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What explains subjective-contour illusions, those bright spots that are not really there?

by Jearl Walker

If you look at the illustration at the left below, scanning the entire pattern without fixing your gaze on a side of the broken triangle, you are likely to see an illusory opaque, white triangle that seems to hide parts of four black circles and an outlined triangle. The illusory triangle, which may take several seconds to appear, probably seems to be appreciably brighter than the white background. (You can sharpen the illusion by slipping a dark sheet of paper under the page to eliminate any interference from what is printed on the other side.)

The opaque triangle is an example of a class of illusions called subjective contours, which were first brought to popular attention in 1976 by Gaetano Kanizsa of the University of Trieste [see “Subjective Contours,” by Gaetano Kanizsa; SCIENTIFIC AMERICAN, April, 1976]. Variations of the patterns that produce illusory triangles are now known as Kanizsa triangles.

Why does the subjective triangle appear, and why is it brighter than the region surrounding it? These questions have resisted definitive answers for more than two decades in spite of the concentrated efforts of physical psychologists and workers in other disciplines. (Patterns that generate subjective contours are easy to construct, and you may want to try your hand at discovering new patterns or testing explanations of their origin.)

One early explanation involved the brightness contrast in the Kanizsa pattern. It maintained that because the corners of the white triangle contrast sharply with the incomplete black circles, the corners are perceived to be brighter than they really are and the brightness somehow spreads to affect the entire illusory triangle. That explanation was easily toppled. If the illusory triangle is outlined with a thin border so that the triangle is no longer subjective, the brightness disappears or at least is so weakened that it may not be noticed by a casual observer. Yet the brightness contrast is undiminished at the triangle’s corners. The brightness-contrast theory also fails because it does not explain why the rest of the white regions bordering the incomplete circles are not also brightened, even though they contrast just as sharply with the circles as the “wedges” cut out of the circles do.

Another early explanation dealt with the parts of the visual system that are responsible for detecting lines, edges and orientations. Could they interact in some way to bring about the illusion of a bright, completed triangle in Kanizsa’s pattern? As tempting as the explanation is, it fails to explain why subjective contours are sometimes more readily seen when the patterns are blurry or badly illuminated.

A different part of the visual system is assigned the task of detecting the repetition of such elements as lines, apparently through a process analogous to Fourier analysis. Might the analysis fill in enough extra lines to complete a subjective figure? Apparently the analysis cannot be the source of the illusion, because subjective contours have been produced in patterns that lack the repetition required to provoke such analysis.

In 1986 Stanley Coren of the University of British Columbia, Clare Porac of the University of Victoria and Leonard H. Theodor of York University reviewed and rejected such explanations, which implicate one or another physiological source. They supported instead a second class of explanations, involving cognitive processes. You might, for example, perceive a subjective triangle because your brain automatically searches for ways to fence in regions and thereby make sense of an initial-
ly strange pattern. Alternatively, the triangle might appear because you regard the pattern as a puzzle, which you must solve by perceiving familiar figures in it.

Coren had previously argued that one strong cognitive mechanism at work in patterns producing subjective contours involves their apparent depth. Notice that in the case of the Kanizsa triangle the subjective figure seems to be in front of the other figures, partially blocking your view of them. Why does the triangle brighten when depth is perceived in the pattern? No one can agree on the answer, but it may well be that the brightness helps you to rationalize your perception of the triangle, which you know is illusory. Coren had also put forward another cognitive mechanism that may have a major role in subjective contours. When you perceive an illusory figure in a pattern, you draw on earlier experiences even if you do not recognize that you are doing so. The body of previous experiences is called a perceptual set. For example, once you have learned to see the triangle in Kanizsa’s original pattern, you then readily see a triangular figure with curved sides in the middle illustration on the opposite page.

A sharper test comes with the third illustration on the opposite page, a pattern taken from experiments reported in 1979 by Irvin Rock of Rutgers University and Richard Anson, who was then also at Rutgers. The pattern is an extension of earlier work by Coren. After covering up the first two figures, ask someone unfamiliar with subjective contours to examine the third figure. The observer is unlikely to pick out an illusory triangle at the center of the pattern or to see any unusual brightening there. Then familiarize the observer with the first two figures. The chances are that a bright illusory triangle in the third pattern will now be recognized. The illusion may not appear for tens of seconds, however. If its source were physiological instead of cognitive, there would presumably be no delay. Can you find an illusory figure in the top illustration on this page, which is also adapted from work by Rock and Anson?

A different kind of illusion can be seen in the incomplete grids in the illustration at the bottom left on this page. The illusion was first investigated by W. Ehrenstein and is now named after him. If you avoid fixation, you will see a circle, square or blob at the points where the lines would intersect if the grid were completed. The figures are particularly bright in the grid of black lines and particularly dark in the grid of white lines. In both cases the figures probably appear to lie above the grid, seemingly hiding intersections of the lines. The illusion is just as apparent if you examine a single cell of the grid, with only one incomplete intersection. If you fix your gaze precisely on the region of intersection, however, the brightened or darkened spot there disappears. It also disappears if you add a circle around the intersection region. A striking variation of the Ehrenstein illusion can be seen in the illustration at the right below: in addition to bright spots at the regions of intersection you also perceive bright diagonal streets connecting the spots.

What accounts for these illusory
spots and streets? The spots might be produced by a desire to close parts of the pattern by mentally superposing something that connects the ends of the lines at each incomplete intersection. Alternatively, the spots might come about because of the contrast in brightness between the ends of the lines and the space at the incomplete intersection. A third possibility is that you mentally add depth to the pattern, transforming a flat drawing into a grid whose intersections are hidden by small spheres or—in the case of the streets—by another grid laid on top of the actual one. This explanation seems to me to be important, because when I examine the illustrations, I have a strong perception of depth.

In the late 1970's John M. Kennedy of the University of Toronto invented a variety of illusions that appear to be related to the Ehrenstein illusion. In the first of the four patterns in the illustration at the upper left below, a simple layout of radial lines generates the illusion that a bright circle fills the center of the pattern. Kennedy argued that the illusory figure is due to the contrast in brightness between the inner end of the lines and the white center. According to theory, the region just beyond the end of each line is darker than the adjacent region, but if several lines are grouped so that the brightened regions are adjacent or overlap one another, the brightening is quite perceptible.

In the next three patterns in the group the lines are progressively reoriented, until they are finally tangential to the central region. As the reorientation continues, the illusion of a bright center weakens and then disappears. According to Kennedy, the reorientation of the lines shifts the regions involved in brightness contrast out of the central region. When the lines are tangential, the white space just beyond the end of each line is near another line; the space is not mentally brightened and the central region no longer exhibits the original illusion.

Critics have argued that the illusion is due not to a contrast in brightness but to the mental connecting of the lines across the central region and the perception of depth in the pattern you imagine that the lines intersect but that the intersection is hidden from view by a bright sphere lying above the intersection. When the lines are reoriented, the idea of a hidden connection becomes less viable, destroying the illusion.

I can add an observation in support of this theory. If the illusion is due to a contrast in brightness at the end of each line, why then is the region just beyond the outer end of the lines not brightened? Even if I include many more lines in the pattern, so that the affected regions near the outer ends are closer together, I find no brightening and perceive no illusory figure outside the lines. The idea that depth and a hidden intersection must be perceived in the pattern in order to create the illusion of a central figure appeals to me. Everyone is accustomed to scenes in which an object blocks the view of more distant objects, and I suspect that I automatically bring such a perceptual set to bear on Kennedy's patterns.

To counter the theory that a hidden connection is necessary to the illusion, Kennedy showed that the illusion remains when the lines are replaced with petal-like figures that are widest at the middle and pointed at the ends, as in the illustration at the upper right on this page. The pointed ends should remove the temptation to imagine a hidden connection. For me, however, the illusion of a central figure is considerably weaker with this pattern than it is in the case of lines, suggesting that although a hidden connection may not be necessary, it certainly helps.

Another pattern investigated by Kennedy consists of radial "lines" that are strips of black dots; the dots fade toward the inner end of each line. A version of Kennedy's pattern, devised by Barry L. Richardson of the University of Toronto, is seen in the illustration at the lower left on this page. It has solid but tapered lines. Both patterns create the illusion of a bright center resembling the sun. A photographic negative of either pattern generates a dark center, as if a black hole were there.

An illusory bright center is also produced by a Kennedy pattern that
resembles a stylized sun [see illustration at lower right on opposite page]. According to Kennedy, the brightening is due to the contrast in brightness between the central region and the sharp bends formed by the line segments. This pattern is important because the illusion does not serve to connect or enclose anything in the pattern: all the line segments are already connected and the center is already fully enclosed. Are Kennedy's illusions due to brightness contrast, perceptual set, the illusion of depth and hidden connection or just a playful desire to see something interesting in an otherwise dull illustration? I leave the matter to you.

In 1983 Alex Stewart Fraser of the University of Cincinnati offered up an intriguing combination of Kennedy and Ehrenstein patterns. When you examine the top illustration on this page from a normal viewing distance, the top half produces bright spots as in the Ehrenstein illusion, whereas the bottom half fails to produce any illusion. Note that the bottom half is filled with lines that could be described as being tangential to circular spots like those in Kennedy's patterns. The spots are not apparent, however, and there is no unusual brightness. Now move away from the illustration. When you are at an appropriate distance, the bright spots in the top half almost disappear, and now the bottom half seems to be filled with spots that are somewhat darker than they should be. Squinting greatly improves the illusion.

The illustration at the right, also from Fraser, contains an embedded pattern. When the illustration is viewed from a normal distance, the pattern is almost impossible to perceive. If you move away from the illustration and squint, a slightly darkened figure appears. It is generated by the spots that are surrounded by tangential lines.

In 1981 Lothar Spillmann and Christoph Redies of the Neurological Clinic of the University of Freiburg, Germany, described how the basic Ehrenstein illusion can be modified if the grid is overlaid with a transparency of randomly placed dots. In the regions where bright spots normally lie, the dots seem to be less densely packed than they are elsewhere. They may even appear to be organized into concentric circles. To me these regions seem to bulge upward, as though they were hemispherical caps lying on the grid. The brightening that is normally produced by the grid is missing.

When the transparency is moved across the grid, the patches "boil" with activity and shift to new positions in the direction of the pull. The shift may be due to a persistence of vision associated with the patches. When the transparency is similarly drawn across an Ehrenstein grid that normally produces an illusion of bright streets, the streets are also shifted in the direction of the pull. If the transparency is pulled diagonally along one set of the streets, those streets come alive, whereas the perpendicular streets may disappear. Transparencies bearing either regularly placed dots or hatched or wavy lines fail to eliminate the normal brightening in the grid or, when they are slid across the grid, to shift the illusory regions.

A similar illusion can be produced if a transparency of the Ehrenstein structure grid is placed on the screen of a television set tuned to an emp-ty channel (a black-and-white set is best). Inside the illusory regions of the grid the random "snow" on the screen seems to swirl either clockwise or counterclockwise. The motion is related to other experiments with kinetic random-dot arrays that were described in this department in April, 1980.