Visual illusions and perception

2005 McGraw-Hill Yearbook of Science and Technology

Donald D. Hoffman

Department of Cognitive Science

University of California, Irvine, 92697

To the casual observer visual illusions may appear to be mere curiosities, amusing tricks for the eye concocted by clever artists. But, to the serious student of perception, visual illusions reveal important secrets.

Vision seems effortless: We simply open our eyes and see the world as it is. This apparent ease is itself an illusion. Tens of billions of neurons, and trillions of synapses, labor together in the simple act of opening our eyes and looking. Visual illusions, far from being mere parlor tricks, allow researchers to peer inside this complexity and discover what all these neurons are doing.

What they reveal is surprising. Most of us assume that our vision is much like a camera, simply taking snapshots or movies, and providing an objective report of what is around us. Visual illusions, and the research that builds on them, reveal that vision does not report objective truth but instead weaves elaborate interpretations based on sophisticated detective work. Vision is more like Sherlock Holmes than movie cameras. Certainly the eye itself is a miniature camera, focusing an image on its retina at the back of the eye. But this retina is composed of hundreds of millions of neurons performing sophisticated operations, and the signals they send to the brain engage a network of billions of neurons. This is where vision really takes place, and where the sophisticated detective work swiftly and expertly proceeds. So swiftly and so expertly that one can hardly be faulted for missing it. Once we catch on, however, it's natural to wonder, like Watson, how Holmes pulls it off. What clues did he use? What train of reasoning? We want Holmes to reveal all, to tell us, "Elementary my dear Watson, I noticed this and reasoned thus." This is the role of visual illusions in vision research, to reveal the clues and trains of reasoning that spawn our vision of the world.

Why should it be so? Why should vision proceed by collecting clues and assembling sophisticated chains of reasoning? Why not simply look at what's there and be done with it?

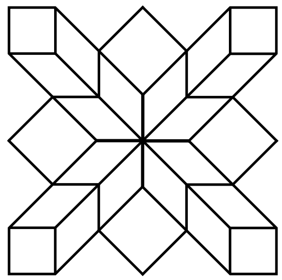
The reason is simple. Each eye has about 120 million photoreceptors, little cells specialized to catch particles of light called photons. The eye does not, and cannot, record shapes, depths, objects, colors, edges, motions and all the other features of our visual world that we take for granted. It records only one thing: How many photons did this photoreceptor catch? How many did that photoreceptor catch? And so on, for 120 million photoreceptors. The eye records the numbers of photoreceptor catches at each of 120 million locations, and how these numbers vary with time. But we don't really care about photoreceptor catches, we care about objects and depths and colors. And since that is what we care about, that is what we must construct from the clues hidden in a haystack of 120 million numbers. This becomes painfully obvious once one tries to build a computer vision system that sees objects and depth. The input to the computer comes from an attached video camera, and all this camera provides is a list of numbers that say, in effect, “It’s this bright at this point in the image, and it’s that bright at that point in the image, . . .” and so tediously on and on for each point of the millions of points of the image. That’s all you have to start with. The job is to find objects and three-dimensional shapes. It becomes clear that the only way to find them is to construct them. That’s what takes many megabytes of software to do in computer vision systems, and that’s what takes billions of neurons and trillions of synapses to do in the human brain.

It is because we must construct our visual world from such sparse clues that visual illusions are possible and, indeed, inevitable. Construction involves risk. The clues available do not, in general, dictate a single construction that is logically guaranteed to be correct. When our visual system decides to interpret the available clues in a certain way, it necessarily makes assumptions that may prove to be false. If they do prove false we have an illusion. This illusion becomes an important clue to the assumptions that, in this case, led the visual system astray. We’re finding out what makes Holmes brilliant by paying close attention to his mistakes. His mistakes may tell us what clues he focused upon and what assumptions he made in reasoning from them. Normally he does an excellent job, and normally his assumptions are warranted. But when they fail, we can often see them more clearly than when they work. A successful magician is hard to figure out; on those rare occasions, however, when the sleight of hand fails, the trick is more readily revealed.

It is in this spirit, then, that researchers study visual illusions. Not as amusing diversions, but as particularly insightful guides to the invisible machinations of the visual system.

What have they told us? A central insight to emerge from the study of illusions is that our visual constructions rely on sophisticated probabilistic reasoning. Now many of us discovered in school that probability theory is not easy, and often runs counter to our untutored intuitions. So it may be surprising to find that there is a part of you, namely your visual system, that is quite at home with probabilistic reasoning.

As an example, consider the "trading towers" illusion:



Trading Towers Illusion.

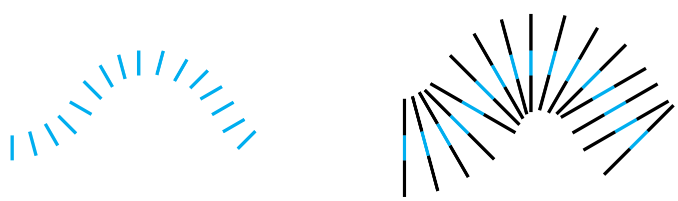
We see this as a three-dimensional shape with four tall, rectangular towers poking up. Then it sometimes switches, and we see four shorter towers poking up. It switches rapidly between these interpretations, and leaves the visual system a bit unsettled.

There are a couple points to observe about this illusion. First, we see it as a three-dimensional shape, even though it is a flat figure printed on the page. The visual system falsely fabricates a three-dimensional shape, despite your knowledge that it should be seen as flat. The reason is that the image at your eye has only two dimensions. Therefore your visual system must fabricate all the depth that you ever see. Once your visual system has evidence that it deems to warrant a three-dimensional interpretation, it fabricates that interpretation and doesn't usually listen to other parts of the brain that may want to contradict it.

Second, notice that you see the various lines in the figure as straight lines in space in your three-dimensional interpretation. The edges of the towers, for instance, look perfectly straight. Your visual system has a rule that says, in effect, "Always interpret a straight line in an image as a straight line in three-dimensional space." The reason for this rule is probabilistic. Suppose you see what looks like a straight line. It is conceivable, even though the curve in three-dimensional space that you are viewing looks straight, that in fact it is wiggly. The wiggles would have to be precisely directed along your line of sight to make this happen. In this case, if you moved your head slightly to get a different view of the curve, suddenly the wiggles would become visible. Only from just the right viewpoint would the wiggles disappear and the curve look perfectly straight. It is highly unlikely, reasons the visual system (unconsciously), that you happen to be looking from just the right viewpoint to make the wiggles disappear. Therefore, it is highly likely that there are, in fact, no wiggles. And this leads to the rule that straight lines in an image must be interpreted as straight lines in three-dimensional space. In this case it is probabilistic considerations that dictate the rule of visual construction. Using these same kinds of probabilistic ideas one can also show that if two lines in an image terminate at precisely the same point to form a corner, then the visual system must interpret the two lines as also meeting to form a corner in three dimensions. For if the lines did not meet in three dimensions, but just happened to look like they meet from one's current viewpoint, then any slight change in viewpoint would make them no longer look like they meet. This kind of probabilistic reasoning is known as the "generic views principle" among vision researchers, and it has proved a powerful method for understanding visual processes and the illusions they can engender.

The rules of construction in vision are usually not inviolable. Instead, different rules interact, sometimes overriding each other in the process of coming to an interpretation. The trading towers illusion also demonstrates this point. At the central point of the figure, the lines comprising the three-dimensional interpretation appear to bend sharply, in contradiction to the rule that straight lines in an image should be seen as straight lines in three-dimensional space. Other rules of construction prompt the visual system to violate this rule at this one point. But the violation is unsettling, and leads to the constant switching of interpretations we experience when viewing this figure.

Similar probabilistic considerations explain why you see a glowing blue worm in the figure below on the right, but not on the left. If you look carefully on the right you will see that the glowing blue you see between the lines is entirely your construction, and not literally printed on the page.



The neon worm.

Using examples like these, and probabilistic reasoning along the lines sketched here, vision researchers are discovering the clues and chains of reasoning used by the visual system to create our visual worlds. The magician is beginning to betray her secrets.

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