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Focusing in on Art*

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Attitudes toward and evaluations of aesthetics have varied over the ages, and sometimes rather quickly. As an illustration of this, consider the positions of the scientist, Hermann von Helmholtz, and the artist, Wassily Kandinsky , on the relationship between art and music. Preceding the modern schools, von Helmholtz[1] argued that art and music are fundamentally different insofar as the role of the painter was to replicate, reflect, or interpret visible nature. Music, in contrast, is not derived from an equivalent auditory nature, but emanates totally from the composer's creative mind. In his book *Concerning the Spiritual in Art*, published in 1912, Kandinsky[2] shared this understanding of music but contended that a painter who finds no satisfaction in mere representation seeks to apply the methods of music to his art. He saw the modern desire for rhythm in painting, for mathematical construction, for repeated notes of color, and for setting color in motion as a result of this.

More radical was the aesthetics of "suprematism" conceived by the Russian artist, Kazimir Malevich,[3] only a few years later:

"The utilitarian constructions of technology, which develop out of the skillful pitting of one natural force against another, have in them no trace of

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* dedicated to Piero Dorazio

an 'artistic' imitation of natural forms; they are new creations of human culture.

A work by a realistic artist reproduces nature as it is and represents it as a harmonious, organic whole. In such a reproduction of nature no creative element can be discerned because the creative element is not to be found in the unchanging synthesis of nature as such but, rather, in the variable synthesis of its interpretation.

An artist who creates rather than imitates expresses himself; his works are not reflections of nature but, instead, new realities, which are no less significant than the realities of nature itself.

The inventive engineer, the creative artist and the professional 'copyist' thus represent three possible forms of productive activity, of which the work of both the inventive engineer and the original artist expresses the creative, while the imitator, as reproducing agent, serves the existing.

The basis of this diversity in activity, in my opinion, resides in the fact that our conceptions of things around us, transmitted mechanically by our senses, with the co-operation of one brain center or another, can turn out to be different from each other."

Two points raised by Malevich are particularly interesting. First, for him the creative element resulted from the changeable character of the artist's interpretation of nature and did not depend on the distinction between nature and mind. Second, he contended that the different interpretations of nature arise from the activation of different states of brain activity. Thus, it appears that the positions of Kandinsky and Malevich were separated by a watershed in the development of epistemology. Kandinsky's ideas were still consistent with Kant's distinction between sensibility and understanding, that is, the mind's capacity to be affected by things as they are and its faculty of acting on the sensibility.[4] For Kandinsky, representational art expressed the former, whereas nonrepresentational art reflected the latter. More recently, perceptions have been seen essentially as interpretations of the world of objects in terms of knowledge represented in the brain. This led Gregory[5] to conceive of the mind as "consisting of hypotheses of perception and understanding," with "the private hypotheses of perception and the shared hypotheses of conception making up our reality." Seen within the context of this epistemology, Malevich's aesthetics seems to imply that the creative element in art depends on the potential to provide us with new forms of reality rather than on the dissimilarity between works of art and physical objects. Below we will attempt to show that recently acquired knowledge of the function and coding properties of the perceiving brain and, in particular, of the human visual system supports this remarkable idea.

Perception as a Mental Construct

To go into the subject more deeply, it is evidently necessary to better understand the nature of perception. Thereby, it is most important to note that modern theories emphasize the active nature of perception as being mediated by processes searching for the best interpretation of the signals conveyed by the afferent nervous pathways.[5] This renaissance of the Kantian notion of perception is a rather recent event. In the nineteenth century, von Helmholtz, although aware of the influence of unconscious inferences on our perception of physical objects, stressed the analogy between the eye and a camera. The assumption of a passive and unbiased transmission of physical stimuli was typical for the empiricists' approach to the problem of perception. Perceived objects were thought to impose their structure upon the mind to an extent determined by previous exposure. Consistent with this view was the idea that ensuing percepts consisted of a summation of sensations and ideas, the latter being copies of previous sensations. This "perceptual atomism" was apparently supported by the success of the concept of atomism in the physical and chemical sciences.[6]

A radically different view was held by Immanuel Kant.[7] He argued that the physical world offers only the substance of sensations, while the mind actively organizes this substance in space and time and provides the concepts to interpret experience. The Kantian position influenced Goethe with his color theory ("Farbenlehre"), which was based on the idea that the eye is an active agent rather than a passive recipient. Otherwise, it had little impact on psychological theories of perception with the exception of Gestalt psychology, which evolved from the writings of Christian von Ehrenfels[8] in the late nineteenth century. According to von Ehrenfels, the percept of form surpassed the percepts of the individual elements composing the whole. Authors like Max Wertheimer, Wolfgang Köhler, and Kurt Koffka even suggested that the very nature of elements of perception is determined by the organization of the whole.[9]

Largely due to the failure of Gestalt psychology to conceive a viable model of how figure-ground relationships and properties like "good continuation" and "enclosedness" could be quantitatively evaluated, its ideas have been neglected by subsequent researchers in the field of perception. In contrast, psychophysics, conceived in the nineteenth century by the physicist, Gustav Theodor Fechner[10], became mainly concerned with the measurement of sensory thresholds as the hypothetical elements of perception. In much the same way, neurophysiologists considered receptive fields as innate and invariant templates subserving the extraction of stimulus properties critical for object recognition.

Psychologists were becoming increasingly aware of the role that the active modification of afferent signals plays in cognition. There are, for instance, the effects of selective attention, as evident in the "cocktail party effect," where the voice of a particular person can be listened to in a room that is buzzing from many people talking at the same time. Other popular examples of this are ambiguous figures[11], such as Jastrow's duck-rabbit or the Necker cube (Fig. 1). Common to such images is that either one or another figure is seen but not both simultaneously. The animal drawing is either a duck or a rabbit; the cube is a box seen either from above or from below.

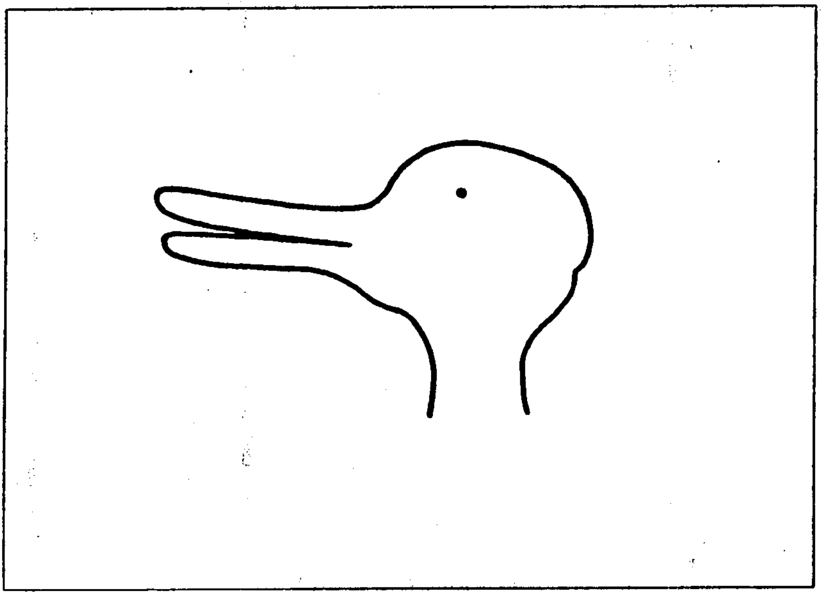
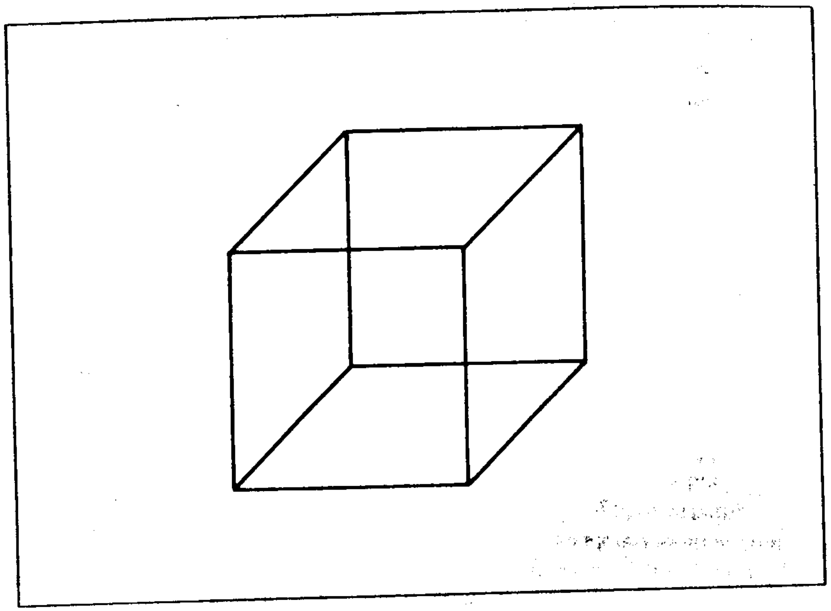


Fig. 1.a) Jastrow's duck-rabbit

Nevertheless, the notion of perception as an active process was more substantially supported by the technical disciplines. Aristotle taught that the world consists of objects provided with numerous properties. He used the term "essence" for those properties, without which an object would cease to be itself and, equally important, to belong to a certain category. A category then, is defined by its essence.[12] In the language of communication engineering, the task of assigning a category or a class to an object is essentially the task of pattern recognition. Therefore, it is not difficult to understand that perception can be equated with pattern recognition. Watanabe[13], in his detailed discussion of the principles underlying pattern recognition, illustrated this with Wittgenstein's comment about "seeing something$_1$ as something$_2$." According to the latter, the verb "see" has two usages, such as, "I see this picture" and "I see this picture as a rabbit." Something$_2$ corresponds to a percept, whereas something$_1$ refers to a physical reality. This led Watanabe to characterize "seeing-one-in-many" or "one-in-two," as in the duck-rabbit example, as one important kind of pattern recognition.



1.b) Necker cube

One gains more insight into the definition of seeing as a classification process by considering how pattern recognition is performed by automata.[13] The process begins with the observation of a large number of variables, e.g., the number of picture elements ("pixels") determined by the raster available for image reproduction. The process ends with a single binary decision as to whether or not the pattern belongs to a given class. In sharp contrast to the requirements for passive image transmission, the reduction of information is essential for solving a pattern recognition problem. This is usually performed by seeking a symbolic representation common to all class samples. Thereby, the original occurrence with its many variables is represented by a much smaller number of substitute patterns, or features, that are (1) simpler than the original and (2) can be associated with it.[14]

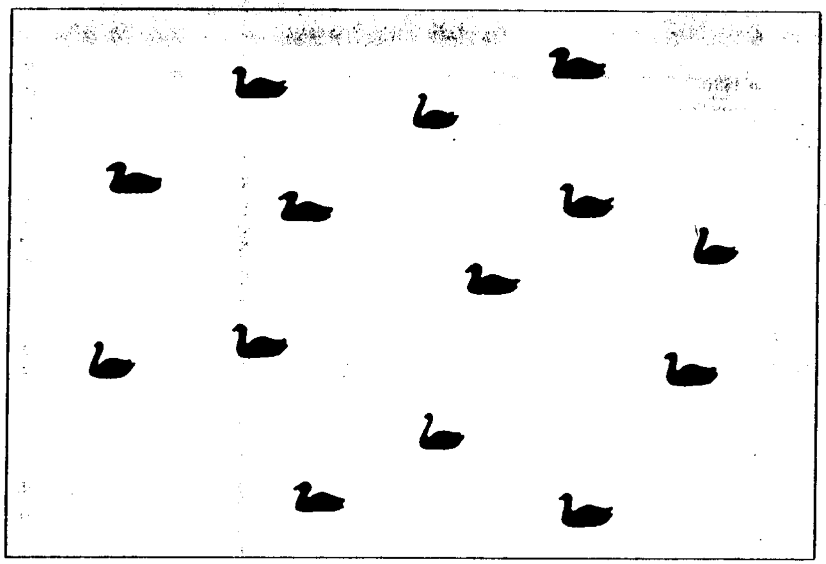
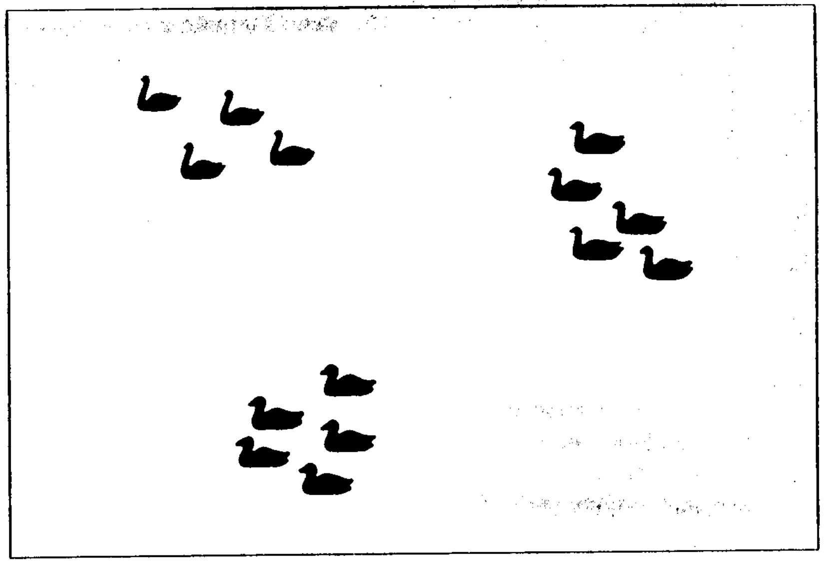


Fig. 2. Seeing birds as ducks, geese, and swans. Thomas Kuhn illustrated the principles of pattern recognition with the example of teaching a child to recognize such water birds (reprinted with permission from ref. 16).

a) Whenever one of them occurs, the father would not only tell his little son which type of bird it is. He would also help the child by pointing out that ducks have short and bent necks, that those of geese are longer and relatively straight, and that swans have even longer necks that are less straight.

Figure 2 shows an example of such a symbolic representation, and further examples will be considered below. At the classification stage of pattern recognition, the similarity of a given pattern and the samples of each class is evaluated in terms of their symbolic representation, and a decision is made as to which class the pattern resembles most.



b) Consequently the child may learn to place each occurring water bird onto an internal map with the coordinates of neck length and curvature. Such a symbolic representation is suitable for solving the task of object (or pattern) recognition if it results in object clusters, or classes, having relatively low within-variance and higher between-variance.

Revolutionary Changes of World View

In much the same way as perception has been considered as an accumulation of sensations, scientific knowledge is commonly thought of as being embodied in a set of rules and theories. Thomas Kuhn[15], in his famous book *The Structure of Scientific Revolutions*, argued that this is not the case. He stressed the role that exemplary past achievements, or paradigms[16], play in the professional judgement of scientific communities. According to Kuhn, students do not primarily gain practice in the application of rules when they are solving problems. Rather they learn to see similarity relationships between physical situations, and this ability is the prerequisite for successfully applying laws and theories. For instance, the student of mechanics adopts the view of Galileo Galilei when he learns to handle the equation of motion for a pendulum. After translating the concept to the formalism of quantum mechanics, this paradigm can be used for understanding more complex situations in terms of superimposed, harmonic oscillations. Thus the use of scientific paradigms is the same as in pattern recognition – having been provided with paradigms of a class of of an image. Such parts are called redundant, or uninformative. The properties of other parts of a message are less predictable and, therefore, convey a great deal of information.

However, the problem of applying communication theory to painting or to images in general is the fact that it is impossible to determine such parts by merely considering the physical properties of an image. How, for instance, should image redundancy be determined for a painting by Claude Monet? The reason for this difficulty is the lack of a generally acceptable set of image features. For the analysis of speech, this difficulty does not exist, as speech contains a variety of features that can be measured, such as volume, pitch, and spectral energy. Speech can also be characterized by a universally accepted set of symbols called phonemes. The sound of "d" in the word "dog," for example, is a phoneme. By using phonemes it is, in principle, possible to obtain a complete representation of an utterance. Thus, the symbolic description of speech consists of describing phonemes in terms of such features.

For visual perception, we do not have an acceptable set of image symbols and probably never shall have such a system, since visual processing seems so adaptive to the type of objects and tasks. On similar grounds, Neisser[26] has already denied the usefulness of applying information theory to psychology in general, and Epstein[27] questioned whether describing the perception of music in terms of information theory is a paraphrase of other existing theories or whether it affords a truly higher level of abstraction.

Visual Representations in the Brain

From our inability to verify the existence of an explicit "brain code" for image information arises the question as to the nature of internal representations of the visual world. Here the most conspicuous result of research is the finding that there is a high degree of functional specificity associated with the location of neural responses in the brain. First, there is a specialization of brain areas onto which the major sensory modalities (vision, audition, somatosensation) project, and such a specialization is also found for various forms of action (e.g., speech and motor functions) (Fig.3). Within each of the major sensory systems, a number of cortical areas have been identified that provide representations for different purposes. At this stage, we know of no less than seven somatosensory areas, four auditory ones, at least twelve visual areas, and a variety of maps that also exist in lower structures of the brain.[28]

For visual information processing, some of the cortical maps are retinotopically organized and others are not. In retinotopic maps, the visual field (i.e., the two-dimensional projection of the world onto the retina) is represented in spatial order, whereas nonretinotopic maps impose further abstractions and syntheses upon the information they receive. The functional differences between these maps are the result of successive transformations and convergences along different neural pathways in the brain. The origin of these differences was a mystery until recently, when the study of processes of self-organization suggested that, both in simple physical systems and in the brain, the representation of knowledge in specific categories of things might assume the form of feature maps.[29]

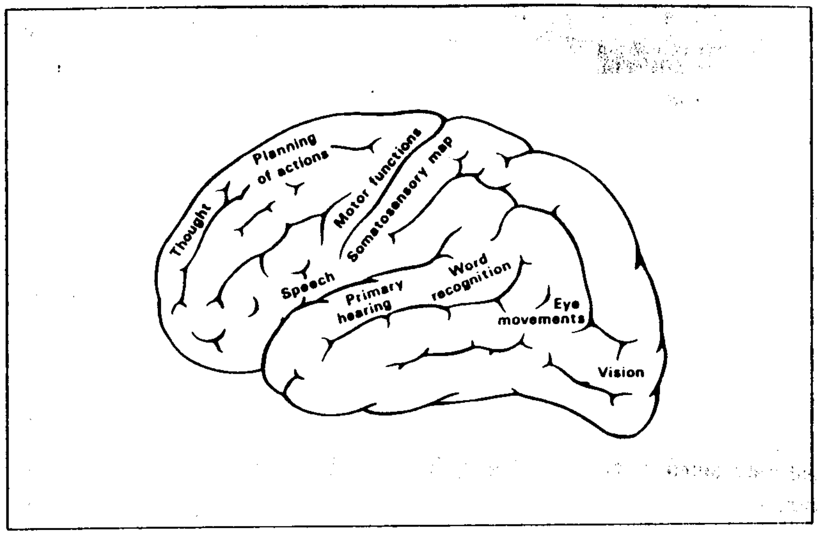


Fig. 3. Functional localization in the brain (reprinted with permission from Kohonen[14])

We have no reason to believe that there exists an area in the visual system onto which these divergent elements of representation converge to produce localized neural correlates of perception. It seems, instead, that our holistic world views are incorporated in the dynamic patterns of activity within the neural network, consisting of the linked cortical areas. Most of the evidence supporting this idea is anatomical in nature, but there are also clinical observations suggesting that the synchronization of information from several visual maps is not always possible: fever, drugs, migraines, or brain damage may produce bizarre symptoms, like fragmentation, selective fading, doubling of contours, jerky movements of objects, brief inversion of parts of the visual world, and dissociation of color and form.[30]

Adding to the reports in the clinical literature is the powerful description of drug-related alterations of visual perception in the personal experiences of the well-known author, Aldous Huxley. In his book, *The Doors of Perception*, he suggests that "what the rest of us see only under the influence of mescalin, the artist is congenitally equipped to see all the time."[31] Taking into account the more recently acquired knowledge of brain function, this (rather exaggerated) claim made by Huxley, nevertheless, supports the idea that the artist may be able to emphasize the selected information contained in specific visual maps in the brain more than is evident in normal observations. This view is clearly consistent with Malevich's, who wrote that "with the co-operation of one brain center or another" the artist may choose his own "conception of things" around him.[3] Shifts of attention to a particular type of visual representation may be brought about by emotional, intellectual, or cultural factors in the painter and result in "style."

We may summarize these considerations by suggesting that when Malevich sees the creative element in art as dependent on a change in the cooperation among brain centers, this may well be related to what has been discovered about the multiple visual representations in the cerebral cortex. In other words, we assume that art can be evaluated along similar dimensions of internal visual representations, although various schools are differentiated by emphases among and within these maps. This concept may be characterized as the "equality of dimensions and plurality of attention."

As the issue of pictorial representation in art is concerned, it is important to note that some visual areas in the brain deal with common features, such as elements of contour, color, and movement, whereas the function of others is still obscure. The former property is more easily understood if one considers the fact that the first primitive type of visual representation involves the retinal receptor mosaic (rods and cones) as a two-dimensional, point-by-point array. However, already within the retina neural responses are determined by the interaction between signals from cells beyond this primary level of encoding[32] – via the complex neural network of bipolar, horizontal, amacrine, and ganglion cells. For example, as a result of the inhibitory character of one type of coupling between such cells, the response from one receptor is counteracted by the responses of its neighboring receptors to result in a "receptive field." The latter determines the type of spatial structures a given cell is specifically sensitive (or "tuned") to (see chapters 6 and 7). Thus, we see that the specific internal organization within the brain determines what physical properties of the world are perceivable. Regardless of whether it be color, spatial, or motion "mappings" of the sensory input onto the perception of the physical world, the vehicles of such encoding processes seem to be units, or functional subgroups of nerve cells in the brain. These units relate localized physical events with feature maps covering a certain range of physical properties and parameters common to the categories to which these events are associated.

Such units are usually represented as filters specifically tuned to the mapping parameters.

More commonly known examples of such filters are the red, green, and blue mechanisms of color vision, which are roughly analoguous to the channels used for communicating signals on color television. Isaac Newton demonstrated that the corresponding color components are related to the ranges of relatively long, middle, and short wavelengths or low, middle, and high frequencies of light. Similarly, we can characterize images in terms of levels of detail analoguous to the low- to high- frequency ranges which, together, compose complex sound patterns. The range of (spatial) frequencies meaningful for vision is obviously restricted by visual resolution thresholds. If this is a 30-second visual angle, then a spatial frequency of 60 cycles (light and dark stripes) per degree of visual angle (cpd) is just resolvable. This corresponds to an apparent width of 10^{-1} mm for one light and one dark stripe at a viewing distance of about 30 cm. The wavelength of light is between 10^{-4} and 10^{-5} mm. Thus, the order of magnitude of spatial frequencies across an image (being inversely related to spatial wavelengths) is rather different from the optical frequencies of light waves.

By accumulating the responses from subgroups of receptive fields differing in average size, one obtains the type of image representation illustrated in Fig. 4. The larger the receptive fields, the lower the image resolution qualities ("region-like" spatial information), while smaller receptive fields offer finer details, like edges and clarity ("boundary-like"). Consequently, the image corresponding to the large receptive field size *(top right)* shows essentially the light and dark regions of the image, whereas the smallest receptive field size *(bottom right)* reproduces mainly the contours present in the original. These images were computer generated by filtering the input image *(top left)* with a given filter size, a process called convolution.[33] Each of the filtered images contains only a limited band of spatial frequencies; hence the name band-pass versions of the input image.

Although these filter operations were conducted in the physical domain, the physiologist, Fergus Campbell, has suggested that similar results may be achieved perceptually by shifting attention between the outputs from variously sized spatial filters.[34] Indeed, at a cocktail party we may enjoy quite different perceptual experiences when switching attention from the appreciation of the texture of a lady's dress (high spatial frequency information) to the more general outlines of her appearance (low spatial frequency information). Campbell's idea is supported by the finding that there are substructures in the visual cortex that selectively respond to limited ranges of spatial frequency.[35] David Marr, however, pointed out if one can inspect the world independently in different bands of spatial frequencies, one should also be able to recognize

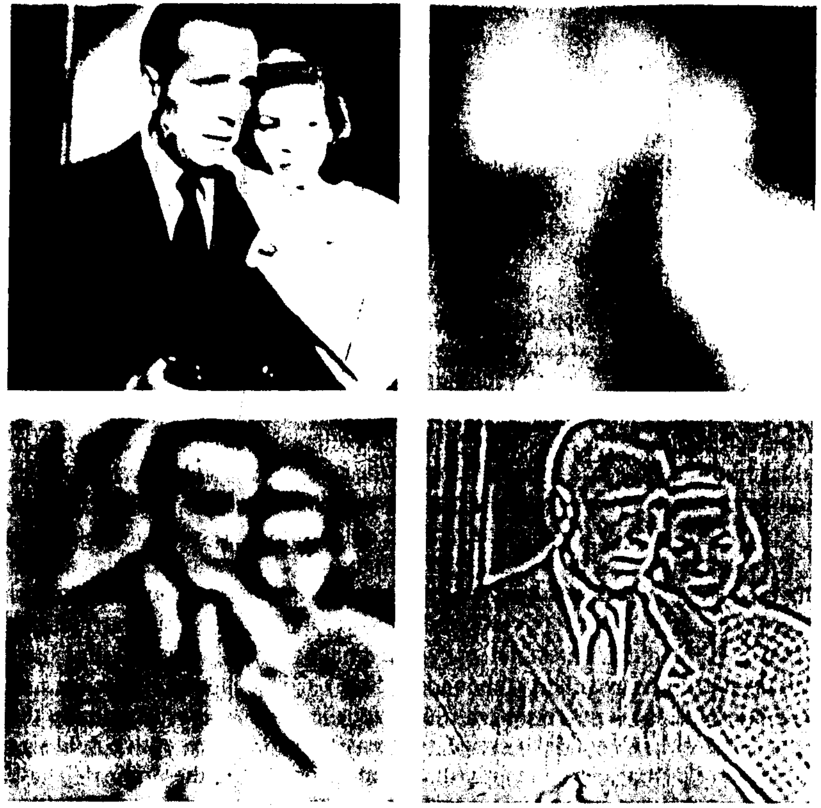


Fig. 4. Original scene and three band-pass filtered versions thereof (Bogart-Bacall photograph copyright AGI SYDNEY)

objects in block-quantized images.[36] This is not the case, as can be seen in Fig. 5, where Bogart and Bacall are hidden by the checkerboard contours that result from the block quantization of their portrait. The actors can only be seen by physically blurring the image (e.g., by squinting or by sufficiently increasing the viewing distance).

This led Marr[37] to suggest that it is not the individual bands of spatial frequencies that constitute the "early" visual representation (before further processing), but special combinations thereof. He considered these combinations to be the result of spatial coincidence between zero-crossings (i.e., the places where the luminance values pass from above to below the mean luminance) from different frequency bands, and this allowed him to construct

edge-only versions of physical objects. For the present purpose, we adopted the idea of combining information from different frequency bands but, unlike Marr, we found it essential to use nonlinear filter operations.

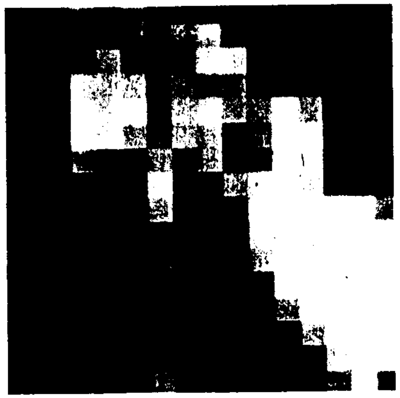


Fig. 5. Block-quantized version of Bogart-Bacall scene. To recognize the actors, squint or increase viewing distance.

In Fig. 6 we show the zero-crossings[38] of the two band-pass images in the bottom row of Fig. 4. The images in the top row of Fig. 7 were generated by "coloring" the areas enclosed by zero-crossings in black and white, depending on whether the corresponding regions in the band- pass image were darker or lighter than the mean value. The image at the bottom left of Fig. 7 resulted

Fig. 6. Zero-crossings of the two band-pass images shown in the bottom row of Fig. 4

Fig. 7. Combination of image information contained in individual bands of spatial frequency. *Top*: zero-crossing versions of Fig. 6 "colored" black and white; *Bottom left*: images from top row combined; *Bottom right*: same process but somewhat different thresholds used for converting high-pass image into binary version

from combining the two pictures in the top row. Thereby we applied the rule that the compound image is white wherever at least one of the component pictures is white. The same procedure was used for generating the image at the bottom right of Fig. 7; the difference in appearance depends on a slight departure from the former conditions that led to the coloring of the component image with the finer details. This demonstrates that the combination of information from different frequency bands results in more interesting representations of the input image than is possible by using individual frequency bands only.

Reducing Image Information by Filtering

It is now time to illustrate the points made above by actual examples. In Fig. 8, we demonstrate how the filtering out of high-spatial-frequency information renders a painting of the Sienese School by Duccio di Buoninsegna more similar to a Renaissance painting by Leonardo da Vinci. In comparison to the work by Duccio, there is less high frequency information in the painting by Leonardo, corresponding to a preponderance of surfaces and less distinctly marked features, a pecularity of style called "sfumato." The correlations between the style of paintings and the ways in which image features are captured within various ranges of spatial frequencies have been investigated more quantitatively by T. Caelli and W. Kelly (1988, What determines an artist's uniqueness – and to whom: A conjecture?, unpublished work). Paintings from the classical, the impressionist, the cubist, and the surrealist periods were ex-

Fig. 8. Details from "Madonna di Crevole" by Duccio di Buoninsegna *(above)* and Leonardo da Vinci's "Madonna with the Yarnwinder" *(below right)*. *Below left*, low-pass filtered version of Duccio's work

amined. The results indicated that the ability to group photographs of paintings into their correct schools is not a function of art education or of the subject matter of the picture. Instead, similarity of style could be assessed according to similarities in texture, brushstroke, quality of light and dark, and spatial qualities. These image features were statistically captured by what is

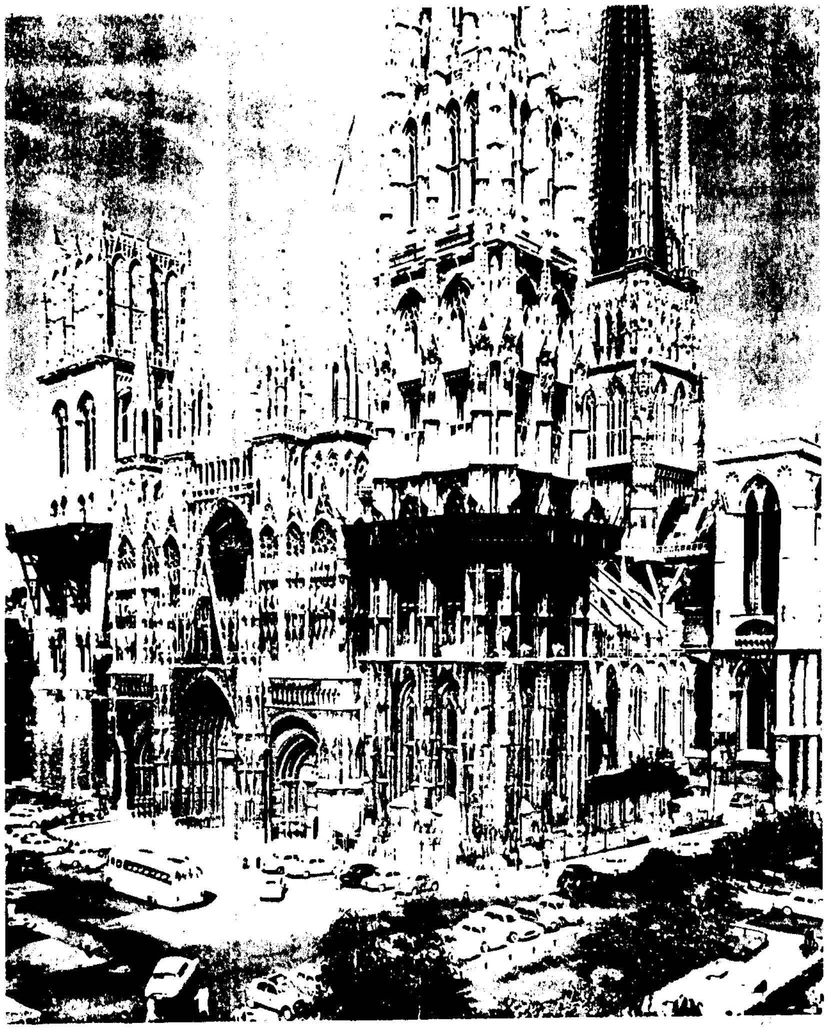


Fig. 9. Rouen Cathedral (photograph courtesy of Giulio Sandini)

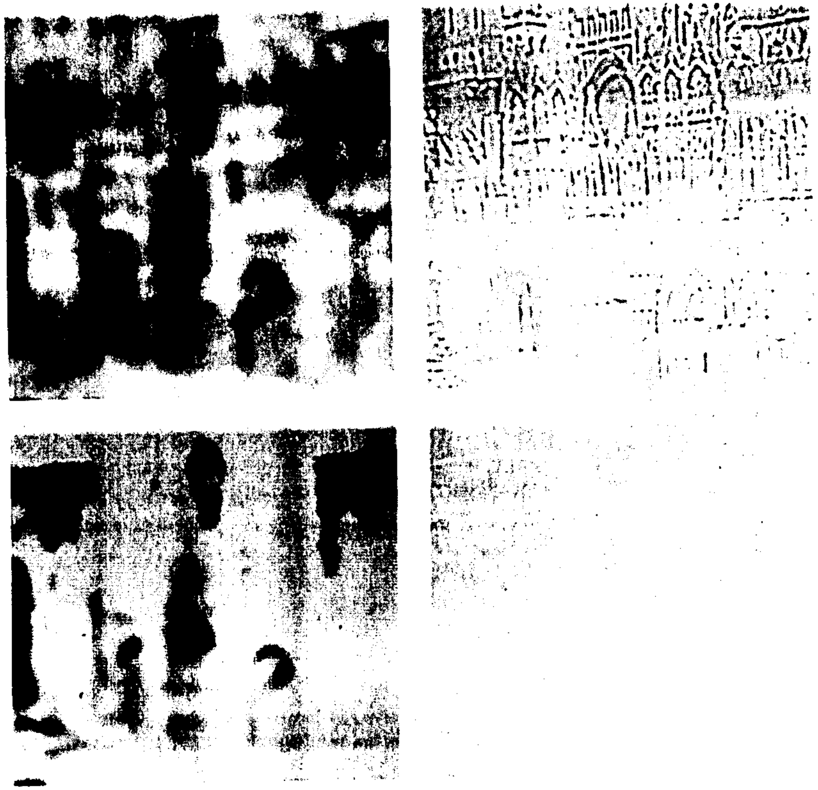


Fig. 10. Simulating an impressionist painting
a) Low- and high-pass filtered detail of photograph of Rouen Cathedral (*top*), as well as dark and light image components thereof (*bottom*)

termed the "power spectrum" of the image, which corresponds to the strengths (amplitude or power) of various frequency components over the image.

The filtering processes considered so far imply the selective reduction of image information within a certain range of spatial frequencies, whereby we suggest that the artist becomes creative not by adding something to the conventional view of the world but rather by depriving it of information irrelevant to his concept of reality. This perspective of the creative act in painting seems to contradict what Malevich[3] called the "additional element" determining the creative quality of a work of art. There is, however, a more general class of

Fig. 10.b) Combination of the images in the bottom row of a)

c) Claude Monet's Rouen Cathedral (1894) The portal, dull weather (reproduced with permission of Musée d'Orsay, Paris)

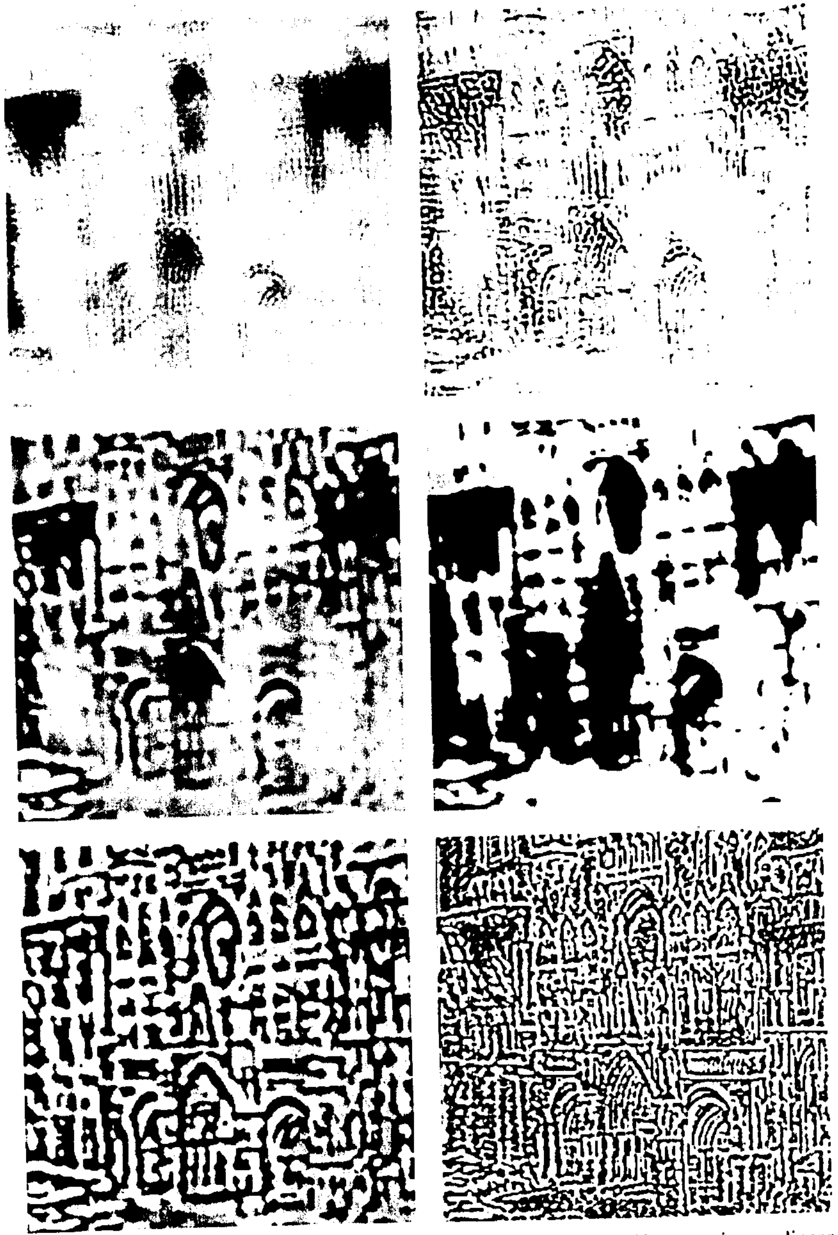


Fig. 11. Six computer-generated images of Rouen Cathedral (as obtained by excerting nonlinear operations on band-pass versions of the original photograph and by subsequent recombination of the resulting images)

filtering operations, which seemingly embrace Malevich's use of the term additional. Consider, for instance, the (nonlinear) selective enhancement and recombination of image components demonstrated in Figs. 6 and 7. We used a detail of a photograph of the Cathedral of Rouen in France (Fig. 9) and generated two band-pass versions thereof (Fig. 10a, *top row*). Of these images, only the gray levels below (Fig. 10a, *lower left*) and above the average (Fig. 10a, *lower right*) were recovered, respectively, and subsequently recombined to result in Fig. 10b. This operation is biologically plausible because the receptive fields underlying the process of band-pass filtering exist in the visual system in two polarities, namely "on-center" and "off-center" units (see chapter 7). The information conveyed in the resulting "brightness" and "darkness channels" is kept separate for further processing.[39]

The comparison of Fig. 10b with one of Monet's paintings of the same subject (La Cathedrale de Rouen, temps gris [1894]) is revealing (Fig. 10c). However, there is nothing unique about this particular type of rendering, as we can generate variations of the same theme by selecting and differentially emphasizing various image components (for some examples, see Fig. 11), and

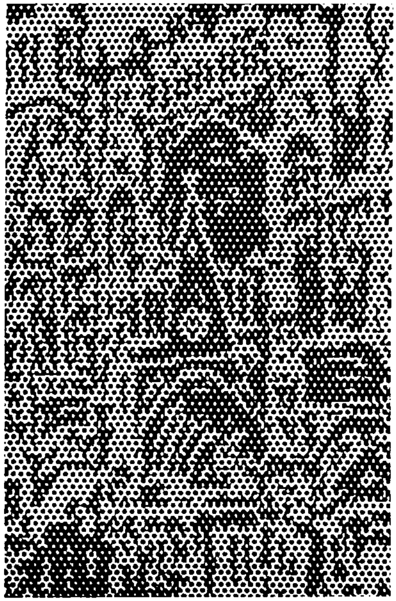
so, apparently, do the artists (e.g. Fig. 12). Within the same conceptual framework, it is also possible, as we have already seen in Fig. 7 *(bottom right)*, to produce "edge only" versions of an original scene (Fig. 13). It is conceivable that such a strategy of information processing may underlie the human ability to sketch a scene.[40]

Having shown that styles of painting from the Middle Ages up to neoimpressionism can be characterized by the preservation of the structure of physical images rendered through different types of spatial filters, we may proceed to more difficult interpretations, such as cubism and abstract art. Typical for such styles is the loosening or disruption of the physical structure of objects. One way to obtain alterations of structure depends on the reduction of information along the orientation (e.g., vertical, horizontal, or oblique) in the image domain. In images with an energy distribution varying along two dimensions, orientation information is represented by the distribution of amplitude values (contrast) along specific orientations. This is illustrated in Fig. 14a, where the original photograph of the Cathedral of Rouen is filtered by using a number of orientation-specific filters. Again, this filter operation is biologically

Fig. 12.a–d) Rouen Cathedral
a) Claude Monet (1893) The Portal and the Tower Saint Romain, Full Sunlight (reproduced with permission of Musée d'Orsay, Paris)

12.b) Claude Monet (1893) The Portal, Morning Sun, Harmony in Blue (reproduced with permission of Musée d'Orsay, Paris)

12.c) Claude Monet (1894) Rouen Cathedral, West Facade, Sunlight. National Gallery of Art, Washington, D.C., Chester Dale Collection (reproduced with permission)



12.d) Roy Lichtenstein (1969) Cathedral #3 (one color lithograph, Gemini)

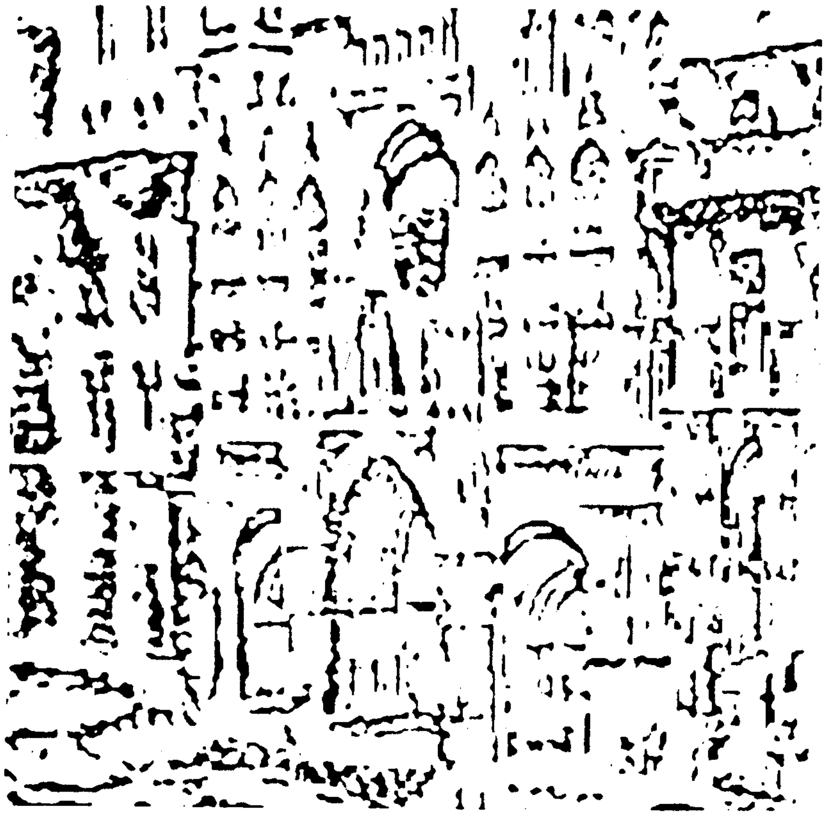


Fig. 13. Edge-only version of Rouen Cathedral (obtained from photograph)

plausible, as orientational selectivity is the most important characteristic of receptive fields in the visual cortex (see chapter 6). For comparison, we add a reproduction of Lyonel Feininger's painting showing the "Marktkirche von Halle" (Fig. 14b).

Another example of orientation filtering is provided in Fig. 15, where the original portrait is filtered by discarding 20% of the amplitude information within evenly spaced, orientation-specific filters. As the percentage of suppressed orientation information is increased to 80%, the appearance of the image is dramatically altered. The new image, in an interpretive sense, provides an aesthetically more interesting experience than the original portrait.

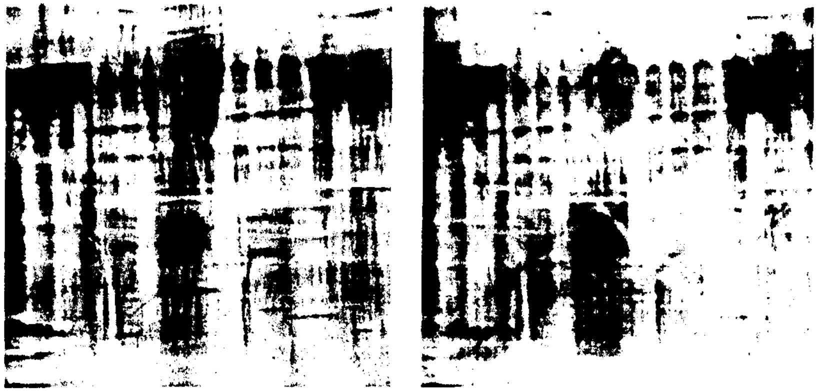


Fig. 14.a) Rouen Cathedral: Results of orientation-selective filtering

While the filtering operations considered so far cause significant alterations of image structure, they are not appropriate for reproducing the type of contour fragmentation common in cubist paintings. In this sense, cubist image representation seems to be more focused upon the shifting of object


b) Lyonel Feininger (1931) Marktkirche von Halle (reproduced with permission of the Staatsgalerie Moderner Kunst, München)

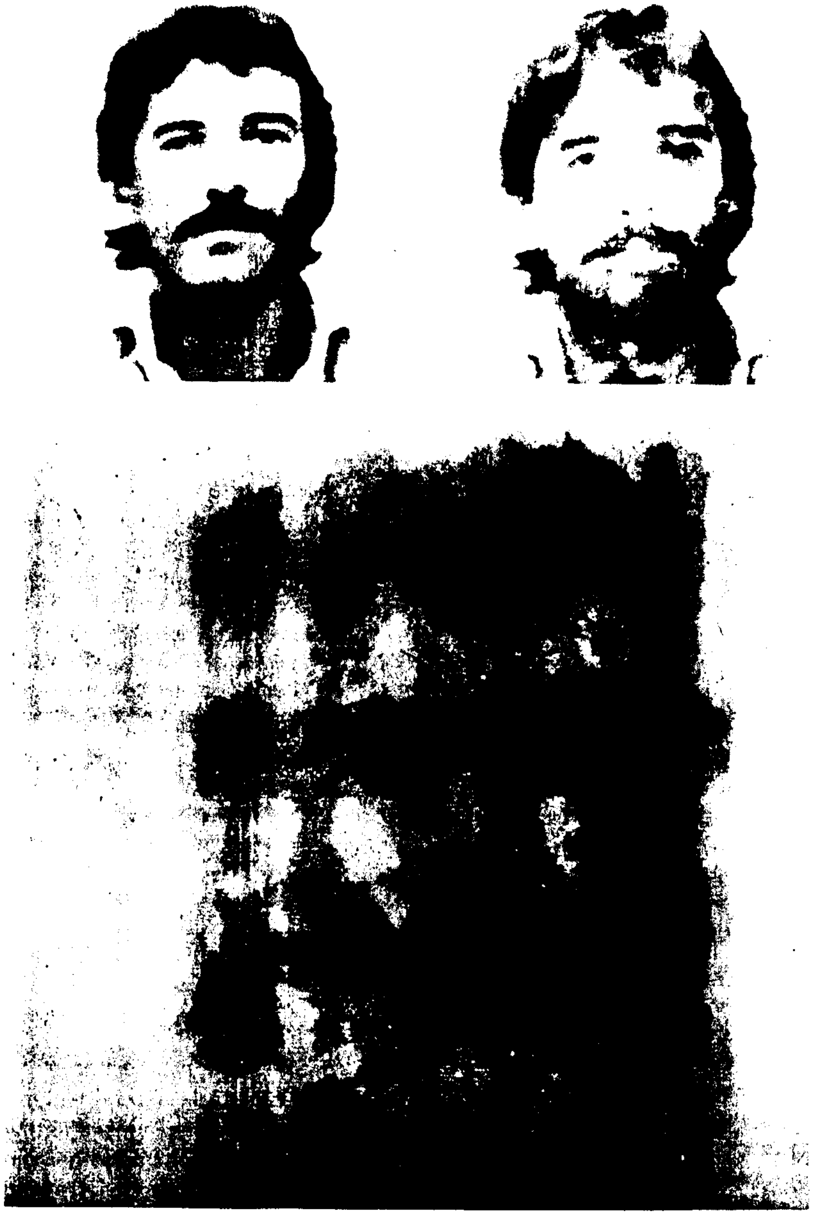


Fig.15. "Harry" – The effect of orientation-selective filtering on a portrait

Fig. 16. Bonnencontre (about 1900) Three Graces. Original and painting seen through wobbly glass (reproduced with permission from Gombrich[20])

relationships in the creative process. To illustrate the possible effects of such a transition to disorder, we reproduced a painting by Bonnencontre unaltered and seen through wobbly glass (Fig. 16). These images have been produced by Gombrich[20] to demonstrate how the artificial degradation of a painting of French nineteenth-century "art officiel" can make it quite interesting.

If, as is maintained here, art can be evaluated along dimensions of internal image representation, various schools of painting, or styles, may be characterized by shifts of attention among and within these dimensions or "maps." The existence of such degrees of freedom has been called plurality of attention. However, we are not suggesting that the artist is using only a particular filter characteristic once he has sufficiently elaborated his skills of painting. A more appropriate perspective would be that he creatively "zooms" across various modes of pictorial representation in much the same way that a biologist changes the focus of his microscope to examine various layers of tissue. We feel that such a process of shifting the focus of attention during the creation of a major work of art is beautifully documented by a series of drawings and paintings by the French cubist Robert Delauney (Fig. 17), which were brought to our attention by Walter Siegfried . They all constitute representations of the "Three Graces," which evolved from the photographic reproduction of a fresco from Pompei found in the artist's atelier. The final version (Fig. 17, *center*)

Fig. 17. Robert Delauney (1911–12) Studies of the Three Graces, after a fresco from Pompei (*top left*)

Fig. 18. Robert Delauney (1912) La Ville de Paris (Musée d'Art Moderne, Ville de Paris)

Fig. 19. Piet Mondrian (1913–14) Composition in Oval KUB (reproduced from Wijsenbeek[42])

became the centerpart of Delauney's famous painting "La Ville de Paris"[41] (Fig. 18). Another possible example of increasing abstraction may be seen in a series of three pictures (Fig. 19) that are related to the view from Piet Mondrian's study in the Rue du Depart 26 in Paris. The photograph taken from this study shows an advertisement painted on a wall. In Mondrian's rather naturalistic drawing of the scene, the advertisement is for "KUB" soup cubes, and the three letters are still visible in the cubist "Composition in Oval KUB," which the Dutch artist created from this view.[42]

Nonrepresentational Art

As the list of art styles considered above is evidently not complete, we shall next discuss the development of nonrepresentational art. In 1885, the French physiologist, Charles Henry, published a book entitled *Introduction à une Esthétique Scientifique*.[43] Based on his knowledge of aesthetics and mathematics, he advanced the hypothesis that correlations exist between the directions of movement (up and down, left and right) and their emotional significance. In subsequent publications, and especially in *Cercle Chromatique* (1888), Henry presented a more elaborate version of his theory and discussed the respective roles of line, tonality, and color as basic elements of pictorial representation. His most important idea was that the emotional impact of these elements is independent of their function in representing a particular object. George Seurat, the key figure in the French school of neoimpressionism, was deeply influenced by Henry's theories, as can be seen from his famous "Aesthetics," a text contained in a letter to Beaubourg written August 28, 1890: "Art is harmony. Harmony is analogy of differences, analogy of the similar, of tonality, colour, and the line in serene, calm, or sad combinations...."[44] Thus the interaction of these two minds strongly influenced the development of nonrepresentational art.[45]

The triad of line, tonality, and color played again a key role in the "General System of Pictorial Media," on which Paul Klee[46] lectured at the Bauhaus in the winter of 1923/24. It has been noted that, for the development of his theoretical position, Klee made use of principles and patterns elaborated earlier by the Gestalt psychologists.[47] This, however, cannot necessarily be taken as evidence for a causal effect of scientific research on art, as Klee anticipated other important results that were obtained in the laboratory only decades later. The most striking example of this is his illustration, well *before* the physiologists, of the principle of contour enhancement.[48] Klee and Henry conceived of the line as an abstract thing, which came into being through perceived motion or intersecting planes in visual space. Similarly, Kandinsky considered "the line an invisible thing ...created by movement."[49] Nevertheless, besides point and plane, Klee's colleague at the Bauhaus viewed the line as a "basic element without which a work in any particular art cannot even come into existence."[50]

The physiologist, Charles Sherrington, went one step further. Where Klee[51] was intrigued by "the open question of (the line's) reality," the former contended: "When we hear that Nature has no such thing as a line, vision answers that all contours are lines. That every contact of fields of light or colours is sharpened and stressed into a line – a psychological line. 'Contrast' develops a 'line' at any contact between abruptly distinguishable areas." But to Sherrington, it was still the *mind* whose "thinking largely accepts 'lines' and manufactures them."[52]

Almost a century after Henry's discovery of the line, the situation changed dramatically. In the early sixties, the neurophysiologists, David Hubel and Torsten Wiesel[53], discovered in the mammalian brain neurons responding selectively to elongated objects of particular orientation in the visual field (see chapter 7). This indicated that the early visual processing stages of the brain contain an arsenal of feature detectors tuned to lines and edges of varying width and orientation. This notion received support from psychophysical measurements of visual sensitivities to contrast and orientation of line segments as well as their mutual spatial interactions.[54] Related developments revealed that the brain is equally well equipped with mechanisms for the perception of tonality and color.[55] These results imply that lines, tonality, and color are not only the basic elements of pictorial representation in art but also in the brain. This supports the proposed relationship between visual information-processing characteristics and the evolution of style.

Conclusions

The main thesis of our paper is that the evolution of style in art is related to shifts in the focus of attention between multiple visual representations in the brain. Some evidence from visual research and art history seems to support this notion. First, recent results from the disciplines of pattern recognition and cognitive psychology suggest that perception is not uniquely determined by the physical properties of nature, but is an active process of constructing interpretations thereof. Second, it seems that brain function, with its adaptivity through learning, is the basis of such interpretive activity. Third, there are many similarities between image representations developed in art history and research in visual image processing. Clearly, more systematic experimental work should be done to explore how far the latter correlations can be confirmed within the framework of the present or any future perspective on visual information processing.