Simple tricks of vision

(Editor's note: Take time out from technical papers and Society news for "The light touch," a fresh Optics & Photonics News column meant to be shared with students and children of all ages.)

We take the human eye for granted, but it is a remarkably powerful and sophisticated optical system. The array of optical sensors that form the retina are connected to a pattern recognition system far more powerful than the fastest supercomputer—the vision center of the human brain. The eye and the brain together give us an extremely detailed picture of the world, compensating smoothly for some of their own limitations. However, a few simple experiments can reveal some of the eye's limits.

Specialized nerve cells in the retina respond to light and transmit signals to the brain. There are two similar types: cones and rods. The roughly seven million cones respond to bright light and sense color. The 125 million rods respond to dim light, but do not sense color. The rods are so sensitive to light that they are essentially bleached out in sunlight and do not respond at all. However, they recover their sensitivity after you turn off the lights.

It takes a minute or two for your eyes to start to "dark adapt" as the rods turn on, to sense light much too faint for the cones. If you go outside on a dark night, you will see faint stars gradually come into view as your eyes dark adapt. It takes about half an hour for your eyes to become fully dark adapted, but the change is most obvious in the first few minutes outside. If you live in a brightly lit urban area, scattered light from street lamps, car headlights, houses, and signs makes the sky so bright that your eyes never fully dark adapt. You will never see colors at night, because the rods lack color receptors.

The differences between rods and cones, and the different patterns they make on the retina, have some interesting consequences that we don't often notice. The cones respond to all the colors in the visible spectrum, from 400 to 700 nanometers. However, the cones are not sensitive to wavelengths longer than 600 nm, so red objects seem darker at night than in bright light.

Many cones are packed tightly together near the center of the retina, a point called the "fovea," where the lens of the eye focuses light from objects straight ahead. Because they are tightly packed, the cones near the fovea have the highest resolution in the

Continued on next page

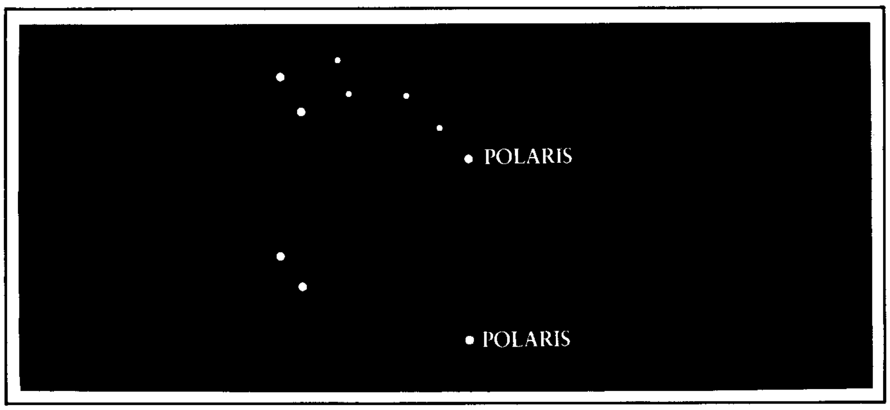


FIGURE 1. The faint stars in the middle of the Little Dipper are easier to see (above) if you look directly at Polaris instead. Try to look directly at the stars in the Little Dipper and they may disappear (below) because your eyes are focusing their light on the less-sensitive cones at the center of the eye.

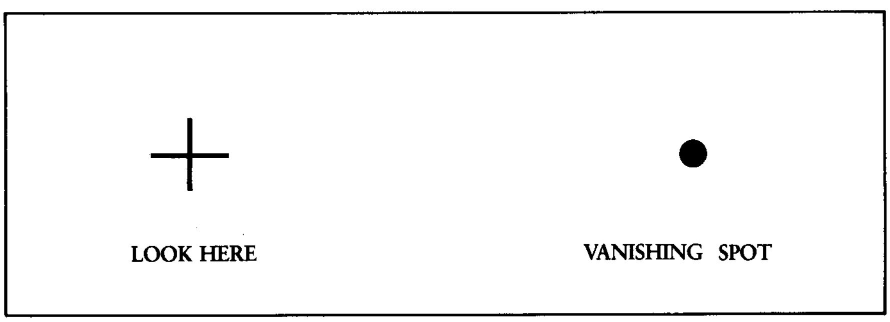


FIGURE 2. Close your left eye and focus your right eye on the cross. Move the page back and forth and the circle will vanish when it falls on your blind spot. (From Jeff Hecht, Optics: Light for a New Age, Charles Scribner's Sons, New York, 1988.)

JEFF HECHT is a contributing editor to *Optics & Photonics News* and *Lasers & Optronics*. He is the author of *Optics—Light for a New Age*.

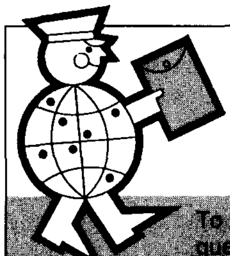
LIGHT TOUCH, *from page 55*

eye, giving us our detail vision. When we read, our eyes focus light onto the fovea and the surrounding area—the "macula"—so we can see the detail needed to make sense of the words. Some elderly people suffer a condition called "senile macular degeneration," which impairs their detail vision, leaving them unable to read books set in normal size type.

The tight concentration of cones near the fovea leaves no room for rods, so there are none near the center of vision. Most of the 125 million rods are on the sides of the retina. This means that at night you see poorly in the area where you direct your eyes, the same area where you can see best during the day. This makes seeing in the dark difficult, because we are so used to being in the light that we automatically turn our eyes toward what we want to see.

Amateur astronomers are well aware of this effect, and use a technique called "averted vision" to better view faint objects in the dark night sky. If they want to see a dim star, they focus their eyes on a nearby bright star. The dim star then appears off to the side. If their eyes wander toward the dim star, it may seem to vanish—because its light is focused onto the fovea, where there are no cones to respond to it. The best way to see averted vision work is by looking directly at a fairly bright star. You will see other, fainter, stars nearby, but those fainter stars will disappear if you try to focus on them. This works well with Polaris and the fainter stars of the Little Dipper, if your sky is not too bright, as shown in Fig. 1.

Rods and cones are not distributed symmetrically around the eye. They are absent altogether from one small area near the back of the eye, where the optic nerve connects with the retina. Normally, our brain conceals this blind spot by using information from our other eye. However, you can demonstrate its existence by closing your left eye and focusing your right eye on the cross in Fig. 2. Move the page back and forth, and at some point the circle will fall on your blind spot and vanish.



AN IMPORTANT MESSAGE

To speed our service to members, all requests for back copies or replacement copies of *Optics & Photonics News* will be handled directly by OSA. Please contact us at: *Optics & Photonics News*/Back Copies, 1816 Jefferson Place, N.W., Washington, D.C. 20036, 202/223-8130, 202/223-1096 (FAX).

Change of address and subscription inquiries will still go through AIP. Please include your current mailing label and provide the correct information on the form below:

NAME

NEW ADDRESS

CITY

STATE/ZIP

TELEPHONE NO.

Send to: AIP S/F Division, 500 Sunnyside Blvd., Woodbury, NY 11797

THE OPTICS SHOPPE

Previously owned optics equipment

Have you hesitated about updating your lab because you're not sure what to do with the equipment you now have? Are you running out of storage space for equipment that's too good to discard but not quite what you need for your current projects? Have you ever wished your company would hold a garage sale?

Optics & Photonics News has a better idea.

"The Optics Shoppe" gives you the chance to let more than 16,000 colleagues know that you have optics equipment to sell or trade. Here are the details on how to take advantage of this feature:

- Type an ad of no more than 25 words, including contact name and phone number.
- Enclose a $10 check payable to The Optical Society of America and mail it to: The Optics Shoppe, *Optics & Photonics News*, 1816 Jefferson Place, N.W., Washington, D.C. 20036.
- Copy that reaches OSA by the 24th of the month will appear in the issue mailed about five weeks later (i.e., copy received by January 24 will appear in the March issue).
- Equipment advertised must be previously owned and must be in good condition.

Questions? Call Larry Lotridge or Dasha Talmy at (202) 223-8130. Then make a list of the items you want to sell and start typing up those ads—that is, if you can find your keyboard under all those extra instruments!

Seeing in the light and in the dark

The human eye is remarkably sensitive. The first stage in the process of seeing is the absorption of light in cells called rods and cones, which lie in the retina, a thin sheet of tissue at the back of the eye. The retina records the image of the world around you somewhat like film does in a camera. Light is composed of small packets of energy called photons, and the eye is so sensitive that the absorption of a single photon is all that is required to stimulate a single rod photoreceptor. If only about 10 rods in a patch of the retina each absorb a photon, a brief flash of light can reliably be seen in the dark. Put another way, the eye is so sensitive that you could deliver 1,000 visible flashes of light to every person who ever lived with the energy required to lift a pea an inch off your dinner plate. On the other hand, our eyes can also operate at light levels much brighter than this. For example, a white piece of paper viewed on a bright sunny day is roughly 10^{11} or 100 billion times brighter than the dimmest flashes we can just make out in total darkness.

How does the visual system allow us to see so clearly over such an enormous range of light intensities? This operating range is all the more impressive because the retina sends visual information to the brain with optic nerve fibers that have a very limited operating range. These nerve cells send impulses to the brain at a rate that increases with the intensity of light. However, their useful range is from perhaps a few spikes/sec to 200 spikes/sec, or a range of about 100/1. How can the $10^{11}/1$ range of light intensities be compressed into a range of 100/1? Some simple experiments you can perform with your own eyes provide some clues.

DAVID R. WILLIAMS is associate professor at the Center for Visual Science, University of Rochester, Rochester, N.Y.

Changing pupil size

One trick the visual system uses is to change the size of the pupil, depending on the light level. In the dark, the pupil dilates, letting in roughly 10 times more light than it does when it is constricted in bright light. Watch someone's pupils when they are standing in a dimly lit room. Illuminate one of his eyes with a flashlight, while shielding the light from the other eye. You can change the size of the pupil of the unilluminated eye by changing the amount of light to the illuminated eye. The pupils of the two eyes are about the same size no matter how differently the eyes are illuminated, indicating that they are yoked together by a single mechanism that controls both eyes.

Changing from cones to rods

Another way the visual system allows us to see over such a large range of light intensities is to split the task between two distinct sets of photoreceptors: the rods operate at dim light levels and the cones, which also provide color vision, function at higher levels. Roughly speaking, when the rods alone are active, the visual system can be a thousand times more sensitive than when the cones are active.

The enhanced sensitivity of the rod system comes at the price of our ability to see fine detail. The visual acuity of the eye when the rods alone are active is about 10 times lower than it is when cones are active. The rod system has an advantage in sensitivity over cones in part because it adds together signals from many rods. The difference in acuity can be observed if you attempt to read under dim illumination. If it is dim enough that the world appears only in shades of gray without color, only your rods are active, and you will be able to read only if the text is very large.

Changing sensitivity

Perhaps the most important mechanism the visual system uses to operate over a large range of light levels is to change its sensitivity depending on the overall light level at any given time. Consider the volume control on a stereo or television. If the sound is too loud, you turn the volume down; if it is too soft, you turn the volume up. The visual system has its own volume control that adjusts itself to different light levels automatically. When the light level increases, the visual system turns down its volume. This process is known as light adaptation. When the light level decreases, the volume is turned up, a process called dark adaptation. We all experience dark adaptation when we step into a dark movie theater from the brightly lit outdoors. Though it is difficult to see initially, after a few minutes your vision seems to improve. This process takes about 30 minutes to complete, though most of the sensitivity adjustment happens within a few minutes.

We are so used to this effortless process that we are rarely aware of it. However, a simple experiment provides a very graphic demonstration of how potent these sensitivity changes of dark adaptation actually are. Find yourself a dark room—the darker the better so long as you can still make out some of the gross features in the room. If you can make out any colors, it is too bright. During the day, a windowless bathroom will do if it is illuminated only by light passing beneath the closed door. At night, a room illuminated only by moonlight is a good choice.

Make yourself comfortable in this room and notice how objects gradually become easier to see. Wait for at least 5 minutes, though the longer you wait (up to about 30 minutes) the better. Then cover one eye with your hand making sure that no light can get in. Keeping your hand over your eye, turn on all the room lights, or step outside, giving your uncovered eye a full minute to adjust to this new light level. Then return to the dark room and uncover your eye. You should experience a quite dramatic (and slightly disconcerting) difference between your eyes. You will find that you are effectively blind in the eye that was recently exposed to the bright light, though your dark-adapted eye will see the dark room quite clearly.

With this procedure, it is easy to make one eye a thousand times more sensitive than the other eye. Unlike the experiment on the pupils, which work together in the two eyes, this experiment shows that there are separate volume controls, or sensitivity adjustments, for each eye.

After-images

These volume controls are not only independent in each eye, but they also operate relatively independently at different locations within the retina of a single eye. When someone uses a flash camera to take a picture of you, you often notice an after-image of the flash that lingers long after the flash itself. The after-image has the peculiar property that it moves with your eye; no matter where you look, it maintains the same relative position to where you are looking. This is because the after-images originate in the retina, which moves just as the eye moves.

Some kinds of after-images can be thought of as indicators of the volume control settings at different locations in the retina. For example, stare at the center of the "d" in the title of this article. Gaze steadily at the "d" for 20 seconds. Then look at the blank white part of the page just above the title. You should see an after-image of the same letters you saw initially, but this time they will appear brighter than the background instead of darker. These "negative" after-images occur because during the time you were looking at the "d", the part of the retina beneath the dark letters became more sensitive than the part beneath the bright background. When you shifted your gaze to the uniform white page, the page looked brighter where your retina was most sensitive, so that the letters look bright. Many after-images are a consequence of the normal process the retina uses to adjust to the overall light intensity, allowing us to see in both light and in the dark.

The power of compound eyes

The compound eye of an insect is made up of many separate visual units (Figure 1). In this article, we discuss the power of the compound eye.

It is clear that the eye of an insect is able to detect the movement of an enemy or prey, as well as patterns of light and dark areas. But this equipment would not seem to give an insect a clear, sharply defined image of the external world. Of course, we do not know that what we see is any more real than what insects see. The signals conveyed to our brains produce certain instinctive reflex actions—we may turn away or close our eyes. By more complicated mental processes, visual memory influences visual perceptions. Insects react by visual memory: for example, returning to a nest and using visual landmarks.

When we compare ourselves to insects, we find a way in which our vision is incomplete. Insects see about the same amount of the red end of the spectrum as we do, but they see much further into the ultraviolet. Insects avoid the light, *e.g.*, when offered a spectrum of colors that includes infrared and ultraviolet, ants carrying their pupae into shelter will avoid all of our visible spectrum and a space beyond it, choosing as "dark" places the infrared and ultraviolet. In precise terms, their general range is from 2,500Å to 7,000Å, compared with the human range of 4,000Å to 7,000Å.

This color range of insects has largely determined the hues of meadows and forest, for varieties of flowers that appealed to insect pollinators had the best chance of survival through the ages of evolution. Few bee-pollinated flowers are solid red, for to the bee red looks the way black does to the human eye. There are numerous blue and violet, yellow and yellowish-green flowers that fall within the range of the bee's color vision. In addition, there are a number of blossoms that appear muted to the human eye, but glow with ultraviolet magnificence for bees.

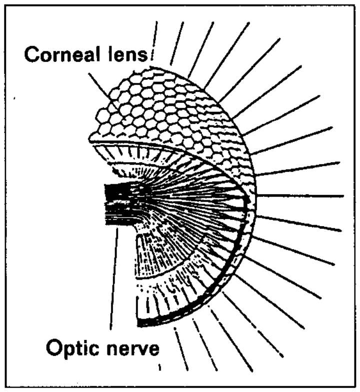


Figure 1. The compound insect eye consists of many tiny individual eyes, each connected to its own nerve endings. The eye as a whole does not move, nor can its lenses be focused. Each catches a small piece of the surrounding scene and the result is a rather coarse-grained picture, like a mosaic.

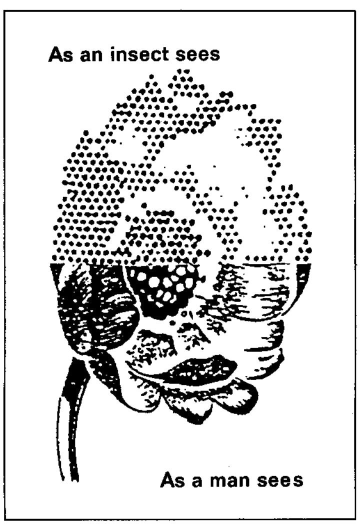


Figure 2.

Insects' ability to get their bearings from sunlight partly depends on polarization, which is generally invisible to man. For the insect, there is a different quality of light coming from north, east, south and west at different hours of the day. As a consequence, insects need only to see the sky to navigate. More remarkable, honeybees can tell where the sun is even in a cloudy sky. This is because a certain amount of ultraviolet light penetrates the clouds and the sun's part of the sky is always about 5% brighter in the ultraviolet than the rest. This difference is enough for the bees to pinpoint the sun on the cloudiest day.

Putting things in perspective

A facet is a part of the cornea, a transparent area of the cuticle. Beneath this may be a crystalline cone, a hard refractive body, which in combination with the facet of the cornea forms a real image of what ever lies in front of it (Figure 2). Some dragon flies are said to have nearly 30,000 facets in each eye, which makes sense because they

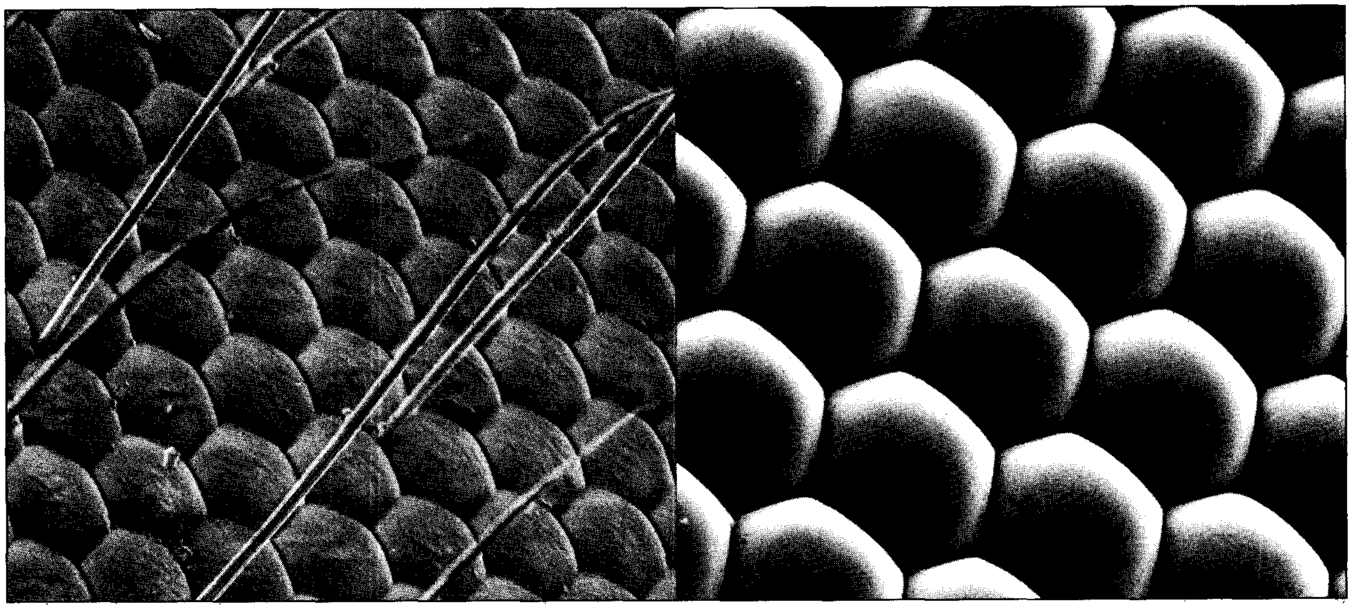


Figure 3. Scanning electron picture of a moth eye (3a) and a house-fly eye (3b) taken on an 840A JEOL microscope.

hunt in flight. Butterflies and moths, which do not hunt in flight, only have 12,000 to 17,000 facets (Figure 3a). The true house-fly must be content with only 4,000 facets (Figure 3b).

Insects cannot close their eyes; they rest with them open. Their vision is believed to be sharp only to a distance of 2 to 3 feet (51 to 91 cm). Insect eyes have no way of focusing to achieve a sharper image; they depend on an increase in the number of individual mini-eyes for an increase of sharpness much as a printer relies on a fine halftone screen to print the tiny dots that make up a sharper picture with a wealth of detail.

The familiar lens of glass that we use in cameras, microscopes, and the like, is made from material with a uniform refractive index. The bending of light rays to form an image is then determined by the curvature of the various surfaces and the distance between them. The cornea and the crystalline cone of the insect eye is a laminated structure, made like the layers of an onion. The refractive index is greatest along the axis and least toward the sides. As a device for bringing light rays to a focus, the lens-cylinders system of the insect eye is thus more complicated than that of the simple lenses made by man.

Marge Elwell and **Lisa Wen** are both development engineers at Hughes Aircraft, Carlsbad, Calif. Elwell is president of the Optical Society of San Diego.

Auto-random-dot stereograms

We perceive depth in our normal vision because our brain stereoscopically combines the two slightly different views from our horizontally separated eyes. Although there are other (monocular) depth cues such as shading and perspective, humans are particularly receptive to this binocular disparity. In fact, picture pairs (or stereograms) can induce stereopsis when they are contrived binocular disparity.

Typical stereograms, such as 3-D movies, contain several monocular depth cues because each component image forms a realistic, two-dimensional scene when viewed separately. Conversely, random-dot stereograms combine two seemingly random black-and-white patterns of dots, which, when viewed stereoscopically, produce a three-dimensional figure solely on the basis of binocular disparity.[1] Because of the lack of several interacting depth cues, it may take several minutes for the observer to recognize depth from the random-dot patterns, while it only takes milliseconds to perceive ordinary stereograms.

While most stereograms require special viewing equipment, such as polarized glasses or color filters, the auto-random-dot stereogram[2] in Figure 1 works by free viewing. In this case, you must only focus your eyes correctly on a single pattern of "random" dots to perceive a three-dimensional scene. You may have already experienced a simple version of this type of stereopsis if you've ever looked at a repetitively tiled floor and had the disconcerting sensation of seeing the tiles floating above your feet.

Lenore Pugliese has a Ph.D. in Optics from the University of Rochester. Her interests include real-time holography, computer-generated holography and 3-D computer display.

To view the auto-random-dot stereogram in Figure 1, focus your eyes on the page while holding a pencil between the stereogram and your eyes. You should see two misfocused pencil images. Move the pencil to align the blurred images with the two fixation markers—the heavy black dots—on the stereogram. Then, without moving your eyes, focus on the pencil. The two blurred pencils should converge into one sharp image that points at the central spot of three blurred markers. Continue focusing on the pencil until the central spot sharpens in focus. (This may take seconds or minutes.) When this happens, you should begin to see the raised checkerboard pattern.

The fixation markers are separated by the convergence distance. This distance is the amount by which the image in the left eye is shifted from the image seen by the right eye. As you saw in trying to view the stereogram, each eye sees both markers, but they are shifted horizontally such that only the right marker in the left eye's image overlaps the left marker in the right eye's image. Thus, you saw three markers at correct convergence. In fact, each eye sees its own view of the entire stereogram shifted with respect to the other by the convergence distance. These two views correspond to the two sides of a stereo pair. However, unlike a standard stereogram, both views are identical, so the single dot pattern itself contains the depth discontinuity information.

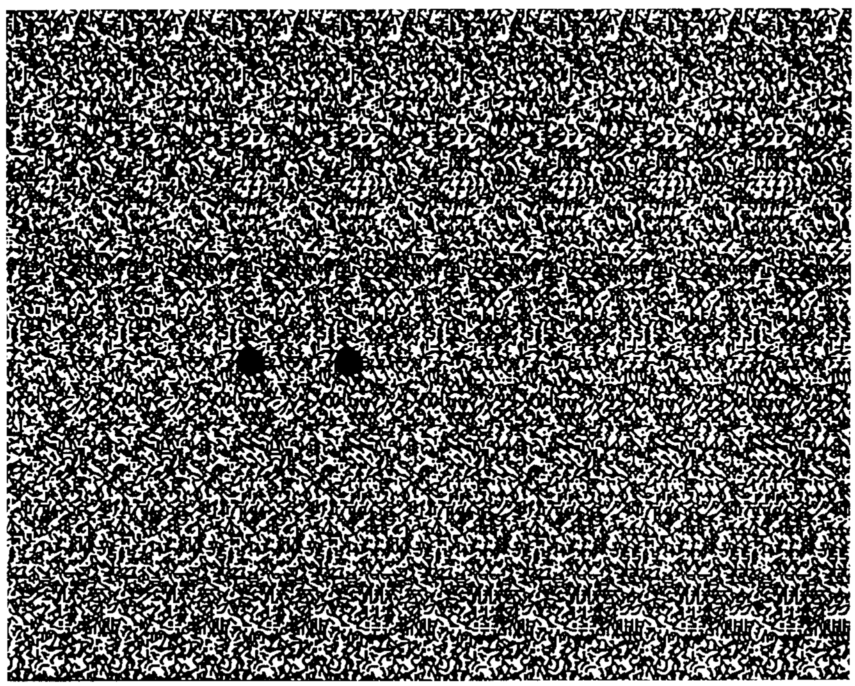


Figure 1. A raised checkerboard pattern appears from this auto-random-dot stereogram. Viewing instructions are given in the text.

Depth is encoded into the stereogram by assigning a nearly random pattern of black-and-white dots to each row of the stereogram array with a length corresponding to the convergence distance. This pattern repeats itself along the row until a depth discontinuity is encountered. The pattern is interrupted by a number of dots

Continued on page 62

Crosstalk—from page 7

3. J. Bronowski, *Magic, Science, and Civilization*, Columbia University Press, New York, 1978, 46-49.
4. G. Ifrah, *From One to Zero*, Viking Penguin, New York, 1985, 475-484.
5. T.S. Kuhn, *The Structure of Scientific Revolutions*, New American Library, New York, 1986, 16.
6. P. Medawar, *The Limits of Science*, Oxford University Press, Oxford, 1984, 9-11.
7. J. Fauvel, *et al.*, *Let Newton Be!*, Oxford University Press, Oxford, 1988, 127.
8. M. Kline, *Mathematics: The Loss of Certainty*, Oxford University Press, New York, 1980.
9. On the modern ill of incessantly seeking instant gratification, my sole comment here is to nudge the reader to a splendid essay: R. Rosenblatt, "Snuff this book! Will Bret Easton Ellis get away with murder?" The New York Times Book Review, Dec. 16, 1990, 16.
10. J. Bronowski, *op. cit.*, 12.
11. "Attitudes toward scientists," Optics and Photonics News, September 1990, 34.
12. J. Fauvel, *et al.*, *op. cit.*, pp. 38, 79, 151.
13. J. Gleick, "The man who reshaped geometry," New York Times Magazine, December 8, 1985, 64+ (especially p. 123).
14. T.S. Kuhn, *op. cit.*, p. 16.
15. S.G. Bush, *et al.* (eds.), *Maxwell on Saturn's Rings*, MIT Press, Cambridge, Mass., 1983, 22-23.
16. "Fraud in the lab needs policing, say researchers," R&D Magazine, October 1990, 146-150.
17. "R.S. Wolff replies," Computers in Physics, November/December 1990, 581.
18. "Pork barrels and test tubes: Mixing politics and science," Optics and Photonics News, November 1990, 31-32.
19. D. Shapley and R. Roy, *Lost at the Frontier*, ISI Press, Philadelphia, 1985, 18-22.
20. "Export rules spawn uncertainty, confusion," Optics and Photonics News, December 1990, 60.
21. J. Bronowski, *op. cit.*, p. 69.
22. J. Bronowski, *op. cit.*, p. 81.
23. W. Whewell, *History of the Inductive Sciences*, 3rd ed., John W. Parker and Son, West Strand, 1857, Book VIII, Chap. II.

Engineering—from page 52

manufacturing environment. Restoring American competitiveness requires putting increased emphasis on high quality efficient manufacturing methods.

- Engineering problems are rarely as "clean" as a course's homework problem set. Advanced courses should involve engineering trade-offs, including the ambiguities that usually accompany real engineering tasks.
- Participation in cooperative education programs and development of summer student internship programs must be encouraged and expanded.

Education—from page 53

week and was consequently more intensive. Future workshops, following the 1990 format, will likely be held every two years beginning in 1992. Proceeding of the 1990 workshop was videotaped and copies are available. For further details, please contact the authors.

Acknowledgements

CHTM is an interdisciplinary organization with a central mission to support research, advanced study, and technology transfer in optics and optoelectronics. Overall management of both workshops was handled by John G. McInerney and Steven R.J. Brueck, with assistance from Vivienne H. Mattox of Management Plus Inc. The authors are grateful to her and to the technical and administrative staffs of the Center for High Technology Materials for extensive logistical support before and during each workshop. We acknowledge financial support from the National Science Foundation through contract numbers USE-8854282 and USE-8954342. Finally, we thank all the workshop alumni for their enthusiastic participation and follow-up.

Light touch—from page 59

proportional to the perceived height of the discontinuity. A new pattern arises from the remaining dots that continues until the next depth discontinuity is reached. Following this recipe, crude stereograms can be made using a typewriter. The more sophisticated stereogram in Figure 1 was produced by David G. Stork at Stanford University using a Macintosh computer. Using his program,[3] a typical stereogram containing 18,000 dots takes only a few minutes to create. According to Stork, future auto-random-dot stereograms will use gray levels and color to enhance the 3-D effect.

References

1. B. Julesz, *Foundations of Cyclopean Perception*, University of Chicago Press, 1971.
2. C.W. Tyler, "Sensory processing of binocular disparity, in *Vergence Eye Movements: Basic and Clinical Aspects*," C.M. Schor and K.J. Ciuffreda, eds., Butterworth, Boston, 1983.
3. D.G. Stork and C. Rocca, "Software for generating auto-random-dot stereograms," Behavior Research Methods Instruments and Computers **21**, 1989, 525-534. Also see the inside front cover of "Seeing the Light," by D. Falk, D. Brill and D. Stork, Wiley, 1988.

Advertisers' index

Abstract deadlines

March 4: OSA Coherent Laser Radar Topical Meeting, July 8-12, Snowmass, Colo.

March 15: OSA Photorefractive Materials, Effects and Devices Topical Meeting, July 29-31, Beverly, Mass.

March 28: OSA Nonlinear Guided Wave Phenomena Topical Meeting, Sept. 2-4, Cambridge, UK

April 5: Optical Amplifiers and their Applications Topical Meeting, July 24-26, IEEE-LEOS/OSA, Snowmass, Colo.

May 1: OSA Persistent Spectral Hole-Burning Science and Applications Topical Meeting, Sept. 26-28, Monterey, Calif.

The blue arcs: An electrifying visual phenomena

Editor's note: Take time out for "The light touch," an OPN column meant to be shared with students and children of all ages.

The proliferation of red LEDs on electronic equipment of every sort has made it easy to observe one of the more interesting entoptic phenomena. Normally, visual experiences are caused when light stimulates the retina, the network of nerve cells at the back of the eye. Entoptic phenomenon are produced when something other than light stimulates the retina. Thus, if you gently poke the side of the eye with your lids closed, you will see a spot of light on the opposite side of the visual field. This so-called pressure phosphene is caused by mechanical stimulation of nerve cells.

A wide variety of interesting effects are produced when an electric current is run through the eye, but this is not generally recommended as a casual demonstration. However, there is one effect of electrical stimulation that can be seen in complete safety. For this you need to find one of those red LEDs (try your camera's flash unit, your stereo system, VCR, etc). When you have an LED, look at it in a dark room with one eye. If you use your right eye, you should see one or two blue arcs emerging from the light source and ending somewhere to the right. The arcs will go in the opposite direction in the left eye. If you move your eyes so that the red light falls in different spots in the visual field, you will see the arcs move and change,

JEREMY M. WOLFE, associate professor, Department of Brain and Cognitive Sciences, Program in Psychology, MIT.

Figure 1 **The blind spot**

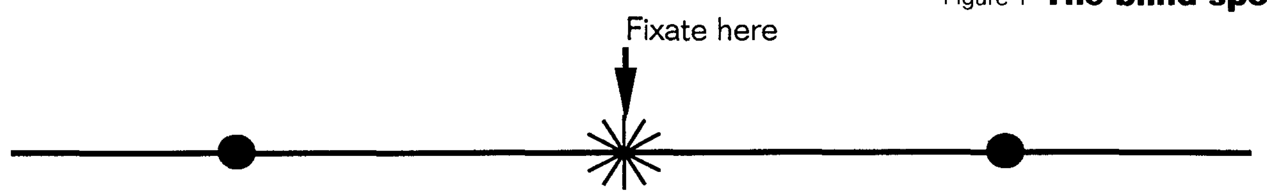


Figure 2 **The wiring of the retina**

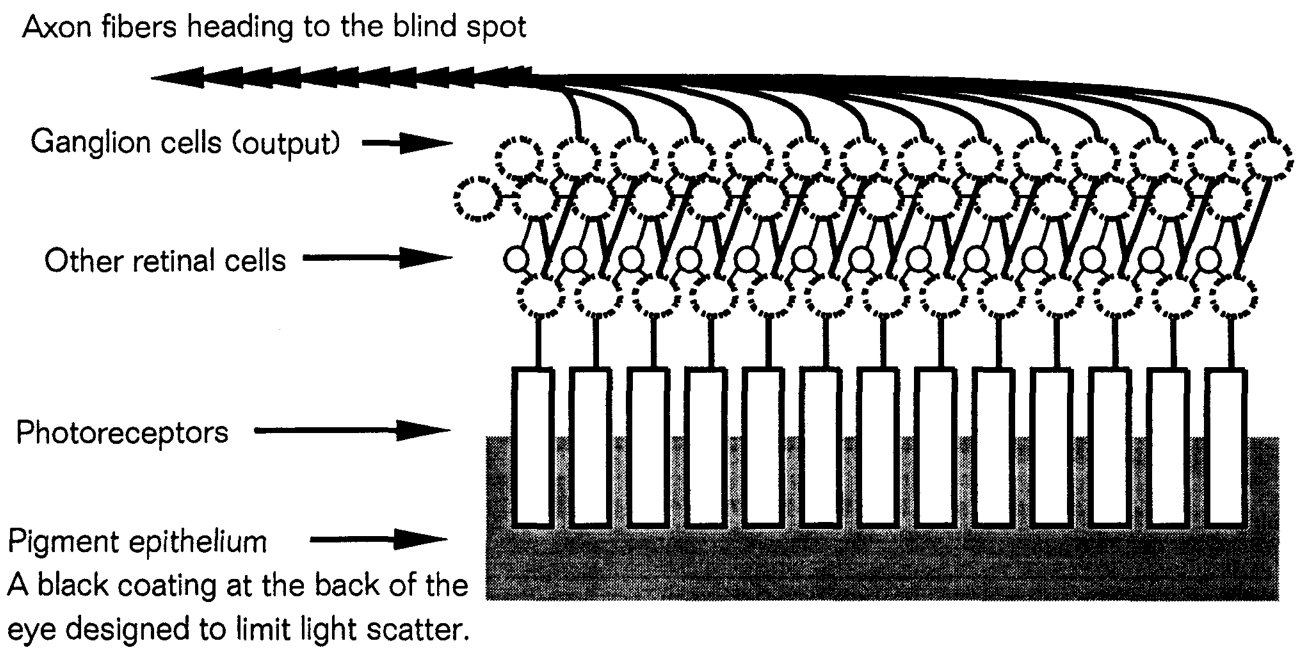
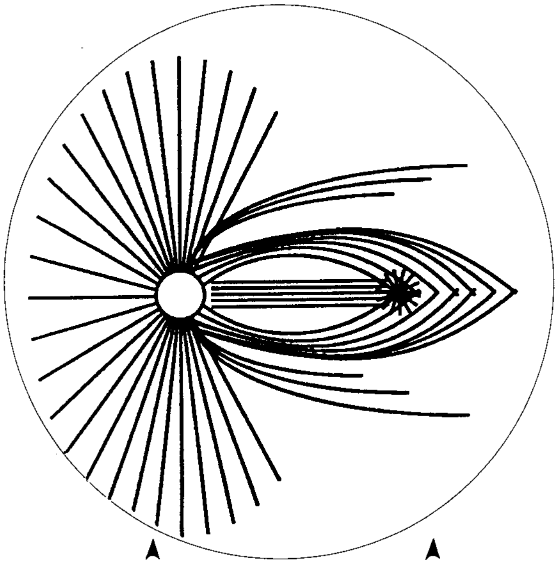


Figure 3
Axons heading to the blind spot



ure 1). Cover your left eye and look at the *. Now move the page closer to you until the black spot to the right moves into the blind spot and vanishes. The blind spot is in the mirror-reversed position in the other eye, so if you close the right eye and open the left, the spot on the right will reappear and the spot on the left will vanish.

You have a blind spot because the retina is built backwards from the design suggested by common sense. Figure 2 illustrates this with a cartoon slice through the retina. Light comes down from the top of the page. To reach the photoreceptors and initiate vision, light must pass through the ganglion cells and other nerve cells of the retina. The axons of the ganglion cells lie on top of the ganglion cell bodies and form the optic nerve. Axons from all parts of the retina must travel to the blind spot (Figure 3). Most take a straight path, but passing axons would interfere with our best vision if they ran across the fovea—the part of the retina corresponding to visual "straight ahead." To avoid the fovea, the axons from cells in the fovea and adjacent regions sweep out two arcs with shapes that look like the shapes of the blue arcs (Figure 4). If you place the red spot elsewhere in the visual field, you will get different blue lines corresponding to the axon path from that location to the blind spot.

So why can you see the path taken by the stimulated axons on their way to the blind spot when you look at a red spot in the dark? Though the exact mechanism is unclear, it is most likely that the electrical impulses, traveling from a normally stimulated part of the retina, abnormally stimulate the retina along their path to the optic nerve. Like other forms of abnormal stimulation, this is seen as light—in this case, as blue arcs.

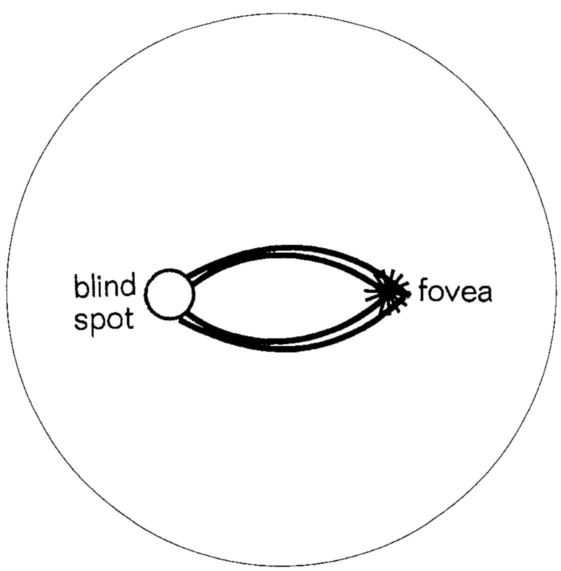
It is not known why the arcs are blue. Perhaps it is comparatively easy to stimulate the pathways carrying information from the short wavelength cones. The fact that they are blue, however, helps to explain why a red light is the best inducing stimulus. Any color light can produce the arcs, but the arcs are dim and are easily hidden by glare or scattered light. Red light stimulates different nerve cells and will interfere least with the perception of a weak blue stimulus. Many everyday stimuli must produce the arcs, but they will be lost in the glare of the more mundane stimulation.

too. However, they will always end in about the same location.

The effect was first described in 1824 by Jan Purkjinje, a great Czech scientist. It could be known as Pukinje's Arcs, but Purkinje already has so many effects named after him that it is probably just as well that this effect is known simply as the blue arc phenomenon.[1] Three obvious questions spring to mind: What causes the arc? What determines its shape? Why is it blue?

The central clue to the cause of the arc came from an understanding of the shape. All the arcs in one eye end in about the same place. With a little further investigation, you can prove to yourself that those arcs end at the blind spot. You have a blind spot in each eye because all of the nerve fibers (axons) that carry information from the retina to the rest of the central nervous system leave the eye at a single location. At that location, there are no photoreceptors and, thus, no possibility of vision. If you have never seen a blind spot demonstration, we have provided one ihe middle of the facing page (Fig-

Figure 4
The blue arcs



Perception is No Accident

Seeing is believing, right? Or is it? Look at Figure 1. To most people, the square region in the center looks brighter than the surrounding white area, but actually they're physically the same. To many, the square region appears to be a flat surface that sits above the rest of the figure and partially covers the lines. The illusory surface has clear illusory contours (edges) that delimit it. Figure 2 was created by adding lines that terminate at the same points as the lines in the first figure, one being added for each line in the first figure. But now the illusory surface and illusory contour are much weaker. Why? After all, the endpoints of the lines are still just as nicely lined up as the previous figure, there are still just as many points of contact to "guide" the illusory contour, and they are spaced apart in the same way as in the previous figure. In fact, since we have added more lines, we might reasonably expect the illusion to be strengthened instead of weakened.

Similarly, in Figure 3, an illusory square appears to be covering the black "Pacman" regions. But when a little more black is added to that figure so that the sharp convex corners of the pacmen are smoothed out (*i.e.*, the corners where the outlines of the Pacmen meet the illusory edges of the surface), as in Figure 4, then the illusion is again weakened.

One explanation of these observations is based on the principle of "genericity." Consider the Necker cube in Figure 5. It appears to be a picture of a three-dimensional object (*i.e.*, a cube), even though it is only a set of lines on a flat page. Figure 6 also could be an image of a "wire frame" cube in a three-dimensional space, but people rarely see it that way. Instead, most people see this figure as flat.

What makes some collections of lines look like a picture of something

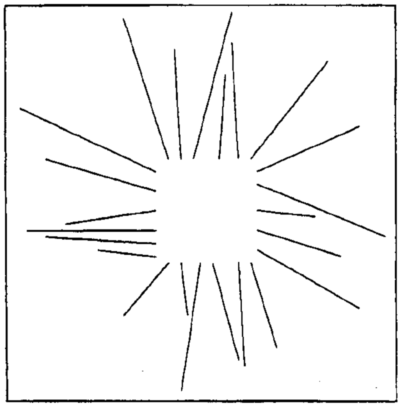


FIGURE 1

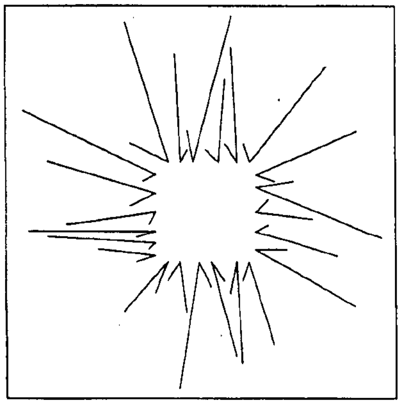


FIGURE 2

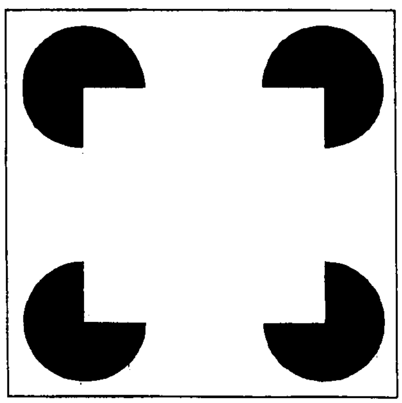


FIGURE 3

three-dimensional, while others just look flat? Figure 6 could be an image of a cube, but in such an interpretation our line of sight would have to be exactly aligned with one of the diagonals of the cube. According to the principle of genericity, a collection of lines (or regions) in an image will be more likely to appear three-dimensional if they represent "generic" as opposed to "accidental" views of a three-dimensional scene. Thus, in Figure 6 there is an accidental coincidence of two distinct corners of the cube, and this destroys the three-dimensional percept.

In Figures 1 and 2, we can understand, by using the principle of genericity, why the first display can produce an illusory surface that appears to partially cover the lines while the second one cannot. In the second display, the edges of the (potential) illusory surface would go right through the intersections of the inducing lines. If the illusory edges were perceived as being closer to the observer than the inducing lines, then the observer would have to be looking at the scene from an accidental viewpoint. (For a similar example involving "neon color spreading," see page 88.)

A similar idea explains why there is no occluding surface perceived in Figure 4. In general, when one object occludes another, the image of the occluded object has a sharp convex corner at the point where its boundary meets the boundary of the occluding object. Only from an accidental viewpoint could the boundary of the occluded object go smoothly into the boundary of the occluding one. This fact makes it highly improbable that there could be an occluding surface in Figure 4, and most human subjects do not perceive one.

Still, many subjects do perceive weak illusory edges in Figures 2 and 4. However, they describe these edges as being at approximately the same depth as the inducers, not as occluding them.

A number of theories of illusory contours have been proposed. Rock and Anson[1] proposed that illusory-contour perception is a two-stage process. First, something cues a figure-ground reversal: In the "literal" percept, all of the black elements are seen as figure, and all of the white area is seen as ground. But when the

Marc K. Albert *and* **Donald D. Hoffman** *study vision at the University of California at Irvine.*

illusory surface is perceived, it is seen as figure, and all of the black elements along with the surrounding white area is seen as ground. In the second stage of the process, the visual system checks the display for its consistency and compatibility with the hypothesis of an occluding illusory surface.

Gregory[2] claims that the human visual system, using the probabilistic information available to it, selects perceptual interpretations on the basis of what is the most likely state of the external world. According to Gregory, an illusory surface is perceived in Figure 3 to "account" for the "gaps" in the inducers. In other words, the visual system has decided that this is the most likely state of the external world.

The view proposed by Kanizsa[3] is that the Gestalt principles of perceptual organization can explain illusory contours. According to this theory, perceptual interpretations that maximize "simplicity" and "regularity" are favored by human vision. Thus, in Figure 3, we prefer to see four complete circles that are partially covered by a square, rather than four Pacmen.

Coren[4] claims that when depth cues in a display allow the visual system to construct a "simpler" perceptual organization by introducing an illusory surface, then an illusory surface will be perceived. So, in Figure 3 it is argued that the depth cue of "interposition" is present, and this allows the perception of four complete circles that are partially covered by an illusory square. The central claim here is that the presence of depth cues is necessary for the perception of an illusory contour.

Grossberg and Mingolla[5] proposed a neural network model of the human visual system. In their theory, illusory contours occur because of short-range competitive interactions and long-range cooperative interactions that are fundamental to all contour-generating processes within the visual system. The contours generated by these interactions define boundaries for diffusive "filling-in" processes that allow the contour to be perceived.

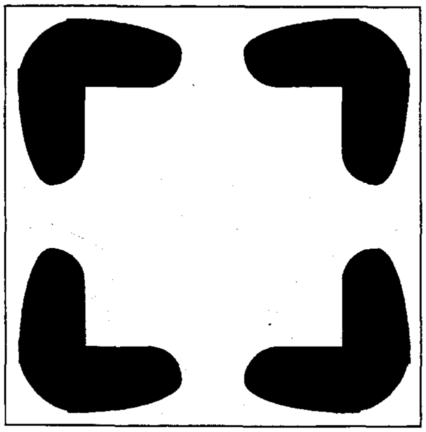


FIGURE 4

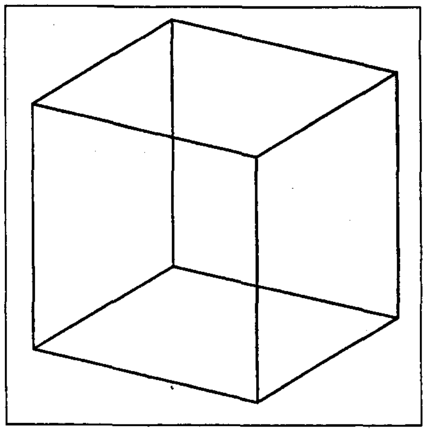


FIGURE 5

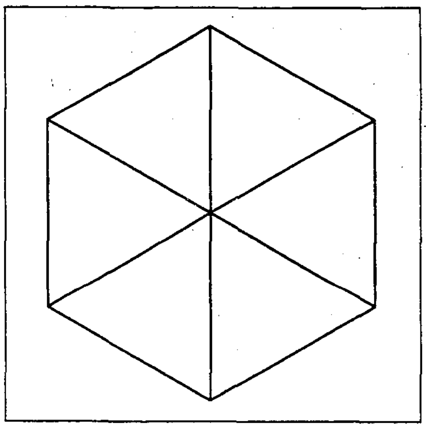


FIGURE 6

According to Kanizsa, a tendency toward "closure" of lines can explain illusory contours generated by line endings. His theory can also account reasonably well for the effects seen in Figures 1 and 2. On the other hand, our fundamental assumption is that the human visual system generally prefers perceptual interpretations that are more likely to "correspond" to the actual state of the external world. This assumption is based on the idea that human vision is biased toward perceptual interpretations that are useful for survival. It means that in the face of uncertainty, human vision must resort to whatever probabilistic information it has at its disposal to decide which, among the logically possible perceptual interpretations of an image, is most likely to be "correct." This is central to the cognitive approach to perception proposed by Gregory. One source of probabilistic information, based on this viewpoint, leads to the generic viewpoint assumption. Kanizsa's theory is not explicitly based on a preference for more probable interpretations. For this reason, we feel that the explanation based on genericity is more satisfactory.

Thus, it appears that human vision prefers to attribute coincidences that occur in images to "special" arrangements in 3-D (as long as they have a reasonable prior probability of occurring), rather than to its own viewpoint. Its prior probabilities about the arrangement of objects lead it to more readily accept, for example, that a bunch of "blobs" could be crowded around a square (*e.g.*, the blobs could be soft and flexible), than that the eye views the square and the blobs from an accidental viewpoint. So while accidents can happen, human vision prefers to maneuver around them if it can.

REFERENCES

1. I.Rock and R. Anson, "Illusory contours as the solution to a problem," Perception 8, 1979, 665-681.
2. R. Gregory, "Cognitive contours," Nature 238, 1972, 51-52.
3. G Kanizsa, "Contours without gradients or cognitive contours?" Ital. J. Psych. 1, 1974, 93-112.
4. S. Coren, "Subjective contours and apparent depth," Psych. Rev. 79:4, 1972, 359-367.
5. S. Grossberg and E. Mingolla, "Neural dynamics of form perception: boundary completion, illusory figures, and neon color spreading," Psych. Rev. 92, 1985, 173-211.

Don't Step on the Toys, Grandpa!

When I was about seven years old, we had to be very careful with toys on the floor, because my grandparents had trouble seeing them, and might step on them. This seemed strange to me, but then older people were a little strange in those days. Some would tilt their heads in funny ways when reading the paper and lots of others wore glasses as necklaces. Many adults would peer at fine print and bring it under a bright light to read it.

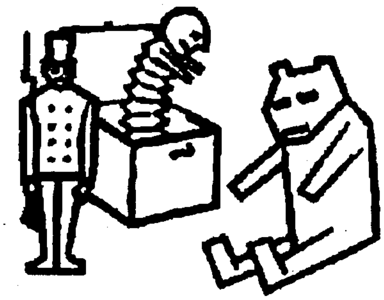
As a child, I never recognized these mannerisms as being more than oddities, but after I passed 40, I suddenly began to notice some of the same mannerisms in myself and my contemporaries. My husband tilts his head just like Grandpa did, so he can read with his bifocals. A friend wears glasses around his neck to read with, and I am forever losing my distance glasses because I have to take them off to read. I tried bifocals and they drove me bananas because I couldn't see the ground.

As I explained to my daughter, there are a couple things involved in this strange behavior. As most *OPN* readers know, but as your kids or grandkids may not know, our eyes have an auto-focus mechanism that degrades as we age. To demonstrate this, my kids and I experimented with how close we could hold a newspaper and still read it. My son doesn't wear glasses, my daughter wears a small correction, and I wear a small correction for distance. With each of us optimizing for distance, we found that I could bring the paper up to about 13 in., and my kids, the rats, could bring it to about 3.5 in. Next I tried the same test with my reading glasses on. I could see from about 10–33 in. My kids, wearing my reading glasses, could see from about 3–50 in. (They were delighted to have concrete evidence of teenage superiority.)

I let my daughter look through a camera lens and adjust the focus mechanism to see what the world looks like without auto-focus. I explained that accommodation is our ability to change the focus in our eyes the same way she was manually changing the focus with the camera. Because we parents can't adjust as well, we need to have an external adjustment. I normally don't wear glasses for reading, but do wear them for distance viewing; others wear reading glasses or bifocals. I had Jamie try looking at the floor while wearing my reading glasses, and she could see why we had to keep the floor clear for Grandpa.

Another factor in "Grandpa behavior" is depth of field. I had Jamie focus the camera on a block wall in our backyard. Then, with the aperture set to f/2, I had her bring in the camera focus until the wall was just out of focus enough that she lost the lines between the blocks. (Optimum focus was about 30 ft., and she lost the lines at about a 5-ft. setting.) Then she changed the aperture to f/16, and the lines popped back into focus. I explained that at any given distance setting, objects a little closer and a little farther are still in focus, but this effect is much stronger if the aperture is stopped down. To further demonstrate how the aperture setting changes the depth of field, you can also use an intermediate distance setting and have the child look at objects of varying distance.

To demonstrate the depth of field effect concept visually, we went into a fairly dark room, and Jamie closed her eyes to adapt them to the dark. Then, starting at about seven feet away, with reading glasses on, she approached me until she could read the paper I was holding. She then backed away until it was just out of focus. Next we turned on the bright lights in the room. She could see the paper come into focus as her pupils stopped down to adjust to the new



light level. (With my more limited accommodation, I could detect the increase in my range at both the near point and the far point.) She thought that effect was pretty neat, and then understood one reason that older people often peer at a paper and then move under a strong light.

I told her that different lens systems may have different depths of field. We set the camera at the shortest focus, and then put a pencil an inch from the lens. Jamie couldn't tell that the pencil was there at all, because the depth of field was not large enough for us to see it. In contrast to this system, one of the imaging systems at work has a fisheye lens with such a large depth of field that objects quite near the lens are in focus even when distant objects are in focus. Occasionally, a bird or spider sits on this camera yielding a wonderfully weird-looking image of clouds and the sky with a well-focused, huge-looking spider in the middle of the scene. (Talk about bugs in the system—or should I say arachnids?)

My daughter is nearly 15 and knew some of this from a camera class. For younger kids, you may need to adjust your approach. For example, in showing the effect of the aperture on the depth of field, you may have to show what an aperture is. This can be done by letting a youngster look at someone's pupils in a dimly lit room, and then turning on a bright light to see them constrict. Another variation is to do these experiments with a video camera. You can run the various experiments with live dialog, commenting as you stop down the aperture or adjust the focus. I'm not sure the kids learn it any better with the video camera, but they would certainly have fun with it.

Janet Shields, *an OPN contributing editor, is a development engineer at the Marine Physical Laboratories, Scripps Institution of Oceanography, University of California, San Diego.*

Feasting on Photons

BY VINCENT P. MALLETTE

Every second, 100 megabytes of information pours into each human eye. This visual storm is piped down the optic nerves—the densest communication channels in the universe—to the cortex, 100 billion cells roaring away at 10^{16} connections per second. What can that "teraflop Jello®" in our skulls do? For starters, it can apply a Laplacian to a two-dimensional Gaussian; it can move from low-bandpass to detect a car to high-bandpass to read the license plate; when Fourier methods fail altogether, as on a herringbone pattern, the eye goes effortlessly to a grouping algorithm that pulls out the vertical structure.

Tricks like these, coupled with our 10-million-hue color sensitivity and wraparound stereo vision, make human eyes the best on the planet. True, we can't read a newspaper headline at $\frac{1}{4}$ mile like the hawk, or see by the moonlight that filters down through 1,400 feet of water like the harbor seal, or react to a blur in 21 milliseconds like the fly (that's why they're so hard to swat), but we can marvel at the Andromeda Galaxy in "tele" mode, then go micro and watch that fly washing its face. When we tire of that, we can bat a baseball closing on us at 100 mph, or sedately judge vernier alignment to 2 arcsec.—a neat feat considering that the foveal cones subtend a fat 27 arcsec.!

Let's follow a swarm of photons from the outside world into our eye. First stop is the cornea, a fibrous but amazingly transparent tissue that must do without blood vessels and receives its oxygen just by diffusion. Most of the eye's focusing is done by the cornea—the lens just finetunes the image (it can achieve about a 6% tweak). This is why you can't see underwater—the water defeats 90% of the cornea's refractive action and leaves the lens with nothing to work on. (As an experiment, try reading a plastic sign with big letters under water. Even high-myopes like me are hopelessly farsighted when our corneas are awash.)

Assuming that the cornea has done its job, the muscles surrounding the lens await orders from the brain to change its convexity by the perfect amount for sharp focusing. How is that done? FM—feedback magic—as the engineers say.

Past the lens, the photons dodge the floaters—some of which have been with us since the womb—in the gelatinous interior of the eye. The moment of truth is now upon us; the photons are going to strike the retina. But wait, something is terribly wrong. The retina is inside-out! The light-sensitive cells are at the bottom, overlaid by a thicket of animal plumbing, the retina's life-support system.[1] It's the same for all vertebrates. We pay the price of backbone (some squids have topside retinas).

Experiments to try

Experiment: Catch a glimpse of your own much bescarred retina. Get a bright little penlight, cover the tip with blue cellophane, and toggle it in the corner of your eye in a dark room. You should get flickers of a vast, rivered, alien planet. Say hello—it's your retina. Where all the rivers come together is your blind spot, as big as 144 full moons and a complete secret to the human race until 1660.

While you've got your penlight handy, let's do another experiment. Punch a pinhole in a large sheet of aluminum foil, hold it close to your eye, and look at the sky (not the sun) through it. You are seeing your pupil. Don't believe it? Slip your trusty penlight under the foil and drench your covered eye with light. You will see the patch of sky contract in sympathy as you switch the penlight on. Physiological note: This "ganging" of the pupils is normal and healthy. Mismatched pupils are a sign of neurological damage.

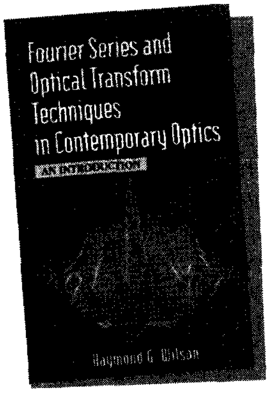
Back to the retina. After wending their way through floaters and vascular flotsam, the lucky photons deliver their packets of energy, hv, to the photoreceptor cells. The light energy drives protons against an electrochemical gradient and isomerizes rhodopsin in 200 fsec, about the fastest reaction known. And there's nothing wasteful about this process—the energy of a pea falling an inch, if completely converted into light, would provide a faint glimmer for every man, woman, and child who ever lived (that's 100 billion people).

When those poor little photons get to sacrifice themselves on the altar of rhodopsin, the image they build up is, of course, upside down. This is completely irrelevant, but it drives nonscientists crazy. In 1625, a man named Scheiner had to strip down an ox-eye from the rear to show the inverted image to nonbelievers.

To show this for yourself, take the leftover pinhole from your pupil experiment and hold a pinhead between the (brightly illuminated) pinhole and your eye. Be very careful—corneas heal like continents drift. Anyway, you will see a shadow of the pinhead oriented opposite to however you are holding it. The pinhead simply intercepts rays from the cone of light—there is no image for the lens to form. But when this shadow hits the back of the eye, it is formatted like anything else on the retina, and it looks "upside down." This is nothing to the formatting done by herons and ospreys, which have learned to "see" fish underwater *Continued on page 60*

alization of important ideas.

The reader is taken from basic periodic functions in one dimension through two-dimensional analysis of simple linear optical systems. The book provides a strong framework for applying Fourier analysis to coherent and incoherent optical imaging systems. Complex apertures including Seidel aberrations are addressed. A majority of the book's subject matter is supported with computer-based analysis using MATLAB® and SURFER®, with extensive discussion of the techniques used to generate the results.



The structure of the book provides a stepping stone to more in-depth texts and topics on Fourier analysis, including a large collection of references. This book is a necessity for anyone just learning about Fourier techniques.

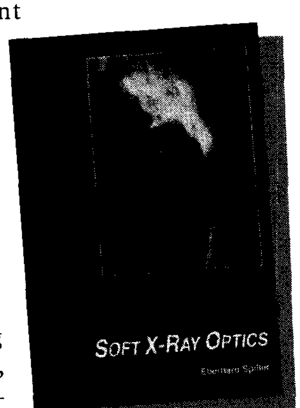
Mike Morrell, Optical Sciences Center, University of Arizona, Tucson, Ariz.

Soft X-Ray Optics

Eberhard Spiller, SPIE Press, Bellingham, Wash, 1994, 278 pp., $81.

A century after the discovery of x-rays in 1895 by Röntgen, Spiller's *Soft X-Ray Optics* details recent developments in optics primarily for the soft x-ray (1–500 Å wavelength) range. The book summarizes significant advances made in the last two decades on nanometer scale optical elements in the form of multilayer interference and zone plate structures that enable a wide range of applications over the 25–10,000 eV range.

The lack of significant refraction in the x-ray range, as noted by Röntgen himself, has prompted development of such reflective and diffractive structures to form lenses in the soft x-ray range, where they are beginning to be incorporated into optical systems used in numerous fields, including telescopes in astronomy, microscopes and microprobes in the physical and life sciences, cavity and transport optics in short wavelength lasers, and optics for future generation integrated circuit lithography research. Multilayers also extend polarization-sensitive techniques into the soft x-ray range. The new generation high-brightness synchrotron radiation sources are beginning to benefit from multilayers and zone plates in numerous ways.



The author, a leader in the development of this field, condenses recent experimental progress and classical optical theories into a rich volume directed at scientists, engineers, and students interested in understanding and exploiting these new capabilities. Introductory and background chapters include discussions of the optical properties of materials in the x-ray range, reviews of classical reflection and imaging optics and systems, and coherence and its relation to imaging. Later chapters delve into the details of zone plate and multilayer structures. The design, fabrication, testing, and application of zone plate and multilayer interference structures, all of which are made possible by technological advances in recent decades, are discussed in detail. Windows and filters for the soft x-ray region are also discussed, but diffraction gratings and detectors for soft x-rays are not covered.

In addition to placing these new optical developments in an interesting historical perspective, the book is rich with recent references in this rapidly evolving field. As such, it is a self-contained source that will allow both experts and novices to assess these new optical elements and their capabilities.

Jeffrey B. Kortright, Center for X-Ray Optics and Advanced Light Source, Lawrence Berkeley National Laboratory.

Capital Eye

Continued from page 14

is now in a state of suspension. It is well to be reminded of a eulogy on OTA given this correspondent by Joseph Coates, a Washington, D.C. consultant on technology assessment and forecasting. Coates was one of the earlier conceptualizers of OTA back in the 1960s.

"It is important to remember," he says, "that one of the reasons underlying the existence of OTA was that the Executive Branch systematically lied to Congress, which had little awareness that it was being lied to. But now that there's perceived to be less Executive Branch lying, there is less perceived need for OTA. But my bet is that they'll go right back to lying, and we'll be right back to the 1960s again. And the primary emphasis for information will be on stakeholders and lobbyists."

***Wil Lepkowski is a reporter for* Chemical & Engineering News.**

Light Touch

Continued from page 58

underwater unrefracted by the air–water interface; they can even tune out ripples.

There's an experiment I don't want you to try at home, but you should know about it as an example of the power of science to get at things indirectly. The frequency at which we perceive a blinking light to be continuous is somewhere around 24 hz (TV is 30 hz). It was thought that the nerve channels couldn't transmit the higher frequencies. But wait! Show a 100-hz blinkie to a subject whose scalp is excited with 101-hz current, and he or she will see the light dim and brighten at a 1-hz rate—classic heterodyning—proving that the nerve channels carry the 100-hz signal.

It is the brain that decides what we're going to be allowed to see; the laws of optics are just the beginning of comprehending the human visual system.

Footnote

1. To be fair, the color cones in the central 0.5 mm of the retina are rightside-up.

Vincent P. Mallette is a project coordinator at Georgia Institute of Technology, School of Physics, Atlanta, Ga.

When Too Much Knowledge is a Bad Thing

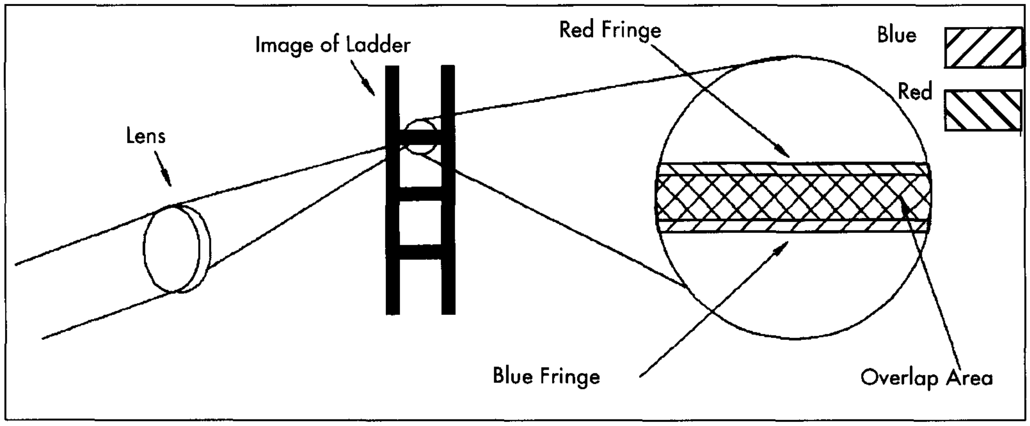
When chefs go out to dinner they notice when their garnish is wilted. And a dripping faucet in a plumber's house irritates its owner more than it would in the house next door. Do you think that postal people mind when they receive a piece of someone else's junk mail? I call these psychological nuisances that plague us "occupational aggravators," and I have a doozy.

As a lens designer, it is my job to ensure that a lens will produce a crisp and clear image that is free from aberrations of all kinds. Spherical aberration and coma are what I eat for breakfast every morning, but what really gets to me is my nemesis: Lateral Chromatic Aberration. Lateral color seems to pop up all over the place, and hopefully this article will provide the basis for some of you to sympathize with my occupational aggravator.

What is lateral color?

My job is to design lenses that produce images at a certain magnification. The specs are very clear. The image will be either larger, smaller, or the same size as the original object, according to the plan. White light that passes through the lens to create the image is made up of a spectrum of colors. Sometimes the amount of magnification of one light color is more than the magnification of another color, with annoying results.

For example, suppose that I want to make a one-foot image of a ten-foot ladder. On close examination, I notice that the image of the ladder in blue light is 11 inches, while the image in red light is 13 inches. This means that the red image of the top rung is slightly higher than the blue image of the same rung. In white light, the top edge of the top rung is red and there is no blue light, and the bottom edge of the bottom rung is blue with no red light. In the middle of the ladder image, the red and blue overlap and the color of the image is normal. I've been known to scream, "Arrgh, my image is ruined by lateral color!" Technically speaking, lateral color is the difference in the magnification of an image with respect to color.



The lens in the illustration is creating an image of a ladder. The image of the ladder in red light is slightly larger than the image of the ladder in blue light. One effect of this can be seen by examining the image around the top rung of the ladder. The image in red light is displaced from the image in blue light. Where the red and blue light overlap, the color of the image is normal, however, the top of the image will have a red edge, and the bottom of the image will have a blue edge.

Where to find lateral color

One of the most common contributors to my occupational aggravation is the overhead projector. Place a pencil on the stage where the transparencies go so that it is near the edge of the field of view. Focus the shadow cast on the screen by the pencil and examine its image on the screen. You should see a red outline of the shadow on the outside edge and a blue outline on its inside edge. Move the pencil to the middle of the field and the colored fringes will almost disappear. This happens because the difference in the magnification between the colors is exaggerated at the edge of the field and minimized in the center. Move the pencil around the field and see how the colored fringes become more and less apparent. With a little practice you will be able to see this aberration in every transparency you are shown and you can share my occupational aggravation. You won't pay attention in meetings.

Lateral color can also be seen at the movies, through binoculars, telescopes, and microscopes, in slide projectors, and in many other optical instruments. Some designs try to compulsively eliminate every noticeable bit of it, but that is too expensive to put into practical use very often. So, optics people like me are left to search the world for everyday images without lateral color, but at least now we are not alone.

Josh Cobb *is an optical systems engineer/lens designer with IBM's Optical Development Services, Poughkeepsie, N.Y., and co-author of* Light Action, *a children's book on optics.*

You can share the joy of exploring the world of optics by writing an article for "Light Touch" or by suggesting topics you'd like to see discussed. Contact contributing editor, Michael E. Knotts, Georgia Institute of Technology, School of Physics, Atlanta, GA 30332-0430; 404/894-3422; (fax) 404/ 894-9958; ph281mk@prism.gatech.edu.

Magic wands and more

BY MICHAEL E. KNOTTS

Here's a very simple demonstration that almost always seems toimpress children and adults. Make an image appear "out of thin air" by waving a "magic wand." There's no trick involved . . . just persistence of vision, which is our ability to retain an impression of an image for a short time after the source of light has disappeared.

AMAZING! . . . But True.

Make a "magic wand" from a wooden dowel (about 3/16 inch diameter is perfect) by cutting it to a convenient length (about 2.5–3 ft.) and painting it white or covering it with white tape. Then, set up a slide projector, and point it toward a dark background (don't use a *projection* screen!). For the most impressive effect, set the projector up in a dark, open area outside at night. Focus the projector at close range, so that the image is approximately 2–2.5 ft. wide. Use a well-exposed slide of an easily recognizable subject that has good contrast. Any slide will do, but the most stunning demonstration can be done with a light colored object photographed against a black background. With the projector intensity set to maximum, wave the magic wand back and forth rapidly through the plane of best focus. Voila! An image will appear, seemingly in thin air.

While we're on the subject of persistence of vision, here's another very simple demonstration. High quality grounded extension cords with a neon power indicator bulb are available from hardware stores and home improvement centers (yellow, with clear plastic connectors, made by Woods Inc.). Connect one of these cords to an outlet and twirl the end in a circle (2–3 ft. radius) in a dark room. Since the neon bulb glows only when the voltage exceeds a certain threshold (regardless of polarity), it pulses at 120 Hz; thus, the arc you see is chopped instead of continuous.

I'll leave you with an observation for your kids to explain, once they understand the neon bulb experiment. While chewing, look at a vacuum fluorescent display, such as the clock on a microwave oven. Explain the wavering image! Hint: most vacuum fluorescent displays are designed with persistence of vision in mind. Instead of lighting the entire display continuously, the segments are rapidly pulsed repeatedly in sequence (this is called multiplexing).

Photo by Michael E. Knotts

Projected image made visible by a "magic wand."

Michael E. Knotts, OPN *contributing editor, is postdoctoral research fellow in the School of Physics, Georgia Tech, Atlanta, Ga.; ph281mk@prism.gatech.edu.*