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Boundaries, Transitions and Passages

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Abstract

Many pictures are approximately piecewise uniform quilts. The patches meet in transitional areas that have a vague, ribbon-like geometry. These borders may occasionally get lost and sometimes pick up again, creating a 'passage' that partly blends adjacent patches. This type of structure is widely dis- cussed in treatises on painting technique. Similar effects (lost outlines, passages) occur in drawing. The border regions are characterized by width, or sharpness and amplitude – which is the contrast between the patches on each side. Moreover, border regions have various textural structures. We propose a formal theory of such transitions. Images can be understood as superpositions of border areas. Stylistic changes can be implemented through the selective treatment of borders. The theory is formally similar to, though crucially different in meaning from, the theory of 'edges' (a technical term) in image processing. We propose it as a formal framework that enables principled discussion of 'edge qualities' (a term used by painters in a way unrelated to the use of 'edge' in image processing) in a well-structured manner.

1. Introduction

Pictures are surfaces covered with 'colors' in some simultaneous order.1 Here 'color' stands for some pigment (charcoal, paint, ...), pixel value, or what have you. They usually come in 'touches' (French) or 'marks', indicative of the technique (pencil, pastel, oil, ... as the case may be). The 'order' is rarely random; typically colors at adjacent locations are strongly correlated. Here we consider the common case of various mutually abutting approximately uniform areas ('patches' or 'macchia' in Italian2). Many paintings fall in this category when the criterion is applied in a sufficiently sloppy manner. Then, technically, the bulk of the structure is defined by the transitions between the areas. For instance, image compression algorithms have to focus on such transitions, for anything uniform enough can safely be ignored (see review by Marimuthu et al., 2012). Phenomenally, some people primarily report on blotches, others on transitions. As we will show, formally these determine each other either way. A painter may well paint blotches by working on transitions and vice versa.

Depending upon implicit scale (the touches say), patches may dwindle to the weight of the tool (for instance, the tip of a sharp steel pen, or the size of a finger print) and become curves or even points (Kandinsky, 1926). Notice that a point can have any size, as Euclid says: "a point is that which has no parts".3 Kandinsky treats the case of a point growing beyond the bounds of the frame.4

Two abutting areas meet in a border region that somehow partakes of both sides.5 The border can be of various kinds, the major distinction being between boundaries and transitions. A 'boundary' bounds a pictorial object, or 'fig- ure'. The other side of the border region is 'ground', that is not some pictorial object. A 'transition' divides as much as it connects two pictorial objects, in that sense one may hardly speak of an 'edge'. Thus:

Ted Seth Jacobs (1986), p. 97:

[edges are] "zones of interchange. ... they occur ... everywhere. In the strictest sense, optical edges do not exist."

Boundaries are one-sided, transitions are two-sided. One might say that Iceland has a boundary, whereas Luxembourg has transitions (with Germany, Belgium and France), in geographical terms. Thus, in an en face portrait the nose should have transitions to both cheeks, whereas in an en trois quart view it may have a boundary on one side.

Different from geographical borders, pictorial border regions also show 'passages' (French) or 'blends' (Fig. 1). At a passage the distribution of col- ors fails to indicate a border. A border region may simply dwindle and become 'lost'.6 If it gets lost and 'found' again, there was a passage in between. In pictures the 'lost and found' properties of border regions are crucial. This is because visual awareness is forced to 'take sides' at a passage: is there a single region or two? Where did the 'figure' go? Psychogenesis is forced to create visual structure. This natural creativity is a source of satisfaction to the viewer. This is only likely to happen if the border region has the right kind of structure. In painting this is known as the problem of 'edge quality'. The handling of boundaries, transitions and passages is an important facet of painting (which will be illustrated by quotes from the art-technical literature below). This is where the painter fits the distribution of colors on the canvas to the psycho- genesis of the observer.

Border regions have many qualities. They have a — perhaps ill-defined — width, which is a size-like entity. We denote it 'sharpness'. This is a major issue in painting

Ted Seth Jacobs (1986), p. 96:

"... treat optical edges as varying in their degree of sharpness while realizing that none is absolutely sharp."

The classical exemplar is, of course, Leonardo da Vinci's sfumato as described by Giorgio Vasari (1550). There is also the difference between the two areas connected by a border, which is like an amplitude-like entity. We denote it 'strength'. These two categorically distinct parameters are often confused, as when people call low-contrast photographic prints 'unsharp'. It is important to keep the distinction. The border region is apparently some kind of 'gradient'. However, there are countless ways to implement transitions according to the medium (Fig. 2). Although this is hardly understood formally, human vision handles such complexity effortlessly. The particular way in which the gradient was made is seen as a textural quality indicative of various material properties. Discussions can be found in technical treatises on painting

Harold Speed (1917), p. 196:

"... the serrated edges of masses, ... are very difficult to treat ..."

(Speed was talking of Jean Baptiste Corot's amazing handling of trees.) For the pictorial structure the border-width and contrast are understood at a suffi- ciently lower scale than that at which the texture vanishes.

Border regions have been studied in image processing and vision science. Although these fields have only marginal bearing on the present topic, we suc- cinctly discuss them here.

1.1. Transitional Areas in Image Processing

In image processing one does not distinguish between boundaries and tran- sitions. The border region is known as 'edge' (Fig. 3). In the ideal case one considers two abutting half-planes of constant tone. This yields an infinitely sharp ('ideal') edge. A variety of 'edge detection' algorithms have been designed. In real images 'the' edge is neither straight nor sharp and the uniform half-planes will be covered with some 'noise'. They will also 'blend into each other', that is to say, there is some measure of blur or unsharpness. There are many algorithms that effectively impose the ideal edge model and fit it in some 'optimal' fashion. This has yielded a plethora of edge detectors (for a useful review see Savant, 2014). The state of the art uses descriptions of a differential geometric nature at a variety of scales. The details need not concern us here. What is of interest is that 'edge detectors'7, at least inside the algorithm, often invisible to the users, compute 'edginess' fields that assign some edginess to any location (Fig. 3). In fact, they internally compute the root mean square sum of contributions to edginess for all directions. 'The' edges are then determined by some decision mechanism, in the simplest case a threshold. This introduces a certain amount of arbitrariness, that is to say, the algorithm is intentionally tuned to come up with 'edges' that are reasonable for the task at hand. Again, the 'edges' of image processing are ontologically distinct from the border regions of the visual phenomenology.

Notice that we avoid image-processing terminology in this paper, since it badly fits the case of the phenomenology of vision.

1.2. Transitional Areas in Vision Research

In vision research one borrowed the term 'edge' from image processing. In neurocognition one identifies certain neurons as 'edge detectors' (Marr, 19828). This has become an extensive topic in its own right (Palmer, 1999), though of minor importance to our present subject, due to the unfortunate conviction that all edges are by their very nature sharp. Some original ideas derive from phenomenology. Examples are the 'Mach bands' (Mach, 1897) as described in some detail by Ratliff (1965) and the Cornsweet (1970)-Craik (1966)-O'Brien (1959) illusion, well studied from the late 1960s. Pinna's 'watercolor illusion' (Pinna, 1987, 2008; Pinna et al., 2001, 2003), of a somewhat later date, belongs here too (Fig. 4). These 'illusions' are interesting because they are purely phe- nomenal effects that have no parallels in image science. They are very important because they show that transitions are to some extent independent of patches. A local transition may be said to generate two local patches. This is very impor- tant in the visual arts because it means that some of the pictorial load can be shifted from the areas to the border regions. It enables one to paint 'whiter than white (the paper)' or 'blacker than black (the ink)' (Fig. 5). There are also obvi- ous applications in the retouching of photographs, and so forth.

We obviously draw on insights from vision research in this paper, espe- cially from experimental phenomenology. However, we avoid the conventional terminology — itself borrowed from

image processing and largely framed in terms of 'edge detection' — because it badly fits the phenomenology of vision.

1.3. Aims of our Approach

In this paper we consider the importance of boundaries, transitions and pas- sages for the structure of pictures meant for visual consumption. Although we attempt a formal framework, this is singularly aimed at a description of the phenomenology. Thus, we make no claims for potential applications in image processing, or relevance to visual psychophysics or neurocognition. It may well have, but we do not explore such issues here. Our attempt is singularly aimed at experimental phenomenology. Our aim is to provide a formal frame- work that will enable formal and structured discussion of the (important!) topic, something that is simply not possible today.

2. The Notion of 'Borderness'

Although borders necessarily have the property of being located, their location is only vague. We can never precisely point out where a border is. However, confronted with two precise locations we can typically say which is 'more bor- derlike' than the other. 'Borderness' is a fuzzy concept (Zadeh, 1965). Thus we arrive at a 'borderness field', which is a continuous distribution of borderness. So the first question is: given a picture, how to forge an operational definition of borderness?

Intuitively, borderness would not be unlike the output of an 'edge detector' as used in image processing. In order to render the idea more precise and use- ful we need to introduce the concept of scale. Pictures can evidently be viewed at different scales. One may look from different distances, or look through one's eyelashes, as artists habitually do, or use a minifying glass (the art direc- tor) or magnifying glass (the art historian).

The formal framework is scale-space, a well-established discipline since the 1980s that has become a bread-and-butter tool in image processing (Florack, 1997; Koenderink, 1984, 1990; Koenderink and Van Doorn, 1992; Lindeberg, 1994; Ter Haar Romeny, 2003). The formal idea is to describe the plane in terms of points of various sizes. This yields a coherent, scale-dependent theory of the Euclidean plane. A measure of scale is simply the diameter of the point (Figs 6, 7).

A border is located where two points on either side of the border have dis- tinct colors. The color difference divided by the mutual distance is an intuitive measure of borderness. Of course, it depends upon the mutual locations of the points. Let their mutual distance become arbitrarily small with respect to the point size and their mutual orientation such as to yield the largest borderness. Then you have a 'bilocal' operator that yields both the spatial orientation and the size of the borderness (Koenderink et al., 2015). This intuitive idea imme- diately translates into formal differential geometry. This allows us to compute borderness images at any scale for any given image. Technically, these are scale-dependent gradient fields (Fig. 8).

Does this help the painter? No, not immediately, because indicating bor- ders is in no way the same thing as indicating the patches at either side of the border. One certainly doesn't want to paint borderness, which would mean a variety of outline drawing. One needs to indicate the two sides for the border connecting these in some desirable — i.e., visually effective — manner. Figures 9 through 11 illustrate this.

What would a 'local' border (not borderness!) be like? Well, it would show both sides as they are, although only locally. It would also show border width. It is what painters call (local) 'edge quality'. The representation would be a kind of local icon. Its shape would be very similar to the bilocal borderness operator (Figure 9).

So how to paint a border region? Well, one could use the border icon as a 'brush' (in the familiar Photoshop terminology) and apply the brush with a pressure set by the local borderness. It makes at least intuitive sense and it indeed works. One gets something reminiscent of both the Cornsweet–Craik– O'Brien and the Pinna watercolor illusions. The width of this border representation is slightly broader than the point size (Figs 10, 11a,b).

From a formal point of view what one gets is equivalent to the difference of a picture and an unsharp version of it — in the lingo of differential geometry the 'Laplacean' of the picture, in scale-space lingo the 'scale derivative' of the picture. Such images are used in the 'unsharp masking' methods used in photo retouching (Margulis, 1998, 2005). The scale-space interpretation is the most relevant here, because it entails that the combination of such images of many scales will simply reproduce the original image.

This is indeed a formal theorem: the sum of border region maps at all scales equals the original image. Simplified, but intuitive, a border region map is the scale derivative, so the sum is the integral over scale of the derivative with respect to scale. In practice, this is somewhat complicated because the range of available scales is necessarily limited, but this is readily dealt with. The theorem is easily demonstrated algorithmically.

3. The Border Model and Painting Practice

This formalism implies that a painter can completely represent a scene by painting only borders! Of course, the painting would need to treat all transi- tions at all scales. This is the implication of the formal theorem. So one obtains the surprising conclusion: painting the transitions automatically produces the patches. Of course, and vice versa (which hardly implies a formal 'theorem').

From the formal, differential geometric perspective, one might start with a very unsharp image and 'complete it' with border images at finer scales. This seems close to much painting practice. One starts by roughly blocking in the patches and then spends the bulk of the effort on 'edges' and especially 'edge quality'. Notice that painters use the term 'edges', although they really mean our 'transitions'. Painters use 'edge' very differently from the usage in image processing.

There is no shortage of discussion in the treatises on painting techniques. Consider:

Ted Seth Jacobs (1986), p. 96:

"we need to ... create the suggestion of the optical edge by variations of the medium edge ..."
Harold Speed (1917), p. 192:
"There is a very beautiful rhythmic quality in the play from softness to sharp- ness on the edges of masses."
Linda Cateura (1995), p. 70:
"a soft edge shows continuity. ... The harder the edge, the more riveting your painting is in that area."
The formal description also suggests numerous shortcuts. For instance, with infinitely many transitions to paint, why not coarse-grain and select? No doubt, one does not need a continuous range of scales, so why not select a finite set? Neither does one need to paint all transitions. It should suffice to focus on the major ones. Such approaches can easily be demonstrated to work algorithmi- cally, by synthesizing images from transitions of the highest borderness — say the top quartile — only. Such synthesized images look fine.
This also fits the fact that 'edges' do not exist, thus the artist has to create them. This is especially evident in the art of drawing. There are no lines in the scene in front of you. Lines are created when you move a pen over the paper.
Such coarse-graining and selection might be combined with a system of selective emphasis. The painter can modulate borderness and turn it into 'experienced borderness'. Thus the formal theory leaves plenty of room for unrestrained creativity that may serve to produce renderings in recognizable 'styles'. This is important, for the 'observer's (or artist's) share' needs some room in order to come into play. Suggestions for such selective editing of bor- der areas are indeed to be found all over the place:
Jack Clifton (1973), p. 47:
"You may diminish or accentuate edges. Two ... tones ... may be put closer together and 'lost' ..."
Harold Speed (1917), p. 195:
"If you regard any scene pictorially, ...; you will find that the boundaries of the masses are not hard continuous edges but play continually along their course, here melting imperceptibly into the surrounding mass, and there accentuated more sharply."
Figure 12 shows an example of a style change through selective emphasis.

4. Mongrel Images

The formal theory allows one to produce 'mongrel images' in a principled and simple manner. What is a 'mongrel image' (notion introduced by Ruth Rosenholtz and collaborators; see Balas et al., 2009)? One might define it as the equivalence class of all images that 'look the same' as some fiducial image. Of course, 'look the same' depends upon the observer as well as the viewing mode. For example, an 'eccentric glimpse' no doubt implies a mongrel of much higher cardinality than a 'focal good look', an amblyopic eye implies a larger cardinality than a generic eye, and so forth. Many observers (most artists are professionals in this art) know how to 'look' with some intended resolution (for want of a better term). Thus an area of rough, painterly han- dling is

fully transparent to them and conversely, they are able to experience a clear view with a 'painterly' eye. This is an important area on which hardly any science exists. From a cursory investigation it is evident to us that there exist huge differences in the generic population.

In this section we show a few examples. The difference with the 'style changes' as discussed above, is that one introduces forms of tarachopia (Hess, 1982), which is a curious form of agnosia characterized by what might be called 'scrambled local sign'. Visual acuity and contrast sensitivity are fully normal, but the observer is a (usually unilateral) strong amblyope. It is a very striking condition of 'soul blindness' with potentially very important consequences for our thoughts about mind and brain.

Just locally scrambling images yields effects that often appear pleasing and may appear 'painterly'.9 More intricate methods involve independent local scrambling of border regions at various scales. In this case the transitions as they appear at various scales get mutually out of step, which results in a kind of 'diffusion' of transitions. This type of diffusion differs from blurring: the transitions look as if due to some combination of random linear marks. The effect depends critically upon the nature of the scale dependent random dislocations. Some examples are shown in Fig. 13.

Such effects have been studied in models of the primary visual cortex. This has a subsidiary relevance to our phenomenological setting. A useful starting reference is Freeman and Simoncelli (2011).

Locally scrambled images are of considerable interest to vision research because they allow one to deteriorate images in a principled, parameteriz- able manner that addresses the very structures likely to be processed by the primary visual cortex. (We are not so much motivated by brain science, as by the phenomenology of visual awareness, though.) They are of more interest than methods such as spatial frequency filtering or the admixture of random signals. Similar methods, based on the Simoncelli 'sparse coding' mongrels, have been pioneered with interesting results in Rosenholtz's group (Balas et al., 2009; Rosenholtz, 2011; Rosenholtz et al., 2012a, b). They hold considerable promise.

5. Conclusion

In various books on painting techniques one finds discussions on 'edge qual- ity', passages and the 'lost and found' quality of edges. Perhaps unfortunately, the connections to disciplines like image processing and psychophysics or neurocognition are only weak. We argue that the academic discipline closest to painting techniques is experimental phenomenology. So we attempted a purely phenomenological analysis–synthesis in this paper.

The theory of transitions appears to be a rare, perhaps unique, case where a rather complete formal theory of the phenomenology is readily avail- able. We needed only a formally minor — though conceptually crucial — addition to the conventional scale-space formalism. This extension converts and applies scale-space theory, which is a formal geometry that extends stan- dard Euclidean differential geometry of Euclidean space with the notion of scale ('point size'), in

the sense that it implements a theory of the phenom- enology of pictorial vision. A summary, formal statement is supplied as a Supplement on the publisher's Internet site. However, reading this is not required in order to understand our text.

The formalism can be put into practice straight away. Because the math- ematical structure is fully explicit, it can be implemented exactly in sim- ple algorithms that require no more than the standard tools of numerical analysis.10 This allows one to synthesize 'mongrel' versions of any given image in a natural and easily parameterized manner. This promises to be useful in the type of experimental phenomenology as pioneered by Ruth Rosenholtz.

Qualitatively, the theory provides formal meaning to talk of 'edge quality', 'lost and found' properties, passages, and so forth, that one finds in treatises on the techniques of painting. We propose that the theory presented here sets a general framework that can serve to organize discussions of the experimental phenomenology of transitions in images.

Notes

1. Maurice Denis (Art et Critique, no. 65, 23 August 1890, pp. 556–58): 'Se rappeler qu'un tableau – avant d'être un cheval de bataille, une femme nue, ou une quelconque anecdote – est essentiellement une surface plane recouverte de couleurs en un certain ordre assemblées.'

2. The term macchia (Fr. tâche, E. patch, blot, stain ...) was in common use in 19th-century Italy to describe qualities of paintings. It is often used to indicate a quick oil sketch capturing the basic structure of a scene ('studio do macchia'). The 'macchiaioli' at Firenze of the late 1850s (Broude, 1987; Boime, 1993; Panconi, 1999) were the evident precursors of impres- sionism, but for some reason art history gave them a bad deal. They con- sidered the macchie (the patches of light, dark and color) to make up a painting. Like the French impressionists they often painted al'aperto. The theoretical manifesto is by Vittorio Imbriano (1868).

3. Euclid never actually uses this definition and it plays no role in the Elements. Perhaps it was added by a later author. If so, then Euclid never made a definition for 'point', which is either stupid, or marks him a genius.

4. Kandinsky (Punkt und Linie zu Fläche, 1926, p.23). "Es ist schwer, die genauen Grenzen des Begriffes 'kleinste Form' zu ziehen — der Punkt kann wachsen, zu Fläche werden un unbemerkt die ganze Grundfläche bedecken — wo wäre dann die Grenze zwischen Punkt und Fläche?"

5. See Bell (2006), p. 204 on Brentano's (1874) notion of 'plerosis'. According to Brentano points on a boundary are connected differently to one side than to the other. A boundary point is connected to both patches.

6. Jack Clifton (1973), p. 42 has a Chapter: Section 'Edges lost and found' which is worth consulting.

7. Of course, from our perspective the concept of 'edge detector' is spurious. Since edges do not exist you cannot 'detect' them. Edges have to be created, that is operationally defined. That is indeed what one does in image processing. The unfortunate terminology remains objectionable though. It often starts people off on the wrong foot, so to speak.

8. In vision science the term 'edge detector' is even more objectionable than it is in image processing. It suggests that one already knows what the brain is doing without so much as starting to consider alternatives. Notice that animals (including humans) are not industrially produced, have been designed by nobody and have no predetermined function. All science deals with are chunks of bones and meat that react to physical stimuli in certain ill understood ways. It is hard to say where a notion like 'edge detector' might fit in here. Phenomenology is at least in a position to consider meanings (such as perceived edges), but it has no dealing with physiological mechanism.

9. This is a very common observation. Take any ordinary picture and deform it as seen through textured glass. The result is likely to look 'interesting' or 'artistic'. Disarray is shown by Clifton (1973, various places, e.g., p. 50) in a book on how to paint, suggesting that a 'painterly style' will easily beat a 'fine brush'. It was exploited effectively by Weegee (1964) — 'Weegee' is the pseudonym of Arthur Fellig (1899–1968) — to produce 'arty' photo-caricatures of American politicians and celebrities. Gombrich (1963) demonstrates how looking through wobbly glass produces local disarray that renders an otherwise 'atrocity' more acceptable, because "we have to become a little more active in reconstituting the image, and we are less disgusted". When the effect is increased the odious Art Officiel even becomes 'interesting'. It is also a common observation among art collectors that the preparatory macchie tend to look more interesting than the finished painting. Such studies tend to be 'mongrels' of the final image at a cursory look.

10. Figures in this paper were largely done in Processing2+, a programming environment aimed at the artist and designer communities. It is freely available on the Internet (https://processing.org/) and runs on all platforms.

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Figure legends

Figure 1. Examples of 'passages'. In the figure at left there are passages at the left and the right sides of the disk. Notice that these are hard to spot! Artistic vision is trained to notice. The 'sphere' looks illuminated from above (compare tones at top and bottom), whereas it is a mere uniform disk. The center figure illustrates a 'lost contour', you still see the sphere. In this case the passage extends over half the contour. At right a passage in drawing. Such 'ovoid drawing' (Hatton, 1904, p. 18) suggests volume, whereas a closed outline would suggest a flat cutout.

Figure 2. Vertical border regions in various styles showing transitions from dark left to light right. Top left an 'ideal border', top center with some unsharpness, top right with smaller contrast. At bottom some different 'styles', an infinite variety is possible. Yet these are all 'vertical borders', albeit of various sharpness and strength. Sometimes a certain technique, such as hatching for certain reproduction processes, is required. However, even in this limited domain there are as many hatching styles as there are pen artists (Guptill, 1928).

Figure 3. An image (top left), and the horizontal and vertical contributions to edginess (top center and top right) and their root mean square sum (bottom left) as used in image processing. The latter is a continuous distribution — a non-zero value at any pixel. Then thresholding yields 'edges'. Of course the value of the threshold decides on the number of edges found. At bottom center 25% of the pixels has been labeled 'edge'', at bottom right 75%. The point is that, strictly spoken, the edges of image processing do not exist, thus you cannot properly 'detect them' at all,

you need to create them. In image processing one uses some arbitrary essential nonlinearity, in the simplest implementation a threshold mechanism, as illustrated here.

Figure 4. At left Mach bands (see the black line at left, light line at right, about one third out from the sides? — they are 'illusory') for a linear ramp between two uniform patches, at center the Cornsweet (1970)-Craik (1966)-O'Brien (1959) illusion, an articulated border region between two identical patches, at right Pinna's watercolor illusion (Pinna, 1987, 2008; Pinna et al., 2001, 2003) where an articulate border region traverses a uniform ground.

Figure 5. Atleftthecentersquareis'whiterthanwhite'.Thesameistrueforthe blobatcenter (inspired by Kanizsa, 1955) although this 'white' looks 'substantial' rather than 'etherial' (like in the example at left, which looks 'radiant' to us). (We do not go into these phenomenologically intriguing issues here.) Notice the many passages! Do you 'see' the 'missing border'? This works just as well for 'blacker than black' (right).

Figure 6. Points of different sizes. The point at right already fills most of the panel. This illustrates Kandinsky's notion that a point may grow and fill the picture.

Figure 7. Scale-space (starting at top left, going left to right, top to bottom), sampled at resolutions spaced by factors of two. Notice that the image of least resolution is really unsharp. You probably couldn't even classify it as a 'portrait' when seen in isolation. The first few images look very similar, but you would notice increasing unsharpness in close scrutiny. Of course, this is a (regular) sample, scale-space has a continuous spectrum of scales.

Figure 8. Borderness fields at different scales. It is not suggested that such representations are particularly enlightening. This is best judged at scales that are barely detailed, say the right top or the bottom left images. We can make little of these. Would you place your dark touches like that in a drawing? It seems unlikely. But this is exactly what borderness is. In image processing and vision sciences one obtains 'edges' by thresholding what we name borderness. In the latter case it is suggested that the brain deals with such structures.

Figure 9. Alocalborder.Thisborderrunsintheverticaldirectionandconnectsablackpatchon the left to a white patch on the right. Notice the fuzzy border region, which is a strip of gradient from black to white. The local border defines both the patches and the 'border itself'. At right the corresponding 'borderness'. This would be computed by Photoshop's 'edge detector'. Notice that borderness does not visually represent a border at all.

Figure 10. Local borders at various scales. Compare this to the borderness distributions (Fig. 8). Borders make visual sense, borderness does not. These images at least look like visually acceptable presentations.

Figure 11. (A) Here is a direct comparison of the borderness distribution and the local borders. Only the latter make visual sense. Here the resolution is about halfway the scale used above (rightmost picture in the top row of Figs 8 and 10). The operators used are Eqn. 8 and Fig. S2 (left) and the Laplacians illustrated in Fig. S4 (right) of the online Supplement. (B) A direct comparison of the borderness distribution and the local borders for a simple Yin-Yang image (left) composed of uniform regions abutting in sharp and strong border regions. The borderness (center) is what would be obtained with a conventional 'edge detector'. (Notice that thresholding will fail to produce the full outline.) The field of local borders (right) is much more informative; indeed, Pinna's 'watercolor effect' goes a long way to show the light and dark patches. We suggest that the local border field represents the phenomenal transitions, whereas the borderness plays a same operators as in (A). The operators used are Laplacians, illustrated in Fig. S4 of the online Supplement.

Figure 12. Left the original photograph, right a stylistic change through selective use of transitions. Facial features are emphasized and a more linear, graphical treatment is substituted for the chiaroscuro.

Figure13. Twoexamplesof'mongrelimages'.Atleftthelocaldislocationsaresmallenoughso that the image remains recognizable. This image perhaps looks like 'done in a painterly manner'.9 Compare the original in Fig. 3 top left and study the nature of the border regions in some detail. Notice that the 'effective resolution' has become rather small in the example at right, although the image does in no way appear 'unsharp'. Blur and local dislocation both decrease the effective resolution, yet their effects are very different. (Compare the scale-space shown in Fig. 7.) The border regions disintegrate in a fibrous manner. Moreover, dislocations leave the tonal range intact, whereas blurring contracts all tones to the global average. The image at right perhaps appeals more to the imagination than that it might be said to 'represent Albert Einstein'.

Note 4. Figures from Kandinsky's Punkt und Linie zu Fläche (1926): Left Kandinsky's Fig. 3 (p. 25) Beispiele der Punktformen (examples of punctal forms), right Kandinsky's Fig. 13 (p. 46) Ein aus kleinen Punkten bestehender grosser Punkt (Spritztechnik — a large point composed of small points).