Filling in the ______

Your brain fills in all kinds of visual gaps

BY STEPHEN L. MACKNIK AND SUSANA MARTINEZ-CONDE

Nature abhors a vacuum.
—François Rabelais, 1534
(after Aristotle)

Nature just loves a vacuum.
It's most of the universe.
—Neil deGrasse Tyson, 2013

AN AMAZING FACT: most of what you see is a confabulation of your brain. Sounds hard to believe, right? After all, you are reading this page. So how inaccurate could your visual system be? Well, it is not that our eyes themselves are inaccurate … just that our brain makes stuff up based on the sparse data it gets from our eyes and then leads you down the garden path.

Let's start with your retina. A terrible imaging device, by any engineer's estimation. So full of design flaws that it is essentially proof positive against intelligent design. The neural circuits that make up the human retina, and the blood vessels that feed them, sit between the eye's lens and the photoreceptors—which lie against the back of the eye. Light must travel through all this semitransparent machinery before photoreceptors can transduce it into neural signals. How dumb! Shouldn't the photoreceptors lie just behind the lens to meet the incident light without obfuscation? Well, yes. The retinal layout of some animals such as squids and octopuses is indeed organized in this way. Yet because your brain conjures up most of what you see anyway, trivialities such as pristine optical transmission are not that important.

YOUR DIRTY LITTLE MIND

Notice the naked nubile young women behind the orange occlusion (as if you hadn't already!)? Turn to page 23 to see the photograph without the masking.

SCIENTIFIC AMERICAN MIND (*orange overlay*); GETTY IMAGES (*girls on beach*)

Case in point: you only have high-resolution vision in the very center of your eye—about 0.1 percent of your entire visual field. You are *legally blind* to objects more than a finger width or two from the center of your vision. But it doesn't *feel* that way. Instead you perceive your entire visual field as a high-resolution and perfectly formed image that is always in focus: a load of pure baloney provided compliments of your brain. In fact, very near the part of your retina where your photoreceptor density is highest lies a region devoid of sensory cells, in which you are completely blind. It is fascinating and counterintuitive, so let's discuss the illusion that makes you think you see in this blind spot, as well as several other algorithms used by your brain to achieve filling in. M

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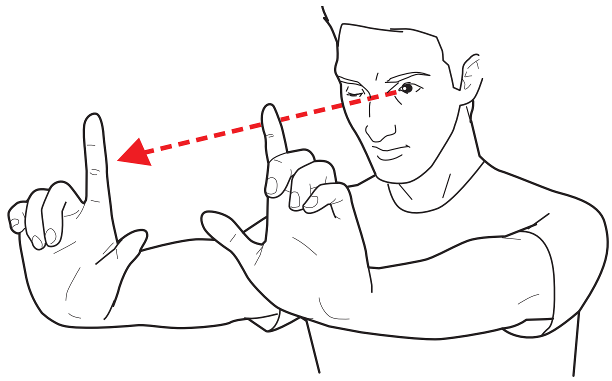
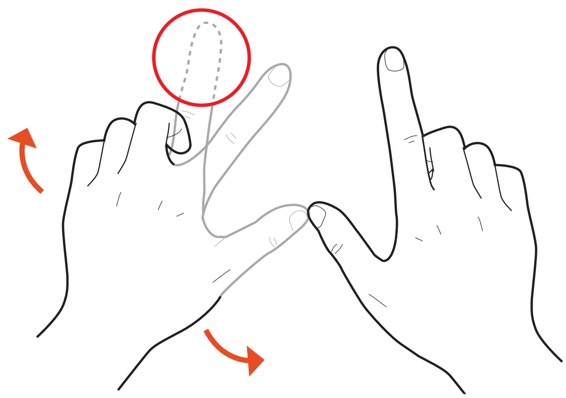
(Your retina is a terrible imaging device. **So full of design flaws** that it is essentially proof positive against intelligent design.)

THE BLIND SPOT

You won't be too surprised to learn that your retinal photoreceptors do not communicate visual signals to the brain via radio waves. A bunch of nerve fibers—more than one million individual wires—come bundled in a structure called the optic nerve, which exits the back of your eyeball to connect the retina to the brain. If your photoreceptors pointed toward the front of your eye, as any sensible sensory cell should, the nerve fibers would gather at the back of the eye—behind the photoreceptors—and the optic nerve could leave the eye without disturbing your visual field. Yet in the human retina, the circuits connecting the photoreceptors to the brain congregate toward the middle of the eye, so nerve fibers must dive back down through the retina to form the optic nerve. The result is a spot where no visual image can exist. Even though this spot lies surprisingly near to the center of your retina, you cannot see a hole in your vision, because your brain fills it in.

To prove this to yourself, first read this paragraph completely and then try this exercise: Hold out your hands at arm's length with elbows straight, thumbs touching, and point your two index fingers straight up [*see illustration below*]. Close your right eye and look at your right fingertip with your left eye. At the same time, pay close attention to your left fingertip. You will notice that it has disappeared into the blind spot of your left retina (if not, rotate your left wrist up and down while maintaining contact between your two thumbs to see your left fingertip disappear). Once your fingertip is gone, notice that *you can still see what is behind it!* Now be honest with yourself, do you have x-ray vision in your blind spot, or are you blind in your blind spot? Assuming that you agree that you are indeed blind in your blind spot, we can now analyze how the brain fills in the hole to understand how filling in works. Notice that the filled-in area looks like the area immediately surrounding your blind spot: your brain fills in the hole with the nearest visual information available. Yet the algorithm is not smart enough to fill in your finger.



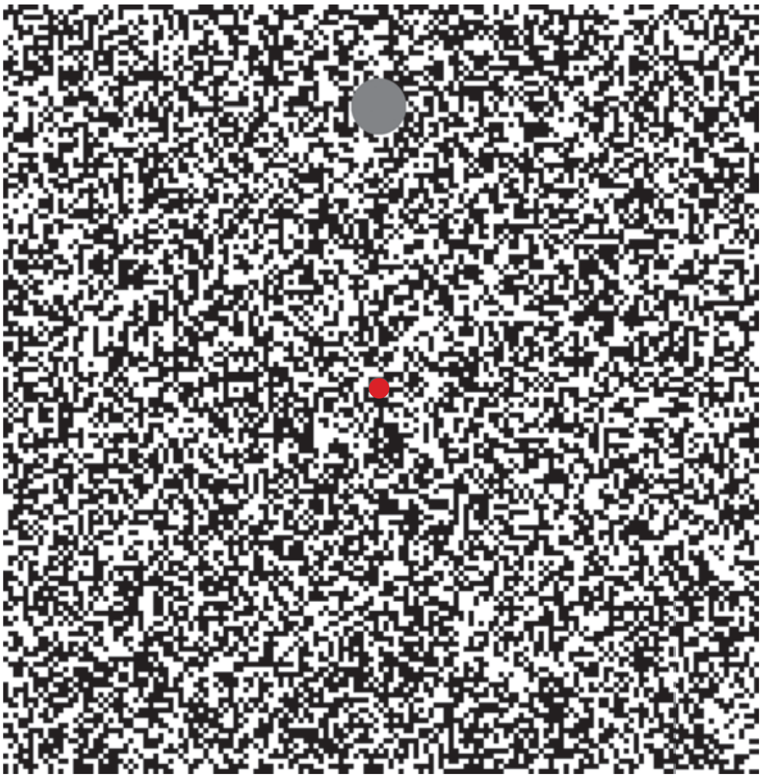


DYNAMIC FILLING IN

In this demonstration, the observer fixates his or her gaze on a small, red spot within a field of noise (for instance, the snow on a television when there is no cable link) while paying attention to a solid gray area—with the same average brightness of the black and white dots. After a few seconds of steady visual fixation, the gray area fills in with the surrounding noise and becomes indistinguishable from the background. This phenomenon is remarkable in that it shows that the brain not only fills in static patterns but can also simulate dynamic changes. Interestingly, there is no real reason why the brain should fill in the gray area in the first place. There is actually a physical gray spot in the visual field (rather than a hole in the retina). The fact that filling in happens in such conditions suggests that the visual system must regularly analyze the visual field for anomalies and fills them in just in case they are errors.

To experience this illusion, go to **http://smc.neuralcorrelate.com/illusions-and-demos/dynamic-filling-in**

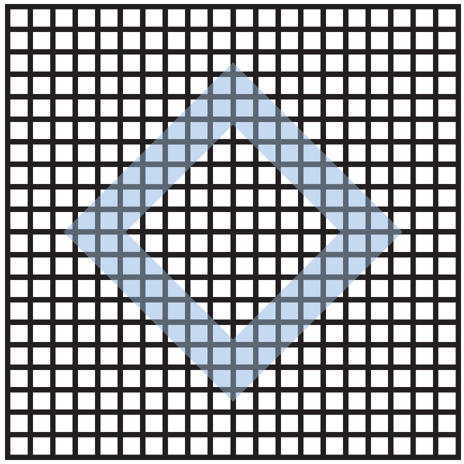
Alternatively, tune your TV to a field of flickering noise and stick to the screen a fixation target (a little corner of a Post-It will do) and a small square (about the size of your thumbnail) of newspaper (use some tape on the back of the square that you can easily remove afterward). The fixation target and the gray square should be four to five inches apart, and your eyes should be at about arm's length from the TV screen, where you can see both the fixation target and gray square easily. Now hold your gaze still on the fixation target and watch the square fill in with the surrounding noise.

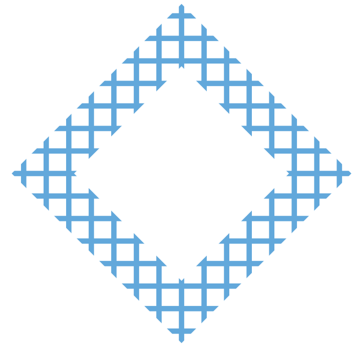


JASON LEE (*top*); COURTESY OF HÉCTOR RIEIRO (*bottom*)

NEON COLOR SPREADING

The brain can fill in color information even if no gap is apparent. H.F.J.M. van Tuijl's neon color spreading effect shows an illusory blue field that appears to emanate from a grid of blue crisscrossing lines (embedded in a larger black grid), like glare from a neon light. The illusion is attenuated when the blue grid stands alone against a white background.

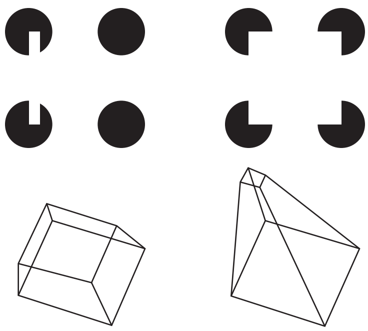




FILLING IN BY MORPHING

Neuroscientist Peter U. Tse of Dartmouth College discovered that two similar, but different, two-dimensional or three-dimensional objects presented in sequence can appear to transform (morph) into each other and that the brain fills in the "missing frames" with illusory motion between the two physical shapes. Instead of two objects, your brain provides you with the perception of a single object changing shape and position in space.

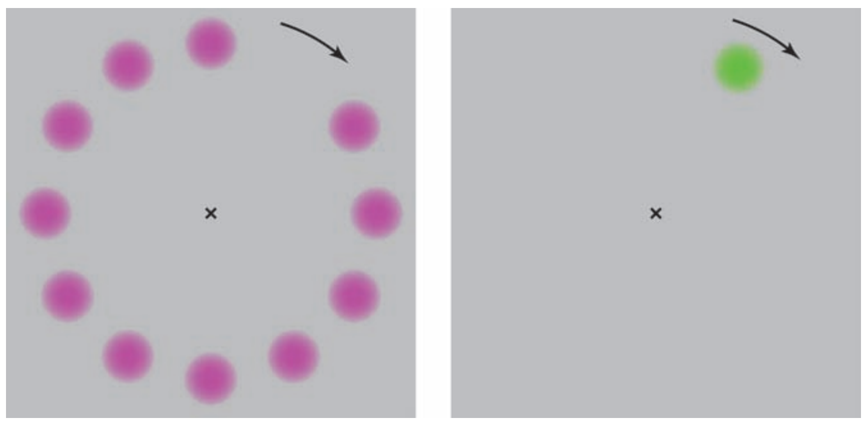
See the demonstrations at www.dartmouth.edu/~petertse/tamdemo2a.htm and www.dartmouth.edu/~petertse/tamdemo3d.htm



LILAC CHASER

This illusion consists of a rotating gap in a circular array of lilac dots over a gray field. When you fix your gaze on the center of the display, the dots fade because of visual adaptation, and what emerges is a single rotating green dot (lilac's opposing color) that does not actually exist. The brain fills in the places occupied by the lilac dots with the gray field around them, but it is still subject to the opposing-color afterimage that each faded lilac dot generates.

See an interactive demonstration of this effect at www.michaelbach.de/ot/col_lilacChaser



Apparently your mind was in the gutter because in reality the women are wearing bathing suits and only appeared to be naked because that is what your crude mind expected you to see.

FURTHER READING

- **A New Visual Illusion: Neonlike Color Spreading and Complementary Color Induction between Subjective Contours.** H.F.J.M. van Tuijl in *Acta Psychologica,* Vol. 39, No. 6, pages 441–445; December 1975.
- **Perceptual Filling in of Artificially Induced Scotomas in Human Vision.** V. S. Ramachandran and R. L. Gregory in *Nature,* Vol. 350, pages 699–702; April 25, 1991.
- **Dynamic Noise Backgrounds Facilitate Target Fading.** L. Spillmann and A. Kurtenbach in *Vision Research,* Vol. 32, No. 10, pages 1941–1946; October 1992.
- **Neural Correlates of Transformational Apparent Motion.** Peter U. Tse in *Neuroimage,* Vol. 31, No. 2, pages 766–773; June 2006.
- **Microsaccades Counteract Perceptual Filling-in.** X. G. Troncoso, Stephen L. Macknik and Susana Martinez-Conde in *Journal of Vision,* Vol. 8, No. 14, pages 1–9; November 4, 2008.

"A NEW VISUAL ILLUSION: NEONLIKE COLOR SPREADING AND COMPLEMENTARY COLOR INDUCTION BETWEEN SUBJECTIVE CONTOURS," BY H.F.J.M. VAN TUIJL, IN *ACTA PSYCHOLOGICA*, VOL. 39, NO. 6; DECEMBER 1975 (*neon color spreading*); COURTESY OF PETER TSE (*filling in by morphing*); COURTESY OF HÉCTOR RIEIRO (*lilac chaser*); GETTY IMAGES (*girls on beach*)