Practical Application of Optical Illusions: *errare humanum est*.

Gavin J. Brelstaff [1] and Francesca Chessa [2]

[1]CRS4, Loc. Pixina Manna, Ed.1, Cp25, I-09010 Pula (CA), Sardinia Italy.
[2]University of Sassari, Via Zanfarino 89, 07100 Sassari, Sardinia Italy.

Abstract

Some practical applications of visual illusions are explored for both real and virtual environments - with an emphasis on the cryptographic domain in which illusions may be employed to distinguish between humans and non-human agents. Non-human agents are unlikely to suffer the same visual illusions as we do. A Turing test differs from our approach since it relies on human-like ability rather than the characteristic human failing intrinsic in visual illusions:- "To err is human...". The CAPTCHA system for on-line challenge-based authentication can be extended so as to exploit visual illusions. In particular we consider PIX the picture-based system, and illustrate a simple steganographic application. The utility of both are discussed.

Visual illusions

We experience illusion whenever our perception disagrees with physical reality, no longer truthfully representing the external world (Gregory 88). Illusion is particularly alarming when it systematically alters our otherwise most trusted and detailed sense: *vision*. Below we invoke those visual illusions that, in plain terms, "stare you in the face": i.e. those that persist, counter to ones will, even if simply drawn as fixed patterns on paper. These have the benefit that they reduce potential ambiguities and are fairly easy to produce. Commonly referred to as optical illusions, they mostly involve distortions of a geometric, photometric or chromatic kind. They are particularly perplexing to anyone able to measure the offending pattern and verify interactively that their visual sense is actually misleading them. In some cases, it is the paradoxical element of the illusion that alerts the observer that "something curious is going on".
Indeed, visual illusions are often still considered mere curiosities and have, to date, found little practical application beyond decorative illustration (e.g. Escher prints, *MagicEye* posters, Op-Art, etc), or psychophysical and neurological research. In the latter illusions are often employed as visual stimuli in experiments designed to progress our scientific understanding of the human brain and visual system. Here we propose some provisional applications that we hope may prove useful in both real and virtual environments. This paper is intended as an initial exploration of the various possibilities, rather than a description of a practical implementation of any particular application.

Some physical applications

Visual illusions have been put to use, to some extent, by artists over the centuries. In particular, the recently uncovered "water-color" illusion (Pinna, Brelstaff & Spillman 01) was employed by 17th century cartographers (Bagrow 85) to achieve added coloration while economizing on ink or pigment. A 1916 Kandinsky painting exhibits a lesser form of color spreading. The recently reported rotating wheel illusion and related phenomena (Pinna & Brelstaff 00, Kitiaoka & Ashida 03) might be adapted to a utilitarian end - in complex tasks that involve turning keys and or screws. For example, the wheel in figure 1 appears momentarily to rotate clockwise (CW) when the observer moves their head inwards towards its central spot, and counterclockwise (CCW) when they move their head out again. Trivially, this design could be printed around an existing keyhole to instruct the user which way to turn the key: CW to move in (enter) and CCW to move away (lock and leave). Although, *clockwise-to-enter* is already an established protocol for keys and screws there may be situations where it would be useful to deviate from that. A cryptographic puzzle might, for example, require a cylinder to turned in a precise sequence of seemingly random CW, CCW directions before it would open - rather like the rotating the dial of a strong-box or security vault (Blaze 05). For instance, a nested set of cylinders - like Matryoshka puzzle dolls - could be engineered so that each cylinder requires either a CW or CCW twist to open it - with the appropriate rotating wheel illusion inscribed upon its cap. The puzzle's charm would be that only those in-the-know move their head and receive the visual cue - other see only an additional decoration. Similar instruction might also be fun to use in the classroom, or hands-on learning center, where concepts such as Fleming's left-hand rule need to be grasped (Gregory 98).

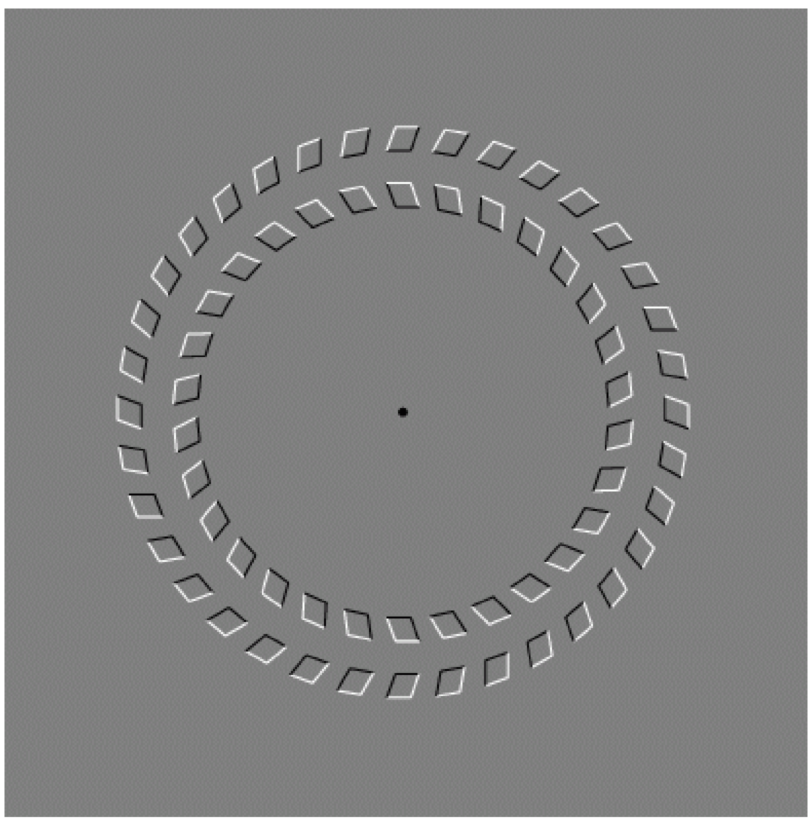

Fig.1: *The Rotating Wheel illusion (Pinna & Brelstaff 00). Gaze at the central spot and move your head in towards it: the inner ring may appear to rotate clockwise. On moving out it may rotate counterclockwise - for possible application in key turning tasks.*

It is not clear whether the illusory rotation beats a non-illusory static circle-of-arrows pattern in most practical situations. For example, the remote assistance of those needing to open locks under duress (fire-fighting, bomb disposal) is probably better served by projecting arrows on to relevant surfaces - not illusory patterns. However, when the participant is in motion (pit-lane, docking, virtual endoscopy) then a rotational illusory cue might some add-value since it alerts as well as instructs the observing human. More fancifully, one might picture a small spacecraft moving and aligning so as to dock with a larger one while needing to rotate in a given direction - which might be indicated by a projection of figure 1 (or its mirror-reverse) onto the docking cylinder. In this case, of course, only human, not aliens, would receive such a visual cue - somewhat, anticipating our discussion below of non-human agents.

Virtual applications: Anti-robot tests

As a failing peculiar to human, or animate, visual systems, visual illusions might be also employed to distinguish humans from robots, "computer bots", or any other artificial intelligence empowered with a visual capacity. Any such artificial entity is unlikely to suffer the same visual illusions as our own, unless, of course, it has been specifically engineered to do so. The approach here inverts, and complements, the logic of the Turing test (Turing 50) since it does not require evidence of an intelligent capacity equivalent to that of human beings, but rather evidence of a characteristic human failing - "*to err is human*...".

Once the realm of science fiction, distinguishing humans from computer-based agents has now become a real problem: with automated bots roaming the Internet gaining access to both intended and unintended information resources. Generally, the gate-keepers of such resources are themselves unattended computer programs and so uninformed whether their client is a benign human or computer-based intruder (e.g. bot, spider, virus, or Trojan). Automated "Turing tests" for human-like intelligence are therefore becoming routine for online registration at web-based email or forum services (Von Ann *et al* ACM 03). These systems, known as CAPTCHA, invoke challenge-response tests in an attempt to determine whether the user is human or not - below we explore how visual illusions can also be incorporated. In general, these tests include quizzes and multiple choice questions designed so only humans should have a good chance of passing them. Despite flouting *W3C accessibility* criteria (May 03), picture-based questions (Von Ann *et al* 04) have become popular because it is relatively quick and effortless for sighted persons, at least, to correctly interpret images while computers typically need considerable resource to do so.

A standard package (PEAR), now included with the PHP web-platform, involves embedding text within images and asking the user to type in what they read. The task is made more difficult for computers by applying geometric distortion and by adding random noise to the images. Although this approach can confound current optical character recognition systems, some generic object recognition algorithms have actually been adapted to solve this task (Mori & Malik 03) in a convincing manner. Thus another more difficult approach, PIX, has since been developed in which participants are required to actually interpret the semantic content of the images presented to them (Von

Ann *et al* PIX 03). They must indicate the "odd-one-out" of four pictures selected from a large database of images. Each image in the database has been pre-assigned to one or more labeled categories by human operators. The test selects three images taken from one category and the fourth (the *target*) from another, and then presents them in a 2x2 image grid. Both category and grid placement are randomized so as to reduce any potential learning cues and tests are continued until participants demonstrate significantly better than chance performance. In effect, candidates here must demonstrate their humanity by their capacity to see and to *think*. However, human web-users are notorious for avoiding, repetitive mental tasks online - especially those involving choices presented on successive pages. Indeed, good web-sites are designed to minimize cognitive load (Nielsen 00). Below we suggest how cognitive load might be reduced by incorporating visual illusions.

Visual illusion and PIX

Some illusions announce themselves simply as being out of the ordinary: although entirely static they are, yet, typically perceived as active or *dynamic*. Notable examples include the activity of the Scintillating Grid (Schrauf et al 95) and the spectacular chaotic movement seen in Kitaoka's rotating snake illusion (Kitiaoka & Ashida 03) - which first-time viewers often mistake for an animated GIF image. Insert such a dynamic illusion as the target image in the PIX system, reported above, and the human observer will be preferentially assisted, with respect to non-human agents, in rapidly distinguishing it. From a robot's point-of-view there is nothing obvious to suggest that the pattern it analyzes appears dynamic - the image file-format is not, after all, that of an animation or a movie. (Nb: the few illusions present in the PIX database are not dynamic nature - being mostly Penrose triangle variants.) However, two practical problems confound the direct adoption of such dynamic target images: (1) They are generally mediated via peripheral vision and so need to be quite large - here the lack of available "screen real-estate" on the web-page may be the main problem, not the bandwidth: each such image is generally made up of a spatially repeating pattern that once downloaded can graphically tiled, as required; (2) Robots might be programmed to defeat the system by recognizing them as one of a small set of specific patterns using special case analysis.

In the latter eventuality, in order to keep the adversarial barrier high, (a) the target should be drawn, at random, from a large pool of different dynamic images, and (b) the non-target images should, as much as possible, correspond in structure to the chosen dynamic target, while remaining entirely inert in illusory terms. It is not clear, however, whether this can be practically achieved for stimuli like the Scintillating Grid or Kitaoka's snake: they do not seem to manifest a sufficient number of manipulatory degrees of freedom. The Cafe Wall illusion may offer some viable alternatives - with no modification of image structure beyond uniform contrast reversal (negative image) the direction of its illusory tilts will flip from right to left, or vice versa. Its many variants are capable of producing easily seen, if not highly dynamic, illusions. Widely varied in form, they may be precisely choreographed according to several recently established graphical rules (Kitaoka, Pinna & Brelstaff 04). In particular, by manipulating the contrast polarity of their constituent micro-elements it is possible to switch between active and inert forms - again without otherwise altering underlying image structure. Two distinct types of illusion can be manipulated in this fashion: (1) those that invoke apparent tilts between physically parallel lines (classical Cafe Wall stimuli), and (2) those that appear to produce curves or wavy lines from entirely rectilinear structures (chessboard-like patterns). Figure 2 shows an active and inert form of each type.

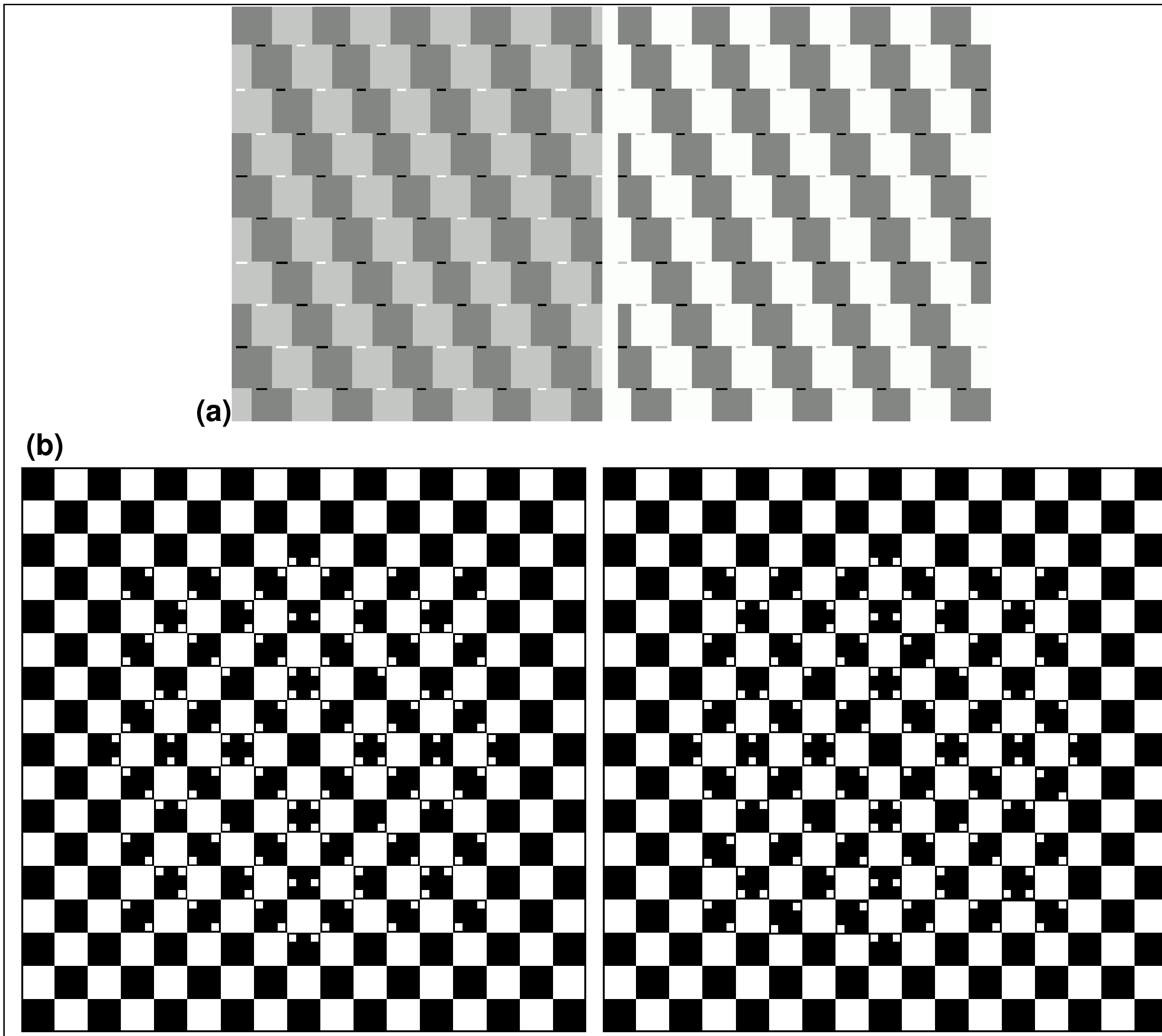

Fig 2: *Active (left) and inert (right) forms: (a) classical Cafe Wall stimuli, and (b) Kitiaoka's chessboard-like patterns.*

Integrating either of these types into a PIX system would require a software component to automate the generation of each image: in its active form and as three inert counterparts. This could be a threefold process:

1. Calling conventional 2D computer graphics routines to render an underlying image structure as a spatial ensemble of micro-elements.
2. Randomizing this ensemble, in some way, to ensure a different image structure every time. This may include image rotation about an arbitrary angle and jittering of spatial location of each micro-element.
3. Assigning contrast polarities to the constituent micro-elements. Here the rules

governing the illusion must be implemented so that only one of the four images rendered is illusory.

A web server might implement this as Perl/PHP module much like the PEAR package.

Illusory Steganography

Visual illusions might also be used to hide information in a basic form of steganography whereby only those observers that “suffer the illusion” would be able to decode the hidden content. For example, a sequence rotating-wheel images could be used to encode a binary number – the apparent direction of rotation of each successive image would signify either 1 or 0, being CW or CCW. To uncover the number each image would be examined in turn and the results collated. As a task in a CAPTCHA system this would likely be too error-prone since the human participant would have to shift gaze and loom in and out repeatedly while remembering each result. A less arduous approach might use the direction of tilt seen in a Cafe Wall image as the binary code – see figure 3.

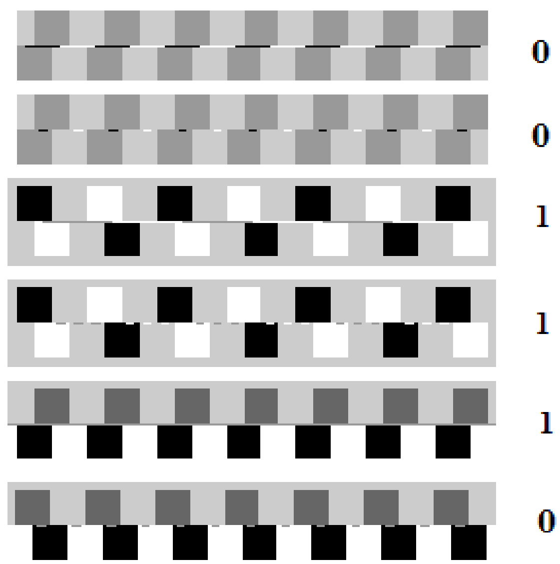

Fig. 3: *Steganographic image that hides a binary code:* **001110** *- using CCW illusory tilts to encode* **0** *and CW tilts* **1** *- reading downwards.*

Discussion and Conclusion

Greater attention has generally been paid to how best *avoid* the unintentional abuse of visual illusions rather than their practical utility. For example, isoluminant colors should be avoided in sign-writing, Mach bands ought not to appear in diagnostic images, and illusory cues should be absent from cockpit, augmented and VR displays (Pitts 67, Bülthoff & Van Veen 01). Here, practical applications, involving on-line authentication, have been our main focus. Clearly, our approach stays ahead of the game only as long as non-human agents are not programmed to understand how illusions affect human vision. Since the various processes occurring along the visual pathways of our brain remain somewhat mysterious, even to visual scientists, some hope persists that this understanding may denied from non-human agents. Nevertheless, the particular Cafe Wall-based PIX system outlined above may not have long to hide since recent research (Kitaoka, Pinna & Brelstaff 04) reveals how existing image processing techniques might be coordinated in order to predict perceived illusory tilts. That solution involves applying spatially and directionally tuned band-pass filters while recording a spatial map of the resulting peak responses. The magnitude and direction of the illusory tilts are then estimated by fitting lines through neighboring peaks in that map.

Several factors differentiate the solution above from one that would naturally result from the application of generic computer vision algorithms as propounded by Mori and Malik (Mori & Malik 03). Firstly, the band-pass filters must be very precisely tuned, and elongated, so as to maximally respond to the mortar of the Cafe Wall - at the expense of any other image feature. Secondly, the system must bizarrely override veridical tilt cues that occur at earlier levels of processing (c.f. retinal or cortical hyper-column) with those extracted later from a second directional derivative image. The *ad hoc*, counter-intuitive nature of the solution for this particular class of visual illusions suggest that it may well be worth while further escalating the authentication arms race by exploring the applicability of other classes of illusions. For one thing, it would boost research into vision science by a community (hackers) that has until now applied its intellectual effort to a somewhat less worthy cause.

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