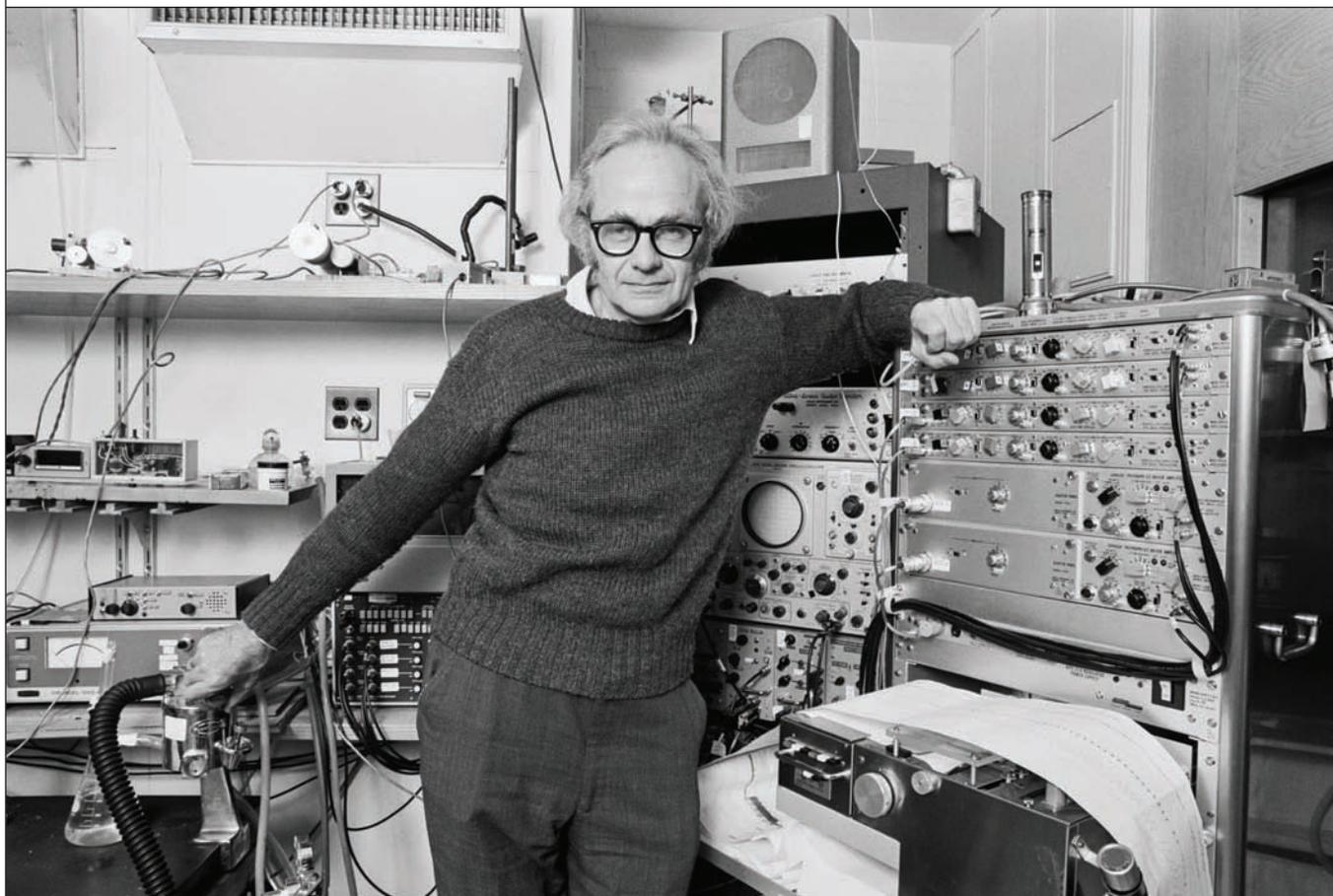


(illusions)

David Hubel's Vision

A Nobel Prize–winning neuroscientist and his quest to crack the brain's visual code

BY SUSANA MARTINEZ-CONDE AND STEPHEN L. MACKNIK



I must admit that what most strongly motivates me ... is sheer curiosity over the workings of the most complicated structure known.

—David H. Hubel (1926–2013)

IN 1958 neurophysiologist David H. Hubel and his new research partner, Torsten N. Wiesel, were working like dogs to understand how cats see the world. They routinely pulled all-nighters in Stephen Kuffler's laboratory at the Wilmer Eye Institute at Johns Hopkins University. One of them would insert thin tungsten electrodes into the anesthetized cats' brains, plugging into neurons in area 17—the first region of the cortex that processes visual information. The other would use a modified ophthalmoscope fitted with glass slides to shine different patterns of light into each animal's eyes. The elec-

trodes were connected to a machine that converted any electrical activity in the brain cells into sounds. Hubel and Wiesel listened carefully for signs of rapidly firing neurons.

For a long time they heard little of interest. Why was this so hard? They were eavesdropping on the brain's *visual* system, right?! Surely they should hear robust activity. Neurons in the retina—the light-sensitive tissue at the back of the eyes—readily responded to spots and rings of light. And neurons in the visual thalamus—the part of the brain connected directly to the retina—dutifully react-

ed to information relayed from the retina. So why wouldn't cortical neurons, just one level up in the visual hierarchy, also respond in kind? It was infuriating. All the more so because other scientists had warned Hubel and Wiesel that this is exactly what would happen. Again and again neurophysiologists like them had tried, and failed, to crack the visual cortex's code.

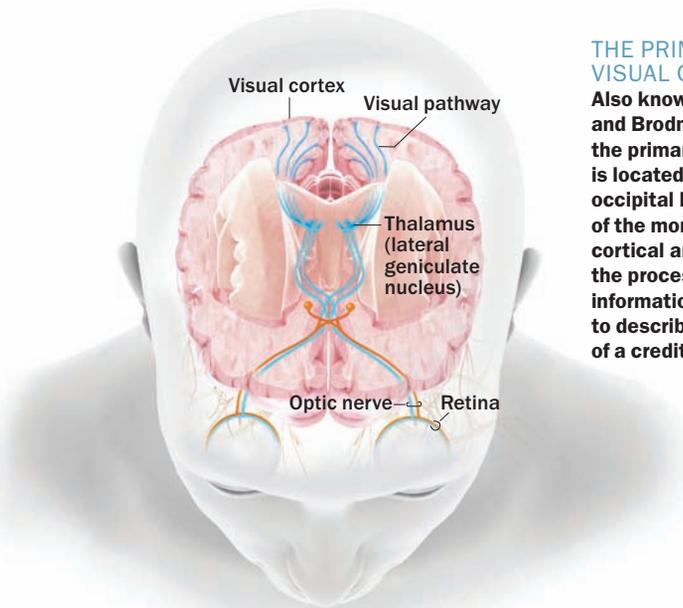
But Hubel and Wiesel were relentless. Unraveling the workings of the cortex was critical not only to understanding vision but also to illuminating the very part of the brain that makes us hu-

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man. The architecture of the cortex looks more or less the same whether you are in the frontal lobe, the auditory temporal lobe or the visual occipital lobe.

One day while conducting their usual experiments, a machine gun barrage of neural impulses surprised them both. Where did that come from? The neuron in question seemed to be teasing them, firing whenever they inserted a new glass slide onto the ophthalmoscope but then falling silent again. Something momentous was happening that they could not yet grasp. Worse, they felt they were running out of time. Often they could only record from the same neuron for just a few minutes, maybe an hour or two, before it died or slipped off the end of the electrode. Fortunately, an explanation struck them like a lightning bolt. Perhaps the neuron was not responding to the patterns of light and shadow made by the slides but rather to the edge of each new slide as it slid into the ophthalmoscope.

Exhilarated, Hubel and Wiesel continued to study the neuron as the hours ticked by. After presenting the brain cell with all kinds of visual patterns—in their previous studies they had tried everything from their own faces to pictures of glamorous female models—they finally concluded that this potentially history-changing neuron responded only to lines and edges that were oriented in specific angles. They could think of no further tests to conduct and looked at



THE PRIMARY VISUAL CORTIX

Also known as area V1 and Brodmann area 17, the primary visual cortex is located in the brain's occipital lobe. The largest of the more than a dozen cortical areas involved in the processing of visual information, Hubel used to describe it as "the size of a credit card."

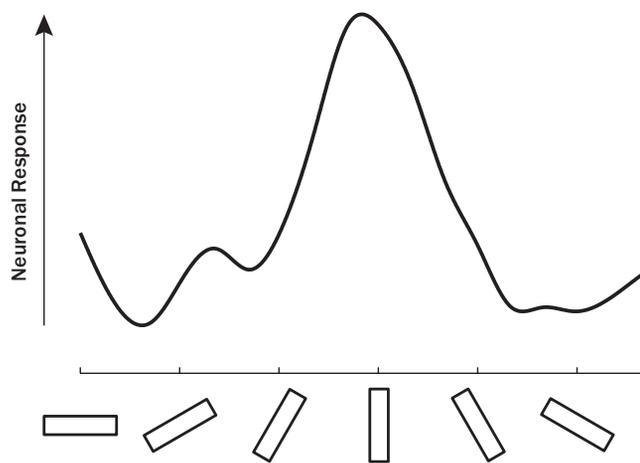
the clock. They had been studying the neuron for nine hours straight.

The primary visual cortex's secret fascination with orientation was the first of many groundbreaking discoveries that Hubel and Wiesel coaxed from the brain—for which they won the Nobel Prize in Physiology or Medicine in 1981. From this original finding, Hubel, Wiesel and others went on to discover cortical neurons that favored other specific attributes of the visual world, such as preference for specific colors, direction of motion, and even specific objects, such as hands and faces.

In memory of our dear friend and mentor, David Hubel, who died in Sep-

tember 2013 at the age of 87, we show some of the most beautiful and interesting perceptual implications of Hubel and Wiesel's initial breakthrough. **M**

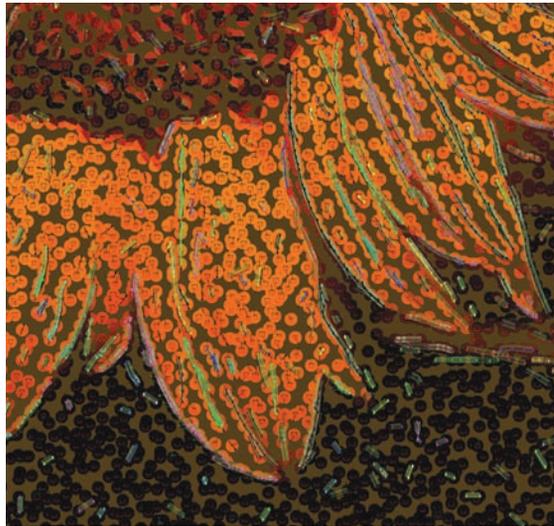
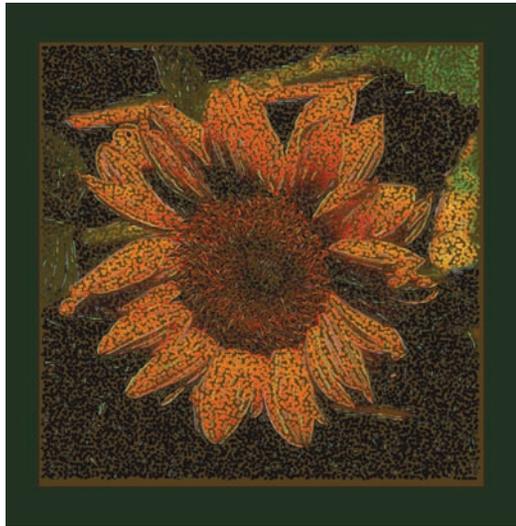
SUSANA MARTINEZ-CONDE and STEPHEN L. MACKNIK are laboratory directors at the Barrow Neurological Institute in Phoenix. They serve on *Scientific American Mind's* board of advisers and are authors of *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions*, with Sandra Blakelee, which recently won the Prisma Prize for Best Science Book of the Year (<http://sleights ofmind.com>). Their forthcoming book, *Champions of Illusion*, will be published by Scientific American/Farrar, Straus and Giroux.



THE SCIENCE OF ORIENTATION SELECTIVITY

Hubel and Wiesel found that whereas retinal neurons preferred dots, an otherwise quiescent cortical neuron would respond vigorously if and only if a straight line, oriented at just the right angle (say, 12 o'clock), was swept across the appropriate location on the retina. The graph shows a cortical neuron's responses (in the form of neuronal impulses, also called action potentials) to bars of different orientations. For this particular neuron, a vertically oriented bar elicited the strongest responses. From such findings, Hubel and Wiesel deduced that the higher a neuron is located in the brain's visual pathway—which stretches from the retina to the farthest regions of cortical tissue—the more complex the stimulus it responds to, for example, dots versus lines versus entire shapes. This type of hierarchy turned out to be fundamental to brain organization overall.

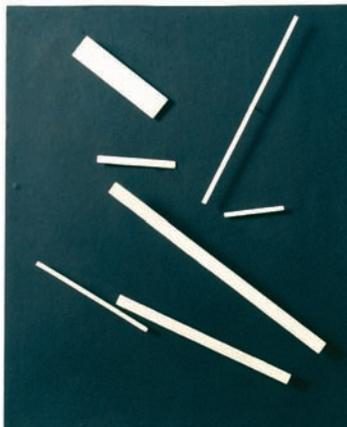
BRYAN CHRISTIE (brain); MACKNIK LABORATORY, BARROW NEUROLOGICAL INSTITUTE (graph)



THE ART OF ORIENTATION SELECTIVITY

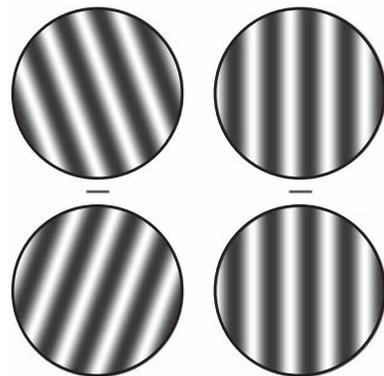
In the 19th century artists such as Georges Seurat and Camille Pissarro pioneered a new kind of painting called pointillism in which many carefully placed dots of color collectively form an image. Many decades later Norbert Krüger and Florentin Wörgötter created a type of digital art modeled on pointillism. This sunflower (left) is an example. Thousands of your orientation-selective visual neurons work in tandem to help your brain form a picture of the flower's contours. A close-up view (right) reveals how visual

neurons in the cortex extract orientation information from the image. Each symbol represents the region of the image "seen" by one simulated neuron in the primary visual cortex. The color, lines and arrows in each dot represent the preferences of the activated neuron, based on Hubel and Wiesel's discoveries. The outputs of this neuronal network feed into downstream neurons that respond to increasingly complex shapes and eventually "see" the big picture—in this case, a sunflower.



CORTICAL PHYSIOLOGY IN THE ART MUSEUM

Lines, rectangles and other elongated solid shapes with varying orientations feature prominently in the minimalist art of Kazimir Malevich (left) and Jean Tinguely (right). One reason these creations are so arresting, says visual neuroscientist Semir Zeki of University College London, is that they make our primary visual cortical neurons fire like crazy.



AN ORIENTATION ILLUSION

Notice that the line gratings on the left are oblique, whereas the line gratings on the right are vertical. Stare at the short horizontal line between the gratings on the left for at least 30 seconds, then quickly move your gaze to the short line between the gratings on the right circles now appear to lean. This occurs because different populations of visual cortical neurons are sensitive to different orientations. When your neurons look at oriented lines for a long enough time, the corresponding cortical detectors become less responsive than those that are tuned to different orientations—a process called adaptation.

FURTHER READING

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- **Brain and Visual Perception: The Story of a 25-Year Collaboration.** D. H. Hubel and T. Wiesel. Oxford University Press, 2004.
- **Symbolic Pointillism: Computer Art Motivated by Human Brain Structures.** Norbert Krüger and Florentin Wörgötter in *Leonardo*, Vol. 38, No. 4, pages 337–340; 2005.

COURTESY OF NORBERT KRÜGER (sunflower); GETTY IMAGES (Malevich); MÉTA-MALEVICH, 1954, © 2013 PROLITTERIS, MUSEUM TINGUELY, PHOTOGRAPH BY CHRISTIAN BAUR (Tinguely); JIE CUI Martinez-Conde Laboratory, Barrow Neurological Institute (lines in circles)