Guest editorial

Illusions and reality-checking on the small screen
There is a long tradition in the study of perception to use illusions, the idea being to trick the underlying neural mechanisms into revealing themselves. The discovery that we see something that isn’t there, when we are prompted by something else that is, reveals the limitations that the visual system works under as well as the liberties that it takes in interpreting its inputs. To borrow from one of Richard Gregory’s examples in a recent editorial on these pages, phi movement—the illusion of a bright object skimming across space, created by the simple switching on and off of two lights separated in space and time—shows that the visual system is limited in its analysis of real movement. My question here is how much the now-entrenched use of computer monitors to display visual images has stolen from the traditional power of illusions in the study of visual perception.

The Mach Card effect
Certain classic illusions do not work on the small screen. Take the Mach Card, for example. To experience the phenomenon as Ernst Mach described it in 1885, you view a convex folded grey card, illuminated from the left, so that its left side is brighter than its right. Although you are aware of the brightness difference between the two sides, you nonetheless perceive them to be equal in colour, that is as the same shade of grey. If you now flip the card’s shape from convex to concave in your ‘mind’s eye’ (Mach recommends that you shut one of your real eyes, because depth is ambiguous in a monocular image), the brightness difference becomes abruptly pronounced, and the right side actually appears to be painted a darker shade of grey than the left.

Mach’s explanation for this illusory change in colour of the right side was that the perceived direction of illumination does not shift when the shape does, and therefore the observer is forced to see the right side, which now appears to be directly under bright illumination but is still dark, as actually made from very dark paper. Mach was careful to emphasise that the effect occurs without the “aid of judgment”. He reasoned that the direction of illumination was indelibly recorded by the transparent eyeball itself, which of course is exposed to the same illumination. He concludes that “a fixed habit of the eye is developed, by means of which illumination and depth are connected in a definite way”. The illusion reveals that the visual mechanisms which determine surface lightness must be influenced by the perception of surface shape and light-source position.

The Mach Card effect on the small screen
The Mach Card phenomenon is robust and easy to reproduce with a simple piece of card. It is also simple to generate an image of a bent grey card under asymmetric illumination, with the use of computer graphics. But, anecdotally, the Mach Card effect is almost impossible to reproduce on the computer screen. Although it is easy to achieve a convincing change in shape of the simulated card—for a single, monocular image, one can rely on the same perceptual fluidity as Mach did to flip the shape from convex to concave; and for a binocular stereogram, one can explicitly reverse the binocular disparities—it is hard to see the predicted concomitant change in lightness. It is not just hard to measure the change—surface lightness and colour judgments are generally difficult to quantify, whether depicted on a computer screen or not—but genuinely hard to see it.
If we take Mach's explanation at face value, the reason for the lack of effect is obvious: the observer's eyeball is no longer fixed in the right habit; it is not bathed in the same illumination that falls on the card. If the observer views the screen in an otherwise black room, his eyeball is bathed in the light emanating from the screen. But this light is not the same in direction or intensity as the simulated illumination on the simulated card. When the shape flips, this fixed record of the illumination does not enforce a new interpretation of the brightness difference between the two sides—there is no conflict introduced by the "connection between illumination and depth".

The problem, Mach would say, is that the simulated illumination on the card does not correspond to the real illumination in the observer's world. Other illusions that require a similar parsing of the scene into surface reflectance and illumination might therefore be expected to suffer in the same way on the small screen—and they do. For example, it is difficult, if not impossible, to reproduce Alan Gilchrist et al's demonstration (1983) of the perceptual transformation of a surface reflectance edge into an illumination edge: the edge between a dark and a light rectangle looks like the edge between two papers, one white and one grey; when a hidden light source is revealed, the edge instantly becomes the border of a shadow falling on a single piece of white paper.

This limitation of the computer display can be summarised in one word: self-luminosity. In the real world, most surfaces are not self-luminous, but are capable only of reflecting light generated by other sources. The screen generates light itself, and yet attempts to portray reflecting surfaces. Even when the simulated image is exactly metameric to the real scene—in terms of photoreceptor responses to the light that ultimately falls on the retina—there is still a paradox: at some level, the observer must know that the screen is a self-luminous object yet believe that the surfaces portrayed within it are lit by another source outside the screen.

Simple stimuli on the small screen
But in much of the study of visual perception computer displays are used for much simpler visual stimuli, which are not simulations of real surfaces under real illumination. These are simulated lights in the void, which are no different from real lights in the void: circular spots of coloured light, small white dots moving against black backgrounds, sinusoidally varying patterns of light and dark. The criticism sometimes leveled at these stimuli is that they are not naturalistic, and that the human visual system might treat them differently from naturalistic stimuli. But the time-honoured premise of vision research is that complex natural images can be constructed from these simple components, and that the complex response of the human visual system can be reconstructed from the responses to these simple components.

Comparing the small screen to reality
There are obvious quantitative and qualitative differences between reality and the small screen that restrict the latter even in its display of these simple images. The computer display can be accused of having: (i) Narrow range. In the real world, luminances comfortably visible to the human cone photoreceptors range at least 10-million-fold from $10^{-2}$ in moonlight to $10^2$ cd m$^{-2}$ in sunlight. An ordinary CRT display, operating within its linear range, might reach only 120 cd m$^{-2}$. Many studies of visual perception are actually carried out in the mesopic range, well below 10 cd m$^{-2}$. (ii) Lack of real depth. The computer screen is shallow, the real world deep. The screen can display only flat images, and must rely on cues from texture, perspective, motion parallax, and binocular disparities to portray three-dimensionality. (iii) Limited field extent. The small screen is very small, subtending only a fraction of our full visual field at typical viewing distances.

What restrictions do these faults impose on the conclusions we draw from research using computer displays? Various enterprising researchers have directly addressed this question. With his custom-built high-intensity full-colour computer-controlled display,
Allen Poirson (1995) has tested whether models that account for colour-matching data from ordinary CRT displays also suffice to explain data for luminances up to 50 000 cd m$^{-2}$. To a large extent, they do—the standard von Kries adaptation model can explain results obtained even at levels of 50% cone bleaching. In an interesting twist, Robert Savoy (1993) constructed real scenes metameric to images on CRT displays: he compared multi-coloured Mondrians, one made from real coloured papers, the other simulated on a screen, both subtending small fields of view at a limited viewing distance, both with ‘hidden’ light sources, and both entirely masked-off from the background, so there were no cues from monitor frames or surrounding objects. Under these contrived circumstances, he found little difference in measurements of colour constancy. David Brainard et al (1997) are pursuing a similar comparison between colour constancy in real and simulated worlds, trying to strip down the real world until colour constancy is as poor there as it is in the simulations, without yet finding a meeting between the two.

May we conclude then that the small screen is perfectly adequate for probing low-level visual mechanisms that act on pure light signals, before they have been parsed at a higher level into surfaces, illumination, filtering media such as stained glass windows, or fog, and the like? The problem with doing so is that the evidence for such purely low-level mechanisms, unsullied by influence from higher levels, is becoming increasingly weak. How are we to ensure that we are actually measuring the low-level output to a low-level input?

What is the small screen good for?

So far in this editorial I have ignored entirely the advantages of computer displays. Quantitative control and the easy production of visual stimuli are of course the obvious advantages. But it is also true—counter to my starting argument—that the inherent ambiguities in the small screen’s image make certain illusions easier to achieve. When viewing computer displays, the observer’s visual system may be already close to the border of its limitations—so it may be pushed around a bit easier (to paraphrase a comment made by Ted Adelson at this year’s CVS symposium in Rochester). Take the illusion of the moving ball and its shadow (Kersten et al 1996). The ball’s movement appears to change radically from a bounce to a smooth roll, with a simple change in the movement of its shadow. There is so little other information in the image (even when the background is an apparently slanted checkerboard) that the shadow movement becomes critical. This is also not an easy effect to have discovered without the control afforded by computer graphics.

Ted Adelson (1993) exploits the features of simple computer graphics to invent new lightness/brightness illusions. In one illusion, the brightness and lightness of a grey square change radically with a simple change in the contour or configuration of surrounding squares of different greys. The effect is akin to simultaneous contrast, but seems to require explanations beyond local contrast mechanisms. It also involves changes in the perception of the three-dimensional structure of the surrounding grey surfaces, although there is no three-dimensional information in the image beyond the contour orientations—no shading, texture gradients, or binocular disparities. The question is: is this a weak version of a real illusion, or a strong version of an illusion peculiar to the small screen? That is, is it like the Mach Card illusion, in that it would be much stronger in the real world, or would it disappear when more features depicting solid three-dimensionality were added?

The usefulness of making illusions from illusions

This question might sound pointless: surely any illusion teaches us something about how the visual system works. But the fact is that everything on the small screen is an illusion to begin with—a narrow, shallow, dull, restricted version of reality. The real world is the environment to which the visual system has specially adapted. The real world dictates
the limitations and liberties with which the visual system works. The failure of the visual system to be forced into an illusion on the small screen might tell us only that it is not adapted to the small screen, not how it has adapted to the real world. The success of an illusion on the small screen might only highlight what it lacks with respect to the real world.

The job of computer-graphics artists is to make the small screen's version of reality ever more real—ie to start with the illusion and make reality. The tradition of vision science is to start with reality and construct illusions. The question is: how far can we go if we make illusions from what is already an illusion? Will we be diverted from real illusions that reveal far more about the interactions between all levels of the visual system?

My own answer is the middle-of-the-roadish "we need both". The use of computer displays is hugely worthwhile in vision research, and we can learn a great deal from the success and failure of illusions on the small screen—not to mention from straightforward detection and discrimination measurements. In particular, I think the failure of the Mach Card effect on the small screen might actually teach us something crucial about the human visual system—and that Mach was right in attributing the effect to the observer's fixed knowledge of the light-source position. In fact, other studies do support Mach's explanation: in possibly the only published quantitative demonstration of the Mach Card effect, Beck (1965) showed that observers' assumptions about the number and position of light sources on the card did indeed influence their lightness matches to both sides.

But where is this fixed knowledge instantiated? Mach suggested that it was low-level, in the eyeball itself. He might have been wrong, but the failure of the effect on the small screen suggested that it cannot be very high-level; in any case, it is not enough for the observer to be consciously aware of the graphics cues that point to where the simulated light source has been placed. Instead, the failure of the effect on the small screen supports the notion that the knowledge of the illuminant direction is instantiated at a very low level. The definitive test might be to rig up a light source external to the computer display which does have the properties of the simulated light source within. But I would wager that Mach could never have discovered the effect using only a computer display.

Anya Hurlbert
Physiological Sciences, University of Newcastle upon Tyne, Newcastle upon Tyne, England

References
Adelson E H, 1993 "Perceptual organization and the judgment of brightness" Science 262 2042–2044
Beck J, 1965 "Apparent spatial position and the perception of lightness" Journal of Experimental Psychology 69 170–179
Brainard D H, Rutherford M D, Kraft J M, 1997 "Color constancy compared: Experiments with real images and color monitors" Investigative Ophthalmology & Visual Science 38(4) S2206
Gilchrist A L, Delman S, Jacobsen A, 1983 "The classification and integration of edges as critical to the perception of reflectance and illumination" Perception & Psychophysics 33 425–436
Kersten D, Knill D C, Mamassian P, Bülthoff H, 1996 "Illusory motion from shadows" Nature (London) 379 31
Mach E, 1885/1959 The Analysis of Sensations (New York: Dover)
Poirson A B, 1995 "Appearance of colored gratings on intense backgrounds" Investigative Ophthalmology & Visual Science 36(4) S391
Savoy R L, 1993 "Color constancy with reflected and emitted light" Perception 22 Supplement, 61

© 1998 a Pion publication printed in Great Britain