CONTRIBUTIONS TO CONTRAST AND MOTION VISUAL ILLUSIONS

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Contents

1 Overview

(Included in the web site http://www.lps.ens.fr/∼ninio) Updated September 28th 2016. Jacques Ninio is emeritus director of research at Ecole Normale Supérieure, Laboratoire de Physique Statistique, 24 rue Lhomond, 75231 Paris cedex 05, France

My main interest, in the field of visual illusions has always been, starting in 1975, understanding the geometrical principles underlying geometrical visual illusions. Nevertheless, I took part in the design of several new contrast or motion visual effects, the best known being the "extinction effect", co-authored with Kent Stevens. The discovery of the new effects was produced by the conjunction of several factors:

i. I had a long experience with computer graphics programming. This competence was developed for the purpose of designing new stimuli for stereoscopic vision [1]. Having from my engineering studies a good training in analytical geometry, and from my early research work in molecular biology a good training in computer programming (see Section on Bioinformatics), writing computer programs to generate whatever figure I had in mind, and making a large number of variations on this figure was rather easy for me.

ii. I was also sollicited to write review articles in popular science magazines, and I also wrote a book on illusions [2]. Instead of asking various authors the permission to reproduce their stimuli, it was just as easy to generate the figures myself, so I had in store a wide collection of computer graphics programs to generate all kinds of visual stimuli.

iii. Occasionally, attending an ECVP (= European Conference on Visual Perception) meeting, I became acquainted with a new visual effect, and wished to try my hands on it.

iv. For reasons that have always been incomprehensible to me, most image designers in the field of visual perception were restricting themselves to stimuli with only horizontal and vertical orientations. The Hermann grid, with its array of squares separated by horizontal and vertical alleys is an example of this trend.

The immediate question which comes to mind is: What are the really important geometric constraints thar are necessary to produce the effect ? The question is almost never raised in the field of visual perception, so "theoreticians" produce models that rely on the usual geometry of the stiumuli. These models can in general be disproved at once by constructing a stimulus that produces the same effect, but does not follow the geometric constraints deemed to be essential to the model. So, I had a practice of fiddling with the geometry of the stimuli to sort out the really important constraints (for instance, in the case of the Hermann grid: would it work with a hexagonal or a triangular lattice, instead of a square lattice ?).

2 Extinction effect

Very few people in the field of vision research have a serious background in geometry. Jan Koenderink, Kent Stevens Johan Wagemans or Jacques Droulez are among the rare exceptions. I met Kent Stevens at a meeting on stereo vision organized by Ian Howard in Toronto in 1993. I knew some of his classical papers on how the brain interprets 3D from line drawings (for instance [3]) and we had a nice discussion at the welcome cocktail. In 1997, I was in the USA as a tourist, and I seized this occasion to pay a visit to his lab at Eugene, in Oregon. On the same day, I paid a visit to Frank Stahl, a molecular geneticist at the same university , both of us being interested in unorthodox mutation mechanisms, and the so-called problem of "adaptive mutations" — See Section on mutation strategies and molecular evolution. I suggested to Kent that it would be nice if he came to Paris for a few months or for a sabbatical period in my laboratory at Ecole Normale Supérieure.

He seemed pleased at the prospect. Ultimately the trip materialized. Kent spent a month in Paris (June 14th - July 13th, 1999). At that time, he had nearly abandoned vision, and was working on modelizing the posture and the gait of dinosaurs. Since Kent had worked in the past on the link between receptive field modelling and contrast illusions of the Munsterberg family, in which there is a strong geometrical component ([4]), I proposed to him to investigate, in the same spirit the link between possible neurophysiological architectures and another contrast illusion — the Hermann grid illusion. At the time of our study, the state of the subject was the following: The Hermann grid was known in its standard form, with squares separated with horizontal and vertical alleys, and a number of fine observations had been made on the subjective grey-level distributions (review in [5]); Bergen had described a very spectacular phenomenon at an ARVO meeting in 1985: when a Hermann grid is made fuzzy by the removal of the high frequency components in the image, the crossings of the alleys start to scintillate [6]. The phenomenon was easily demonstrated on a computer screen, but Bergen did not produce a convincing paper version of his illusion. Then Schrauf and co-workers [7] produced a modified Hermann grid with black squares separated by grey alleys, having white disks at the intersections of the alleys. Scintillation could be seen inside the disks. There were mathematical models of the Hermann grid [8] but these were based on the square lattice geometry of the grid, and since this configuration had not been shown to be in any way necessary for the effect, these models counted for nothing.

Both Kent and I were aware of the existence of Schrauf's scintillating grid, but we were unaware of Bergen's contribution. On the first or the second day of his visit, Kent produced a fuzzy Hermann grid, and rediscovered Bergen's effect. We were both very excited, but ultimately, reading carefully Schrauf's paper, I found there the reference to Bergen. In any event, we had at least two phenomena to consider: the pure Hermann grid effect, and the scintillation effect, and did not know whether they were two aspects of a same phenomenon or not. So I proposed to study systematic geometric variations of the Hermann and Schrauf grids in parallel, trying to determine whether or not there were common geometrical requirements for the two phenomena (for instance, could it be the case that if one replaced the square lattice by a triangular one, one of the two effects would persist, while the other effect would vanish ?).

Kent was mainly working on some project he had with a private company, and in relation to our work, he was suggesting a number of variations to try. I was doing the computer graphics, and producing stimuli by the dozens. I would examine them, show them to Kent, and we would confront our reactions to these Hermann and Schrauf's grids variants. On one occasion, making a variant in which Schrauf's disks were smaller than usual, and the grid was rotated by 45 degrees, I noticed something strange. When I later gave the stack of stimuli to Kent, he almost jumped to the ceiling. He had made the same observation. He said "do you see what I see?" and found that extremely interesting. That was it! In the extinction effect, black or white disks which are at the crossings of grey alleys simply disappear. The trick was to surround a white or black disk by a band of opposite colour so that the disk + the band had an average grey level coming close to that of the crossing alleys. When the eye is fixating a particular portion of the image containing disks, the disks are well perceived, but the disks which are away from the fixation point are not perceived at all, and instead one perceives continuous grey alleys which had been completed as in the case of alleys going across the blind spot. Our interpretation of the phenomenon was that objects at the periphery of the visual field do not catch attention, unless they have a sufficient local contrast with their surroundings.

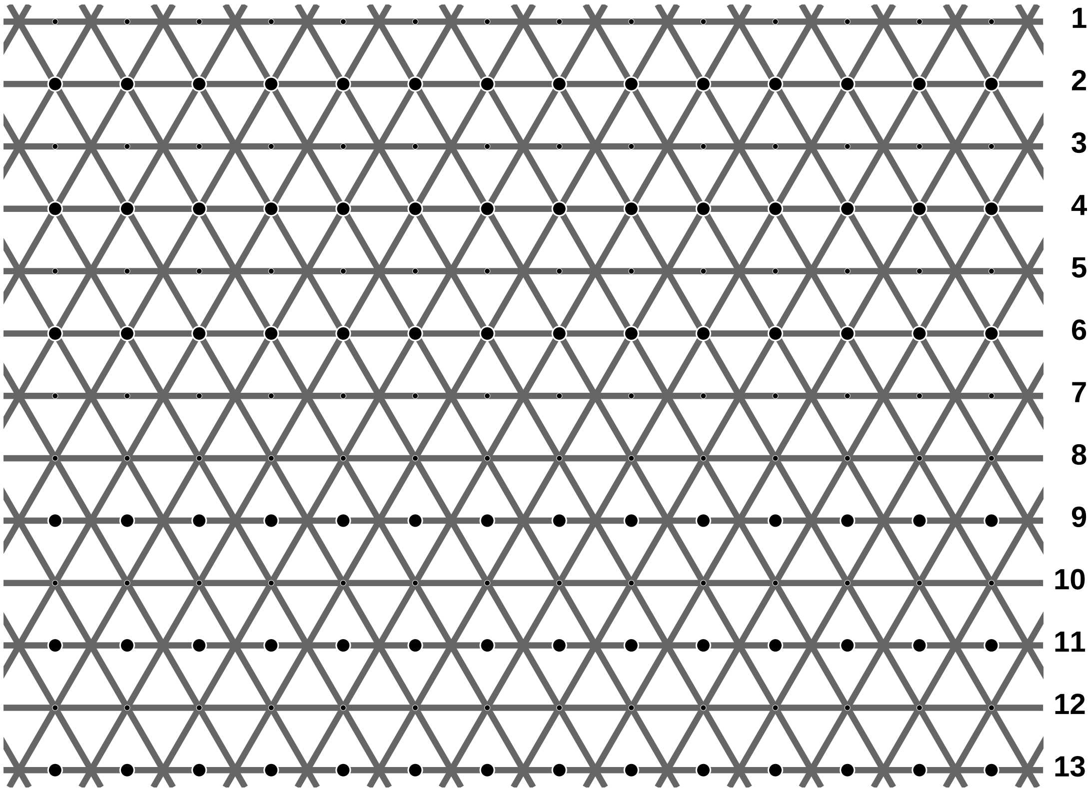

Figure 1: The extinction effect on a white background.On lines 9, 11, 13, containing disks half-way from alley crossings , all disks are seen, while many of them are extinguished on lines 2, 4, 6, irrespective of their size, when they are situated at the crossings. One sees only a few of them at a time, in clusters which move erratically on the page First published as Figure 5 of [9]. Figure 4 of [9] was the same pattern, but with the opposite grey levels.

It would not be a question of central versus peripheral acuity, but a question of contrast thresholds. After that, it was almost child play for me to produce the more effective version of the extinction effect, with a triangular lattice (see here Figure 1), which was later published without difficulty in Perception [9]. A reviewer (who else than Nicholas Wade could it be ?) made an extremely pertinent link between our paper, and an earlier informal observation in a natural environment, made by Jeremiah Nelson, also published in Perception [10]. Nelson quoted an earlier paper by MacKay[11] on the fading of details in peripheral vision, and the tendency to perceive an arrangement of dots as more regular than one should.

The Ninio-Stevens paper contained a number of original features. It included for the first time a version of Bergen's scintillation effect which really worked on paper. This was obtained by introducing a "fuzziness gradient" in the image, so that people sensitive to the effect at different levels of fuzziness could all experience the phenomenon. Next, we mentioned the main geometrical constraint needed for the Hermann grid (the facilitatory effect of alignments of the crossings "may be mainly mediated through thre local lengthening of the branches of the crosses") and produced a quite sophisticated version of the Hermann grid (Fig. 1 of [9], top right panel) showing when the effect is, and when it is not produced. Four years after the publication of our article, which did not go unnoticed, there was in "Vision Research" a paper by two persons from the USA claiming that they had discovered a "new visual phenomenon", to which they gave the name of "blanking phenomenon". The paper was published during the dark era of the presidency of George Bush Jr in the United States, an era of arrogance towards the civilized world, an era of ruthless lies and appropriation of foreign property. McAnany and Levine's paper [12] came logically within the political context of this period. What is strange is that not only the authors dared to submit their paper in a scientific journal, but also that there were reviewers who tolerated the publication of this work. Very kindly, Akiyoshi Kitaoka noted in his website that he did not see in which way the "blanking phenomenon" was anything else than the previously published extinction effect.

Later, Araragi and Kitaoka [13] made a chronometric study of the illusion, showing that the illusion takes some time to dvelop. For me, this suggests the following speculative interpretation (1) During a very short period of time, the brain has access to the complete grey-level distribution. There would be no illusion, from this point of view. (2) But when the eyes focus on a few dots, the "scene" is recalculated, and there is some grey level averaging on the periphery, unless some feature attracts attention. (3) The correct interpretation of stage (1) does not reach consciousness, a kind of phenomenon know in memory studies. Then an extinction effect was recently described for a quite different pattern. Bertamini, Herzog and Bruno called it the “honeycomb” illusion [14]. The phenomenology is the same: parts of the figure are seen sharply at the point of focus of the eye, whereas details are lost in the periphery. We do not know as yet whether or not there would be a set of successive steps through which one pattern might be transformed into the other.

The extinction illusion became sudddenly popular in September 2016, when Akiyoshi Kitaoka published in his Facebook chapter a variant of Figure 5 of [9] that was suitable for display on the mini screen of a smartphone. Within a day it was downloaded 7,000 times, then Will Kerslake advertised it on twitter on Sunday September 11th, and received 27,000 reactions by Monday morning, then it was shown on BBC news on September 12th, and it has then be spreading like fire over the whole planet.

3 Flashing lines

Among the hundreds of variants of the Hermann grid I had produced during Kent Stevens stay at Ecole Normale Supérieure, I had tried distorted square lattices. How straight the alleys needed to be to produce the Hermann grid effect? I knew already that the alleys could be curved, (Fig. 6-6 in [2]) but what about more severe disruptions of continuity? I therefore tried several types of distorsions. So I used a matrix to produce periodic shape distorsions in the square lattice. In one of them, I noticed an effect which was much less impressive than the extinction effect, but which had perhaps more profound implications. I published it under the name of "flashing lines" [15].

Here, it seems that the brain picks up correctly some geometric feature in the figure: There are many white patches across which straight lines can go through. However, the lines cannot be white all the time, they are interrupted by black patches. So, it is like

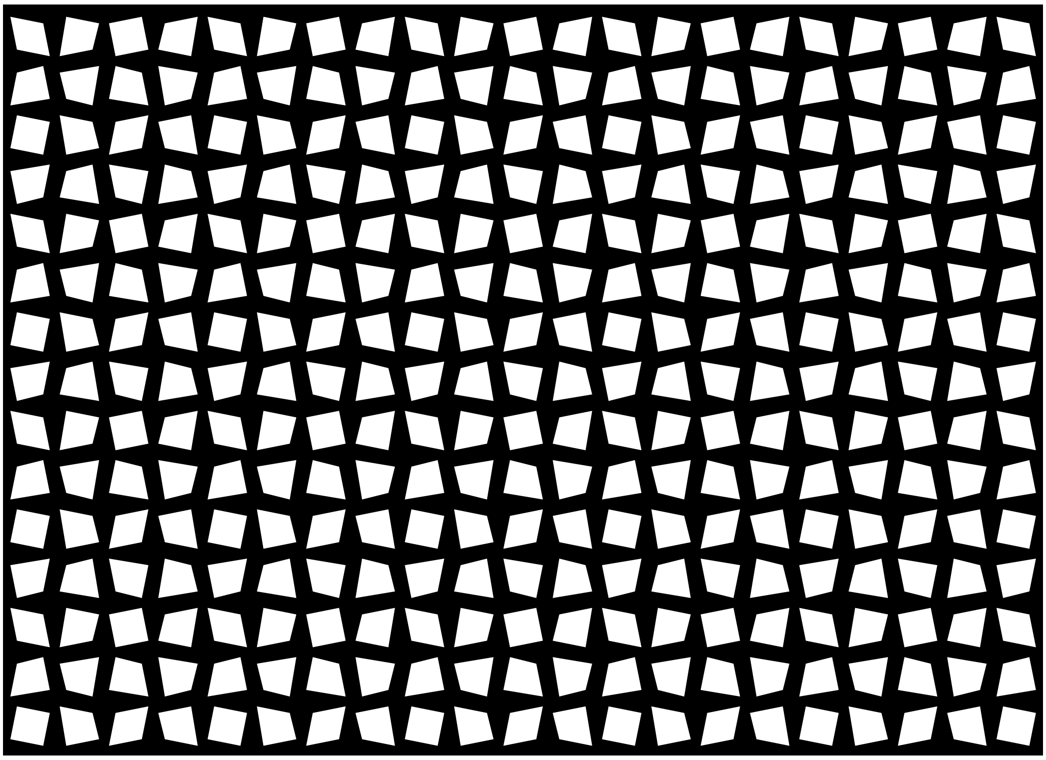

Figure 2: Flashing lines. Two sets of bright lines are seen pulsating at about 30 degrees and 120 degrees with respect to the horizontal. Reproduced from Figure 2 of [15]

having dashed white lines, and the brain so to speak alternates between perceiving a continuous white line, or not perceiving it at all. The same phenomenon also exists in the opposite contrast.

4 Orientation-dependent contrast

I do not remember the precise motivations which made me design the stimuli giving rise to this effect. The basic observation was made on arrays of patches, each of which containing stripes at three different levels of grey and a single orientation. The figure contained two types of patches, differing only by the orientation of their stripes. While one family of patches, with stripes at one of the orientations seemed to be sharply contrasted, the patches having stripes at the other orientation had a washed out appearance. So, in this type of displays, the perceived contrast of a striped pattern depends upon the orientation of the stripes. People might immediately think that this is simply revealing some kind of astigmatism of the eyes. However, if this were the case, it would imply that a substantial fraction of the population have a form of astigmatism which is not usually revealed in current ophthalmological tests. I tend to believe that the orientation-dependent contrast is a real perceptual phenomenon. Old stimuli for the study of visual perception were often high contrast pure black and white figures. With the development of computer tools for graphic design, it is becoming very easy to produce high quality figures that use several intermediate levels of grey, in addition to black and white, and this boosted the emergence of a new generation of visual effects. The orientation-dependent contrast effect was described in [16]. The article also contained a figure showing a misorientation illusion, occurring when black or white lines went diagonally across a square tiling pattern, composed of striped tiles, in which the tiles had horizontal or vertical stripes in alternation (See section on geometrical visual illusions).

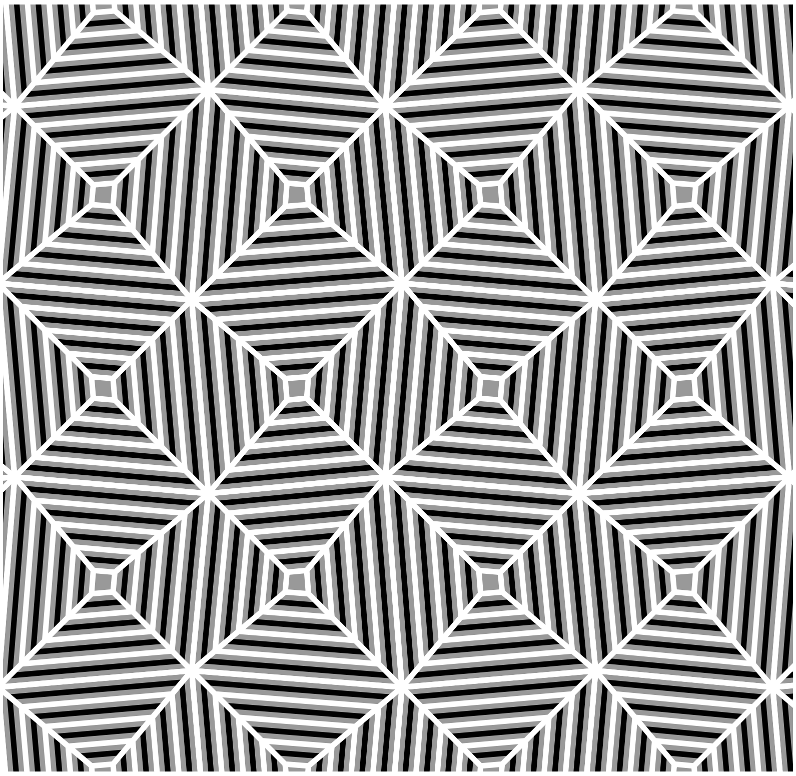

Figure 3: Orientation-dependent contrast. To most observers, the grey-level range appears narrower, either in the domains with horizontal stripes, or the domain with vertical stripes. One type of domain appears well contrasted, and the other type appears toned down, although the stripes in it are seen with normal resolution.

5 Ouchi variants

At ECVP 1994 in Eindhoven, I listened to a talk by Nicola Bruno in which he described the work he had done with Paola Bressan on the Ouchi illusion [17]. I was fascinated by the talk, and all the experiments which the authors had performed to characterize the effect. For incomprehensible reasons, the work could not be published at that time in a regular journal, but a much inferior work, by other authors, soon appeared in Vision Research in 1995 [18]. After this talk, I designed hundreds of variants of the Ouchi illusion. Two among the innovative variants were published in a popular science magazine [19], then in my book on illusions [2]. In one of the variants, I showed a section containing several distinct orientations, which was cohesively floating on a background also containing several distinct orientations (See Figure. 4). Presumably, it is not the orientation content of the figure and the ground that matter most, but how the orientations connect at the frontier between figure and ground. This seemed to me to be an important point, but new stimuli, invented by Baingio Pinna and Akiyoshi Kitaoka, with circles or squares, showed that Ouchi-like motion effects did not require an encounter of two orientations on the two sides of a border. This made my contribution obsolete.

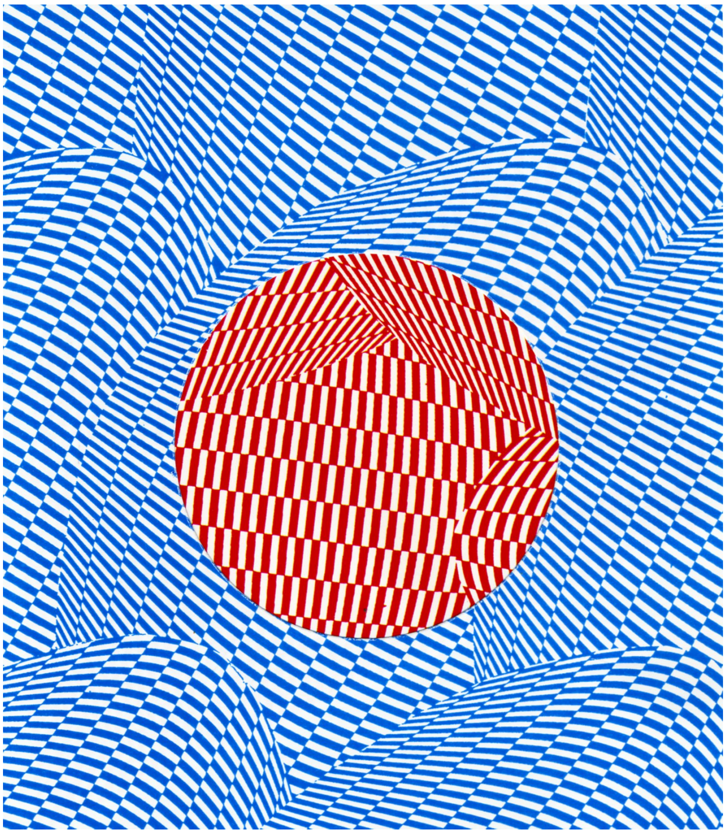

Figure 4: A variant of Ouchi pattern. When the page is moved with back and forth translations in the ascending diagonal direction, the central red disk appears to move independently of the background (19). See also color plate 1 of [20] for a more ludic pattern, in which a form with holes moves above nackground.

The other variant was a stereogram representing a truncated cone (a lampshade shape) above a flat background. Both were represented with striped textures typical of Ouchi stimuli. The cone is perceived as floating in 3D (Fig. 5). Whereas it was already known that the Ouchi effect worked in stereograms, this had been demonstrated for a flat figure over a flat ground. In my stimulus, the stereoscopic interpretation had to be carried out one step further, since a 3D shape had to be assigned to a figure in depth.

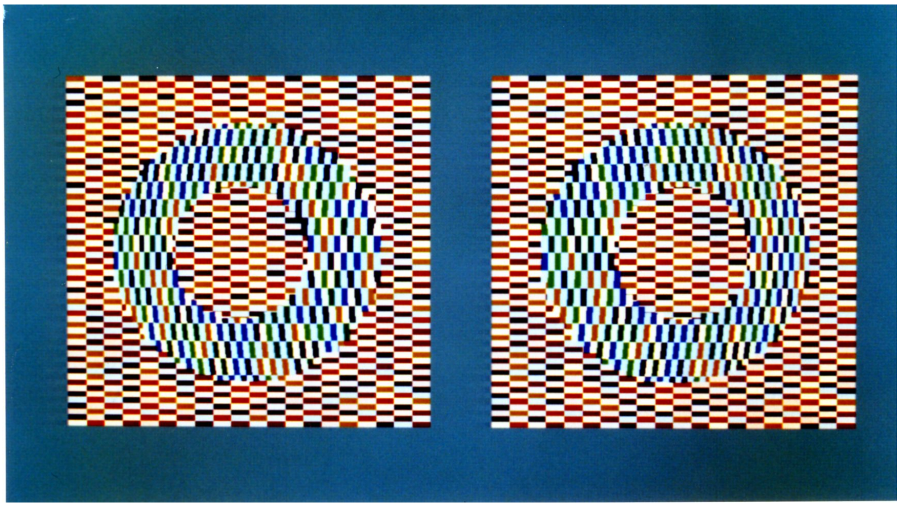

Figure 5: A stereoscopic variant of Ouchi pattern. A conical surface is represented at the center. When the stereogram is moved back and forth from left to right, the conical surface also moves, but with some independence with respect to the background. First published in [19].

6 Hula-hoop illusion

I was looking for a variant of the Ouchi illusion which would work by rotation instead of working by translation. I produced the pattern in Fig. 6, page 10, which has interesting properties, whether one wishes to call it an Ouchi pattern or not. If this image is represented on a sheet of paper, and you submit the sheet to a rotating motion, without changing its orientation (the way you would move a cup of coffee, to dissolve the sugar in it) the inner circle, which is at the frontier between the striped patterns is seen to move with respect to the outer frontier of the image. If you move the sheet at the right speed, you can carry the inner circle in the rotation, and see it move as a hula-hoop around the hips. The pattern appeared as Fig. 11.6 in [2]. It was reproduced with its legend (but without indication of origin) in an American book of illusions.

7 Lagging shapes

More generally, when striped patterns are separated by a curve, and you move the figure, you can observe lagging motions of the curve. An example (Fig. 7, page 10) was shown as Fig. 3 of [21] and Fig. 3a of [22].

8 Gliding circles

In the figures prepared to demonstrate the extinction effect (Fig. 4 and 5 in [9], and Fig. 1 here), I included very small disks, to show that the extinction effect was not due

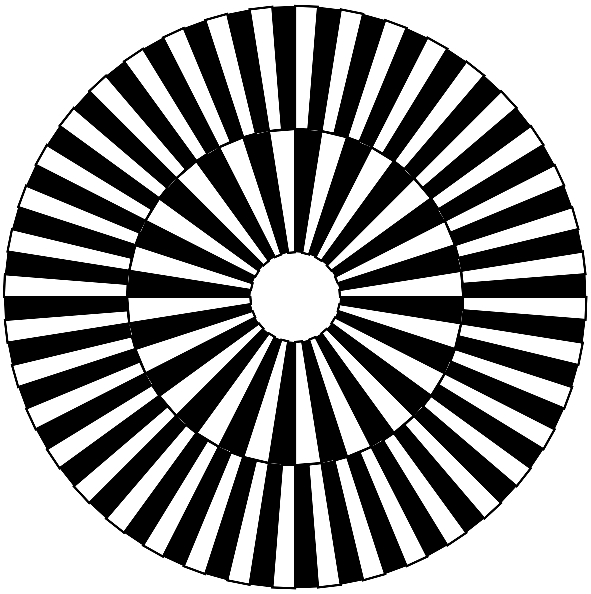

Figure 6: The vagabond circle, or "hula-hoop" illusion. When the page is given a wide, quick circular movement (the kind of movement given to a cup to rinse it or to dissolve sugar in it) without changing its orientation, we see the intermediate circle move along with this movement, like a hoop being spun slowly around the hips. We also see subjective colors near the center. First published, in a slightly different version, as Figure 11-6 in [2].

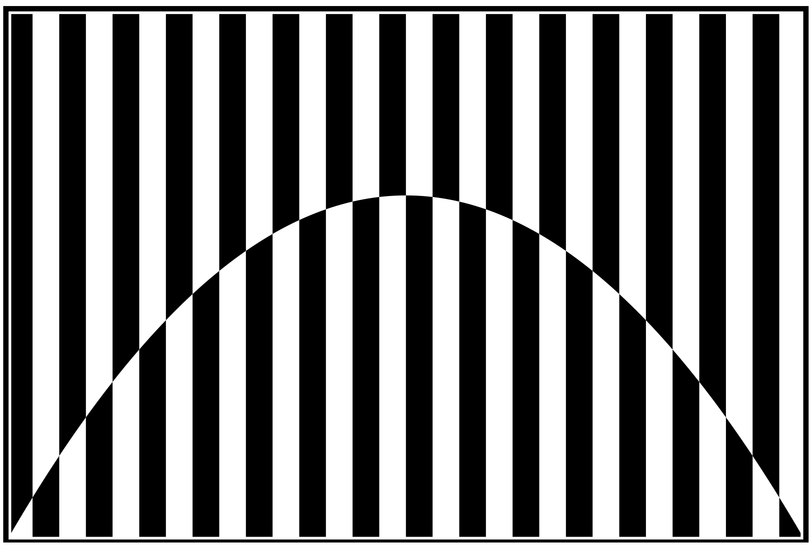

Figure 7: Lagging shapes. Move back and forth horizontally the pattern. The border between the two families of stripes moves in the opposite direction. Shown e.g., as Figure 3a in [22].

to insufficient spatial resolution. I noticed that when the figure was translated back and forth in the direction of the numbered lines carrying the small disks, they were perceived as gliding back and forth between the two closest crossings. The effect was mentioned in the legend to Fig. 4 in [9]. It is shown here for its own sake in Fig. 8, page 11, and it was also published in [22] and in the Japanese edition of [2].

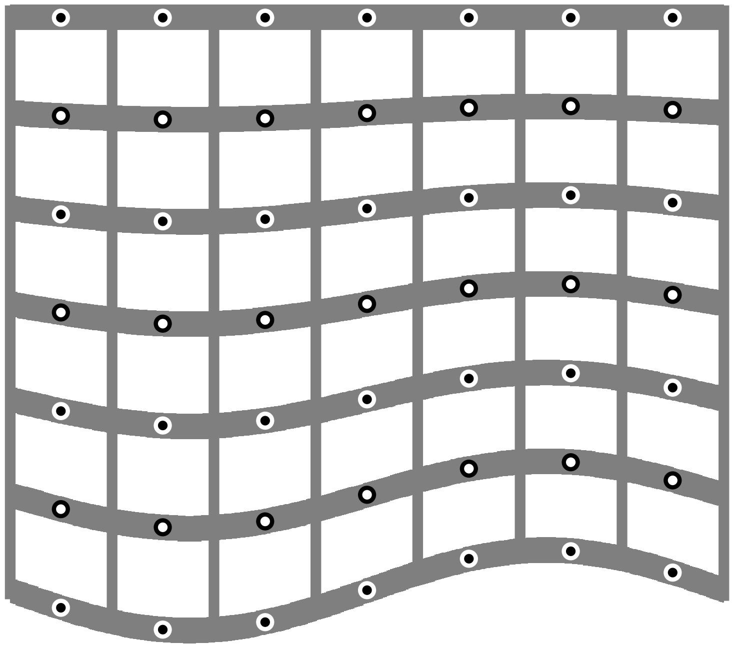

Figure 8: Gliding circles. If you give small horizontal pushes to the page, you will see disks glide in their grey corridors in the interval between the closest grey vertical stripes. Shown, e.g., as Figure 3b in [22].

9 Color-emitting wheels

I do not remember the origin of this pattern. When the sheet on which this pattern is printed is moved in the same way as for the Hula-hoop illusion (as for dissolving sugar in a cup of coffee), the various black, grey or white rings can be seen rotating like wheels, and a subjective colour may appear at the center (Figure 9, page 12). The pattern was published in Fig. 2 of [22] and in the Japanese version of [2]. For a long time I had been interested in producing an equivalent of the Benham top, that did not require a motor. This color-emitting wheel might well be a step in this direction.

10 External Mach band illusion

Vasarely painted several pictures in which squares of uniform colour but different saturations are positioned one inside the other, as in Figure 10, page 13. Here, the color is increasingly darker from the most external to the most internal square. As one moves away the pattern, making its apparent size smaller, one sees thicker and thicker dark

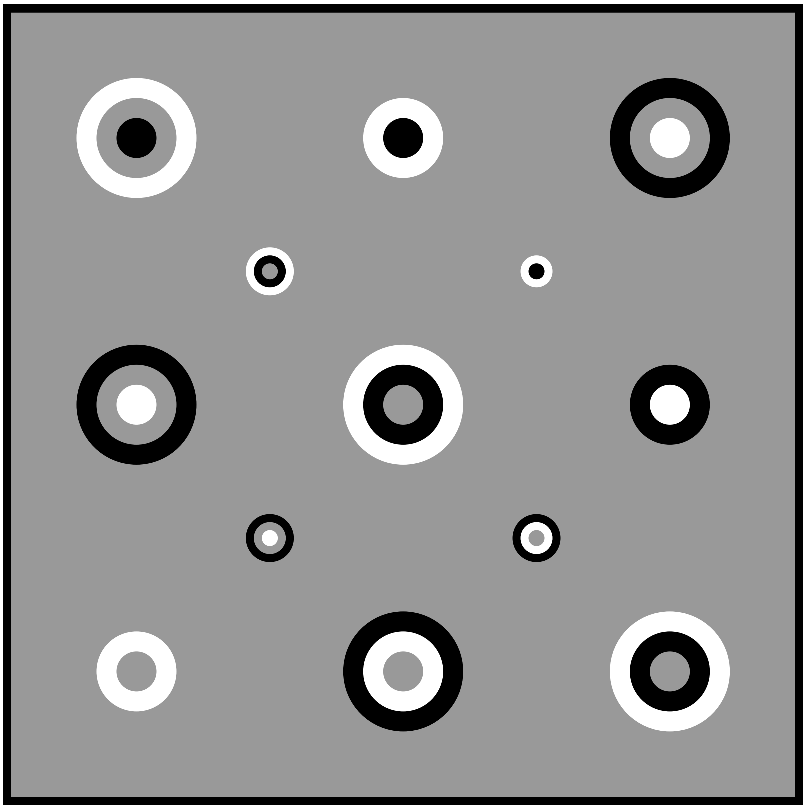

Figure 9: Color emitting wheels. Move the page as for Figure 6, by rotation without a change in orientation. At small amplitude, the extrenal bands of the larger disks appear also to rotate, and one can see illusory colors in the center. At larger ampllitudes, the small disks move and leave comet-like tails.

lines along the diagonals. These belong, in all likelihood, to the Mach band family. In traditional Mach bands, there is a grey level ditribution as often produced by the shadow of an edge, and it is as though the brain added a dark or a clear line to signal emphatically the presence of the edge. The originality, in Vasarely's Arcturus pattern, is the presence of the aligned apexes of the nested squares, and it is as thouh the brain emphasized the alignments. This is reminding of the flashing lines illusion (Figure 2) in which the brain captures hidden geometric alignements, and produces pulsating bright lines.

When the darkness of the nested squares goes in the opposite direction (from dark outside to clear in the centre), the "edges of the pyramid" are bright instead of dark. Susana Martinez-Conde produced an obvious variant of the nested squares, a pattern with nested stars of increasing or decreasing brightness, from the centre to the periphery. There was again a production of bright or dark illusory lines, connecting the apexes of the stars. To me, this was an obvious complexification of the nested squares pattern, but for reasons incomprehensible to me, Martinez-Conde claimed to have developed a novel visual illusion the "alternating brightness star". For instance, she and her colleagues wrote [23] that "the same corner can be perceived as either bright or dark depending on the polarity of the angle (ie whether concave or convex : 'corner angle brightness reversal').

Wishing to have a closer look at nested star patterns, I used regular shapes, looking like cells with rounded extensions, and obtained dark and bright illusory edges, although the corners in these pattern were rounded shapes. There are four such nested patterns

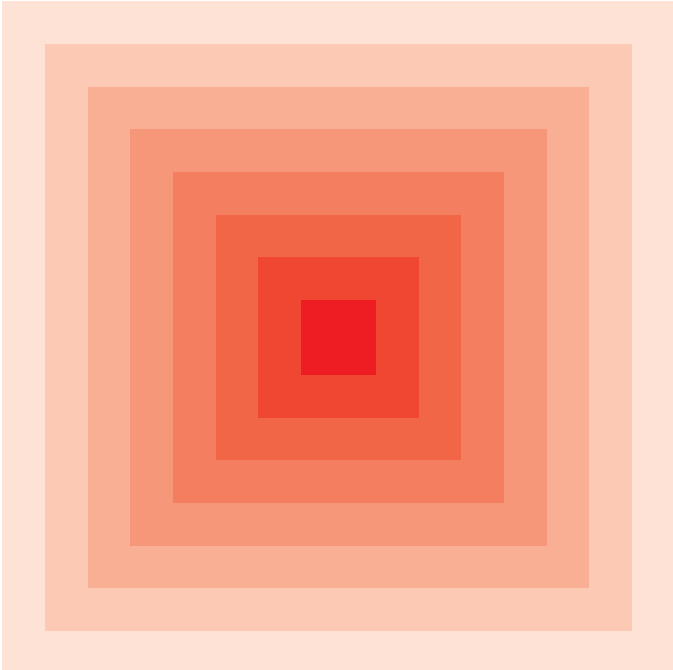

Figure 10: Vasarely's Arcturus illusion. At close viewing, one sees nested squares homogeneously filled with red colour. As one moves away the pattern, making it smaller and smaller in apparent size, one perceives four dark lines connecting the apexes of the squares. The pattern may thus be interpreted as a pyramid, with its edges emphasized by the illusory lines.

in Figure 11, page 14, and one finds there two additional effects: first, there are very bright lines at the region of contact between two patterns, these seem to be instances of Zavagno's glare effect [24] and one effect that seems to me to be aboslutely new : In Figure 11, there are four Vasarely-like patterns, but what is new and unpredicted by current theories is the fact that the whole surface outside the patterns and inside the square frame has acquired a grey coloration. So, it is a case of a contrast phenomenon producing its effect outside the pattern from which it was generated.

11 Color equalization accross a symmetry axis

One of my main hobbies, during two decades has been to produce symmetric patterns from random textures, trying to generate suggestive shapes that would extend as far as possible from the symmetry axis [25]. One day, in assembling in a mirror-symmetric way strips from different photographs of a same texture, I inadvertently mixed strips differing in hue, but did not notice the difference in their hues. I became aware of the incongruity much later, when I made a count of the strips taken from different batches of photographs. So, it seemed, the colour differences between strips were attenuated when strips slightly different in color were symmetrically juxtaposed, as though the existence of a symmetry axis was forcing the resemblance between the two sides of the axis I then explored the insensitivity to hue inequality by preparing computer generated color textures in which the color components were varied in a controlled way. Three pictures were presented in a poster at the 31st ECVP congres in Utrecht [26]. About thirty people reacted to the poster. Most of them were sensitive to the effect, but a few were definitely resistant to

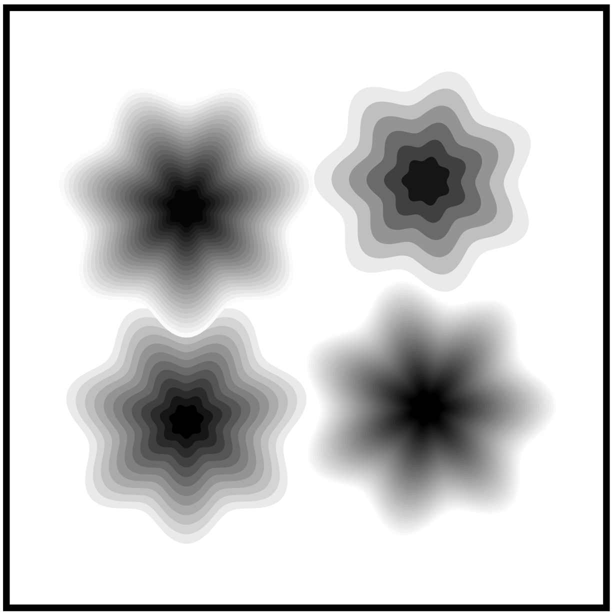

Figure 11: External Mach band effect. On top right, there are nested similar shapes, as in a Vasarely pattern. The number of nested shapes is increased in the three other patterns, and one sees clearly black or dark lines connecting the aligned peaks or troughs. The very original effect in this figure is the the grey level outside the four blocks, and limited by the square border.

it — color vision specialists who could focus sharply on the two sides of the symmetry axis, and detect immediately the color differences on the two sides of the axis. Frederic Boy attended the poster, and suggested that colors were apparently equalized on the two sides of the symmetry axis because the two sides would fall into the receptive fields of the same neurons, and a single color may thus be bound to a receptive field that crossed the symmetry axis. I later published, at the invitation of Chritopher Tyler, an aticle on symmetry perception in which I mainly discussed chronometric data. I included there a section on color equalization around a symmetry axis [27]. An example of stimulus, reproduced from my book *l'empreinte des sens* [20] is shown here in Figure 12, page 15.

In the top, there are 2 pairs of strips with identical motifs. but with moderate differences in colors between the two members of each pair. The two members, are well differentiated when they are observed side by side. The two other images are triptychs. In each image there is a central strip from one pair, and two copies of the mirror-image of the companion strip on the left and right sides, thus creating two vertical symmetry axes. The color differences between the strips in a same panel are attenuated. The structure of the triptychs in contrasted vertical strips does not jump to the eyes. The sensitivity to the effect varies from person to person. A few persons alternate between high and low sensitivity.

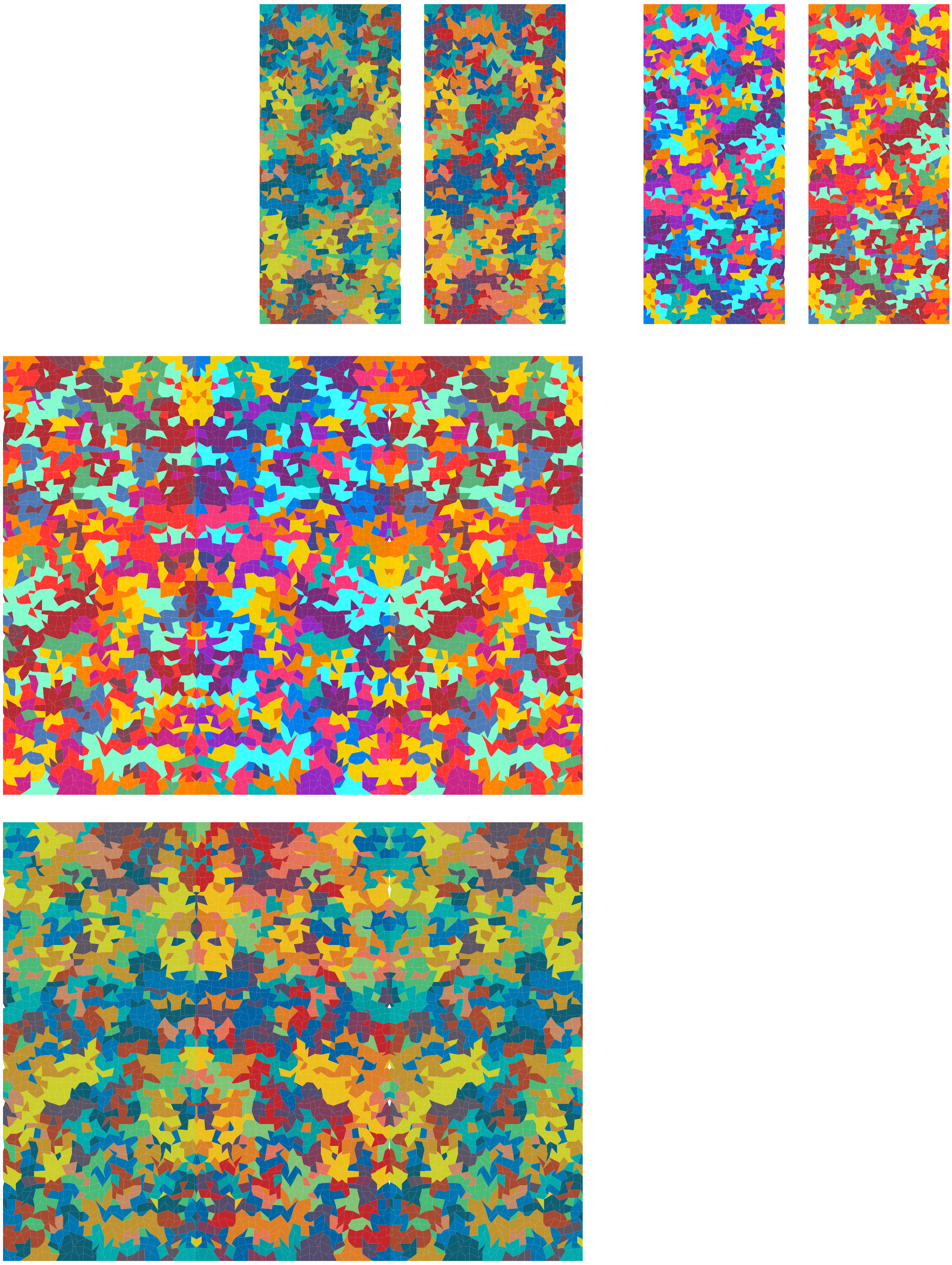

Figure 12: Previously published as colored plate 12 in [20]- see main text, Section 11 for the explanations

In the same book, I show in plate 13 a control without symmetry. It requires greater skill to produce.

12 The colors of grey

This is more a striking demo than a new visual effect. During half a century, grey objects were in fact colored with a neutral grey, a grey in which all color components were almost equal, as in cement or concrete. But a small touch of color can make grey more appealing, and artists easily recognize when a grey is bluish or reddish. Here I show (Figure 13, page 18) that by juxtaposing grey patches of slightly different color components, some of these patches now appear to be vividly colored, contrary to the controls in which they are included separately, within an already colored environment.

13 Colored diffusions

In 1987, Baingio Pinna discovered a striking effect of color diffusion, the "watercolor illusion" [28, 29]. In the examples initially produced by Pinna, there are double contour lines of different colors, facing each other the inside color of a double contour matching the outside color of the other (see the top left panel in Figure 14, page 19). The space between the contours with matching colors seem to be filled with a lighter shade of the same color, although it is strictly as white as the background. The watercolor effect can also be obtained under slightly different conditions. Here, I contribute further variants, which, to my knowledge, have not yet been taken into consideration, and should be useful for a complete theory of the phenomenon (top right and bottom panels in Figure 14, page 19).

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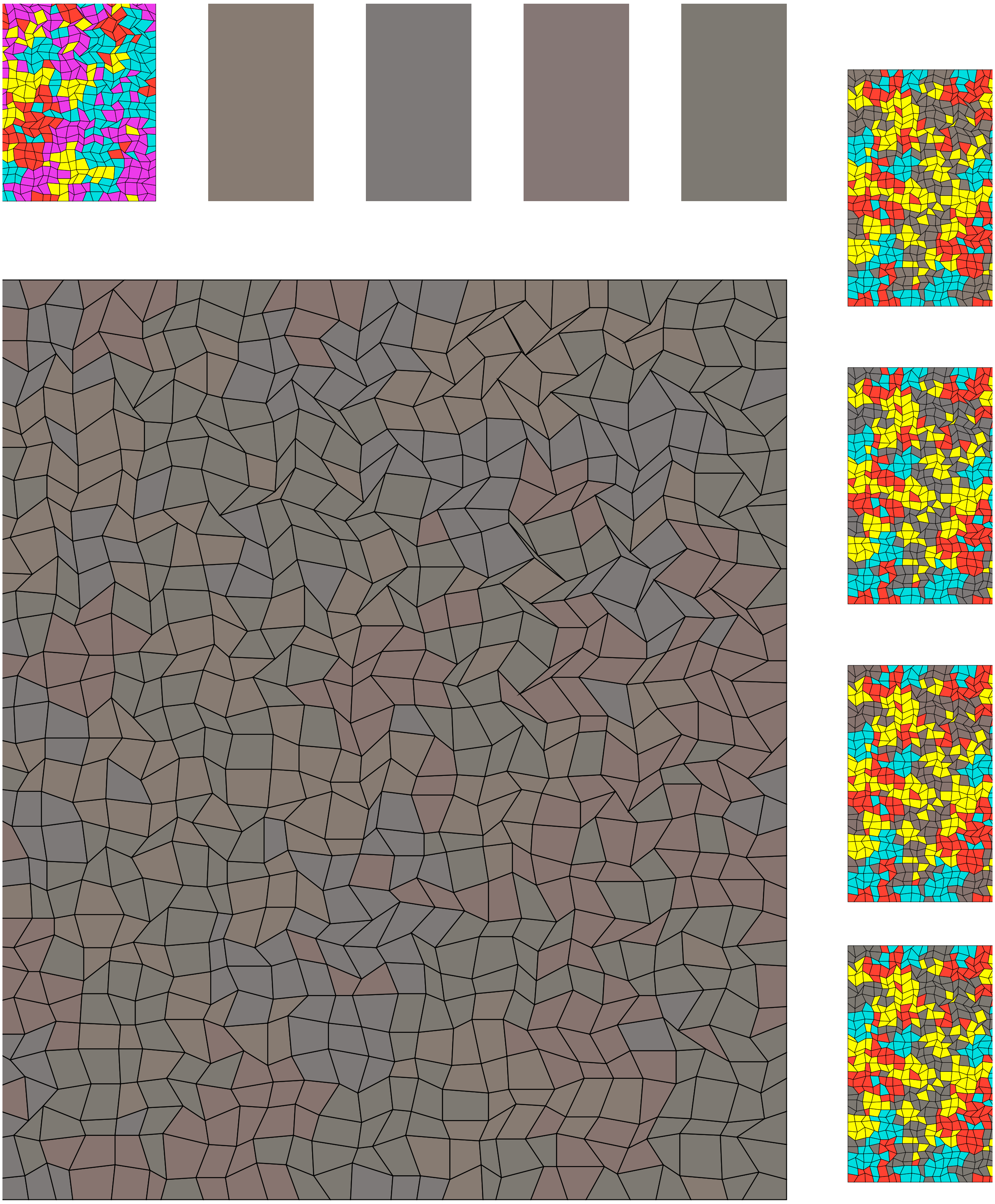

Figure 13: The four vertical rectangles shown at the top have slight differences, of the order of a few per cent in their cyan, magenta and yellow components. The first is slightly yellowish, the second third and fourth have increased cyan, magenta and green components respectively. The four greys of the rectangles were used to replace the violet patches of the top right panel, thus generating the four small squares on the right. Now, the greys are hard to distinguish in their (richly) colored environments. However, when the four greys are juxtaposed in the large panel, their color components become obvious (exaltées), and one can see red or blue patches. Previously published as colored plate 5 in [20].

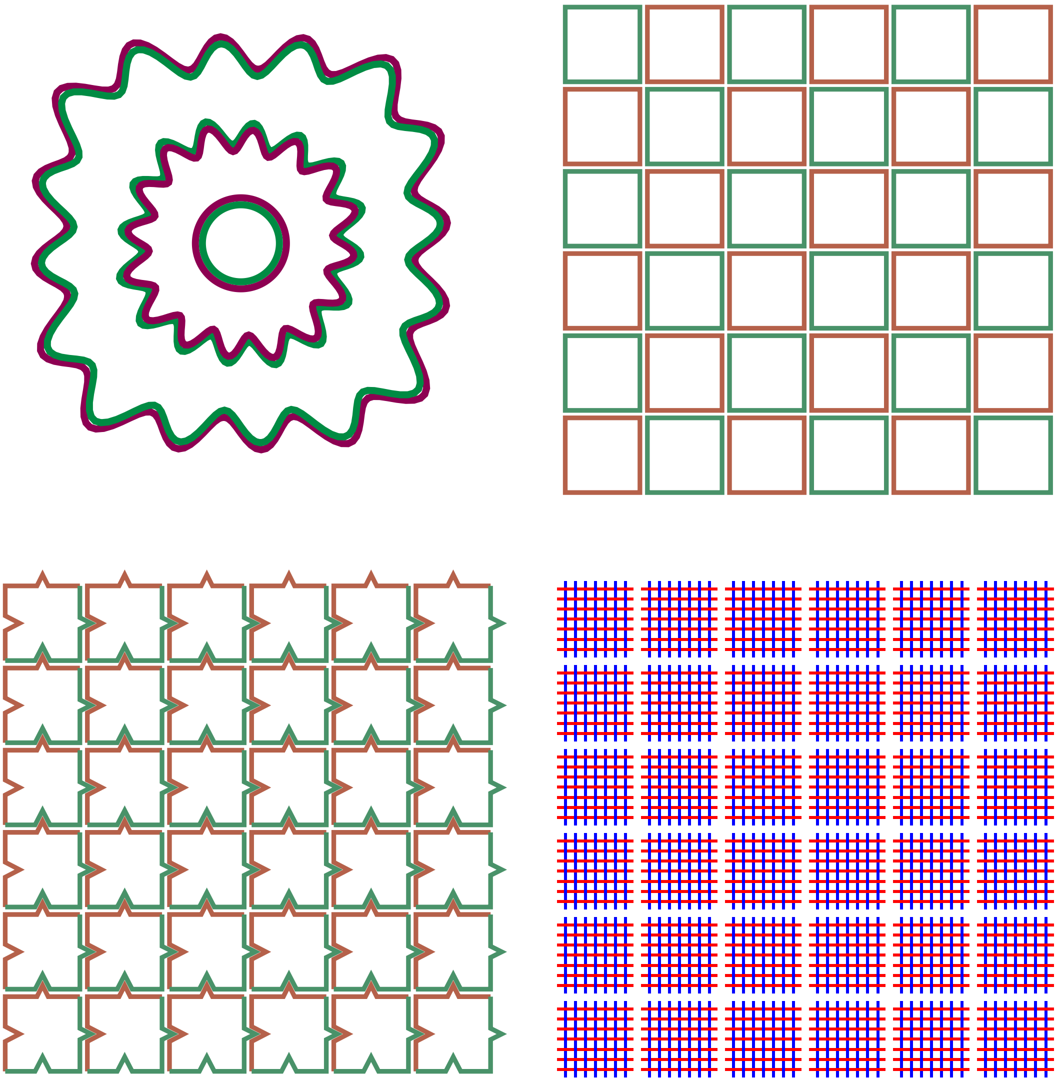

Figure 14: Variations on the watercolor illusion. The top left panel is an example of Pinna's water color illusion. The colored double contours are on a white background, yet the background seems to take the same colors as those of the contours facing each other. The other panels illustrate unusual variations on this theme. Previously published as colored plate 4 in [hh].