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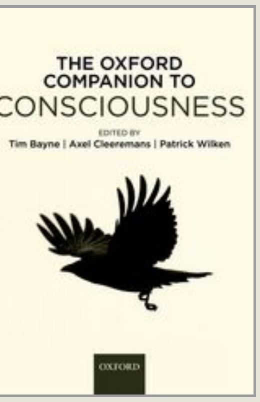

The Oxford Companion to Consciousness

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Publisher: Oxford University Press
Print Publication Date: 2009
Print ISBN-13: 9780198569510
Published online: 2010
Current Online Version: 2010
eISBN: 9780191727924

illusions

Illusions confuse and bias the machinery in the brain that constructs our representations of the world, because they reveal a discrepancy between what we perceive and what is objectively out there in the world. But both illusions and accurate perceptions are governed by the same lawful perceptual processes. Despite the deceptive simplicity of illusions, there are no fully agreed theories about their causes.

Illusions include geometrical illusions, in which angles, lengths, or shapes are misperceived; illusions of lightness, in which the context distorts the perceived lightness of objects; and illusions of representation, including puzzle pictures, ambiguous pictures, and impossible figures.

1. Geometrical illusions

Figure I1 shows some illusory distortions in perceived *angles*, named after their discoverers; the Zollner, Hering and Poggendorff illusions, and Fraser's LIFE figure. *Length* illusions include the Müller–Lyer, the vertical–horizontal, and the Ponzo illusion. *Shape* illusions include Roger Shepard's tables and Kitaoka's bulge illusion.

In the Zollner illusion, the long oblique lines are parallel, but they appear to be tilted away from the small fins that cross them. In the Hering illusion the verticals are parallel but appear to be bowed outward, again in a direction away from the inducing lines. In the Poggendorff illusion, the right-hand oblique line looks as though it would pass above the left-hand oblique if extended, although both are really exactly aligned.

Geometrical illusions are not retinal, since they can be seen in random-dot stereograms, in which the patterns exist not on the retina but only as a correlation between the eyes, which is present only after the point of binocular fusion. And they are not caused by eye movements, since they can still be seen during a brief flash, and also in the (retinally stable) afterimage resulting from such a flash (see AFTER-EFFECTS, PERCEPTUAL).

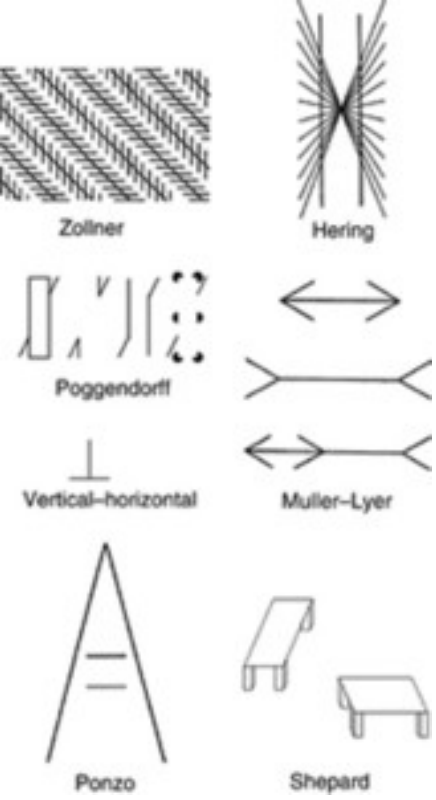

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Fig. I1. Some well-known illusions.

There is no single accepted theory of the geometrical visual illusions. We shall consider four: (1) low-level interactions between neural detectors of length, angle, or spatial frequency; (2) depth processing theory; (3) contrast theory; and (4) statistical probability theory. The first is based upon properties of single neural cells, the second and third on more general mechanisms, and the fourth on the statistics of natural stimuli.

1. *Neural interactions*. Neurons in the primary visual area (VI) of the cortex are tuned to lines of different orientations. If neurons tuned to similar orientations (say, 1 o'clock and 2 o'clock) inhibit each other, this will make acute angles look bigger than they really are. This would explain the Zollner illusion. In the same way, V1 neurons are tuned to different sizes, and inhibition between these might perhaps explain the Ponzo illusion.

The Poggendorff is an illusion of angle, not length. The two oblique lines are aligned but appear to be misaligned. The angular overestimation theory proposes that acute angles are overestimated, because each line comprising the angles is sensed by a population of orientation-tuned neurons, probably in brain area V1, and these two populations tend to inhibit each other, shifting the excitation peaks of the populations further apart. However, this theory cannot be quite right because the Poggendorff illusion disappears if only the acute angle are shown, though it survives if only the obtuse angles are shown. The angle theory does provide a good fit to other illusions such as the Zollner and Hering illusions, in which the test lines appear to bend away from the inducing lines that cross them. The angle theory has trouble with a Poggendorf illusion produced by an illusory vertical contour. The brain supplies the missing contour to give the overall illusion, but it cannot supply acute angles for the supposed orientation detectors to distort. Although this does not disprove a theory of misperceived angles, it goes against the idea of lateral inhibition between orientation detectors. In Kitaoka's bulge illusion, the tiny black and white squares give rise to perceived obliques, probably owing to low-level neural interactions, and the apparent obliques in turn generate an illusory three-dimensional bulge.

2. One of the most successful theories relates the illusions to *depth processing* (Thiery 1910 cited in Purves and Lotto 2003, Gregory 1966/1997). For example, the Müller–Lyer illusion is the best-known illusion of length. The line with the outgoing arrowheads looks up to 25% longer than an equal line with ingoing arrowheads. Gregory has argued that the two arrowed lines look different lengths because the arrows act as depth cues, triggering an impression that the line with the outward arrows represents a concave corner, like the corner of a room, while the line with the inward arrows triggers the perception of a three-dimensional box seen from the outside. Therefore the room corner looks further away than the box corner, and since the two vertical lines in the figure cast the same size retinal image, the brain concludes that the apparently further away line must be a physically larger object. Similarly, the horizontal lines in the Ponzo illusion look like two railway ties or sleepers, and the oblique lines are interpreted as a perspective picture of two rails receding into the distance. The upper line looks further away, so it is interpreted as a more distant, hence larger object. According to this depth processing theory, the oblique lines look like the flat projection of a three-dimensional scene of lines receding into the distance like a railway line. So we see the figure as if it had depth, and because the upper line looks further away it must be longer, because *size constancy* perceptually expands more distant objects to compensate for their smaller retinal size. Gregory (1966/1997) has argued that depth need not be consciously perceived; the presence of depth cues, such as angles, can trigger a primitive *primary size constancy*, whether or not the usual *secondary size constancy* driven by conscious depth perception, is occurring. But this theory is rather hard to test.

There is also an aptly named *confusion theory*, to the effect that one is unable to isolate the shafts from the arrow heads perceptually, so the line lengths assimilate perceptually to the full length of the outward arrows.

In Roger Shepard's table illusion, the left-hand tabletop looks long and narrow, while the right-hand table looks more nearly square. Yet the two tabletops are geometrically identical, and give identical retinal images. The illusion occurs because the vertical dimension lies in depth and is foreshortened by perspective. According to the depth processing model, the brain compensates for this by perceptually expanding the vertical (near–far) dimension.

3. Against the depth processing theory, it is not clear why the concave corner in the Müller–Lyer diagram should appear to lie at an absolutely greater distance from the observer than the convex corner. Also, the Müller–Lyer still works when the arrowheads are replaced by squares or circles, which give no particular depth cues. This has led Irvin Rock (1995) to propose a *contrast* theory of this and other illusions. He suggests that observers judge the length and angle of an object by comparing it with other objects in the field, and by exaggerating the differences. Thus the upper line in the Ponzo illusion fills most of the space between the obliques, whereas the lower line looks smaller in contrast to the large empty spaces on either side of it. Brightness contrast is already well known—a grey spot looks darker when on a white background than on a black background. *Assimilation* is the opposite process to contrast; a grey field looks lighter when criss-crossed with white lines rather than with black lines. Rock suggests that analogous processes happen in the size domain. Contrast is the tendency to compare an object with the properties of its surround and to exaggerate the differences. In the Ponzo illusion, the lower line looks short in contrast with the large empty space at either end of it. Size assimilation illusions exist, for instance in the Delboeuf illusion the outer circle in the upper half looks apparently smaller than the inner circle in the lower half; each circle assimilates to its companion.

4. Purves and Lotto (2003) propose an extreme empiricist theory, in which the lines in the illusion figures (and indeed in all other stimuli) are interpreted according to the *statistical probability* of the objects that they might represent, based upon the observer's life-long perceptual diet. They examined the statistical relationship between the retinal image and the probability distribution of its possible real-world causes. For instance, vertical-line images tend to come from long objects because ground planes are statistically so common, leading to retinal foreshortening, so the observer overestimates vertical lines.

2. Illusions of lightness

Perceived brightness is strongly affected by contrast. When two identical grey patches are exposed side by side, a patch on a white surround looks darker than a identical patch on a dark surround. This phenomenon is called *simultaneous brightness contrast*, or *brightness induction*, and it is usually attributed to lateral inhibition within, or between, nearby retinal ganglion cells. (Retinal, not cortical, because backgrounds viewed by one eye have no effect on test patches viewed by the other eye.) The receptive field of a retinal ganglion cell comprises an excitatory ON-centre with an inhibitory OFF-surround, or vice versa. So if the grey test patch just fills the ON-centre on a dark surround the ganglion cell will fire, but if a white surround is added that activates the OFF-surround, this will reduce the firing rate and hence the perceived brightness. A similar lateral inhibition within separate colour-cone channels explains why a grey patch looks greenish when it lies on a red surround.

This story fails for White's effect (1979, 1981), in which the right-hand grey bars look lighter than the identical left-hand bars, even though the right-hand bars are surrounded by a larger area of white and therefore ought to look darker than the left-hand bars. This puzzling illusion is still not really understood. Some attribute it to banks of low-level oriented filters with elongated receptive fields. Others believe that the visual system parses the stimulus into three-dimensional layers, with the grey areas parsed as transparent greys in front of the stripes. Probably the right-hand gray bars are judged in comparison to the black embedding bars, to which they are interpreted as ‘belonging’, so the grey bars look light. Similarly, the right-hand bars are compared with the white embedding bars to which they perceptually ‘belong’, so they look dark.

In addition, many higher-level processes may be involved in brightness induction. In Adelson's figure, the square marked A is printed with the same grey ink as the square marked B. This illusion, which is far stronger than the conventional simultaneous contrast, is based upon lightness constancy that splits up the retinal luminance, assigning it partly to the illumination and partly to the reflectance of the surface. Thus, cues that increase the perceived illumination can hugely darken the perceived reflectance of a surface.

The diamonds in Cavanagh's figure are all identical, but each row looks lighter than the one above because the sharp dark–light edges are more salient that the gradual light–dark gradient within each diamond, and these edge effects accumulate. Probably, low-level processes account for simultaneous contrast and the edges of the diamonds, whilst the Adelson phenomenon also involves higher-level interpretive processes.

3. Illusions of representation

Pictures are like a language whose syntax consists of the internal picture geometry and whose semantic content, or meaning of the picture, lies in the objects represented. Thus low-level theories of the geometric illusions refer to the picture syntax, and depth processing theories refer to the semantics. Other illusions are more openly and specifically semantic; *puzzle pictures* at first have zero meanings but then settle on one meaning after the brain solves the puzzle. *Ambiguous* pictures, such as two faces/one vase, alternate between two (or more) meanings. Finally, *impossible* pictures at first seem to have one three-dimensional meaning but then settle on zero meanings.

Most pictures represent an easily recognized scene, but in *puzzle pictures* the meaning is hard to grasp, until an 'aha!' experience reveals the object represented, which once seen is never forgotten and is immediately recognized on a subsequent viewing, even years later. An example is the famous Dalmatian dog (see MULTISTABLE PERCEPTION, Fig. M6a). Here, 'bottom-up' scattered spots provide an input that is matched to a 'top-down' model or theory of what object is out there. On the other hand, *ambiguous pictures* have more than one possible meaning, and the percept often flips between these different meanings. The perceptual process of settling upon a meaning is related to the figure–ground process. Priming can affect ambiguous percepts; before viewing an ambiguous duck–rabbit figure, persons pre-exposed to a picture of a real duck tend to see it as a duck, whilst those pre-exposed to a picture of a real duck tend to see it as a rabbit.

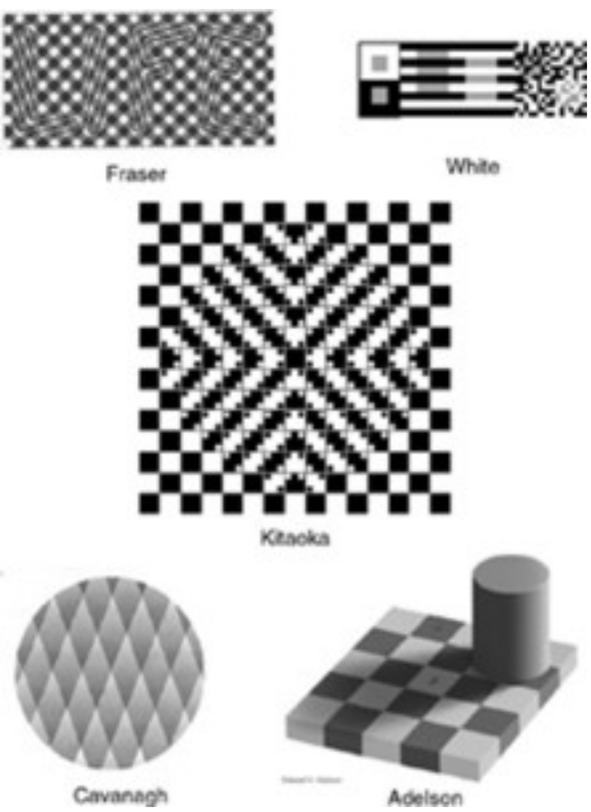

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Fig. I2.

An *impossible* figure is a two-dimensional flat representation of what at first looks like a three-dimensional object, but in fact there is no possible object that it can represent. Examples are the impossible triangle, the impossible staircase of Penrose (père et fils), and Shepard's many-legged elephant. The object cannot be globally separated from the non-object or background, and a flat impossible picture cannot be consistently coloured with paints. The local features at each corner of an impossible triangle are fully consistent with a three-dimensional object, and are perceptually accepted. It is only the long-range relationships between corners that are inconsistent. This shows that perception operate here, as in the Fraser 'LIFE' figure, upon local votes and not on a long-range scale. In the same way, try slowly uncovering the elephant from the top, or from the bottom. The Dutch engraver Maurits Escher (1898–1972) has made much use of ambiguous and impossible figures.

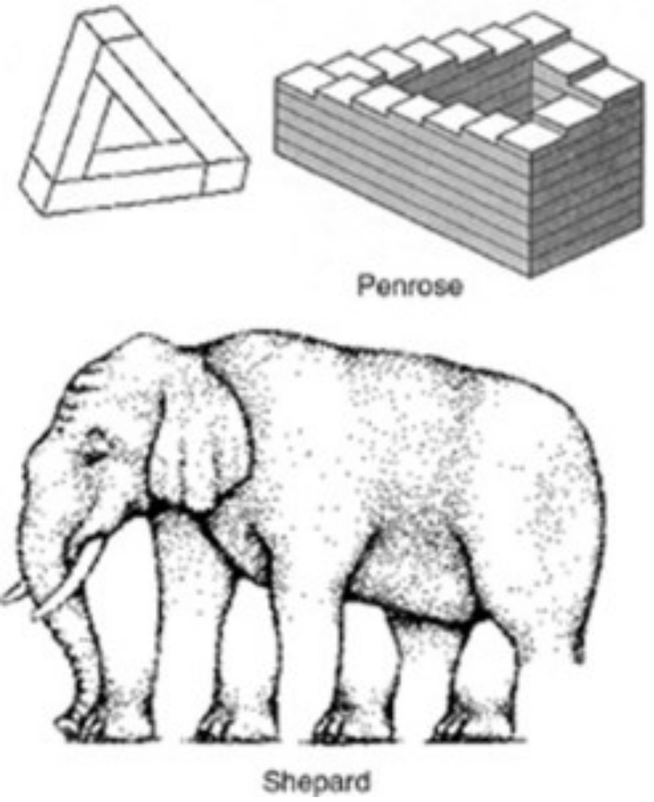

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Fig. I3.

Stuart Anstis

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http://www.eyetricks.com/

http://www.lottolab.org/

http://www.michaelbach.de/ot/index.html Michael Bach has assembled an excellent collection of illusions, many of them involving motion.

http://www.purveslab.net/

http://www.ritsumei.ac.jp/~akitaoka/index-e.html Akiyoshi Kitaoka's web page has an array of dazzling illusions. Many of these new illusions are not well understood.

http://www.skytopia.com/project/illusion/illusion.html