Why do Monet’s poppies stir in the breeze? Why does Mona Lisa’s smile disappear, then reappear, as our gaze shifts? A neurophysiologist reflects on how our visual processing system affects our perceptions of art.

by Margaret Livingstone

When the art critic Louis Leroy attended a new Paris show in the spring of 1874, he expected to see “the kind of painting one sees everywhere, rather bad than good, but not hostile to good artistic manners.” Instead, he found a “hair-raising exhibition” whose nadir was Claude Monet’s Impression, Sunrise. Leroy pronounced the seascape “at once vague and brutal” and “worse than anyone has hitherto dared to paint.” Despite his revulsion—and that of many of his contemporaries—history has acknowledged this painting from Leroy’s sneering review came the name for the art movement Impressionism. But what made Leroy object so fervently?

The answer may lie in part with the painting’s luminance, or perceived lightness. The elements of visual art have long
Most people are comfortable talking about color. Yet luminance, even though it is more fundamental, is dimly understood.

The luminance system, which is evolutionarily older than all mammals, the parts of the brain that process color information are present only in primates. That is probably why the most primitive visual information about a scene is found in variations of luminance. It does not matter which color is used to convey the luminance signal, because the parts of our brains that analyze the most basic features of a scene are, quite literally, colorblind.

On a gross level, the visual system is a single pathway in the brain. On a finer scale, however, this pathway consists of two major subdivisions. The evolutionarily older large-cell subdivision is responsible for our perception of motion, space, position, depth, figure-ground segregation, and the overall organization of the visual scene. This subdivision is called the “Where” system. The small-cell subdivision is the one that is well developed only in primates and is responsible for our ability to recognize objects, including faces, in color and in complex detail. This newer system is called the “What” system.

The “Where” and “What” systems differ not only in the kind of information they extract from the environment, but also in how they process light signals. The “Where” system is colorblind, the “What” system carries color information about the world. The “Where” system has a much higher sensitivity to small differences in brightness. It is also faster and more transient in its responses and has a slightly lower acuity, or resolution. In the retina, thalamus, and early cortical areas, the “Where” and “What” systems are physically interdigitated, yet they keep the information they process largely separate. At higher levels, the two subdivisions become even more spatially segregated.

Evolution likely accounts for these subdivided visual tasks. The “Where” system in humans and other primates resembles the entire visual system of lower mammals. These animals are much more sensitive to color than we are, and they cannot perceive color information, whereas humans can. Instead, they are sensitive to objects in motion, because things that move—whether prey or predator—are likely to be important.

Also, because the primitive visual system must have been used to navigate through three-dimensional environments, it had to have been able to process depth information and distinguish objects from their backgrounds. As the more complicated primate visual system evolved, the original system was maintained, probably because it was simpler to overlay color vision and object recognition onto the existing system rather than having to build a new visual system from scratch.

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Rembrandt created another illusion by painting the philosopher’s head on a darker background and the crosspiece of the window frame on a lighter background. The head thus appears relatively light and the window frame relatively dark, even though the head is darker than the frame. We cannot easily perceive the differences in the backgrounds because they meld gradually into one another. By using a combination of grad- ual background changes and local abrupt changes in luminance, Rembrandt simulated a much larger range of luminances than his pigments could supply. Over the centuries, artists continued to increase their command of luminance to enhance their ability to represent depth on a two-dimensional canvas. This trend toward representationalism reached a pinnacle in the early nineteenth century with the work of Jean-Auguste- Dominique Ingres, whose paintings have an amazingly photographic quality. Art historians have suggested that Ingres must have used a camera lucida or other optical aid to project an image of the scene onto the canvas or drawing tablet, so unaccountably does he capture the gradations of luminance in his subjects. Then, toward the end of the nine- teenth century, the Impressionists aligned themselves against the representa- tional style of art epitomized in the work of Ingres. Some experimented with color and luminance, sometimes using unrealistic color gradations or abandon- ing luminance differences entirely.

Still Lifes in Motion

One of the Impressionists’ most novel accomplishments is the shimmering, alive quality they achieved in many of their paintings. The sensation of move- ment in Impression Sunrise—and some of Louis Leroy’s disdain for the painting—stemmed in part from Monet’s use of quick dabs of paint, which required the viewer’s eye to blend the colors. “Wall paper in its original state is more finished than this seascape!” Leroy groused.

And yet it is clear that some of the color combinations the Impressionists used have so little luminance contrast that they create the illusion of motion. We perceive illusory motion in images made from equiluminant colors for the same reason we don’t see appropriate depth in these images: our Where sys- tem can’t distinguish between equilumi- nant colors. Therefore if an image is composed of equiluminant colors, our What system can see those objects, but our Where system—which is responsi- ble for our ability to see medium and position, as well as depth—cannot reg- ister their position and stability, so they can seem to jitter.

Monet’s The Poppy Field Outside of Argen- tueil is a good example of this illusion. The red of the flowers is nearly equiluminant with the green of the grass and the skirt of the woman in the foreground. Our color-selective What system can easily distinguish the poppies and the skirt from the grass. But the colors, although bright, do not have enough luminance contrast for our Where system to see them. Their position seems uncertain, giving them an illusory instability. They can seem to move, as if stirred by a breeze.

Our eyes can be similarly tricked by repetitive high contrast lines, which tend to create motion perpendicular to their own orientation. Light shining through horizontal venetian blinds, for example, will induce the appearance of vertical motion on an adjacent wall, a pheno- menon known as the McKay illusion.

An extreme example of this illusion is Lisa Levine’s Enigma. The juxtaposition of luminance-contrast borders with areas of equiluminance can cause the illusion of motion; after looking at Enigma for a minute or so, the viewer should notice a streaming effect in the colored circles. The streaming always moves perpendicu- larly to the high-contrast lines, which induce it. We do not yet understand why a large field of high contrast lines induces an illusion of motion. Some of Monet’s paintings likely induce a mild form of this deformation to help create their illusory sense of movement.

Art Mystery

Five hundred years after Mona Lisa sat for Leonardo da Vinci, we’re still trying to understand what makes her painted image so lifelike. She seems to smile until you look at her mouth, then her smile fades, like a clim star that disappears as soon as you gaze directly at it. One popu- lar idea is that Leonardo used sfumato—a technique of subtly blurring sharp out- lines—to make her expression ambigu- ous. That hypothesis would mean that her smile would vary depending on the viewer’s imagination or state of mind, but its variability is more systematic than that. While looking at the painting one day, I noticed that Mona Lisa’s expression changed according to how far the center of my gaze strayed from her mouth. These systematic transformations suggested that her lifelike quality was not so mister- rious after all. Her smile, I realized, is dif- ferentially apparent in different parts of our visual field.

To understand how Mona Lisa’s smile would look at a range of eccentricities, I processed images of her face to reveal its fine, medium, and coarse components. A clear smile is more apparent in the coarse and medium components of the image than in the fine detail image. This means that if the center of your gaze falls on the background or on Mona Lisa’s hands, her mouth—which is then seen by your peripheral, low-resolution vision—appears cheerful. When you look direct- ly at her mouth, your high resolution foveal vision sees details that take away the grin. This explains the elusive quality of her expression: you literally can’t catch her smile by looking at her mouth.

The spatial impression of our periph- eral vision has interesting implications for our perception of some Impressionist paintings, too. In Monet’s Rue Montorgueil in Paris, Festival of June 30, 1873, for example, details are spatially jumbled. If you look carefully at the flags just to the left or right of the center of Rue Montorgueil you can see that the blue, white, and red brushstrokes, representing the stripes of the tricolored flags of France, are not always well-aligned or even adjacent to one another. This spatial impression differs from a simple blurring: it mimics the spatial impression in our peripheral visual field.

Our peripheral vision occasionally makes erroneous correlations between objects seen and objects known to exist. This phenomenon, called illusory con- junction, occurs when items are present- ed either peripherally or transiently. The flags along the Rue Montorgueil look fine when you first glance at the paint- ing, but not if you look directly at them, or after you study those parts specifica- ly. The painting’s spatial impression is
Artists must learn to see luminance gradation and to evaluate even then, they often find it impossible to duplicate those luminance independent of color. luminance ranges with pigments.

LOOSE LIPS: Mona Lisa’s expression depending on how far the viewer’s center of gaze is from her mouth. A clear smile is more evident on her face in details that show the course and medium image components (left and center) than in the one that shows only fine details (right).

not immediately noticeable because our own spatial impression allows illusory conjunctions to complete the objects. That explains why we see complete flags, even though many of them are just single strokes of paint.

Low spatial precision can lend vitality to a painting, because our visual system fills in the picture differently with each glance. It also gives the painting a transient feel because such impression

is compatible with a single glance, a fleeting moment in time. Because of the low spatial resolution of peripheral vision, we cannot take in a detailed percept of the entire scene in a single glance; we see clearly only the part of the scene that our center of gaze happens to light on. “The visual sensation that imprints itself on the retina lasts but a second, or even less,” wrote Impressionist painter Gustave Caillebotte, a master of the art of capturing a fleeting moment. “That’s the impression that we had to pursue.”

By comparison, Nicolas Poussin’s highly detailed, action-packed Rape of the Sabine Women looks relatively static, because we can see hundreds of details. Seeing so many details is incompatible with the transience of the incident depicted—by the time our eyes move from one act of savagery to another, the scene should have changed. The longer you look, the colder and more frozen the figures in the painting seem.

In the Shade

When a light source illuminates a three-dimensional object, different parts of the object’s surface reflect different amounts of light, depending on the angle of the light hitting them. We see these differences as changes in luminance, or shading, which is another depth cue that, like perspective, artists must learn to render. To use shading effectively, artists have to surmount several challenges. They must learn to see luminance gradation and to evaluate luminance independent of color. Even then, they often fail to duplicate those luminance ranges with pigments because of the limited range of reductances available even with the best paints. The range of luminances in a given scene is almost always far greater than the array of values an artist can achieve using pigments. Inside a typical room, for example, luminances vary widely: a light source, such as a window or lamp, might be hundreds of times brighter than the shadowed region under a desk. The luminance in outdoor scenes usually varies by a factor of a thousand.

We know that luminance contrast, not color, is necessary for depth perception. A corollary of this principle is that, as long as you have the appropriate luminance contrast, you can use any hue you want and still portray a shape in three dimensions with shading. In Henri Matisse’s La Faimme au Château, for example, the shadows and most of the planes of the subject’s face are peculiar colors. Although it is difficult to imagine what kind of lighting would cast blue and mauve shadows, the three-dimensional shape of the woman’s face does not seem unnatural because the patches of bizarre colors have the correct relative luminance to represent planes and shadows. Matisse himself explained, “While following the impression produced on me by a face, I have tried not to stray from the anatomical structure.”

Matisse had discovered that he could use any hue and still portray the three-dimensional shape he wanted as long as the luminance was appropriate. The art collector Leo Stein, who eventually bought the painting, wrote, “It was a tremendous effort on his part, a thing brilliant and powerful, but the nastiest smear of paint I had ever seen.”

A Double Take

Although late Renaissance painters attained a photographically realistic use of perspective and shading, those techniques alone could not convey to the viewer an authentic feeling of three-dimensionality. No matter how convincingly an artist renders shading and perspective, two other important cues—stereopsis and relative motion—inform the viewer’s brain that the painting is, in fact, flat.

Since our two eyes view the world from slightly different positions, the images on the two retinas differ slightly. Stereopsis is the ability of our visual system to interpret the disparity between the two images as depth. A stereo, a device popular in the mid-twentieth century, presented two slightly different pictures, one to each eye, to give a vivid sense of depth. The View-Masters many of us enjoyed as children also work on this principle, showing three-dimensional images of pterodactyls, volcanoes, and Donald Duck.

The same principle explains that codes stereopsis codes depth from relative motion, so movements as small as the distance between our eyes are large enough to produce a strong depth signal. We glean information about distance from the relative motion of objects as we move past them. When you walk down a street at night, for example, the objects close to you, such as the trees along the sidewalk, seem to pass more quickly than the houses or trees farther away. Those at even greater distances, such as the moon, seem stationary.

We also pick up relative movement cues from the small head motions we make even when we stand still in front of a painting. No matter how skillfully the artist conveys depth through the use of perspective and shading, because the images in our two eyes are identical and because there is no relative movement between objects in the painting, our brains register the painting as flat.

The Impressionists found multiple ways to trick our brains, though. In most Impressionist paintings, cues such as perspective or shading, rendered in luminance contrast, convey a sense of depth. The blurriness and deliberate lack of details characteristic of many Impressionist paintings also contribute to a sense of three-dimensionality. To see stereoscopic depth, the image needs to

UNFLAGGING ENERGY: The spatial impression in Monet’s Rue Montorgueil depicts a great deal of action, yet it seems more static than Monet’s Rue Montorgueil, because our visual system cannot register so many details at once.

FREEZE FRAME: Nicolas Poussin’s The Rape of the Sabine Women depicts a great deal of action, yet it seems more static than Monet’s Rue Montorgueil, because our visual system cannot register so many details at once.
be detailed enough to allow us to detect the slight differences between our two eyes’ images. By eliminating some spatial details and blurring others, an artist can hinder stereopsis from revealing the flatness of the image. This allows other depth cues in the painting, such as shading and perspective, to produce a more powerful signal because they are not as strongly contradicted by stereopsis.

The notable ability of some Impressionist and Post-Impressionist paintings to invoke an illusion of depth, can be explained in terms of atmosphere, also allows an illusion of distance, because of the semipermanent patterns of the flags. Ironically, this effect goes beyond what realism could achieve—short of making two slightly different paintings and using stereo viewers—to generate a sense of depth.

The sense of atmosphere is particularly striking in Pierre-Auguste Renoir’s A Girl Gathering Flowers. The dabs of paint can be mismatched in the images in our two eyes, giving the painting an illusory sense of a three-dimensional volume filled with small floating elements, such as flower petals, insects, and pollen.

**Vision Quest**

The ways in which we process color and luminance hold ramiﬁcations for more than paintings; they also affect our perceptions of television, computer graphics, photography, color printing, and movies. These technologies are all flat, like paintings, so they use the same kinds of cues—perspective, shading, and occlusion—to give an illusory sense of depth. They also have the same problem as paintings in that our stereopsis registers the images as ﬂat.

But movies and television have the potential for a powerful additional depth cue—relational motion. If you close one eye and gaze steadily at, say, the edge of this magazine, you may ﬁnd that it does not seem clearly in front of background objects. But by moving your head slightly from side to side you can make it jump back into proper apparent depth. That is because relative motion of objects at different distances is a strong cue to their distance from the observer. Relative motion of objects in movies and television can be a powerful cue to depth and can even induce an illusion of being propelled through space. Who didn’t have to grip their seat the ﬁrst time they saw the opening credits for Star Wars?

**HAD TRICK:** Despite its odd colors, the shape of the woman’s face in Matthew’s La Femme au Chapiteau seems central because the relative luminance of the pigments is appropriate, even if the hues are not.

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he higher levels of the “Where” system are located above the ears, in the parietal lobe, and the higher levels of the “What” system are located in front of the ears, in the temporal lobe. Because these areas are distinct, people can experience damage—from stroke or injury—to one system without the other being at all affected. When the Where system is damaged, people have trouble locating objects; they have difﬁculty perceiving motion and depth, distinguishing right from left, and seeing complex objects in their entirety. Much of our knowledge of the function of the Where system comes from neurological studies of people who have sustained damage to the parietal lobe, such as Zaselsky, a Russian soldier who sufﬁered a bullet wound to his left parietal area during World War II. After his injury, Zaselsky described his vision as being severely disorganized and spatially fractured, though his recognition of individual objects was unimpaired. He had trouble gauging objects that he could plainly see because they would turn out to be on one side or the other of where he perceived them to be. He could not tell right from left, and he could see only one small part of an object or a scene at a time. His world would “glitter ﬁtfully and become displaced, making everything appear as if it were in a state of ﬂux.”

The neurologist Zeki has described a stroke victim whose world, unlike Zaselsky’s fragmented universe, appeared strangely static. Bilateral damage to her parietal lobe had affected her motion perception. She found herself in danger crossing streets because she could not perceive the rising level of the tea in the cup. She found herself in danger crossing streets because she could not perceive the rising level of the tea in the cup. The process of object recognition must also be further subdivided, because strokes can occasionally result in uncommonly speciﬁc losses of object recognition abilities. Some patients retain a capacity to recognize living things only, for example, or lose their ability to iden-

**Brain Teaser**

**LIFE’S A STRUGGLE:** In 2001, the art historian and photographer Joan Mertens wrote an essay for The New York Times Magazine about the experiences of her husband, who had suffered a stroke, which led to a loss of visual perception. Here are some of her observations: “I can see the eyes, nose, and mouth quite clearly, but they just don’t add up.” At his social club one day the stroke victim noticed that a stranger kept staring at him; when he finally asked the steward who the demented bloke was, he learned that he had spent the afternoon gazing at him himself in a mirror.

REPRODUCTION ISSUES: As part of a vision test, Oliver Stacks asked two of his patients to try to reproduce the image in the left panel. The center panel shows a reproduction made by a red/green colorblind person; the right panel shows a reproduction made by a man with a lesion in the color processing part of his brain. The perception and drawing ability of the man with the lesion were intact, but his color perception was worse. He was much more profoundly colorblind than the red/green colorblind patient.