a failure of source monitoring, Intraub & Dickinson, 2008; Seamon et al., 2002). Such a role of a perceptual schema is consistent with Hochberg's (1978, 1986) proposal that a mental schema guides integration of successive glimpses of the larger world into a coherent representation of that larger world (cf. Intraub et al., 1992). If information in a bounded picture is analogous to information available in a single fixation, then picture comprehension might include schematic expectations of what the next fixation might bring into view if the scene were actually viewed. Also, effects of allocation of attention on boundary extension are consistent with activation of a perceptual schema (e.g., Courtney & Hubbard, 2004; Intraub et al., 2008).

Memory schema

The memory schema account suggests that a prototypical viewing distance exists for each type of scene (Intraub et al., 1992) and that information regarding viewing distance of a specific scene is shifted or regressed toward that prototypical viewing distance. A close-up view (including relatively less background) will be remembered as a little farther away (i.e., as including more background, consistent with boundary extension), whereas a wide-angle view (including relatively more background) will be remembered as a little closer (i.e., as including less background, consistent with boundary restriction). As Intraub et al. (1998) point out, such normalization is consistent with other findings in the memory literature (e.g., Bartlett, 1932; Franks & Bransford, 1971). However, and as discussed earlier, although the memory schema account is consistent with boundary extension for close-up pictures, the memory schema account is not consistent with repeated findings that memory for wide-angle stimuli typically exhibits a weak boundary extension, no displacement of remembered boundary location, or boundary restriction. Thus, the hypothesis that boundary extension results solely from a memory schema, and the related notion of regression or normalization to the prototypical viewing distance of that type of scene, can be rejected.

Extension–normalization

The extension–normalization account is a hybrid of the perceptual schema account and a modified memory schema account. This model suggests that two different processes contribute to memory for the scene (Intraub et al., 1998; Intraub et al., 1996). The first process involves activation of a perceptual schema, and, as noted above, a perceptual schema involves a mental map of the likely structure of the scene that is only partially revealed by the limited view provided by a single photograph or a single fixation. The perceptual schema includes general expectations about the types of stimuli that would be likely to be present just outside the picture's boundaries and is responsible for the "extension" part of the extension–normalization account. The second process involves normalization of the remembered view toward the average view depicted in the stimulus set. This is similar to the memory schema account, but the normalization component of the extension–normalization account suggests that memory is normalized toward an average of the specific stimulus set, whereas the memory schema account suggests that memory is normalized toward the prototypical distance of that type of scene. Activation of a perceptual schema leads immediately to boundary extension in memory, and as time passes, displacement in boundary location due to boundary extension diminishes, and the representation is normalized toward the average of the stimulus set.

Scene schema

DeLucia and Maldia (2006) proposed a framework for visual memory intended to incorporate boundary extension and representational momentum. Boundary extension is attributed to a scene schema, and representational momentum is attributed to a motion schema. Scene or motion schemata are different from perceptual or memory schemata, as the latter focus on processes, and the former focus on content. Mechanisms underlying a scene schema process global and spatial features, but not local or temporal features, of a scene. When a scene is static, the area beyond the current view is predictable because of the continuity of spatial layout (cf. Intraub, 2002). However, when a scene is changing (i.e., an element of the scene is in motion), predictability only occurs if potential changes in that scene can be extrapolated. Such prediction or extrapolation is facilitated by a motion schema. DeLucia and Maldia suggest that information from motion (e.g., optic flow) influences a motion schema but does not influence a scene schema. More broadly, this suggestion predicts that a scene schema (and boundary extension) should not be influenced by local or temporal properties of a scene (e.g., motion, but see Munger et al.'s, 2005, discussion of prior exposure for an alternative view). This notion is consistent with a lack of differences between implied motion and continuous motion on boundary extension in DeLucia and Maldia's data and suggests that boundary extension and representational momentum are separate and distinct processes arising from different mechanisms.

Attentional selection and focus

Mathews and Mackintosh (2004) suggested that effects of emotion and arousal on boundary extension reflect attentional selection and a narrowed focus of attention. More specifically, they suggested that attention in high-anxious participants is more likely to be focused on a central object, especially if that object is perceived as threatening (e.g., weapon focus, Steblay, 1992). If more attention is allocated to a central object, then less attention is available to be allocated to the periphery. Mathews and Mackintosh argued that decreased attention to the periphery would result in peripheral regions of a scene being less well encoded, and, as a result, peripheral regions would be encoded as smaller than if the participant attended more to the periphery. A smaller encoded size would result in an apparent decrease in boundary extension (although whether this results from equivalent boundary extension applied to a smaller encoded picture or from an actual decrease in boundary extension is not clear). However, it could be argued that if participants allocate less attention to (a region of) the target scene, then there should be greater activation of a perceptual schema and increased boundary extension (cf. Courtney & Hubbard, 2004). It is not clear why a decrease in attention allocated to a target would decrease boundary extension if an object in a target scene is perceived as threatening (Mathews & Mackintosh, 2004) but increase boundary extension if an object in a target scene is not perceived as threatening (Courtney & Hubbard, 2004; Intraub et al., 2008).

Source monitoring

Seamon et al. (2002) suggest that boundary extension might reflect an error of source monitoring. In such an error, the source or origin of information is mistaken or misattributed (Johnson, Hashtroudi, & Lindsay, 1993). More specifically, Seamon et al. suggest that when participants view targets in a boundary extension task, those participants interpret targets as scenes embedded in an extended context. When later responding to a memory test for the original target, those participants do not distinguish between what was in the original stimulus and their understanding of that scene (see also Chapman et al., 2005). Such a view is consistent with the notion that boundary extension only occurs when the viewed object is perceived or interpreted within the context of a scene, as in everyday experience objects are usually in some type of extended spatial layout and not in a featureless nonextended background. Intraub and Dickinson (2008; Intraub et al., 1998; Intraub et al., 1996) suggest the similar notion that participants during a memory test are unable to distinguish between externally generated information (visual input) and internally generated information in the form of amodal perception and activation of a spatial framework accompanying the presentation of the stimulus. However, it is not clear how an account based on source monitoring is different from accounts based on schemata, and processes involved in (the failure of) source monitoring appear similar to processes involved in schemata.

PART IV: SUMMARY AND CONCLUSIONS

In boundary extension, memory for the location of the boundary of a scene is extended (displaced) outward. As a result, information likely to have been present just outside the boundary of the actual view is often incorporated into memory for the scene. Boundary extension has been examined with a variety of measures that involve (a) drawing the remembered scene, (b) adjusting boundaries or magnification on a probe stimulus to match boundaries or magnification of the remembered scene, (c) reconstructing the scene using cut-out figures of varying sizes, (d) using a rating scale to indicate whether the viewpoint in a probe picture is closer than, the same as, or further than the viewpoint in a remembered scene, and (e) choosing which of several simultaneously presented probes matches the remembered target. One potential issue is that some of these measures (e.g., using a rating scale to judge the distance of the probe viewpoint relative to the remembered viewpoint, reconstructing the scene using cut-outs) do not actually measure boundary location per se and at best provide an indirect indication of boundary location. However, other measures (e.g., drawing the remembered scene, adjusting the boundaries of a probe to match the boundaries of the remembered scene) provide a more direct measure of boundary location. Although different measures do sometimes yield different results, there is generally more convergence than divergence regarding boundary extension in conclusions that are based upon different response methods. Indeed, boundary extension appears to be very robust.

Effects of variables known or suspected to influence boundary extension were reviewed, and a typology involving characteristics of the stimulus, display, and observer was proposed. In the first category, characteristics of the stimulus, boundary extension is (a) observed only when the stimulus is a spatially extended scene, (b) larger for scenes interpreted as close-up views than for scenes interpreted as wide-angle views, (c) unrelated to whether objects in the scene are cropped by edges of the view, (d) larger in the direction of anticipated movement of an object or an anticipated shift in fixation, (e) decreased with negatively valenced or traumatic stimuli in some studies but not influenced by emotional content in other studies, and (f) established for visual scenes but not yet established for nonvisual scenes. In the second category, characteristics of the display, boundary extension (a) is larger if probe scenes are viewed through a larger aperture, (b) is not influenced by whether a viewing aperture is rectangular, elliptical, or irregular in shape, (c) is usually not influenced by duration of scene visibility, and (d) occurs within milliseconds after a viewed scene vanishes, increases during the first quarter second, and can last for several days. In the third category, characteristics of the observer, boundary extension (a) increases when less attention is available, (b) occurs in infants, (c) is larger in young children and in older adults than in young adults, (d) does not depend upon binocular or depth information, (e) interacts with arousal and emotional reactivity of the participant, and (f) involves activity in cortical areas implicated in perception of layout but not in cortical areas implicated in object recognition.

Boundary extension has been attributed to several different types of mechanisms, the most common of which involve some type of schema. Different types of schema involving perceptual, memory, and scene information have been suggested to contribute to boundary extension. Other mechanisms attribute boundary extension to (a) a narrowed attentional focus on the central elements of a scene, (b) a combination of processes such as an initial extension followed by a subsequent normalization, or (c) a failure of source monitoring in which an observer is not able to distinguish between perceptually sampled information and schematically provided information. Some aspects of boundary extension appear automatic and cognitively impenetrable (e.g., rapid onset of boundary extension, inability to explicitly inhibit boundary extension), but other aspects of boundary extension appear nonautomatic and cognitively penetrable (e.g., influences of expectations regarding eye movements or object movements on boundary extension). This pattern is consistent with the possibility that displacement of scene boundaries does not result from a single undifferentiated process, but might rather reflect a combination of automatic (modular) processes and nonautomatic (nonmodular) processes. Potential mechanisms of boundary extension based solely upon object completion or upon the prototypical distance from which scenes are viewed were rejected.

Potential relationships between boundary extension and other cognitive phenomena were noted. Boundary extension might contribute to transaccadic memory. Several possibilities regarding the relationship of boundary extension to representational momentum were considered, but the nature of this relationship is not yet agreed upon. Similarly, the relationship between boundary extension and psychophysical judgements of remembered distance or remembered area is not clear. Boundary extension has been suggested to result from the continuity of spatial layout, and the lack of boundary extension for stimuli in which spatial continuity is not salient (e.g., visual objects on a blank background, musical performance or spoken prose) suggests that boundary extension might be limited to stimuli for which continuity of spatial layout is salient. Indeed, it is possible that boundary extension—for scenes (backgrounds)—and amodal continuation—for objects (figures)—arise from this same general property of continuity of spatial layout. Properties of spatial representation in addition to continuity might be important, as boundary extension appears to be influenced by the dynamics within a scene. The wide range of variables that impact boundary extension, coupled with the range of other cognitive phenomena that might be related to boundary extension, suggests that boundary extension is not limited to visual picture perception. Rather, boundary extension might be an adaptive property of mental representation that reflects deeper principles involving anticipation, dynamics, and application of previous knowledge to subsequent perception.

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