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Binocular Depth Inversion

Sometimes a solid object seen with both eyes can seem to reverse perspective. A study of this geometrically irrational experience suggests that ordinary depth perception is somewhat precarious

by John I. Yellott, Jr.

A visitor to the "Haunted Mansion" at Disneyland in California sees among other things a pair of human faces that appear to rotate in a mysterious and sinister way as he walks by. They are in fact inside-out relief masks, but because of the lighting and the way they are mounted the visitor unwittingly reverses their depth, perceiving them incorrectly as normal faces. This unconscious reversal of perspective gives rise to the apparent rotation.

Besides mystifying visitors to the "Haunted Mansion" this illusion presents a problem for theories on the perception of visual form. The problem is not the apparent rotation of the faces; psychologists have known for some time that whenever a three-dimensional object is perceived in reverse perspective, it will seem to rotate as the observer's head moves. What is puzzling is the perspective reversal itself. Ordinarily people see the three-dimensional forms of things correctly, and reversals of perspective occur only in special circumstances that deny the brain its normal visual cues to depth. One such circumstance is viewing the three-dimensional form with one eye closed, so that the depth cues provided by binocular vision are eliminated. The masks at Disneyland, however, show that sometimes objects are routinely perceived inside out in spite of the availability of all the normal depth cues, including those due to binocular vision. How can such a major perceptual mistake occur? And given that it does happen sometimes, why is it so rare?

In this article I draw a distinction between the kind of perspective reversals produced by ambiguous pictures such as the famous Necker cube and those experienced in viewing actual three-dimensional objects, such as the masks in the "Haunted Mansion." I shall refer to the latter type of illusion as "depth inversion." Reversible-perspective pictures and their perceptual consequences are quite well known; drawings such as the Necker cube have illustrated countless psychology textbooks since the 19th

century, and artists have explored the same theme for much longer.

Depth inversion of solid objects also has a long scientific history. References to the phenomenon date from the 18th century, and in the 19th century it was studied by such notable figures as Hermann von Helmholtz and Ernst Mach. In this century, however, it seems to have been neglected until 1970, when the British psychologist Richard L. Gregory drew attention to it again in his book *The Intelligent Eye*. Gregory's discussion stimulated my interest and led me to devise several experiments to determine whether objects can be seen in reverse perspective when the brain is truly in full possession of all the depth information available in normal vision, including in particular the information provided by binocular vision, which according to classical accounts should make the illusion impossible. The results of these experiments indicate that under appropriate conditions the brain is prepared to override all its sensory cues to depth and create an inside-out visual world that defies geometrical analysis but nonetheless seems just as realistic as normal visual experience.

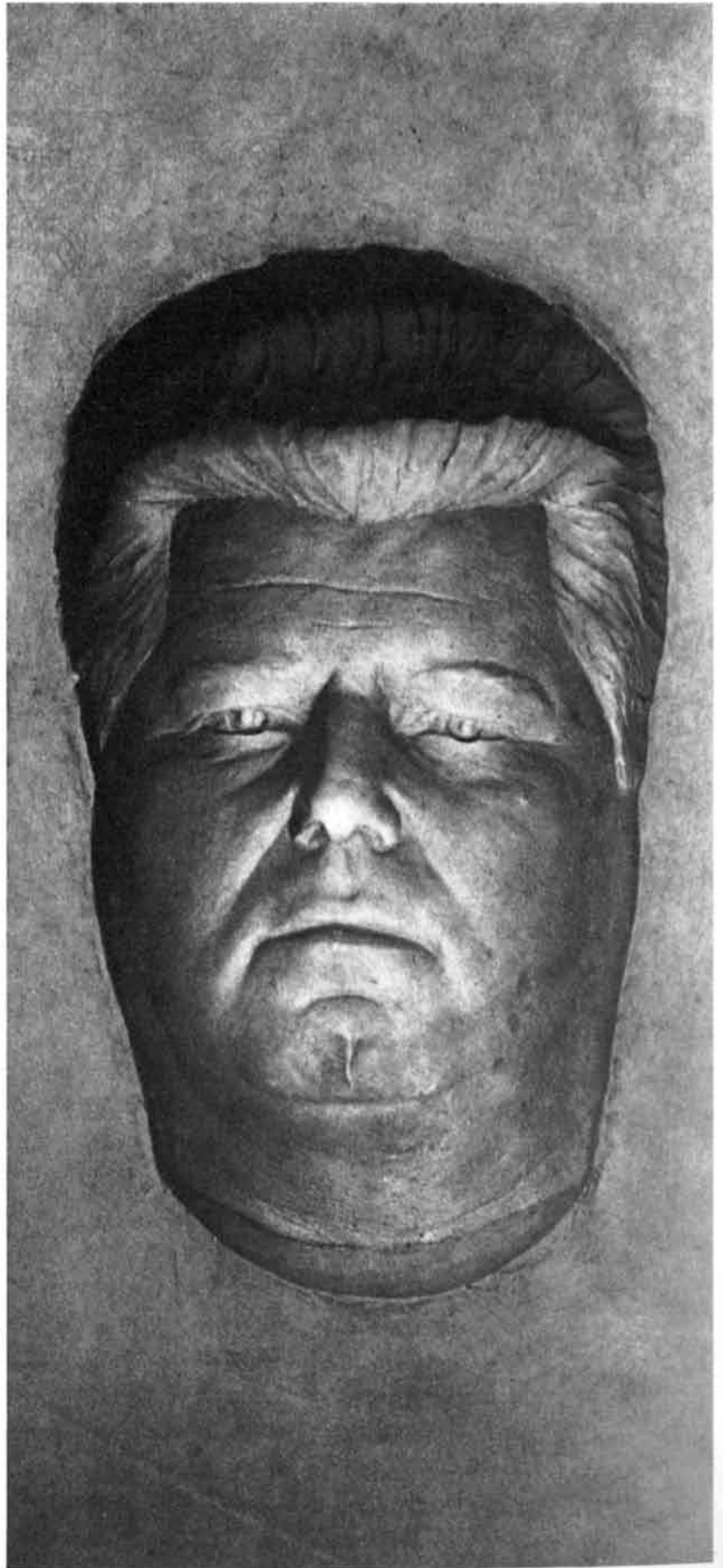
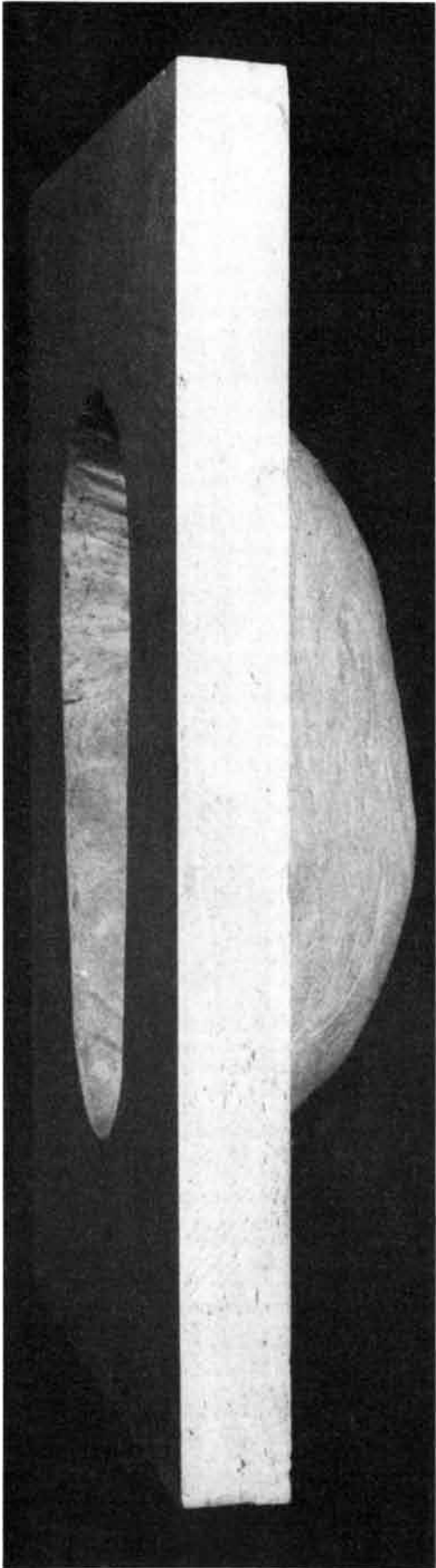
These experiments on binocular depth inversion are the subject of this article, but to put them in context it will be helpful to first consider monocular inversion, which is much easier to explain. Depth inversion of a three-dimensional object viewed with one eye can be understood if one thinks of visual experience as the outcome of a process in which the brain tests hypotheses about the three-dimensional shapes of objects against the evidence provided by their retinal images. With one eye alone the only potential source of unequivocal in-

formation about depth is accommodation, or change of focus, and the brain normally gives this cue little or no weight in its judgment of distance. Accommodation therefore presents no barrier to the acceptance of an inside-out shape as being real. All the other monocular cues to depth are intrinsically ambiguous. The evidence they provide cannot exclude inside-out hypotheses, although they can render such hypotheses statistically unlikely in the sense that, say, a tree rotating in synchrony with movements of the head is an improbable object.

Apparently this is normally enough to enable the brain to guess correctly about the shapes of things seen monocularly. If sensory evidence becomes sufficiently impoverished, however, the brain may accept an inside-out hypothesis that is compatible with the retinal image. In such a case visual experience is totally transformed to agree with the hypothesis, intellectual knowledge of the correct form notwithstanding. Yet the inverted object now seen still incorporates all the information available on the retina, just as in normal vision. The only difference is that now every depth cue is visually reinterpreted in order to agree with a false premise.

Now consider the situation in binocular vision. The key to my explanation of monocular inversion (an explanation borrowed from Helmholtz, Mach and Gregory) is the fact that all the monocular cues to depth can be consistently reconciled with an inverted-object hypothesis. When both eyes view an object, however, no such reconciliation is possible. Binocular vision provides depth information that is geometrically incompatible with depth inversion, in other words information that should enable

INSIDE-OUT FACE, made as the mold of a bust, is shown in side and front views on the opposite page. Looked at from the front it is more easily seen as a normal face because the brain overrides the depth cues that suggest an object as improbable as an inside-out face. (The reversal is made easier when, as in the front view here, the lighting eliminates shadows that might aid the brain in making the correct interpretation.) A three-dimensional inside-out face seen in reversed perspective seems to rotate and to follow an observer who is moving laterally past it.



the brain to categorically reject inverted-object hypotheses.

That information stems from the difference between simultaneous retinal images of an object in the left and right eyes, a depth cue termed binocular disparity. Its effect is that none of the inverted-depth hypotheses consistent with the left eye's view can simultaneously be consistent with the right eye's view. If the key to depth inversion is geometrical compatibility between retinal evidence and inverted-object hypotheses, binocular depth inversion should be impossible, or at least a most unnatural visual experience, quite unlike monocular inversion.

Binocular vision actually provides not one new cue to depth but two cues. One is the muscular cue produced by the act of convergence, that is, the action of the eye muscles in aiming both eyes at a common fixation point. This action gives the brain information on the convergence angle of the line from each eye to the fixation point, and the angle gives a cue to the distance of that point. At a given instant, however, this muscular cue does not provide any information on the depth of other points that are not being fixated.

That information is supplied by the

second binocular cue to depth: binocular disparity. When the eyes converge on a point, the images of the point fall on corresponding places on the two retinas, namely the center of each fovea (the small area that affords the sharpest vision). Points nearer or farther than the fixation point necessarily fall on noncorresponding places on the two retinas. The magnitude of this positional disparity is conventionally measured in angular units. The binocular disparity of any nontargeted point X is the difference between the convergence angle and the angle formed by the lines of sight to X . This angular measure is proportional to the absolute distances between the retinal locations of the two images of the point; one minute of binocular disparity corresponds to a six-micrometer difference in the retinal positions.

Although convergence is a better cue to depth than accommodation, it still provides rather uncertain distance information. Binocular disparity, however, is an extremely powerful cue to depth. Under experimental conditions normal observers can detect depth differences that give rise to disparities of about 10 seconds of arc, equivalent to a one-micrometer difference in retinal position. In other words, the brain can reli-

ably detect disparities that are substantially smaller than the diameter of the smallest photoreceptors (about two micrometers). Cues furnished by binocular disparity therefore seem sufficient in principle to rule out hypotheses of depth-inverted objects.

The foregoing arguments make it plausible a priori that binocular depth inversion should not occur because the brain cannot construct an inverted visual model consistent with all its retinal evidence. Both Helmholtz and Mach apparently believed binocular depth inversion is impossible. Gregory, studying the binocular inversions of a three-dimensional wire cube, noted that they are rare and brief, and that when an inversion does occur, the cube looks unnatural. Historically it seems to have been generally accepted that binocular depth inversion simply does not happen, at least in any stable way compared with monocular inversion.

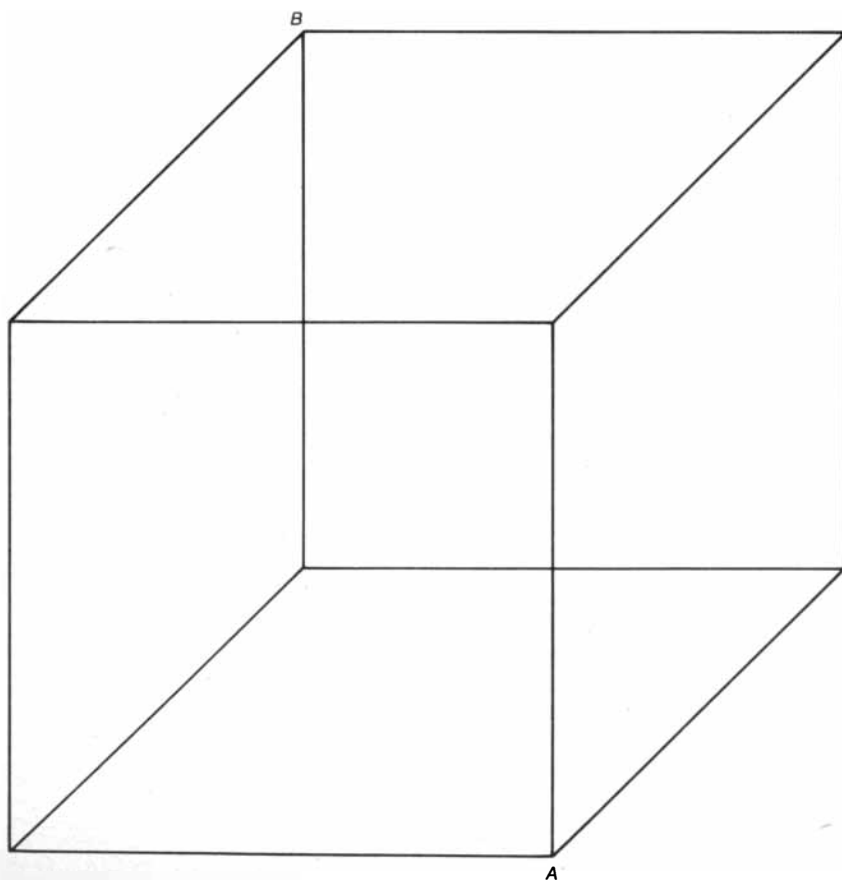
It is easy to show that things are not so simple. Under appropriate conditions binocular depth inversion can occur quite easily, yielding a stable perception much like the one resulting from monocular inversion in spite of binocular-disparity cues that would be detected readily in normal vision. The trick is to use an object with an overwhelmingly improbable real form, so that it looks normal only when it is seen inverted in depth. The best example is an inside-out human face like the two in Disneyland. Such a face is the mold of a normal relief. The inside of an ordinary Halloween mask will also do.

With a little practice one can easily achieve stable binocular depth inversions of such a face at a viewing distance of about an arm's length. An excellent stimulus is a plastic mask mounted inside out on a sheet of cardboard and illuminated from behind. This arrangement eliminates informative shadows that can slow down inversion.

With such a setup monocular inversion is easy. At first opening the other eye tends to disrupt a monocularly stable inversion, just as movements of the head initially disrupt monocular inversions achieved with the head stationary. With practice, however, one learns to tolerate the new depth information provided by binocular vision, and the perceptual result is a depth-inverted face that appears to be natural and stable.

Trying the illusion for the first time, observers often find that the surface of the inside-out face does not invert all at once. Instead inversion begins in one region, typically the nose, and then other regions gradually become incorporated into the inverted percept. Thus at early stages one may find that during a movement of one's own head the inverted nose will seem to wobble on an otherwise immobile face.

The fact that binocular inversion



NECKER CUBE is a reversible-perspective drawing named for the Swiss naturalist Louis Necker, who in 1832 described the perceptual consequences of ambiguous perspective in pictures. The perspective of the cube tends to reverse back and forth as one stares at the picture.

can occur with an inside-out face is not entirely surprising. One can simply say that the brain is prepared to override even unequivocal sensory evidence when the evidence supports a highly improbable object hypothesis. Conversely, when past experience is compatible with both an inverted and a noninverted version of an object, binocular-disparity cues tip the scales in favor of the correct hypothesis. This explains why objects such as three-dimensional wire cubes are easy to invert monocularly but difficult to invert binocularly.

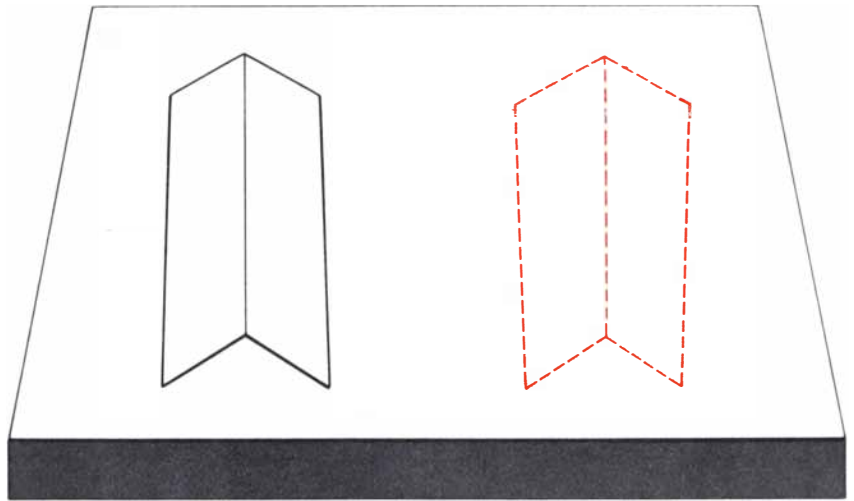
When binocular inversion does occur, however, there still remains the critical question of what happens to the binocular-disparity information that should, if it is properly incorporated into perception, prevent inversion altogether. To put the issue another way, how can the retinal images in the two eyes be combined into a single three-dimensional visual experience when that experience cannot be geometrically reconciled with both images simultaneously?

Two answers suggest themselves immediately. The first and simplest one is that a binocular inversion is not truly binocular. Even though both eyes view the object, perhaps the information from only one eye is incorporated into visual experience. This would mean that information from the other eye is suppressed at some preconscious level.

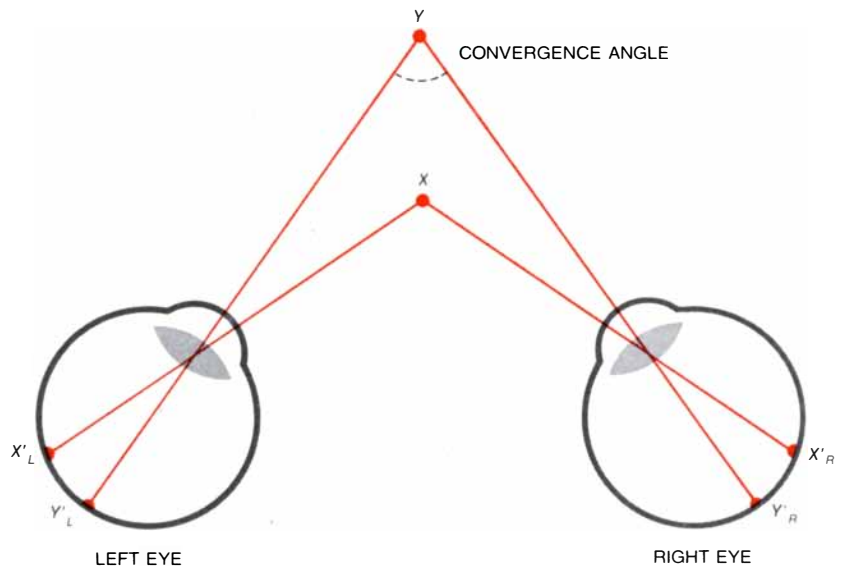
Such suppression occurs regularly in normal vision when the two eyes are exposed to quite different stimuli. The phenomenon is known as binocular rivalry. It is easily demonstrated. With both eyes open hold your right hand about six inches in front of your right eye and look across the room at, say, a lighted lamp, making sure the lamp is visible to the left eye but not to the right eye. Closing your left eye, you see your hand, and closing your right eye, you see the lamp: two irreconcilable views of the same region of visual space. Yet when both eyes are open, you see only the lamp. Your hand is suppressed, at least in the region of the visual field where the two stimuli are in conflict. Indeed, you can see the lamp "through" your hand.

Since this kind of suppression of one eye's view in favor of the other's is routine in normal vision, one might suppose it could account for binocular depth inversion. If the brain discards the information from one eye, it is then free to construct an inverted object that is entirely consistent with information from the other eye. On this hypothesis binocular inversion would be only monocular inversion coupled with suppression of the information from one eye.

The other answer I thought of originally was that binocular inversion might be truly binocular in the sense that the information from both eyes is incorporated into visual experience but with the signs of all the binocular-dis-



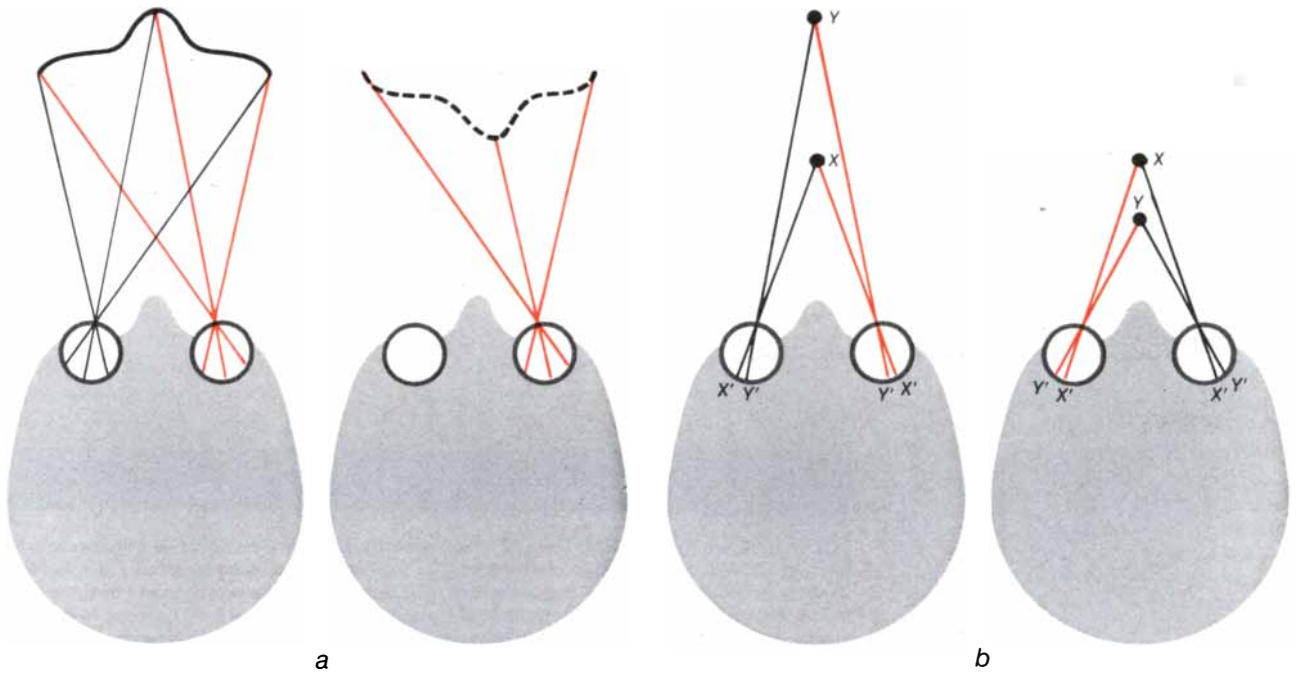
MONOCULAR INVERSION is readily achieved with an experiment devised by Ernst Mach. A blank card such as an index card is folded in half lengthwise and placed on a flat surface with the bend upward (left). If one looks at it long enough with one eye, trying to imagine that it is in the configuration of an upright book open for reading (right), it will appear to reverse and be turned inside out, so that its bend points down and the card seems to perch on one end.



GEOMETRY OF BINOCULAR VISION suggests that depth inversion should be difficult or impossible. Here both eyes view points X and Y , with X the nearer one; the respective retinal positions are designated X'_L and so on. If the eyes converge on Y , the images of Y fall on the center of the fovea of each retina. The lines of sight projected outward from the images X'_L and X'_R meet at a unique point in space: the real location of X . Hence the combined retinal images in the eyes cannot be reconciled with hypothesis that X is more distant than Y .

parity cues reversed, as though the brain had lost track of which eye is which and had interpreted the retinal image in the left eye as coming from the right (and vice versa). In experiments that present flashes of light randomly to one eye or the other, normal observers often have great difficulty telling which eye has been stimulated. Moreover, in normal vision involving binocular rivalry one is not consciously aware of which eye sees what. (For example, hold a finger a few inches above this page so that some letters are invisible to one eye and some

to the other. With both eyes open you can read every letter, but unless you alternately close one eye and then the other you will not be able to tell whether a given letter is seen by the left eye or the right eye.) Hence it seemed possible that the brain might exploit this condition in order to reconcile an overwhelmingly plausible object hypothesis with all the sensory evidence. Such an explanation would at least make binocular inversion a more or less direct extension of monocular inversion. Visual experience would still incorporate all the depth



TWO HYPOTHESES on binocular depth inversion are **monocular suppression (a)** and **disparity reversal (b)**. In each case what is actually seen is portrayed at the left and the inversion the hypothesis would explain is shown at the right. In monocular suppression the left eye's view is depicted as being suppressed, so that the inside-out face is

seen depth-inverted as it would appear in a monocular inversion when it is viewed by the right eye alone. In disparity reversal point X is really nearer the observer than point Y, but the brain treats the retinal image in the right eye as though it came from the left eye and vice versa, with the result that point Y appears to be closer than point X.

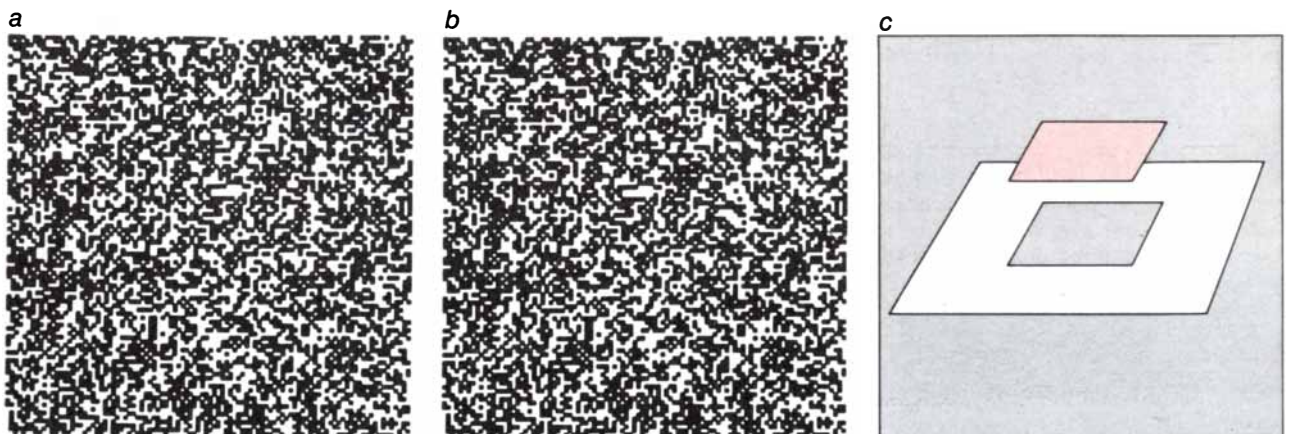
cues available to the brain, but one cue, namely binocular disparity, would appear to be transformed in an unjustifiable way.

These two potential explanations of binocular depth inversion can be termed "monocular suppression" and "disparity reversal." I shall describe two easily reproducible experiments, each of which tests both hypotheses simultaneously. Both experiments lead to the same conclusion: neither monocular suppression nor disparity reversal can account for what one sees during binocular inversion.

The first experiment makes use of a fascinating class of stimuli known as random-dot stereograms, which were invented in 1959 by Bela Julesz of Bell Laboratories. (I did the experiment in my laboratory at the University of California at Irvine in collaboration with Jerry Kaiwi, who was then a graduate student.) A stereogram is a pair of pictures designed to create a sensation of depth when one picture is viewed by the left eye and the other is viewed simultaneously by the right eye. The sense of depth is elicited by discrepancies between the left and right pictures that

simulate the binocular disparities a solid object would generate. The process of perceiving depth on the basis of binocular-disparity cues is known as stereopsis.

Random-dot stereograms provide a definitive test of whether the viewer is achieving stereopsis. Not everyone can; about 2 percent of the population is "stereo blind." To make such a stereogram one constructs a pair of identical pictures consisting of randomly scattered dots. Then all the dots in a given region are shifted slightly to the left in one picture and slightly to the right in the other to create a binocular disparity



RANDOM-DOT STEREOGRAM provides a basis for testing the monocular-suppression and disparity-reversal hypotheses. The left and right halves of the stereogram (a, b) are identical except that the dots in a square region in the center are shifted horizontally (to the right in the left-hand picture and to the left in the right-hand picture)

to create a binocular disparity. An observer with normal stereoscopic vision, viewing the pictures in a stereoscope or by some other means that presents the pictures separately to the left and right eyes, perceives the central square as floating above the background (c). Random-dot stereograms were made by Bela Julesz of Bell Laboratories.



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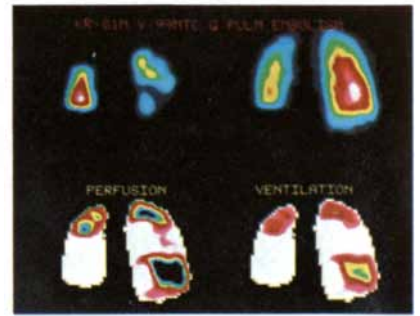
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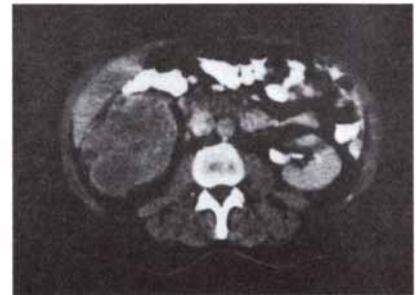
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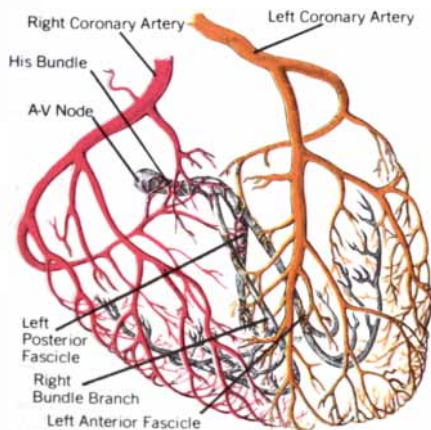
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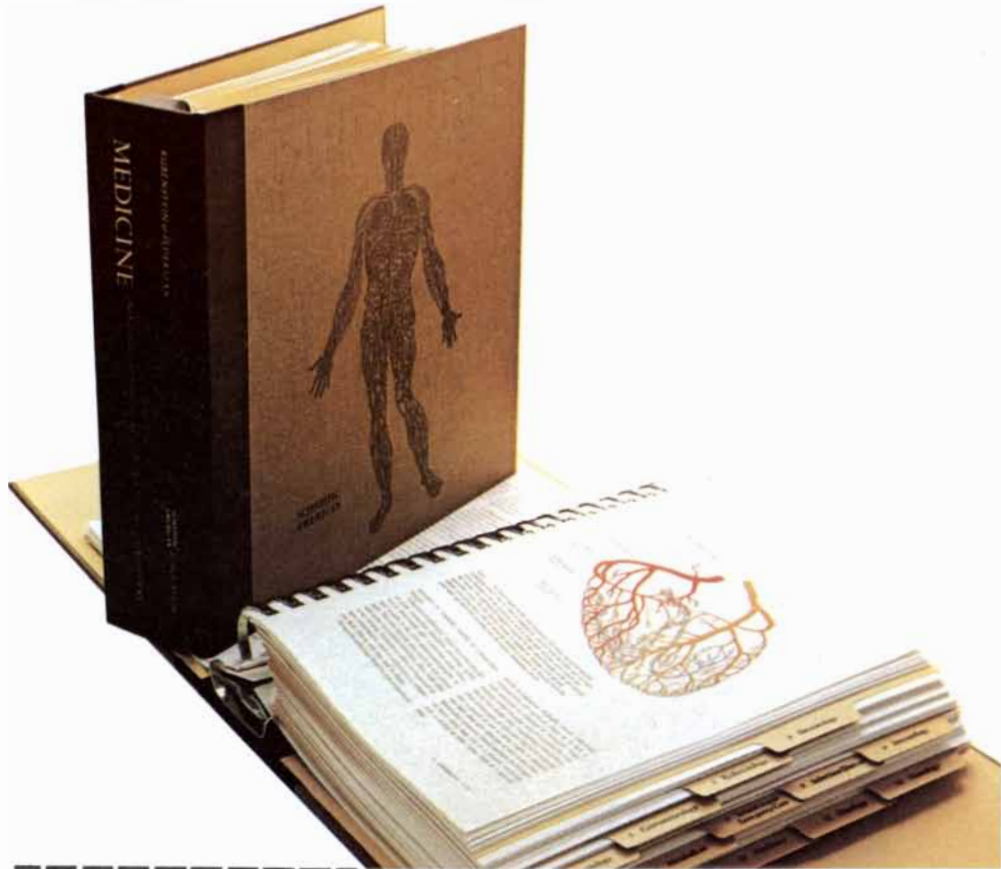
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in that region. When the two pictures are viewed separately with both eyes, the regions of shifted and unshifted dots seem to lie in different depth planes. Through either eye alone one sees only a flat field uniformly speckled with dots.

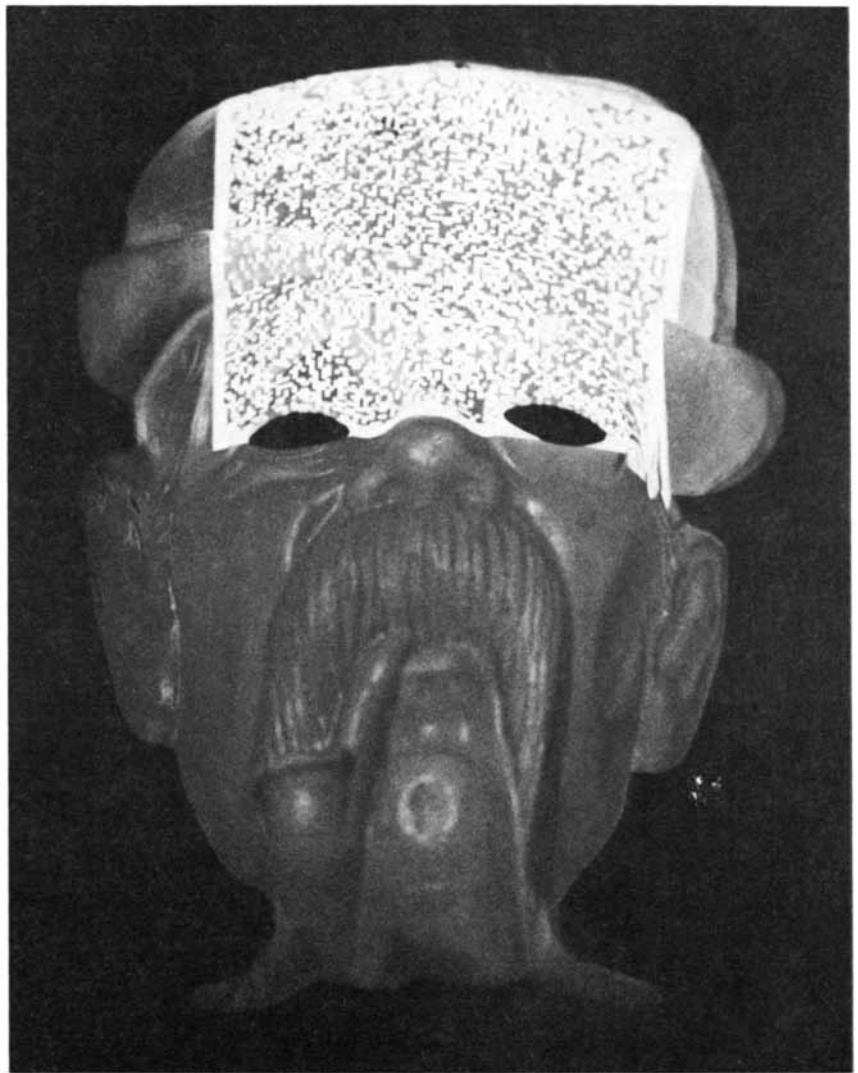
To present the left and right halves of a random-dot stereogram (or any other stereogram) separately to the two eyes a convenient technique is to print one picture in green ink and the other, superposed, in red and to view the composite through glasses equipped with a red filter for one eye and a green filter for the other. Through the red filter green dots look black and red dots are invisible; that eye therefore sees only the green half of the stereogram. Conversely, the eye covered by the green filter sees only the red half. This kind of stereogram is called an anaglyph.

The next step is to project an anaglyph version of a random-dot stereogram onto an inside-out face mask and to view the combination through red-green glasses. If the stereogram properly perceived seems to show a central square region floating in front of a plane background, what will it look like when the face is seen in depth inversion? According to the monocular-suppression hypothesis, no depth should be seen in the stereogram (that is, the central square should be invisible) because stereopsis requires the integration of the view from both eyes. On the other hand, according to the disparity-reversal hypothesis, depth should be seen in the stereogram but with its direction reversed from the normal perception. The central square should seem to be recessed behind its random-dot surround instead of floating in front of it.

The experiment therefore provides a straightforward test of both hypotheses, and both turn out to be wrong. Every observer reports that depth can be seen in the stereogram while the face is perceived as being depth-inverted. Thus monocular suppression cannot be a factor. Every observer also reports that the direction of depth in the stereogram is the one implied by the actual disparities of the dots, not the opposite as predicted by the disparity-reversal hypothesis.

The second experiment exploits an illusion of depth known as the Pulfrich effect (after the German physicist Carl Pulfrich, who described it in 1922). To demonstrate the illusion one needs a pendulum that swings in a plane arc. A weighted yardstick swinging on a nail works well enough. The observer stands in front of the pendulum and views it binocularly with one eye covered by a light-attenuating filter, such as one lens from a pair of dark sunglasses.

Seen with either eye alone the end of the pendulum appears correctly to be swinging back and forth in a plane. Viewed with both eyes, however, the end of the pendulum appears distinctly to be swinging back and forth in an el-



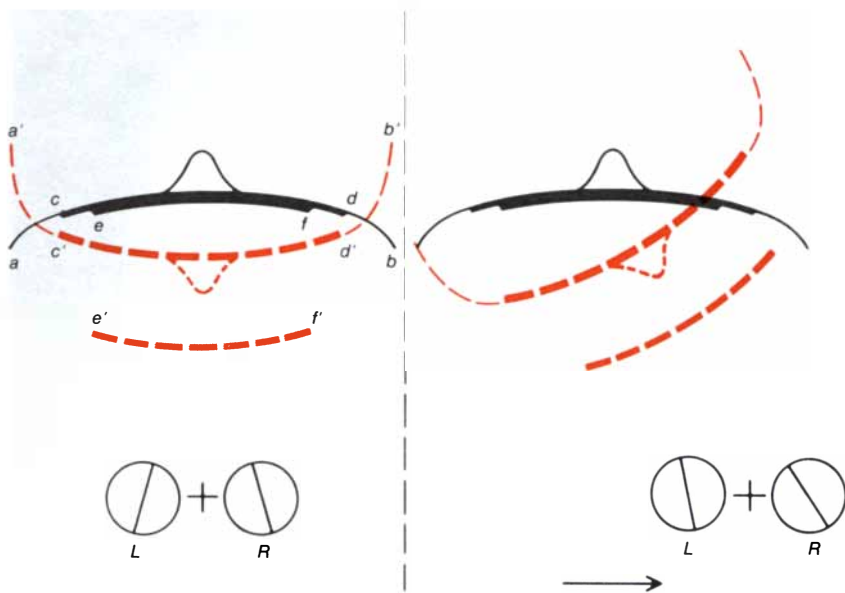
TEST OF HYPOTHESES was made by the author with a setup in which an anaglyph version of a random-dot stereogram (in which the left and right pictures are superposed, with one printed in green and one in red, and viewed through a hand-held filter that is green for one eye and red for the other) is projected onto an inside-out face mask. Because of the color each eye sees only half of the stereogram. According to the monocular-suppression hypothesis, no depth should be seen; according to the binocular-disparity hypothesis, depth should be seen but with its direction reversed. Observers do see the depth, however, and its direction is not reversed.

lipse. If the filter covers the observer's right eye, the pendulum seems to swing outward toward him as it moves from left to right and away from him as it moves in the opposite direction. If the filter is placed over the other eye, the direction of this apparently elliptical movement is reversed. The magnitude of the illusion (the bulge of the ellipse) increases with viewing distance and also as the filter is made darker, provided that the observer can still see through it.

The accepted explanation for the Pulfrich illusion was proposed initially by Pulfrich himself, apparently following a suggestion from an associate. (Pulfrich was blind in one eye and therefore could not see his own illusion.) The explanation is that the eye covered by the filter has a slower response time than the uncovered eye and that the delay

gives rise to what is in effect a binocular disparity between the left and right retinal images as registered at some higher level in the brain. As the pendulum moves across the visual field its momentary position on each retina is the same, but the signal sent to the brain from the covered eye indicating the presence of the pendulum at any given retinal location lags behind the corresponding signal from the uncovered eye. Hence at the level of the brain where simultaneous left and right retinal images are compared it seems there is a disparity between the two eyes' images of the swinging end of the pendulum, and the "disparity" is interpreted in the usual way to signify depth. Pulfrich's original explanation has subsequently been confirmed by many experiments.

My variation was to mount an inside-



TWO ASPECTS of binocular depth inversion of a random-dot stereogram on an inside-out face are depicted. In the panel at the left *ab* represents the face, *cd* the stereogram and *ef* the central square. During depth inversion of the face (*a'b'*) the stereogram appears convex (*c'd'*) and the central square floats in front of it (*e'f'*). Panel at the right shows how the inverted-face-stereogram combination rotates when the observer moves his head to the right.

out face mask on the end of a pendulum and then carry out Pulfrich's demonstration in the usual way. Here again the basic question is whether binocular depth inversion of the face can occur at the same time as stereopsis. According to the monocular-suppression hypothesis, the Pulfrich effect should be absent when the face is seen as being inverted, because that effect depends on the brain's registering binocular-disparity cues and incorporating them into visual experience. On the other hand, the disparity-reversal hypothesis implies that the Pulfrich effect should arise during a depth inversion of the face but that the apparent direction of the illusory elliptical arc should be reversed, as though the filter had been shifted to the other eye.

Neither prediction stands up. Instead one finds that the face can be seen as depth-inverted and can still appear to swing in an elliptical arc. The monocular-suppression hypothesis is therefore ruled out. And since the direction of the movement is the one normally seen, the disparity-reversal hypothesis can be ruled out too.

What do these experiments reveal about depth perception and about the perception of form in general? The central result is that inversion can occur even when the brain mechanism responsible for constructing visual experience has demonstrably registered all the depth information available in normal vision, including the geometrically unambiguous information provided by binocular disparity. On this point, then, Helmholtz and Mach were wrong; mon-

ocular vision, with its inherent three-dimensional ambiguity, is not a prerequisite for seeing things inside out. Evidently binocular vision can be equally precarious when the stimulus offers sufficient provocation.

This finding raises two questions. How is the apparent three-dimensional form of a binocularly depth-inverted object related to the two retinal images that give rise to it? What prevents inversion in ordinary vision?

The first question is perplexing because, according to the standard geometry of binocular vision, depth inversion creates an impossible object. What one sees in the mind's eye cannot be geometrically reconciled with the retinal images. The brain appears to ignore this paradox, presenting consciousness with a seemingly coherent visual object. Apparently depth-inverted percepts are constructed from sensory evidence according to definite perceptual rules, but it is not obvious what the rules are.

Initially I was inclined to look for the rules among variations on the disparity-reversal theme. That idea now seems to me to be increasingly implausible. For one thing the theme's geometrical implications for the apparent shapes of binocularly inverted objects do not seem to agree well with what one actually sees in the illusion.

Moreover, the brain appears not to reverse disparity readily, even when the provocation is strong. Mark Georgeson of the University of Bristol has tested this point by creating reliefs of human faces in which the depth is given entirely by binocular disparity; they are fac-

es sculptured by the three-dimensional surfaces seen in random-dot stereograms. Depending on which eye sees which half of such a stereogram, the disparities may create a face that is either normal or inside out.

When the stereogram actually depicts an inside-out face, one might expect perceptual depth inversion to develop easily if the brain is geared to create inverted percepts by reversing binocular disparities. This does not happen. Georgeson finds that these purely stereoscopic faces are always seen in correct depth (that is, inside out, as is implied by their actual disparities), notwithstanding the normal human bias for seeing faces the other way. The finding suggests that disparity reversal is not a trick the brain performs easily, and so it seems to be an unlikely basis for understanding the perceptual geometry of binocular depth inversion. The architectural key to this novel visual world remains to be found.

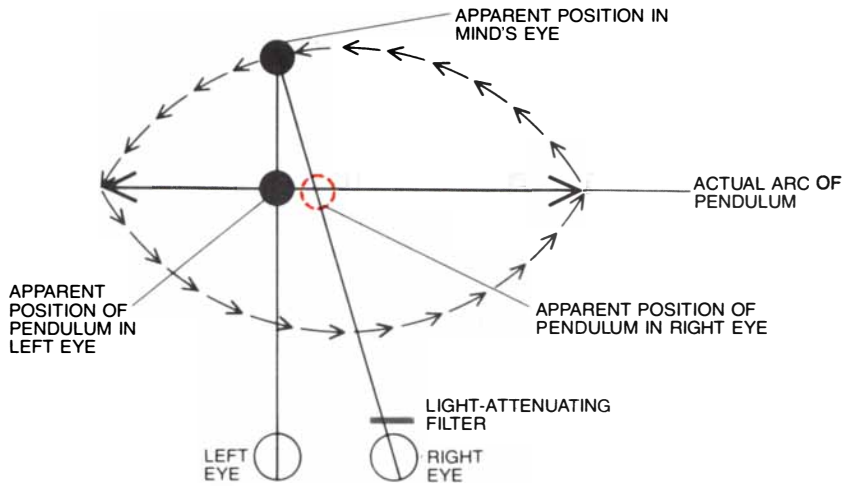
The second question raised by binocular depth inversion is more general. If one can sometimes see objects as being inverted in spite of the availability of every possible cue to depth, why is the mistake so uncommon in normal vision? One thought might be that binocular inversion is an anomaly confined to the special case of inside-out human faces. Perhaps the perception of faces invokes unique mechanisms that do not apply to the perception of other objects.

This idea is easily disposed of, because one can achieve binocular inversion with a broad range of familiar objects. The critical factor seems to be not "facedness" but rather a lifelong habit of seeing certain classes of objects in standard three-dimensional configurations. Thus to explain why inversion is rare one can only say that most of the time the object hypotheses favored by perceptual biases turn out to be correct.

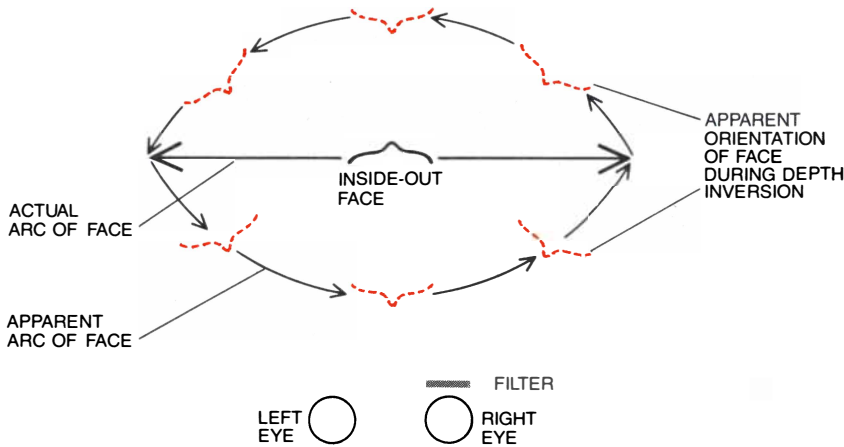
To say that is to say not enough. The basic problem is to understand precisely how mental preconceptions mesh with immediate sensory input to create visual experience. The metaphor of the brain as a tester of hypotheses does not carry one very far.

For example, it is clear that before the visual system can decide to interpret its sensory data according to some specific object hypothesis it must be guided to a roughly appropriate class of hypotheses, otherwise each new object would present an impossible problem in searching. (One could spend a lifetime testing cow-shaped hypotheses against retinal trees.) This guidance must come primarily from immediate sensory evidence, and so the key problem in perception is how the visual system manages so successfully to pull itself up by its own bootstraps.

The question of how much of what a person sees is forced on him by immediate sensory stimulation and how much is



PULFRICH ILLUSION provides the basis for another test of the two hypotheses on binocular depth inversion. In the illusion a pendulum that is in fact swinging in a flat plane appears to follow an elliptical path when one of the observer's eyes looks through a dark but not opaque filter.

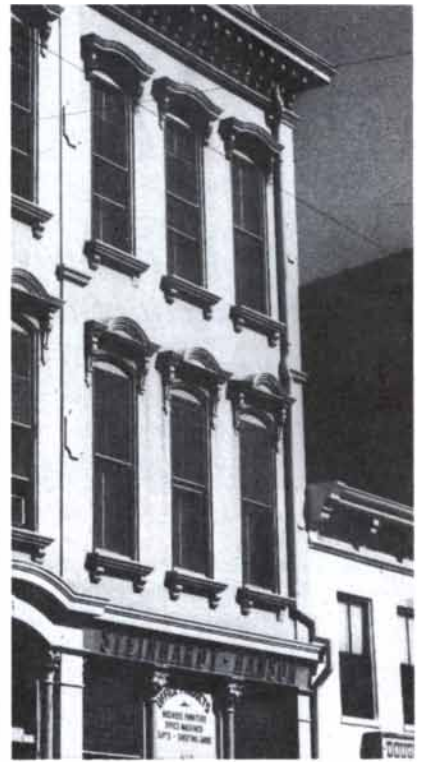


SECOND TEST of hypotheses involved mounting an inside-out face mask on a pendulum. The heavy black lines denote the face and its real arc, and the curved arrows show its apparent arc when the right eye is covered by a light-attenuating filter. The colored shapes indicate the apparent orientation of the inverted face along the illusory arc. According to the monocular-suppression hypothesis, the Pulfrich effect should not occur when the face is seen inverted; according to the binocular-disparity hypothesis, the Pulfrich effect should be observed during depth inversion of the face but the apparent direction of the illusory arc should be reversed, as though the dark filter had been shifted to the other eye. Neither prediction proves to be correct.

supplied by the imagination is a long-standing issue in visual science, and this is not the place to discuss it at length. One point, however, does seem to emerge from the study of depth inversion: the critical role of unconscious perceptual learning.

After achieving depth inversion with many different objects one gains the impression that in order to achieve a stable inversion of any object the brain must construct a complete visual model of the object in inverted form: a model that assigns a three-dimensional interpretation to all the idiosyncratic features of the object. This process is evidently much easier with some objects (such as faces) than it is with others.

Nevertheless, it does not seem that the real-world plausibility of the inverted model is really a decisive factor. Plausibility does determine the amount of time and mental effort required to achieve inversion, but my impression is that there is no sharp division between objects that can be inverted in depth and those that cannot be inverted in depth. Instead it seems to be just as likely that the critical factor is the time required to construct an appropriate visual model. Some objects can be inverted in a reasonable period of time and others simply take too long to be inverted. In other words, it may be that you could learn to see everything inside out if you only had time to practice.



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