Living in The MATRIX:

Can we sense the real world, or are we living in our brain's imagination?

By Ashish Agrawal

What if the things we were seeing, hearing, touching, tasting, and smelling weren't actually as they seemed? What if what we perceived wasn't the same as reality? It sounds like a re-run of *The Matrix*, but it's true of our everyday life. Because of the way our brain processes reality, what we sense may not be exactly what exists.

In this issue of the *Harvard Science Review*, the feature articles examine how our human senses help us perceive reality. However, this article will remind us that in many cases, our senses distort reality. Our brain does not sense; it processes. Anyone who has ever watched TV or seen a ventriloquist realizes that senses are misleading. The speakers on a TV, for example, produce sound from the side of the image, not from the image itself. Yet, when we watch TV, we "hear" the sound as if it was coming directly from the character's mouth. Our brain, realizing that voices do not naturally come out of boxes, "corrects" our perception so that we hear voices come from the closest available person. This same effect is true of ventriloquists. A ventriloquist who can throw his voice but who performs without a puppet is not very convincing; our brain realizes that the sound is coming from the person and corrects for it, despite the intended illusion. However, by animating an object and by making us believe that it is capable of speaking, a ventriloquist can throw his voice and convince us that the puppet is actually speaking.

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So, what do we actually sense that is "real?" Is our reality the same as the reality for other species? Is our reality even the same as that of other humans'? By exploring issues of illusions, perception, and artificial reality, we can understand a little more about what we sense and what is real.

Illusions: Tricking our brain's processing mechanism

As anyone who has gone to see a magic show realizes, things are often not as simple as they may seem. A magician's entire livelihood is based around his ability to make people perceive a reality that doesn't exist, and that makes magic a useful tool to study how our brain processes the world. Gustav Kuhn, a cognitive psychologist and researcher at the University of Durham in England, studies magic tricks to determine how our brain processes information to produce a world view that often conflicts with reality (1).

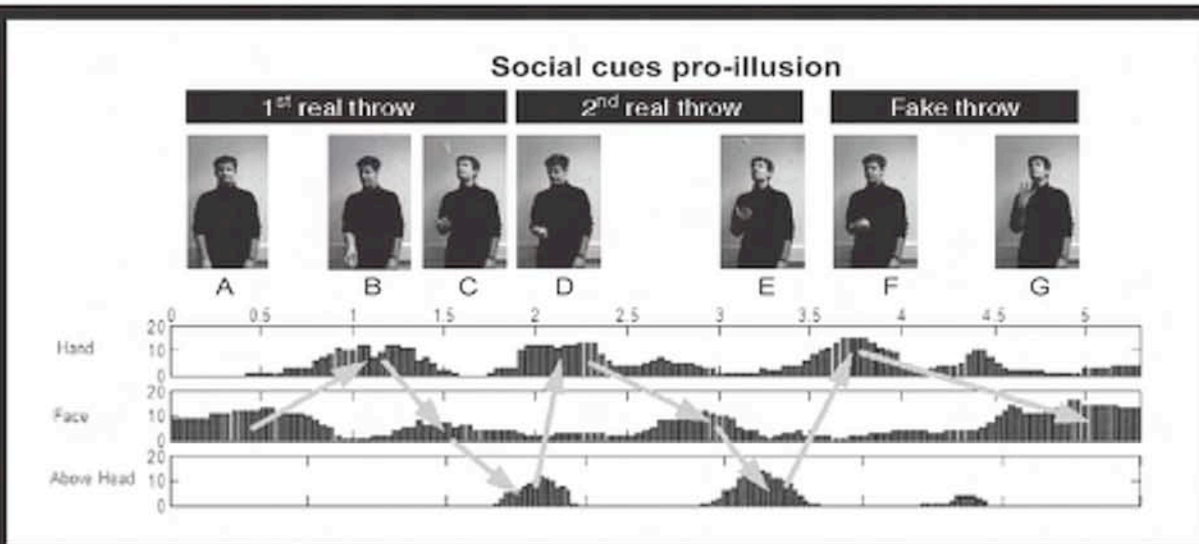

Figure 1: This figure shows Kuhn's analysis of the vanishing ball illusion. The top half of the figure shows pictures of the magician performing the illusion. The bottom half tracks the observer's eye movements throughout the performance. For the first two throws (sections A-E), the eyes track the ball through the hand, face, and above the head. In the false throw, however, the eye is not fooled; it does not track the false ball into the air. Instead, it watches the face of the performer. The social cues from the magician are processed by the observer's brain and used to create the visual illusion. (2)

credit: Kuhn, G. and Land, M.F. "There's more to magic than meets the eye." Curr. Biol. 16.22 (2006): R950-951.

"So, what do we actually sense that is "real?" Is our reality the same as other species' reality? Is our reality the same as other humans' reality? And how can we harness this in new technology to improve our daily life? By exploring issues of illusions, perception, and artificial reality, we can understand a little more about what we sense and what is real."

In a recent paper, Kuhn studied a trick known as the vanishing ball illusion, a trick in which a magician appears to throw a colorful ball vertically in the air three times (2). The third time, however, the ball appears to vanish at the top of its trajectory. How does the trick work? The first two times, the magician throws the ball in the air normally and catches it on its way down. The third time, however, the magician retains the ball in his hand as he makes the motion of throwing the ball in the air and follows the imaginary ball's trajectory with his eyes. Yet, if the ball wasn't actually thrown the third time, why do spectators swear that they saw the ball fly in the air before disappearing?

Kuhn attempted to solve this question by tracking the eye movements of his human subjects while they watched a video of this magic trick. He found that during the first few throws of the ball, the eye movements of his spectators were consistent. When the ball was actually thrown in the air, eyes would start by tracking the ball in the magician's hand, then the magician's face, then the area above the magician's head where the ball was located. In the final "fake" throw, however, the pattern changed; eyes followed the hand, then moved to the face, but they tended not to look above the magician's head (2). In other words, the spectator's eyes realized that the ball had not been thrown, so they never actually looked at the spot where the imaginary ball would have been. Instead, they spectator's eyes remained fixated on the magician's face.

So if the eyes were not fooled by this magician's illusion, why was the brain? Kuhn predicted that the brain saw the magician's reaction, and assumed that since the magician's eyes looked upwards to the sky, there must be an object there. Indeed, when Kuhn did the experiment again but used a video where the magician kept his gaze at his hand on the third throw, where the ball was retained, the illusion was much less convincing (2). The social cues of an action, and not the information from our senses, affected how individuals perceived the world.

Illusions are not always visual, they can be tactile as well; in 1896, T. Thunberg unveiled the thermal grill, a device about the size of one's palm containing alternating metal rods, each which could be controlled individually and set to a different temperature. Thunberg found that if he set all the rods to 20 degrees Celsius and had someone hold

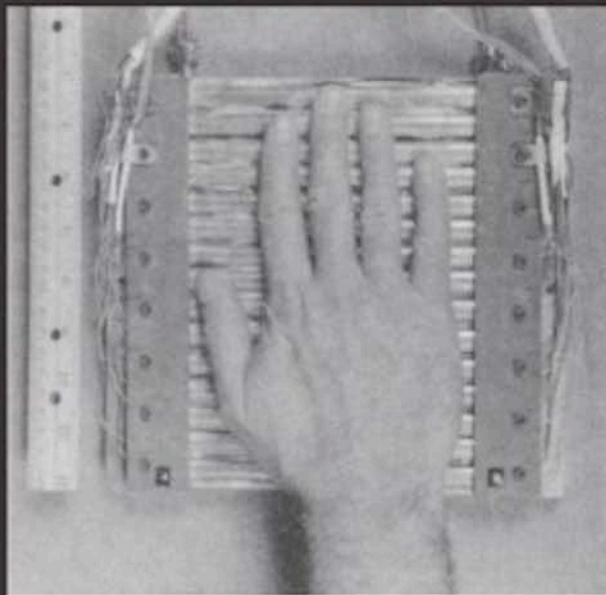

Figure 2: Thunberg's thermal grill is a device the size of one's hand that has alternating independently controlled thermal bars. (5)

credit: Craig, A.D. "How do you feel? Interoception: the sense of physiological condition of the body." Nat. Rev. Neuroscience 3 (2002): 655-666.

their hand to the grill, they would feel a cool but not painful sensation. He also found that if he set all the rods to 40 degrees Celsius and again had someone hold their hand to the grill, they would feel a warm but not painful sensation. However, if Thunberg alternated the rods so that every even numbered rod was 20 degrees Celsius and every odd numbered rod was 40 degrees Celsius then the subject would feel strong painful sensation, much like the pain that one feels if they douse their hand in ice water (3,4).

Why again do our sensations differ even if the objective reality (like the temperature of each individual rod) is the same? This illusion works because our brain is wired to detect contrasting signals more than stand-alone signals. When the cold in the thermal grill is associated with mild warmth, the brain treats it as a colder signal than it actually is. The exact mechanism and neuron map for this phenomenon is complex, but the principle is simple. There is one signal that activates a "painful cold" sensation, called the polymodal-C-nociceptors, that is activated whenever these receptors are exposed to cold (4,5). However, there is also another signal, this one centrally mediated, that inhibits the "painful cold" sensation. So, for example, when our subject puts his hand on the 20 degree thermal grill the "painful cold" receptor is activated, but so is the centrally mediated "painful cold inhibitor." If we were to put our hands in an ice bucket, then the "painful cold" receptor would be more active than the painful cold inhibitor, and we would feel pain. The Thunberg thermal grill illusion works because the cold bars activate the "painful cold" receptors, but the warm bars relieve the centrally mediated "painful cold inhibition" signal. The cold bars are not colder than before, but they feel more painful because the warmth from nearby bars turns off the inhibitor signal.

The human worldview: A collective experience?

If we are subject to our senses' interpretations of reality instead of actual reality, we can argue in many cases that different people can literally live in different worlds. For example, a person with hereditary red-green color blindness sees different images than a person with normal color vision (6). In some ways red-green color blindness is a disadvantage—some individuals have difficulty telling the difference between

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colors in a traffic light—but in other ways it is an advantage—some color blind individuals are more effective at spotting a person who is camouflaged into a background. In either case, two individuals perceive identical objects in the "real world" differently.

Individuals with strabismus also see a starkly different world than many of the rest of us. Strabismus is a condition where an individual's two eyes are not properly aligned, usually because of a weakness of the extra-ocular muscles or a deficiency in the part of the brain that controls the eyes (7). Since coordination between the two eyes is critical to depth perception, individuals with severe strabismus often see the world more 2-dimensionally. Interestingly enough, strabismus can be easily diagnosed even through a photograph. Because the eyes of an individual affected by strabismus are not aligned, a distinctive reflective skew from ambient light can be seen in the individual's eyes. Researchers have used photographs and self-portraits of famous artists, such as Rembrandt, to determine whether an unusual number of great artists suffered strabismus, and indeed found that was the case (7). It makes sense that individuals who see the world as more two-dimensional would be more effective at translating their world to a canvas. Thus, again we see that a person's senses can process a single objective reality into different subjective realities.

Twisting reality for our own personal gain: The role of technology

Now that we have begun to understand how the brain tricks us into accepting its version of reality, we have begun to devise ways to use this to our advantage. For example, usually when our brain tells us that something is sweet (such as desserts and candy), it is because that food contains a form of sugar. However, by realizing that sweetness is actually only a product of how the brain interprets sugar, we can attempt to synthesize a compound that can trick the brain. Aspartame—which was discovered in 1965 and goes by the brand name Nutrasweet—is a classic example (8). Though this molecule is a combination of the amino acids phenylalanine and aspartic acid, it tastes as sweet as sugar.

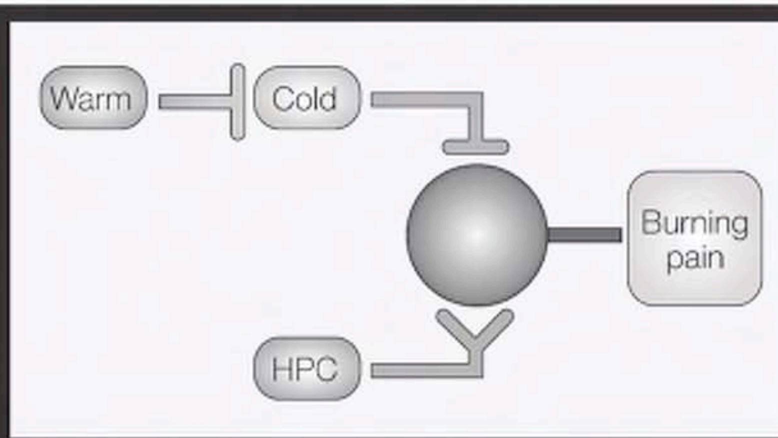

Figure 3: Thunberg's thermal grill illusion is explained by this map of neurons. Burning pain is activated by the "painful cold" neurons, called the polymodal-C-nociceptors, which is labeled HPC on this diagram. However, the painful cold neurons are inhibited by the "cold" neurons. Warmth eliminates the inhibitory "cold" neurons and unmasks the painful cold sensation, which leads to the thermal grill illusion.

credit: Craig, A.D. "How do you feel? Interoception: the sense of physiological condition of the body," Nat. Rev. Neuroscience 3 (2002): 655-666.

The prevailing theory for the biochemistry of sweetness is the multipoint attachment theory, which says that there are eight potential points of interaction with the sweetness receptor (9). Sugars, for example, are sweet because they attach to this receptor at multiple points. Synthetic sweeteners like aspartame simply have to do the same to mimic sweetness, whether or not the compounds are sugars themselves. Does this mean that we can call aspartame "sweet?" In humans, perhaps that is true, but mice, for example, do not taste aspartame at all because they possess slight different sweetness receptors than those of humans (10). We sense the phenomenon of sweetness in aspartame because that is how our brain has choosen to represent that chemical.

This is true of many chemicals, usually esters, used in manufacturing plants to synthesize various artificial tastes and smells. By distilling natural tastes into their chemical constituents, we can learn what gives a particular taste

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its distinctive character. Eventually, we can mimic nature's own chemicals to synthesize these tastes and smells in a laboratory without ever involving actual food. Octyl acetate, for example, is naturally present in oranges and gives the fruit part of its distinctive "orange" taste and smell. However, we can now synthesize "orange" without using an actual orange, simply by synthesizing octyl acetate (11). Despite its synthetic origin, our brain can be tricked into thinking that these chemicals, and the food with which they are mixed, taste just like the original. In some cases, even entirely new flavors can be synthesized in a lab. The taste of Juicy Fruit gum, for example, is not natural; it is a novel combination of flavors that cannot be found in nature.

Perhaps the most interesting, and least well-known, technological developments designed to manipulate our senses synthetically is the field of haptics, or the science of synthetic touch. Picture the Apple iPhone. One of the strongest criticisms of the iPhone since its release is that the touch screen, since it involves only virtual buttons, has no tactical feedback to tell you when you have successfully pressed a button. However, companies like Immersion have created a technology that could make using a digital keypad on an iPhone feel exactly like using a mechanical keypad (12). The secret to the technology lies in the careful programming of the "vibration" setting that is common to almost every modern cell phone. Through quick and precise vibrations, phones of the future may be able to convince our brain that we are clicking physical buttons, even when we are not.

Some might argue that haptic technology is a science of the future and not the present, but they could not be more wrong. Ever since the days of force feedback joysticks or Nintendo 64 Rumble Packs, haptic technology has been an important part of our day-to-day life. Even more sophisticated versions of these products have started appearing on shelves. In January 2007, the Novint Falcon, a 3-dimensional force feedback controller was presented at the yearly consumer electronics show (CES) in Las Vegas (13). This controller, in addition to providing realistic kickback in games such as Half-Life, allows the user to "feel" the texture and contours of virtual objects.

Haptic technology also has exciting applications for the medical field. As more and more surgeries become less invasive, usually through the use of robotics or laparoscopic surgery, physicians lose much of the tactile feedback present during more traditional surgical procedures. Recent research has discovered that adding haptic feedback to these new techniques can increase the accuracy and reduce the procedure time for common surgeries (14). This improvement has been measured in small controlled studies in neurological surgery and cardiac surgery, among many other fields (15, 16). Larger studies are in progress.

Conclusion

When we talk about "sensing reality," we realize now that what we perceive may not be what actually exists. Whether we are perplexed by visual or tactile illusions or medical conditions that influence how we see the world, the processing that occurs in our brain can distort our worldview. Recent technological developments, however, use these processing techniques to trick our brain, effectively taking advantage of the fact that we don't sense what actually exists. As these technologies allows us to taste, smell, see, touch, and hear things that are simulated or synthetic, it brings a whole new meaning to the old adage, "I'll believe it when I see [or sense] it for myself." H

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