Intraub, H. (2007). Scene Perception: The World Through a Window. In Peterson, M. A., Gillam, B., Sedgwick, H. A. (Eds.), In the Mind's Eye: Julian Hochberg on the Perception of Pictures, Films and the World. NY: Oxford University Press.

# 26

# Scene Perception

## The World Through a Window

*Helene Intraub*

If photoreceptors coated our bodies instead of our retinas, we'd be able to see in all directions simultaneously—thus eliminating one of the fundamental mysteries of perception. Instead, the visual field is spatially limited, preventing us from ever seeing our surroundings all at once. Retinal inhomogeneity limits the view further—with the best visual acuity restricted to the tiny foveal region (only 2° of visual angle). In a sense, it as if the world is always viewed through a "window": an imperfect window, with graded clarity. Thus, movement is critical for scene perception; ballistic saccades shift the position of the foveae up to four times per second, and head movements rapidly bring new areas into view. How we come to experience a coherent representation of our surroundings based on these discrete, inhomogeneous samples is one of the mysteries of perception.

Hochberg's (1978, 1986a) approach to the puzzle of visual coherence is multifaceted. He has addressed it through innovative analyses of both perceptual errors (visual illusions) and perceptual "successes" in the face of impoverished input (e.g., aperture viewing, perception of motion pictures). He proposes that one's current view is incorporated within a *schema*, which is a cognitive structure that includes memory for prior views as well as anticipatory projections of upcoming information as determined by the viewer's goals and actions. Successive views are understood within the context of this schema, or "mental map." He has provided numerous compelling means of exemplifying this idea. I will describe just two examples, in which he drew on situations in which sensory input is even more constrained than during normal free viewing.

In his fascinating discussion of film editing and perception, Hochberg (1986a) describes a situation in which the camera sweeps across a scene. If it sweeps to the right, layout shifts across the screen toward the left and disappears beyond the left-hand edge. Yet, he points out, "in most situations there is a compelling perception of space, in which an extent has been traversed and about which the viewer has a clear visual knowledge. That extent is larger than the screen and exists nowhere but in the mind of the viewer" (Hochberg, 1986a, p. 22.43). The viewer's representation beyond the screen is palpable—creating the sense of continuous, complex spaces that in reality do not exist (e.g., interiors of starships, old western towns) except as movie sets that are noncontinuous, truncated bits of the to-be-created world with no continuity beyond the deliberately constrained viewpoint of the camera.

Experimental support for the proposed schema has been provided by Hochberg's aperture-viewing experiments. In one study, using stop-motion photography, a pair of perpendicular lines was animated so that it rotated around the inside of a circle (Hochberg, 1978, 1986a; see Figure # in chap. # of this book). Viewers reported seeing a clock face with hands at a fixed angle moving around the dial. However, the successive positions of the perpendicular lines were selected so that they were identical to what would be seen if an outline cross () was moving behind a peephole. If an "establishing shot" (showing a full view of the cross) or a verbal description of the cross preceded the animation, viewers' perception was markedly different. They reported seeing an outline cross moving behind a round aperture. Perception was "concrete" enough to allow them to note when one of its four arms was skipped. This could not be based on *sensory* integration because none of the "arms" was ever actually shown in the animation (just two perpendicular lines). Nor could it be based on a "good guess" given the establishing shot, because in addition to noting a missing arm, perception of the moving cross was sensitive to the presentation rate at which successive views were shown (described in Hochberg, 1986a).

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Hochberg stressed the "abstract" nature (i.e., sketchy rather than picturelike) of the mental schema that facilitates view integration (e.g., Hochberg, 1978, 1982, 1986a, 1986b). This was initially not a widely accepted view in the eye-movement literature (e.g., Davidson, Fox, & Dick, 1973), but over the years, research on eye movements and transsaccadic memory has provided widely accepted support for this position (e.g., Irwin, 1991, 1993; McConkie & Currie, 1996; Rayner & Pollatsek, 1992). Although a sketchy representation is likely to be more forgiving than a rigid sensory representation in integrating layout, there is also a cost. Lack of detail can result in the failure to detect changes from one view to the next—exemplified in cinema by filmgoers' frequent failure to detect continuity errors (see Hochberg, 1986a, for an example). This important observation was subsequently supported in a series of influential papers on "change blindness" (Rensink, O'Regan, & Clark, 1997; Simons, 2000; Simons & Levin, 1997). Clearly, Hochberg's theoretical analyses and associated observations have presaged the direction of current research on scene representation. Borrowing terminology from filmmaking, I will now cut to a close-up and discuss the impact of his work on my own research in that area.

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### *Perception Through a Window: Aperture Viewing and Boundary Extension*

When I was a student, first studying Hochberg's work, it was the aperture studies that I found to be most accessible in explaining how an abstract schema could play a fundamental role in something as seemingly concrete as visual perception. Years later, these studies came to mind when I noticed a curious error in viewers' memory for photographs of scenes. They tended to remember having seen a surrounding swath of unseen but highly likely layout (see Figure 26.1) from beyond the camera's point of view. The error was not limited to their drawings but was strikingly evident in recognition tests as well. These observations were first reported by Intraub and Richardson (1989), who coined the term "boundary extension" to describe the phenomenon.

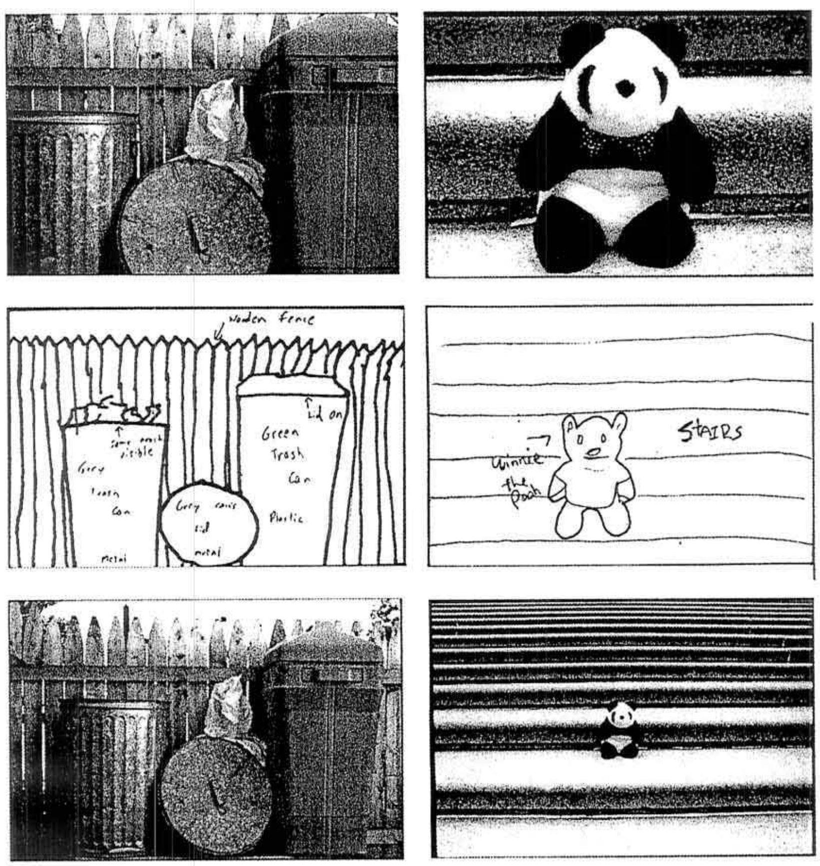


**Figure 26.1.** The top row shows close-up views of scenes; the middle row shows representative participants' drawings from memory; and the bottom row shows a more wide-angle view of the scenes. Note that the information added by the participant was an excellent prediction of what actually did exist just beyond the view. Column 1 is from Intraub and Richardson (1989; 15-s exposure and 2-day retention interval), and column 2 is from Intraub et al. (1996; 250-ms exposure tested minutes later).

Because it was originally inconceivable that these memory errors would occur immediately, memory was tested after relatively long retention intervals in the first experiments (e.g., 35 min or 2 days). It seemed plausible that the error reflected changes over time consistent with other known memory distortions (e.g., memory changing toward the "prototypic view" or becoming distorted due to Gestalt object completion of background objects; Intraub, Bender, & Mangels, 1992; Intraub & Richardson, 1989). Hochberg's theory, however, suggested an alternative explanation. Perhaps viewers spontaneously perceive a photograph as a "view of the world through a window" with all of the attendant expectations of continuity inherent in aperture viewing. Thus, instead of reflecting changes over time to an initially veridical representation, boundary extension might instead faithfully reflect the schematic representation that Hochberg proposed as the basis of scene perception. Anticipatory projection of layout may in fact become "visible" (in the form of boundary extension) when viewers are explicitly required to express a remembered expanse. Subsequent research ruled out long-term memory accounts (e.g., Intraub et al., 1992; for a review, see Intraub, 2002), and evidence has continued to accrue in support of the perceptual schema explanation.

Boundary extension occurs rapidly and is difficult to eliminate. For example, Intraub and Bodamer (1993) demonstrated that prior knowledge of the phenomenon can attenuate but not eliminate it—something that colleagues and experimenters in my lab have all informally experienced (see Figure 26.2). Intraub and Berkowits (1996) attempted to prevent it by encouraging more effortful encoding by inverting the to-be-remembered photographs. Not only did boundary extension persist, but the amount of extension was virtually the same in the inverted and upright conditions. Boundary extension is ubiquitous and has been reported in people ranging in age from 6 years to 84 years (Candel, Merckelbach, Houben, & Vandyck, 2004; Seamon, Schlegel, Heister, Landau, & Blumenthal, 2002). In ongoing research with Paul Quinn at the University of Delaware, using a habituation/looking procedure, we have obtained preliminary evidence that 6- to 7-month-old infants also remember having seen beyond the boundaries of a view.

change 6- to 3-
change 7-month to 4-month

## *Schema Theory: Caveats and Possibilities*

These observations are consistent with the notion of a perceptual schema but do not prove the point. "Schema" is still a somewhat vague construct. In addressing the role of schematic construction in perception, Hochberg (1982) himself has cautioned, "All of this may be too good to be true, however, and should not be taken too seriously until we can specify better what is meant by schema (i.e., by what in Helmholtzian terms would be the premises of unconscious inference), and until we can put limits on the

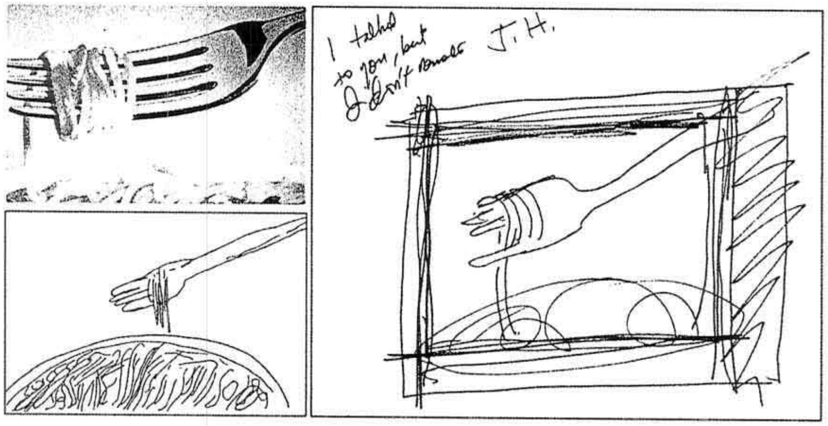

**Figure 26.2.** Viewers in the Intraub and Bodamer (1993) experiment studied the fork photograph (along with two other pictures that weren't tested); their drawings of the fork moments later included extended boundaries (as shown in the example in the lower left panel; pictures based on figures in Gottesman & Intraub, 1999). Although the error was pointed out to them, and they were challenged to prevent it from happening as they memorized a new set of pictures, they were unable to do so. Similarly, in 1987–1988, Julian Hochberg drew the fork picture from memory (right panel). He noted that I had mentioned the phenomenon to him, but he couldn't remember the upshot. When reminded, like most other viewers, he thought he could correct his drawing by adjusting the boundaries; however, comparison with the photo shows that he was not successful in eliminating the mentally extrapolated region (drawing reproduced with Hochberg's permission).

theory as I have been trying to put limits on the other theories of perceptual organization" (p. 214). In a later paper, he indicated disappointment at the lack of direct research addressing "the qualitative and quantitative nature of the space . . . behind an aperture" and then offered suggestions about how the field might begin to achieve this end (Hochberg, 1986a, p. 43).

Boundary extension may provide one means by which some of these goals can be accomplished. I will provide a brief sketch of recent and ongoing research aimed at (a) providing qualitative and quantitative assessments of anticipatory spatial representation, (b) establishing boundary conditions for the occurrence of boundary extension, and (c) developing direct tests of its potential role in view integration in both the visual and haptic modalities.

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## *Perceptual Schema Theory: Not All Boundaries Are Equal*

Unlike Hochberg's aperture studies, in the case of boundary extension, there is no "establishing shot." In this case, a single, isolated view elicits an anticipatory projection of layout. Thus boundary extension provides a means for focusing on the anticipatory aspects of Hochberg's proposed schema (Intraub, 1997, 2002). My colleagues and I have argued that *view boundaries* (Gottesman & Intraub, 2003) are treated by the visual system as if they were the edges of an aperture, and thus they signal the occlusion of surrounding space. Such boundaries would be expected to elicit both relatively low-level "filling-in" processes (amodal continuation of surfaces or textures; e.g., Kellman, Yin, & Shipley, 1998; Nakayama, He, & Shimojo, 1995; Yin, Kellman, & Shipley, 1997) and more high-level constructive processes based on world knowledge (e.g., knowledge about fences in Figure 26.1).

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Nakayama, He, & Shimojo, 1995 (like in reference)

This characterization suggests a *boundary condition*. Boundary extension should not occur in memory for all types of pictures—only those in which the edges of the picture are construed as being *view boundaries* that delimit the view of an otherwise continuous environment (i.e., the edges of an aperture). To test this, Intraub, Gottesman, and Bills (1998; also see Legault & Standing, 1992) tested recognition memory for outline drawings of single objects on blank backgrounds. Such backgrounds putatively depicted "nothing"—the blank space was simply the paper on which the artist drew the object—thus the edges of the picture should not be construed as view boundaries. As predicted, boundary extension did not occur (spatial errors were bidirectional rather than unidirectional). However, boundary extension did occur for the same stimuli if viewers were instructed to *imagine* a real-world background for the object during encoding (e.g., while looking at an outline drawing of a traffic cone, the viewer was told to "imagine it is on an asphalt road that fills the background"). Boundary extension also occurred without imagination instructions, when a sketchy background was added to the outline drawings (e.g., stippling to indicate an asphalt road), which were then shown to another group of viewers.

These results show that boundary extension isn't simply the result of objects becoming compressed in memory, or a bias to remember more space between an object and a surrounding boundary. When the picture was understood to be a view of a scene, anticipatory projection of the background occurred. Gottesman and Intraub (2002) reported an analogous outcome using photographs of objects that were cut out of their natural backgrounds and presented on a blank background within a clear set of borders. When viewers construed the blank background as being a truncated view of a bland but continuous region, boundary extension occurred; but when the context was biased so that viewers interpreted the blank background as being completely unrelated to the cut-out object (i.e., not part of the picture at all but a rectangular surface on which the cut-out picture rested), boundary extension did not occur. Again, only when the display edges were construed as being *view boundaries* did boundary extension occur.

Are view boundaries "special"? All view boundaries are borders that *surround* the content of a picture. Gottesman and Intraub (2003) addressed the possibility that any surrounding boundaries in a scene will cause a spatial distortion like boundary extension to occur—even if the boundaries are not

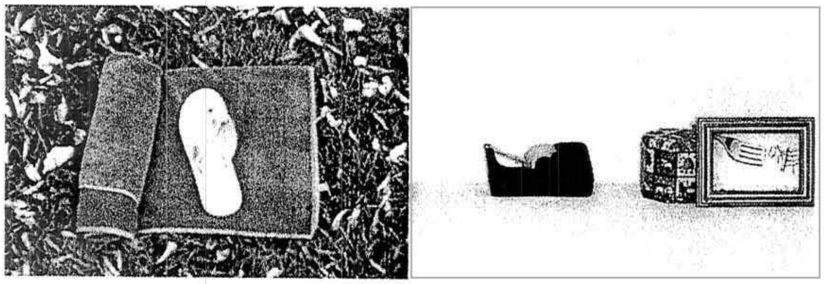


**Figure 26.3.** In addition to the edges of the photograph itself (the *view boundaries*), each picture includes a *surrounding* boundary *within* the view: In the left panel, the surrounding boundary is an object boundary (the edge of the towel surrounding the sandal), and in the right panel the surrounding boundary is also a *view boundary* (the picture frame surrounding the photo on the desk). All view boundaries yielded boundary extension, whereas object boundaries did not (based on figures in Gottesman & Intraub, 2003).

view boundaries. Photographs were taken that always included a surrounding boundary *within* the view: In Figure 26.3 (left panel), a sandal rests on a towel, which is lying on a grassy field. The border of the towel surrounds the sandal; it is a surrounding boundary but not a view boundary. We expected viewers to remember seeing more grass around the objects (typical boundary extension), but would they also remember seeing a greater expanse of terrycloth around the sandal?

Drawing and reconstruction tests (in which viewers constructed the remembered view by choosing from among a set of variously sized parts) showed that boundary extension occurred beyond the edges of the picture (the view boundaries) but not beyond the edges of the towel (an object boundary). However, a surrounding boundary within a view did yield boundary extension when that boundary was in itself a view boundary. A photograph of objects on a desktop that included a framed photograph was presented (Figure 26.3, right panel). In the case of this "picture within a picture," boundary extension occurred not only for the picture as a whole (viewers remembered seeing more of the desk) but also for the view within the tiny picture frame on the desk.

Memory for occluded objects in scenes provides additional evidence for the special status of view boundaries. Intraub, DiCola, and Akers (2004) tested memory for the visible portion of an occluded object in a multi-object scene that was cropped either by a view boundary or by another object *within* the view. Images were presented using a multilayered graphics program so that viewers could independently adjust the boundaries of the view and the position of the objects. Using a mouse, they could move the target object behind other objects or behind the view boundary (depending on condition) and reconstruct the remembered occlusion relation. The portion of the object that remained visible in the reconstruction was measured in pixels. On average, viewers increased the visible portion of the occluded object when it had been cropped by a view boundary but *not* when it was cropped by another object *within* the to-be-remembered view (i.e., on average, object relations within the view were preserved). View boundaries are fleeting, accidental boundaries (not a part of the scene). The goal of the visual system isn't to remember the fleeting boundaries of successive fixations, but to perceive the continuous scene that is being sampled. Might anticipatory representation of the layout just beyond the given view play a role in the integration of successive views during visual scanning?

## *Eye Movements: Can Boundary Extension Facilitate Integration of Successive Views?*

We've known for some time that a brief pictorial exposure similar to "a fixation's worth" (e.g., 250 or 333 ms) is sufficient to elicit boundary extension moments later (Intraub, Gottesman, Willey, & Zuk, 1996). Perhaps the extended region serves to prime upcoming layout during visual scanning, facilitating the integration of views into a coherent representation. However, this would only be possible if boundary extension occurred on the to-be-fixated side of a view—and there is good reason to question whether or not this would occur. Attention precedes the eyes to a to-be-fixated target, and there is evidence that it serves to enhance the detection of target details before the eyes arrive at the new location (Hoffman & Subramanium, 1995; Kowler, Anderson, Dosher, & Blaser, 1995). Thus, if a fixation is planned near a view boundary, detail enhancement might serve to "pin down" the location of that boundary, eliminating boundary extension at that boundary.

To test the effects of a planned fixation on scene representation, Intraub, Hoffman, Wetherhold, and Stoehs (2004) monitored eye movements in the following task. Viewers centrally fixated a photograph. After 250 ms, a 50-ms cue directed the viewer to fixate an object near either the left or right boundary. A mask replaced the picture before the eyes landed. Two seconds later, the picture reappeared, and using the mouse, the viewer adjusted each of the four view boundaries independently to reconstruct the studied view. We ran three experiments, varying details of the recognition test, and boundary extension always occurred on the to-be-fixated side. In fact, the amount was similar to that obtained in a no-movement control condition in which the viewers simply maintained central fixation.

The top and bottom borders (which were never the target of the cue) also were remembered with extended boundaries. However, the *plan* to shift fixation had a striking effect on the shape of the boundary-extended region. Boundary extension was minimized or eliminated not on the to-be-fixated side, but on the side *opposite* the planned fixation. In other words, given these competing actions, following the cue, boundary extension was inhibited on the "path *not* taken." This pattern of results is consistent with the *biased competition model of attention* (Desimone & Duncan, 1995). But what is most important for the present discussion is that this change in the extrapolated region did not affect boundary extension at the leading edge of the representation—the to-be-fixated side always included an extended swath of anticipated layout. Attention may enhance the detection of specific details of a targeted object (e.g., Hoffman & Subramaniam, 1995), but layout extrapolation beyond the edge of the view occurred nonetheless. At the least, it is available to facilitate the integration of successive views during visual exploration.

### *Visual and Haptic Exploration: Integrating Partial Views in Different Modalities*

Does boundary extension reflect the underlying mental structure of perception? Or might it be limited solely to memory for pictures (a position that would be consistent with Gibson's, 1951, acceptance of the role of mental structure in picture perception but not in perception of 3D objects and surfaces)? To determine if boundary extension occurs in memory of the 3D world, Intraub (2004) tested memory for regions of 3D space directly in front of the viewer. Small "movie sets" were constructed (e.g., kitchen counter, dining-room place setting, bureau top, carpenter's workspace) within a laboratory. Windows limited the view (see Figure 26.4). After inspecting six such scenes for 30 s each, the windows were removed, and participants reconstructed the edges of the original view. They remembered

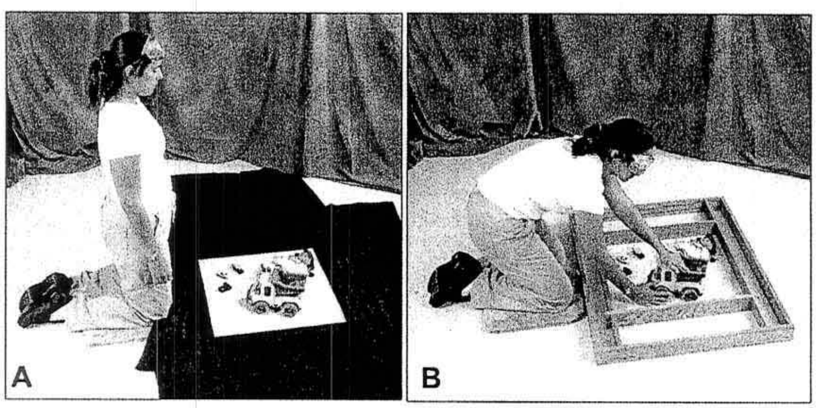
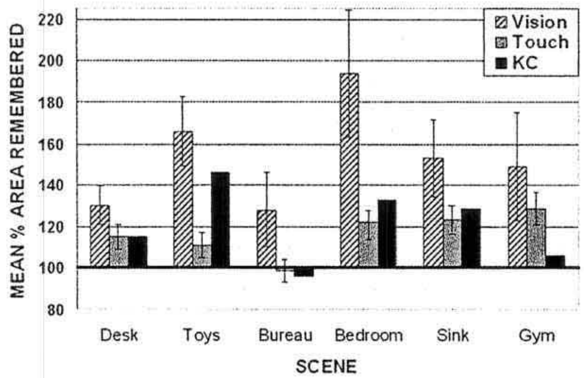



**Figure 26.4.** Visual exploration (panel A) and haptic exploration (panel B) of the "toys" scene. (All borders were removed prior to test.) From Intraub, 2004.




insert ("vision")
insert ("touch")
insert after KC: a deaf and blind participant

**Figure 26.5.** Mean percentage of the area of each region remembered by sighted participants in the visual and haptic conditions and the percentage of each region remembered by KC. Error bars show the .95 confidence interval around each mean. (Boundary extension occurs when the mean remembered area is significantly greater thai 100%, that is, when 100% is *not* included in the confidence interval.) From Intraub, 2004.

having seen a sizable amount of previously unseen area, just beyond the original view. When other subjects explored the region haptically (while blindfolded), they too experienced boundary extension—remembering having *felt* beyond the edges of the window. The percentage increase in area that occurred in memory for each modality is shown in Figure 26.5.

Haptic boundary extension could not be attributed solely to sighted participants' reliance on visual representations (e.g., visualization of the felt surface) because the same results obtained when a "haptic expert"—a woman who has been deaf and blind since early life—explored the same scenes. The amount of extension she experienced was, in all but one case, similar to or greater than that remembered by the blindfolded-sighted participants (see Figure 26.5). It is important to note that vision resulted in a greater amount of extension than did haptic exploration (whether the latter was performed by a haptic expert or by sighted participants who were temporarily blindfolded). This suggests that input modality may play a role in constraining extrapolation. Indeed, cross-modal conditions in an experiment similar to the one just described (Intraub, Morelli, & Turner, 2004) demonstrated that visual encoding resulted in greater boundary extension than did haptic encoding, irrespective of which modality was used during the memory test (test modality had no effect on performance).

, KC
(insert, comma KC)
"Touch",

Vision and haptics differ in many ways, but one salient characteristic is a difference in scope; the visual field is much greater than the reach of our hands (see William James's, 1890, discussion of the spatial cognition of blind and sighted individuals; and O'Regan & Noë, 2001). Put another way, a small shift of the eyes can bring considerably more new information to the observer than can a small shift of the hands. The smaller scope of the haptic modality may constrain the size of the projected region. After all, to support a coherent representation of surrounding space, spatial projection needs to be large enough to aid integration but not so large that it causes confabulatory errors and confusion.

## Conclusions

Hochberg's perceptual theory has provided the groundwork for current trends in the study of scene representation and the integration of successive views. Research on transsaccadic memory and change blindness has borne out critical aspects of his claims about the schematic nature of moment-to-moment representations. Research on boundary extension shows that both immediate and long-term representations of truncated views of natural scenes typically include projections of the surrounding layout. These observations indicate that, similar to aperture viewing and cinematic communication, scene representation essentially "ignores" the spurious boundaries of a given view. Whether exploring the world through vision or touch, we sample it only a part at a time and yet experience a coherent representation of a continuous world.

## A Personal Note

I had the honor, in 1987–1988, of being a National Science Foundation visiting professor in Julian Hochberg's lab. As a scientist (and as a filmmaker—a critical aspect of my life from age 9 through college), that visit meant more to me than I can say. During my stay, I wrote the first paper on boundary extension (Intraub & Richardson, 1989). I did so surrounded by students studying perception, students analyzing cinema, rotating windows, gloriously tall stacks of film canisters, and the latest in computer graphics—but, most important of all, I experienced the generous hospitality of someone who first opened the "window" for me (so to speak) on what is most exciting about perception.

## Acknowledgement

Chapter preparation was supported in part by NIMH grant R01MH54688.

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