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On the filling in of the visual blind spot: some rules of thumb

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Abstract. In monocular viewing there is a region in the peripheral visual field that is blind owing to the absence of photoreceptors at the site where the optic nerve exits the eye. This region, like certain other blind spots, nonetheless appears filled in. Several novel demonstrations of filling in at the blind spot have recently been reported. Here the implications of many of these effects are critically reevaluated. Specifically, it is argued that many blind-spot phenomena taken to support early filling in (eg pop out and alteration in apparent motion) are actually consistent with the thesis that the visual blind spot is treated by early perceptual processing as a region of reduced or absent information. In support of this, it is shown that many perceptual effects observed in blind-spot completion are similar in detail to the amodally perceived completion of partly occluded objects viewed somewhat peripherally. The goals were to point out striking similarities between blind-spot completion and the amodal completion of occluded parts of surfaces, and to provide a common theoretical framework for understanding these phenomena in the context of surface segregation and perceptual interpolation.

1 Introduction

The blind spot of each eye corresponds to the region of the retina where the optic nerve exits the eye. Because there are no photoreceptors associated with that region, objects obscured entirely by the blind spot remain, of course, unseen in monocular vision. However, the region of the visual field corresponding to the blind spot is never perceived as a gap in perception, even in the case of monocular viewing. The apparent filling in of the blind spot may be considered a case of perceptual surface interpolation which would presumably take place as part of the segregation of surfaces. In the present paper many of the interesting blind-spot demonstrations of Ramachandran and his colleagues and others will be reevaluated and shown to be similar in detail to the completion of occluded objects. In addition, we will discuss findings of axial asymmetry and size distortion in blind-spot interpolation.

The goal in this paper is to make explicit comparisons between blind-spot interpolation and other kinds of normal perceptual interpolation. After demonstrating that a number of important blind-spot phenomena are consistent with normal interpolation, we will describe how comparisons with normal interpolation may help illuminate an interesting axial asymmetry of blind-spot interpolation. Our intention is to argue that many of the intriguing phenomena associated with completion in the blind spot (eg Ramachandran 1992a) are entirely consistent with the following principle and its corollary:

The blind spot is a region of no information and is treated by early image processing as such: it is an 'occluded' region of vision, without an occluder.

Corollary: The edges of the blind spot are not treated as real edges in the visual array.

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How does the blind spot get filled in? We will argue that 'filling in' may be a rather general phenomenon that occurs under a variety of conditions (Walls 1954; see also Ramachandran 1992a, 1992b) and that the 'filling in' of objects that pass through the blind spot results from perceptual constructions which are accomplished in ways similar to the modally and amodally perceived completion of objects presented away from the blind spot (von der Heydt et al 1984; Kanizsa 1979; Kellman and Shipley 1991, 1992; Shimojo and Nakayama 1990). We will show that (i) the content of our perceptual experience of surfaces passing through the blind spot is functionally similar to the amodal completion of parts of surfaces occluded by other means (eg by a thumb), when the surfaces are viewed peripherally; (ii) several demonstrations of blind-spot phenomenology (eg by Ramachandran) require reevaluation (in particular, these demonstrations do not in themselves provide evidence that filling in precedes the detection of motion or the preattentive processing that produces pop-out); (iii) axial asymmetries in the perception of alignment across the blind spot may suggest a polar, rather than a Cartesian coordinate system for visual perception. We will present some novel amodal-completion phenomena that support this viewpoint.

To accomplish these goals we will briefly review some background information on visual interpolation and edge extraction outside the blind spot and then consider in detail several rather interesting demonstrations of blind-spot effects.

2 Perceptual interpolation

Two perceptual phenomena that are structurally similar to blind-spot interpolation are subjective or illusory contours and amodal completion. The most familiar cases of subjective contours are variants of the Kanizsa triangle such as is shown in figure 1a. In this figure, the 'subjective' triangle appears to be brighter than the background white of the paper and a luminance edge is seen around its entire perimeter, where in reality no physical luminance edge exists. Von der Heydt et al (1984) have demonstrated the physiological 'reality' of certain kinds of subjective contours in neurons in visual area V2. A unit that responds to edges of a certain orientation may also respond when (i) moving stimuli are presented outside of its receptive field so as to specify an appropriately oriented illusory bar passing through the receptive field (figure 1b) or (ii) when an edge specified by orthogonal line discontinuities is presented (figure 1c).

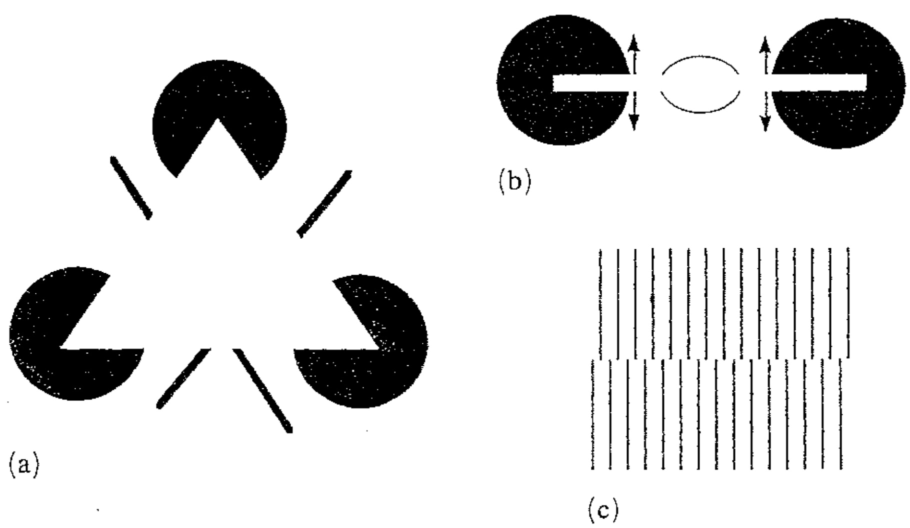


Figure 1. Three stimuli which illustrate subjective contours. (a) A Kanizsa triangle. The triangle appears to be whiter than the rest of the page. (b) Common motion of two 'ends' of a bar results in the perceptual completion of the bar. (c) Collinear line terminations produce a continuous illusory edge.

Such findings indicate that early vision is indeed working efficiently to extract surface edges that might be specified by occlusion and that there is cooperativity across space in this effort.

Amodal completion refers to the perceptual completion of an object behind an occluder, while modal contours refer to contours seen in the foreground. The 'pac-men' of figure 1a are perceived (amodally represented) as circles which are occluded by the triangle. Sekuler and Palmer (1992) have demonstrated that partly occluded shapes like these will prime the perceptual discrimination of their unoccluded counterparts. Moreover, perceived occlusion and amodal completion have been shown to have important influences on many basic visual phenomena, such as motion perception (Shimojo and Nakayama 1990) and visual search (He and Nakayama 1992). While tradition and common sense would suggest that blind-spot interpolation is based upon 'modal' completion, because the completed contours are *experienced* as seen, the distinction between amodal and modal completion may be irrelevant for purposes of early visual processing. The blind spot represents an unusual situation in which, for monocular viewing, a portion of the visual field is occluded, although there is nothing out there in the world that is doing the occluding.

To make the converse point, although there is clear evidence that certain illusory contours may be 'physiologically real' in area V2 (von der Heydt et al 1984) and perhaps as early as V1 (Lamme et al 1993), it should also be noted that these representations of edges may not always constitute a perceived *image*. Thus, although Sekuler and Palmer (1992) have demonstrated that partly occluded shapes can prime perceptual discrimination, there is no illusion of 'seeing' these shapes as physically completed. Rather, one is aware 'amodally' of the shape. To individuals who entertain a cathode-ray-tube model of perceptual representation, this distinction may seem odd. However, there are ample demonstrations available that the contents of conscious perception, though usually *consistent* with the visually extracted information, can, in Bruner's words (eg 1957), go "beyond the information given". For example, we normally walk about with the illusion that the entire visual field is of equal perceptual resolution, even when we may have learned that foveal acuity (present in only the central 1 deg of vision) is of a different order of magnitude from what is available in the periphery.

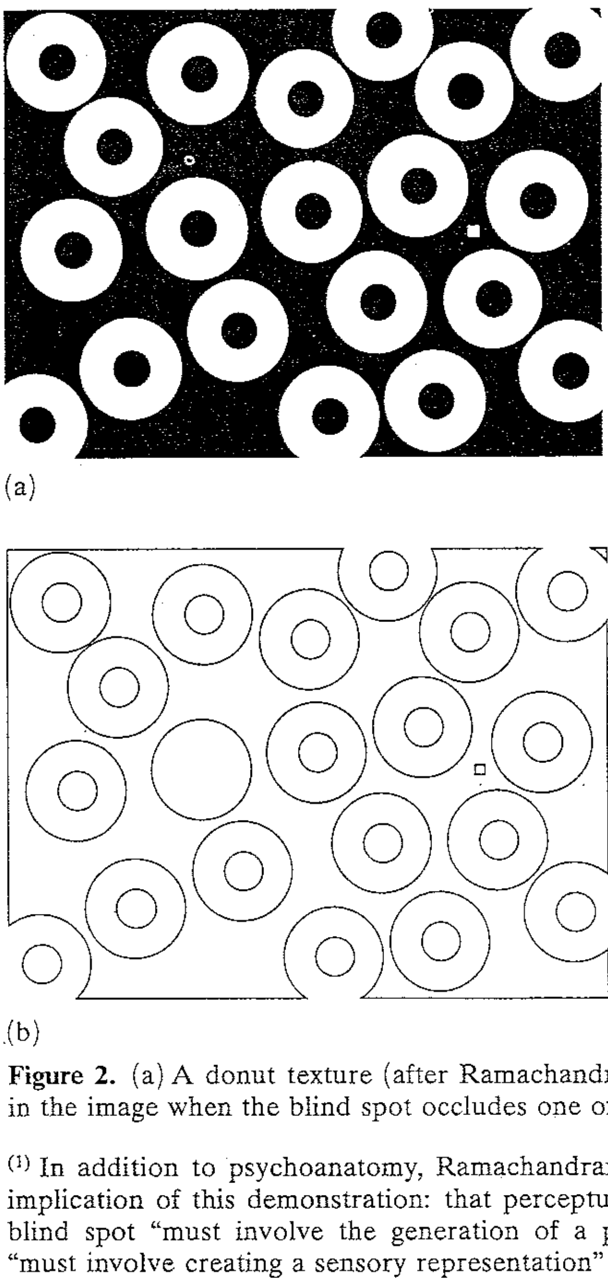
3 A rough sketch of the traditional model

In most computational theories of early vision (eg Marr 1982) it is supposed that vision entails the extraction of surfaces largely by means of the processing of visually available information. Without a need to agree about the particulars, in most models it is assumed that important initial processes include the rough location of contrast boundaries (known as zero crossings, because of the mathematics of their derivation), a crude local-spatial-frequency analysis to assess the lay of the luminance, and other specialized processes, such as motion detection and the analysis of binocular disparity—all of which aid in the segregation of surfaces. In addition to these kinds of visually available information, the evidence reviewed above suggests that the interpolation of surface contours may also occur. However, the final description of surfaces probably is not settled by any single early mechanism, because information about edges may be specified in many forms including disparity, motion, and texture.

In some cases, blind-spot effects result from the *absence* of information necessary for interpolation. We will use zero crossings and edge extraction for the analysis of some blind-spot effects, although an analysis of local spatial frequencies would come to an equivalent conclusion. The important thing about traditional theories is that, as is consistent with the relevant neurophysiology, they tend to work with contrast information rather than luminance information per se. For example, a zero-crossing map of an image represents the places in the image where there are sharp changes in luminance. The second important distinction about these theories is that their major goal is the segregation of surfaces from one another, which requires a refinement of the contrast and luminance information available.

4 The hole in the donut demonstration

To understand how this model of the representation of object boundaries might interpret perception in the blind spot, consider Ramachandran's demonstration of 'pop out' which was originally (1992a, 1992b) offered as evidence of how early in the visual pathway filling in must occur.[1] This display consists of a texture of donuts, as in figure 2a. When the blind spot 'occludes' the 'hole' in one of the donuts, the donut appears as a disk and seems to pop out from the rest of the texture elements.



(a)

(b)

Figure 2. (a) A donut texture (after Ramachandran 1992a), and (b) a map of the zero crossings in the image when the blind spot occludes one of the donut holes.

[1] In addition to psychoanatomy, Ramachandran (1992a, 1992b) argues for at least one other implication of this demonstration: that perceptual 'filling in' in the region corresponding to the blind spot "must involve the generation of a perceptual representation" (1992a, page 89) or "must involve creating a sensory representation" (1992b, page 201). We agree that filling in, like all perceptual interpolation, involves perceptual representation of some sort! Indeed, following Kanizsa and Gerbino (1982), we regard amodal completion as perceptual rather than as, say, a thought process. However, if Ramachandran intended to suggest that the donut demonstration of pop out substantiates this claim, the principal issue with respect to the display is, what processes must be complete for pop out to occur? We believe the filling in of surface color, for example, may be a red herring.

Although no experimental evidence of true pop out has been offered (eg apparent pop out for subjects not initially attending to their blind spots) the phenomenon appears subjectively compelling. However, as shown in figure 2b, a zero-crossing analysis of the information available when the hole is 'occluded' offers a clear picture of why perceptual pop out could occur. The contrast boundary that would correspond to the hole is not represented because no information is available to specify it. Nothing special needs to be 'filled in' for an apparent difference in texture to arise. Note that the filling in of surface color could occur much later than the texture differences that might produce the subjective pop-out effect.

5 The gap in the motion argument

Similar interpretations may be applied to experiments on the temporal relationship between filling in and the detection of motion (Ramachandran 1992a). Figure 3 shows a schematic diagram of the relevant apparent motion displays. In each condition, a black horizontal bar (ours was 36 deg × 2 deg, 99.7% contrast on a background of 80 cd m^{-2}) stepped vertically between two locations, separated by 10 deg, every 250 ms. A 1.7 deg gap was always present in the bar when in the upper position, 12 deg from the righthand end. When the gap appeared in the lower position, it was displaced by 10 deg to the left. In figure 3a, the displacement of the gap within the lines produces the impression of diagonal motion when viewed outside of the blind spot, but at a comparable eccentricity. When there is no gap in the lower line, vertical motion is perceived (figure 3b). The critical display occurs when the blind spot is positioned to 'occlude' the gap in the lower line of figure 3a: a display like that of figure 3b is perceived. Ramachandran reasons that this perception of vertical motion requires that the line be filled in across the blind spot *prior* to the detection of motion. However, if the gap is occluded with a gray spot (4 deg in diameter,

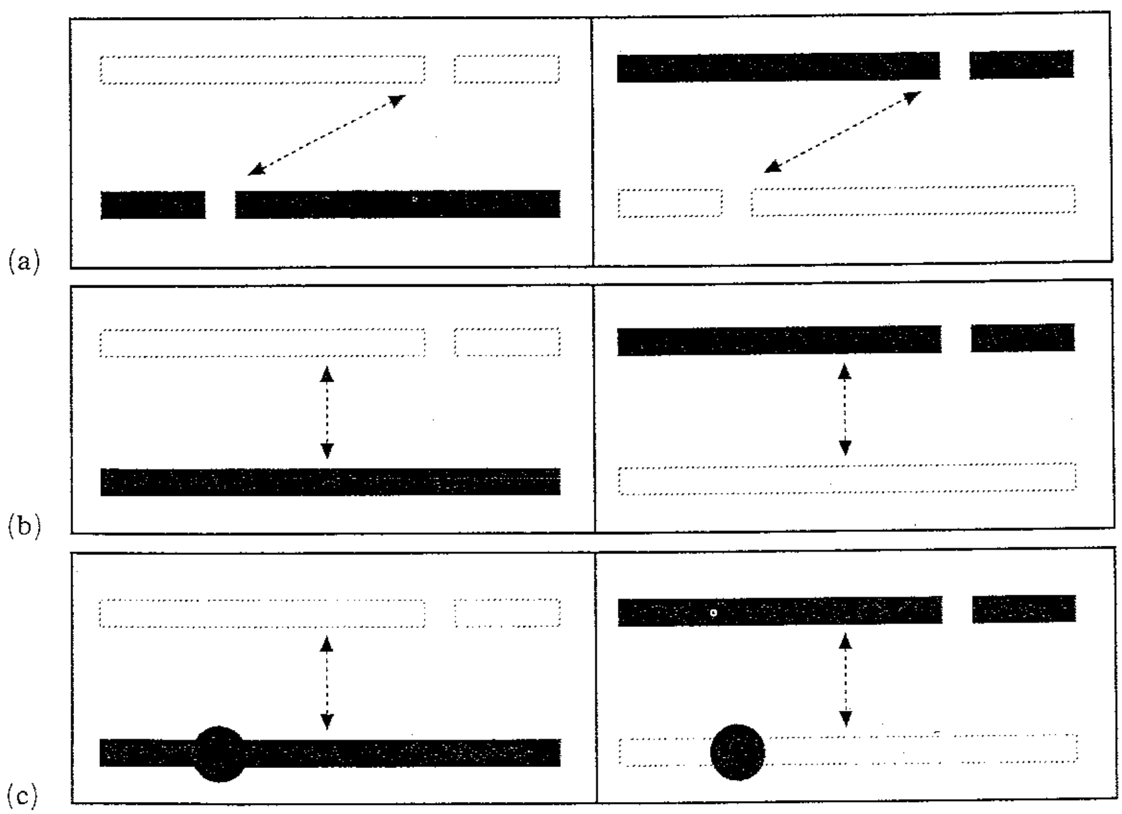


Figure 3. Three apparent-motion displays represented schematically. (a) Occlusion of the lower gap produces a perception like that seen in (b); (c) represents a control condition. For details see text.

16 cd m^{-2}) as in figure 3c, vertical motion is perceived. Using a thumb to cover the gap works too. In all of these cases, one simply cannot see a correspondence between the gap in the upper line and the occluded region of the lower line. The gap in visual information produced by the blind spot is not represented as a gap in the image. The contrast edges which would specify a gap in the line are simply not seen when they are 'occluded' by the blind spot. We suggest the following rule of thumb: if the same perception arises whether the thumb or the blind spot is used to occlude a portion of an image, then the results at the blind spot are probably not special.

Ramachandran (1992b) attempted to reject the 'no-edges-are-there-to-see' interpretation of the situation by modifying the motion paradigm so that the blind spot occludes the end of a line, thus shortening it perceptually, as depicted in figure 4. In this case diagonal motion is seen. But this trick works with the thumb, too. To make the demonstration convincing, we covered the end of the (black) line with a black circle so that there would be no luminance edge where the line was cut off. Diagonal motion of the line is still seen.

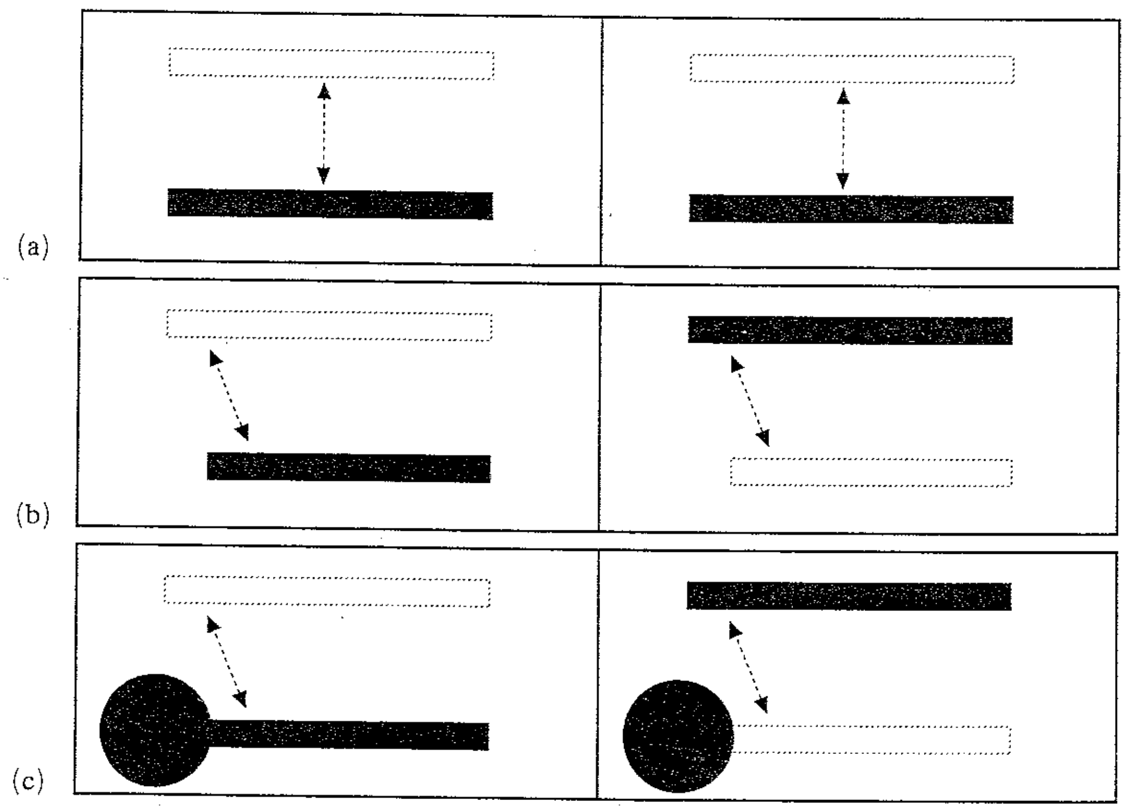


Figure 4. An apparent-motion display in which (a) a single bar moves vertically can be altered by occluding the end of the bar with either (b) the blind spot, a thumb, or (c) simply a black disk. The resulting perceived motion includes a diagonal component.

6 Persistent noise

Ramachandran (1992a, 1993; see also Ramachandran et al 1993) has argued that filling in involves the activation of spatially appropriate neurons, and in support he refers to the demonstration of Ramachandran and Gregory (1991). They found that a small square of gray light that was stabilized by fixation would 'fill in' with surrounding dynamic visual noise. They further reported that once the gray region had been subjectively filled in, the perception of dynamic noise in that square region persisted for several seconds even after the surrounding visual noise has been replaced with a matching gray. Recent evidence suggests that this 'persistence' may be misleading, however. It has since been demonstrated that a similar aftereffect of induced visual noise can be generated even when the region has not been perceptually filled in, and indeed, that the aftereffect and the perceived filling in have very different spatial characteristics (Hardage and Tyler 1995). Thus, it appears that the aftereffect is not a consequence of perceptual filling in, but rather of differential adaptation, a possibility also recognized by Ramachandran (eg Ramachandran and Gregory 1991).

Last, we note that there are important differences between the filling in of artificial scotomata and of (retinal) blind spots. With regard to the dynamic-noise effect, we observe that if the blind spot is used instead of the grey square, the filling in of dynamic noise is instantaneous but there is no aftereffect.

7 Completing the picture

In general, the blind spot may be regarded as a physical occluder. Both with the blind spot and with occluded objects, only the surrounding information is available for visual analysis. As discussed above, it is a striking fact about the perceptual experience of partly occluded objects that we typically have a definite perceptual sense of how these objects are completed (Kanizsa 1979; Kanizsa and Gerbino 1982; Kellman and Shipley 1991; Michotte et al 1964). Figure 5 shows several examples of shapes that are amodally completed behind other figures. In each case, one 'sees' how the occluded shapes are completed despite not representing the completed part as 'seen'. Interestingly, most demonstrations of things that get filled in (eg Ramachandran 1992a) produce the same (amodal) perceptual content when a thumb or a coin is placed over the region to be occluded instead of the blind spot.

Using figure 6, a thumb, and a blind spot, the reader may make the following observations. (i) As with the blind spot, the lines of figure 6a appear to continue behind one's thumb. Even when a luminance change without a clear border produces a mild paradox, one does not (amodally or with the blind spot) perceive a border. (ii) Viewed either in the blind spot or behind the thumb, the crossed lines of figure 6b produce a pair of surfaces of which the larger is usually perceived as occluding the smaller (perhaps owing to an interpretation of depth from relative size). (iii) Similarly in figure 6c, the spokes appear to continue to the center whether a thumb or the blind spot is placed over the gray disk.

The effects of thumb and blind spot are similar in detail. Note, for example, that for figure 6c, neither completion through the blind spot nor amodal completion behind a thumb produce any impression of the central blob that is seen when the spokes are actually completed. The occluded T-shape in figure 5 represents a novel demonstration of a blind-spot phenomenon consistent with amodal completion: the gray bar appears to terminate in a rectangular edge at the black bar both amodally and in the blind spot.

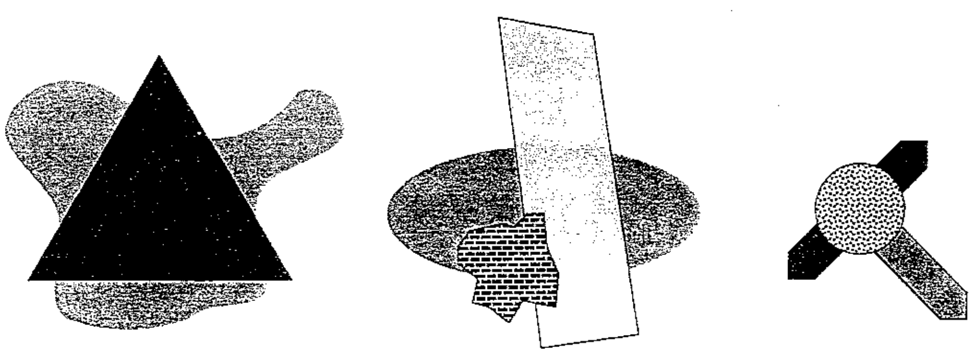


Figure 5. Three examples of amodal completion. Note that the boundaries of the apparently occluded regions seem well defined despite the lack of unambiguous information.

In cases where there appears to be some difference between amodal completion and the percepts reported around the blind spot (eg Ramachandran 1992a), the difference disappears when the display is viewed somewhat peripherally (as displays in the blind spot must be). For example, foveal presentation of figure 7a suggests

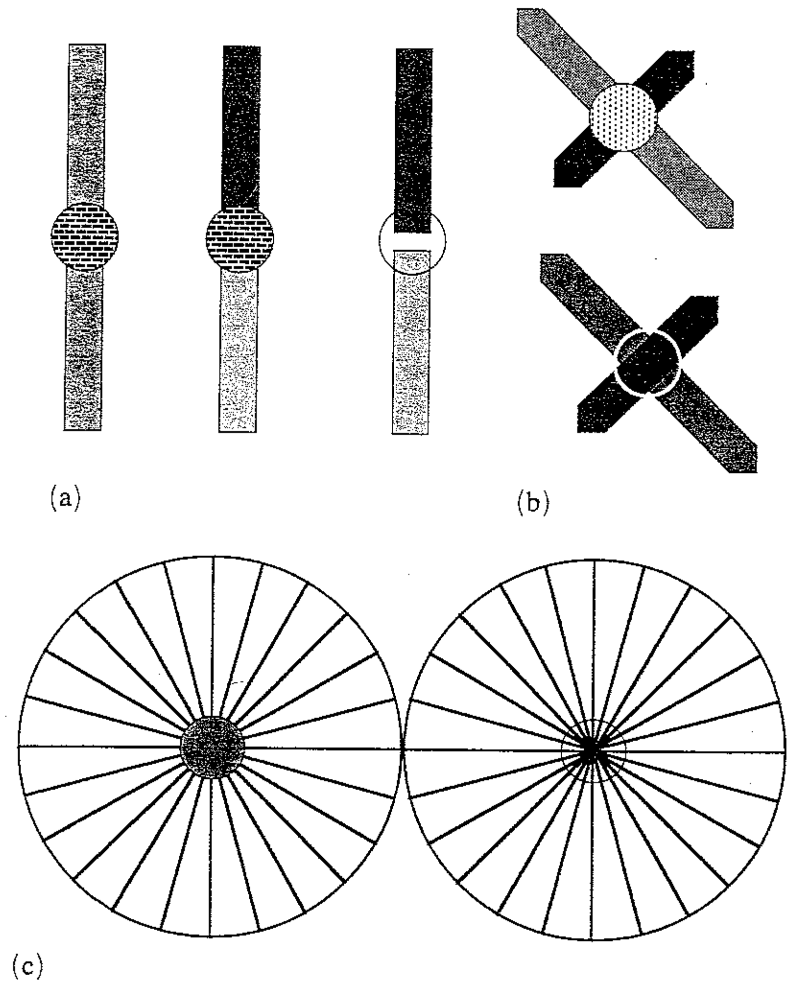


Figure 6. Structurally similar impressions of completion occur for these displays (after blind-spot demonstrations of Ramachandran 1992a) whether the areas enclosed by the small circles are occluded by the blind spot, or by a coin, or by a thumb.

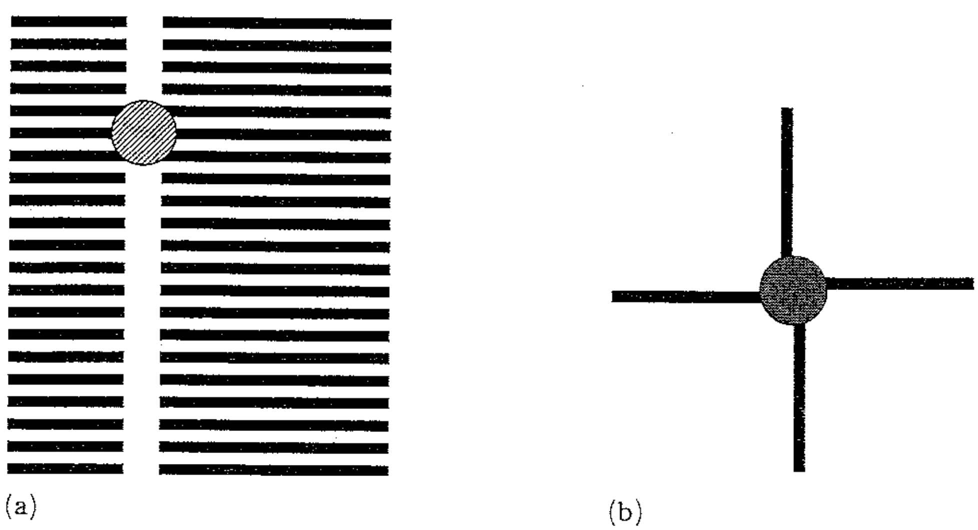


Figure 7. Patterns (after blind-spot demonstrations of Ramachandran 1992a) for which amodal completion is different foveally from in the periphery. Blind-spot completion resembles peripheral amodal completion.

completion of the horizontal lines beneath the occluding disk, but peripheral presentation by 10–15 deg (where receptive field sizes are larger) results in perceiving the continuity of the vertical white bar behind the occluder. This same perception occurs when the disk is 'occluded' by the blind spot, which is at a similar eccentricity. Note that it is probably more appropriate to describe this as the completion of a luminance bar rather than a 'subjective contour' (Churchland and Ramachandran 1993; Ramachandran 1992a, 1992b).(2)

8 Revealing asymmetries

Though it may be obvious to the skeptical viewer, it is probably worth noting that perceptual observations around the blindspot are often 'indistinct' as described by Lettvin (1976). This is a general property of spatial vision in the periphery, and it raises difficulties for relying on phenomenological observations regarding percepts in the blind spot. To make stronger claims about structural similarities or differences in performance will require more-rigorous methods. Nonetheless, in some cases, the comparison with amodal completion can help to discriminate between hypotheses concerning completion in the blind spot.

For example, when the misaligned cross of figure 7b is presented in the blind spot, Lettvin (1976; also see Ramachandran 1992a) has noted that the vertical lines appear (incorrectly) to be aligned, while the horizontals do not. The reader may observe that the same phenomenon occurs for this figure when it is simply presented in the left or right periphery in an amodal-completion condition.(3) Thus, it is not a blind-spot property, but a periphery property. Is this evidence of greater sensitivity to the horizontal axis of Cartesian space? It is possible instead that it is the result of a polar visual geometry in which we are more sensitive to position in terms of orientation relative to the fovea than to eccentricity. White et al (1992) have shown that there are marked asymmetries in sensitivity to absolute eccentric position in the periphery, which is consistent with isoeccentric thresholds being markedly superior to radial thresholds (see also Yap et al 1987). This asymmetry in positional sensitivity might account for the asymmetrical sensitivity to misalignment. Cartesian and polar axes are difficult to dissociate with the retinal blind spot, because it cannot easily be moved to a new location. However, by presenting the cross in the upper or lower periphery and observing the resulting amodal completion, it is easy to tell that the polar hypothesis is the correct one: in the upper or lower periphery the horizontals appear aligned and the misalignment of the verticals becomes evident. In other words, this spatial asymmetry is not merely a blind-spot phenomenon and it seems to depend, at least in part, on a spatial representation of position which is effectively polar, rather than Cartesian.

(2) Another case where peripheral completion may appear to differ dramatically from completion near central vision is that of partly occluded (geometrical) forms. Ramachandran (1992a, 1992b) reports that occluded portions of circles and squares may appear bitten off in the blind spot, but appear to become completed across scotomata that are "*near the center* of [the patient's] field of view" (1992a, page 91, emphasis added). Even in situations supportive of amodal completion, the perception of a 'mosaic' produced by the subtraction of the occluded portion of a surface may sometimes arise. Lettvin (1976) has argued that perception in the periphery is more like texture perception than form perception (see also Ramachandran and Gregory 1991). 'Mosaic' perception in the periphery is consistent with this insight. It would therefore be interesting to determine experimentally whether the perceptual representation of partly occluded geometric forms is, in general, modulated by eccentricity of regard.

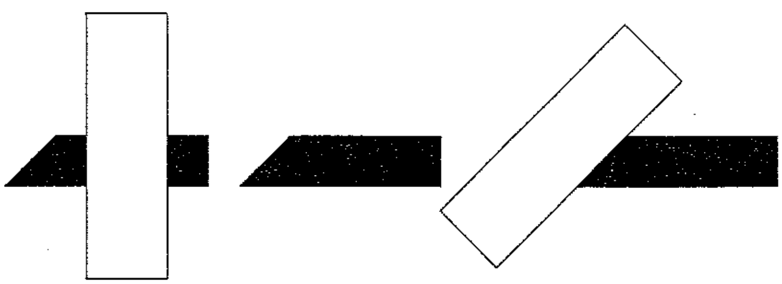
(3) Ramachandran has noted similar phenomena, though with different temporal properties: he reports that misaligned vertical line elements may appear to *become* aligned after 10–15 s in the periphery in normal vision (1993) or, after several seconds, across a scotoma (1992a).

9 Something is missing

Several researchers in the early part of this century examined size distortions for objects presented across the blind spot (eg Ferree and Rand 1912; Helson 1929), but their results have always remained controversial. A number of recent investigations have reexamined size distortions associated with lines completed monocularly through the blind spot (Andrews and Campbell 1991; Sears and Mikaelian 1989). The general finding is that lines or bars completed through the blind spot may sometimes appear shorter than their geometrical length. Tripathy et al (1995) examined this phenomenon by using several careful quantitative methods and found only slight (if any) size distortions, once they had controlled for eye movements. These distortions, when present, were very much smaller (<1 deg) than the size of the blind spot.

Gatass et al (1992) have shown fascinating evidence of 'interpolative' neural response in the nominally monocular regions in area V1 associated with the blind spots. They discuss these responses in terms of interpolative receptive fields extending beyond the classical receptive field. We suggest that the interpretation of these findings should be tempered by the recognition that slight size distortions may remain even when a bar crossing the blind spot appears complete.

Interestingly, analogous size distortions are found in normal situations involving partial occlusion. Kanizsa and Gerbino (1982) have demonstrated that amodally completed objects appear slightly smaller than their unoccluded counterparts. Conversely, they have also shown that a shape that abuts a second region in a manner suggestive of occlusion will seem larger than it is, as if the implied occlusion produces a perceptual extension of the occluded surface. These two phenomena (shrinkage of the whole and expansion of the parts) are illustrated in figure 8. Although we do not wish to argue that these effects are identical to blind-spot size distortions, we would like to note the extent of the apparent analogy between the two situations.



(a) (b)

Figure 8. Demonstrations of size distortion of occluded objects (after Kanizsa and Gerbino 1982). (a) An amodally completed object appears smaller than an unoccluded version; (b) implied occlusion expands the apparent size of the visible portion of the object.

10 Conclusion

Unlike objects that are occluded by other surfaces, objects in the blind spot are occluded by nothing real in the environment. Because we typically have two eyes open and would in any case not normally be likely to keep the blind spot directed at some specific stimulus (so far as we know!), this anomaly of the blind spot is of little consequence. We often experience objects as completed when they are partially occluded. The completion is called 'amodal' when the content of our perception is [this surface (completed), behind x (eg a thumb)]. Completion through the blind spot may have the same perceptual content as amodal completion except that there is no 'x'. Although there may be important differences between blind-spot interpolation and amodal completion,[4] several demonstrations offered by Ramachandran to support the thesis that the filling in of the blind spot occurs prior to motion and preattentive processing have been found to be interpretable within this framework. In all of the cases that we have examined the results are consistent with the null hypothesis that the blind spot is treated visually as a region of little or no information.

Our findings are consistent with an 'evidentiary' view of perception in which the content of perception is informed by, but not limited to, the transduction of various kinds of information indicative of size, motion, form, continuity, orientation, and the like. Thus, we do not consider that the content of perception in the blind spot must directly reflect the activity of 'filled in'[5] visual maps. We emphasize that the utility of this analysis of the blind spot is indicated by comparisons between blind-spot interpolation and amodal completion in other parts of the periphery, for example. This is not to say that the blind spot is not interesting in its own right. The gaps in retinal afferents to the cortical region corresponding to the blind spot present a special challenge for the topographical mapping of binocular visual space and the representation of binocular information which has been investigated both at a neural level (Fiorani et al 1992) and psychophysically (Tripathy and Levi 1994). What we have demonstrated here is that the present evidence concerning the perceptual filling in of the blind spot does not require that this perceptual filling in be completed at any particularly early level of visual analysis.

11 Postscript

Part of the philosophical dispute over the nature of perceptual 'filling in' has been over whether filled-in images are 'really' filled in. Dennett (1991) has criticized this view as a return to the Cartesian Theater in which some homunculus (or soul) is assumed to be presented with images (or three-dimensional sketches) upon an inner stage. In fact, the visual cortex is laid out spatially so as to map onto the retinally recorded visual world, and there are indeed processes that take place in the visual cortex that can be best described as the interpolation of edges. In this sense, perception really is 'filled in', though our perceptual experience may frequently go even farther 'beyond the information given'. The demonstrations presented above are consistent with a number of philosophical interpretations. However, we feel it may be argued from our observations that perceptual interpolation in the periphery does not take place in a Cartesian Theater. If an internal perceptual theater for the soul does exist, its coordinate system is, with respect to position, polar.

12 Codicil

It is proper that Dr Ramachandran should have final reply to the points made above regarding his interpretations of many of his blind-spot demonstrations, and we leave it to the reader to compare the arguments made in each article on these points.

(4) For example, the blind spot is fixed, whereas extrinsic occluders must be identified as such. On the other hand, the 'blind spot' of the optic disk does not exist in normal binocular vision, and so may be (effectively or metaphorically) ignored most of the time. Last, it has also been suggested that retinal scotomata (such as the optic disk) tend to fill in instantaneously whereas cortical scotomata take time (eg Gerrits and Vendrik 1970). Amodal completion may be subjectively instantaneous, yet have a time course that is not perceived (eg Sekuler and Palmer 1992).

(5) With regard to color assignment in scotomata, Ramachandran (1993) has clearly stated that he believes the term 'filling in' is metaphorical in the sense that the actual process is not one that "begins from the outside and invades" a filled-in region (page 60). Such a description had been proposed by Gerrits and Vendrik (1970), for example, for the filling in of brightness in artifical scotomata. However, Ramachandran does argue that filling in involves "creating a neural representation of the surround in the region of the scotoma," (1993, page 59) which seems rather like literal filling in.

Indeed, we are pleased that Dr Ramachandran (see Ramachandran 1995) feels he is in such substantial agreement with our principal observations. However, we believe some further clarification is appropriate in order to complete the gaps.

The point of dispute can be brought to a single issue: can the process underlying blind-spot filling in be distinguished in essence from processes underlying amodal completion on the grounds that they result in modal rather than amodal percepts?[6] We were at pains in the introduction to our article to note that this distinction was less critical than it might first appear. It should be noted that we believe that the content of perception has at least 2.5 dimensions so that it makes sense to talk of perceiving (not *believing*!) things as extending behind other things.[7]

Ramachandran (1995) says that what he means by filling in is that one literally sees the area filled in. This is a sensible operational definition of blind-spot completion ("Did you see it filled in?"), but not of the filling-in process. For if filling in is equivalent to literally seeing then questions of whether filling in precedes or follows the perception of motion, for example, can only be a question for an odd sort of introspection, for it amounts to asking, which qualia happened first?[8]

An alternative gloss would have it that 'seeing' can be translated directly into the neural activity underlying the corresponding mental state. We believe, with Dr Ramachandran, that every mental state corresponds to a neural state, but doubt that every local neural state has a single corresponding mental content. We therefore think it may be safer to speak of neural processes when trying to do psychoanatomy (though one must not forget that the feedback channels in vision are quite as dense as the feedforward channels, so even this tactic is not foolproof for studying temporal precedence). To come back to the main issue, we do not think it necesary that the neural processes responsible for filling in be identical to those responsible for 'literally seeing'. Indeed, it was our thesis, and appears to be Dr Ramachandran's as well, that an interpolation process might precede (or occur in parallel with) the final decision about what to perceive as 'seen'.

Perception, in our view, is not of the contents of the retina, but of the world (see Gibson 1966). Although our eyes move about many times each second, the world is not jumpy. Although retinotopic visual maps may signal the possible existence of a contour, our visual system need not treat that contour as 'in front' of all others, merely by virtue of recording its possible existence. These points seem hardly controversial in principle, but it remains to be seen, as Dr Ramachandran notes, what the fact of the matter is with regard to the filling-in process.

Our principal argument has it that the structural similarities between modal blind-spot completion and amodal completion are striking and that apparent differences in the structure of the resulting perceptions can, in the cases we examined, be attributed to peripheral vs central observation of the test patterns. Dr Ramachandran (1995)

[6] This issue is the crux of points numbers 1, 5, and 6 of Ramachandran (1995). Ramachandran's point number 3 suggests that subjectively modal completion of a line and non-completion of a blind-spot-occluded moving dot are distinct from a peripheral amodal-completion case. We disagree: even if the line was composed of lots of little dots and was 'completed' behind an occluder that wouldn't mean that one was 'really' seeing the dots. Imagine trying to count them. On the other hand, the purported sense of a 'smudged' occluder to account for the disappearance of a large (and individually resolvable) spot is consistent with just the kind of evidentiary view we are advocating.

[7] Titchener would of course accuse us of something amounting to the "stimulus-error" (see Boring 1950, pages 417ff) in reporting our introspection of amodally perceived forms as 'seen', but he is no longer quite as influential as he once was.

[8] This strategy can actually work if the qualia arise at measurably distinct times, but does not appear to have been the strategy employed by Ramachandran (eg 1992a, 1992b).

has suggested a counter-example (see his point number 2), but the crucial experiments controlling for peripheral presentation do not seem to have been done.[9] We are pleased that Dr Ramachandran feels positively about the contributions we have made following upon his and hope that these papers together will serve to clarify rather than obscure these important issues.

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[9] Indeed, Gibson has reported a different view of the matter altogether: "My observations suggest that the slant of a surface, or the curvature, or an edge or *a corner* is also continued within the area [of the blind spot]." (1966, page 263, emphasis added).

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