# VISUAL COMPLETION OF PARTLY OCCLUDED OBJECTS: INSIGHTS FROM BEHAVIORAL STUDIES

A. B. SEKULER[1], J. M. GOLD., R. F. MURRAY, & P. J. BENNETT
*DEPARTMENT OF PSYCHOLOGY*
*UNIVERSITY OF TORONTO*

The primary goal the visual system is to recognize objects so that we may interact with them appropriately. Although our perception of objects appears instantaneous and automatic, complex processing is required by the visual system for the recognition of objects in the real world. One of the primary obstacles faced by the visual system is the fact that objects occlude parts of themselves and parts of neighboring objects -- the information describing objects is often incomplete. Yet, when we perceive the world, we do not perceive distinct, dissociated regions and contours -- we perceive meaningful wholes. For example, the shape shown at the top of Figure 1 is typically described by people as a circle partly hidden behind a square, although many other physical possibilities exist. Somehow, the visual system seems to fill in missing information, connecting related regions to each other behind occluding surfaces.

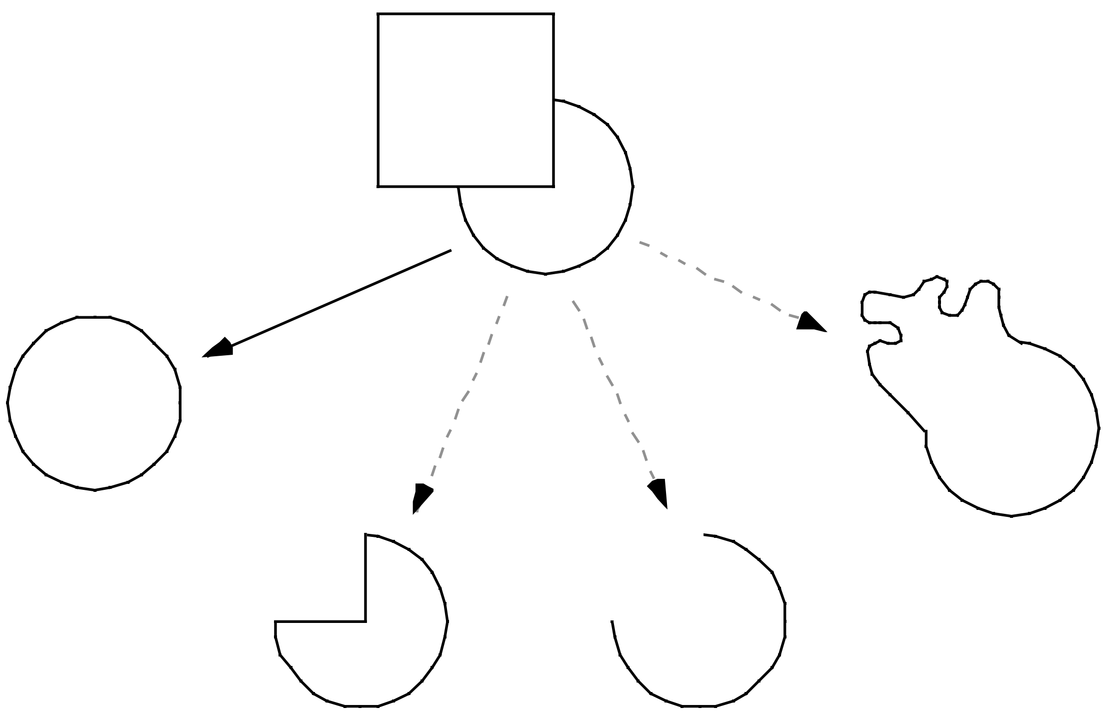

**FIGURE 1.** Observers typically describe the combination of shapes shown at the top as a circle partly occluded (or hidden) by a square, as illustrated by the solid arrow. However, this interpretation is only one of an infinite number of physically plausible possibilities, examples of which are illustrated by dashed arrows.

[1] Author to whom correspondence should be addressed:
Department of Psychology, University of Toronto
100 St. George St., Suite 4020
Toronto, Ontario, CANADA M5S 3G3
sekuler@psych.utoronto.ca

Here, we describe several techniques we have developed to provide evidence that the visual system effectively treats partly occluded objects as functionally complete by the visual system, although completion requires some measurable time. We also describe a technique that can be used to determine precisely what information observers use in making perceptual judgements about objects (occluded and otherwise).

In our first set of studies (Sekuler & Palmer, 1992), we adapted a priming paradigm (primed-matching) to provide objective evidence for visual completion and to measure the time course, or microgenesis, of completion. When people are asked to make judgments about whether two shapes are the same as each other or different from one another, the time to make their responses are affected by a priming stimulus they see just before the shape discrimination task. For example, after seeing a complete circle prime, people are faster at saying "same" to a pair of complete circles than to a pair of incomplete circles. In contrast, after seeing an incomplete circle prime, people are faster at saying "same" to a pair of incomplete circles than to a pair of complete circles. In this way, the relative response times (or priming effect) can be taken as an index of the similarity of the visual representation of the primed object and objects within a "same" pair. Thus, complete circles prime complete circles, and incomplete circles prime incomplete circles.

The obvious question to ask with respect to occlusion is what happens when the initial, priming stimulus is a partly occluded stimulus -- a stimulus with the same retinal representation as the incomplete circle, but that people would describe as being completed behind an occluder? If the pattern of priming is the same as that for complete objects, that would suggest that occluded objects are, in fact, being represented by the visual system as complete. However, if the pattern of priming is the same as that for incomplete objects, that would suggest that occluded objects are being represented as incomplete. The answer one gets depends on several factors, most critically time.

For relatively short stimulus durations we found that the pattern of priming by occluded objects was more similar to that by incomplete than complete objects. However, over time, the pattern of priming changed, and for long durations priming by occluded objects was statistically indistinguishable from priming by complete objects. In other words, if the pattern of priming can be used as an objective index of visual completion, we found that the visual system effectively treats occluded objects as though they are complete, but that this completion requires some measurable time (Sekuler & Palmer, 1992).

We have since gone on to show that the time course of completion can be mapped out using other paradigms as well. For example, in a recent study (Murray, Sekuler & Bennett, submitted), we asked people to categorize line drawings of rectangles as being vertically or horizontally elongated. In one condition (complete), the entire rectangle was visible. In another condition (occluded), only a portion of the rectangle was visible, and the remainder was blocked by visible occluders. In a third condition (fragmented), the same portion of the rectangle was visible as in the occluded condition, but no occluders were visible (they were set to the same luminance as the background, so only four disconnected line segments were visible). Performance was generally better in the complete condition than in the fragmented condition -- consistent with evidence that people are better at processing information within a single object than across several objects (e.g., Duncan, 1984). However, performance in the occluded condition varied considerably with stimulus duration. At relatively short stimulus durations, people performed as poorly in the occluded condition as they did in the fragmented condition. But at relatively long durations, people performed as well in the occluded condition as they did in the complete condition. As in the experiments using primed-matching, these results suggest that the visual system treats occluded objects as though they are complete, but only after some time has elapsed.

How much time must elapse before an object is represented as complete by the visual system? Initial estimates from our lab (Sekuler & Palmer, 1992) and others (Ringach & Shapley, 1996) suggested that 100- 200 ms was required for completion. However, in Murray et al.'s (submitted) experiments, effective completion occurred in less than 100 ms. Other experiments confirm that time-to-completion is not fixed, but depends on various factors. For example, recent results suggest that highly occluded objects require more time for completion than do less occluded objects (Guttman & Sekuler, submitted; Shore & Enns, 1997). In addition, when stereoscopic cues are presented that are consistent with occlusion cues, results from the primed matching paradigm are consistent with a speeded completion process (Bruno, Bertamini & Domini, 1997). The effects of factors such as amount of occlusion and the presence of consistent stereo-depth cues may be explained in terms of the physiological properties of different parts of the visual system. Recent electrophysiological results suggest that neurons in monkey primary visual cortex (area V1) may be capable of signaling completion under limited circumstances, such as small amounts of occlusion or when consistent stereo-cues are present (Kovacs, Vogels & Orban, 1995; Sugita, 1999). Under other circumstances, completion may not be processed until later in the visual system (e.g., prestriate or inferotemporal cortex, where higher level aspects of perceptual organization and object recognition occur). Thus, the behaviorally-estimated time to completion may be an assay of the cortical level at which completion is processed under different stimulus conditions.

Regardless of where in the brain completion occurs, previous research has shown that, eventually, the brain does effectively treat occluded objects as though they were complete. However, previous research had not shown that observers actually used the occluded portion of contours to recognize objects. In a recent study, we adapted the "reverse-correlation" technique to determine precisely what information people used in making judgements about the shape of partly occluded objects. In this technique, observers are asked to discriminate two shapes from one another. For example, are the shapes shown in the left and right column of Figure 2 "fat" or "thin"? In an experiment, such target shapes are presented at relatively low contrast embedded in visual noise (like snow on a de-tuned television). Because the shapes are hard to see, sometimes the noise will make the shape look more "fat" or more "thin" -- the noise might reinforce the correct answer, or cause the observer to respond incorrectly.

By keeping track of what the noise looked like on trials where the observer responds "fat" or "thin", we can see what biases an observer to make one or the other response -- in other words, we can see what locations in the stimulus observers use to make this shape discrimination -- defining a sort of behavioral receptive field.

As expected, when real, vertical contours determine the difference between "fat" and "thin" objects, the reverse-correlation technique shows us that observers make use of those vertical contours (Figure 2, middle figure in top row). Amazingly, though, even when no physical contours are present in those locations because of occlusion, people

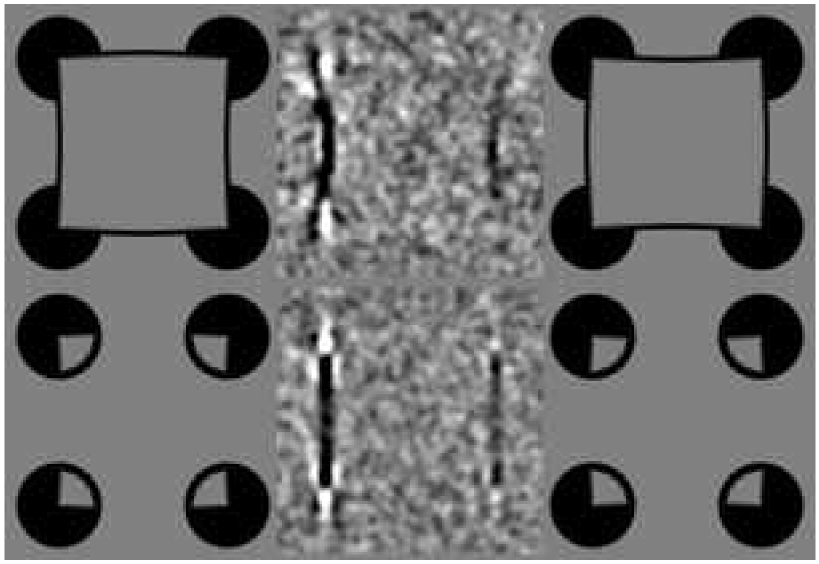

**FIGURE 2.** Illustration of stimuli and results from Gold et al. (2000), mapping the behavioral receptive field for visually completed contours. Left and right columns show "thin" and "fat" stimuli, respectively, for real contours (top row) and occluded contours (bottom row; the occluded stimuli are typically perceived as a light rectangular surface against a black background, viewed through four holes punched out of an occluding light surface). The middle column shows the locations of the stimuli observers used in discriminating "thin" and "fat"; black and white pixels indicate the most significant locations. Note that for both real and occluded contours, observers use information in essentially the same locations, although there is no physical contour located there in the case of occluded objects.

rely on information in the same regions of the stimulus as if the contours really were there (Figure 2, middle figure in bottom row). The behavioral receptive fields for complete and occluded objects are essentially identical -- people use information from the same contour locations to judge shape whether the contour really is present or not. This result provides the first direct evidence that observers upse perceptually interpolated contours, constructed by the brain, to recognize objects. Recent results from our lab also suggest that the closer the behavioral receptive fields are for real and occluded objects, the better an observer will perform under conditions of occlusion (Murray, Bennett, Sekuler & Gold, 2000). Thus, although it may require tremendous neural resources, filling-in this missing information provides a tremendous benefit for object recognition.

Research over the past decade has added much to our understanding of visual completion, and of object recognition more generally. However, a thorough understanding of visual completion will require the integration of the best aspects of behavioral and physiological methods. To this end, we are currently planning a combination of behavioral, neuropsychological, and functional neuroimaging studies to help us better understand the interactions among neural systems required to help the visual system achieve its primary goal.

## REFERENCES


Bruno, N., Bertamini, M., & Domini, F. (1997). Amodal completion of partly occluded surfaces: Is there a mosaic stage? *Journal of Experimental Psychology: Human Perception and Performance, 23*, 1412-1426.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*, 501-517.

Gold, J. M., Murray, R. F., Bennett, P. J., & Sekuler, A. B. (2000). Deriving behavioural receptive fields for visually completed contours. *Current Biology, 10, 663-666.*

Guttman, S., & Sekuler, A. B. (submitted). Visual completion: Spatial and temporal limits. Submitted to *Journal of Experimental Psychology: Human Perception and Performance.*

Kovacs, G., Vogels, R., & Orban, G. A. (1995). Selectivity of macaque inferior temporal neurons for partially occluded shapes. *Journal of Neuroscience, 15*, 1984-1997.

Murray, R. F., Bennett, P. J., Sekuler, A. B, & Gold, J. M. (2000). Effect of visual completion on calculation efficiency. *Investigative Ophthalmology and Visual Science*, *41*, S440.

Murray, R. F., Sekuler, A. B., & Bennett, P. J. (submitted). Time course of amodal completion revealed by a shape discrimination task. Submitted to *Psychonomic Bulletin and Review.*

Ringach, D. L., & Shapley, R. (1996). Spatial and temporal properties of illusory contours and amodal boundary completion. *Vision Research, 36,* 3037-3050.

Sekuler, A. B., & Palmer, S. E. (1992). Perception of partly occluded objects: A microgenetic analysis. *Journal of Experimental Psychology: General, 121*, 95-111.

Shore, D. I., & Enns, J. T. (1997). Shape completion time depends on the size of the occluded region. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 980-998.

Sugita, Y. (1999). Grouping of image fragments in primary visual cortex. *Nature, 401,* 269-272.