Transparently Obvious

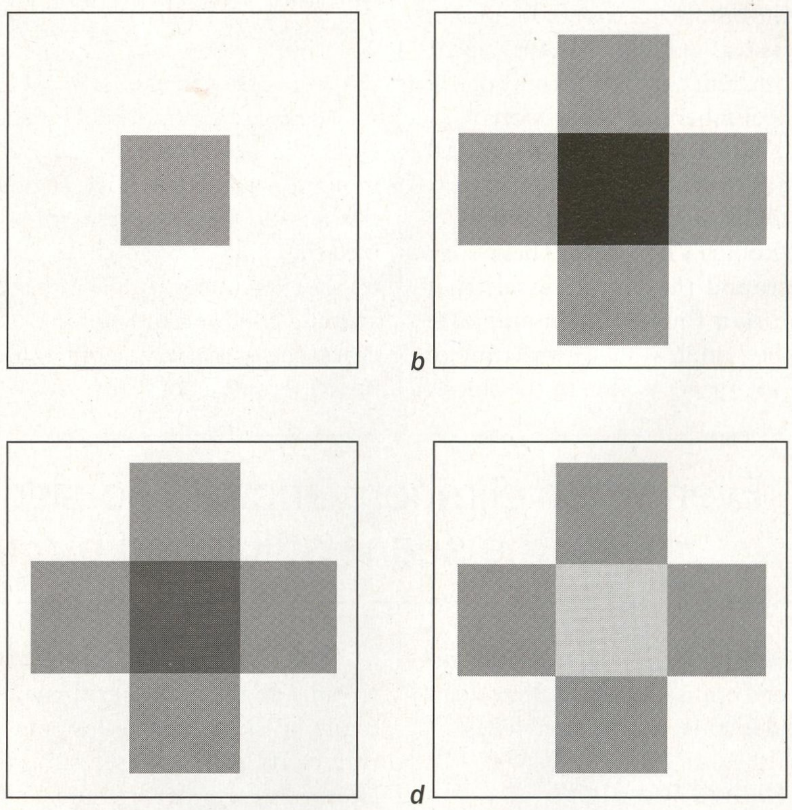
How the brain sees through the perceptual hurdles of tinted glass, shadows and all things transparent

BY VILAYANUR S. RAMACHANDRAN AND DIANE ROGERS-RAMACHANDRAN

OUR ABILITY to perceive visual scenes effortlessly depends on intelligent deployment of built-in knowledge about the external world. The key word here is "intelligent," which raises the questions: Just how smart is the visual system? What is its IQ? For example, does the visual system know the laws of physics? Does it use inductive logic only (as many suspect), or can it perform deductions as well? How does it deal with paradoxes, conflicts or incomplete information? How adaptable is it?

Some insight into perceptual intelligence comes from the study of transparency, a phenomenon explored by Gestalt psychologist Fabio Metelli. He first drew attention to the fact that compelling illusions of transparency can be produced by using relatively simple displays.

The word "transparency" is used loosely. Sometimes it refers to seeing an object, such as a sunglass lens, and the objects visible through that object, and sometimes it means seeing something through frosted glass, known as translucency. In this column we will restrict ourselves to the former, because the physical and perceptual laws pertaining to it are simpler.



a b c d

Physics of Transparency

First let us consider the physics of transparency. If you put a rectangular neutral-density filter, such as dark glasses, on a sheet of white paper, the filter allows only a certain proportion of light through—say, 50 percent. Put another way, if the paper has a brightness, or luminance, of 100 candelas (cd) per square meter, the portion covered by the filter will have a luminance of 50 cd. If you then add a second such filter so that it partially overlaps the first, the overlapping region will receive 50 percent of the original 50 percent of the light—that is, 25 percent. The relation is always multiplicative.

So much for physics. What about perception? If, as in *a,* you simply have a dark square in the middle of a light square (with the former being 50 cd and the latter 100 cd), the inner square could be either a filter that cuts light by 50 percent or a darker square that reflects only 50 percent as much of the incident light as does the surrounding background. Without additional information, there is no way the visual system could know which condition exists; because the latter case is far more common in nature, that is what you will always see.

But now consider two rectangles that form a cross with an overlapping region in the middle. In this case it is not inconceivable—and, indeed, it is more probable—that this configuration really does consist of two overlapping rectangular pieces of filters rather than five blocks arranged to form a cross. But if it is the former, then the luminance ratios must be such that the central square (the overlapping region) should be darker than the other squares and, of course, darker than the background. In particular, the central square's luminance should

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be a multiplicative function in terms of a percentage of the two filters. If the nonoverlapping regions of the two rectangles are, for instance, 66 and 50 percent of the background, respectively, then the inner rectangle should be 50 percent of that 66 percent—or roughly 33 percent (that is, 33 cd assuming the white paper is 100 cd).

Now the question is: Does the visual system have tacit "knowledge" of all these factors? We can find out by using a series of displays (*b, c, d*) in which the background and rectangles are of a fixed luminance (such as 100 and 50 cd, respectively) while the luminance of the inner square alone changes. In terms of the luminance that would exist with physical transparency, the inner square is set to be too dark (*b*), appropriately dark (*c*) or too light (*d*). If you look at these figures without knowing anything about physics, you see the rectangles as transparent in *c* but not in *b* or in *d*. It is almost as if your visual system knows what you do not know (or did not know until you read this column).

This experiment suggests that two conditions must be fulfilled for transparency to be seen. First, there must be figural complexity and segmentation to justify this interpretation (hence no transparency in *a*). Second, the luminance ratios have to be right (no transparency is visible in *b* or *d*).

Shadowy Influences

Transparency is infrequent in nature, but shadows are not. It is possible that the "laws" of perception we have explored so far evolved mainly to deal with shadows and to distinguish them from "real" objects, which would also produce luminance differences in the visual scene as a result of differences in reflectance (for instance, a zebra's stripes or a white cat on a black mat).

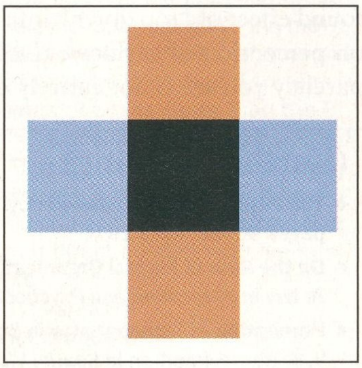
The shadow cast by an object such as a tree could, in theory, be pitch black if there were a single distant light source, without scattering or reflections. Ordinarily, however, ambient light from the environment falls on the shadow so that a dark, but not black, shadow results. If the tree shadow falls on a sidewalk and darker grass (*e*), the manner in which the magnitude and sign of luminance vary along the shadow's boundary would be identical on both sides of the boundary, the shadow side and the light side. This covariation of luminance clues the brain that it is a shadow, not an object or texture.


e

It turns out that the luminance changes in transparency mimic those seen in shadows. The visual system may have evolved to discover and react appropriately to shadows rather than to transparent filters. If it could not, you might try to grab a shadow or gingerly step over it to avoid tripping, not realizing that it is not an object at all.

Interestingly, although our perceptual mechanisms seem to be aware of the physics of transparency pertaining to luminance, they appear to be blind to the laws pertaining to color "transparency." In *f* and *g*, we have two bars crossing each other, both with luminance of, say, 50 percent of the background. We have contrived it so that in *g* the overlapping region has 25 percent of the background luminance, as it should be if we were dealing just with luminance. But if the colors of the two filters are different—as they are—the overlap zone should be pitch black, not gray. The reason is that the red filter transmits only long ("red") wavelengths when white light shines through it and the blue filter transmits only short ("blue") wavelengths. So if you cross the filters, *no* light passes through; the overlap zone would be black. In fact, transparency is seen not when the midzone is black but when it is 25 percent (*g*). Apparently, the visual system continues to follow the luminance rule and ignores the color incompatibilities.

A curious effect occurs if you place a gray cross on a white background when the middle of the cross is a lighter shade of gray (*h*). Instead of seeing the lighter cross for what it is, the brain prefers to see it as if there were a circu-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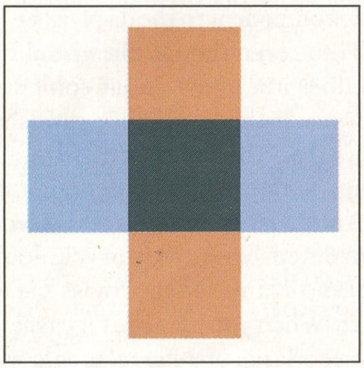
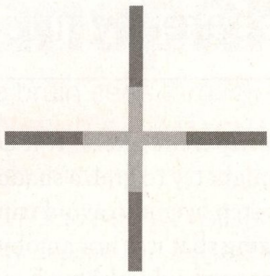
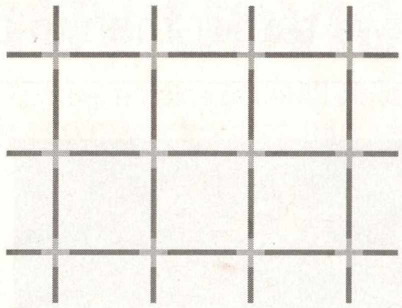

g

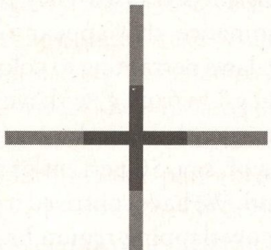
GETTY IMAGES (*top*); SCIENTIFIC AMERICAN MIND (*bottom*)



h



i



j

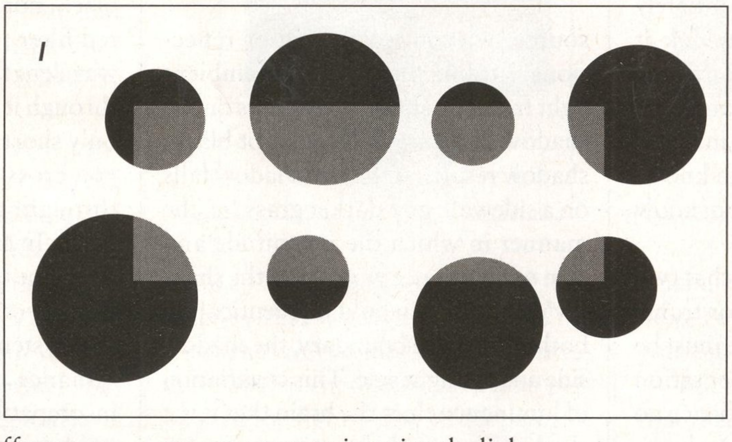
k

lar piece of frosted glass or vellum superimposed on the larger gray cross. To achieve this perception, the brain has to "hallucinate" an illusory frosted glass spreading, even in the area surrounding the central region of the cross. The effect is especially compelling if you have a patch of several such crosses (*i*).

Once again the luminance ratios between the surround (white), the cross (dark gray) and the central region (light gray) have to be just right for the effect to occur; if they are wrong, the effect disappears (*j*). In other words, the ratios must be compatible with what would occur with actual translucent surfaces (for example, fog or frosted glass). The effect is even more striking if there is a chromatic component to the display (*k*).

Thus, even though the visual system does not know about color subtraction, if the luminance ratios are right, then the colors are "dragged along" with the spread of luminance.

Another intriguing effect is seen in *l*, invented by Italian psychologist Gaetano Kanizsa: the Swiss cheese effect. When you glance at it casually, you see a large opaque rectangle with holes in it superimposed on a smaller gray rectangle sitting on a black background. But with some mental effort, you can start to imagine the light-gray rectangle behind the holes as actually a translucent white rectangle in front of the holes and then start to perceive a transparent rectangle through which you see black spots in the background. This illusion demonstrates the profound effect of "top down" influences on perception of surfaces; the transparency you see is not entirely driven bottom up through serial hierarchical processing of the physical input on the retina.



l

Taken collectively, these demonstrations allow us to conclude that a remarkable degree of "wisdom" about the statistics and physical laws of transparency are wired into visual processing, through a combination of natural selection and learning. Yet there are limits to this wisdom. The visual system seems tolerant of incompatible colors. It is incapable of applying the physics of color subtraction, partly because color perception evolved much later in primates and did not get wired in adequately and partly because in the luminance domain color overlap is much less common in the natural world than transparency and translucency are.

We may conclude that even though the visual system can make sophisticated use of such abstract properties as the physics of luminance ratios and the statistics of segmentation required for transparency, it is "dumb" with regard to other characteristics such as color because of the happenstance manner in which its hardware (or "squishyware") evolved through natural selection—strong evidence against "intelligent design." M

VILAYANUR S. RAMACHANDRAN and DIANE ROGERS-RAMACHANDRAN are at the Center for Brain and Cognition at the University of California, San Diego. They serve on *Scientific American Mind*'s board of advisers.

With fond memories of Daniel J. Plummer (1966–2006), a dear friend and brilliant student of transparency and other phenomena.

(Further Reading)

- **The Perception of Transparency.** Fabio Metelli in *Scientific American,* Vol. 230, No. 4, pages 90–98; April 1974.
- **On the Role of Figural Organization in Perception of Transparency.** J. Beck and R. Ivry in *Perception and Psychophysics,* Vol. 44, pages 585–594; 1988.
- **Perception of Transparency in Stationary and Moving Images.** D. J. Plummer and V. S. Ramachandran in *Spatial Vision,* Vol. 7, pages 113–123; 1993.