CHAMPIONS OF ILLUSION

THE SCIENCE BEHIND MIND-BOGGLING IMAGES AND MYSTIFYING BRAIN PUZZLES

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Frontispiece courtesy of Jorge Otero-Millan

TO THE THREE JOSEFINAS: NOVA, FELUCHA, AND CUQUITA

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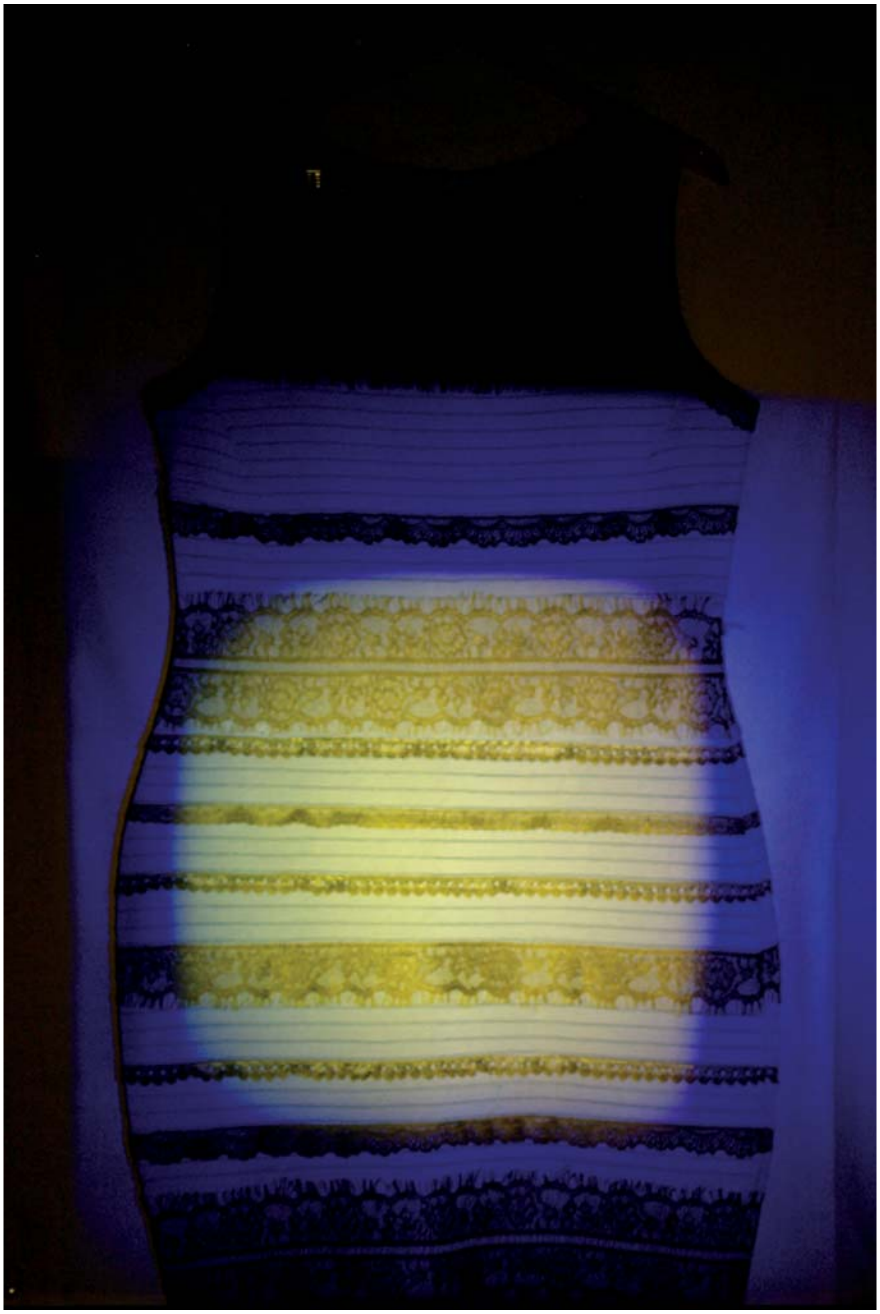


A re-creation of "The Dress" shows the effect of ambiguous illumination on the garment.

INTRODUCTION

Do you remember experiencing that incredible Internet sensation "The Dress" for the first time? The two of us learned about the phenomenon when a science reporter sent us an e-mail asking for our comments. When we opened the image file attached to the reporter's e-mail, both of us saw a white-and-gold dress and were puzzled to learn that many people claimed to see the same dress in blue and black. Huh? A quick Google search revealed that the mystery had a global scale: roughly half of humanity saw the dress as blue and black, and the other half as white and gold. A-list personalities like Taylor Swift and Kim Kardashian were arguing over it on Twitter! Our children told us that they saw blue and black on the same screen where we saw white and gold, while all of us viewed the dress at the same time. Incredible! It took weeks for the story to develop—and for some fast-moving research labs to do scientific testing—before we knew what had occurred. "The Dress" was a new class of perceptual effect, never before described. It is now considered to be the first illusion of color ambiguity, which causes different people—all with normal color vision—to see the same object as having completely different hues. As for what it means for the brain, the research is still ongoing. But one of the most important take-home messages presented by "The Dress" is that your perception is a very personal and subjective experience. There is nothing objective about it.

Your brain creates a simulation of the world that may or may not match the real thing. The "reality" you experience is the result of your exclusive interaction with that simulation. We define "illusions" as the phenomena in which your perception differs from physical reality in a way that is readily evident. You may see something that is not there, or fail to see something that is there, or see something in a way that does not reflect its physical properties.

Just as a painter creates the illusion of depth on a flat canvas, our brain creates the illusion of depth based on information arriving from our essentially two-dimensional retinas. Illusions show us that depth, color, brightness, and shape are not absolute terms but are subjective, relative experiences created actively by our brain's circuits. This is true not only of visual experiences but of any and all sensory perceptions, and even of how we ponder our emotions, thoughts, and memories. Whether we are experiencing the feeling of "redness," the appearance of "squareness," or emotions such as love and hate, these are the result of the activity of neurons in our brain.

Think of *The Matrix*, a movie about a future world in which humanity has lost the war against the machines. The robot victors keep humans subjugated by immersing them—without their knowledge—in a virtual reality simulation called the Matrix. In an iconic scene, Morpheus—one of the leaders of the human resistance—tries to recruit the reluctant hero Neo to the cause, but first needs to convince him that his whole life experience to date has been an illusion devised by their machine overlords. "What is real? How do you define 'real'?" asks Morpheus. "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." Morpheus then produces two pills—one red, one blue—and asks Neo to choose between them. The red pill will wake Neo up from the Matrix and release him into the real world. The blue pill will make Neo forget that he ever met Morpheus: he will remain in the Matrix, perpetually unaware that his complete experience is—and has always been—nothing more than a sophisticated dream. Neo takes the red pill, of course, and his adventures start. 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 continues to construct his subjective experience, as all our brains do. In other words, Neo remains stuck in the biological Matrix of his own mind.

Yes, there is a real world out there, and you perceive events that occur around you, however incorrectly or incompletely. But you have never actually lived in the real world, in the sense that your experience never matches physical reality perfectly. Your brain instead gathers pieces of data from your sensory systems—some of which are quite imprecise or, frankly, wrong. Accuracy is not the brain's forte, and so, like Neo, we all live inside our own heads, in an illusory Matrix.

(How can you know there is an actual reality out there? The short answer is that you can't. Not in any fundamental fashion. You could be dreaming, or you could be living as a disembodied brain in a vat, deluded into experiencing a computer simulation created by evil robots. However, for the purpose of advancing our discussion, we will make two fundamental assumptions: 1. There is a reality outside of your brain. 2. You experience this reality through your sensory organs [retinal photoreceptors, taste buds, etc.], which are part and parcel of your neural machinery.)

Some people think illusions are simply mistakes made by the brain: erroneous computations, failures of perception that we would do well to overcome. But what if illusions are good things? Could it be that these peculiar mismatches between the inner and outer worlds are somehow desirable? Certainly, illusions are the product of evolution; we know that several illusions occur because of shortcuts that your brain takes to help you survive and thrive. Some of your misperceptions allow you to make lightning-fast assumptions that are technically wrong but helpful in practice. They can help you see the forest better—even if they make you discern the trees less precisely.

For example, you may underestimate or overestimate distances depending on various contextual cues. The psychologists Russell E. Jackson and Lawrence K. Cormack reported that when observers guessed the height of a cliff while looking down from the top, their estimates were 32 percent greater than when they were looking up from the cliff's base. This discrepancy appears related to the way we observe the same precipice from above versus below: a vertiginous cliff edge falling away from us versus a cliff face sloping into open land. Given that accidents are more likely to happen while climbing down rather than up, this height overestimation, when you look down from the top, may make you descend cliffs with greater care, reducing your chances of falling.

Illusions also offer a window into how our neural circuits create our subjective experience of the world. The simulated reality your brain creates—also known as your consciousness—becomes the universe in which you live. It is the only thing you have ever perceived. Your brain uses partial and flawed information to build this mind model and relies on quirky neural algorithms to alleviate those flaws.

Because illusions enable us to see objects and events that do not match physical reality, they are critically important to understanding the neural mechanisms of perception and cognition. They expose the structure that our mental universe is based on. To encourage the discovery and study of illusions, we created the annual Best Illusion of the Year Contest in 2005 to honor the best new illusions from the previous year and celebrate the inventiveness of illusion creators around the world: researchers, software engineers, mathematicians, magicians, graphic designers, sculptors, and painters fascinated with mapping the boundaries of human perception. The contest is playful, but for scientists it serves a deeper purpose. All the little perceptual hiccups that the contest showcases are opportunities to peer behind the neurological curtain and learn how the brain works. The contest has become an annual point of convergence for visual artists and scientists, and an event that illusion creators of all backgrounds look forward to, and prepare to compete in, every year. We have been particularly thrilled that the contest has spurred the creation and dissemination of new illusions that might otherwise remain undiscovered and unknown.

We are professors of ophthalmology, neurology, physiology, and pharmacology at the State University of New York (SUNY) Downstate Medical Center in Brooklyn, New York. Susana directs the Laboratory of Integrative Neuroscience, and Stephen directs the Laboratory of Translational Neuroscience. Both of us trained in neuroscience as Ph.D. students, and we've worked together, studying the neural bases of illusions, since 1997. (It was not until 2002 that we started dating, and we got married only nine months afterward. Our friends still think that we were dating for years before we married, because we spent so much time together—just another illusion!)

When attending scientific conferences, we loved to check out the talk and poster sessions for the newest and coolest illusions. One need not be a Harvard-trained neuroscientist to enjoy the puzzlement and intellectual challenge posed by illusions, but they are particularly irresistible to perceptual researchers, because they provide us with a great handle on the problem of what, exactly, our brains are doing when we experience anything. If illusions, by definition, dissociate reality from objective perception, then to understand conscious experience we must locate the neurons, circuits, and brain areas that activate in such a way as to match our perception of the illusion rather than reality itself—no matter how large the discrepancy might be.

Early in our careers, we volunteered to host the twenty-eighth gathering of the European Conference on Visual Perception (ECVP), the premier transnational conference for visual researchers. We were longtime fans of the ECVP and, encouraged by the conference cofounder Lothar Spillmann, we proposed to hold the annual meeting in Susana's hometown of A Coruña, Spain.

We were terrified and exhilarated in equal measure—terrified that we'd screw it up and exhilarated that we might not—when our offer to host was accepted. Around that time, we became faculty members at the Barrow Neurological Institute in Phoenix, Arizona—which meant that we now had to plan a conference with more than eight hundred attendees from over five thousand miles away!

Despite this challenge, we wanted to do something new—something more—with the opportunity we had been given to organize this important conference. Our goal was to make the meeting special for academics as well as the general public. Illusions, we realized, were the answer: we resolved to hold the world's first contest in which scientists, artists, software designers, mathematicians, and creative people from any field could submit new illusions that they had created or discovered. They would all compete for the title of Best Illusion of the Year.

That's how we hosted the first edition of the Best Illusion of the Year Contest as part of the 2005 ECVP conference. We came up with a simple set of rules. Illusions competing in the contest would need to be novel—previously unpublished, or published no earlier than the previous year. Then an international panel of illusion experts—artists, scientists, and science educators—would select ten illusions that were the most innovative, counterintuitive, spectacular, beautiful, and significant to the understanding of the human mind. Finally, the top ten illusion creators would present their awe-inspiring brain twisters at an awards gala, and the audience would vote for first-, second-, and third-place winners. It was the Oscars of illusion.

The contest was a huge success. Because the organizers of the ECVP change every year, we had imagined that the contest would be a one-time event, but everybody, it seemed, loved the competition and wanted more. Both our colleagues and the public asked for future editions of the Best Illusion of the Year Contest.

We were intrigued by the possibility but also a little wary. Could we have an illusion contest every year? We received more than seventy illusion submissions in the first year, but perhaps some of these were illusions that had been sitting in people's drawers for years, if not decades. Could illusion creators around the world keep up with the demand of a yearly contest? Or would the quantity, and especially the quality, of the illusions decline after the first few years? We decided to give it a shot.

The practicalities of organizing what would become an annual contest required that we hold it in the same place every year—ideally, on the same continent as where we lived. So we set out to hold future contests in Florida, coinciding with the annual gathering of the Vision Sciences Society. We also created the Neural Correlate Society, a nonprofit organization that brings together researchers from fields as diverse as art, mathematics, psychology, and neuroscience to promote scientific understanding of perception and cognition, and that runs the contest today.

We were delighted to discover that our initial concern—that the illusion well would run dry—was wrong. Amazing illusions kept coming in, and we learned that many illusion creators around the globe marked the dates of the contest in their calendars and set out to invent new illusions specifically for our annual event. Because of its very existence, the contest actually spurred the creation of new and better illusions! By the fifth or sixth year of the contest, we realized that, as long as people remained captivated by the workings of the human mind, they would keep on inventing ways of challenging their perceptions and the perceptions of others. More than ten years on, the illusions are as strong as ever.

The Best Illusion of the Year Contest also allows us to see art and science merge in beautiful ways. Previously, scientists tended to create illusions from simple lines and geometrical shapes, and artists focused on eye-popping illusions without much thought of state-of-the-art neuroscience. But today, science and art overlap more than ever. Scientists increasingly use graphic-design tools to enhance the aesthetics of their illusions, and artists have grown more knowledgeable about the neuroscience behind the magic.

In 2014, after living in Phoenix for ten years, we accepted professorships in New York, and moved to the city with our three children. Around the same period, we felt that it was time to revamp the contest—which had just celebrated its tenth anniversary—and take it to the next level.

Holding a live event during which creators presented their illusions in front of one thousand spectators was a lot of fun. Over the years, a number of magicians, musicians, and other entertainers have emceed the event or performed during the vote counting. The renowned magician and skeptic James Randi—aka the Amaz!ng Randi—performed in two contests, and the Las Vegas headliner and champion of comedy magic Mac King emceed an unforgettable tenth-anniversary gala.

Still, the contest's main audience was always the millions of Internet users who follow the competition, invent new versions of the illusions, and make the most mind-warping entries go viral.

If we moved the contest completely online, we reasoned, anybody in the world with an Internet connection could submit illusions and vote for the winners—not just people with the time or means to travel to Florida for the event. We knew we previously had lost international contestants who had stunning illusions for these reasons.

Whereas the top ten contestants used to have five minutes each to present their illusions to a live audience—who then voted using paper ballots—having an online contest meant reducing the time allotted per illusion. We could no longer expect voters to view illusions for fifty minutes (an eternity, by Internet standards!) before choosing their favorite.

So, in 2015, we asked contestants to send one-minute videos to compete online for the first time. An international judging panel still pared down submissions to the top ten, but anybody in the world with Internet access could vote. The contest was no longer limited to a specific audience.

It was a great move. The illusions in 2015 were terrific, and the savings from moving the contest online allowed us to offer cash prizes to the winners.

We hope that you will help select the next Best Illusion of the Year—and especially that you submit your illusion creations to the contest! Anybody can compete, and the instructions are posted online. In the meantime, this book showcases some of our favorite illusions from the contest's first decade, and offers you a chance to glimpse the world of misperception, where neuroscience, art, and magic converge. We'll also tell you a bit about how the illusions were created and what they reveal about the way our brains operate in everyday life. The mind tricks you are about to experience will provide you with an increased awareness of the subjective quality of your private reality, and insider knowledge that these apparent neural failures—illusions—are critical to how we perceive the world.

Each chapter is dedicated to a specific type of illusion, such as color, shape, size, and so on. Most of the illusions featured here come from the contest, but we have also incorporated a few additional illusions to help explain important ideas. At the end of the book, you'll find a special section devoted to dynamic illusions that are best viewed on the screen. Be sure to go online and check these out if you wish to delve deeper into the limits and wonders of your perception. We've also included more information about the people behind these illusions. We hope you enjoy the show!

1

BRIGHTNESS AND CONTRAST ILLUSIONS

Nothing is more fundamental to our vision than how we see the brightness of an object. But even so, our visual system plays fast and loose with reality and serves up—for your viewing pleasure—monstrously bizarre and perplexingly inaccurate interpretations of the physical world. And this raises the question that constantly cycles through the brains of vision scientists: Why doesn't human vision faithfully represent the world we see? The answer, as any student of Darwin should agree, is that illusions must help us survive (or at the very least not hinder our survival). If illusions were harmful, it is likely that they would have been weeded out of the gene pool by now. Mutations that work against survival—and reproductive success—are self-limiting.

But how can a visual illusion be useful? To illustrate, we'll do an experiment. Go to a dark room in your domicile with a cell phone and a book (an actual book, made of paper). Then dimly illuminate the pages of your book, using your phone, just enough to see the letters. White pages, black text—looks like a book, right? After you have completed this part of the experiment, head outside on a sunny day with the same book. Under direct sunlight, look at the same page; it looks identical, right? If you think it through, that's impossible, because the physical reality under the two lighting conditions is very different! When you read black text on a page lit by a dim cell phone, the amount of light reflected by the white paper is around 100,000 times lower than the amount of light reflected by the black letters in direct sunlight. So why don't the black letters seem super-white (100,000 times brighter than white) outside? The reason is that your brain doesn't care about light levels; it cares about the contrast between the lightness of objects. It interprets the letters as black because they are darker than the rest of the page, no matter the lighting conditions.

The illusion that allows us to identify an object as being the same under different lighting conditions is a very useful one. It helps us survive. For one thing, it might have allowed our ancestors to recognize their children inside and outside the cave . . . and therefore not eat them!

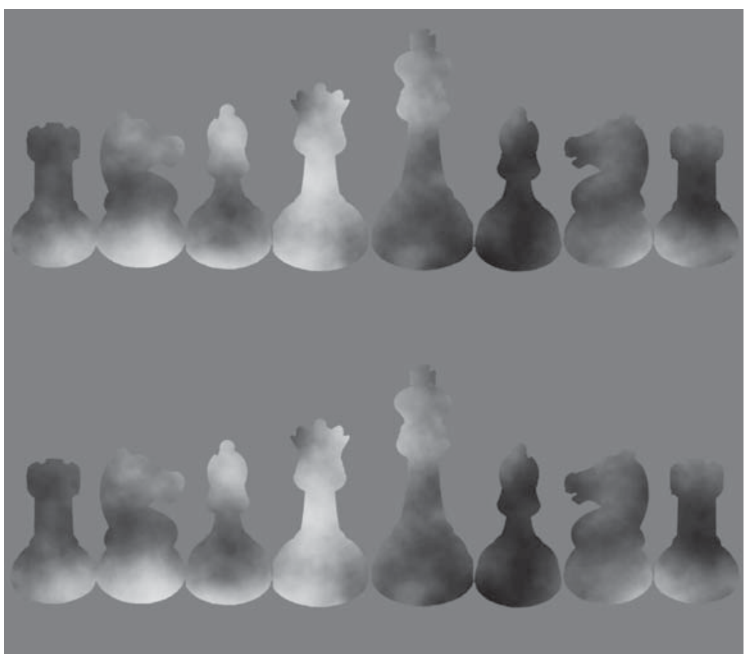
THE WORLD'S LARGEST BRIGHTNESS ILLUSION

BY BARTON ANDERSON AND JONATHAN WINAWER

UNIVERSITY OF SOUTH WALES, AUSTRALIA, AND MASSACHUSETTS INSTITUTE OF TECHNOLOGY, U.S.A.

2005 FINALIST

Our brain does not perceive the true brightness of an object in the world (for instance, measured with a photometer), but instead compares it with that of other nearby objects. For instance, the same gray square will look lighter when surrounded by black than when it is surrounded by white. This illusion by Anderson and Winawer extends this concept dramatically. In the images, the four sets of chess pieces are identical. The backgrounds are the only things that change: the images on the two bottom rows show the same chess pieces as the images on the top two rows, only with the backgrounds removed. We perceive the first-row pieces as white and the second-row pieces as black because of the variations in the clouds engulfing them. Checkmate!



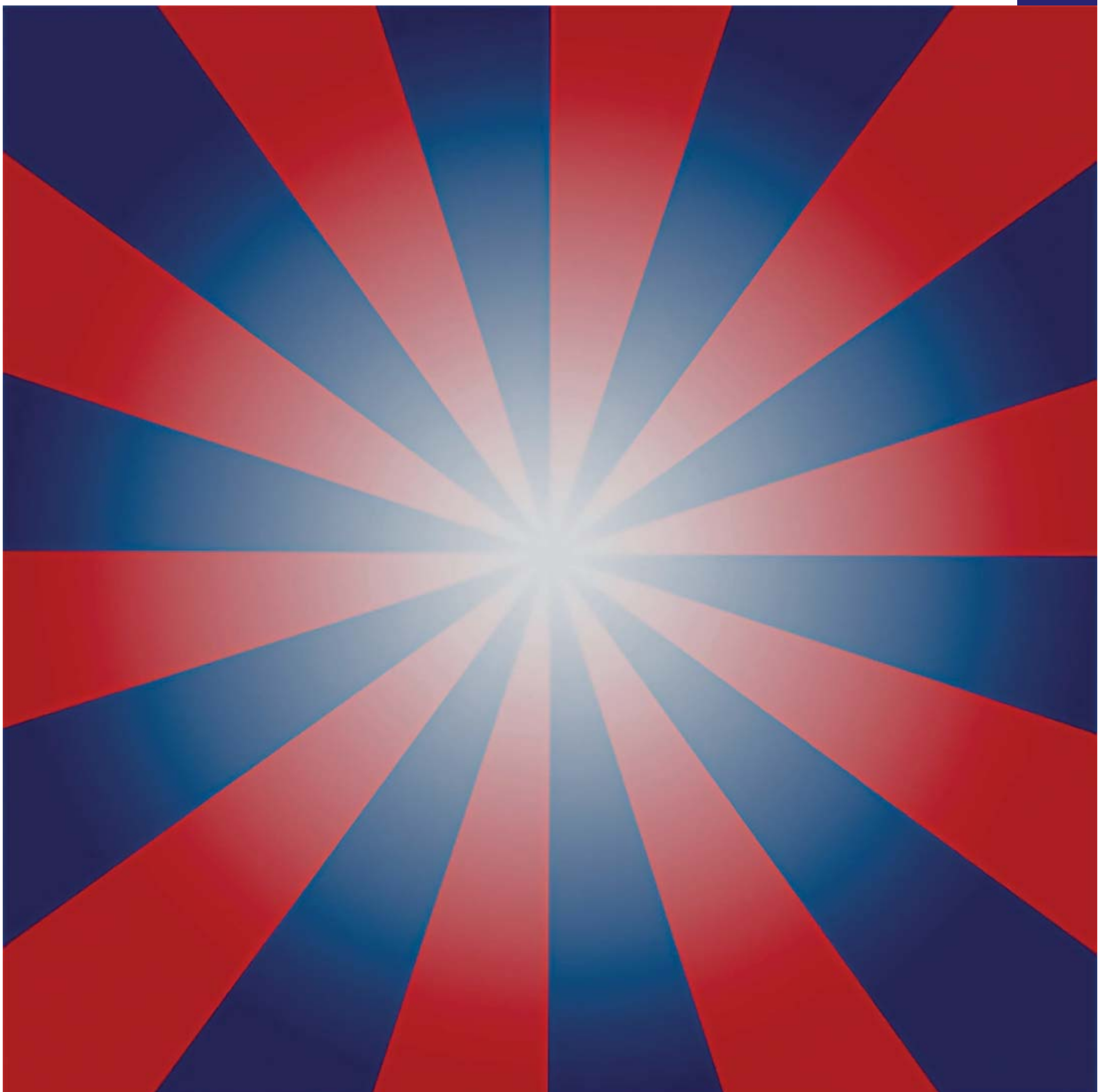
HERE COMES THE SUN

BY ALAN STUBBS

UNIVERSITY OF MAINE, U.S.A.

2006 FINALIST

Hold this book at a comfortable distance from your eyes while looking at the picture. Then bring the book gradually closer. As the image approaches, you should notice that its brightness seems to increase. Move the book back and forth to make the brightness increase and decrease repeatedly. The neural bases of this effect are not yet understood, but the explanation may reside in how our visual system reacts to expanding versus contracting objects as a function of their distance from the observer. Some motion-sensitive neurons of the visual pathway become selectively activated when visual objects either loom (expand) or recede (contract). It could be that the ghostly, transparent white cloud radiating from the center of the image appears less salient to those neurons than the highly visible red-blue background. If so, when the cloud and the background expand and contract together, your neurons may signal a difference in the relative amounts of expansion and contraction—so that one element appears to loom or recede more than the other, even though no difference actually exists.



THE PRIMAL FLASHLIGHT

BY LOTHAR SPILLMANN, JOE HARDY, PETER DELAHUNT, BAINGIO PINNA, AND JOHN WERNER

UC DAVIS MEDICAL CENTER, U.S.A.; UNIVERSITY OF FREIBURG, GERMANY; POSIT SCIENCE, U.S.A.; UNIVERSITY OF SASSARI, ITALY

2009 FINALIST

All you will need to experience this illusion is a cardboard tube, such as a paper-towel roll or a poster tube. Look through the tube with one eye, and keep the other eye open. Point the tube at a bright wall. After just a few seconds, the circle you see through the tube will look much brighter than the rest of the wall! If you look at a textured surface, the illusion will enhance not only the brightness and color but also the details in the pattern. Vision scientists do not fully understand this phenomenon, but it could be that the dark inner cardboard walls enhance the brightness of the scene trapped inside the tube, compared with the rest of the visual field. Another nonexclusive possibility is that looking through the tube helps focus your attention in one eye more than in the other.

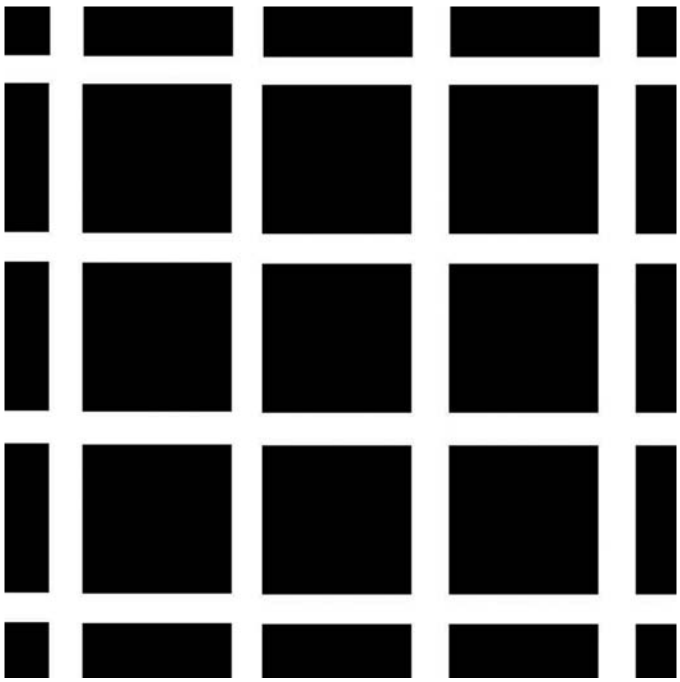
WEAVES AND THE HERMANN GRID

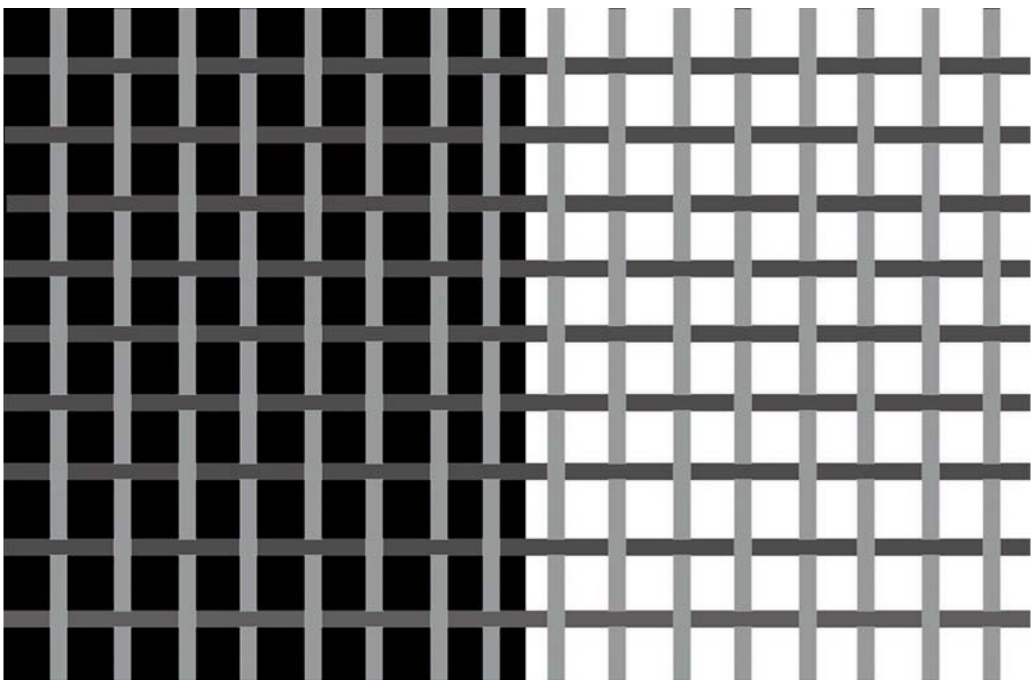
BY KAI HAMBURGER AND ARTHUR G. SHAPIRO

UNIVERSITY OF GIESSEN, GERMANY, AND BUCKNELL UNIVERSITY, U.S.A.

2007 FINALIST

The Hermann Grid Illusion, reported by the German physiologist Ludimar Hermann in 1870, consists of a white grid on a black background or a black grid on a white background. Faint, ghostly spots appear at the grid's crossings, even though there is nothing there. The classical explanation for this illusion is based on experiments carried out by the neurophysiologist Günter Baumgartner in 1960. Baumgartner proposed that neighboring neurons of the early visual system—the first areas of the brain to respond to visual information—enhance the perceptual contrast at the grid's crossings by suppressing each other's activity. This process—known as lateral inhibition—was first described in neurons in the horseshoe crab's eye, a discovery that led to Keffer Hartline's 1967 Nobel Prize. Hamburger and Shapiro's novel variant of the Hermann Grid Illusion interlaces light gray vertical columns with dark gray horizontal rows (or the other way around, however you prefer to think about it). As the lightness of the background varies from black to white, the apparent brightness of the illusory spots at the crossings reverses.



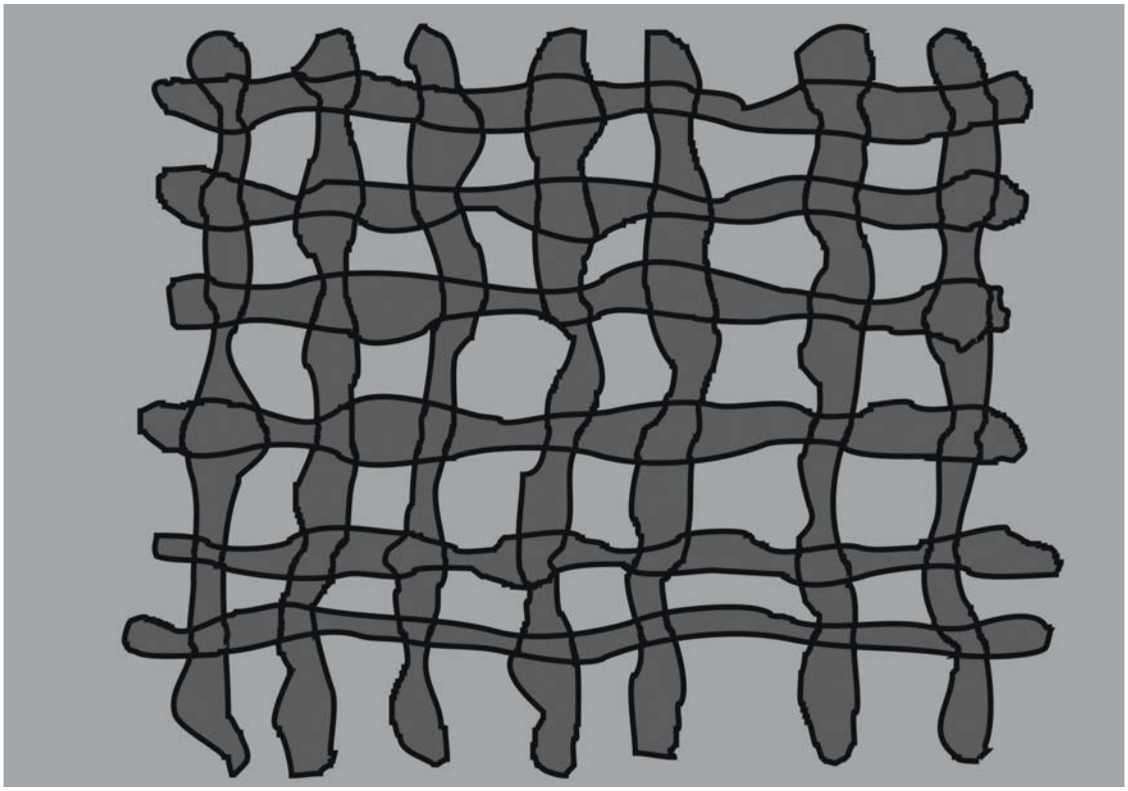


BRIGHT PATCHES

BY ROB VAN LIER AND MARK VERGEER

RADBOUD UNIVERSITY, NIJMEGEN, THE NETHERLANDS

2006 FINALIST



This perceptual effect is another novel variation of the classic Hermann Grid Illusion. The "patches" at the intersections of the grid above look brighter than the rest of the grid. And yet the entire grid is in a single tone of gray.

THE ILLUSION OF SEX

BY RICHARD RUSSELL

HARVARD UNIVERSITY, U.S.A.

2009 THIRD PRIZE

You may perceive these two side-by-side faces as female (left) and male (right). But both are versions of the same androgynous face. The two images are identical, except that the contrast between the eyes and mouth and the rest of the face is higher for the one on the left than for the one on the right. This illusion shows that contrast is an important cue for determining gender: low-contrast faces appear male, and high-contrast faces appear female. It may also help explain why females in many cultures darken their eyes and mouths with cosmetics: a made-up face looks more feminine than a face without makeup.

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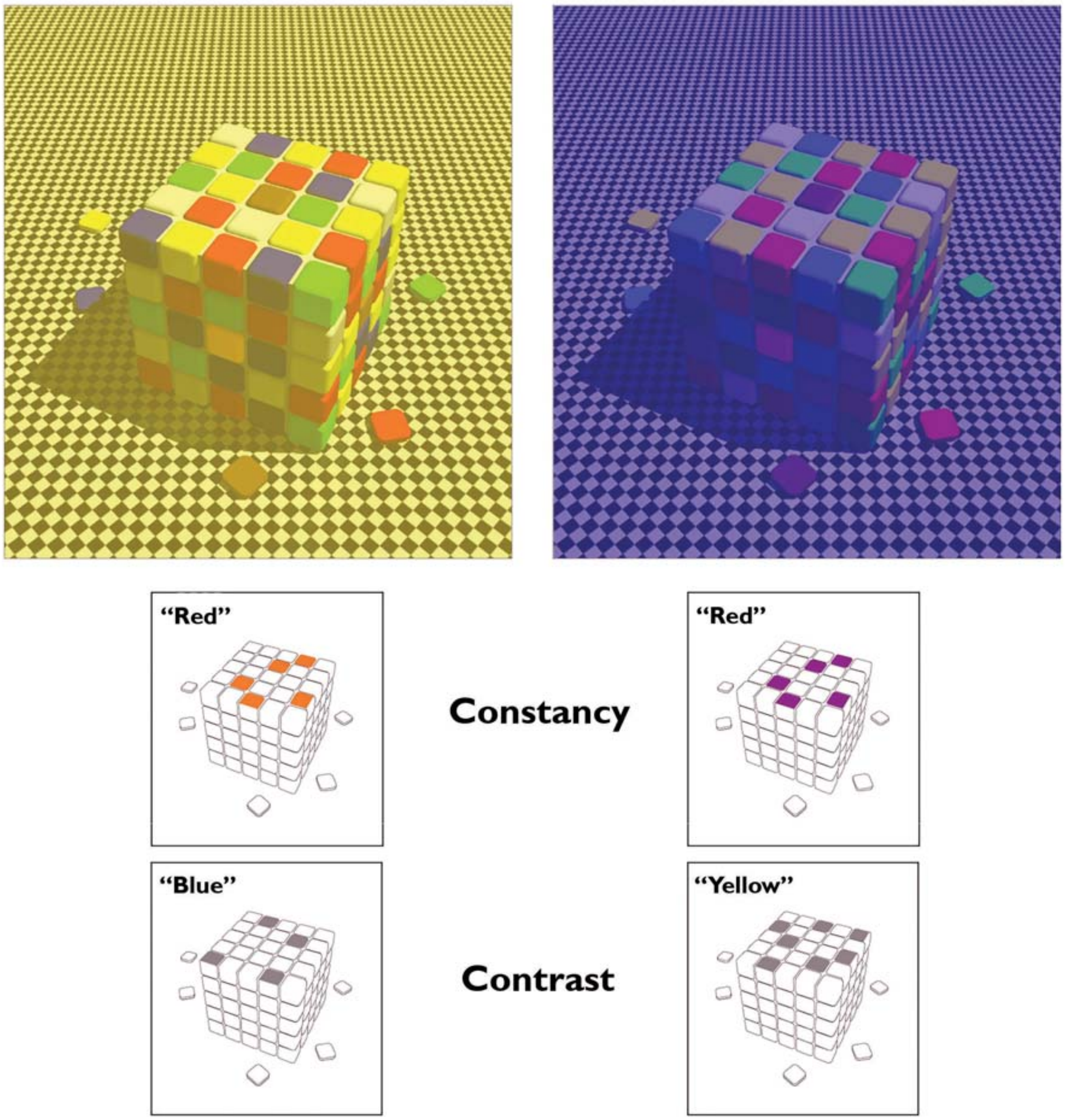
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