Seeing Is Believing

2-D or not 2-D, that is the question: test yourself to learn what shapes formed by shading reveal about the brain

BY VILAYANUR S. RAMACHANDRAN AND DIANE ROGERS-RAMACHANDRAN

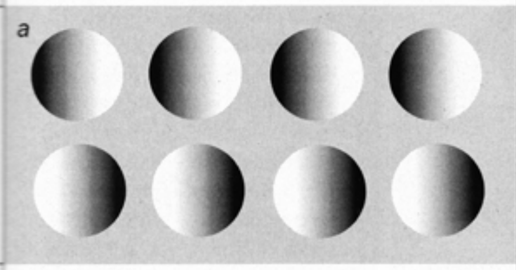
A dark back and light belly help this caterpillar avoid detection.

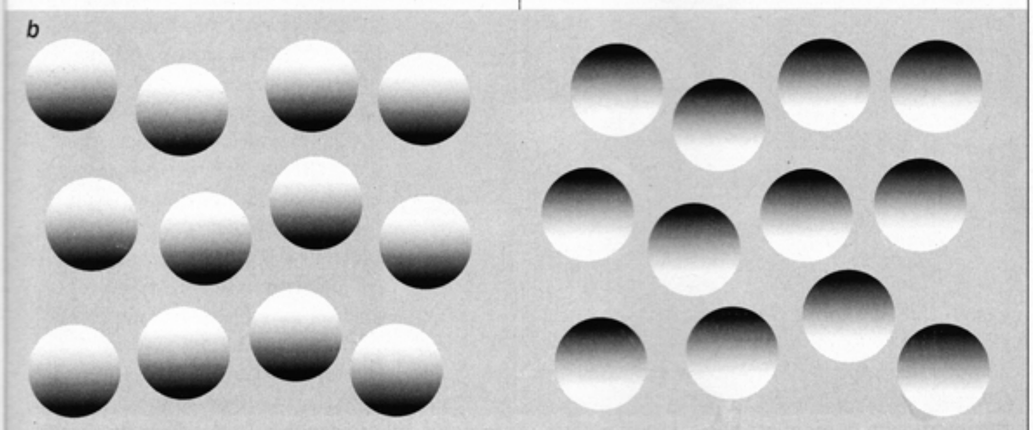
THE VISUAL IMAGE is inherently ambiguous: an image of a person on the retina would be the same size for a dwarf seen from up close or a giant viewed from a distance. Perception is partly a matter of using certain assumptions about the world to resolve such ambiguities. We can use illusions to uncover what the brain's hidden rules and assumptions are. In this column, we consider illusions of shading.

In *a*, the disks are ambiguous; you can see either the top row as convex spheres or "eggs," lit from the left, and the bottom row as cavities—or vice versa. This observation reveals that the visual centers in the brain have a built-in supposition that a single light source illuminates the entire image, which makes sense given that we evolved on a planet with one sun. By consciously shifting the light source from left to right, you can make the eggs and cavities switch places.

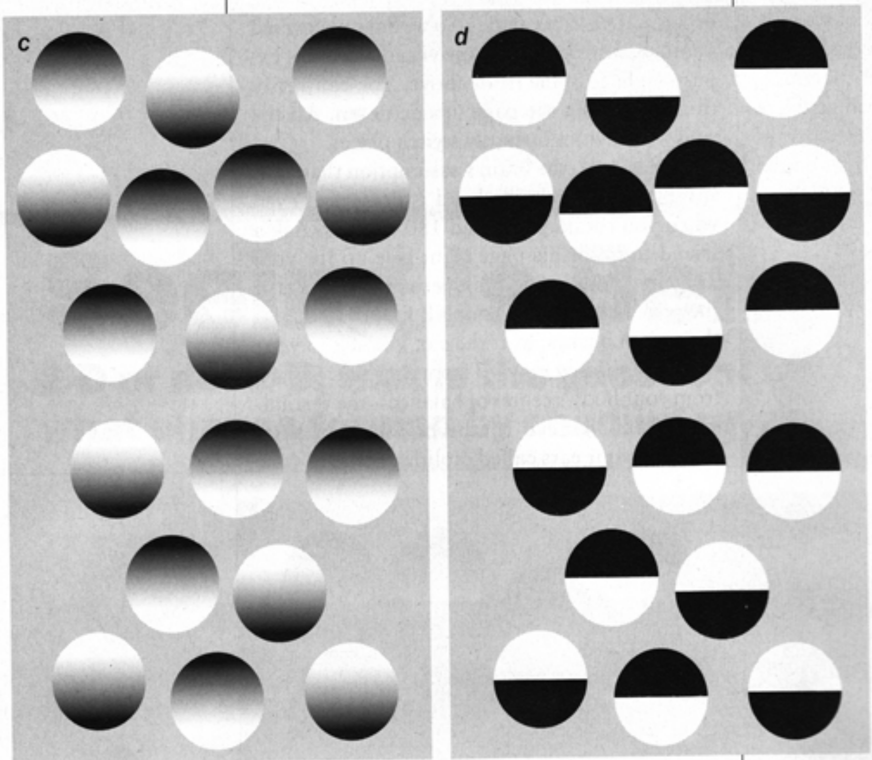
In *b*, the image is even more compelling. Here the disks that are light on the top (*left*) always look like eggs, and the ones that are light on the bottom (*right*) are cavities. So we have uncovered another premise used by the visual system: it expects light to shine from above. You can verify this by turning the page upside down. All the eggs and cavities instantly switch places.

Amazingly, the brain's assumption that light shines from above the head is preserved even when you rotate your head 180 degrees. Ask a friend to hold this page right side up for you. Then bend down and look between your legs at the page behind you. You will find that, again, the switch occurs, as if the sun is stuck to your head and shining upward from the floor. Signals from your body's center of balance—the vestibular system—guided by the positions of little stones in your ears called otoliths, travel to your





The brain automatically assembles fragments of similar color, enabling you to easily spot the lion behind the foliage.



visual centers to correct your picture of the world (so that the world continues to look upright) but do not correct for the location of the sun.

From this experiment we learn that despite the impression of seamless unity, vision is actually mediated by multiple parallel information-processing modules in the brain. Some of the modules connect to the vestibular system; however, the one that handles shape from shading does not. The reason might be that correcting an image for placement in so-called world-centered coordinates would be too computationally expensive and take too much time. Our ancestors generally kept their heads upright, so the brain could get away with this shortcut (or simplifying assumption). That is, our progenitors were able to raise babies to maturity often enough that no selection pressure acted to produce vestibular correction.

If you look at *c*, you find that you can almost instantly mentally group all the eggs and segregate them from the cavities. As visual scientists discovered decades ago, only certain elementary features that are extracted early during visual processing "pop out" conspicuously and can be grouped in this manner. For example, your brain can discern a set of red dots in a background of green ones but cannot group smiles scattered among a backdrop of frowns. Color is thus a primitive feature that is extracted early, whereas a smile is not.

(It makes survival sense to be able to piece together fragments of similar color. A lion hidden behind a screen of green leaves is visible merely as gold fragments, but the visual brain assembles the pieces into a single, gold, lion-shaped form and warns: "Get out of here!" On the other hand, objects are not made up of smiles.)

The fact that you can group the eggs in *c* implies that shading information, like color, is extracted early in visual processing. This prediction was verified in recent years by recording activity in the neurons of monkeys and by conducting brain-imaging experiments in humans. Certain cells in the visual cortex fire when the observer sees eggs; others respond only to cavities. In *d*, where the circles have the same luminance polarities as in *c*, you cannot perceive the grouping; this fact suggests the importance of perceived depth as a cue that is extracted early in visual processing.

Of course, over millions of years, evolution has "discovered" and taken advantage of the principles of shading that researchers have explored only lately. Gazelles have white bellies and dark backs—countershading—that neutralize the effect of sunshine from above. The result reduces pop-out so that gazelles are not as conspicuous; they also appear skinnier and less appetizing to a predator. Caterpillars have countershading, too, so they more closely resemble the flat leaves on which they munch. One caterpillar species has "reverse" countershading—which did not make sense until scientists real-

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ized that the insect habitually hangs upside down from twigs. One type of octopus can even invert its countershading: if you suspend the octopus upside down, it uses pigment-producing cells called chromatophores in the skin, which are controlled by its vestibular input, to reverse its darker and lighter areas.

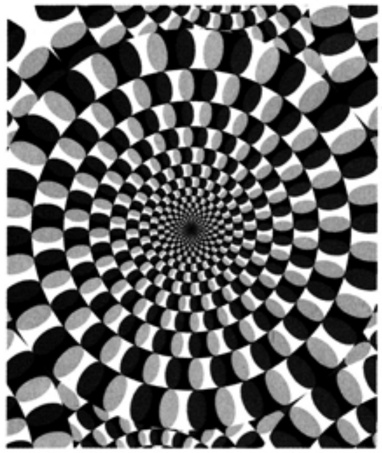
Charles Darwin noticed a striking example of nature's use of shading in the prominent eyelike spots on the long tails of argus pheasants. With the tail feathers at horizontal rest, the orbs are tinged from left to right. During the bird's courtship display, however, the tail feathers become erect. In this position, the spots are paler on top and duskier at bottom, so the disks seem to bulge out like shiny metallic spheres—the avian equivalent of jewelry.

That a few simple shaded circles can unveil the underlying assumptions of our visual systems—and even how such principles have played a role in shaping evolutionary adaptations—shows the power of visual illusions in helping us to understand the nature of perception. **M**

VILAYANUR S. RAMACHANDRAN and DIANE ROGERS-RAMACHANDRAN collaborate on studies of visual perception at the Center for Brain and Cognition at the University of California, San Diego. Ramachandran is co-author of *Phantoms in the Brain* (Harper Perennial, 1999). Among his honors are a fellowship at All Souls College of the University of Oxford and the Ariëns Kappers medal from the Royal Netherlands Academy of Arts and Sciences. He gave the 2003 BBC Reith lectures. Rogers-Ramachandran was a researcher at the University of North Carolina at Chapel Hill before moving to U.C.S.D.

(Further Reading)

- **Perceiving Shape from Shading.** Vilayanur S. Ramachandran in *Scientific American*, Vol. 259, No. 2, pages 76–83; August 1988.
- **On the Perception of Shape from Shading.** D. A. Kleffner and V. S. Ramachandran in *Perception and Psychophysics*, Vol. 52, No. 1, pages 18–36; July 1992.
- **Neural Activity in Early Visual Cortex Reflects Behavioral Experience and Higher-Order Perceptual Saliency.** Tai Sing Lee, Cindy F. Yang, Richard D. Romero and David Mumford in *Nature Neuroscience*, Vol. 5, No. 6, pages 589–597; June 2002.



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The "Real" World

"The camera does not lie," the saying goes. And we tend to think of our eyes and our other sensory organs as video equipment, faithfully recording all the details of our busy lives. As you will learn from the articles on illusions collected in this special issue, however, we see with our *brains,* not with our eyes. And our brains make instant value judgments about the jumble of incoming sensory information, depending on what is important at that moment to us, to create a sensible narrative of the world around us.

Rather than pondering every bit of light that enters our orbs, the brain quickly jumps to conclusions, based on millions of years of evolution. Humans are intensely visual creatures, and we have developed an incredible apparatus for detecting things that are critical to our survival, such as predators, prey and mates. For instance, we can instantly mentally assemble several tiny patches of orange with stripes peeking through dense foliage: "tiger!" As we glance around a room, the image bounces on the retina (the light-receiving tissue at the back of the eye) as various areas of the scene excite different groups of cells. Yet the world appears stable to us, the view a smooth pan across our surroundings. The brain even fills in missing bits of picture in the eye's blind spot, where the optic nerve pierces the retina.

On the other hand, we do not see everything. Something that is irrelevant to a particular task will not make it to our conscious awareness. In one telling experiment, volunteers had to count how many times a basketball got passed between players. A person in a gorilla suit then strutted across the room. Concentrating on those ball passes, about half the volunteers did not see the gorilla.

Of course, the brain cannot actually tell us about what it is thinking as it processes sensory inputs, focusing on certain items and ignoring others. But our responses to illusions can be just as revealing. Scientists have long used these disarmingly simple—and fun—sensory tricks to probe the mind's inner workings. This special edition offers an amazing collection of such illusions and the lessons that they teach us about the brain. We can promise you one thing: you won't believe your eyes.

Mariette DiChristina
Executive Editor
editors@SciAm.com