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## *The Grand Illusion and Petit Illusions*

*Interactions of Perception and Sensory Coding*

*The Grand Illusion, the experience of a rich phenomenal visual world supported by a poor internal representation of that world, is echoed by petit illusions of the same sort. We can be aware of several aspects of an object or pattern, even when they are inconsistent with one another, because different neurological mechanisms code the various aspects separately. They are bound not by an internal linkage, but by the structure of the world itself. Illusions exploit this principle by introducing inconsistencies into normally consistent patterns of stimulation.*

The Grand Illusion (O'Regan & Noë, in press) is a disturbing contrast between what the visual system offers and what the viewer perceives. To most people, the visual world appears in sharp, vivid focus and full colour throughout its extent. It takes a lecture demonstration of the limits of peripheral vision to convince astonished undergraduates that their internal representation of the visual world is much poorer than it seems, that acuity for both form and colour drop off rapidly with distance from the fovea. This mismatch between high-quality perception and low-quality sensory information is what defines the Grand Illusion.

Illusions have a long history in the study of perception, predating even the experimental phase of the discipline. They are of interest not as entertaining parlour tricks, but for what they reveal about the normal processes of perception. Most illusions are not grand, but are restricted to a particular aspect of an object or pattern's appearance.

### **The Design of Sensory Systems**

If the visual system had been designed all at once, like a stereo or a computer, engineers might have given it a geometric engine to map all the spatial relationships that would be needed, and a powerful, general pattern recognizer to compare input with stored information. Inside the brain, however, we find not a single visual area but more than twenty (Felleman and Van Essen, 1991).

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Similarly, the brain uses not general solutions but a welter of limited algorithms and heuristics that deal with limited problems. Instead of general solutions, the brain offers a bag of ‘cheap tricks’ to apply to problems of pattern recognition (Ramachandran, 1990). Each trick applies in only a limited setting. Normally, a cheap trick can be expressed in a few words, requiring no mathematics.

An example of such a trick is the familiar experience of seeing a bump on a surface, such as a rivet, that is illuminated from above. The bump in the surface appears convex only as long as you assume that the illumination is coming from above. If you can convince yourself that the illumination is coming from below, the bump will pop in and appear as a concavity on the surface. The brain’s default

assumption is that illumination comes from above, as it normally does in the natural world, and this source of information can be used to interpret patterns in the world. The cheap trick might read something like ‘if the top of a disturbance in a surface is darker, there is a dimple’. It complements ‘if the top of a disturbance in a surface is lighter, there is a bump’.

Another cheap trick specifies that all objects are three-dimensional, for even the most meagre information will demand a three-dimensional solution. Try interpreting the surface in Fig. 1 as a two-dimensional surface.

*Figure 1.* A surface with dimples and bumps, defined only by shading by a localized illuminant.

### Application to Illusions

Some cheap tricks are so simple that they sound ridiculous. An ecologically generalized version of the Ebbinghaus illusion, illustrated in Fig. 2, is based on two simple rules: First, the smallest of a bunch of things is pretty small, and second, the biggest of a bunch of things is pretty big. The smallest thing in the top array is the smaller circle, while the biggest thing in the bottom array is the larger circle. It doesn’t sound like sophisticated pattern processing, or even good kindergarten wisdom, but it usually works. Only in simplified, systematically biased environments like that in Fig. 1 do the generalizations lead us astray.

The visual system relies on an assumption of a random or near-random distribution of sizes of objects to make this trick work. In the case of the Ebbinghaus illusion, the normally safe assumption of randomness is systematically violated. The assumption is part of a rich tradition in psychology discussing the role of generic or non-accidental views, a perceptual ‘cosmological principle’, related

to a concept used by cosmologists to emphasize that their data should be interpreted as though there is nothing unique about the position of the earth in the cosmos. We circle an average star, at an average location in an average galaxy.

Similarly, there is an assumption built into every visual system that there is nothing unique about the station point of the eye. It is unlikely, after all, that we should just happen to find ourselves at the start of a continuously changing texture density, or looking at a cube from the one angle at which it projects as a hexagon. More likely, the texture density is uniform and it is distance that causes the retinally projected sizes of texture elements to change in a non-random way

across the visual field. A projection of a hexagon on the retina is more likely to be a hexagon seen from a generic angle than a cube seen from a unique station point.

Another violation of structural assumptions occurs in the Poggendorff and the Müller–Lyer illusions (Fig. 3). These illusions reveal a dual nature of perception — on one hand, we can perfectly well perceive the fine structure of the illusion figures, even at the vertices where the illusions must originate. On the other hand, we perceive the illusions as though this fine structure were not resolvable. The inconsistency between the fine structure and the gross structure in these figures violates assumptions of consistency upon which the visual system normally relies to interpret the visual world.

**Illusions as Inconsistent Codings**

These illusions rely not on easily discernable cheap tricks, but on the tenuous relationship between awareness and the neural coding of sensory properties. Explaining the source of the illusions requires a brief diversion into the

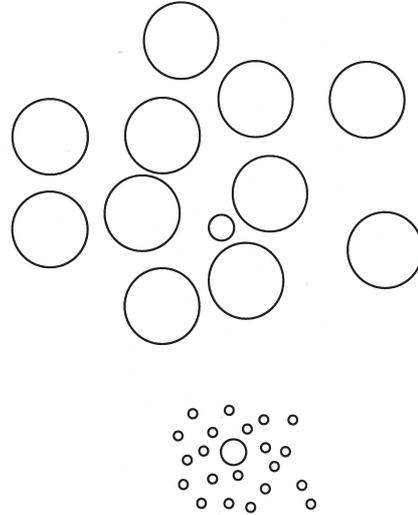


Figure 2. A modification of the traditional Ebbinghaus illusion, using irregular textures rather than circular arrays of inducing objects. The small circle in the top cluster and the large circle in the bottom cluster are the same size.

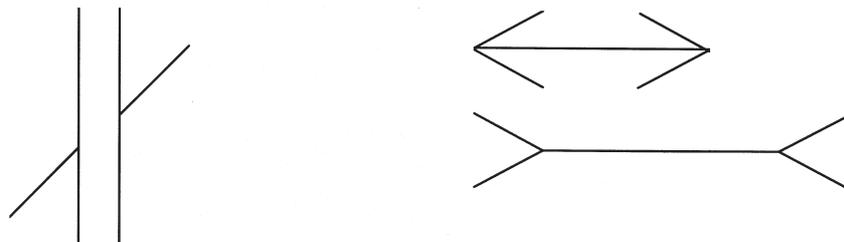


Figure 3. The Poggendorff illusion (left) and the Müller–Lyer illusion (right).

physiology of information coding in the visual cortex. Each neuron in that cortex responds to a region of space, a 'receptive field'. The structure of the receptive field is like the structure of ripples in a pond just after an elongated object is dropped into it: waves and troughs (excitatory and inhibitory regions) alternate, and decrease in magnitude away from the centre. Neurons respond best to elongated patterns; all receptive fields have about the same shape but their sizes vary. The size of a receptive field is measured in spatial frequency, the number of cycles of waves and troughs one encounters in a degree of visual angle; thus their unit is cycles/degree. In humans, the smallest receptive fields are sensitive to about 30 cycles/degree, the largest to perhaps 0.1 cycles/degree. Each neuron's receptive field can be characterized by its orientation, spatial frequency, and position in the visual field.

The dominant explanation for the mechanism of the Müller-Lyer and Poggendorff illusions is that the positions of the critical vertices are coded by low spatial frequency 'blob' detectors, visual neurons whose receptive fields are very large. The receptive fields coding the lengths of the Müller-Lyer figure's lines, for example, must be large enough to encompass the entire lengths of the lines. Receptive fields sensitive to such low spatial frequencies cannot encode the details of the geometry at the vertices in the illusion; they see only the gross structure of the figure. Since the gross structure of the fins-out line really is longer than the gross structure of the fins-in line, the illusion in a sense is not an illusion at all — it is literally present in the low spatial frequency domain (Ginsburg, 1984). Because the receptive field optimally sensitive to the fins-out line really is larger, we perceive that line as longer.

In the meantime, other receptive fields of higher spatial frequency are accurately coding the fine details of the geometry around the fins of the figure. For the fins-out figure we can use the higher spatial frequency information to see that the horizontal line whose length we are to judge does not reach through the entire extent of the line. But that line appears longer nonetheless. We are in a sense both aware and unaware that the length of the line is confounded with the extraneous length added by the fins. The 'blob' coding necessary to judge the length of the lines does not interfere with the fine coding necessary to perceive the geometry of the vertices. Both properties are available simultaneously, even though they are contradictory.

This illusion occurs because we use different information to make different judgments about the same scene. Normally, the visual information at all scales is consistent (another cheap trick), but the illusions are designed to violate this assumption. We have a petit illusion in that we can see the fine detail, and therefore know everything about the figure. Knowledge about the size of the figure, though, comes from receptive fields that are too large to detect the detail. The result is an illusion that the detail is available, but it is available only in a special way — to inspect the local geometry. If we need to know about the big picture, the details are lost. Since local and global structures are consistent in most normal perceptual situations, there is no pressure to link the independent processing of details and of gross features.

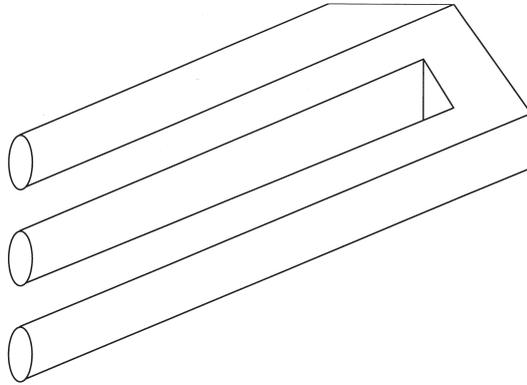


Figure 4. A variant of the 'devil's pitchfork'. A self-consistent structure on one side maps into a different self-consistent structure on the other.

The Poggendorff illusion has a similar explanation. The details of the geometry at the vertices are coded by small, high-spatial-frequency-receptive fields that are not deceived by the angles. Judgments about the positions of the lines, though, are biased by the asymmetric geometry, so that the low-spatial-frequency-receptive fields that best respond to the vertex regions do not line up. Again, the perceived pattern

is really present in the figure, but only in the low spatial frequencies (Morgan, 1999; Bridgeman, 2001). Like all stimulus patterns, this one is analyzed not only by low-spatial-frequency filtering but also by other visual-processing algorithms, such as frames of reference, that affect the strength of the illusion (Spivey-Knowlton and Bridgeman, 1993).

Other visual experiences show how perception can be deceived at a higher level after the positions of lines and edges are already established. Figure 4, a version of the well-known 'devil's pitchfork', shows that the visual system uses the local geometry of lines and edges to infer visual structure. Since local geometry and global structure always agree for real-world objects, the strategy works very well. If the local geometry is violated at a more global level, however, the resulting 'impossible' figure cannot be resolved. The pitchfork relies on the poverty of line-drawing representations where figure and ground are identical uniform areas separated only by lines. A perceived surface that is figure because of its local geometric structure in one location becomes ground at another. The visual system reaches no conclusion about the figure because the cheap tricks that might resolve the ambiguity are exhausted. Normally, local-level solutions to the identity of an object will apply throughout the object, leaving simultaneous but contradictory interpretations of the figure at its two ends. The visual system's ability to interpret a consistent three-dimensional geometric object from a few two-dimensional lines enhances our ability to see consistent objects with little sensory input, and backfires only in contrived 'impossible' figures such as this one.

Such petit illusions are ubiquitous in perception, not only in vision but in other modalities as well. In audition, for instance, we hear melodies, timbres, patterns, even though at any instant there is only a single dimension, a momentary air pressure, in the stimulus. The rest of the auditory world is made available by temporal integration and structuring in the auditory system, aided by top-down expectations about what is present.

For instance, a gradually rising tone can begin very quietly at the bottom of a fixed tonal range, gradually increase in amplitude, and then decrease in

amplitude as it reaches the top of the tonal range. As it begins to fade away, a second gradually rising tone begins quietly at the bottom of the tonal range, reaching its maximum amplitude as the first tone disappears. A third tone replaces the second in the same way and the process repeats indefinitely. The resulting and rather disturbing perception is of a tone that gradually rises forever, a consequence of the auditory cheap trick of sampling all of the sound available in a short time interval and judging whether the frequency is increasing, steady, or decreasing. The answer is always ‘increasing’ because the gradual replacement of one tone by another is too slow for this simple mechanism to pick up. In the world of real sounds the cheap trick works very well; it takes a contrived laboratory experience to deceive it.

### Conclusion — Grand and Petit Illusions Unified

The disconnections that create grand and petit illusions usually do not bother us. Why not? In the normal visual world, the various ways of describing a sensory experience are consistent with one another. They are linked not by internal checks on consistency but by the structure of the world itself. What we had thought was a binding within us turns out to have been all around us all along in the structure of the world itself.

Applied to the grand illusion, this analysis relies on the consistency of the properties of the real world to give the impression of completeness. Since the world is assumed to be complete — a non-sensory assumption — the sensory systems have only the job of sampling the complete world at particular locations and along particular dimensions. The perception of a rich perceptual world, then, can result from failure to violate the completeness assumption. If I assume that the world is rich with detail at all scales, and my senses do not contradict my assumption, I can continue to perceive a rich world even while sampling only bits and pieces of it.

In the same way, the petit illusions arise from the assumption of self-consistency of particular objects and patterns in the world. I can use local information to sample these objects with the confidence that the local solutions will apply to the whole object. Though contrived situations violate the consistency assumption and lead perception astray, in the real world the assumption serves us very well.

### References

- Bridgeman, B. (2001), ‘Polarity reversal does not destroy the Poggendorff illusion’, *Optic Express*, **9**, p. GV13.
- Felleman, D.J. and Van Essen, D.C. (1991), ‘Distributed hierarchical processing in the primate cerebral cortex’, *Cerebral Cortex*, **1**, pp. 1–47.
- Ginsburg, A. (1984), ‘Visual form perception based on biological filtering’, in *Sensory Experience, Adaptation, and Perception*, ed. L. Spillman and B. Wooten (Hillsdale, NJ: Lawrence Erlbaum).
- Morgan, M.J. (1999), ‘The Poggendorff illusion: a bias in the estimation of the orientation of virtual lines by second-stage filters’, *Vision Research*, **39**, pp. 2361–80.
- O’Regan, K. and Noë, A. (in press) ‘The grand illusion’.
- Spivey-Knowlton, M. and Bridgeman, B. (1993), ‘Spatial context affects the Poggendorff illusion’, *Perception & Psychophysics*, **53**, pp. 467–74.