SPECIAL ISSUE: 169 BEST ILLUSIONS

SCIENTIFIC AMERICAN MIND

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THE SCIENCE OF PERCEPTION

169 BEST ILLUSIONS

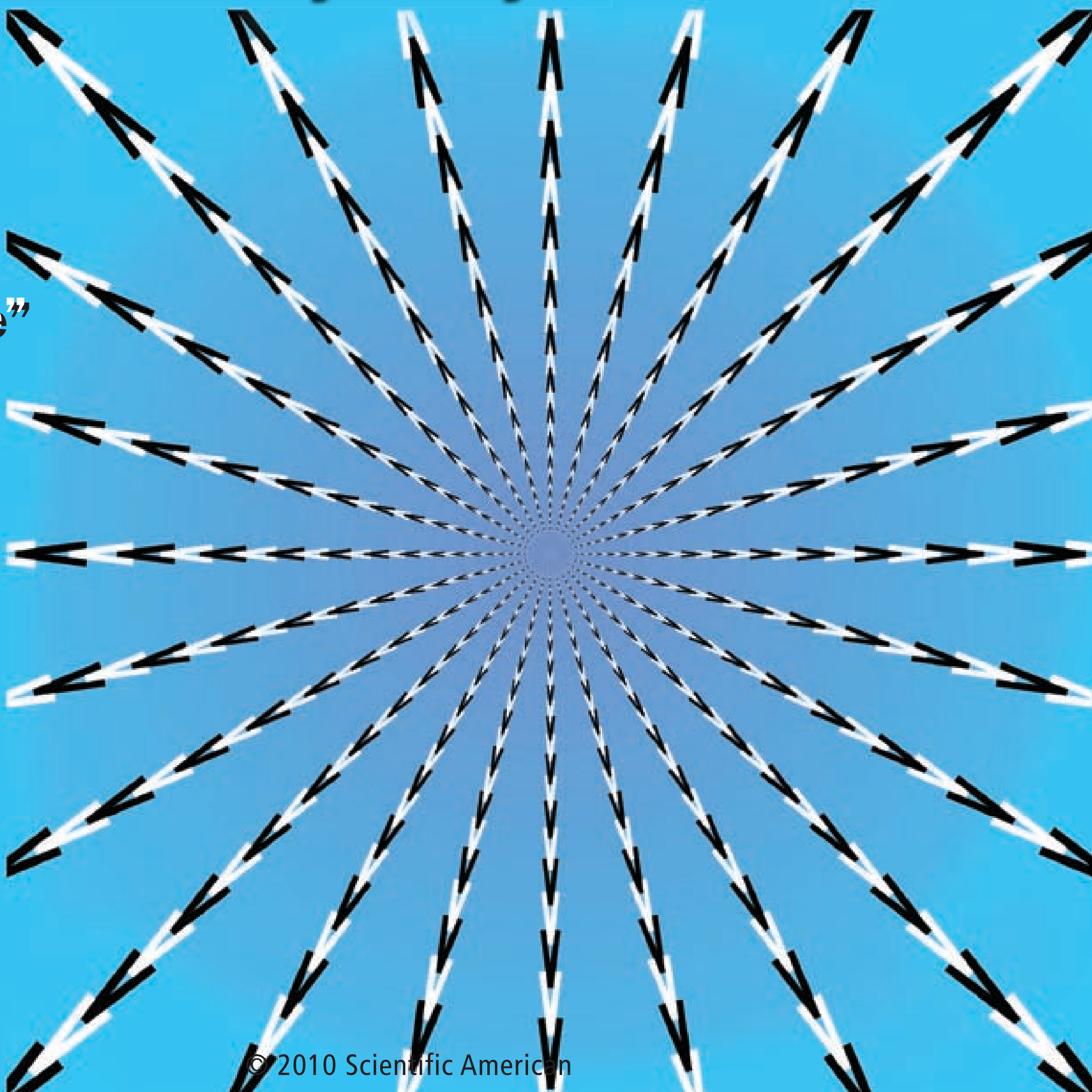
You won't believe your eyes

Illusory Motion
How It Arises

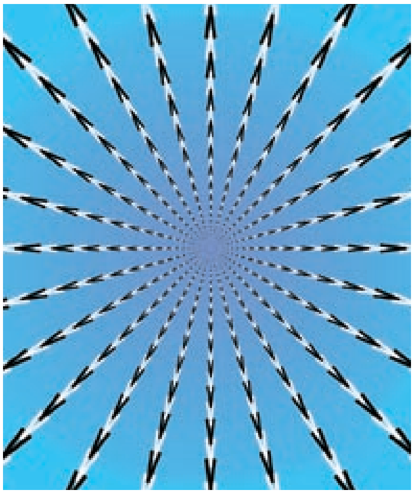
"Impossible" Figures
From Real Sculptures

Ghostly Visions
Effects of Afterimages

Morphing Colors
Hues That Shift and Spread



COVER IMAGE COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University*



Now See This

Who says science isn't fun? Visual illusions, such as the dozens you will find in this special issue, make great eye candy. But they also serve a serious purpose for researchers. How? Illusions push the mysterious and wondrous brain into revealing its secrets.

From the confusing and fragmentary inputs gathered by our senses, our brains create our seemingly fluid conscious perceptions and a sensible narrative of the world around us. Brains do not, however, *talk* to us about how they perform those impressive tasks. Scientists can learn a lot by using imaging equipment and by making other observations. But sometimes they also have to "trick" brains, the better to probe perception. That's where illusions come in.

"It is a fact of neuroscience that everything we experience is actually a figment of our imagination," write Susana Martinez-Conde, director of the Laboratory of Visual Neuroscience at the Barrow Neurological Institute in Phoenix, and Stephen L. Macknik, director of the Laboratory of Behavioral Neurophysiology at Barrow, in "The Neuroscience of Illusion," starting on page 4. "Although our sensations feel accurate and truthful, they do not necessarily reproduce the physical reality of the outside world." Martinez-Conde and Macknik, whose articles fill this special edition, study these disconnects between reality and perception for clues about the brain's operations. On the following pages you will learn, among other things, about "impossible" figures, 3-D visualization and kinetic illusions in op art.

Want more? Martinez-Conde is president of the Neural Correlate Society, which runs the annual Best Illusion of the Year Contest, sponsored by the Mind Science Foundation and *Scientific American*. This year's event took place on May 10 at the Philharmonic Center for the Arts in Naples, Fla.; attendees select the winners. For full details and to see articles and illusions by past winners, go to http://illusion-contest.neuralcorrelate.com.

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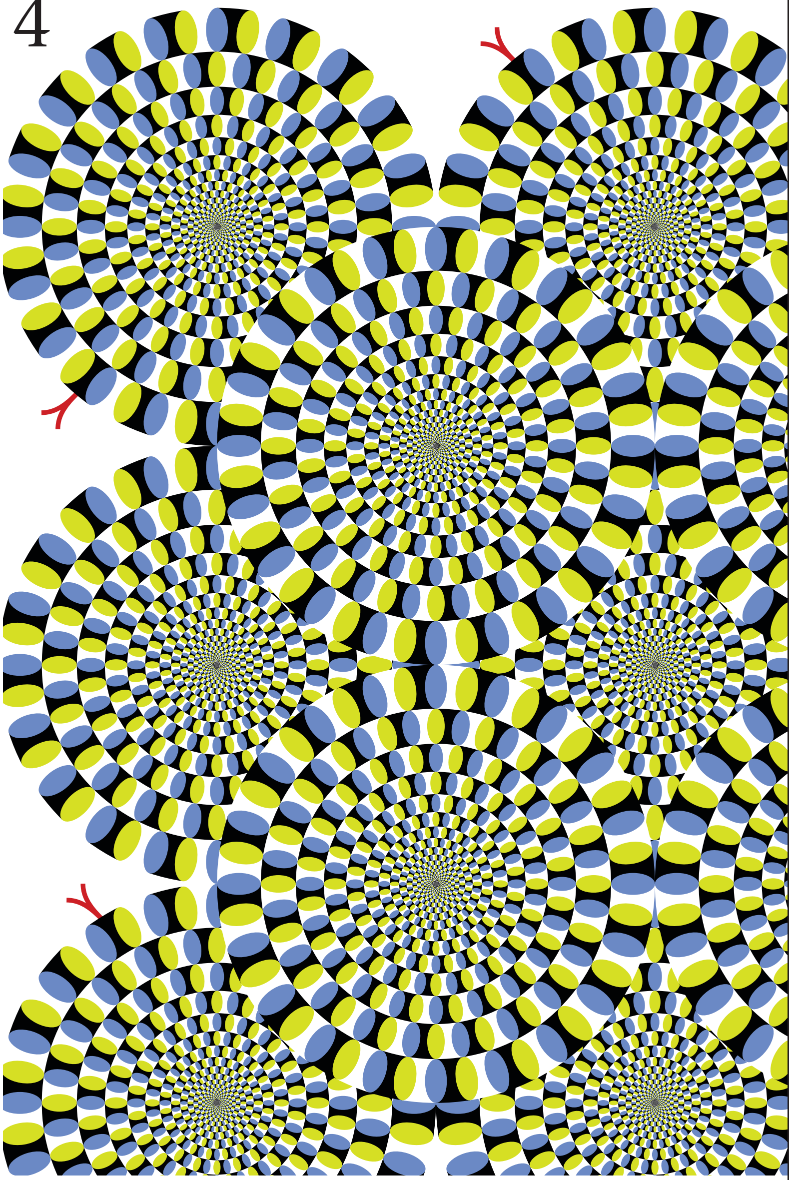

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Articles in this special edition are updated from Mind Matters, an expert-written online section of *Scientific American Mind*.

GAZING AT EACH OTHER

ART AND ILLUSION

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The Neuroscience of Illusion

How tricking the eye reveals the inner workings of the brain

By Susana Martinez-Conde and Stephen L. Macknik

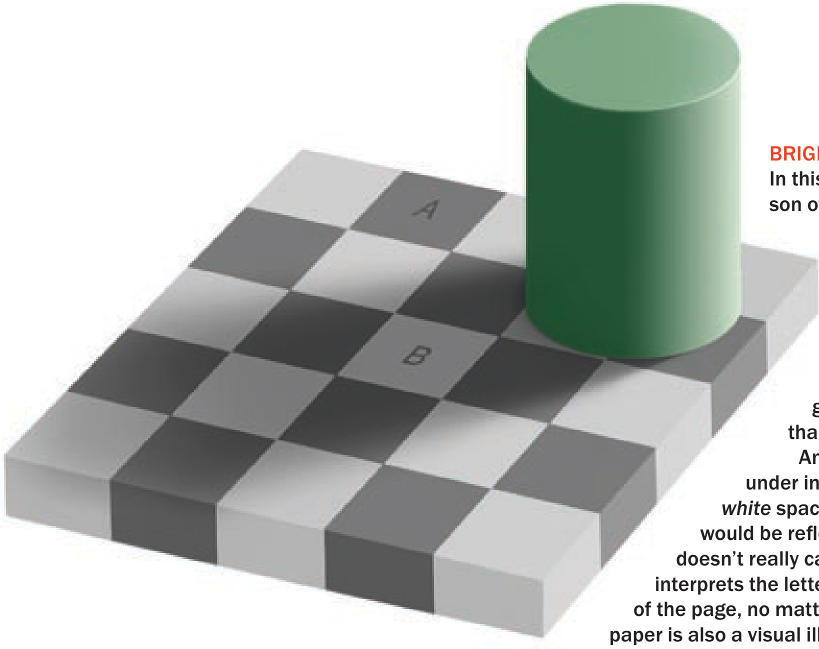
It is a fact of neuroscience that everything we experience is actually a figment of our imagination. Although our sensations feel accurate and truthful, they do not necessarily reproduce the physical reality of the outside world. Of course, many experiences in daily life reflect the physical stimuli that send signals to the brain. But the same neural machinery that interprets inputs from our eyes, ears and other sensory organs is also responsible for our dreams, delusions and failings of memory. In other words, the real and the imagined share a physical source in the brain. So take a lesson from Socrates: “All I know is that I know nothing.”

One of the most important tools used by neuroscientists to understand how the brain creates its sense of reality is the visual illusion. Historically, artists as well as illusionists have used illusions to gain insights into the inner workings of the visual system. Long before scientists were studying the properties of neurons, artists had devised a series of techniques to deceive the brain into thinking that a flat canvas was three-dimensional or that a series of brushstrokes was indeed a still life.

Visual illusions are defined by the dissociation between the physical reality and the subjective perception of an object or event. When we experience a visual illusion, we may see something that is not there or fail to see something that is there. Because of this disconnect between perception and reality, visual illusions demonstrate the ways in which the brain can fail to re-create the physical world. By studying these failings, we can learn about the computational methods used by the brain to construct visual experience.

Brightness, color, shading, eye movement and other factors can have powerful effects on what we “see.” In this series of images, we showcase several basic categories of visual illusions and what they can teach us about perception in the brain.

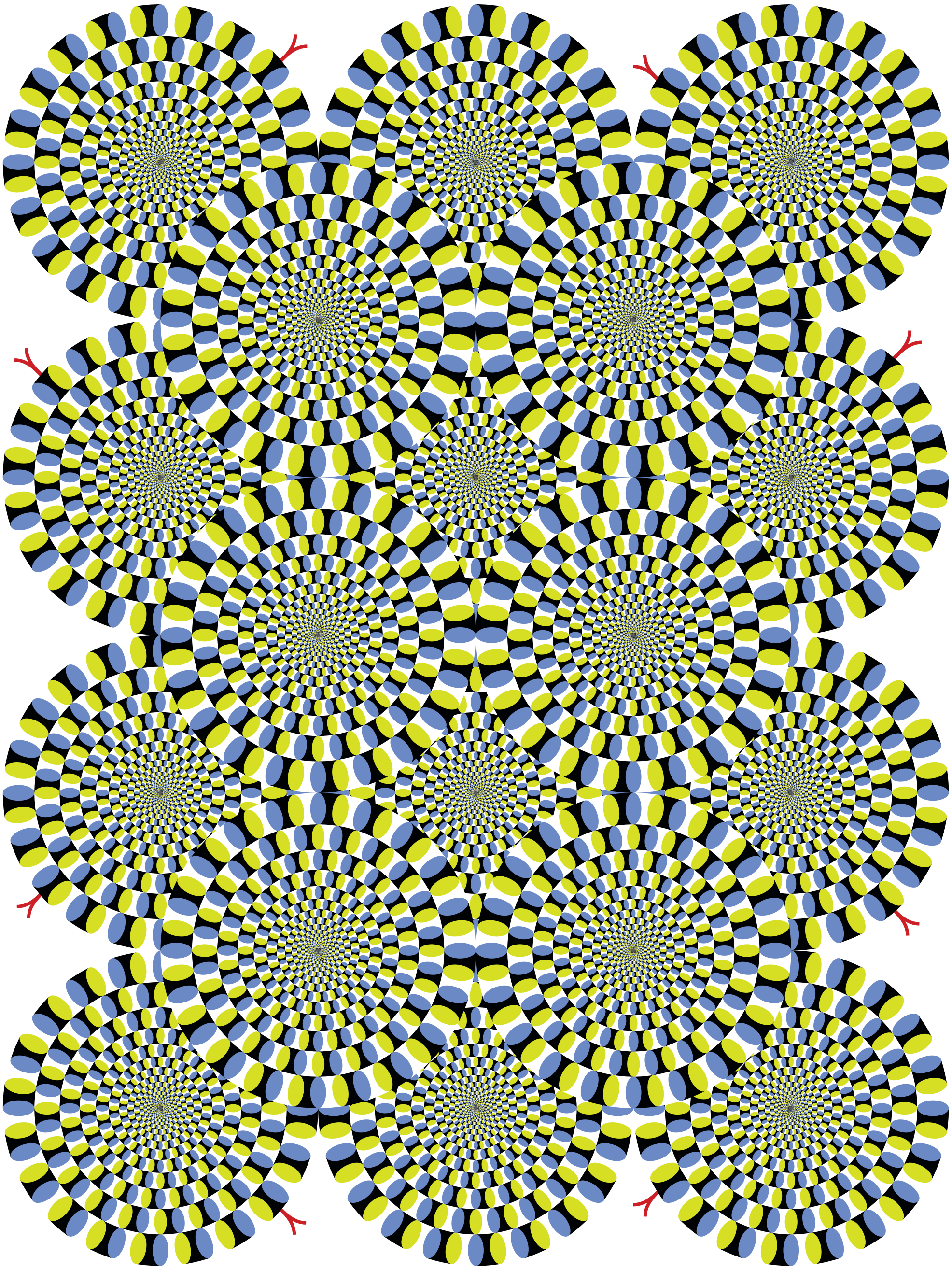
SUSANA MARTINEZ-CONDE and STEPHEN L. MACKNIK are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.



BRIGHTNESS ILLUSIONS
In this illusion, created by vision scientist Edward H. Adelson of the Massachusetts Institute of Technology, squares *a* and *b* are the same shade of gray. (If you don’t believe it, cut out the two squares and place them side by side.) This trick of the eye occurs because our brain does not directly perceive the true colors and brightness of objects in the world but instead compares the color and brightness of a given item with others in its vicinity. For instance, the same gray square will look lighter when surrounded by black than when it is surrounded by white.

Another example: when you read printed text on a page under indoor lighting, the amount of light reflected by the *white* space on the page is lower than the amount of light that would be reflected by the *black* letters in direct sunlight. Your brain doesn’t really care about actual light levels, though, and instead interprets the letters as black because they remain darker than the rest of the page, no matter the lighting conditions. In other words, every newspaper is also a visual illusion!

EDWARD H. ADELSON *M.I.T.*



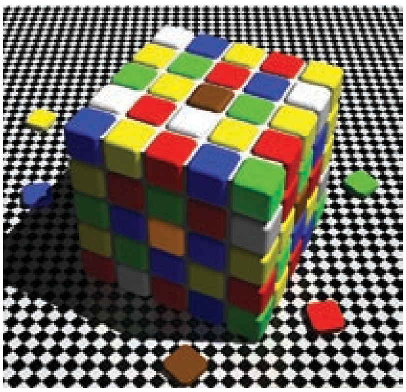
ILLUSORY MOTION

Some stationary patterns generate the illusory perception of motion. This unsettling effect is usually stronger if you move your eyes around the figure. For instance, in this illusion created by Akiyoshi Kitaoka, a professor of psychology at Ritsumeikan University in Japan, the "snakes" appear to rotate. But nothing is really moving other than your eyes!

If you hold your gaze steady on one of the black dots in the center of each "snake," the motion will slow down or even stop. Because holding the eyes still stops the false sense of motion, eye movements must be required to see it. Vision scientists have shown that illusory motion activates brain areas that are similar to those activated by real motion.

COLOR IN CONTEXT

This illusion, created by Beau Lotto and Dale Purves of Duke University, is another example of how the brain can perceive the same color differently when viewed in a different context. The central brown square on the top of the cube is exactly the same color as the central orange square on the side of the cube facing the viewer. The latter square looks orange because the lighting and surrounding squares make it appear brighter than the brown square in the mind's eye.



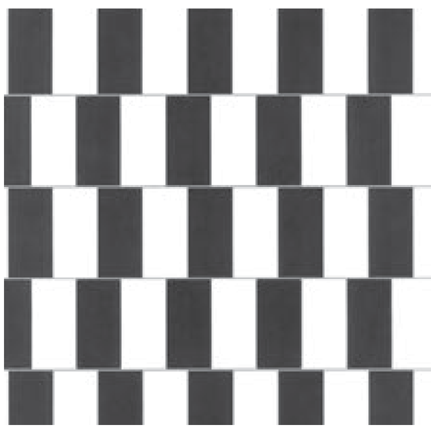
COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University* (*snakes*); BEAU LOTTO AND DALE PURVES *Duke University* (*cube*)

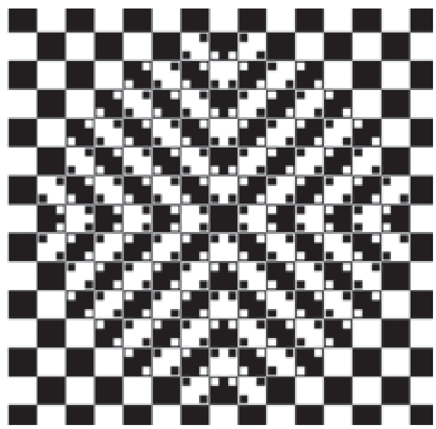
AMBIGUOUS FIGURES

This bunch of violets contains the faces of Napoleon Bonaparte, Marie Louise of Austria and their son. Can you find them among the flowers? Napoleon's admiring troops gave him the name of "*Petit Caporal,*" or "Little Corporal": their leader's short stature had not prevented him from defeating four armies larger than his own during his very first campaign. Years later, when Bonaparte was banished to the isle of Elba, he told his friends he would return with the violets, thus earning the nickname of "Corporal Violet, the little flower that returns with spring." When he broke his imposed exile to return to France, women supporters assembled to sell violets. They would ask passersby, "Do you like violets?" Answering "*oui*" indicated that the person was not a confederate; "*eh bien*" signaled that the respondent adhered to Napoleon's cause. Napoleon's supporters distributed reproductions of this 1815 engraving.

In ambiguous illusions such as this one, the brain interprets the same picture in two different ways, with the two interpretations being mutually exclusive. You can see one of two possible images, but not both at the same time.

These so-called ambiguous figures are especially powerful tools to dissociate the subjective perception from the physical world. The physical object never changes, yet our perception alternates between two (or more) possible interpretations. For this reason, ambiguous illusions are used by many laboratories in the search for the neural correlates of consciousness.





RICHARD GREGORY (*café and café wall illusion*); COURTESY OF AKIYOSHI KITAOKA (*bulge*)

SHAPE DISTORTION

The visual oddity above, known as the café wall illusion, was discovered on the exterior of a small restaurant near Richard Gregory's psychology laboratory in Bristol, England. (The photograph, taken a few months ago, shows Gregory outside the café.) Steve Simpson, a member of Gregory's lab at the time, noticed that the parallel grout lines between the green and white tiles on the wall appeared to be tilted, even though the tiles were actually straight.

Scientists use a simplified black-and-white version of the café wall illusion (*above, center*) to demonstrate how objects or patterns can appear to take on shapes that are different from their true physical form. The illusion works only when the contrasting black and white "tiles" are offset and when every tile is surrounded by a border of gray "grout." Because different types of neurons in the brain react to the dark and light shades of the tiles, the grout appears to be dimmer in some places and brighter in others—and the brain interprets this contrast as a sloping line.

As with brightness and color illusions, shape distortion effects are produced by the interaction between the actual shape of the object and the shapes of nearby figures. For the brain, perception is very often dependent on context.

In another illusion, created by Kitaoka, a circular section of black-and-white tiled "floor" appears to bulge out toward the viewer, even though the image contains nothing but perfect squares—and all the floor "tiles" are of equal size (*above, right*). As with the café wall, this geometric illusion is an example of shape distortion. The smaller, contrasting squares provide context that deceives the brain.

3-D ILLUSIONS

Visual artists often try to imitate reality closely. Painters convey the illusion of reality, volume or distance by making intuitive use of perspective, color, lighting and shadow. When they are successful, the artwork is sometimes difficult to distinguish from the subject itself.

Pliny the Elder, in his *Natural History* encyclopedia, narrated the legendary competition between two renowned painters in ancient Greece: Zeuxis and Parrhasius. Each of the artists brought a covered painting to the contest. Zeuxis uncovered his work: he had painted grapes so realistic that birds flew from the sky to peck at them. Convinced of his victory, Zeuxis tried to uncover Parrhasius's painting to confirm the superiority of his work. He was defeated, however, because the curtain he tried to pull back was Parrhasius's painting itself.

Such techniques were carried to the limit in trompe l'oeil, a French term that means "to trick the eye." This style of photographic realism first appeared in the Renaissance and flourished in the 17th century in the Netherlands. The lifelike pictures sometimes appeared to literally jump from the frame. In *The Attributes of the Painter,* a 17th-century work by Cornelius N. Gysbrechts, a painting appears to curl off the artist's easel (*above, left*).

The cupola of the St. Ignatius of Loyola church in Rome (*above, right*) is a great example of Baroque illusionism. The architect of the church, Orazio Grassi, had originally planned to build a cupola but died before finishing the church, and the money was used for something else. Thirty years later, in 1685, Jesuit artist Andrea Pozzo was asked to paint a fake dome on the ceiling over the altar. Although Pozzo was already considered a master in the art of perspective, the results he accomplished could hardly be believed. Even today many visitors to the church are amazed to find out that the spectacular cupola is not real but an illusion.

Architects soon realized that they could manipulate reality by warping perspective and depth cues to create illusory structures that defied perception. Need a big room in a small space? No problem. Francesco Borromini accomplished just that at the Palazzo Spada, a palace in Rome (*below, right*). Borromini created this spectacular trompe l'oeil illusion of a 121-foot-long courtyard gallery in a 28-foot-long space. There is even a life-size sculpture at the end of the archway. Not really. The sculpture looks life-size but is actually just two feet tall.

RÉUNION DES MUSÉES NATIONAUX/ART RESOURCE, NY (The Attributes of the Painter); SCALA/ART RESOURCE, NY (*cupola*); ANDREA JEMOLO *Corbis* (*Palazzo Spada*)

A Perspective on 3-D Visual Illusions

What the leaning tower and related illusions reveal about how your brain constructs 3-D images

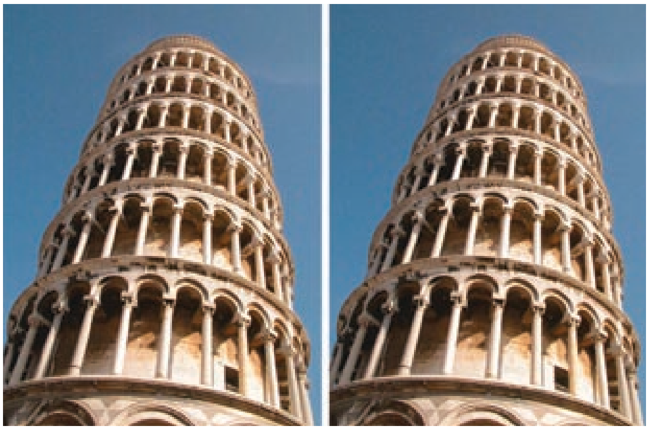
By Stephen L. Macknik and Susana Martinez-Conde

How could we have missed it? Hundreds, perhaps *thousands,* of visual scientists, psychologists, neuroscientists, visual artists, architects, engineers and biologists all missed it—until three years ago. The "it" in question is the leaning tower illusion, discovered by Frederick Kingdom, Ali Yoonessi and Elena Gheorghiu of McGill University. In this illusion, two identical side-by-side images of the same tilted and receding object appear to be leaning at two different angles. This incredible effect was first noticed in images of the famed Leaning Tower of Pisa, but it also works with paired images of other receding objects.

The leaning tower illusion is one of the simplest visual tricks one can produce, but it is also one of the most profound in relation to our understanding of depth perception. This fact is why vision scientists are shaking their heads in disbelief that they did not notice the illusion earlier. Kingdom and his colleagues announced the illusion at the 2007 Best Illusion of the Year Contest, where it won first prize.

The annual contest, which we organize and which is hosted by the Neural Correlate Society, celebrates the ingenuity and creativity of the world's premier creators of visual illusions, both artists and scientists. Contestants submit novel visual illusions (that is, unpublished or published no earlier than the previous year). An international panel of impartial judges conducts the initial review and narrows the dozens of submissions down to the 10 best entries. The top 10 creators then compete in Naples, Fla., during a gala celebration, in which the audience chooses the top three winners. First, second and third prizes take home the coveted "Guido" (a three-dimensional illusion sculpture that was created by renowned Italian sculptor Guido Moretti).

STEPHEN L. MACKNIK and SUSANA MARTINEZ-CONDE are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.



TWIN TOWERS?

In the leaning tower illusion, the tower on the right appears to be leaning more than the tower on the left. Yet these two photographs of the Leaning Tower of Pisa are duplicates.

The illusion reveals the way in which the human visual system uses perspective to help construct our perception of 3-D objects. We say "construct" because the visual system has no direct access to 3-D information about the world. Our perception of depth results from neural calculations based on a set of rules.

These rules include the following: perspective (parallel lines appear to converge in the distance); stereopsis (our left and right eyes receive horizontally displaced images of the same object, resulting in the perception of depth); occlusion (objects near us occlude objects farther away); chiaroscuro (the contrast of an object as a function of the position of the light source); and sfumato (the feeling of depth that one gets from the interplay of in- and out-of-focus elements in an image, as well as from the level of transparency of the atmosphere itself). Because the towers pictured in these paired images do not converge as they recede, the brain mistakenly perceives them as nonparallel and diverging.

To learn more about this illusion, go to http://illusioncontest.neuralcorrelate.com/2007/the-leaning-tower-illusion.

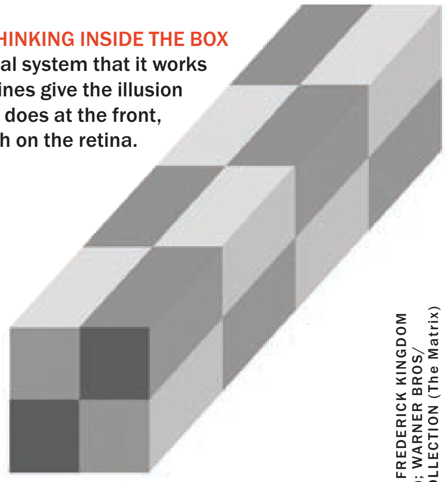
ADRIANA OLMOS; FROM "THE LEANING TOWER ILLUSION: A NEW ILLUSION OF PERSPECTIVE," BY F.A.A. KINGDOM, A. YOONESSI AND E. GHEORGHIU, IN *PERCEPTION,* VOL. 36; 2007

COMING TOGETHER
The leaning tower illusion shows that the brain uses the convergence angle of two reclining objects as they recede into the distance to calculate the relative angle between them. When two parallel towers appear in the same photograph, such as the Petronas Twin Towers in Kuala Lumpur, we perceive them as parallel because they appear to converge in the distance as they recede.

BREAKING THE RULES
Further analysis of similar images reveals subtleties in the way our visual system processes the perception of depth and perspective. For instance, the leaning tower illusion also works with paired images of train tracks, violating the classical rules of perspective. It is hard to believe, but these are actually identical images of parallel train tracks. Although the angles are the same in both images, the brain perceives them as being quite different.

LACKING DEPTH
The leaning tower illusion does not occur when viewing two leaning Japanese *manga* girls, even though the two cartoon images are tilted. The reason is that the cartoon girls do not appear to recede in depth, so our brain does not expect that they would converge in the distance. This phenomenon demonstrates that the brain applies its depth-perception tool kit only in specific situations.

THOMAS HALTNER (*Petronas*); COURTESY OF B. MICKLETHWAIT, PUBLISHED IN *PERCEPTION*, VOL. 36; 2007, BY PION LIMITED, LONDON (*tracks*); COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University* (*manga girls*)



THINKING INSIDE THE BOX
The leaning tower illusion is such a fundamental feature of our visual system that it works even if one draws a 3-D solid object as it recedes into the distance. The parallel lines give the illusion of diverging in the distance. That is, the box appears wider at the back than it does at the front, when it fact the back and front are precisely the same width on the retina.

WHAT IS REAL?

Just as the painter creates the illusion of depth on a flat canvas, our brain creates the illusion of depth based on information arriving from our essentially 2-D retinas. Visual illusions show us that depth, color, brightness and shape are not absolute terms but are subjective, relative experiences actively created by complicated brain circuits. This is true not only of visual experiences but of any sensation. Whether we experience the feeling of "redness," the appearance of "squareness," or emotions such as love and hate, these are the results of the electrical activity of neurons in our brain.

In the movie *The Matrix,* Morpheus asks Neo: "What is real? How do you define real? If you're talking about what you can feel, what you can smell, what you can taste and see, then real is simply electrical signals interpreted by your brain." What the movie doesn't tell us is that even when Neo awakens from the fake world of the "Matrix" into the "real world," his brain will continue to construct his subjective experience, as all our brains do, and this experience may or may not match reality. So in a way, we all live in the illusory "matrix" created by our brain.

COURTESY OF FREDERICK KINGDOM (*receding box*); WARNER BROS/ THE KOBAL COLLECTION (*The Matrix*)

ANAMORPHIC ART

Thanks to the brain's rules of perspective, artists can fool the brain into perceiving two-dimensional drawings as three-dimensional. Artist Kurt Wenner's 3-D pavement paintings—such as *Muses* in Lucerne, Switzerland—are anamorphic illusions that create an impression of three dimensions when seen from one particular viewpoint (*above*). From the "wrong" side, however, you can see the distortions that Wenner uses to create the 3-D effect (*right*). The word "anamorphic" comes from the Greek meaning "formed again."

KURT WENNER

The Neuroscience of Yorick's Ghost and Other Afterimages

Staring at images can temporarily reset retinal cells and cause ghostly visions

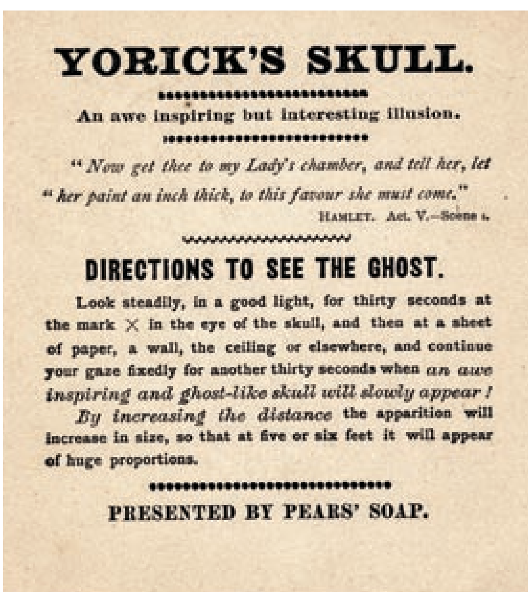
By Stephen L. Macknik and Susana Martinez-Conde

Alas, Poor Yorick! I knew him, Horatio; a fellow of infinite jest, of most excellent fancy; he hath borne me on his back a thousand times; and now, how abhorred in my afterimage he is!

Well ... that's what William Shakespeare's Hamlet might have said, had he been looking at a vintage Pears' Soap advertisement bearing court jester Yorick's skull, rather than holding an exhumed and rotting Danish cranium. Stare long enough at the skull in the ad, and it will be "burned" into your vision even after you look away.

Afterimages such as Yorick's skull help us understand how neurons in various areas of the brain adapt to the visual environment. Adaptation, in this case, is the process by which neurons habituate to, and eventually cease responding to, an unchanging stimulus. Once neurons have adapted, it takes a while for them to reset to their previous, responsive state: it is during this period that we see illusory afterimages. We see such images every day: after briefly looking at the sun or at a bright lightbulb or after being momentarily blinded by a camera flash, we perceive a temporary dark spot in our field of vision.

STEPHEN L. MACKNIK and SUSANA MARTINEZ-CONDE are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.



YORICK'S SKULL.

An awe inspiring but interesting illusion.

"Now get thee to my Lady's chamber, and tell her, let "her paint an inch thick, to this favour she must come."

HAMLET. Act V.—Scene i.

DIRECTIONS TO SEE THE GHOST.

Look steadily, in a good light, for thirty seconds at the mark X in the eye of the skull, and then at a sheet of paper, a wall, the ceiling or elsewhere, and continue your gaze fixedly for another thirty seconds when *an awe inspiring and ghost-like skull will slowly appear!* *By increasing the distance* the apparition will increase in size, so that at five or six feet it will appear of huge proportions.

PRESENTED BY PEARS' SOAP.

TO SEE OR NOT TO SEE ...
To experience this antique illusion (*left*), stare at the X in Yorick's left eye socket for about 30 seconds. Then look away at a flat surface such as a piece of paper, wall, ceiling or sky, and you will see Yorick's afterimage as a ghostly apparition.

Vision scientists believe that the adaptation effect producing poor Yorick's ghost largely takes place in the neurons of the retina. How can we know? Close your right eye and stare at the X again. Then look at the wall again to see the afterimage, but this time switch back and forth between closing one eye and the other. Only the left eye—which was open during the adaptation period—will reveal Yorick's ghost. This means that the adaptation must have taken place only in neurons responding to stimulation from the left eye. If the adaptation had occurred in the binocular neurons of the brain (in the primary visual cortex and higher visual areas), you would see Yorick's ghost with either eye.

LIVEWIRE PUZZLES (WWW.PUZZLES.CA)

EVOLUTION AND ADAPTATION

In celebration of the 200th anniversary of Charles Darwin's birth, psychologists Rob Jenkins of the University of Glasgow in Scotland and Richard Wiseman of the University of Hertfordshire in England created an illusory homage to Darwin's evolutionary roots. Stare at the center of the image for 30 seconds, then look away at a white surface. The two monkeys turn into an afterimage of Darwin's portrait! An afterimage is never as sharp as the original. Jenkins and Wiseman took advantage of this difference in resolution to create an image that looks one way in "normal" high-resolution vision and a different way as a lower-resolution afterimage.

BOVINE FLY

This illusion shows the interaction between color perception and afterimages. First, notice that the left image has a color imbalance to the right and left of the fly: the left side is bluish, and the right side has too much yellow. Now fixate your gaze on the fly in the right image for 30 seconds: this staring will make the neurons in your retina adapt to a blue hue on the left and yellow on the right. As a result, your left visual field will become less sensitive to blue and your right visual field less sensitive to yellow. Then look back at the fly on the cow's nose, and the image will appear to have a perfect color balance.

This illusion helps to explain why objects look the same color under different lighting conditions. For example, your shirt looks the same whether you are indoors or outdoors, even though light from a lamp and light from the sun have different color spectra. Your visual system adapts to the illumination and "discounts" it to maintain color constancy. Some of this processing happens in the retina rather than the brain.

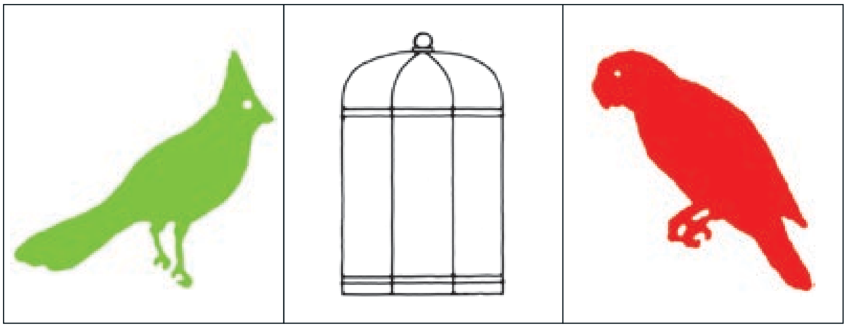
Notice, too, that the color-selective adaptation is still constrained to a single eye: if you close one eye during the adaptation period and then switch eyes while looking at the cow, the color balance will revert to blue and yellow in the unadapted eye.

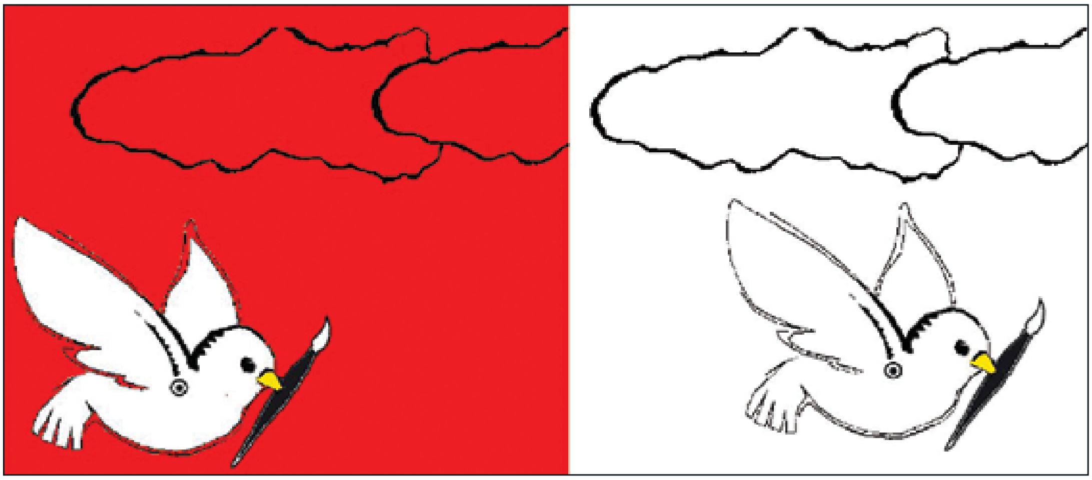
ROB JENKINS *University of Glasgow* AND RICHARD WISEMAN *University of Hertfordshire* *(Darwin and monkeys image)*; © 2002 G. SARCONE *(cow and fly images)*

BIRDS IN A CAGE

When you stare at a color image, its afterimage takes on a shade of its own. For example, stare at the eye of the red parrot for 30 seconds, then immediately look at the center of the empty birdcage. You should see a ghostly blue-green parrot inside. Try the same thing with the green cardinal, and you should see a pink bird. This illusion is part of an exhibit at the Exploratorium museum in San Francisco.

Gazing at any colored surface can induce a vivid afterimage of the complementary color. For example, staring at the color red induces a blue-green afterimage because the cells in your retina that respond to red light adapt to the red environment by reducing their activity—to save energy and to prepare themselves for detecting any future changes in redness. When you look away to a white background, your retina remains adapted to the red environment for a few seconds. With the red "subtracted" from the white, you can see red's opposite: blue-green.



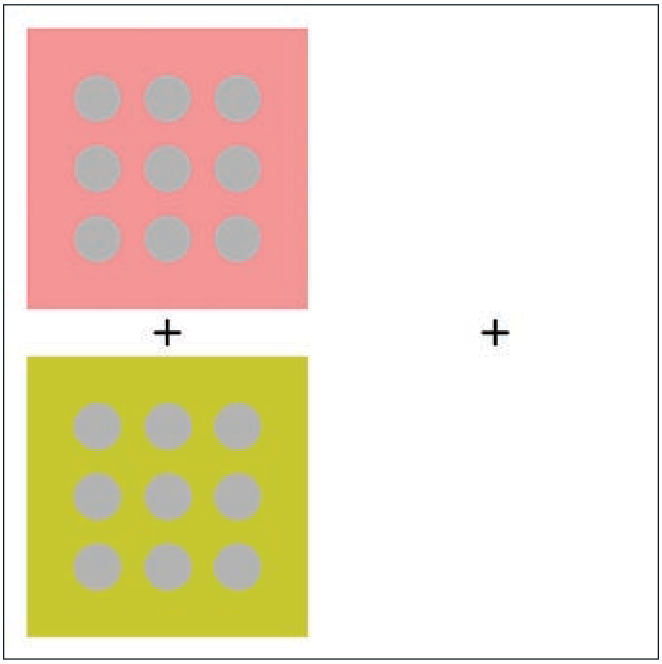


A BIRD OF A DIFFERENT FEATHER

Positive afterimages can be captured from a complementary surrounding color, as in this demonstration of an uncolored bird that captures the reddish color of its background. Stare for about 30 seconds at the "target" on the bird in the left panel. Then look immediately at the same spot on the bird in the right panel.

In this illusion, created by vision scientists Yuval Barkan and Hedva Spitzer of Tel Aviv University in Israel, the red background in the left panel causes the bird to fill in with a complementary blue-green color, which gives rise to a surprisingly strong and long-lasting red afterimage of the bird once the red background is removed.

This illusion won second prize in the 2009 Best Illusion of the Year Contest. To experience an even more striking version of this illusion with a "flying" bird, visit http://illusioncontest.neuralcorrelate.com/2009/color-dove-illusion



RED AND YELLOW BEADS

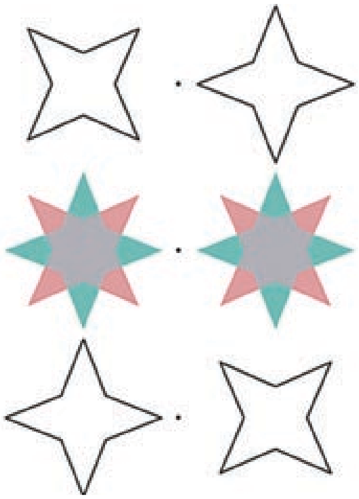
Gaze at the cross between the upper and lower squares for about 30 seconds. Then look immediately at the cross on the right, and you should see 18 colored beads: nine red beads above the cross and nine yellow beads below the cross. The beads are all gray in the image itself, but the surrounding colors induce colored afterimages.

EXPLORATORIUM (WWW.EXPLORATORIUM.EDU) (*birds in cage*); YUVAL BARKAN AND HEDVA SPITZER *Tel Aviv University* (*flying birds*); COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University* (*red and yellow beads*)

THE SPANISH INQUISITION

This incredible afterimage illusion shows just how powerful a little color can be. First, fixate your gaze on the tiny black spot in the center of the left image. Notice that no contours are present in the image, just splotches of pure color. Once you have adapted your retina for about 30 seconds, look at the black-and-white image of the Manzanares el Real Castle, near Madrid, Spain, on the right (again, fixate on the black spot in the center). *¡Olé!* The Spanish castle has gone from black-and-white to glorious color.

This illusion demonstrates that the brain can assign color to monochromatic objects, even when the color is from an afterimage. The illusion is effective only when the afterimage lines up perfectly with the actual image—otherwise the actual image dominates, and the color is suppressed. The neural details of this complex process are largely unknown.



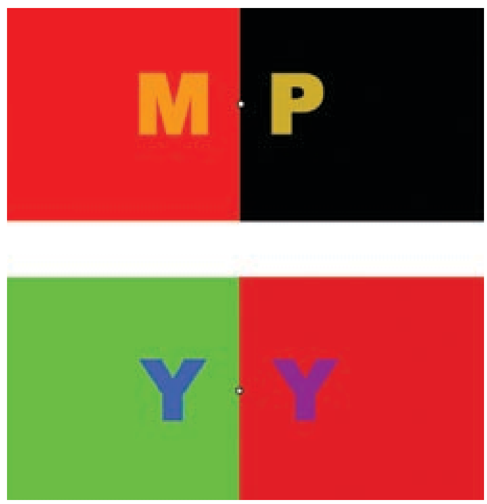
SHAPE-SPECIFIC AFTERIMAGES

In this illusion a single colored image produces two afterimages of different colors, depending on the shapes you look at afterward. Fixate your gaze on the black dot between the colored stars in the middle panel and stare at it for 30 seconds without moving your eyes. Then look at the empty outlines in the top panel. The left one fills in with a ghostly blue-green, and the right one looks reddish. When you look at the bottom panel, the colors are reversed.

How does one image produce two afterimages of different colors? And how does the shape of the outline determine the filled-in color? The creators of this illusion, Rob van Lier and Mark Vergeer of Radboud University Nijmegen in the Netherlands, suggest that patches of an afterimage can spread and merge to fill the contours of an outlined shape. The shape at the upper right takes on a reddish hue because it has the same outline as the complementary blue-green patches in the original color image. Likewise, the blue-green-tinged shape on the upper left matches the red patches in the color image.

NOTHING IS THE SAME

These incredible illusions by Abigail E. Huang, Alice J. Hon, Christopher W. Tyler and Eric L. Altschuler of New Jersey Medical School and the Smith-Kettlewell Eye Institute show that objects of the same apparent color can look like different colors in an afterimage and that differently colored objects can appear to be the same color in an afterimage. Gaze at the white spot between the yellow letters M and P in the upper image. Hold your gaze for 30 seconds and then look at a white wall. You will see an afterimage of the letters, which are now magenta (M) and purple (P). In the lower image there are two Y's, one blue and one purple. Look at the white spot between them for 30 seconds and then move your eyes to a white wall. You will now see that the Y's are the same shade of yellow in the afterimage. In fact, the M and P in the upper image are different colors that only look the same shade of yellow because of the effect of the red and black backgrounds. In the afterimage, the complementary background colors—blue-green and white—have the opposite effect: they make the M and P look more different than they really are. The Y's are also different from each other, in the real image, but the complementary background colors in the afterimage make them look the same color.



THE LEAST COLORFUL PLACE ON EARTH

Afterimage color assignment works very well with objects to which humans are exquisitely well tuned, such as faces. Gaze for 30 seconds at this reverse-color portrait of John Bortniak, commander in the National Oceanic and Atmospheric Administration Corps, at the South Pole (*left*) and then look at the image on the right to see it in color.

JOHN SADOWSKI (*castle images*); FROM "FILLING-IN AFTERIMAGE COLORS BETWEEN THE LINES," BY R. VAN LIER, M. VERGEER AND S. ANSTIS, IN *CURRENT BIOLOGY*, VOL. 19, NO. 8; 2009 (*star afterimages*); FROM "METAMERIC INTRANSITIVITY," BY A. E. HUANG, A. J. HON, C. W. TYLER AND E. L. ALTSCHULER, IN *ATTENTION, PERCEPTION & PSYCHOPHYSICS* (IN PRESS) (*letters*); JOHN BORTNIAK NOAA (*South Pole images*)

Colors Out of Space

Colors can change with their surroundings and spread beyond the lines

By Stephen L. Macknik and Susana Martinez-Conde

It was just a colour out of space—a frightful messenger from unformed realms of infinity beyond all Nature as we know it; from realms whose mere existence stuns the brain and numbs us with the black extra-cosmic gulfs it throws open before our frenzied eyes.

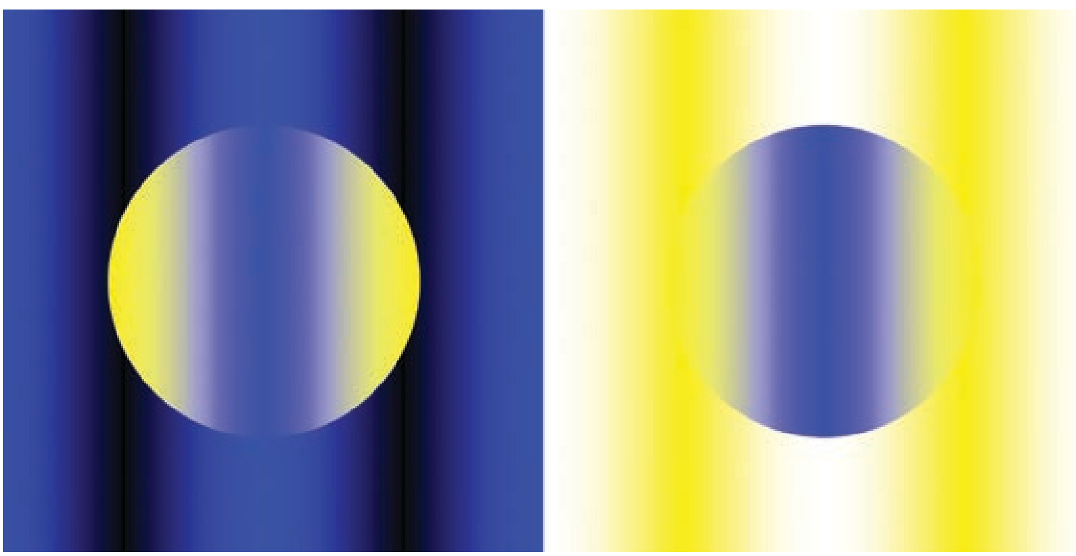
Science-fiction author H. P. Lovecraft considered *The Colour Out of Space* his best story. In this 1927 classic tale of cosmic horror, a small Massachusetts farming community faces unspeakable evil from the outer reaches of the universe. The extraterrestrial villain is not a face-hugging or chest-bursting alien but something far more terrifying: a weird color.

Slowly but surely the otherworldly color mutates and destroys crops, insects, wild animals and livestock. It impregnates the land and the water. The unfortunate farmers who encounter the bizarre hue fall prey to insanity and untimely death.

And you thought vision research was for wimps.

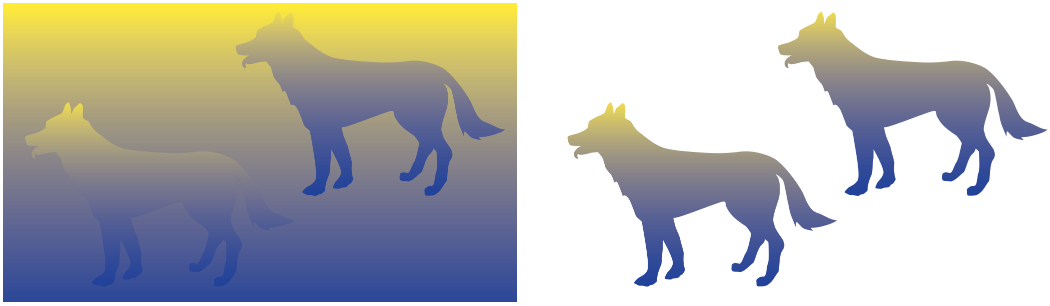
This article features some of the most spectacular color phenomena this side of the galaxy. You won't see any extraterrestrials, but many strange illusions arise from taking colors out of place and putting them in an unusual context. Use caution: the peculiar shades and tints you are about to experience could blow your mind.

STEPHEN L. MACKNIK and SUSANA MARTINEZ-CONDE are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.

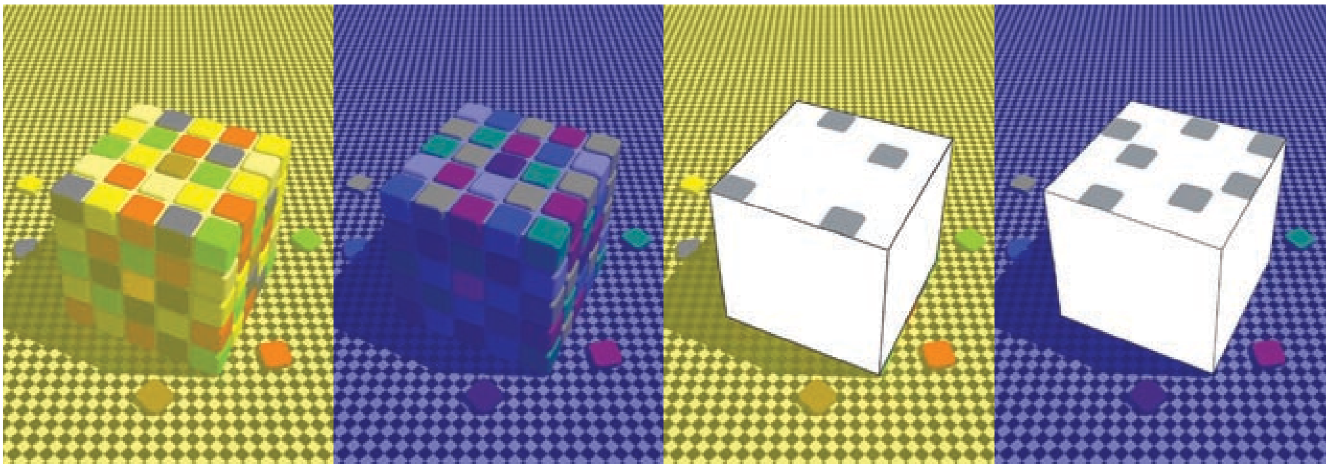


YELLOW MOON AND BLUE MOON Here we have two moons out of space. One yellow and one blue. Or are they? Actually both moons are exactly the same color in this illusion by psychologist Akiyoshi Kitaoka of Ritsumeikan University in Japan; only the surrounding colors are different. If you don't believe it, cut out the two moons—you'll find them to be identical. The appearance of colors is all about their context.

COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University*

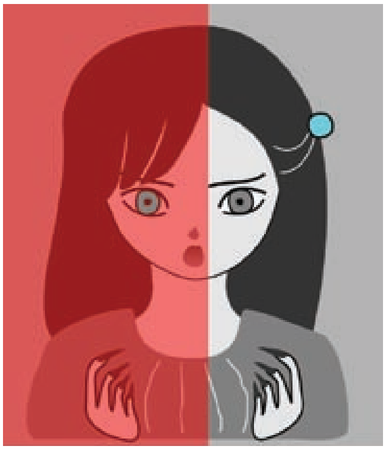


REX AND FIDO
Legend has it that Rome was founded by warring twin brothers, Romulus and Remus, born to a vestal virgin named Rhea Silvia and fathered by Mars, the god of war. Vestal virgins, as it turns out, are not supposed to conceive children, even if the father is a god. The family shame was too much for Rhea's father, who killed her and then condemned the twin baby boys to die of exposure. The wolf Lupa found the boys and adopted them. But hey, what about Lupa's biological pups, Rex and Fido, younger brothers to the feral Romans? These nonidentical twins (*left*) become identical when the background is removed (*right*). Had this pair been born before their mother discovered Romulus and Remus, surely Rome would have gone to the dogs.

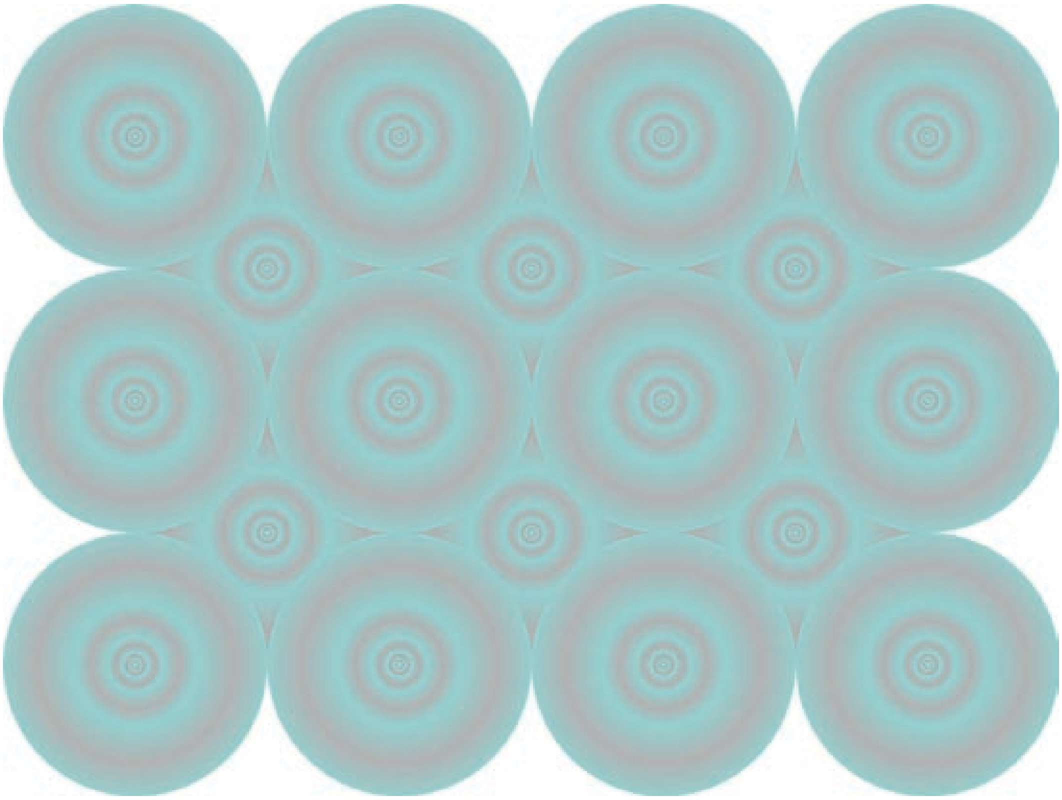


RUBIK'S FOLLY
Rubik's Cube is a three-dimensional puzzle in which the player rotates the tiled faces of a cube until each face shows the same color on all nine tiles. Sound easy? Only if the lighting conditions are stable. As this illusion by Beau Lotto and Dale Purves of Duke University shows, if the lighting changes, it can be hard to know which color is which. The masked version of the illusion (*above, right*) reveals that the blue squares on the left and the yellow squares on the right are actually all gray when viewed under white light. Color perception is not based strictly on the wavelengths of the light that strikes your retina; instead the brain assigns colors based on the lighting conditions and uses the wavelengths only as a guideline to determine which objects are redder or bluer than other objects in the same scene.

EYE SHADOW
It looks like this Japanese *manga* girl has one blue eye and one gray eye. In fact, both eyes are exactly the same shade of gray. The girl's right eye only looks the same as the turquoise hair clip because of the reddish context. Part of the process of seeing color is that three different kinds of photoreceptors in the eye are tuned to three overlapping families of color: red, green and blue (which are activated by visible light of long, medium and short wavelengths). These signals are then instantaneously compared with signals from nearby regions in the same scene. As the signals are passed along to higher and higher processing centers in the brain, they continue to be compared with larger and larger swaths of the surrounding scene. This "opponent process," as scientists call it, means that color and brightness are always relative.



ADAPTED FROM WWW.MOILLUSIONS.COM (*dogs*); DALE PURVES *Duke University* (*cubes*); COURTESY OF AKIYOSHI KITAOKA (*eye shadow*)



RED RINGS

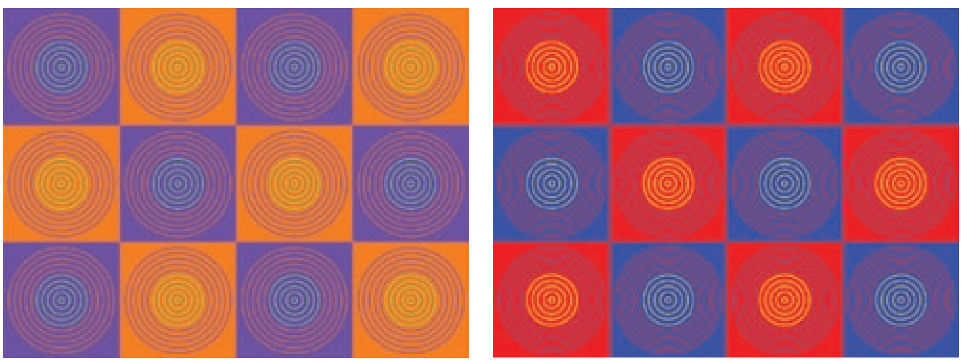
This image by Kitaoka contains a number of blue-green circular structures. The red rings are purely a creation of your brain.

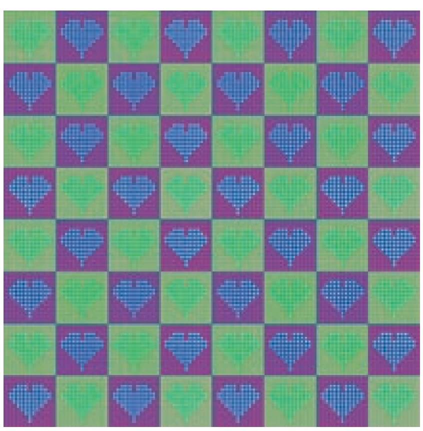
A process called color constancy makes an object look the same under different lighting conditions, even though the color of the light reflecting from the object is physically different. Color constancy is an incredibly important process that allows us to recognize objects, friends and family both in the firelight of the cave and in the bright sun of the savanna.

Because the rings here are drawn in shades of blue, the brain mistakenly assumes that the image is illuminated by blue light and that the physically gray rings inside the blue structures must therefore be reddish. The visual system subtracts the blue "ambient lighting" from the gray rings, and gray minus blue results in a pastel red color.

MULTICOLORED RINGS

Here is another example of how the brain determines color depending on the context. In the bull's-eye structures in the left checkerboard, the center rings look either green or blue, but they are all the same color (turquoise). The center rings in the right checkerboard are all the same shade of yellow. Unlike the previous images, this type of color illusion is difficult to explain by an opponent process because the apparent color of the rings is more similar than dissimilar to the background.

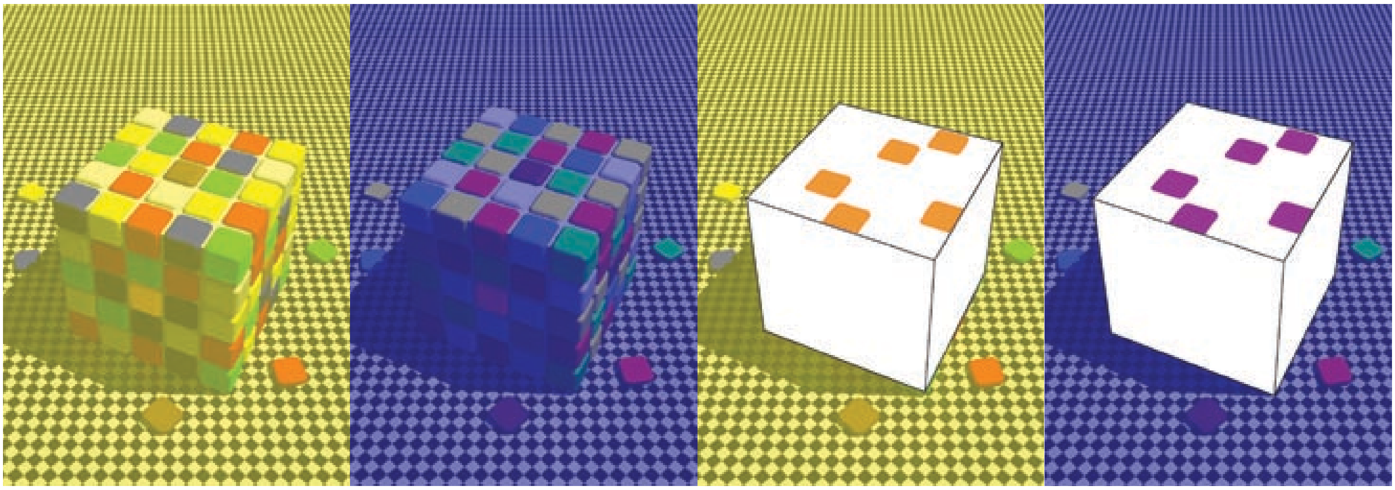




FICKLE HEARTS

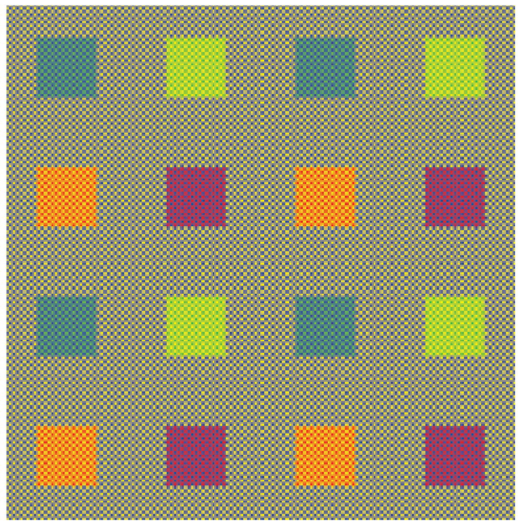
All the hearts in this checkerboard are made out of the same cyan-colored dots, but they look green against the green background and blue against the blue background. The image, by Kitaoka, is based on the dungeon illusion discovered by vision scientist Paola Bressan of the University of Padua in Italy.

COURTESY OF AKIYOSHI KITAOKA



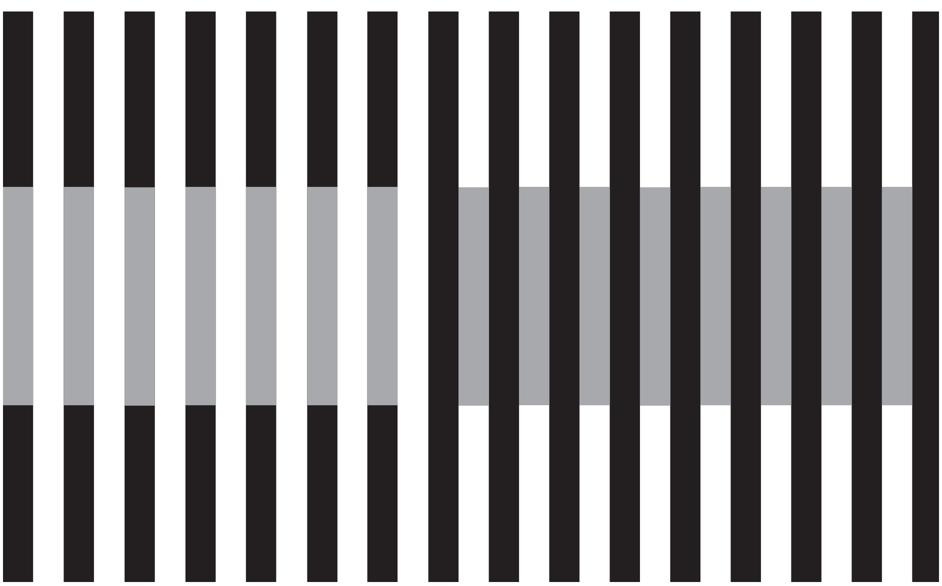
RUBIK'S CONFUSION

We have seen that the same colors can look different from each other, depending on context. This illusion shows that context can also make different colors look similar. Check out the red tiles on the top face of the left and right Rubik's Cubes. They look more or less like the same color. If we mask the rest of the tiles with white (*above, right*), you can see that the tiles on the left cube are actually orange and that the tiles on the right are purple.



FOUR WRONG COLORS

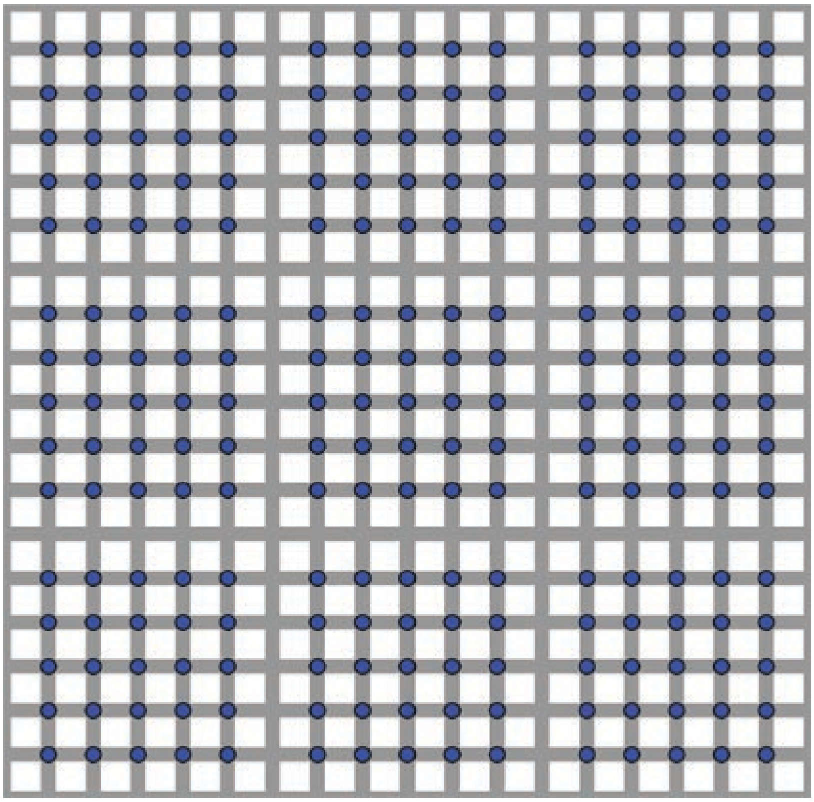
We see four differently colored squares on a gray background, right? Wrong. The gray is actually a mixture of little blue and yellow pixels. Because the pixels are so small, they blend together and do not activate the opponent processes that would create contrast. This is how a color television creates different colors from just a few differently colored pixels (hold a magnifying glass to your TV and prove it to yourself). The turquoise and chartreuse squares are actually little green pixels mixing with either the blue background pixels (turquoise) or the yellow background pixels (chartreuse). Mixing red pixels with either the yellow or blue pixels in the background creates the orange and purple.



WHITE'S EFFECT

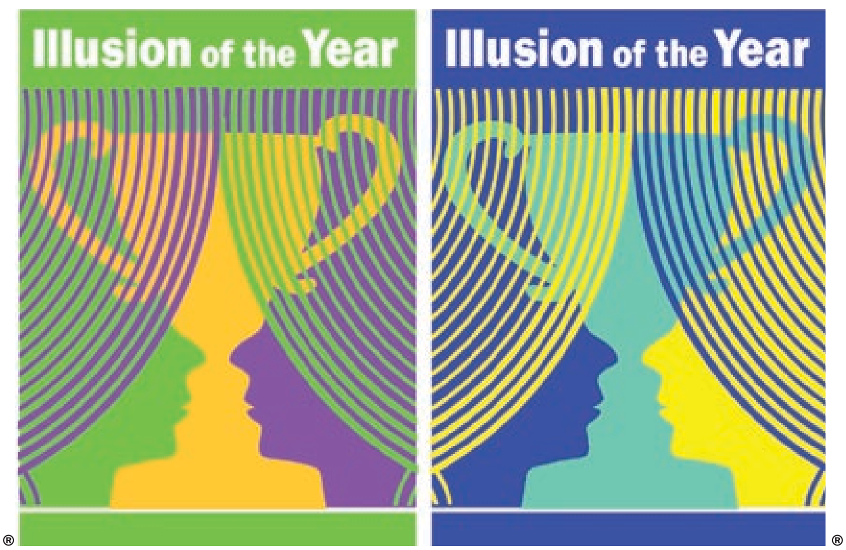
In 1979 Michael White of the Tasmanian College of Advanced Education described an illusion that changed everything in visual science. The gray bars on the left look brighter than the gray bars on the right. In fact, all the gray bars are physically identical. Before White discovered this effect, all brightness illusions were thought to result from opponent processes—that is, a gray object should look dark when surrounded by light and light when surrounded by dark. But in this illusion the lighter-looking gray bars are surrounded by white stimuli, and the darker-looking gray bars are surrounded by black. The brain mechanisms underlying White's effect remain unknown.

DALE PURVES (*cubes*); COURTESY OF AKIYOSHI KITAOKA (*four colors* and *White's effect*)



SPARKLING COLOR

In *Light of Sapphires,* the blue dots appear to scintillate as you move your eyes around the image. But when you focus on one dot, the scintillation stops. The blue color appears more saturated for the dot in focus than for dots in the visual periphery. This effect is a colorful variant of the scintillating grid illusion discovered in 1994 by Elke Lingelbach of the Institute for Optometry Aalen in Germany and her colleagues Michael Schrauf, Bernd Lingelbach and Eugene Wist.



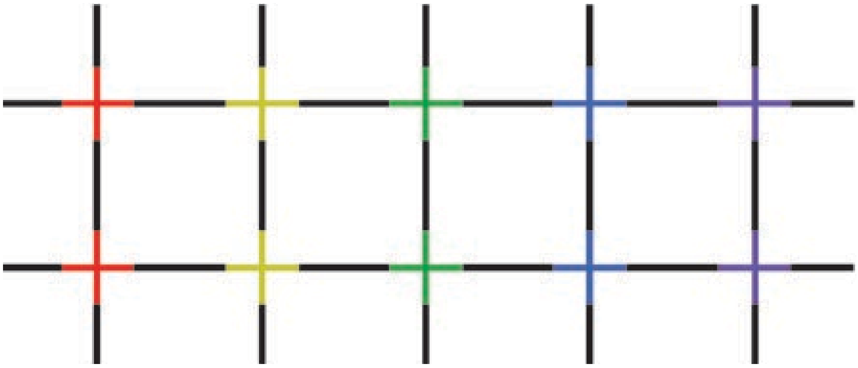
ILLUSION OF THE YEAR

White's effect also affects the way colors look. The logo for the Best Illusion of the Year Contest is a combination of White's effect (the vase appears to be different colors behind the two curtains) and the famous face-vase illusion (in which the "vase" is a trophy for the winner). See more color combinations at http://illusioncontest.neuralcorrelate.com.

UNREAL SPIRALS

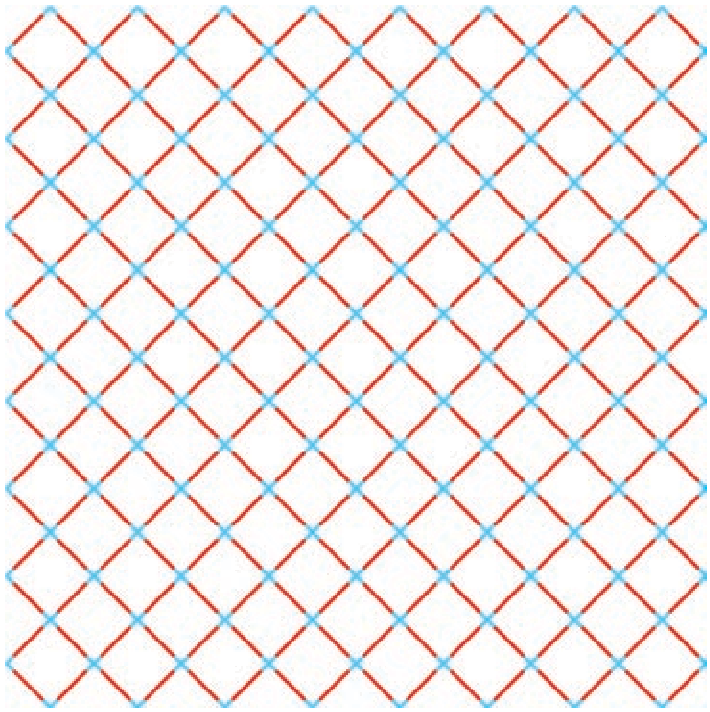
These spirals, created by Kitaoka, are particularly strong examples of White's effect as applied to color. The green and cream-colored spirals (*bottom*) are made from stripes that are physically yellow. In the other two examples above, the stripes are physically red and cyan, rather than purple, orange, blue and green.

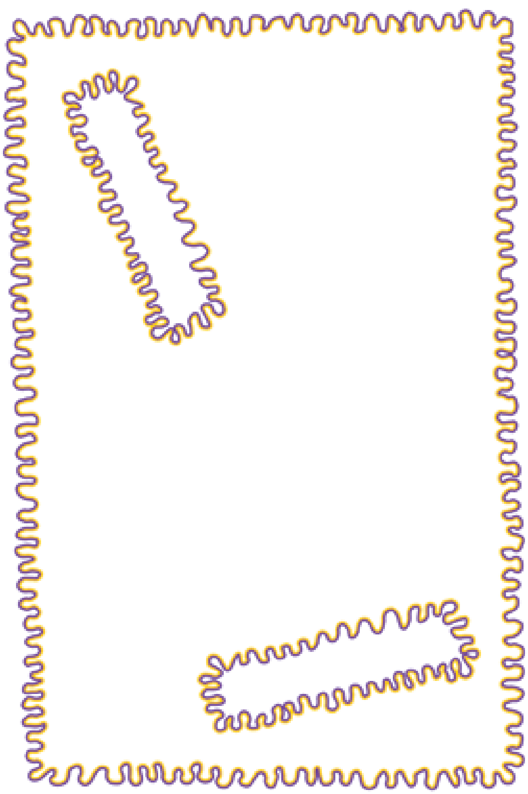
NEURAL CORRELATE SOCIETY (*logos*); COURTESY OF AKIYOSHI KITAOKA (*sapphires* and *spirals*)



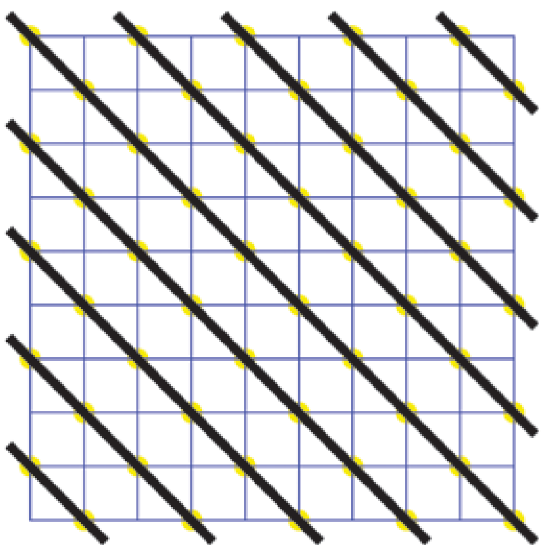
NEON COLOR SPREADING
The colors from the small crosses appear to spread onto the white expanse surrounding each intersection. The effect resembles the glare from a neon light. This illusion was reported in 1971 by Dario Varin of the University of Milan in Italy and a few years later by Harrie van Tuijl of the University of Nijmegen in the Netherlands. Its neural causes are currently unknown.

CHROMATIC PINCUSHION GRID
Here the neon color spreading produces a rectilinear grid of north-south and east-west streets on the map—but only in the periphery of your vision. It is absent from whichever intersection you happen to be staring at.



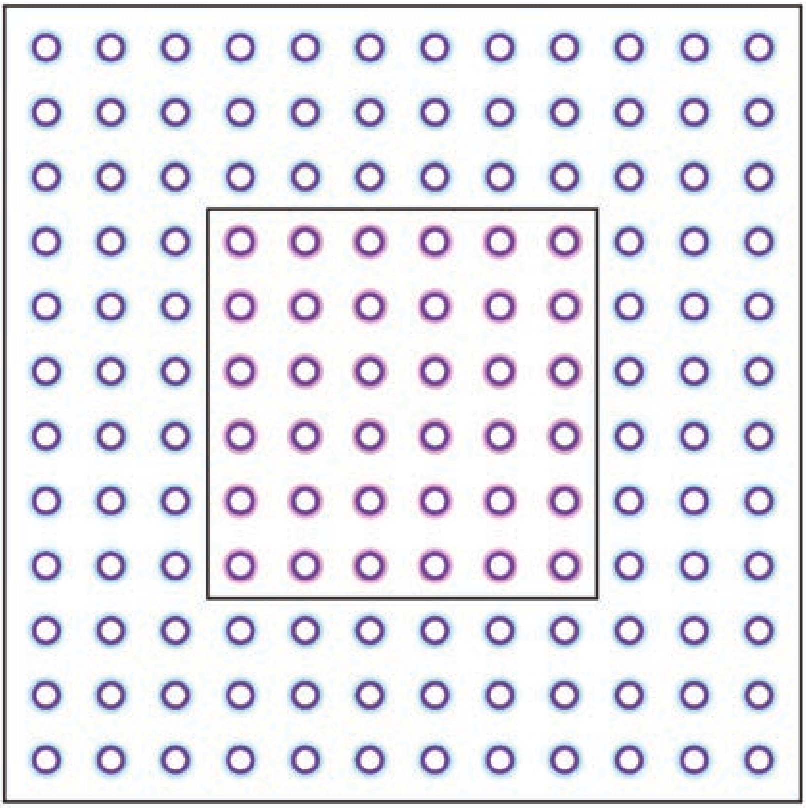


THE WATERCOLOR EFFECT
In this illusion by Italian vision scientist Baingio Pinna, a thin, orange contour adjacent to a darker purple contour casts an orange tint over long distances—as though a watery paint was filling in the gaps between the orange lines [see "Illusory Color and the Brain," by John S. Werner, Baingio Pinna and Lothar Spillmann; SCIENTIFIC AMERICAN, March 2007]. On the opposite side of the purple contour, the outlined areas look white.



COLORED RAY
In this neon color spreading illusion, the yellow spreads in a direction that is perpendicular to the black bars.

COURTESY OF AKIYOSHI KITAOKA (*top left, middle right and bottom right*); BAINGIO PINNA *University of Sassari* (*middle left*)

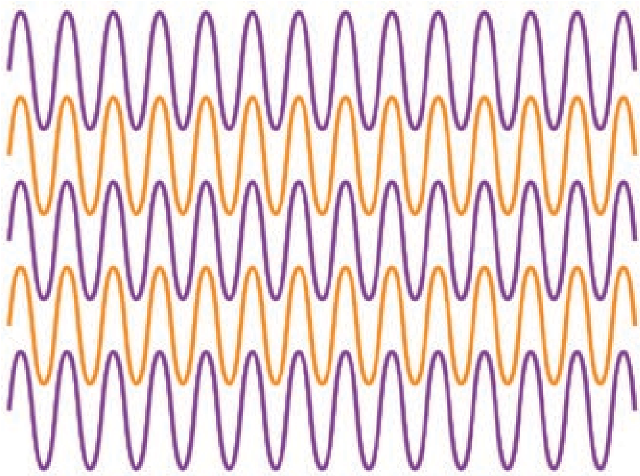


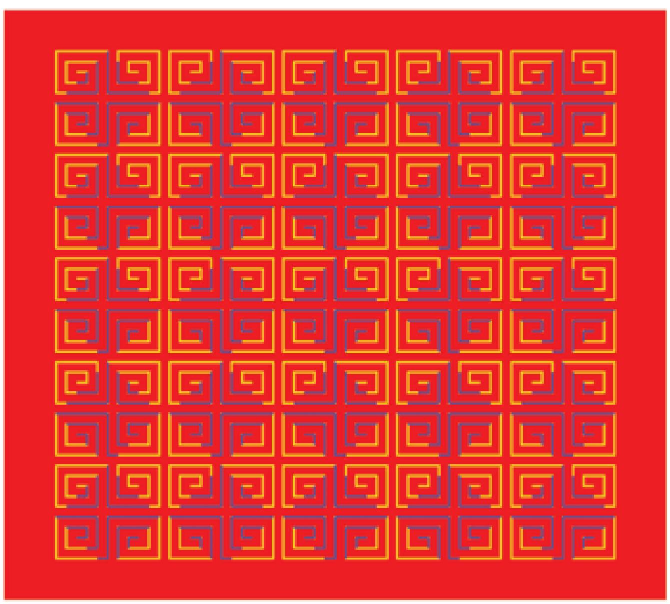
SMOGGY INTERSPACES

In this image by Pinna, the inner square appears to have purple smog around the dots, and the outer square appears to be filled with blue. The illusion is caused by the watercolor effect.

WAVE-LINE ILLUSION

The watercolor effect inspired the wave-line illusion by Japanese vision scientist Seiyu Sohmiya. In this version by Kitaoka, the white background behind the pattern is tinged by the color of the waves.





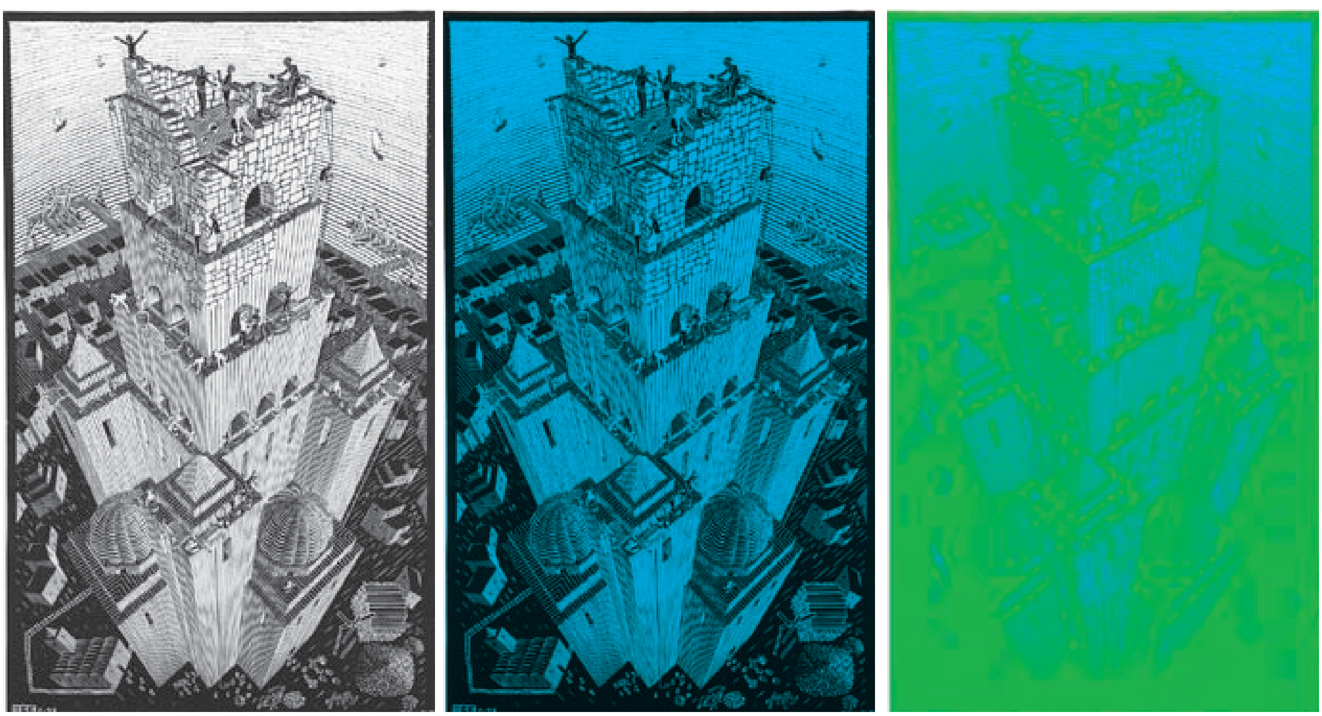
CHINESE RUG

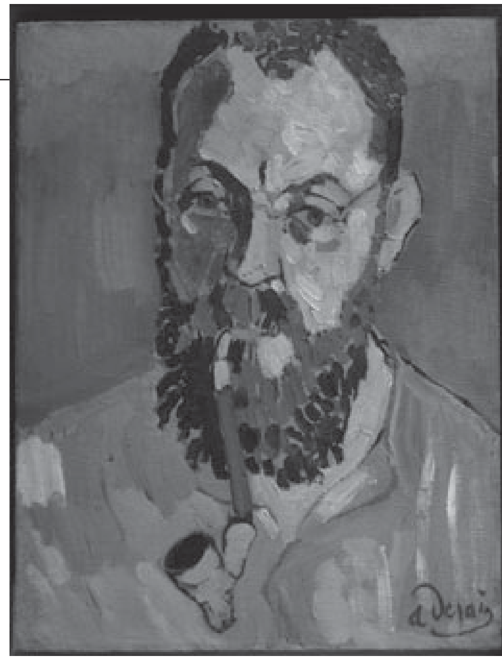
The red color behind the blue lines appears to be magenta, whereas the same red color behind the yellow lines appears to be orange. This "color assimilation" illusion shows that colors can blend with each other in some situations, rather than contrasting with each other.

BAINGIO PINNA *(top)*; COURTESY OF AKIYOSHI KITAOKA, FROM "A WAVE-LINE COLOUR ILLUSION," BY S. SOHMIYA, IN *PERCEPTION*, VOL. 36; 2007 *(middle)*; COURTESY OF AKIYOSHI KITAOKA *(bottom)*

PICASSO'S BLUE PERIOD
During his blue period, Pablo Picasso painted everything—including shadows and gradations of sunlight—in shades of blue (*left*). How do we recognize the people if they are all the wrong color? Margaret S. Livingstone of Harvard Medical School has shown that although Picasso used blue, he was careful to maintain the luminance relations—contrasts in lighting within the scene [see "Art, Illusion and the Visual System," by Margaret S. Livingstone; Scientific American, January 1988]. Those luminance relations, which we use to make sense of the image, are apparent in a grayscale version of the painting (*right*). This is why color-blind people see just fine in almost every way—sometimes they do not even know they have a deficit.

ESCHER'S COLOR TOWER
Here Livingstone and her Harvard colleague David H. Hubel took an Escher woodblock, *Tower of Babel* (*left*), and colored the white spaces light blue (*center*). You still see the tower, because the luminance relations remain intact. But when the black spaces are replaced by a green shade with the same luminance as the blue (previously white) spaces, the 3-D character of the image falls apart (*right*). Our visual system cannot perceive volume, form and distance with only color information available. Luminance information is also required.

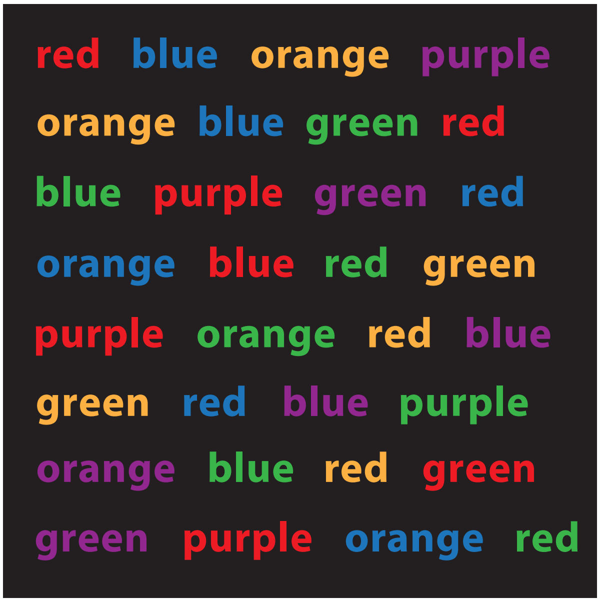




MATISSE'S MULTI-COLORED FACE
A group of 20th-century European artists led by Henri Matisse and André Derain used such vivid, unusual colors in their paintings that one critic dubbed these works *les Fauves* ("wild beasts"). This style became known as Fauvism. Derain's 1905 portrait of Matisse (*left*) is characteristic of this style. Using a grayscale version (*right*) of a similar painting, Livingstone showed that the weird colors work because they have the correct luminance.

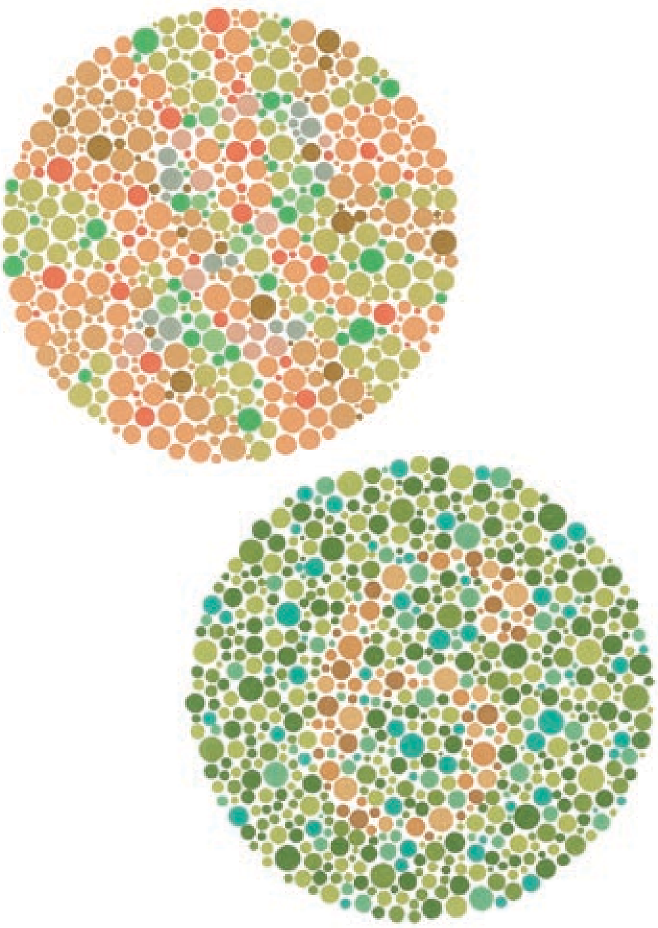
PICASSO'S COLOR SPREADING
This painting by Picasso shows that coloring within the lines is unnecessary. Our brain assigns the colors to the correct shapes even though the shapes are depicted minimally with sparsely drawn lines.

Pablo Picasso, Spanish, 1881–1973
Mother and Child, 1922
Oil on canvas
39-3/8 x 31-7/8 in
(100 x 81 cm)
The Baltimore Museum of Art: The Cone Collection, formed by Dr. Claribel Cone and Miss Etta Cone of Baltimore, Maryland
BMA 1950.279



DISCOMBOBULATING COLOR

Here is a great cognitive visual illusion that involves a conflict between the syntactic and symbolic processing systems in your brain. Look at the words one after the other without stopping or slowing, but instead of reading each word, just say its color out loud. It's hard, isn't it? You are experiencing the Stroop effect, named after psychologist John Ridley Stroop. Even if you try not to read the words, you cannot keep the content of the words from conflicting with their color.



COLOR BLINDNESS TEST

Japanese ophthalmologist Shinobu Ishihara developed 38 color plates, including the two above, to test patients for color blindness. Each plate is a circle filled with dots of different sizes and colors. People with the most common types of color blindness find it difficult or impossible to see the numbers hidden within the patterns shown here.

THE McCOLLOUGH EFFECT

Discovered by vision researcher Celeste McCollough, this illusion demonstrates that the interactions between color perception and form perception can be surprisingly long-lasting. The effect takes discipline, though, so suck it up before you try it, soldier! We can't make you do it, of course, but it won't work correctly unless you do, and we promise it will be worth the effort.

Look at the black dot at the center of the vertical magenta-striped grating for one full minute. (One minute will seem like forever, but trust us on this.) Then fixate on the dot in the horizontal green grating for one minute. Then shift back to the vertical magenta grating and then back to the green, for one minute apiece. Repeat another cycle. Okay, now you're ready. After six minutes of alternating between the two gratings, look back and forth between the uncolored patched gratings below. You will see that the horizontal patches are tinged magenta and that the vertical patches are tinged green.

This illusion shows that adaptation, the process by which neurons in the brain become less responsive to unchanging stimuli, can be simultaneously selective for both color and orientation of edges. That is, you have neurons that are attuned to both magenta and vertical orientations, and when you stared at the vertical magenta grating for minutes on end, that allowed the horizontal-detecting neurons that are sensitive to magenta to seem more responsive. So when you are presented with a horizontal white grating after the adaptation, it looks tinged with magenta. The same is true for the green adaptation, for the opposite orientations.

McCollough's illusion was the first to show that adaptation can last a long time. If you come back in an hour and look at the white gratings, you will still see an effect, albeit weaker.

ORIGINALLY PUBLISHED IN "STUDIES OF INTERFERENCE IN SERIAL VERBAL REACTIONS," BY JOHN RIDLEY STROOP, IN *JOURNAL OF EXPERIMENTAL PSYCHOLOGY,* VOL. 18; 1935 (*Stroop effect*); COURTESY OF AKIYOSHI KITAOKA (*McCollough effect*); ORIGINALLY PUBLISHED IN *TESTS FOR COLOUR-BLINDNESS,* BY SHINOBU ISHIHARA (HANDAYA, TOKYO, HONGO HARUKICHO, 1917) (*color blindness*)

What's in a Face?

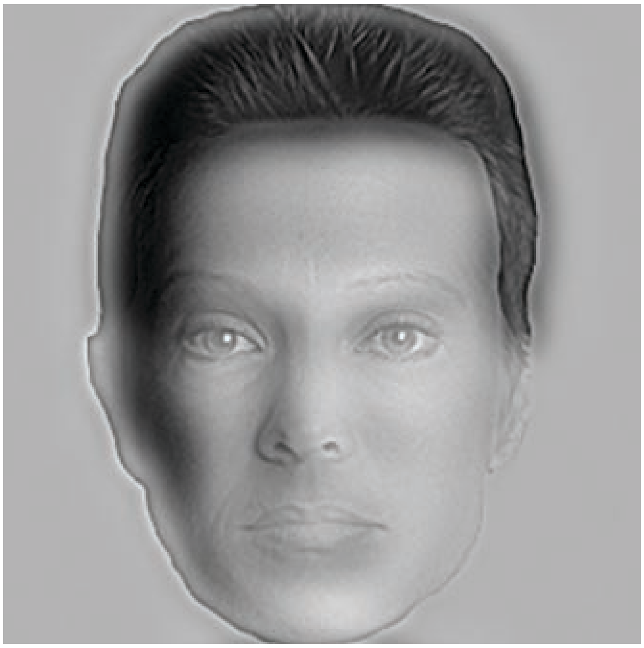
The human brain is good at identifying faces, but illusions can fool our "face sense"

By Susana Martinez-Conde and Stephen L. Macknik

Our brains are exquisitely tuned to perceive, recognize and remember faces. We can easily find a friend's face among dozens or hundreds of unfamiliar faces in a busy street. We look at each other's facial expressions for signs of appreciation and disapproval, love and contempt. And even after we have corresponded or spoken on the phone with somebody for a long time, we are often relieved when we meet him or her in person and are able to put "a face to the name."

The neurons responsible for our refined "face sense" lie in a brain region called the fusiform gyrus. Trauma or lesions to this brain area result in a rare neurological condition called prosopagnosia, or face blindness. Prosopagnostics fail to identify celebrities, close relatives and even themselves in the mirror. But even those of us with normal face-recognition skills are subject to many illusions and biases in face perception.

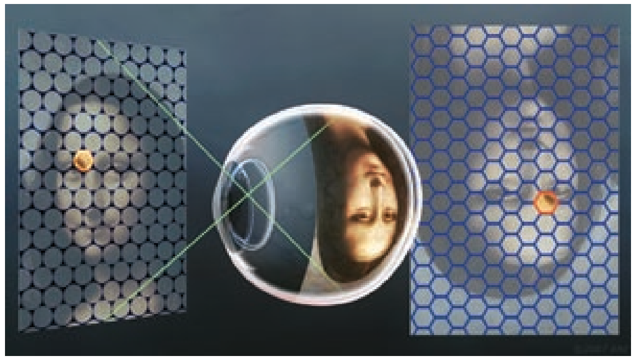
SUSANA MARTINEZ-CONDE and STEPHEN L. MACKNIK are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.



AUDE OLIVA *M.I.T.* AND PHILIPPE G. SCHYNS *University of Glasgow*

DR. ANGRY AND MR. CALM
Massachusetts Institute of Technology vision scientist Aude Oliva and University of Glasgow researcher Philippe G. Schyns created this illusion by producing hybrids of two images. The left picture shows Dr. Angry, and the picture on the right is Mr. Calm. But if you step away from this page, you will see that appearances can be deceiving. Nice Mr. Calm becomes Dr. Angry, and nasty Dr. Angry turns out to be a pretty decent fellow after all.

Fine details become blurred at a distance, leaving you with only the overall shapes and shadings of the images: what vision scientists refer to as the low-spatial-frequency content of an image. When you move closer, the images are once again dominated by their fine details, which are referred to as high spatial frequencies. The illusion works because the face on the left is composed of a high-spatial-frequency angry face combined with a calm face in low spatial frequencies. The right face is exactly the opposite: a low-spatial-frequency angry face with a high-spatial-frequency calm face. When the images are blurred (by stepping away), the different layers of the hybrid are revealed.



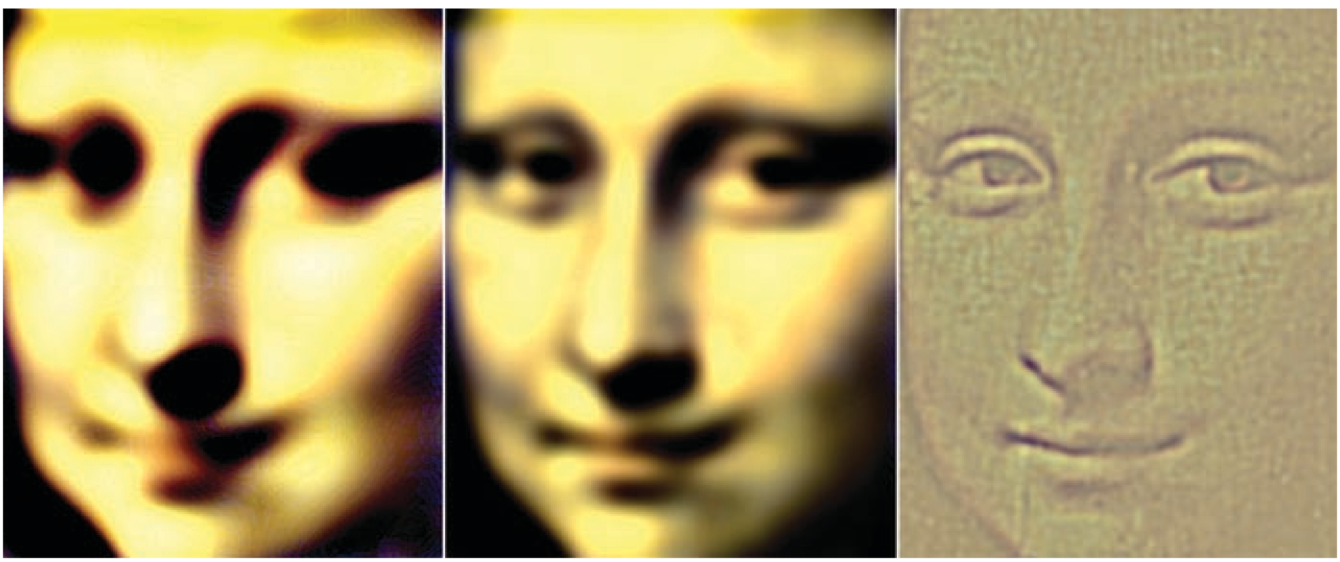
"MONA LISA" SMILE

Mona Lisa's captivating smile (*left*) is perhaps the most renowned art mystery of all time. Margaret Livingstone, a neurobiologist at Harvard Medical School, showed that Mona Lisa's smile appears and disappears owing to different visual processes used by the brain to perceive information in the center versus the periphery of our vision.

Look directly at Mona Lisa's lips and notice that her smile is very subtle, virtually absent. Now look at her eyes or at the part in her hair, while paying attention to her mouth. Her smile is now much wider. The movement of our eyes as we gaze around Mona Lisa's face makes her smile come alive, flickering on and off as our perception of it changes.

The center and periphery of the visual field have this differential effect on perception because the neurons at the center of our vision see a very small portion of the world, giving us high-resolution vision. Conversely, the neurons in the periphery see much larger pieces of the visual scene and thus have lower resolution.

This is what happens in the eye while viewing Mona Lisa: the eye focuses light that is reflected from the painting onto the retina, upside down and backward (*above*). Adjacent photoreceptors within the retina are activated by adjacent points of light reflected from the painting.



THE DA VINCI CODE OF PERCEPTION

Mona Lisa's smile can be explained by the fact that images are blurred in the periphery of our vision, so that her smile is only seen when blurred. Livingstone solved this mystery by simulating how the visual system sees Mona Lisa's smile in the far periphery, the near periphery, and the center of our gaze (*above, left to right*). The simulation was done in Adobe Photoshop by simply blurring and deblurring the painting to simulate the change in resolution from the center of vision to the far periphery. The smile appears on the left and center panels (far and near visual periphery) but is gone on the right panel (center of gaze). The effect is similar to the hybrid images of Dr. Angry and Mr. Calm and is likewise explained by the fact that different retinal neurons are tuned to different spatial frequencies. In a sense, Leonardo da Vinci painted the Mona Lisa as a hybrid, with a happy Mona Lisa superimposed on a sad one, each having different spatial-frequency content.

LOUVRE, PARIS/GIRAUDON/THE BRIDGEMAN ART LIBRARY (Mona Lisa); MARK SCHORNAK, MICHAEL HICKMAN, SUSANA MARTINEZ-CONDE AND STEPHEN L. MACKNIK *Barrow Neurological Institute* (*retina*); MARGARET S. LIVINGSTONE *Harvard Medical School* (*blurring and deblurring*)

HONEST ABE

Surrealist painter Salvador Dalí also experimented with combining high- and low-spatial-frequency content in a single image (*right*). The title of the painting says it all: *Gala Contemplating the Mediterranean Sea, which at Twenty Meters Becomes the Portrait of Abraham Lincoln* (*Homage to Rothko*). The finer details of the painting, such as the edges of the colored blocks, blur when you view the painting from a distance or squint your eyes—and you can then see the low-spatial-frequency shapes and shading that make up Lincoln's face.

ILLUSION OF SEX

This illusion, created by psychologist Richard Russell, won third prize in the 2009 Best Illusion of the Year Contest. The side-by-side faces are perceived as female (*left*) and male (*right*). Yet both are versions of the same androgynous face (see http://illusioncontest.neuralcorrelate.com/2009/the-illusion-of-sex). The two images are identical, except that the contrast between the eyes and mouth and the rest of the face is higher for the face on the left than for the face on the right.

This illusion shows that contrast is an important cue for determining the sex of a face, with low-contrast faces appearing male and high-contrast faces appearing female. It may also explain why females in many cultures darken their eyes and mouths with cosmetics: a made-up face looks more feminine than a fresh face.

FELINE FACE

Cat Woman (*right*), created at Aude Oliva's M.I.T. laboratory, is a hybrid image of a woman (*left*) and a cat. At close range, *Cat Woman* has a cat's face. But at a distance, coarse features obscure the whiskers, fur texture and other details. Simply superimposing a transparent cat's face on a woman's face would not produce the same effect; this illusion works only by combining two images that differ in their spatial detail—one fine and one coarse.

MUSEO DALÍ/THE BRIDGEMAN ART LIBRARY, © 2010 SALVADOR DALÍ, GALA-SALVADOR DALÍ FOUNDATION/ARS, NEW YORK (*top*); RICHARD RUSSELL *Gettysburg College* (*middle*); AUDE OLIVA *M.I.T.* (*bottom*)

MARGARET THATCHER ILLUSION

This illusion by vision scientist Peter Thompson of the University of York in England was critical to our understanding of face perception. When the illusion was discovered in 1980, scientists already knew that faces were difficult to recognize upside down. But the assumption was that because the brain always sees faces right side up, the face-recognition cells were optimized for right-side-up faces. This assumption was partially true, but the Margaret Thatcher illusion went further to show that the brain does not simply process and store representations of whole faces; rather it recognizes representations of individual facial features such as the mouth and eyes.

The top and bottom row of Thatcher images are identical to each other but flipped vertically. The top row looks like two upside-down Thatchers, no problem there. But the bottom row looks like a Thatcher on the left and a horrible mutant on the right. The reason is that whereas the left column depicts normal faces (although the upper face is upside down), the right column shows Frankenstein-ish composites of Thatcher with only the eyes and mouths flipped vertically. The Thatcher at the upper right does not freak you out, because the eyes and mouth are right side up (although the overall face is upside down), and your face-perception neurons therefore see them as “normal” (even though they do not match the rest of the face).

The bottom right image, on the contrary, is creepy because the eyes and mouth are upside down and thus all wrong, despite the fact that the face as a whole is right side up. Harvard neuroscientists Winrich Freiwald, Doris Tsao and Livingstone have now found neurons in the brain that respond to specific face features such as mouths and eyes, confirming the predictions that were made from this illusion several decades earlier.

TONY BLAIR ILLUSION

Vision scientist Stuart Anstis of the University of California, San Diego, created this illusion in 2005 to celebrate the 25th anniversary of the Thatcher illusion. Anstis reasoned that if face-detecting neurons prefer right-side-up facial features, they should also be selective for other evolutionarily stable aspects of faces. He tested this idea by comparing positive and negative images of Tony Blair. Because we have evolved to see faces only in positive contrast, it follows that the perception of individual facial features should fail if shown in negative. As with the Thatcher illusion, showing the whole face in negative (*top left*) makes it less recognizable than the normal face (*bottom left*). Using positive images of the mouth and eyes overlaid on a negative face does not look particularly grotesque either (*top right*). But a positive image of Blair with a negative mouth and eyes (*bottom right*) is just as horrid as the upside-down mouth and eyes in the right-side-up Thatcher.

PETER THOMPSON *University of York*, FROM *PERCEPTION*, VOL. 9; 1980, PUBLISHED BY PION LIMITED, LONDON (*Thatcher*); STUART ANSTIS *U.C.S.D.* (*Blair*)

MOONEY FACES

Our nervous systems are hardwired to detect and process faces rapidly and efficiently, even with scarce details. Pictures such as the ones shown above are often referred to as Mooney faces, after cognitive psychologist Craig Mooney, who used similar images in his research on perception. Mooney faces illustrate how little visual information it actually takes to "see" a face.

The artist who created the movie poster for *Premonition* understood this phenomenon (*opposite page, bottom*). The tree branches, leaves and birds in the poster form only the barest outline of actress Sandra Bullock's face. Our brains fill in the gaps and construct a finished face from sparse visual content.

AARON SCHURGER *Princeton University*

COFFEE FACE
Our face-detection neural machinery can be overloaded. There is a man's face hidden in this image. But before we spill the beans about its location, look around and see if you can find it yourself. It's difficult! Don't give up too quickly: finding the face may take you a few minutes the first time you look. But once you have seen it, you will always find it immediately in every subsequent search. Given up? It's in the lower left quadrant near the bottom edge, about one third of the way across the image from the left.

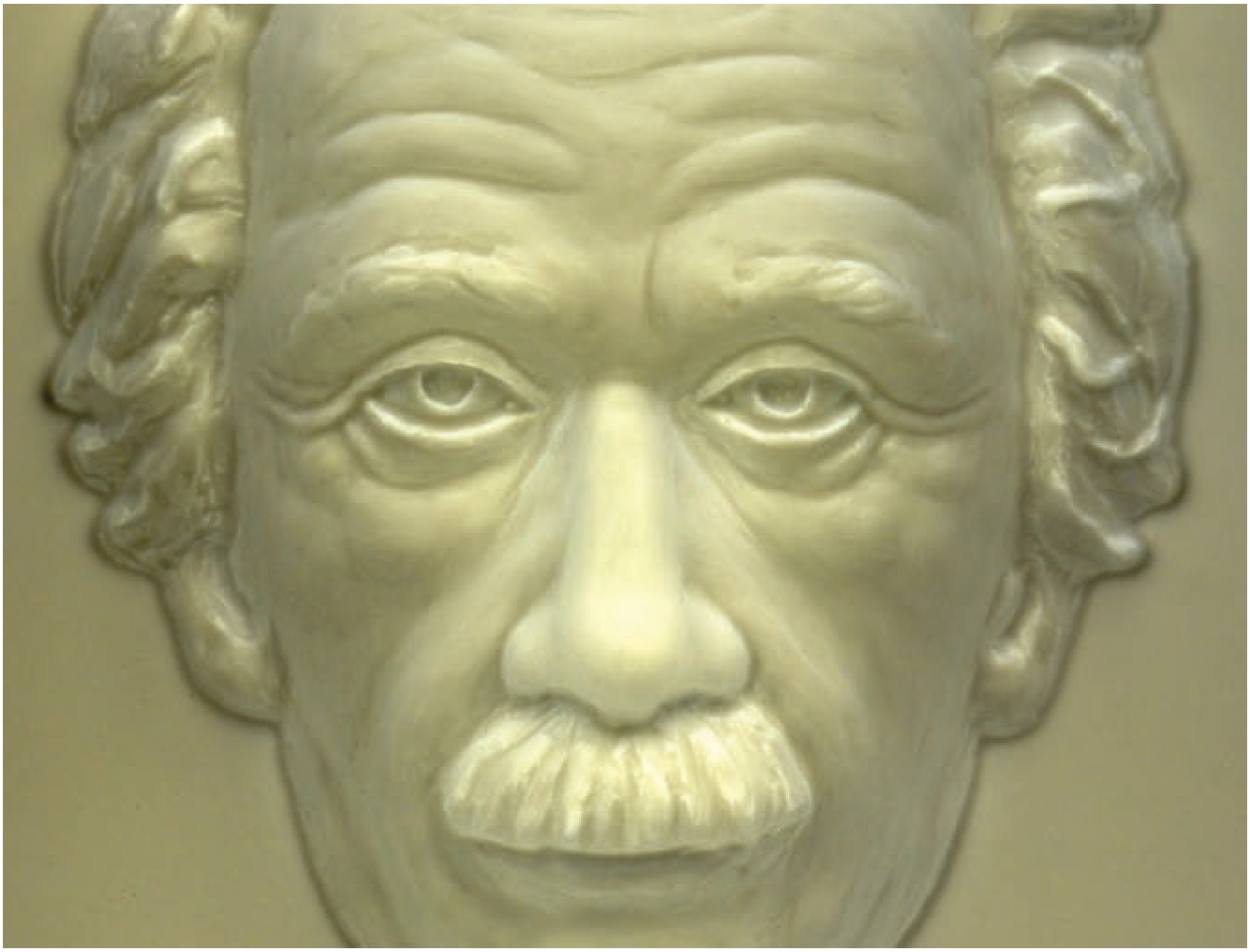
IMAGE COURTESY OF FRITS BONJERNOOR (*coffee beans*); TRI-STAR/THE KOBAL COLLECTION (*movie poster*)



HOLLOW MASK ILLUSION

This hollow mask created by sculptor Bryan Parkes gives the eerie impression that Albert Einstein's face is following you as you move around the room (*below*). The mask is placed in front of a window, with its open back facing toward you, so that sunlight illuminates the plastic face. Although the mask is concave, your brain assumes that all faces are convex. While a convex face would look in only one direction, Einstein's hollow face seems to look forward when the viewer is directly ahead, but at an angle when the viewer moves sideways. In another demonstration of this well-known illusion, when a hollow mask rotates on a turntable, it appears to turn opposite to the actual direction of the turntable.

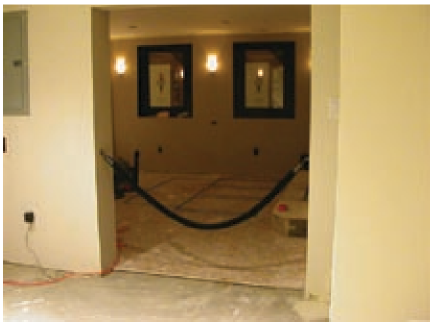
Vision researcher Thomas Papathomas of Rutgers University created an interesting variation on this illusion by attaching three-dimensional eyeballs and a nose ring to a hollow mask. As shown in these three frames from a movie of the rotating mask, the eyeballs and nose ring appear to rotate in the opposite direction to that of the mask (*above*). This illusion won third prize in the 2008 Best Illusion of the Year Contest. You can view the movie at http://illusion-contest.neuralcorrelate.com/2008/rolling-eyes-on-a-hollow-mask.



THOMAS PAPATHOMAS *Rutgers University (faces at top)*; WWW.GRAND-ILLUSIONS.COM *(Einstein)*


SURROUNDED BY FACES

Because our brains are so good at detecting faces, we sometimes see them where they do not exist. Were you ever scared as a child by strange faces popping up from an abstract wallpaper design or formed by shadows in the semidarkness of your bedroom? Ever noticed that cars seem to have faces, with the headlights as eyes and the grilles as mouths? These effects result from the face-recognition circuits of our brains, which are constantly trying to find a face in the crowd. These circuits are so powerful that we see faces in an old telephone, a bowling ball, a roped-off room, a USB drive, a faucet and a log (*from upper left*).




FLICKR (*telephone, roped-off room, USB drive, sink*); TSUNEO YAMASHITA *Getty Images* (*log*)

THE MANE DIFFERENCE

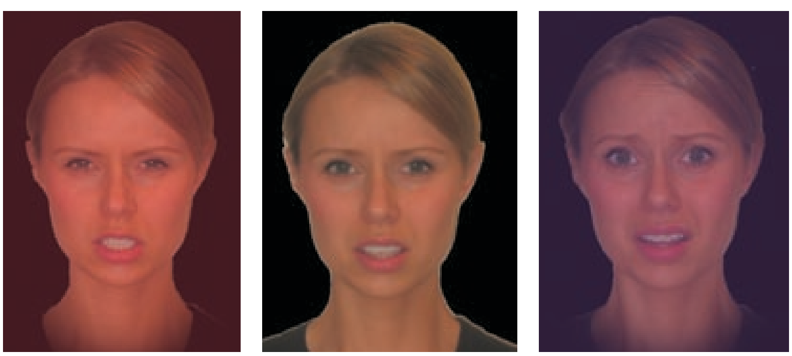
Visual illusions showcasing politicians are all the rage. At first sight it looks like Al Gore standing behind Bill Clinton, but notice that Gore is really a doppelgänger Clinton, only with Gore's gorgeous head of hair (*left*). A set of face features (Clinton's) mixed with a different set of features (Gore's hair) isn't easily recognized as being misplaced.

Superman relies on the same illusion to protect his identity: thanks to a pair of glasses, a change of clothes and a different hairstyle, nobody in Metropolis realizes that he and Clark Kent are the same person (*below*).

EMOTION ADAPTATION

Gaze at the angry face (*left*) for about 30 seconds while looking around the face from the eyes to the mouth, to the nose, back to the eyes, and so on. Then look at the center face. It looks scared, right? Now look at the scared face (*right*) for 30 seconds and then look at the center face again. This time it is angry! In reality, the center face is a 50–50 blend of an angry and a scared face.

Created by Andrea Butler and her colleagues at the University of British Columbia, this illusion shows that our visual-processing system adapts to an unchanging facial expression by temporarily becoming less responsive to it. As a result, the other facial expression dominates when you view the blend. This adaptation occurs in higher-level brain circuits, rather than in the retina, because the illusion works even if you view the left or right image with one eye only and then look at the center image with your other (unadapted) eye.



RACE FACE ILLUSION

While viewing composites of racially black (*left*) and white (*right*) faces that reflect exactly the same amount of light, psychologist Mahzarin R. Banaji of Harvard University noticed an interesting illusion: the white face appears lighter. Banaji and Daniel T. Levin of Vanderbilt University have proposed that the distortion occurs because abstract social expectations about skin tone influence our perception of faces.

CREATED BY PAWAN SINHA AND TOMASO POGGIO *M.I.T.* (*Clinton/Gore*); WARNER BROS./DC COMICS/ THE KOBAL COLLECTION (*Clark Kent/Superman*); COURTESY OF JASON BARTON *University of British Columbia*; FROM "FACTORS CONTRIBUTING TO THE ADAPTATION AFTEREFFECTS OF FACIAL EXPRESSION," BY A. BUTLER ET AL., IN *BRAIN RESEARCH*, VOL. 11; 2008, WITH PERMISSION FROM ELSEVIER (*angry/scared faces*); DANIEL T. LEVIN *Vanderbilt University* (*black/white faces*)

FAT FACE THIN ILLUSION

Peter Thompson, who discovered the Thatcher illusion, has now identified a new illusion that he calls the "fat face thin illusion." In this example of the illusion, the photographs are identical, but the upside-down face appears strikingly slimmer than the right-side-up version.

One possible explanation is that it is easier for the brain to recognize distinctive facial features, such as chubby cheeks, when they are viewed in the normal upright position. But that does not explain why thin faces don't look fatter—or thinner still—when viewed upside down.

FOCUS ON FACES

Facial expressions play a key role in our everyday social interactions. Even when watching movies or looking at photographs, we spend most of our time looking at the faces they portray. Our intense focus on faces is at the expense of other potentially interesting information, however. Take a quick look at this woman and child. Their smiling faces suggest they are having a good time. But is that it? Look more closely, and you may notice that the girl has an extra finger on her right hand: something that you probably missed at first because your attention was fixed on the faces.

DAN KITWOOD *Getty Images* (*fat/thin faces*); PHOTOCOMPOSITION BY SMITHA ALAMPUR; THOMAS POLEN *iStockphoto* (*woman and child*)

The Eyes Have It

Eye gaze is critically important to social primates such as humans. Maybe that is why illusions involving eyes are so compelling

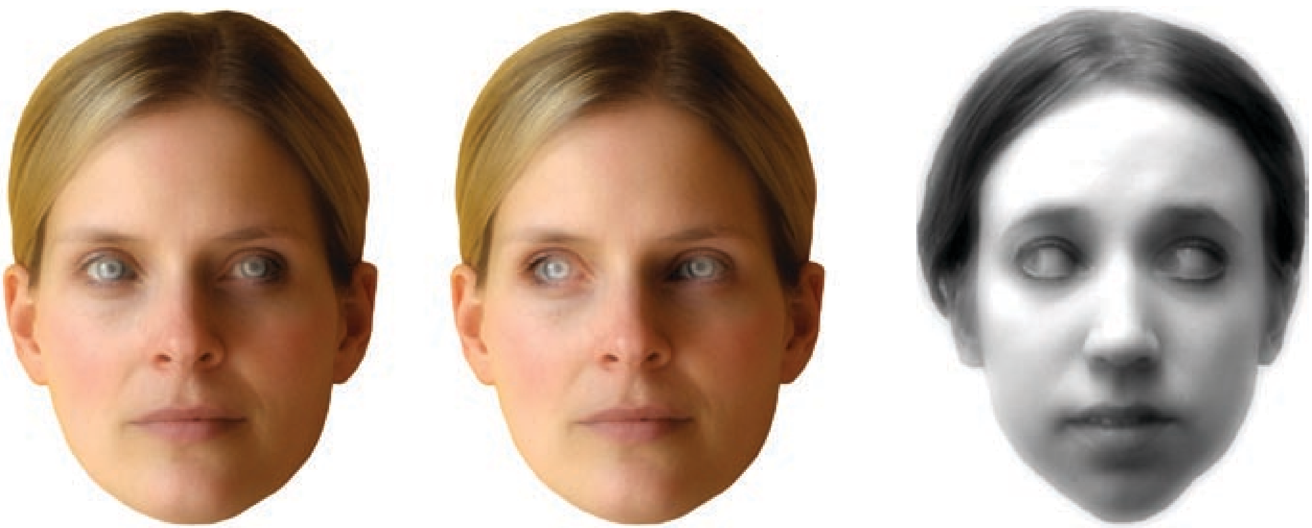
By Susana Martinez-Conde and Stephen L. Macknik

The eyes are the window to the soul. That is why we ask people to look us in the eye and tell us the truth. Or why we get worried when someone gives us the evil eye or has a wandering eye. Our language is full of expressions that refer to where people are looking—particularly if they happen to be looking in our direction.

As social primates, humans are keenly interested in determining the direction of gaze of other humans. It is important for evaluating their intentions and critical for forming bonds and negotiating relationships. Lovers stare for long stretches into each other's eyes, and infants focus intently on the eyes of their parents. Even very young babies look at simple representations of faces for longer than they look at similar cartoonish faces in which the eyes and other features have been scrambled.

In this article, we investigate a series of illusions that take advantage of the way the brain processes eyes and gaze. It turns out that it is fairly easy to trick us into thinking that someone is looking somewhere else.

SUSANA MARTINEZ-CONDE and STEPHEN L. MACKNIK are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.



GHOSTLY GAZES

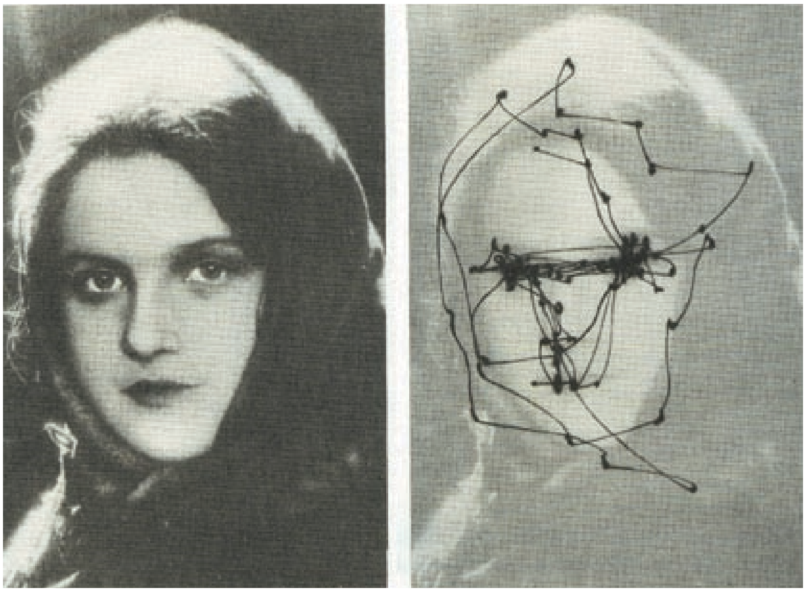
Not knowing where a person is looking makes us uneasy. For this reason, it can be awkward to converse with somebody who is wearing dark sunglasses. And it is why someone might wear dark sunglasses to look "mysterious."

A recently identified visual illusion takes advantage of the unsettling effect of uncertainty in gaze direction. The "ghostly gaze" illusion, created by Rob Jenkins of the University of Glasgow in Scotland, was awarded second prize in the 2008 Best Illusion of the Year Contest, held in Naples, Fla. In this illusion (*left* and *center*), twin sisters appear to look at each other when seen from afar. But as you approach them, you realize that the sisters are looking directly at you!

The illusion is a hybrid image that combines two pictures of the same woman. The overlapping photos differ in two important ways: their spatial detail (fine or coarse) and their direction of gaze (sideways or straight ahead). The images that look toward each other contain only coarse features, while the ones that look straight ahead are made up of sharp details. When you approach the pictures, you are able to see all the fine detail, and so the sisters seem to look straight ahead. But when you move away, the gross detail dominates, and the sisters appear to look into each other's eyes. See an interactive demo at http://illusioncontest.neuralcorrelate.com/2008/ghostly-gaze.

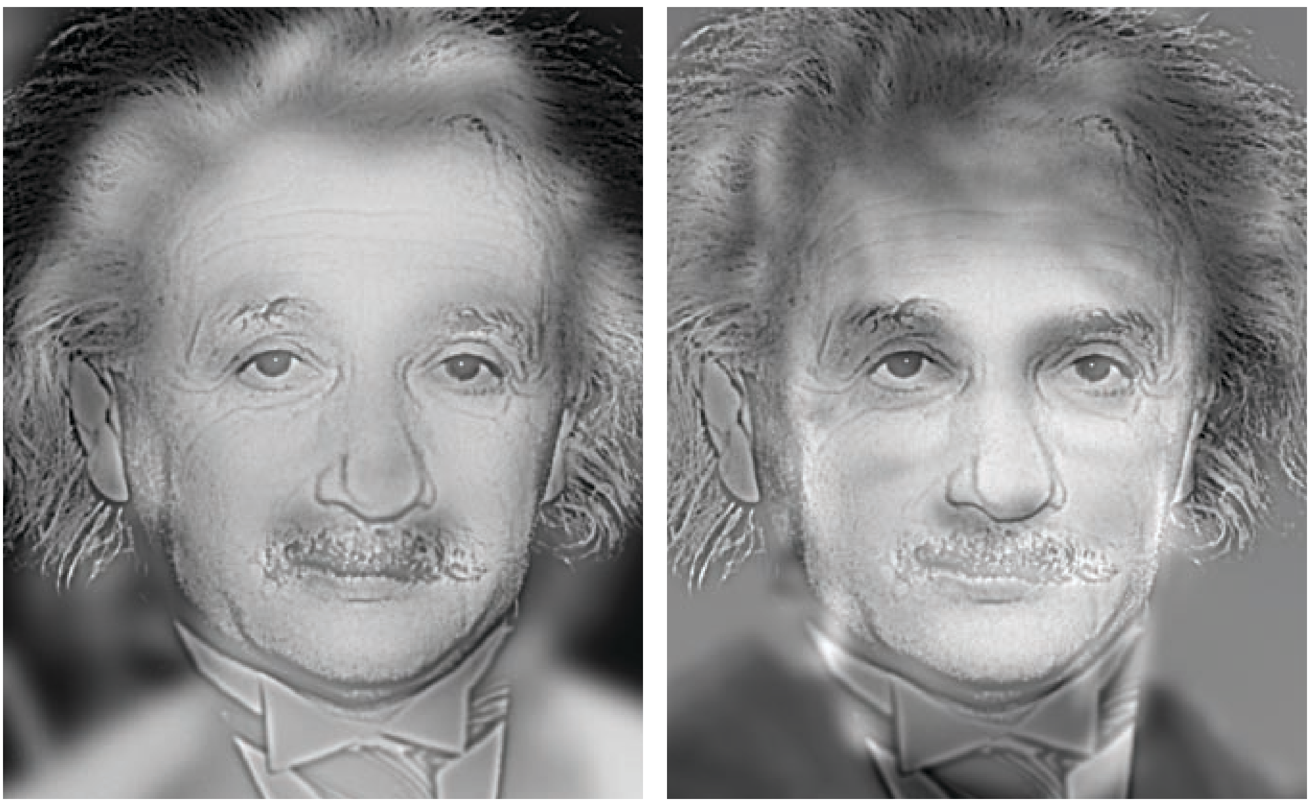
In another example of a hybrid image (*right*), a ghostly face appears to look to the left when you hold the page at normal reading distance. Step back a few meters, however, and she will look to the right.

ROB JENKINS *University of Glasgow*



FOCUS ON THE EYES

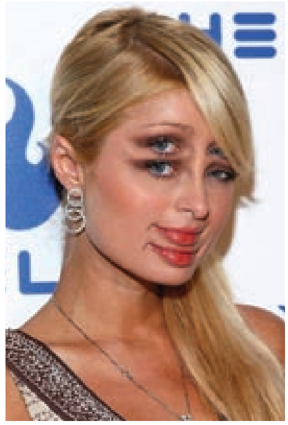
About 50 years ago Russian psychologist Alfred L. Yarbus tracked the eye movements of volunteers as they viewed photographs of human faces and found that most observers were primarily interested in the eyes shown in the portraits. But even though most of us pay close attention to the area of the face around the eyes, we are still forced to take lots of shortcuts when figuring out where someone is looking. These sensory shortcuts are what make us so vulnerable to visual illusions involving gaze.



EINSTEIN'S ALTER EGOS

The ghostly gaze illusion is based on a hybrid-image technique created by Aude Oliva and Philippe G. Schyns of the Massachusetts Institute of Technology. In a shocking example of how perceptual interpretation of hybrid images varies with viewing distance, Albert Einstein, seen from up close, becomes Marilyn Monroe (*left*) or Harry Potter (*right*), when seen from a few meters away. For more hybrid images created by the Oliva laboratory, visit the hybrid image gallery at http://cvcl.mit.edu/hybrid_gallery/gallery.html.

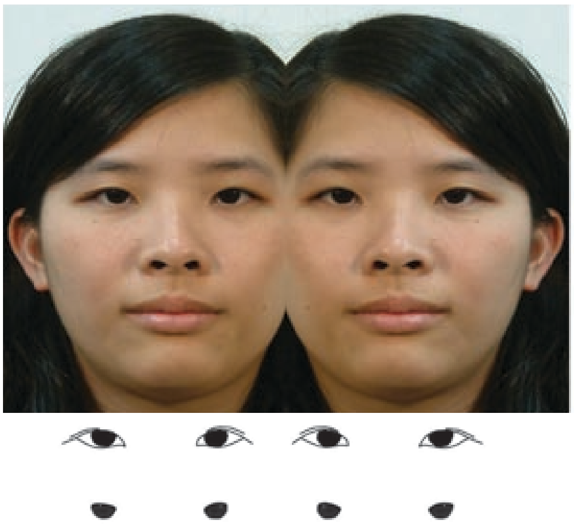
FROM "EYE MOVEMENT AND VISION," BY A. L. YARBUS, PLENUM PRESS, 1967, © SPRINGER (*top*); AUDE OLIVA *M.I.T.* (*bottom*)

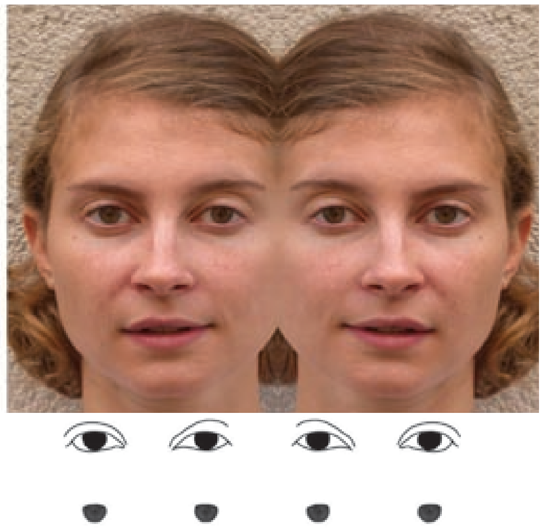


SEEING DOUBLE?

What if you duplicate some of the features of a portrait without overlapping them completely? It is relatively easy to create images in Photoshop in which the eyes and the mouth, but no other facial features, have been doubled. The results are little short of mind-bending: as the brain struggles (and fails) to fuse the doubled-up features, the photograph appears unstable and wobbly, and observers experience something akin to double vision.

The neural mechanisms for this illusion may lie within our visual system's specialized circuits for face perception. If you double up the eyes and mouths in a portrait, the neurons in the face-recognition areas of the brain may not be able to process this visual information correctly. Such failure could make the faces unsteady and difficult to perceive.



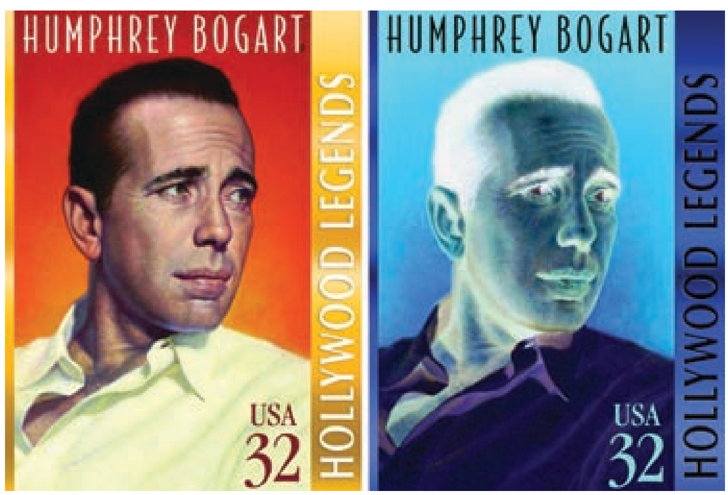


THE IRIS ILLUSION

This illusion, by vision scientists Jisien Yang and Adrian Schwaninger of the Visual Cognition Research Group at the University of Zurich, was one of the top 10 finalists in the 2008 Best Illusion of the Year Contest. It shows that context, such as the shape of the eyelids and face, affects the apparent distance between the irises. Consider the pair of Asian faces shown here: the distance between the left eye of the right face and the right eye of the left face seems short. In the Caucasian faces, the separation looks wider. Notice the reconstructions of the eyes and irises below each face: without the context of the face and eyelid shapes, it is clear that the irises are equally spaced. Visit http://illusioncontest.neuralcorrelate.com/2008/yangs-iris-illusion for more details.

HERE'S LOOKIN' AT YOU, KID

Vision researcher Pawan Sinha of the Massachusetts Institute of Technology shows us with this illusion that our brains have specialized mechanisms for determining gaze direction. In the normal photograph of Humphrey Bogart (*left*), the actor appears to be looking to his left, but in the photo negative (*right*) he appears to be looking in the opposite direction. Yet Bogart's face does not look backward; only the eyes are reversed. Why? The answer is that we have specialized modules in our brain that determine gaze direction by comparing the dark parts of the eyes (the irises and pupils) with the whites. When the face is negative, the whites and irises appear to swap position. Our knowledge that irises are light rather than dark in a negative does not change our perception of this illusion.



FREAKINGNEWS.COM (*top*); JISIEN YANG *University of Zurich* AND ADRIAN SCHWANINGER *University of Applied Sciences Northwestern Switzerland and University of Zurich* (*middle*); PAWAN SINHA AND TOMASO POGGIO *M.I.T.* (*bottom*)

FOLLOW MY FINGER

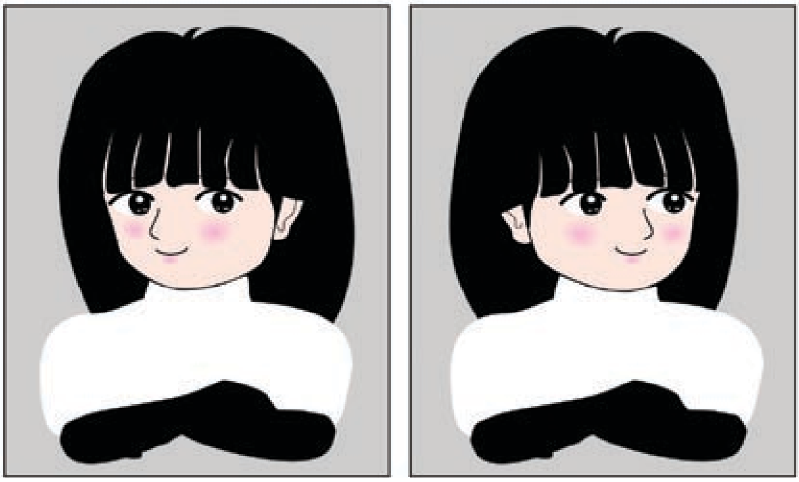
The artists who drew these World War I recruiting posters knew something about eye tracking. No matter how you look at Uncle Sam (*right*) or British Field Marshal Lord Kitchener (*left*), the eyes and finger seem to be pointed directly at you. Today you can experience the same phenomenon in an art museum, where the painted eyes in portraits sometimes seem to follow you around the room.

Such eye tracking is not only a B-movie horror flick cliché but also a powerful illusion that continues to inspire visual science studies. In 2004 vision psychologists Jan Koenderink, Andrea van Doorn and Astrid Kappers of the University of Utrecht in the Netherlands, along with James Todd of Ohio State University, concluded that, contrary to popular belief, this compelling illusion does not require special artistic abilities on the part of the painter. Surprisingly, all that is required is that the person portrayed looks straight ahead, and the visual system takes care of the rest.

The deceptively simple explanation is that when we look at a real human face or anything else in our three-dimensional physical world, the visual information that specifies near and far points changes with our viewing angle. But when we observe a two-dimensional painting or photograph hanging on the wall or a poster such as the ones above, the visual information that defines near and far points remains unaltered by our viewing angle. The brain interprets this information as if it pertained to a 3-D object, however. That interpretation is what creates the eerie sensation that a portrait's eyes are following you.

CONTEXTUAL CUES

Contextual cues, such as the position of the face and the head, also influence the perceived direction of gaze. In this illusion created by Akiyoshi Kitaoka, a professor of psychology at Ritsumeikan University in Japan, the girl on the left appears to gaze directly at you, while the girl on the right appears to be looking to her left. In reality, the eyes of both girls are identical. This illusion was first described in 1824 by British chemist and natural philosopher William Hyde Wollaston, who also discovered the elements palladium and rhodium.



COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University (bottom)*

ANIMAL "EYES"

A fascination with eyes is not solely a human trait. Many species of fish, insects and even birds sport false (one could say illusory) eyes on their wings, stalks or even the back of their head. These eye-catching patterns do not necessarily mimic real eyes, but they serve to dissuade, confuse or startle potential predators. Get an eyeful of these animals that sport eyespots (*clockwise from upper left*): an emperor moth with four false eyes, a northern pygmy owl with "eyes" in the back of its head, a butterfly fish with a fake eye that draws attention away from its head, an insect named the eyed click beetle and a spicebush swallowtail caterpillar.

C. M. BAHR *Peter Arnold, Inc.* (*moth*); GEORGE GRALL *National Geographic Stock* (*caterpillar*)

DONALD M. JONES *Minden Pictures* (*owl*); K. HINZE *Peter Arnold, Inc.* (*fish*); DARLYNE A. MURAWSKI *Getty Images* (*beetle*)

The Illusions of Love

How do we fool thee? Let us count the ways that illusions play with our hearts and minds

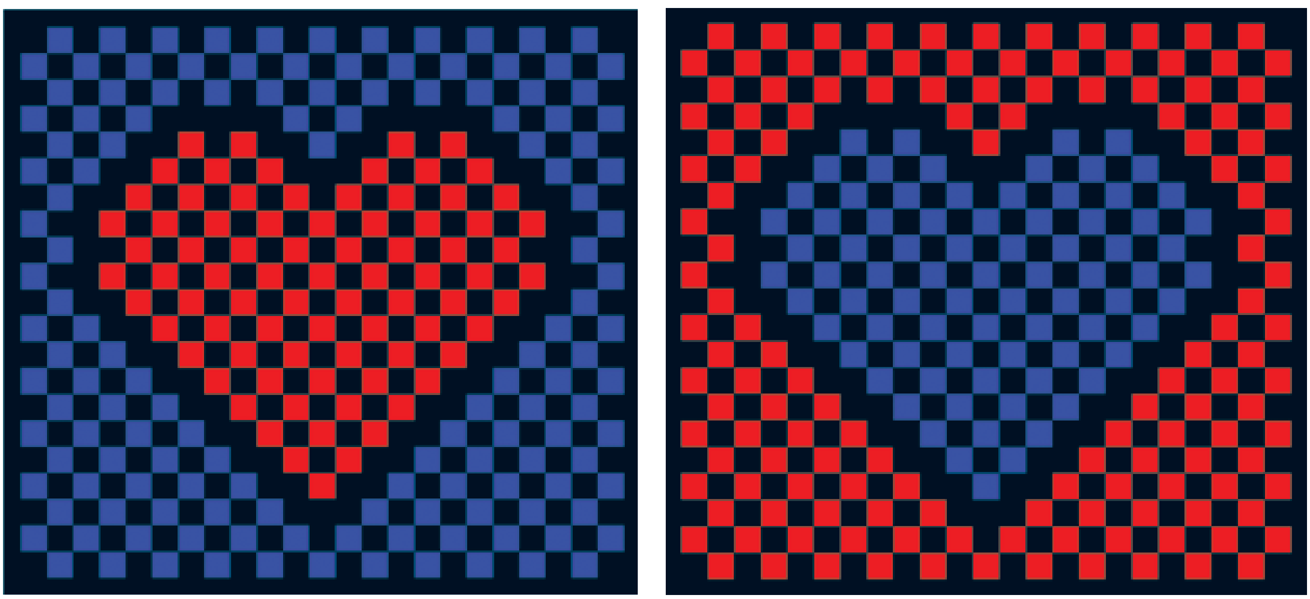
By Stephen L. Macknik and Susana Martinez-Conde

On Valentine's Day, everywhere you look there are heart-shaped balloons, pink greeting cards and candy boxes filled with chocolate. But what is true love? Does it exist? Or is it simply a cognitive illusion, a trick of the mind?

Contrary to the anatomy referenced in all our favorite love songs, love (as with every other emotion we feel) is not rooted in the heart, but in the brain. (Unfortunately, Hallmark has no plans to mass-produce arrow-pierced chocolate brains in the near future.) By better understanding how the brain falls in love, we can learn about why the brain can get so obsessed with this powerful emotion. In fact, some scientists even see love as a kind of addiction. For instance, neuroscientist Thomas Insel and his colleagues at Emory University discovered that monogamous pair bonding has its basis in the same brain reward circuits that are responsible for addiction to drugs such as cocaine and heroin. Their study was conducted in the prairie vole, a small rodent that mates for life. But the conclusions are probably true for humans, too, which may explain why it is so hard to break up a long-term romantic relationship. Losing someone you love is like going through withdrawal.

In this article, we feature a number of visual illusions with a romantic motif. We hope that you and your special one will enjoy them. And remember, even if love is an illusion, that doesn't mean it's not meaningful and real (to our brains, anyway).

STEPHEN L. MACKNIK and SUSANA MARTINEZ-CONDE are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.

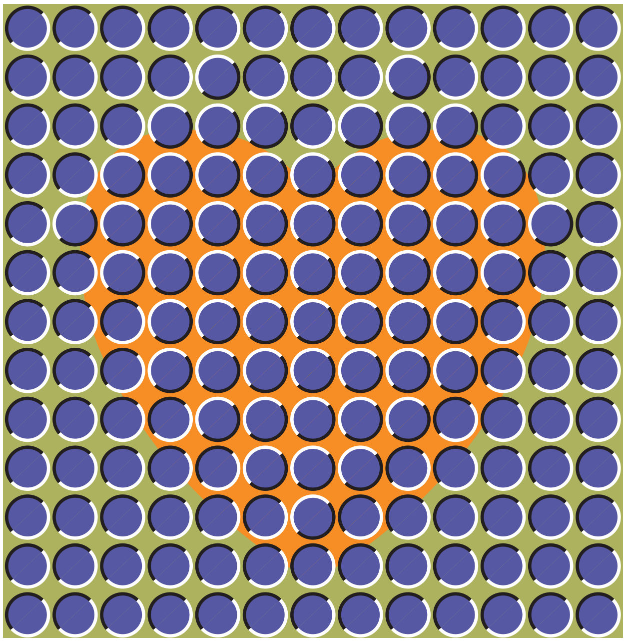


COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University*

POP! GOES MY HEART

Nothing is more romantic than curling up in front of a fire with your loved one on Valentine's Day as you lovingly whisper "chromostereopsis." Okay, maybe it's not as passionate as a sonnet—unless you are a vision scientist. Look at the red and blue hearts and examine their depth with respect to the background. Most people find that the red heart pops in front of the blue background, whereas the blue heart sinks beneath the red background.

This illusion comes about because the lenses in our eyes refract blue light more than red. This phenomenon is called chromatic aberration; another example of this effect is seeing a rainbow when you shine white light through a prism. When both eyes view the red and blue images simultaneously, the cornea and lens of the eyes refract different amounts of the colors. The brain deals with this sensory aberration by imagining depth—the red heart is in front of the blue background, and vice versa—even though none actually exists.

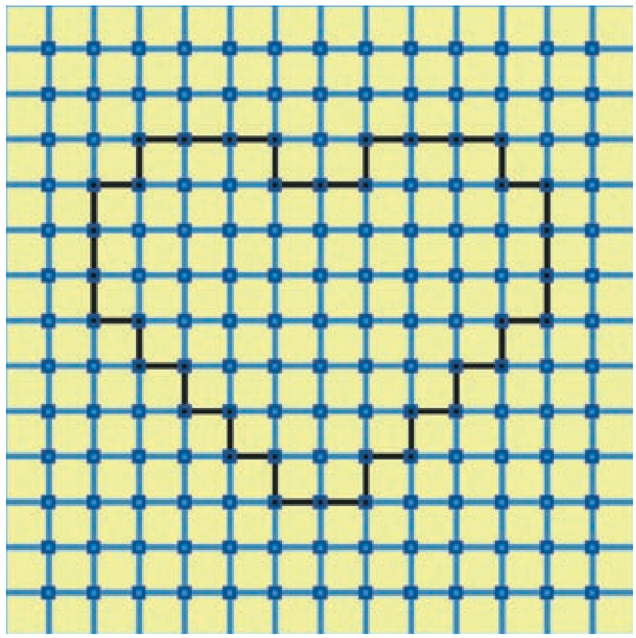


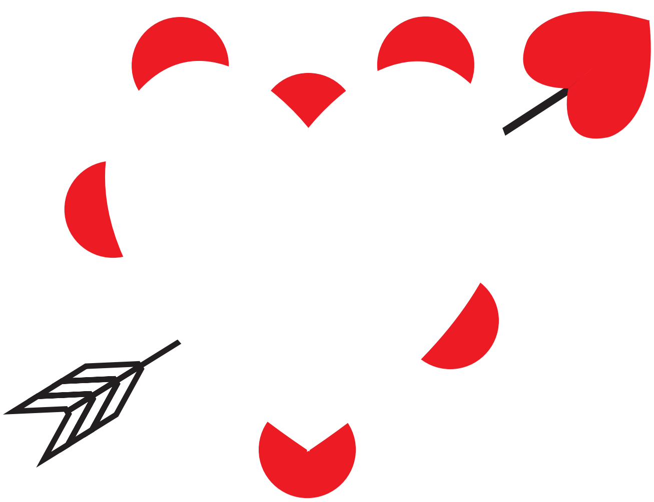
ILLUSIONS THAT MOVE THE HEART

Your wandering eyes pull at your lover's heart-strings. In this illusion, the heart appears to move and even pulsate as you look around the image. When your eyes move, they shift the retinal images of the black-and-white edges in the pattern, activating the motion-sensitive neurons in your visual cortex. This neural activation leads to the perception of illusory motion. Notice that if you focus your gaze on a single point, the illusory motion slows or stops.

ILLUSORY NEON HEART

Notice that the yellow fields inside the heart seem paler than the fields forming the contour of the heart, which appear to be a darker shade of yellow-orange. Right? Wrong. Actually all the yellow fields in the figure are identical. Any differences that you see are all in your mind. This effect is called neon color spreading, because it resembles the effect of the light spreading from a neon lamp. The neural underpinnings of this effect are not yet understood.



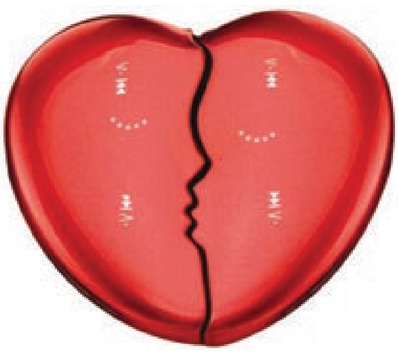


IS LOVE AN ILLUSION?

Spanish essayist Miguel de Unamuno said, "Love is the child of illusion and the parent of disillusion." Is this view cynical or biologically based? Illusions are, by definition, mismatches between physical reality and perception. Love, as with all emotions, has no external physical reality: it may be driven by neural events, but it is nonetheless a purely subjective experience. So, too, is the wounded heart we have drawn here. Where the arrow enters and exits the heart, there is no heart whatsoever, only an imaginary edge defined by the arrow.

This effect is called an illusory contour. We perceive the shape of the heart only because our brains impose a shape on a very sparse field of data. Neuroscientist Rüdiger von der Heydt and his colleagues, then at University Hospital Zurich in Switzerland, have shown that illusory contours are processed in neurons within an area of the brain called V2, which is devoted to vision. The illusory heart even looks slightly whiter than the background, although it is actually the same shade. Much of our day-to-day experience is made up of analogous feats of filling in the blanks, as we take what we know about the world and use it to imagine what we do not know.

MELISSA THOMAS, ADAPTED FROM WWW.AMAZING-ILLUSION.COM (*top*); G. SARCONE (*middle*); SUSANA MARTINEZ-CONDE AND STEPHEN L. MACKNIK (*bottom*)



A MATCHED SET
Is it a broken heart or two people kissing? Both, in the case of this two-piece Newman digital audio player. One for him and one for her.

LOVE AND AMOR
Here we see that love and amor are two sides of the same ambiguous object. This sculpture is an ambigram—an artwork or typographical design that can be read from two different viewpoints. Judith Bagai, editor of *The Enigma,* the official journal of the National Puzzlers' League, coined the term by contracting the words "ambiguous" and "anagram" (many ambigrams feature the same word seen from different directions).

AMBIGUOUS EMBRACES
Ambiguity is affected by our frame of mind. In the image on the left, *Message of Love from the Dolphins,* adult observers see two nude lovers embracing, whereas young children see only dolphins. If you still can't see the dolphins (we promise you they are there), look for more than two. In the image on the right, a Valentine's Day rose predicts the outcome of the evening's festivities.

BEIJING NEWSMY IDEAL DIGITAL TECHNOLOGY CO., LTD. *(top left);* FRANCIS TABARY *(top right);* SANDRO DEL PRETE *(bottom left and right)*

JIM WARREN

HIDDEN ROMANCE
Ambiguity and camouflage both make it difficult to understand what you are seeing. In this painting by Jim Warren, *Seven Hearts,* the hearts are hidden in the romantic scenery (*upper left*). Warren also painted *Romantic Day* (*upper right*) and *Last Embrace* (*left*).

FOR COFFEE AND TEA LOVERS
Yuan yang is a typical Hong Kong beverage mix of tea and coffee and also a symbol of marriage and love. Sculptor Tsang Cheung-shing has united both concepts in a beautiful ceramic work, in which tea and coffee poured from two stylish cups meet in a kiss.

TSANG CHEUNG-SHING

THE SHADOW OF LOVE

Almost any object can cast a heart-shaped shadow. For example, love can be seen through rose-colored glasses (*left*) or writ large (*right*).

LOVE IS ALL AROUND

Romance is not just for humans and prairie voles. Elephants and other animals also embrace the concept.

DIMITRI VERVITSIOTIS *Getty Images (eyeglasses)*; WEEPING WILLOW PHOTOGRAPHY *Getty Images (book pages)*; SUKREE SUKPLANG *Reuters/Corbis (elephants)*

Art as Visual Research: Kinetic Illusions in Op Art

Art and neuroscience combine to create fascinating examples of illusory motion

By Susana Martinez-Conde and Stephen L. Macknik

Scientists did not invent the vast majority of visual illusions. Rather they are the products of artists who have used their insights into the workings of the human eyes and brain to create illusions in their artwork. Long before visual science existed as a formal discipline, artists had devised techniques to "trick" the brain into thinking that a flat canvas was three-dimensional or that a series of brushstrokes in a still life was in fact a bowl of luscious fruit. Thus, the visual arts have sometimes preceded the visual sciences in the discovery of fundamental vision principles through the application of methodical—though perhaps more intuitive—research techniques. In this sense, art, illusions and visual science have always been implicitly linked.

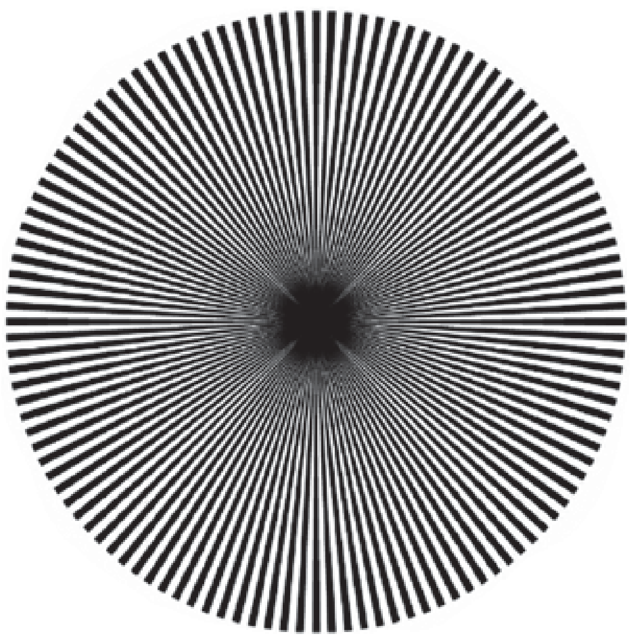
It was only with the birth of the op art (for "optical art") movement that visual illusions became a recognized art form. The movement arose simultaneously in Europe and the U.S. in the 1960s, and in 1964 *Time* magazine coined the term "op art." Op art works are abstract, and many consist only of black-and-white lines and patterns. Others use the interaction of contrasting colors to create a sense of depth or movement.

This style became hugely popular after the Museum of Modern Art in New York City held an exhibition in 1965 called "The Responsive Eye." In it, op artists explored many aspects of visual perception, such as the relations among geometric shapes, variations on "impossible" figures that could not occur in reality, and illusions involving brightness, color and shape perception. But "kinetic," or motion, illusions drew particular interest. In these eye tricks, stationary patterns give rise to the powerful but subjective perception of (illusory) motion.

This article includes several works of art in which objects that are perfectly still appear to move. Moreover, they demonstrate that research in the visual arts can result in important findings about the visual system. Victor Vasarely, the Hungarian-French founder of the op art movement, once said, "In basic research, intellectual rigor and sentimental freedom necessarily alternate."

Op artists have created some of the illusions featured here; vision scientists honoring the op art tradition have created others. But all of them make it obvious that in op art, the link between art and illusory perception is an artistic style in and of itself.

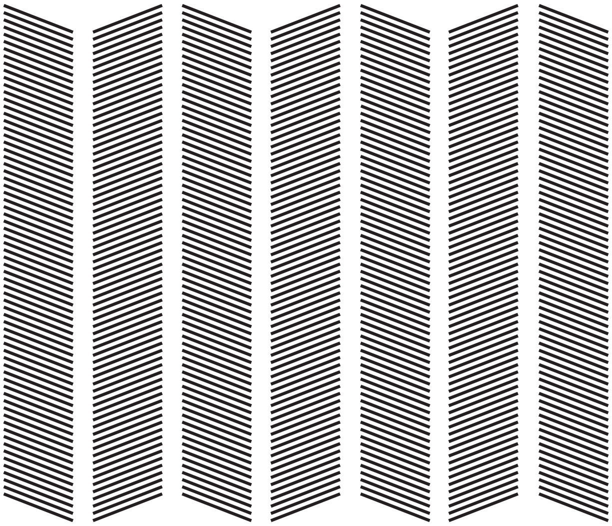
SUSANA MARTINEZ-CONDE and STEPHEN L. MACKNIK are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.



MACKAY RAYS

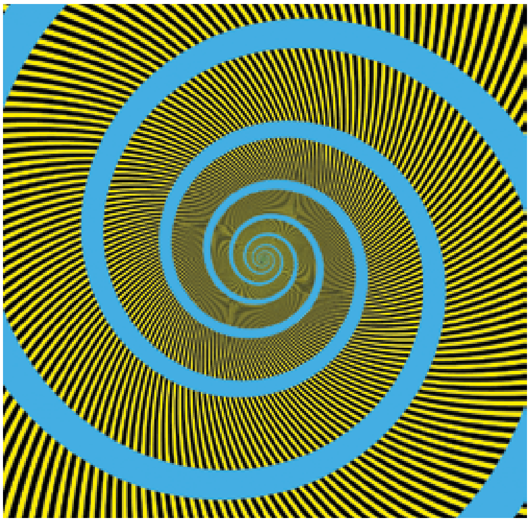
This illusion, created in 1957 by neuroscientist Donald M. MacKay, then at King's College London, shows that simple patterns of regular or repetitive stimuli, such as radial lines (called MacKay rays) can induce the perception of shimmering or illusory motion at right angles to those of the pattern. To see the illusion, look at the center of the circle and notice the peripheral shimmering.

FROM "TRAVERSING THE HIGHWIRE FROM POP TO OPTICAL," BY C. W. TYLER, IN *PLOS BIOLOGY,* VOL. 3, NO. 4; APRIL 2005



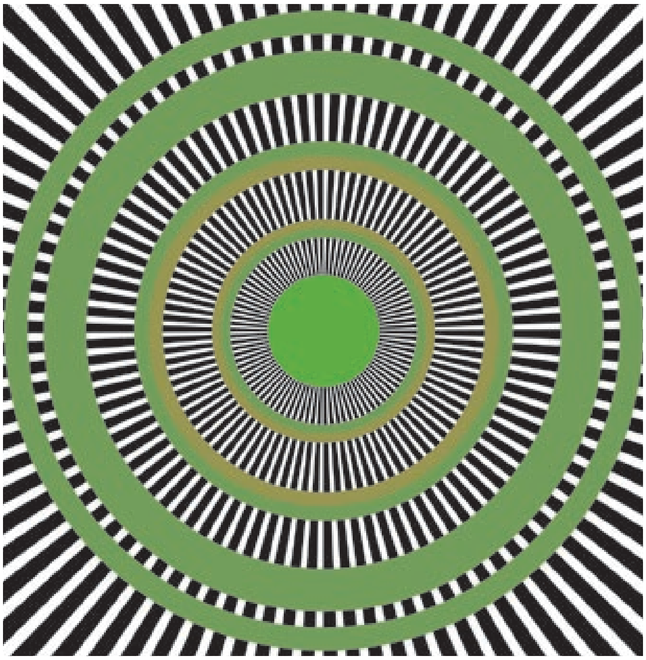
BBC WALLBOARD

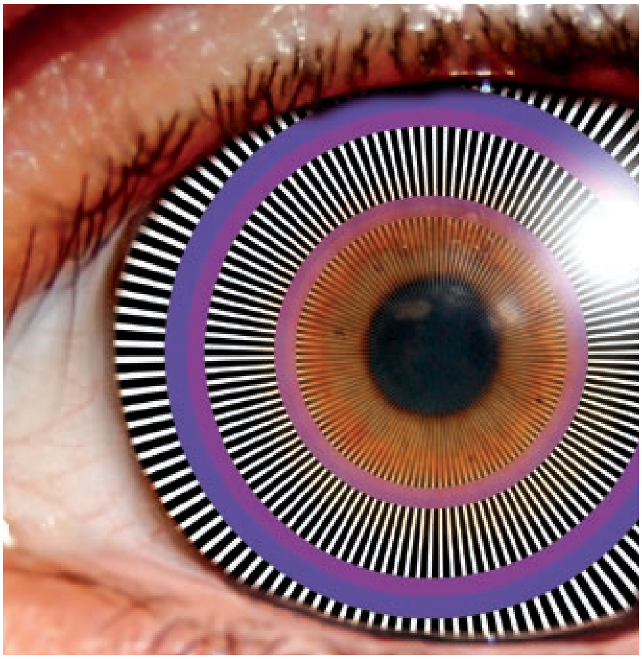
This illusion began with a chance observation. MacKay first saw it on the wallboard of a BBC studio: the broadcasting staff had been annoyed by illusory shadows running up and down blank strips between columns of parallel lines.



OP ART IS ALIVE AND WELL

Akiyoshi Kitaoka, a professor of psychology at Ritsumeikan University in Japan, follows in the footsteps of the great op artists of the 20th century. *Waterway Spirals* is a compelling and powerful version of French op artist Isia Léviant's now classic *Enigma*. Observe the strong illusory motion along the blue spiraling stripe.





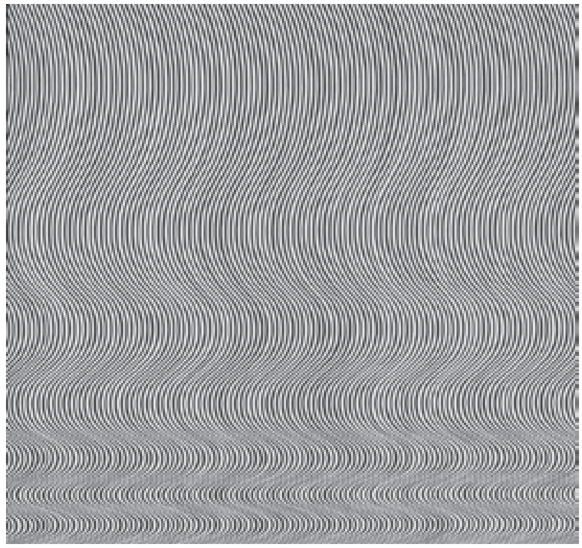
THE ENIGMA ILLUSION

Look at the center of the above image and notice how the concentric green rings appear to fill with rapid illusory motion, as if millions of tiny and barely visible cars were driving hell-bent for leather around a track. Neuroscientist and engineer Jorge Otero-Millan of the Barrow Neurological Institute in Phoenix created this image as a reinterpretation of *Enigma* by Léviant, who unknowingly combined the MacKay rays and the BBC wallboard.

But does the illusion originate in the mind or in the eye? The evidence was conflicting until we found, in collaboration with our Barrow colleagues Xoana G. Troncoso and Otero-Millan, that the illusory motion is driven by microsaccades: small, involuntary eye movements that occur during visual fixation. The precise brain mechanisms leading to the perception of the illusion are still unknown, however. One possibility is that microsaccades produce small shifts in the geometric position of the peripheral areas of the image. These shifts produce repeated contrast reversals that could create the illusion of motion. Otero-Millan's *Enigmatic Eye* (*right*), also a tribute to *Enigma,* reflects the role of eye movements in the perception of the illusion.

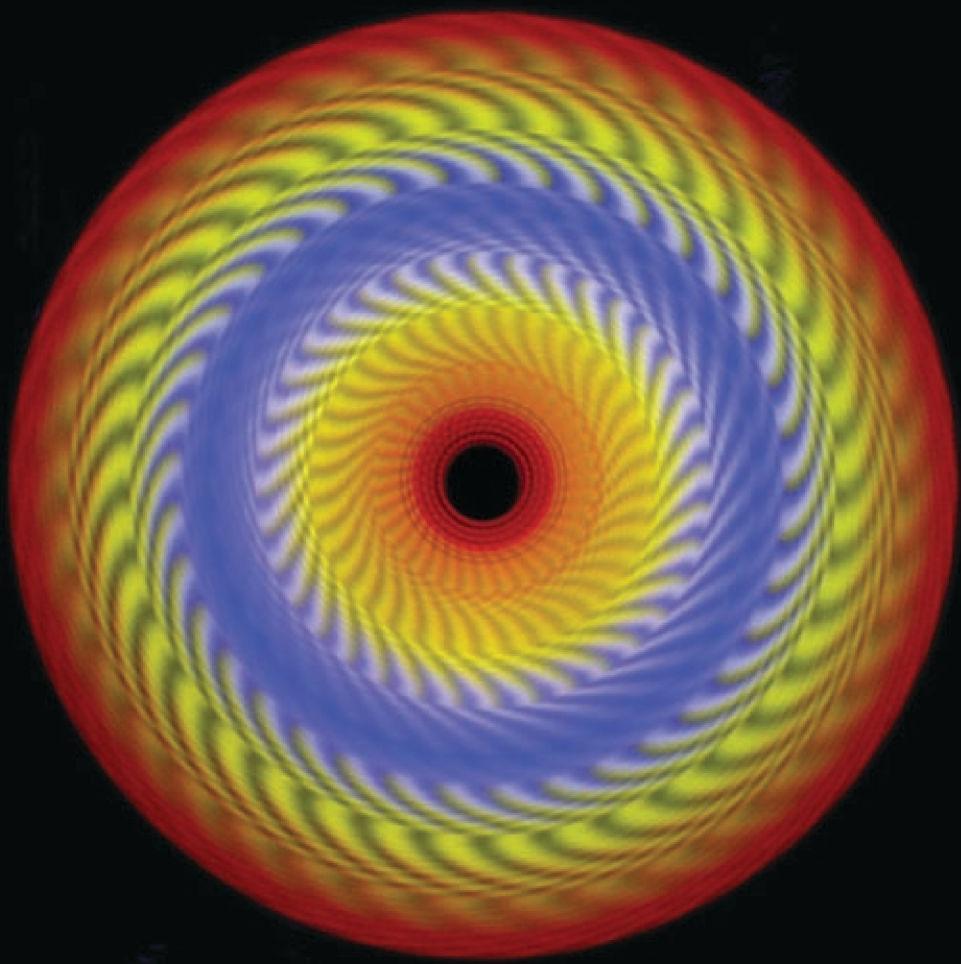
Neuroscientist and artist Bevil Conway and his colleagues at Harvard Medical School recently demonstrated that pairs of stimuli of different contrasts are able to generate motion signals in visual cortex neurons, and they have proposed that this neural mechanism may underlie the perception of illusory motion in certain static patterns.

COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University (top right);* JORGE OTERO-MILLAN *Barrow Neurological Institute/University of Vigo (bottom images)*

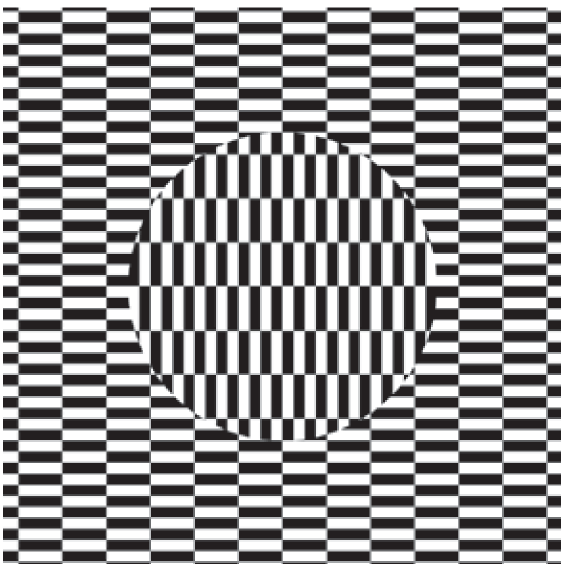


BRIDGET RILEY'S MOTION ILLUSIONS
Eye movements, both large and small, can trigger most of the motion illusions in this article. *Blaze,* a 1964 screen print by English op artist Bridget Riley (*left*), gives the impression of fast spiraling motion as observers move their eyes around the image. *Fall* (*right*), painted by Riley in 1963, has curved lines that create illusory undulations and volume. Both works are in the Tate gallery in London. The 1965 MOMA exhibition "The Responsive Eye" drew worldwide attention to Riley's op art.

RILEY REVISITED
In a work reminiscent of Riley's, vision scientist Nick Wade of the University of Dundee in Scotland created an example that features both streaming and shimmering motion. An eye is clearly visible in the center of the design, and a face becomes visible if you view the illusion from across the room or shake your head. The hidden face is a portrait of Wade's wife, Christine, and the title *Chrystine* is a reference to the chrysanthemum shape.



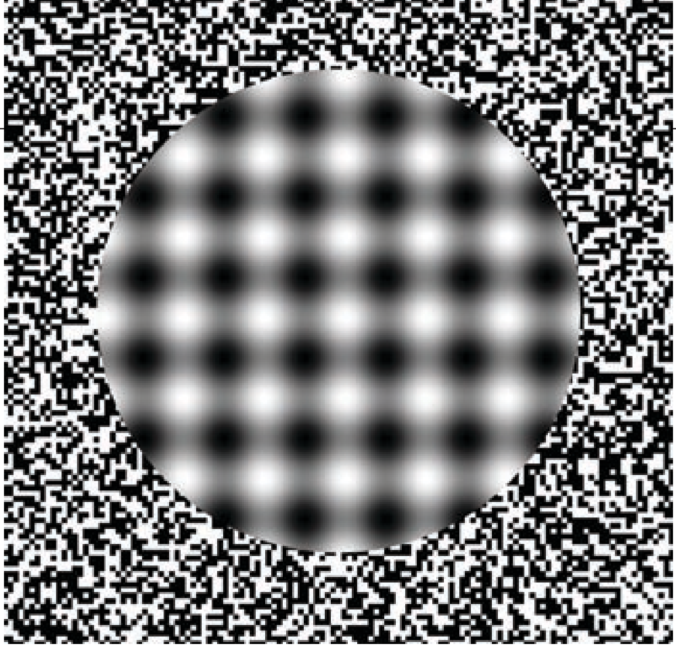
CIRCLES OF COLOR
British artist Peter Sedgley was Riley's partner for a decade and an important figure in the op art world. His paintings explore the optical interaction of concentric colored circles, which echo the geometry of the human eye and seem to pulsate on the black background. Sedgley airbrushed bands of color to create soft, overlapping rings in this 1968 work, *YOU.*



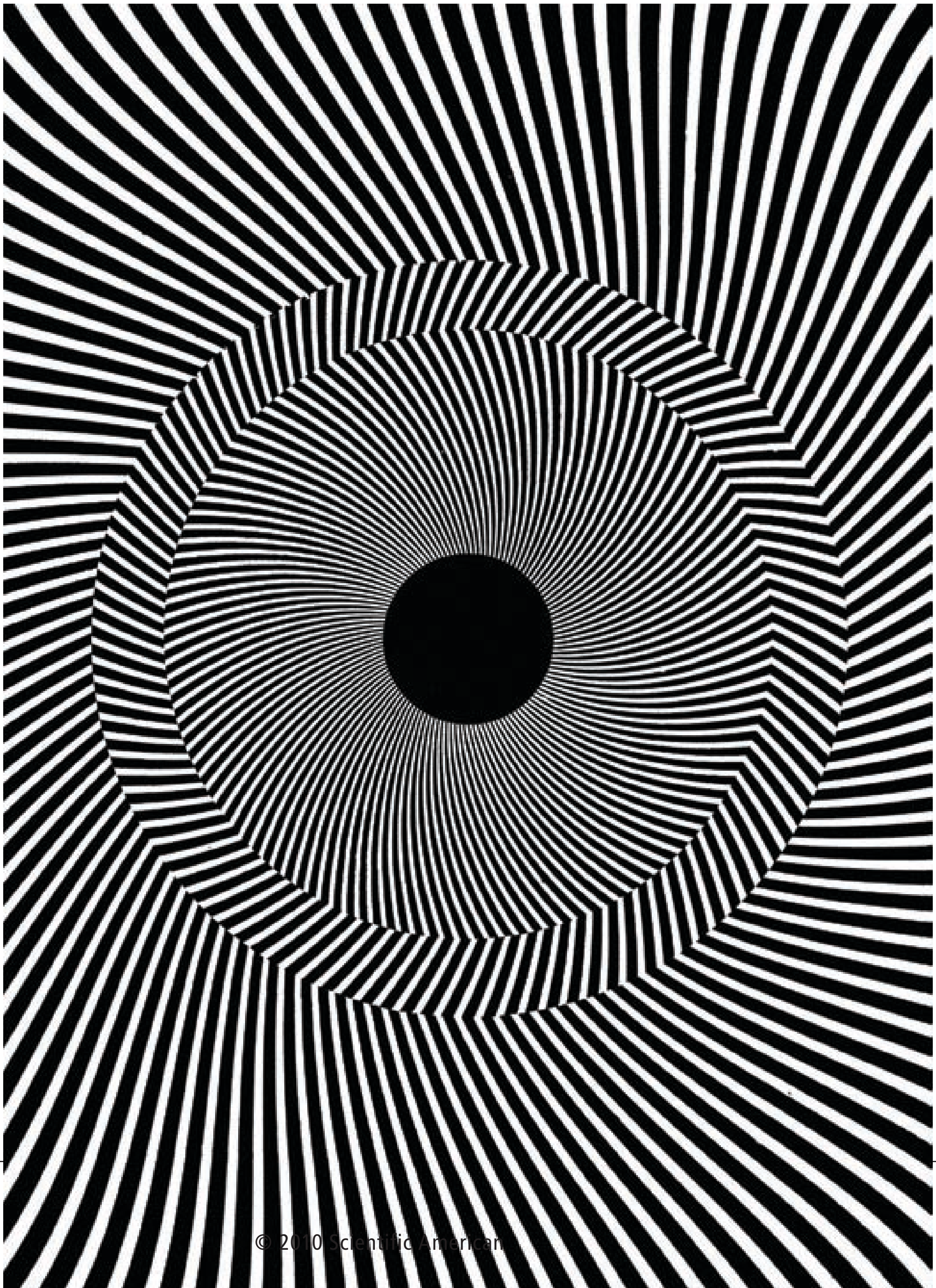
THE OUCHI ILLUSION
This illusion is by Japanese op artist Hajime Ouchi. Move your head back and forth as you let your eyes wander around the image and see how the circle and its background appear to shift independently of each other. Vision scientist Lothar Spillmann of the University of Freiburg in Germany stumbled on the illusion while browsing Ouchi's book *Japanese Optical and Geometrical Art,* which was first published in 1973. Spillmann then introduced the Ouchi illusion to the vision sciences community, where it has enjoyed immense popularity.

PETER SEDGLEY (YOU); FROM *JAPANESE OPTICAL AND GEOMETRICAL ART,* BY HAJIME OUCHI, DOVER PUBLICATIONS, 1977 (*Ouchi illusion*)

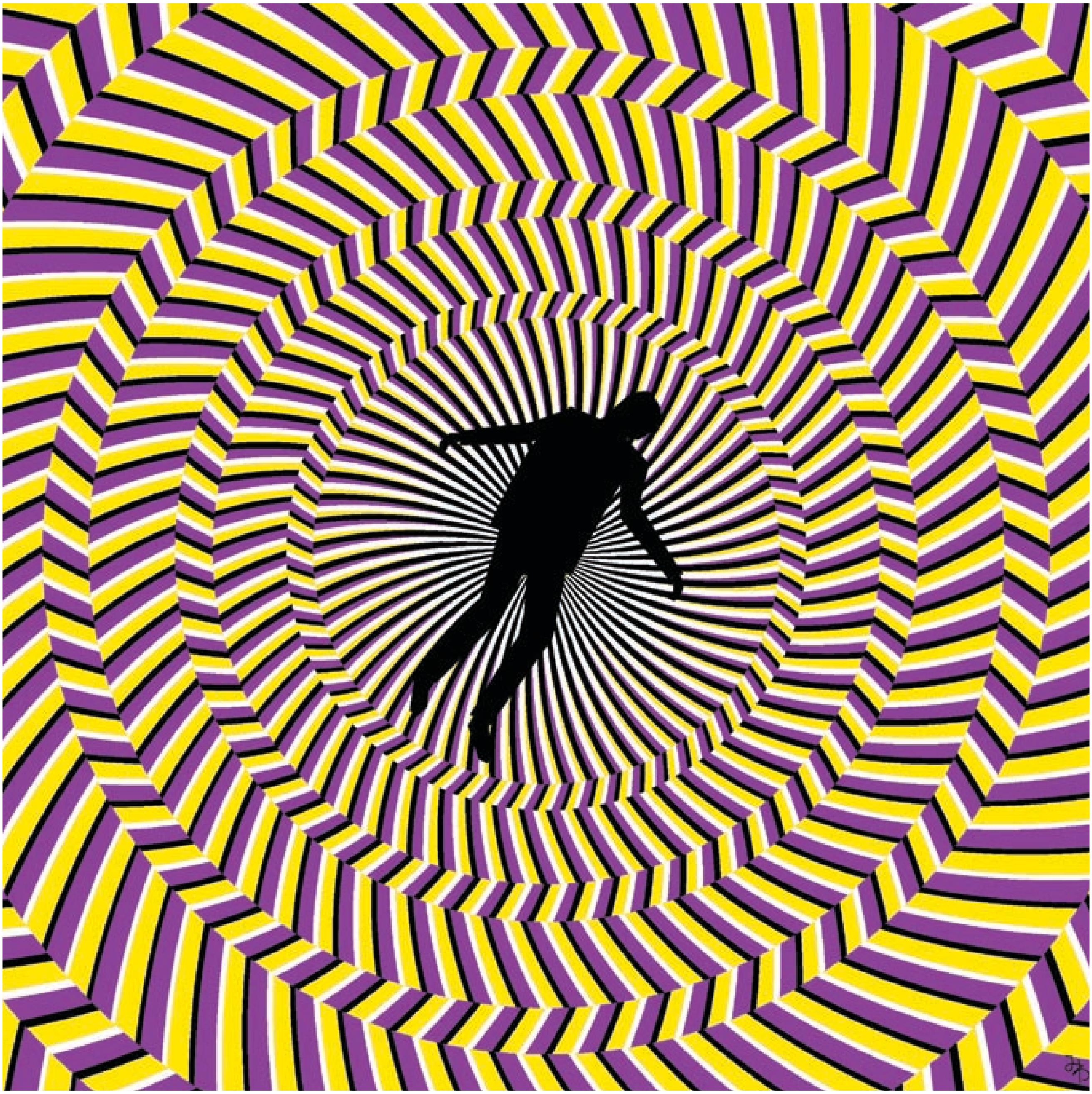
HOMAGE TO OUCHI
This illusion (*right*) is a contemporary variation on the Ouchi pattern, drawn by Kitaoka in 2001.

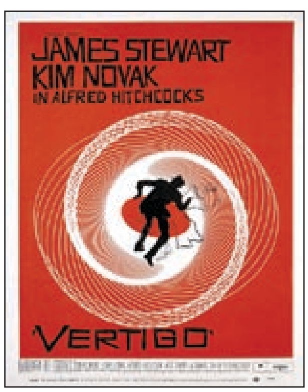


THE ROTATING-TILTED-LINES ILLUSION
An illusion (*right*) developed by vision scientists Simone Gori and Kai Hamburger, then at the University of Freiburg in Germany, is a novel variation of both the enigma effect and Riley's *Blaze*. To best observe the illusion, move your head closer and then farther away from the page. As you approach the image, notice that the radial lines appear to rotate counterclockwise. As you move away from the image, they appear to rotate clockwise. This illusion was featured in the first edition of the Best Illusion of the Year Contest, held in 2005 in Spain (see http://illusioncontest.neuralcorrelate.com/2005/rotating-tilted-line-illusion).



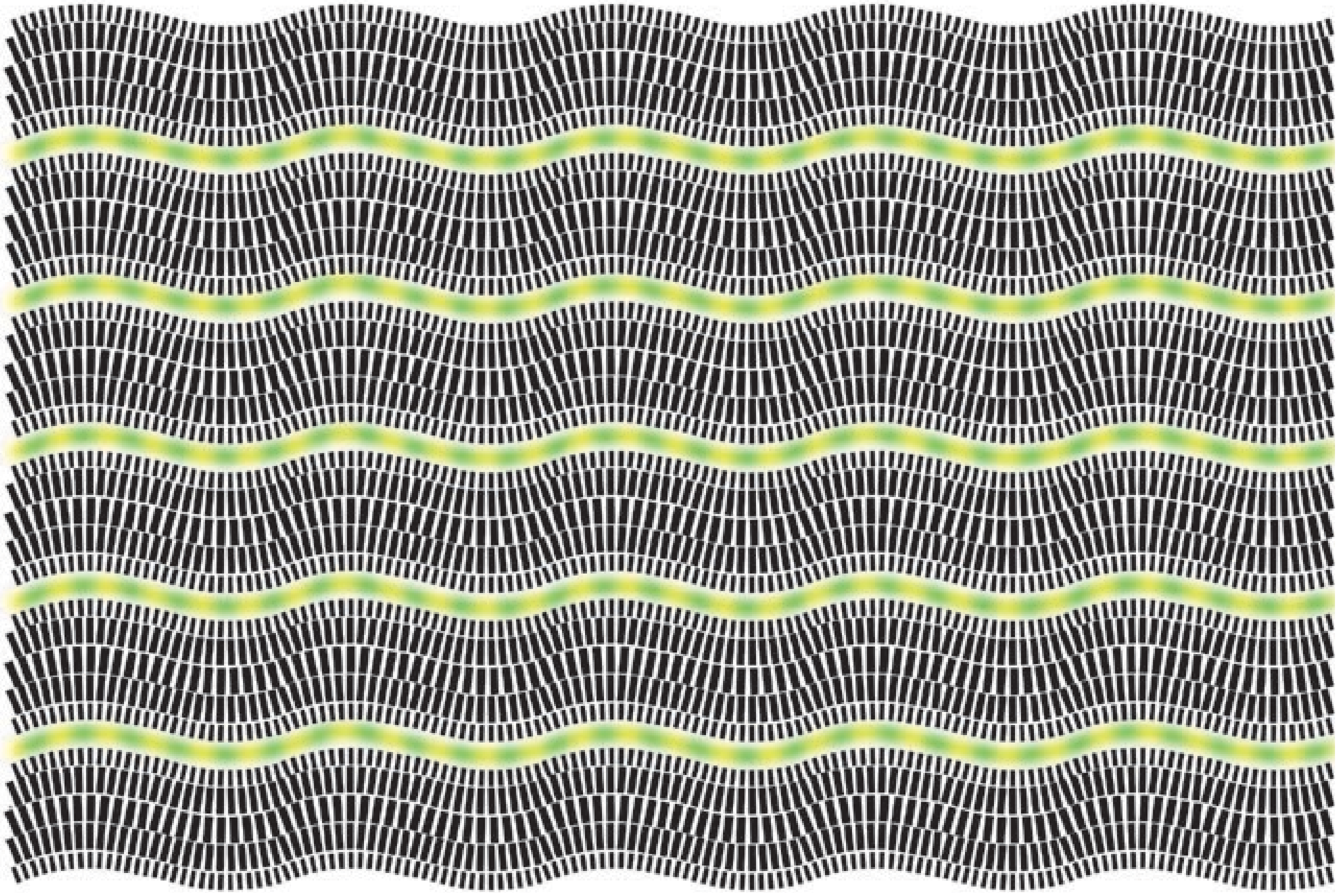
COURTESY OF AKIYOSHI KITAOKA (*top*); SIMONE GORI (*bottom*)





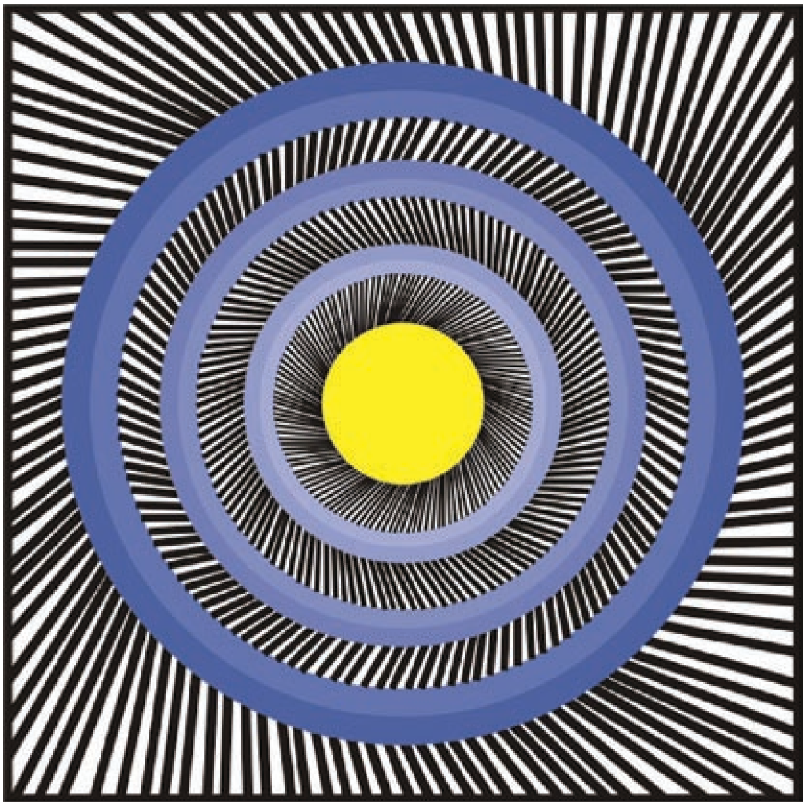
VERTIGO VARIANT
Artist Miwa Miwa's variant of the rotating-tilted-lines illusion (*above*) pays homage to *Vertigo,* the classic 1958 film by Alfred Hitchcock (*left*).

MIWA MIWA (*top*); PARAMOUNT/
THE KOBAL COLLECTION (*bottom*)



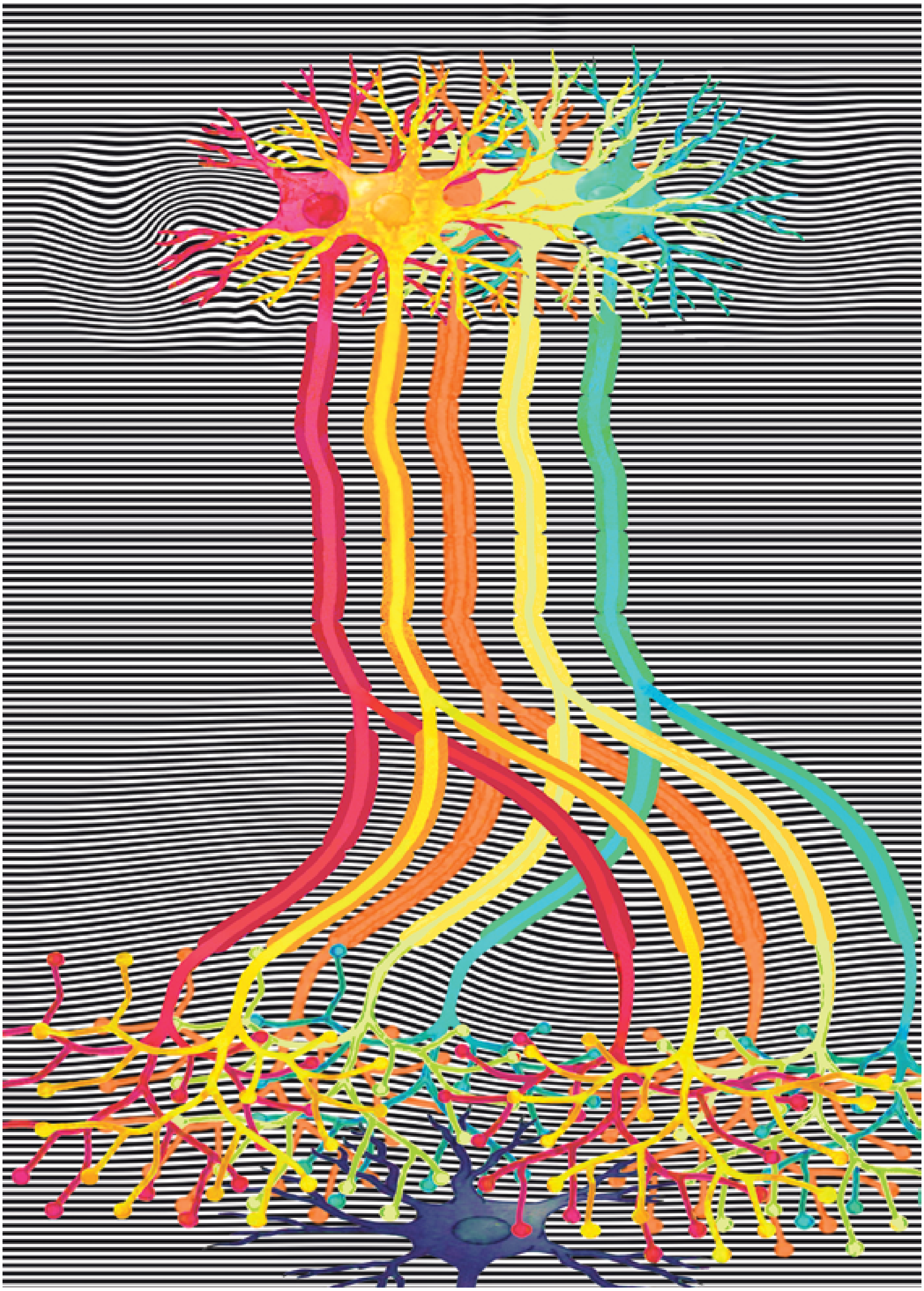
CHRISTMAS LIGHTS ILLUSION

The Christmas Lights illusion, by Italian artist and author Gianni A. Sarcone, is also based on Léviant's *Enigma*. Notice the appearance of a flowing motion along the green-yellow stripes.



TWO IN ONE

Gori and Hamburger's combination of the rotating-tilted-lines illusion and the enigma illusion is both visually arresting and a powerful demonstration of illusory motion from a static pattern. The enigma illusion, almost three decades after its creation by Léviant, continues to inspire visual science as well as visual arts.



ART MEETS SCIENCE

This recent work by French artist José Ferreira, *Nerve Impulse,* not only reprises the Léviant effect but also illustrates how nerve cells relay information from the eye to the brain: triggered by a flood of chemicals called neurotransmitters, nerve cells (*at top*) send electrical signals racing down slender structures called axons. At the axon's knoblike terminals, each nerve cell releases its own neurotransmitters, which diffuse across a narrow synapse gap and bind with receptors on the branchlike dendrites of the next nerve cell to trigger a new electrical signal. Each successive neuron passes the message to its neighbor, like a bucket brigade passing a pail of water.

JOSÉ FERREIRA

Sculpting the Impossible: Solid Renditions of Visual Illusions

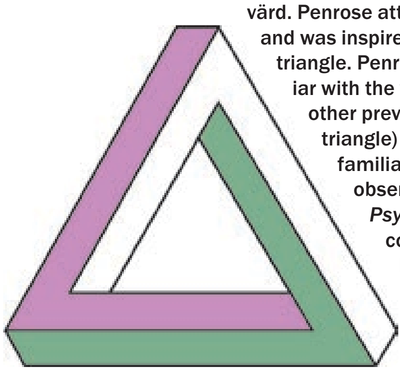
Artists find mind-bending ways to bring impossible figures into three-dimensional reality

By Stephen L. Macknik and Susana Martinez-Conde

In an impossible figure, seemingly real objects—or parts of objects—form geometric relations that physically cannot happen. Dutch artist M. C. Escher, for instance, depicted reversible staircases and perpetually flowing streams. Mathematical physicist Roger Penrose drew his famously impossible triangle, and visual scientist Dejan Todorović of the University of Belgrade in Serbia created a golden arch that won him third prize in the 2005 Best Illusion of the Year Contest. These effects challenge our hard-earned perception that the world around us follows certain, inviolable rules. They also reveal that our brains construct the feeling of a *global* percept—an overall picture of a particular item—by sewing together multiple *local* percepts. As long as the local relation between surfaces and objects follows the rules of nature, our brains don't seem to mind that the global percept is impossible.

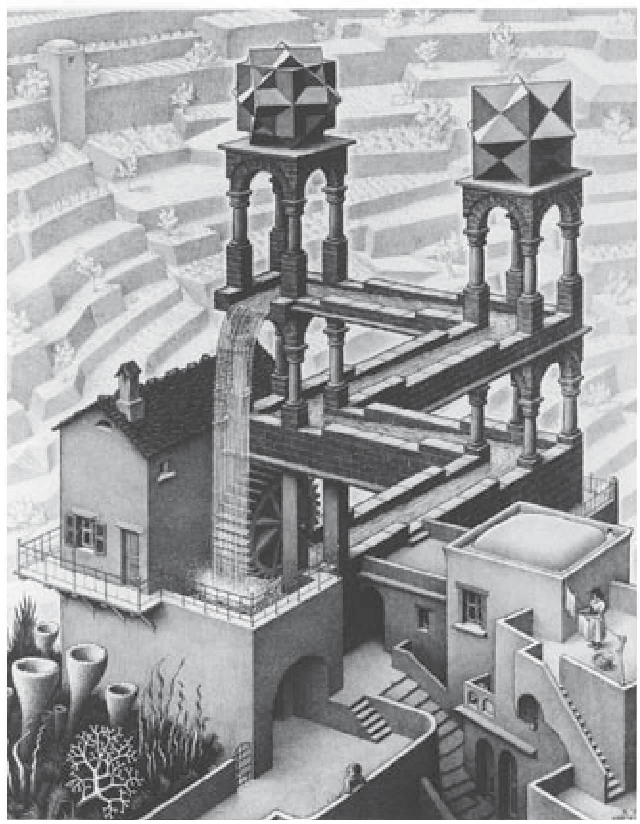
Several contemporary sculptors recently have taken up the challenge of creating impossible art. That is, they are interested in shaping real-world 3-D objects that nonetheless appear to be impossible. Unlike classic monuments—such as the Lincoln Memorial in Washington, D.C.—which can be perceived by either sight or touch, impossible sculptures can be interpreted (or *misinterpreted,* as the case may be) only by the visual mind.

STEPHEN L. MACKNIK and SUSANA MARTINEZ-CONDE are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.



PENROSE TRIANGLE

The impossible triangle (also called the Penrose triangle or the tribar) was first created in 1934 by Oscar Reutersvärd. Penrose attended a lecture by Escher in 1954 and was inspired to rediscover the impossible triangle. Penrose (who at the time was unfamiliar with the work of Reutersvärd, Piranesi and other previous discoverers of the impossible triangle) drew the illusion in its now most familiar form (*left*) and published his observations in the *British Journal of Psychology* in 1958, in an article co-authored with his father, Lionel. In 1961 the Penroses sent a copy of the article to Escher, who incorporated the effect into *Waterfall,* one of his most famous lithographs (*right*).



IMPOSSIBLE ARCH

Elusive Arch, by Todorović, shows a new impossible figure. The left-hand part of the figure appears as three shiny oval tubes. The right-hand part looks corrugated, with three alternating pairs of shallow matte ridges and grooves. The bright streaks on the figure's surface are seen either as highlights at the peaks and troughs of the tubes or as inflections between grooves. Determining the direction of the apparent illumination falling on the figure is difficult: it depends on whether we interpret the light as falling on a receding or an expanding surface. Further, determining the exact position and shape of the transition region near the center of the arch is maddening, because the local 3-D interpretations defy the laws of illumination. For more about the arch, see http://illusioncontest.neuralcorrelate.com/2005/elusive-arch.

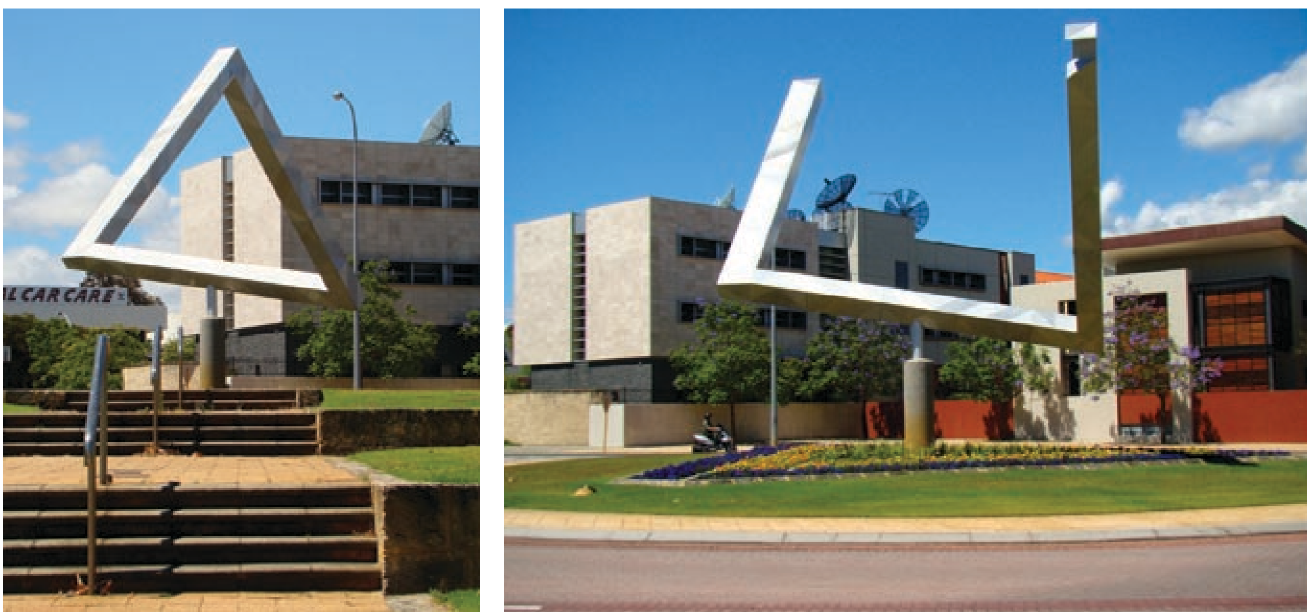
HOMAGE TO ESCHER

Escher's *Belvedere* (*left*) showcases columns that switch walls between their bases and capitals, a straight ladder whose base rests inside the building yet nonetheless enters the building from the outside at its top, and a sitting man holding an impossible cube. Mathieu Hamaekers, a Belgian mathematician and sculptor, created an homage to *Belvedere* that features a real-life impossible cube. This photograph (*below*) shows the artist holding the sculpture *Upside Down,* built in 1985.

IMPOSSIBLE BOX
Hans Schepker has built outstanding sculptures of impossible objects, such as this *Crazy Crate* made from glass (*above, left*). Other views of the crazy crate show the method behind the madness (*above, center* and *right*). Notice that the illusion works only from a specific vantage point. At any other angle, the illusion fails. Scientists refer to this as the accidental view, but there is nothing accidental about it. To perceive the illusion, the view must be carefully staged and choreographed, or else the audience will fail to see the "impossible" sculpture.

BACKYARD MAGIC
The late magician Jerry Andrus created this crazy crate, shown here from two different angles, in his backyard. The photograph on the right reveals the magic.

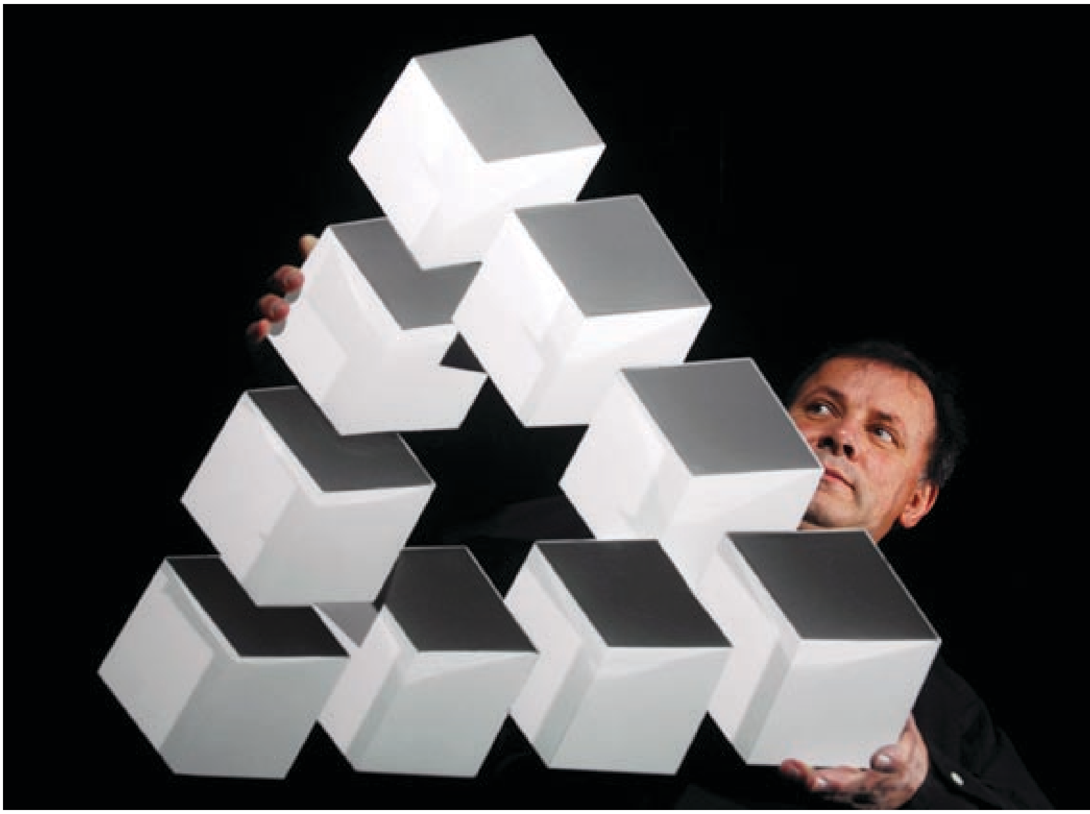
INDUSTRIAL-SIZE TRIANGLE
Artist Brian McKay created a giant version of the impossible triangle (*below, left*) in Perth, Australia, in collaboration with architect Ahmad Abas. How did they do that? A photograph taken from another angle (*below, right*) reveals the trick.



HANS SCHEPKER (*glass boxes*); COURTESY OF GEORGE ANDRUS (*wood crates*); BJØRN CHRISTIAN TØRRISSEN (BJORNFREE.COM) (*triangles*)

A TWIST ON THE TRIANGLE

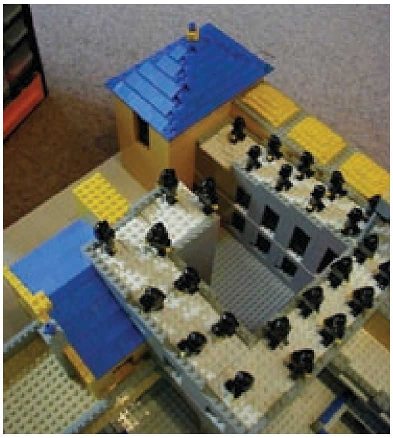
Unity, an impossible triangle created by Hamaekers in 1995, is now installed in Ophoven, Belgium. Again the viewer's location relative to the object is critical. But in this case, Hamaekers used a different physical method to achieve the illusion.

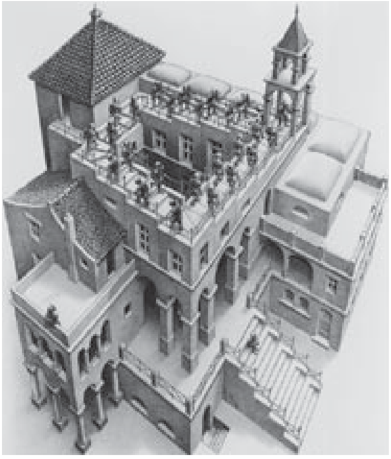


A CLOSED TRIANGLE

Unlike most 3-D Penrose triangles, the sculptures by French artist and magician Francis Tabary are neither twisted nor open. They look impossible from a relatively large range of vantage points, although they do fail when seen from some viewpoints. The Tabary sculpture shown here is a four-cube-sided Penrose triangle.

MATHIEU HAMAEKERS (*twisted triangles*); FRANCIS TABARY (*cube triangle*)

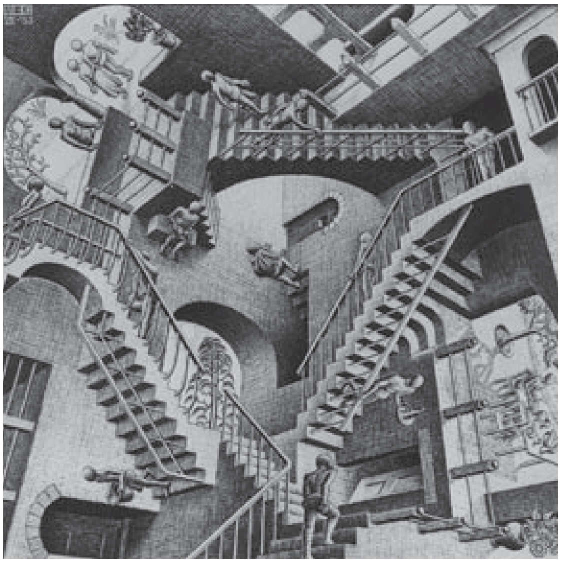




MAKING ESCHER 3-D
Andrew Lipson, a self-described “professional nerd” with no official connection to the Lego Group, and his friend Daniel Shiu have rendered five Escher works in Lego blocks, including this model of Escher’s *Ascending and Descending* (*left*). The original work by Escher, a 1960 lithograph, shows a large building with an endless staircase on its roof (*bottom right*). Some of the people are ascending the staircase, while others are descending.

Lipson and Shiu spent considerable time studying Escher’s work before beginning construction. In their photograph of the finished sculpture, it looks as though the staircase is continuous. But in this picture taken from another angle (*top right*), you can see that the edges of the staircase do not meet. The Lego illusion works only if the photograph is taken from exactly the right viewing angle.

WHICH WAY IS UP?
The Terrace, a 1998 work by British artist David MacDonald, is an example of impossible perspective. Are we looking at this scene from above or below the checkerboard? MacDonald produces impossible perspectives akin to those created by Escher, but photographically. He made this image by creating a computer wireframe matrix and filling it in with digitally photographed textures and objects.



IT'S ALL RELATIVE

Lipson and Shiu also worked together on a Lego rendition of Escher's *Relativity* (*top*). The original version, a popular lithograph first printed by Escher in 1953, depicts a surreal architectural structure in which there seem to be three separate sources of gravity (*bottom left*). The stairways are double-sided, and each stair is double-treaded.

A photograph taken from a slightly different angle and farther away (*bottom right*) shows how the sculpture is made. Lipson and Shiu used lots of scaffolding to hold it up. This was their fourth Escher picture rendered in Lego blocks.

ONE-MAN BAND

Encore, by the late Japanese artist Shigeo Fukuda, uses similar principles to represent a pianist and violinist in the same sculpture when viewed from two vantage points. You can see only half of the duet at once, and neither is visible unless the sculpture is viewed from the side.

MIRROR IMAGE

Another work by Fukuda, *Underground Piano,* looks like a pile of piano parts unless you stand in the right place and view the "reassembled" piano in the mirror.

SHADOW PLAY

Fukuda welded together 848 forks, knives and spoons to make *Lunch with a Helmet On.* Here he cleverly resolves the illusion by placing a light at the critical vantage point, making the motorcycle obvious only in the shadow cast by the utensil pile.

© SHIGEO FUKUDA, USED BY PERMISSION OF THE SHIGEO FUKUDA ESTATE *(all photographs)*

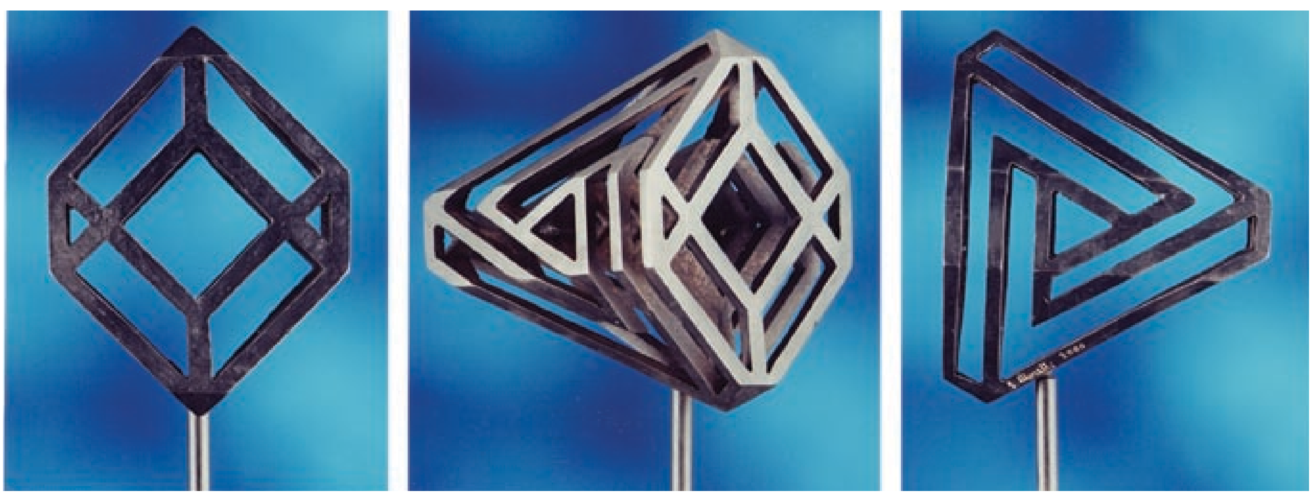
IMELDA'S DREAM COME TRUE

Imelda Marcos, widow of the former Philippines dictator Ferdinand Marcos, was infamous for her shoe collection but also for quotes such as this one: "People say I'm extravagant because I want to be surrounded by beauty. But tell me, who wants to be surrounded by garbage?" Well, Imelda, now you can be surrounded by both, courtesy of artists Tim Noble and Sue Webster, who create eye-catching artwork from rubbish.

In 1998 Noble and Webster created this sculpture, *Dirty White Trash (with Gulls),* using six months' worth of their own garbage. Like Fukuda, they used a strategically placed light source to cast their own shadows on the wall. The sculpture appeared in a 2003 exhibition at the P.S.1 Contemporary Art Center in Long Island City, N.Y.

AND THE WINNER IS …

For several years, Italian sculptor Guido Moretti has donated copies of his *Three-Bar Cube* and other impossible sculptures as trophies for the Best Illusion of the Year Contest. Depending on your vantage point, *Three-Bar Cube* can appear to be a cube, a solid structure or an impossible triangle. For more information, see http://illusioncontest.neuralcorrelate.com/trophies.



COURTESY P.S.1 CONTEMPORARY ART CENTER (*garbage sculpture*); GUIDO MORETTI (WWW.GUIDOMORETTI.IT) (*cube sculptures*)

Food for Thought: Visual Illusions Good Enough to Eat

Face or food? The brain recognizes edible artwork on multiple levels

By Susana Martinez-Conde and Stephen L. Macknik

Are you impressed with meals that look like one food but are actually made of something else? Tofu burgers and artificial crabmeat, for example, are not what they appear to be.

It's actually an old trick. In medieval times fish was cooked to imitate venison during Lent, and celebratory banquets included extravagant (and sometimes disturbing) delicacies such as meatballs made to resemble oranges, trout prepared to look like peas and shellfish made into mock viscera. Recipe books from the Middle Ages and the Renaissance also describe roasted chickens that appeared to sing, peacocks redressed in their own feathers and made to breathe fire, and a dish aptly named Trojan hog, in which a whole roasted pig was stuffed with an assortment of smaller creatures such as birds and shellfish, to the amusement and delight of cherished dinner guests.

Unwelcome visitors were also treated to illusory food, but not for their own amusement. Instead they were served perfectly good meat that was made to look rotten and writhing with worms. Maybe not good enough to eat, but good enough to send your in-laws packing!

Food illusions are alive and well in the 21st century. Our buffet of contemporary lip-smacking illusions will appeal to both your eyes and your stomach … for the most part. We hope you'll enjoy the spread. Bon appétit!

SUSANA MARTINEZ-CONDE and STEPHEN L. MACKNIK are laboratory directors at the Barrow Neurological Institute in Phoenix. They are authors of the book *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions,* with Sandra Blakeslee (http://sleightsofmind.com), to be published in November 2010.

SAME BOWL OF VEGGIES … OR IS IT?
This still life by Italian painter Giuseppe Arcimboldo (*left*) includes the ingredients for his favorite minestrone soup and the bowl to serve it in. Turned upside down (*right*), Arcimboldo's bowl of vegetables becomes a whimsical portrait of a man's head, complete with bowler hat.

There are several interesting aspects to this illusion. First, why do we see a face in the arrangement, when we know that it is just a bunch of vegetables? Our brains are hardwired to detect, recognize and discern facial features and expressions using only minimal data. This ability is critical to our interactions with other people and is the reason that we perceive personality and emotion in everything from crude masks to the front end of cars.

Second, why do we see the face much more clearly when we flip the image vertically? The answer is that the same brain mechanisms that make face processing fast and effortless are optimized to process right-side-up faces, so upside-down faces are much harder to see and recognize.

MUSEO CIVICO ALA PONZONE, CREMONA, ITALY/THE BRIDGEMAN ART LIBRARY

A LOT TO DIGEST

Arcimboldo's composite heads demonstrate that, neuroscientifically speaking, the whole can be much more than the sum of its parts. Clever arrangements of individual fruits, flowers, legumes and roots become exquisite portraiture in their entirety, such as in the likeness of the Hapsburg emperor Rudolf II (*left*), here depicted as Vertumnus, the Etruscan god of transformations, or in the artist's self-portraits as *Summer* and *Autumn* (*center* and *right*).

The brain builds representations of objects from individual features, such as line segments and tiny patches of color. You see a nose in the *Summer* portrait not because there is a retinal cell that perceives noses but because thousands of retinal photoreceptors in your eye react to the various shades of color and luminance in that area of the painting. High-level neuronal circuits then match that information to the brain's stored template for noses. The output from those same photoreceptors also activates the high-level object-tuned neurons that recognize turnips, figs and pickles, which is what makes images like these so much fun to look at.

Last but not least, Arcimboldo's masterpieces also bring to mind the old adage that you are what you eat. "Avoid fruits and nuts," advises Garfield, the cartoon cat created by Jim Davis.

HUMMINGBIRD FOOD

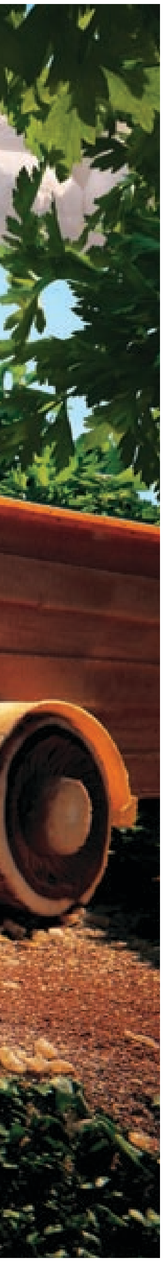
The human brain simultaneously recognizes animal features (such as eyes, wings and tail) and plant parts (such as an eggplant and artichoke leaves). The combination tickles our fancy.

ERICH LESSING *Art Resource*, NY (Rudolf II); KUNSTHISTORISCHES MUSEUM, VIENNA, AUSTRIA/THE BRIDGEMAN ART LIBRARY (Summer); LOUVRE, PARIS, FRANCE/LAUROS/GIRAUDON/THE BRIDGEMAN ART LIBRARY (Autumn); VANESSA DUALIB (*hummingbird*)

MEDUSA MARINARA

Brazilian-born artist Vik Muniz likes to play with his food. His *Medusa Marinara* (*far right*) is a visual pun on Caravaggio's *Medusa* (*right*), and it portrays an illusion of ambiguity that works at multiple levels. The red marinara sauce in Muniz's Medusa reminds the viewer of the blood spurting from Medusa's severed neck in Caravaggio's version, and the spaghetti around Medusa's head can be perceived as Caravaggio's snakes-for-hair Medusa (an ambiguity illusion in and of itself).

GALLERIA DEGLI UFFIZI, FLORENCE, ITALY/THE BRIDGEMAN ART LIBRARY (Medusa); VIK MUNIZ *licensed by VAGA, New York, NY* (Medusa Marinara)



FOODSCAPES

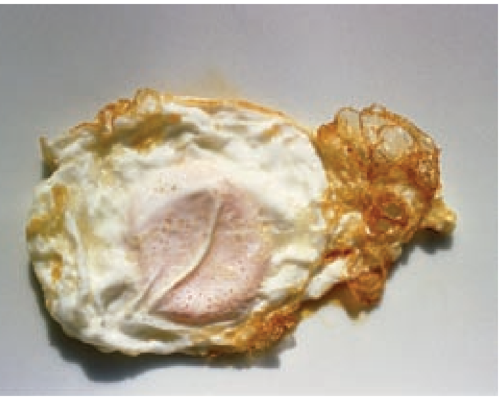
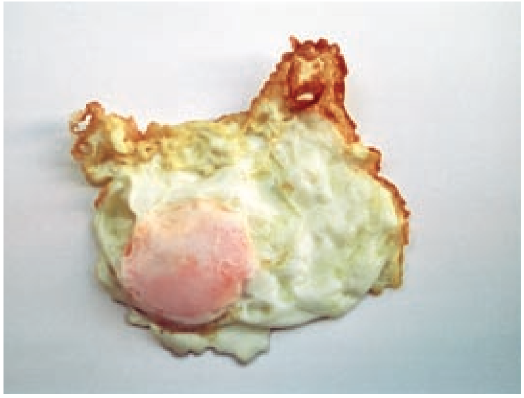
Art can be more than just a feast for your eyes. The image at the left looks, at first sight, like a painting of a landscape. But look closer. These are actual photographs of foods laid out to recreate various types of scenery and terrain. London photographer Carl Warner (*top right*) arranges meats and vegetables to create each environment as if from a Brothers Grimm fairy tale and then photographs the scene in layers from foreground to background.

By using solely meats and breads in the image at the bottom right, for example, Warner captures the feel of old sepia postcards from the late 19th-century American prairie—complete with a breadstick-rail fence, serrano ham skies and a salami lane. Yum.

Warner's work is another example of how the brain puts together information from multiple streams. Visual data from every point of the image are converted from light to electrochemical signals in the retina and then transmitted to the brain—where individual features are constructed from the information in the image. These discrete features are broadcast to multiple high-level visual circuits simultaneously: circuits that recognize faces, circuits that detect and characterize motion, circuits that recognize landscapes and places, and circuits that recognize and process food are just a few of the brain paths that receive this basic information.

In Warner's art, both the landscape and the food-processing circuits are activated (the other circuits receive the information but ignore it as irrelevant because there are no faces, motion or other triggers in the image). And voilà! Our mind recognizes a delicious plate of cold cuts, as well as an overcast sky, in the same visual data.

CARL WARNER (*foodscapes on this page and opposite page; studio photograph*)

CHICKEN AND EGG

Spanish artist Din Matamoro provides a unique perspective on developmental biology's most fundamental question: Which came first, the chicken or the egg? In Matamoro's fried eggs, ontogeny recapitulates phylogeny in an unusual and slightly unsettling fashion: the shape of each fried egg resembles that of the chicken that the egg would have become or perhaps the hen that laid the egg in the first place.

Such ambiguity illusions recapitulate visual perception as a type of ontogeny in and of itself. Objects, in this case chickens, are built in the henhouses of our mind from nuggets of visual information sent from the retina. These little visual giblets activate circuits that process animal shapes (birds in this case) as well as circuits that process food data. This kind of multiple-channel processing is at the heart of all ambiguity: the neural basis of ambiguous perception is two or more brain circuits that compete for dominance in our awareness.

EDIBLE POINTILLISM

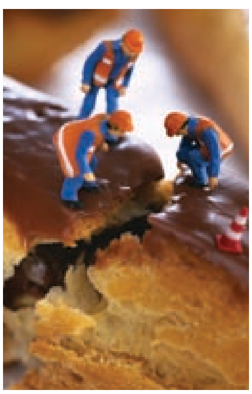
Pointillist painters such as Georges Seurat and Paul Signac juxtaposed multiple individual points to create color blends that were very different from the colors in the original dots. But in a very real sense, all art is pointillism. In fact, all visual perception is pointillism. Our retinas are sheets of photoreceptors, each sampling a finite circular area of visual space. Every photoreceptor then connects to downstream neural circuits that build our perception of objects, faces, loved ones and everything else. Thus, vision itself is largely a pointillist illusion, colored by a tremendous amount of "guesstimation" and filling in on the part of our brain. It doesn't matter whether the painter uses brushstrokes or fields of dots to define surfaces.

The dots that compose these images of a cherry-topped cupcake (*left*) and Laurel and Hardy (*right*) are made from multicolored jelly beans, a technique that is not only clever but also delicious. Eat your heart out, Seurat.


DIN MATAMORO (*egg chickens*); KRISTEN CUMINGS *Jelly Belly Candy Company (cupcake)*; PETER ROCHA *Jelly Belly Candy Company (Laurel and Hardy)*

MOUTH-WATERING MASTERPIECES

If you agree that jelly-bean pointillism is a great idea, you'll also appreciate these replicas of famous masterpieces: Vincent Van Gogh's *Self Portrait in a Grey Felt Hat* (*left*), Edvard Munch's *The Scream* (*below left*) and Rembrandt's *The Anatomy Lesson of Dr. Nicolaes Tulp* (*below right*). Everything in the accompanying images is fit for human consumption.



JU DUOQI *Galerie Paris-Beijing* (*Van Gogh portrait, screamer and anatomy lesson*);
AKIKO & PIERRE *Minimiam* (*little people in food*)

FOOD ART WITH LITTLE PEOPLE

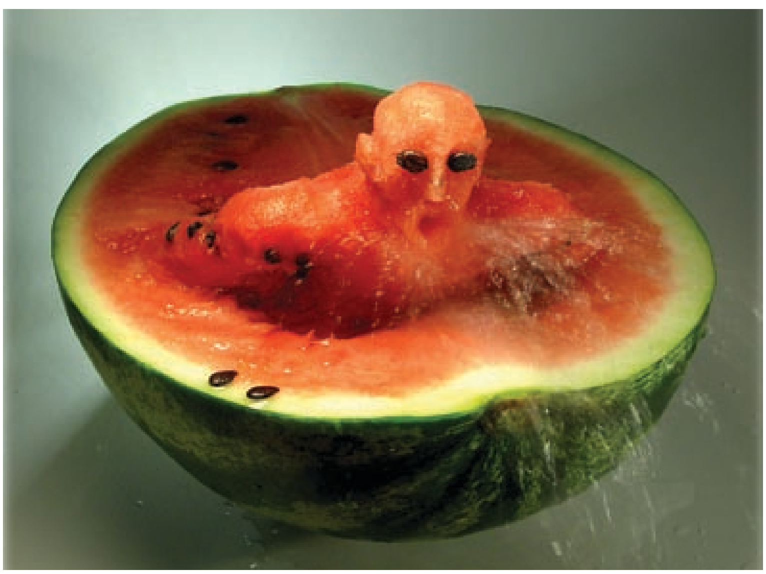
Dramatist George Bernard Shaw said that there is no sincerer love than the love of food. If so, the miniature workers depicted here are living the dream. Of course, it's all a matter of scale.

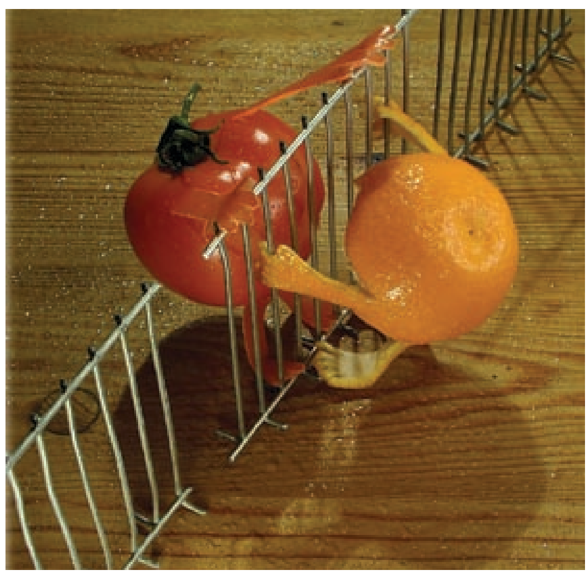
The juxtaposition of Lilliputians and huge fruit has the dual illusory effect of making the potentially normal-size people look tiny and the possibly typical fruit look supersized. It happens because the human brain uses context, the relative dimensions of nearby objects in the world as a primary means to determine their scale and absolute size.

Think about it: we can't simply use the size of the projection on our retinas to determine the size of an object, because the size of the projection depends on how far away the object is. A small, nearby object can have a retinal projection of the same size as a larger object that is farther away. To compensate for distance, the brain compares the sizes of unknown objects with those of known objects that are in the same scene. Juxtaposing tiny people with enormous fruit plays havoc with that scaling system, and both categories of object are affected.

A SMORGASBORD OF ILLUSIONS

Peeling and paring can transform fruits and vegetables into a variety of amazing, strange and tasty illusions. Just in case your eyes are bigger than your stomach.





SAXTON FREYMANN ©*Play With Your Food LLC (top images)*; TAMÁS BALLA *(bottom images)*

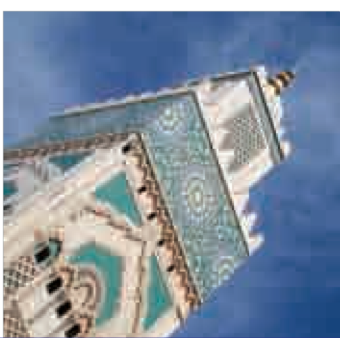
www.InSightCruises.com/SciAm8

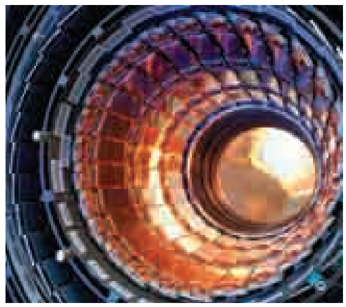
SEEK OUT UNCHARTED TERRITORY AND REVISIT CLASSIC SCIENCE in a Western Mediterranean whirl on Bright Horizons 8. Join a cadre of experts who share critical traits — juggling the pragmatic and the possible, driven to challenge the status quo. Foster your need to know. Explore Iberia, where science went mainstream in medieval times. Venture into Casablanca with a companion, and chart the geometry of North Africa.

Gravitate to a new understanding of magnetism's role in terrestrial and scientific exploration. Absorb the cultural importance of space exploration and implications of our new comprehension of space and time. Ponder nature's preference for matter over antimatter, and the superlatives of CERN's Large Hadron Collider. Practice mind over matter thinking about the structure and function of the brain. Unfold the story behind the science with cutting edge, Nobel-grade ribosomal knowledge.

Carpe diem. Set a course beyond the obvious and gain insights and new angles into space exploration, neuroscience, particle physics, ribosomes, and magnetism. Join the Bright Horizons 8 community on Costa Cruises' mv Magica October 28 – November 6, 2010. Plan now to share tapas with a friend, explore a Moroccan kasbah, and advance your science agenda. Get the details at **InSightCruises.com/SciAm-8 or call Neil or Theresa at 650-787-5665.**

SCIENTIFIC AMERICAN TRAVEL





PARTICLE PHYSICS

Speaker: **James Gillies, Ph.D.**

Particle Physics: Using Small Particles to Answer The Big Questions — Particle physics is the study of the smallest indivisible pieces of matter — and the forces that act between them. Join Dr. Gillies and catch up on the state of the art and challenges ahead as physicists continue a journey that started with Newton's description of gravity. We'll look at the masses of fundamental particles, dark matter, antimatter, and the nature of matter at the beginning time.

The Large Hadron Collider: the World's Most Complex Machine — The LHC is a machine of superlatives — a triumph of human ingenuity, possibly the most complex machine ever built. James Gillies traces particle physics technologies from the invention of particle accelerators in the 1920s to today, and then focuses on the LHC itself. You'll get a perspective on how these tools have allowed us to make phenomenal progress in understanding the Universe, and how they have revolutionized our everyday lives.

Angels, Demons, Black Holes, and Other Myths: Demystifying the LHC — Along with humankind's natural curiosity comes a fear of the unknown. As LHC's first beam day approached in 2008, a handful of self-proclaimed experts struck up an end-of-the-world tune — and the whole world knew they were there. Like its predecessors, the Large Electron-Positron Collider (LEP) and Relativistic Heavy Ion Collider (RHIC), the LHC never posed the slightest risk to humanity. However, the dangerous scientist has always made for a good story and that's something that Dan Brown exploited to the full when writing Angels and Demons. Dr. Gillies will cover the fact behind the fiction of Angels and Demons and black holes at the LHC, and share the behind-the-scenes on how CERN lived with the hype.

THE AMAZING BRAIN

Speaker: Jeanette J. Norden, Ph.D.

General Organization of the Central Nervous System — We begin with an introduction on how the central nervous system is divided into structural and functional areas. This knowledge will allow us to understand why after a stroke an individual might be blind, but not know it; why an individual might lose the ability to speak, but not to understand language; why an individual might be able to describe his wife's face, but not be able to pick her out from a crowd.

Cellular and Molecular Organization of the Central Nervous System — In this session we will focus on the structure of individual neurons and on how neurons in the central nervous system are believed to be connected to each other by an estimated 100 trillion synapses. This understanding of the structure of individual neurons and on how neurons communicate with each other allows us to have insight into disorders as diverse as depression and multiple sclerosis.

Parkinson's Disease and Other Disorders of the Motor System — Movement is a complex behavior controlled by a number of different subsystems in the brain and spinal cord. Knowing what each of these subsystems do to allow us to move will provide the knowledge necessary to understand the loss of normal motor movement in Parkinson's disease, spinal cord injury, and other disorders of the motor system.

Alzheimer's Disease — Alzheimer's disease is the most common neurodegenerative disease in the United States. We will explore what is currently known about this devastating disorder, and about the specific areas of the brain which are affected. Next we discuss the risk factors associated with Alzheimer's disease. Finally, we will end this lecture series with a discussion of what you can do to decrease your risk of getting this disease and on how to keep your brain healthy!

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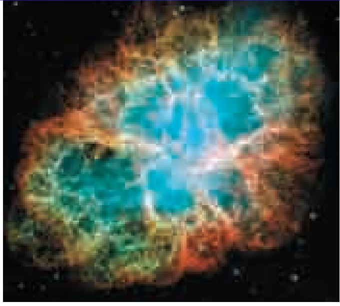

ASTRONOMY

Speaker: **Steven Dick, Ph.D.**

Life on Other Worlds — It's a unique time in human history as we explore for life beyond Earth. Where do we stand in the search for life, both inside the solar system and beyond? And what would be the impact of the discovery of extraterrestrial intelligence on our society? Dr. Dick's answers will beget more questions — get in on the discussion!

A Tour of the Universe: Astronomy's Three Kingdoms — Our view of the universe has evolved over the last century, from a static anthropocentric cosmos a few thousand light years across to a dynamically evolving universe spanning billions of light years. We've discovered cosmic objects like pulsars, quasars, and black holes. Travel with Dr. Dick through billions of light years of space and time as we explore the discovery and classification of objects in astronomy's three kingdoms: the planets, the stars, and the galaxies.

Exploration, Discovery, and Culture: The Importance of the Space Age — Fifty years into the Space Age and 40 years after the Apollo program put 12 men on the Moon, exploration is at a turning point. Should humans return to the Moon and go to Mars? Are robotic emissaries enough? What motivates spaceflight? Should we spend money on space with so many problems on Earth? Join Dr. Dick in contemplation of the importance of exploration to culture.

Cosmic Evolution and Human Destiny — We now see the universe in the context of 13.7 billion years of cosmic evolution. What are the implications of this understanding of space and time in the short and long term? How does it affect our religions and philosophies? What is the long-term destiny of humans? Join us in a journey through science fiction, science fact, and scientific extrapolation as we ponder human destiny in a new context.

MAGNETS

Speaker:
Michael Coey, Ph.D.

What the Ancients Knew — The mysterious behavior of lodestones — rocks naturally magnetized by lightning strikes — and their strange love for iron was known in ancient China, Greece, Sumer, and Mesoamerica. The directional property was used first for geomancy and then, a millennium later, for navigation. The great voyages of discovery of Africa by the Chinese and America by the Europeans all depended on the compass. The ancients dreamt of levitation and perpetual motion. So do we.

Science Rules the Earth: OK? — Robustly polemical, but insistently evidence-based, William Gilbert's De Magnete (c. 1600) was the first modern scientific text. His insight that the Earth was a great magnet and insistence that data trumps speculation led to the heroic magnetic crusade of the 1830s, an understanding of how the Earth moves by plate tectonics, sunspots, and a way to date pottery. Join Dr. Coey and learn how science trumped charlatans with the truth and predictive power of their "magic".

The End of an Aether — The modern world began in 1820, when Hans-Christian Oersted stumbled on the connection between electricity and magnetism. The news spread like wildfire across Europe as electromagnetism spawned motors and generators, electric trains and mains power, telegraphs, radio and magnetic recording — all before 1900. If Maxwell's equations were the greatest intellectual achievement of the century, the origin of magnetism was one of its greatest puzzles — a puzzle that could only be understood with relativity, quantum mechanics, and Dirac's electrons with spin.

Billions of Magnets for Billions of People: How and Why — When the magnet shape barrier was shattered in 1950, the technology that serves our modern lives could emerge. Tune in and learn about the small, powerful rare-earth magnets that power countless gadgets and one of the greatest modern scientific miracles — magnetic recording. Why and how have magnets have multiplied a billion-fold? Is it true that today we now make more magnets than we grow grains of rice? Dr. Coey will give you the answers to these questions, plus those to questions you hadn't even pondered.

Private, Insider's Tour of CERN

October 25, 10am–4pm — From the tiniest constituents of matter to the immensity of the cosmos, discover the wonders of science and technology at CERN. Join Bright Horizons for a private pre-cruise, custom, full-day tour of this iconic facility.

Whether you lean toward concept or application there's much to pique your curiosity. Discover the excitement of fundamental research and get a behind-the-scenes, insider's look of the world's largest particle physics laboratory.

This trip is limited to 50 people. For questions and hotel pricing, please contact Neil or Theresa, or give us a call at (650) 787-5667.

Our full day will be led by a CERN official and physicist. We'll have an orientation; visit an accelerator and experiment; get a sense of the mechanics of the large hadron collider (LHC); make a refueling stop for lunch in the Globe of Science and Innovation; and have time to peruse exhibits and media on the history of CERN and the nature of its work.

To take advantage of this unrivaled insider access to CERN, rendezvous on October 25, 2010 in Geneva, Switzerland. The additional price is $175 and includes

- Entrance to CERN
- Lunch at CERN
- A round-trip transfer from our Geneva hotel to CERN
- And then on October 27, the transfer from our hotel to Genoa, Italy.

THE GEOLOGY OF THE MEDITERRANEAN BASIN

Speaker: **Zvi Ben-Avraham, Ph.D.**

Tectonics of Continental Margins Around the Eastern Mediterranean Sea — We know the fate of the Mediterranean basin. Nestled in the midst of Africa-Eurasia convergence, it is progressively shrinking and will eventually vanish. Basin margins record these dramatic events. The Mediterranean seafloor is being consumed, sliding northward under the seismically active Calabrian, Ionic, Hellenic, and Cyprian margins. Tune in to Dr. Ben-Avraham's discussion of the geological, ecological, and human consequences of the geological evolution of the Mediterranean basin.

The Dead Sea Fault and its Effect on Civilization — The Dead Sea fault (DSF) is the most impressive geological feature in the Middle East. It is a plate boundary, which transfers sea floor spreading in the Red Sea to the Taurus collision zone in eastern Turkey. The DSF is an important part of the corridor through which hominids set off out of Africa. Join Dr. Ben-Avraham for a look at the remarkable paleoseismic history of the DSF, going back about 70,000 years. Learn how geological activity affected human history and politics in ancient days, and how the interplay of geology, ecosystem, and human activity are of ongoing concern and discussion.

PARTICLE PHYSICS IN TREATING CANCER

Speaker: **James Welsh, M.D.**

Subatomic Frontiers of Radiation Therapy — The connection between quarks and cancer therapy might at first appear a bit obscure but hadrons may prove to be a critical component of twenty-first century oncology. In this lecture we shall review the basic molecular and cellular mechanisms whereby normal cells transform into cancer cells and then discuss some of the means through which this understanding has been exploited, such as the advent of the molecular targeted therapies. We shall then briefly review some principles of radiobiology and radiation therapy. Finally we will review some basics of the Standard Model and how this relates to the next frontier in cancer management — hadron therapy.

SCIENTIFIC AMERICAN TRAVEL

Cruise prices vary from $969 for an Inside Stateroom to $2,829 for a Full Suite, per person. For those attending our program, there is a $1,375 fee. Government taxes, port fees, and InSight Cruises' service charge are $270 per person. For more info **contact Neil at 650-787-5665 or neil@InSightCruises.com**