Criteria for the Creation of Aesthetic Images for Human-Computer Interfaces: A Survey for Computer Scientists

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ABSTRACT

Interaction in modern human-computer interfaces is most intuitively initiated in an image-based way. Often images are the key components of an interface. However, too frequently, interfaces are still designed by computer scientists with no explicit education in the aesthetic design of interfaces and images. This article develops a well-defined system of criteria for the aesthetic design of images, motivated by principles of visual information processing by the human brain and by considerations of the visual arts. This theoretic disquisition establishes a framework for the evaluation of images in terms of aesthetics and it serves as a guideline for interface designers by giving them a collection of criteria at hand; how to deal with images in terms of aesthetics for the purpose of developing better user interfaces. The proposed criteria are exemplified by an analysis of the images of the web interfaces of four well known museums.

Keywords: *Aesthetic Interfaces, Human-Computer Interaction, Image Aesthetics, Information Visualization, Interface Design*

1. INTRODUCTION

Images are often the key components of user interfaces. Examples of such interfaces from several applications of augmented reality (i.e., geovisualization, navigation, maintenance, museum guides, etc.) are shown in Figures 1 and 2. Figure 1 shows an image of the environment which is augmented by data indicating a possible path for a boat.

One could be of the opinion that such a real-time navigation system has to show "just the image the camera captures". But the interface designer has to decide for the specification of numerous variables that determine how the captured image is presented in the user interface. To name but a few, she has to choose color space, contrast, dynamic range, spatial arrangement of the image components (e.g., the position of the horizon), depth of field, and focal length. Figure 2 shows an example for maintenance instructions for an engine. The previous statements hold true for this example, as well. Even in a case where *some* parameters of an image are user-controlled - as is the case for the maintenance example, where the viewing

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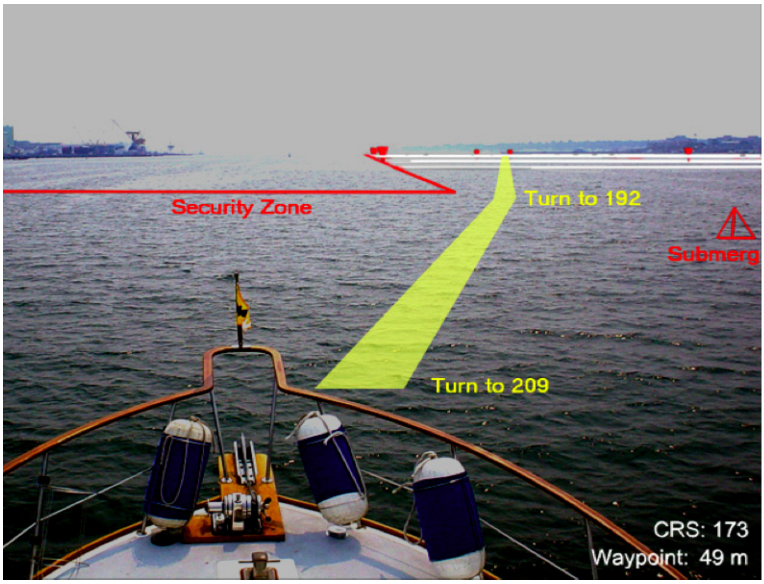
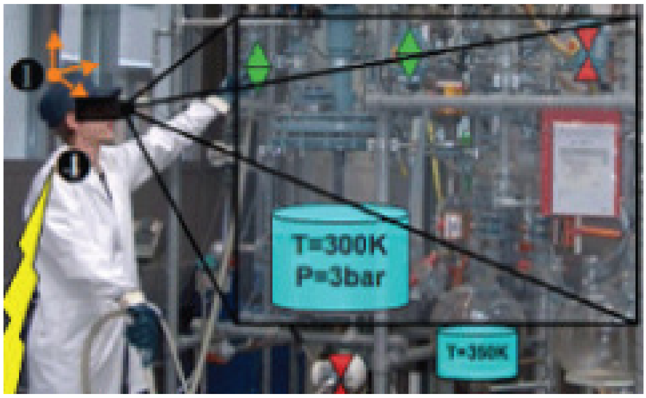
Figure 1. Images as key components of user interfaces: navigation (Adapted from WisdomTools LLC, 2009)



direction is user-controlled – the interface designer still has to control other image parameters (such as the color space or the dynamic range in this example). There are still voices claiming that images in augmented reality applications are "literal depictions of the real-world scene". However, there is no such thing as a "literal depiction of the real-world". It simply does not exist, because *every* image (independent of whether it was generated by a human or by a technical device) can depict only a part and only a particular view or perspective of the real-world. Among the many parameters that determine the appearance of an image are those mentioned earlier (contrast, depth of field, etc.). For a concrete image these parameters have concrete, determined values. The *choice* of these values is in the responsibility either of the human who generates the image or (in the case of augmented reality applications) in the responsibility of the designer of the computer system which generates the image, and this choice should be a conscious and well-considered decision rather than being left to chance.

Topics such as the importance of aesthetic qualities of graphical elements of user interfaces (Tufte, 1990), the aesthetics of interaction (Norman, 2002), or the aesthetics of websites in particular (Lavie & Tractinsky, 2004) have frequently been addressed. There are also early publications on aesthetics in general, even in the context with mathematics (Birkhoff, 1933), (Bense, 1965). What is underrepresented in the literature is the role of *image* aesthetics in interfaces. This paper is an attempt to fill this gap. The roles of images in human-computer interaction are manifold. Stone et al. (2005) name four main benefits. Images motivate and attract the attention of the user and have the function to persuade her. They communicate information, which is often exploited in computer-based learning. Furthermore, they have the great power to overcome language barriers, and last but not least they support interaction. Images are especially powerful whenever it is difficult to describe the depicted information by words or numbers. This is the paradigm for most human-computer interaction applications.

Figure 2. Images as key components of user interfaces: maintenance (Adapted from Ecole Polytechnique Federale de Lausanne, Automatic Control Laboratory, 2011)



In Section 2 we propose aesthetic categories that, on the one hand, allow for the evaluation of the aesthetic qualities of an image (and thus of an important component of human-computer interfaces) and, on the other hand, enable an interface designer to adapt her tools to the needs of the user. Section 2 closes with an analysis of the images of the web interfaces of four well known museums to exemplify the described criteria by means of practical instances, where images are key components of human-computer interfaces. Furthermore, to justify the proposed categories we take a closer look at the user and her visual system in Section 3, where we describe basics about human visual processing and the possible connections to our aesthetic experience. We summarize results from cognitive neuroscience and psychology, that give an understanding of the basic principles of the human visual system. This system solves a perceptual problem by filtering out the salient features of an object from the details and varieties of its appearance. This is akin to visual artist's abilities to cull from the sensory manifolds those image features that enhance the clarity of the representation. Thus, cognitive neuroscience as well as artistic principles represent the foundations for the defined categories and criteria of visual aesthetics.

2. CRITERIA FOR THE CREATION AND ASSESSMENT OF IMAGES IN TERMS OF AESTHETICS

In this section we will consider which criteria of image composition are capable of evoking an aesthetic sensation. We divide these criteria into six categories, the motivation of which is described later in Section 3. Many books have been filled with principles of art work of images, i.e., the layout and arrangement of color and form in visual arts, whether it is drawing, painting, or photography. In this section we refer to the classic benchmark by Feininger (1961) as it summarizes the most basic principles of aesthetic composition and is still a reference for photographers and artists. For each criterion described in this section we give an example, mostly in form of a photograph, but the described principles hold true for all kinds of images.

Reading only the captions of this section it can be regarded as a quick guide for the creation and assessment of images in terms of aesthetics. In the last subsection we analyze the images of websites of four museums with respect to the introduced criteria.

2.1. Category Color

Many examples of color-blind animals support the opinion that color is not the most important feature of the visual world. Even humans with an impairment of their color sense are able to cope excellently with the requirements of life. Nevertheless, color is a modularity of the visual system, which just in the context of beauty is an important means to evoke aesthetic experiences. Three criteria of color and its distribution in an image, which are known to appeal to our aesthetic sense, are examined in this subsection.

2.1.1. Usage of a Few Strong Colors

The maximum number of strong colors for an image still to be pleasant to the eyes usually is two to three. If more than a few strong colors occur in an image usually the effect of beauty is lost. (Maybe this corresponds to the isolated process in the human visual system triggered by only one special visual attribute which will be explained in subsection 3.2.) In principle, color in an image should correlate with its content (Feininger, 1961). If color is not the salient feature of an object depicted in the image, as it holds true, for example, for a butterfly, the visual system of the observer is overcharged and an aesthetic impression is missed. The left image of Figure 3 shows an example. The orange color of the turbans of the musicians is the dominant property of them in this image. Thus, as a consequence they are depicted in such a way that the orange color is also the dominant property of the whole image itself. All other colors of the image are subordinate or even non-colors (white). Also the right image of Figure 3 gets by with only a few strong colors, the yellow of the taxis and the red rear lights of the cars.

The deliberate choice of only one main color in an image, called monochromaticity, represents an extreme variation of this rule. Quite aesthetic results can be achieved if only a small range of colors adjacent in the color circle are chosen, e.g., only red, brown, and orange tones in a picture of autumn foliage. The images of Figure 4 shows an extreme example of this principle, where only a brown tone is used and this even in a quite unsaturated way.

Such a subtle monochrome coloration allows for the accentuation of important elements which come to the fore, as the bench and the person in these examples.

2.1.2. Application of Complementary Contrast

Pairs of colors that are in some way opposites of each other are called complementary colors. The traditional sets of complementary pairs in art are red and green, blue and orange, and

Figure 3. Usage of a few strong colors and application of complementary contrast (If otherwise mentioned the images of this article are taken from Peters, 2011).

yellow and purple. They face each other in the color circle, as for example advocated by van Goethe (1810) or Itten (1961) (Figure 5).

Two complementary colors reinforce themselves mutually in their luminance. By a moderate application of this effect the attention of the observer can be directed, which is especially important for human interaction with information systems. The most beautiful effect often is achieved if the complementary colors are the only strong colors. The hHindu picture of Figure 3 with the dominant orange of the turbans and the zither and the contrasting blue tone of the blanket may hold as an example for this effect, as well. The complementary contrast becomes evident in two phenomena, the simultaneous and the successive contrast, where the nonexistent complementary color is anticipated either simultaneously in the environment of an existent color or immediately after the exposure of a color, respectively. Colloquially speaking, the human visual system requests the complementary completion and generates it on its own authority if it is not present. This can hold as another argument that supports the thesis of the foundation of aesthetics in cognitive neuroscience, as exposed in Section 3.

2.1.3. Exploitation of the Dynamic Range

The distribution of tonal values in an image is characterized by the dynamic range. Although it applies for colored as well as for black and white images the principle is best explained by means of gray value images. The dynamic range describes the ratio of luminance values from the brightest highlights to the deepest shadows in an image (i.e., white and black, respectively).

Our visual system can perceive much a greater dynamic range than that which can be rendered in an image via a monitor or a print.

When we consider the instantaneous dynamic range (where our pupil opening is unchanged) this ratio is indicated between 1:1000 and 1:10,000 (McHugh, 2010). But our visual system is extremely adaptive and the dynamic range actually changes depending on brightness and contrast of a scene. If we consider situations where our pupil opens and closes for varying light, we can see over a range of nearly 1:1,000,000. In contrast to this, the dynamic range of prints is about 1:250 and those of monitors can reach values of about 1:1000.

One can say that an image looks pleasing to the eye if the display medium (print or

Figure 4. Subtle monochrome coloration

monitor) is able to render the dynamic range of the depicted scene in a similar way as it is perceived by the human visual system. The contrast ratio of an image should be controlled in such a way that the wide range of intensity levels from the brightest light to the deepest shadow is represented in an image. As a rule of thumb, an image is said to be aesthetic only if the full tonal range is present and, in addition, the tonal values are distributed in a well-balanced manner. The images of Figure 6 can pass off as examples for that. As an indicator for an advantageous distribution of the tonal values the histogram of an image can serve (Figure 7).

In the first example the dynamic range of the image is smaller than the dynamic range of the scene. The histogram indicates that some shadow and highlight detail is lost. The second histogram is one of an image of low contrast. The dynamic range of the scene is smaller than

Figure 5. Color circles from the 18th century (left) and by Josef Itten, 1961 (right)

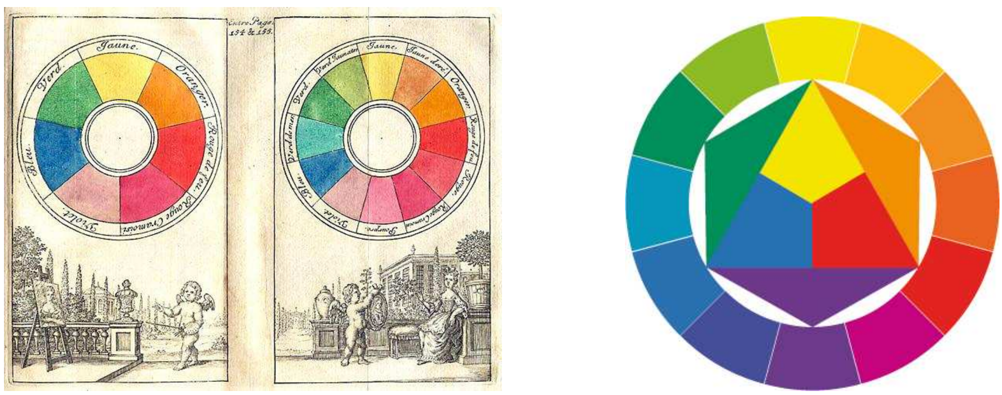
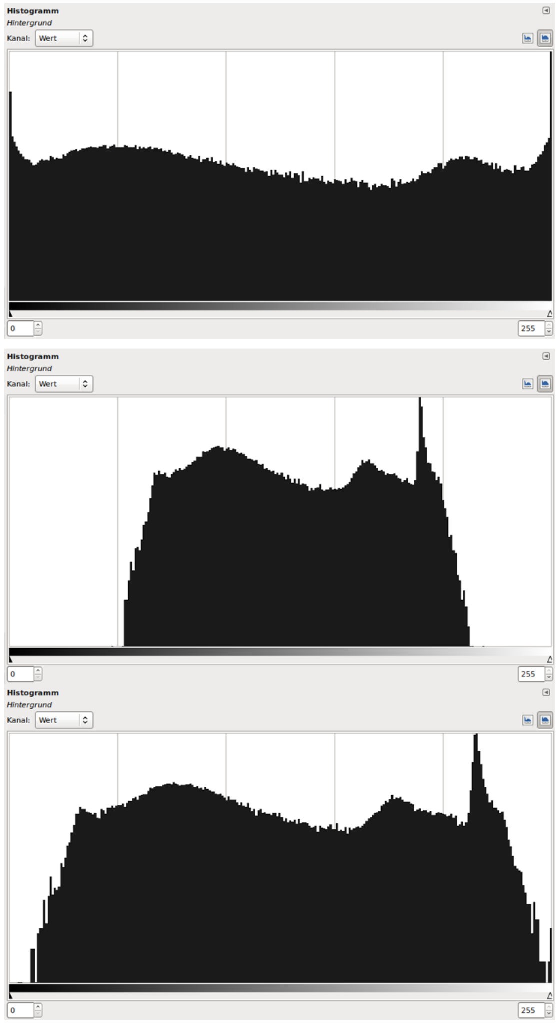


Figure 6. Exploitation of the dynamic range

Figure 7. Histograms as indicators for image quality



the dynamic range of the image. In contrast to this, a histogram shape which covers the whole range of gray level values as depicted in the last example is a good precondition for an aesthetic image. It indicates that both shadow and highlight detail is captured. In general, the very bright and dark parts of an image should only take up small portions of an image, just as it holds true for the images of Figure 6. A technique that should be mentioned in this context is Ansel Adams' zone system (Adams, 1981). With this system he gave a recipe to bridge the gap between the limited dynamic range of prints or monitors in comparison to our visual system. The zone system allows for the prints or monitor displays to approximate the way the world looks to our eyes. It does this by providing a simple way to control the contrast of images. Although originally developed for film negatives, its principles can easily be adopted for digital imaging.

A temporary fashion worth mentioning is high dynamic range imaging (Reinhard et al., 2005; Brown, 2006). As a field primarily evolved in computer graphics, it provides a set of methods to generate an image of high dynamic range from multiple exposures of the same scene. The source images are overlapped and masked appropriately so that the resulting composite represents a wider gamut of colors and tones. However, images generated with this technique often evoke an artificial impression and the effect tends to become stale if exaggerated.

2.2. Category Form

More important than color perception, form perception is one of the most basic visual functions, to master the demands of the environment. It provides the source of information necessary for basic survival functions such as navigation, recognition of prey, predators, and mates, as well as for high level behaviors such as reading. But form and shape of objects do not only allocate essential information on the world surrounding us, they are also a source of aesthetic sensation.

Two aesthetic criteria of form, clarity and silhouettes, are known to be judged as being beautiful and are described in the following.

2.2.1. Forms Should Be Clear and Simple

Speaking about form in the context of elements constituting an image usually lines and surfaces are meant. Lines can actually be present by the contrast gradient or color changes or they can emerge through our perception. For example, elements of an image can be arranged in such a way that they are connected by imaginary lines. Those can be attributed by their orientation, as well. It is known since a long time, that an image, that appeals favorably to our visual system, should comprise only a few predominant orientations in any case, either evolving from actual lines, by edges and boundaries of surfaces, or by imaginary lines. The main orientations in the left image of Figure 8, for example, are constituted only by straight lines (verticals, horizontals, and diagonals), those of the right image by straight and curved lines and concentric ovals.

The few and overall shapes of both images are consistent, simple, and clearly recognizable. This is what Feininger means when he speaks of clarity and simplicity of form (Feininger, 1961).

To put forward a few generalizations, one can say that horizontal lines tend to evoke emotions of stability, constancy, and reliability.

Figure 8. Clarity and simplicity of form

Vertical lines can induce the impression of rigidity and strength, whereas diagonals, besides of their graphical appeal, are adequate if a feeling of tension has to be created. If curved lines obey a continuous function in a mathematical sense and if they take a uniform course within the image as a whole they seem to appear beautiful.

2.2.2. Silhouettes Evoke Aesthetic Impressions

Silhouettes are explicitly listed by Feininger as components of aesthetic images (outlines which are typical for an object, vigorous and unusual; clear silhouettes) (Feininger, 1961).

Also artists from other disciplines have realized the value of silhouettes for the visual effect. Giacometti with his sculptures of men and animals can hold as an example. The strong impact of his works is achieved mainly by their silhouettes, viewed from a distance (Sartre, 1948), rather than by their three-dimensionality. Giacometti was a master in reducing objects (mainly humans and animals) to their characteristic outlines. Figure 9 shows an example.

Another prominent example is the series of photographs of moving humans and animals by Muybridge (1887) (Figure 10). Here the outlines of the objects play a decisive role in the aesthetic classification of his works, as well.

But not only shapes of animals and humans are perceived as being beautiful, also the silhouettes of other objects can be aesthetic elements of an image, such as the bench or the couple under the umbrella in Figure 11.

As a rule of thumb, one can say that silhouettes appear beautiful, if they capture the main characteristics of an object. The outline of the object should either be clearly identifiable or graphically interesting. In addition, silhouettes are supposed to be sharp-edged and clearly distinct from the background rather than ambiguous and bleary. However, this last rule does not apply unrestrictedly. The shape of the human body can be regarded as an exception to this rule, as already indicated by the fact that the human brain handles body shapes separately. This is pointed out in more detail in Section 3. Apparently, even if human silhouettes are depicted in a blurry fashion (Figure 12), they can evoke a sense of beauty.

2.3. Category Spatial Organization

A major role for the aesthetics of an image as a whole is not only played by the shapes of the elements constituting an image, rather also their mutual spatial relations in the two-dimensional surface of the image are of importance for its aesthetic appearance. Analogously to the form criterion *clarity* in the last subsection, we will here comment on the aesthetic criterion *clarity of spatial organization*. Other criteria of spatial organization are the *golden mean*, *texture* and *pattern*, *rhythm*, *repetition*, and *variation*, described next.

Figure 9. Animal Silhouettes (Replica of the sculpture "Cat" by Alberto Giacometti, original sculpture from 1954)

Figure 10. Animal silhouettes (Adapted from The Horse in Motion by Eadweard Muybridge, 1887)

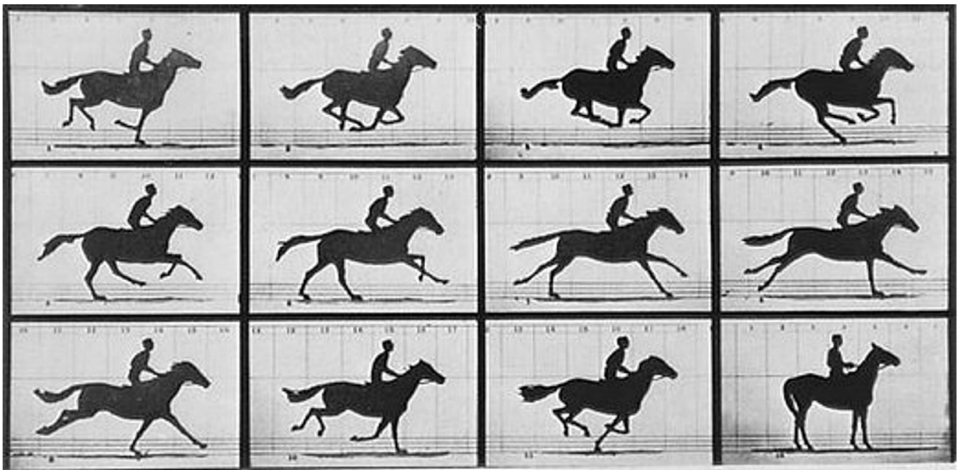


Figure 11. Silhouettes of other objects

Figure 12. Human silhouettes - Dark Days - Venice, 2006 (Photographs taken from Peters, 2011)

2.3.1. Clarity of Spatial Organization of Image Elements

According to Feininger clarity and simplicity of spatial organization are the silver bullet for an aesthetic image (Feininger, 1961). Too many objects in a single image cause confusion and derangement. An image should not be overloaded by details, as well. Figure 13 shows an example which demonstrates the power of spatial organization.

The attention of the viewer is focused on the person in the center, although the visible parts of the boy occupy only a very small portion in the image. This effect is only in part due to the form contrast between curved and straight lines, but mainly due to the spatial arrangement of the image elements. In general, an image appears aesthetically, if no element be omitted or be added without destroying the visual balance. There are also some more restrictive rules concerning the distribution of light and dark parts of an image. The usual way to scan an image is supposed to be from the left upper part diagonally to the right lower part. Accordingly, the most important portion of an image is the left upper part, because here the image inspection starts. As exemplified by the pictures of Figure 8, an image should have its lighter parts in the upper left and its darker parts in the lower right, because humans are more inclined to examine lighter parts of an image rather than darker parts.

2.3.2. Application of the Golden Mean

A particular ratio of an asymmetric line division is defined by the so-called golden mean

Figure 13. Clarity of spatial organization of image elements

or golden section. Whereas symmetry appears rather static and boring, divisions in accordance with the golden mean are considered as being harmonic and interesting. A line should be divided in such a way that the ratio of the smaller part *a* to the larger part *b* is the same as the ratio of the larger part *b* to the whole *a*+*b*. Put in formulas it reads like this:

$$\varnothing = \frac{a}{b} = \frac{b}{a+b} \tag{1}$$

As solutions for the ratio $\varnothing$ we obtain the two possibilities

$$\varnothing_1 = \frac{\sqrt{5}-1}{2} \approx 0.618 \text{ and}$$
$$\varnothing_2 = -\frac{\sqrt{5}+1}{2} \approx -1.618 \tag{2}$$

As we deal only with positive lengths here, solution 2 drops out and the geometric definition of the golden mean is

$$\varnothing = -\frac{\sqrt{5}-1}{2} \approx 0.618 \tag{3}$$

It has the continued fraction expansion

$$\varnothing = \frac{\sqrt{5}-1}{2} = \cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{1+\ldots}}} \tag{4}$$

and the best rational approximations to $\varnothing$ are given by the convergents of this infinite continued fraction, arrived at by cutting it off at different levels in the expansion: 1/1, 1/2, 2/3, 3/5, 5/8,… Thus, the convergents of the golden mean are the ratios of successive Fibonacci numbers (Cartwright, 2002). Therefore, a division of a line, surface, or volume in the ratio of about 3:5 appears harmonic, i.e., aesthetic. From antiquity until today $\varnothing$ has constantly been present in art. Even ancient Chinese paintings show the golden section in an accuracy of three decimal places. Examples from architecture are the Great Pyramid of Cheops and the Parthenon of Athens. The main explanation for the usage of this proportion in art is that it is found frequently in nature, e.g., in sea shells or in human proportions (for example in the ratio of finger limbs).

An image constructed according to the rule of the golden mean is shown in Figure 14. The woman is approximately placed in the golden mean. The majority of the images in this article obey this construction rule.

2.3.3. Wholistic Impression by Textures and Patterns

Texture denotes the structural characteristics of a surface. In a classical study (Tamura, 1978) texture was classified into 6 dimensions, namely coarseness, contrast, directionality, line-likeness, regularity, and roughness. *Patterns* are regular visible surface structures which underlie a more or less repetitive entity. These structures can be graphical ones, which means that they are arrangements of combinations of certain visual themes (e.g., stripes, zigzags, or checked patterns). Patterns are not to be confused with noise, which are visual signals without a recognizable pattern.

Nature is full of patterns. Sand dunes, tree branches, snowflakes, or crystals display most beautiful patterns, to name but a few. It is an open question as to why patterns evoke aesthetic feelings in humans, but our visual system seems to look for patterns in visual stimuli even if they are actually not present. For example, we are able to detect an organizing principle (i.e., something meaningful) even in arbitrary structures of low information content such as clouds. This phenomenon is known as *clustering illusion* (Gilovich, 1985). For Feininger (1961) “pattern, rhythm, and repetition of interesting, related forms” is one of the ten most important properties of an aesthetic image. Examples for images which appeal mainly because of their overall pattern and texture character are given in Figures 15 and 16.

Figure 14. Application of the Golden mean

The images in Figure 15 are made up of fairly regular patterns, those in Figure 16 display more random textures, but for all holds true that the entire image plane is filled with consistent structure and thus evokes a wholistic impression. Other examples of images mainly being effective because of patterns are given in Figure 18, and maybe even the images of Figure 8 works partly because of their pattern character.

2.3.4. Repetition of Image Elements

Many visual patterns are strongly related to repeated shapes or objects, sometimes referred to as elements of a series. These copies can occur in regular spatial distances or they can be arranged arbitrarily. All things significant for animals or humans show a minimum of *repetition*. However, only those (not only visual) patterns seem to be essentially relevant, the complexity of which ranges somewhere *between* perfect symmetry (e.g., the ticking of a clock) and noise without any structure (e.g., the rush of a stream). Patterns of largest relevance for animals are those of a medium amount of information. Regarding aesthetics conditions are similar. Perfect symmetry in images as well as chaos (or noise) is not ranked beautiful. Figure 17 demonstrates the beauty of repetition by copying single slices of an image and combining them without modification. Repeated structures are also present in the images of Figure 8 and contribute to their aesthetic appeal.

Figure 15. Wholistic impression by patterns

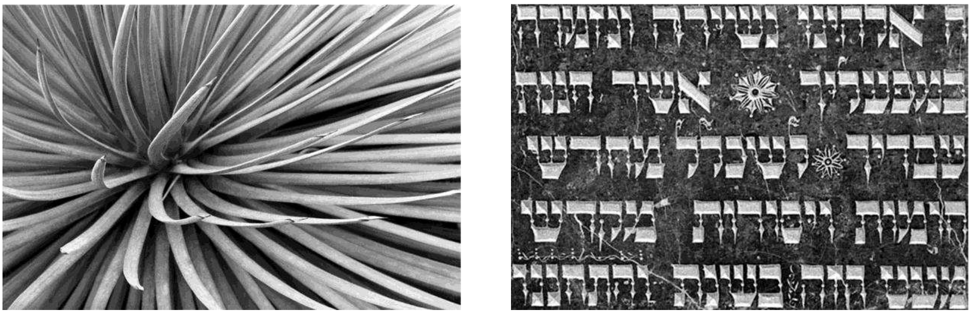


Figure 16. Wholistic impression by textures

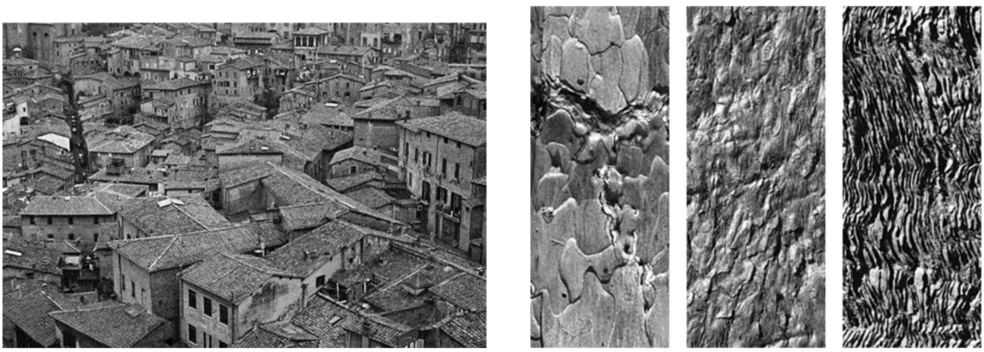


Figure 17. Repetition of image elements

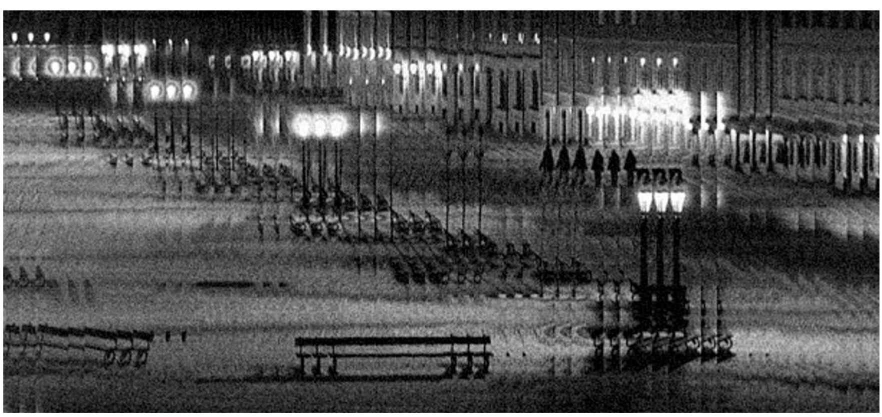
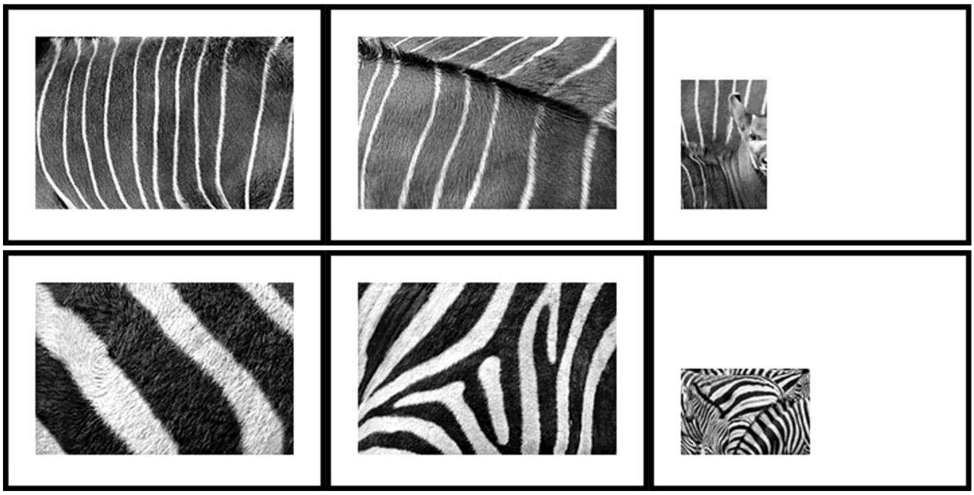


Figure 18. Rhythm by repetition of patterns and application of variations. Selection of the collection "Streifzüge", 2000 (Photographs taken from Peters, 2011)



2.3.5. Application of Variations to Patterns

As pure repetition often is said to be monotonous and thus boring another principle of art consists in *variation*, which means an instance of change in present structures. This is usually applied to increase the visual interest. Figure 18 shows variations over a theme, namely stripe patterns in animal fur. Another example is given in Figure 15. Variation of a pattern is realized here in the right image by the details of the different letters.

2.3.6. Rhythm Induced by the Repetition of Elements

Visual rhythm is the last aesthetic primitive of spatial organization we will explain. It is an artistic principle closely connected to repetition and often described by the flow of how the viewer's eye is drawn across an image, for example, whether the eye is forced to jump rapidly or glide smoothly from one image element to the next. The most common explanation as to why humans appreciate rhythm, either in music or in the visual arts, is that it recalls how we walk and the heartbeat we heard in the womb.

An art dictionary defines visual rhythm as "regularities of repetition of image elements to produce the look and feel of movement" (Delahunt, 2010). There are several types of visual rhythm. These include:

1. *Regular Rhythms: ab ab ab* ... is the most common type. Another example is *abbb abbb abbb* ... The picture in Figure 17 exploits the schema *aaa bbb ccc* ...
2. *Alternating Rhythms*: for example: *aba cdc aba efe aba* ...
3. *Progressive Rhythms*: Progression occurs when there is a gradual increase or decrease in the size, number, or some other quality of the elements repeated. A sample pattern would be: *ab aabb aaabbb aaaabbbb* ... The left image of Figure 8 displays a progressive rhythm.

In these examples the letters *a, b*, etc. stand for visual elements of any sort. In Figure 18 the effect of visual rhythm is even more evident: in the left image of the first row the viewer's

Figure 19. Motion blur of high contrast

gaze is led horizontally from the left to the right by the arrangement of the vertical stripes, whereas in the middle picture of the same row it is directed diagonally from the upper left to the lower right.

2.4. Category Motion

Motion refers to life and action. As this article is about images rather than movies, we will illuminate the means by which motion can be conveyed in an image. Calder, most famous for inventing the mobile, used black, white, and red as the only colors for his kinetic sculptures, because he was of the opinion that all other colors would confuse the clarity of motion (Calder, 1952). This opinion is interesting because of the coincidence with the functional specialization of the color and motion pathways in our visual system, mentioned at the end of subsection 3.1. According to Calder, motion is most effectively represented by placing highly contrastive surfaces side by side. Translated into images, this means that motion is best expressed in an image (even a color image), if it is based on contrast changes, rather than color. The graphical means by which this can be realized are manifold. For example, motion can be "freezed". This can be effective if an unusual phase of a moving object is catched, such as a horse jumping. But we will concentrate here on *blur* and the depiction of *distinct motion phases*, which are two of the most expressive motion symbols.

2.4.1. Expression of Motion by Blur of High Contrast

A strong indicator for movement is given by blur. Feininger defines it as "unsharpness in one direction", namely the direction of the moving object (Feininger, 1961). The stronger the blur, the stronger the impression of speed. In photography it can be achieved either by a static camera taking a moving object (so-called *motion blur*) or panning the camera with a moving object (so-called *panning blur*).

Blur as an indicator for motion is an aesthetic primitive if the blurred parts of the image contain lines or stripes of high contrast rather than being of homogeneous luminance. Figure 19 shows two examples of motion blur.

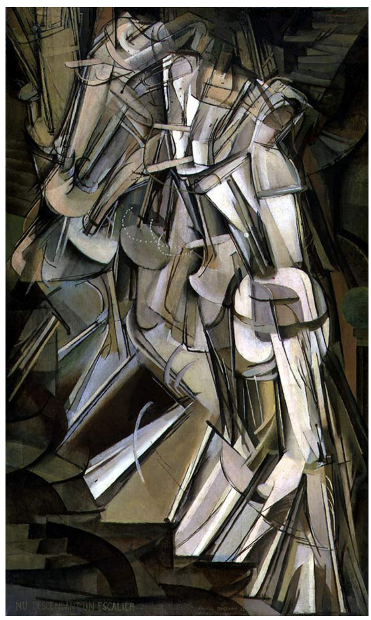
Note the high contrast changes in the blurred regions. The same holds true for the images of Figure 20. Here the blur was induced by a panning of the camera. In the upper image it was panned with the walking woman, thus she is depicted almost sharply. In the lower image the camera was panned with the right car. For both images it is essential for the evocation of an aesthetic impression that the blurred regions exhibit high contrasts.

2.4.2. Depiction of Distinct Motion Phases

The depiction of a number of distinct motion phases in a single image represents another

Figure 20. Expression of motion by panning blur

Figure 21. Depiction of distinct motion phases. Marcel Duchamp's Nude Descending a Staircase No. 2, 1912 (Source: http://www.philamuseum.org used with permission)



technique to illustrate movement in images. Its high aesthetic appeal is probably partly due to the element of repetition. A series of sharp, slightly different, partly overlapping copies of an object, which is captured in different phases of movement, can symbolize the concept of motion in a graphically smart way. Marcel Duchamp practiced this principle in his famous painting pictured in Figure 21. As shown in Figure 22, in photography distinct motion phases are usually obtained by multiple exposures of a not necessarily moving object.

2.5. Category Depth

To depict the three-dimensional world in the two-dimensional image plane it has to be simulated by means of artistic devices. A number of basic techniques of picture language can be used to create the illusion of depth in an image.

Figure 22. Depiction of distinct motion phases. Double exposure indicating slight movement

Figure 23. Visualization of linear perspective

Examples of these techniques are: controlling the variation between sizes of depicted objects, overlapping them, and placing those that are on the depicted ground as lower when nearer and higher when deeper (Delahunt, 2010).

We concentrate here on the *visualization of linear perspective*, the *exploitation of the contrast between sharpness and unsharpness*, and *the light and shadow distribution*.

2.5.1. Visualization of Linear Perspective

Filippo Brunelleschi's experiments in perspective painting in the early 1400s mark the invention of linear perspective. It works by following geometric rules for rendering objects as they appear to the human eye. For instance, we see parallel lines as converging in the distance, although in reality they do not. The lines of

Figure 24. Visualization of linear perspective

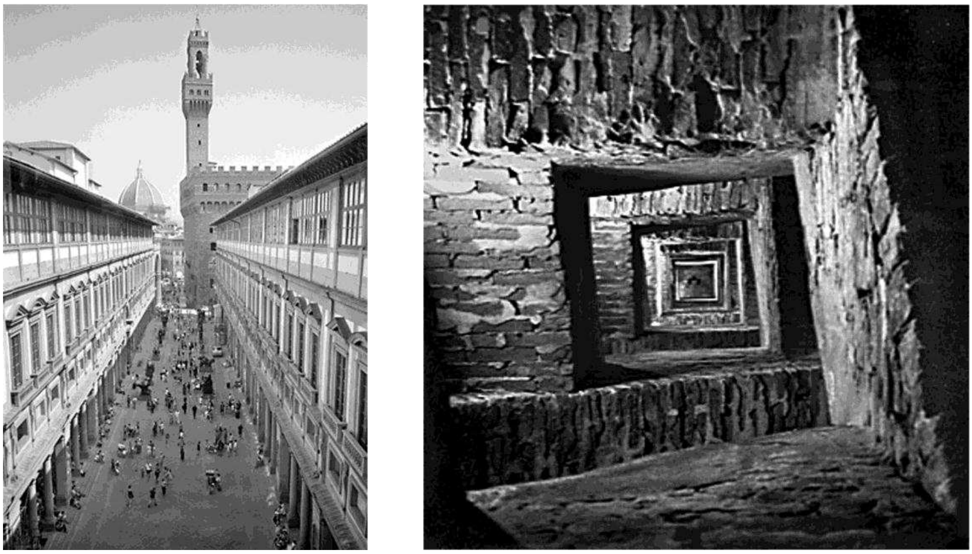
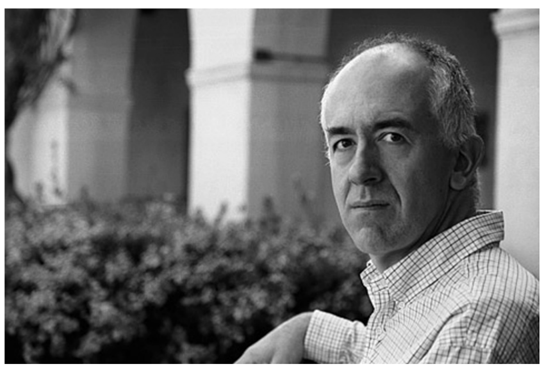


Figure 25. Contrast between sharpness and unsharpness



buildings and other objects in a picture are slanted inward making them appear to extend back into space. If lengthened, these lines will meet at the vanishing point along an imaginary horizontal line representing the eye level (Delahunt, 2010). Figures 23 and 24, each with its vanishing point in the center, give examples for images composed in linear perspective.

2.5.2. Exploitation of the Contrast between Sharpness and Unsharpness

Blur can be interpreted as unsharpness in one direction. In this subsection we consider unsharpness more generally as absence of high frequency content. The visual impression of the contrast between sharp and unsharp parts of an image can affect quite aesthetic to the viewer. This can be exploited for the purpose of focusing attention to the important image elements. The most common application of this principle can be found in portrait photography, where a large aperture is used to obtain a small depth of field, which results in an unsharp background and thus emphasizes the portrayed person as seen in Figure 25.

2.5.3. Depth by the Distribution of Light and Shadow

A large field of research in machine vision, called *shape from shading* (Zhang, 1999), still considers the question how the shape of a three-dimensional object can be recovered from shading in a two-dimensional image. Different illumination conditions cause different shadings of the objects we perceive. Somehow our brain is able to suggest the form of an object from this shading. Put in terms of image areas, the human visual system is able to perceive depth from the distribution of light and shadow in an image. A strong visual effect is achieved, for example, if objects are depicted as if illuminated under extreme conditions. We often find sharp contrasts then on the surface of the object, and our recognition is accompanied by a feeling of beauty.

The pictures of Figure 26 give examples of this principle.

2.6. Category Human Body

The human body represents the last aesthetic category we turn to in this section. As will be explained in subsection 3.1 the body and its parts such as hands and heads take up a special position in visual information processing, which reflects the importance of these visual stimuli for our survival. Analogously, also in our aesthetic sensation it seems to be worth to be regarded as a separate category. *Principal axes* of an object are a particularly important concept in this context.

2.6.1. Visibility of the Principal Axes of a Body

Axes of symmetry or elongation around which the local parts of objects are grouped in order to constitute their global form are called *principal axes*. If an object is enlarged, shrunk, or

Figure 26. Depth by the distribution of light and shadow

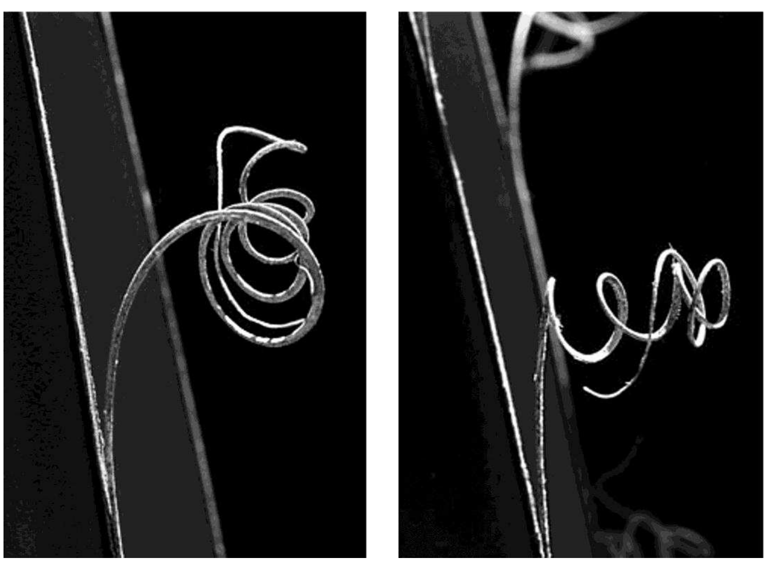
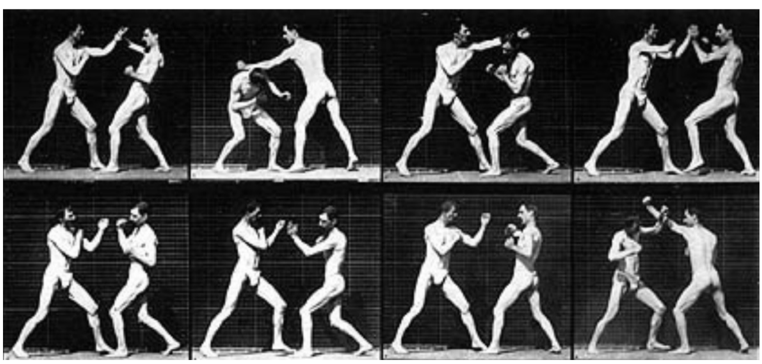


Figure 27. Human body (Replica of the sculpture "Walking Man" by Alberto Giacometti, original sculpture from 1961)

Figure 28. Human body (Adapted from Two Nude Men Wrestling by Eadweard Muybridge, 1887).



rotated around its principal axis the relationship between the parts and the principal axis remains constant across all variations. Principal axes are considered as being aesthetically relevant (Latto, 1995). Supporting arguments for this opinion can be derived from the arts as well as from cognitive neuroscience. Stick figures have been used by artists ever since, even humans in cave paintings have been depicted by means of their principal axes. On the other hand, it has been shown in a study that little animal models made of pipe-cleaners are sufficient to represent

Figure 29. Silhouettes of the human body. Selection of the Collection "Dark Days - New York", 2007 (Photographs taken from Peters, 2011)

the animals (Marr & Nishihara, 1978). They are easily recognizable although no information on the surface of the shape is present. The authors supposed that the success is due to the correspondence between the pipe-cleaners and the axes of the volumes they stand for.

To name yet another argument, theories of object recognition can be divided into two types: view-centered and object-centered (Peters, 2000). In order to accommodate novel views, they both must appeal to a minimal set of structural descriptions defining the global form of an object. Principle axes representations are thought of as likely candidates for structural descriptions appealed to by both theories (Tarr & Bülthoff, 1998). To come back to aesthetics, Giacometti again provides examples for the thesis that the human body intrinsically is capable of evoking a feeling of beauty. What distinguishes his human statues is the fact that they almost only consist of their principal axes. Giacometti reduces the human body to its basic shape, and thus we recognize the concept of a human at once (Figure 27). He creates the "idea" of man or woman with his works (Gross, 2002). Sartre put this as follows: "As soon as I see them [these figures], they spring into my visual field as an idea before my mind; the idea alone is at one stroke all that it is" (Sartre, 1948).

Other examples are given again by a motion study of Muybridge in Figure 28, this time boxing men, and the shapes of humans in Figure 29, which illustrate both, the aesthetic criterion of silhouettes dealt with in subsection 2.2, as well as the beauty of the human body defined by its principal axes.

Summarizing, it seems that the human body does not appear beautiful arbitrarily, but because its shape, especially in the extreme version of principal axes, corresponds to the simplifications and transformations our visual system performs to analyze and represent it. We will address this issue in more detail in Section 3.

2.7. Instances from Practice

To exemplify and concretize the described criteria we will describe some practical instances in this section, where images are key components of human-computer interfaces. For the clarification of the established rules we present examples which meet the rules as well as examples which do not. Generally, websites of museums are good examples as they usually avail themselves of images to attract visitors. The websites of the following four museums are considered: Josef Albers Museum Quadrat, Bottrop, Germany (Figure 30), Wallraf-Richartz-Museum, Cologne, Germany (Figure 31), Deutsches Museum, Berlin, Germany (Figure 32), and Tate, London, UK (Figure 33) (The main Tate home page will be changing within the next months). We analyze the main images of two screenshots for each museum. The left parts of the figures show the main webpages, the right parts show subordinate webpages of the same website, respectively. For this analysis we chose only such museums that are well known and thus promise to meet already a certain design standard. Although images are only one of many aspects that contribute to a website's success, the overall web design is not the concern of this article. We refer to the aesthetic appeal of the used *images*, only. Thus, from the results of this analysis one cannot deduce anything relating to the usability of the considered *website as a whole*.

2.7.1. Color

Josef Albers Museum: In the only image of the main website (Figure 30a) brown and gray tones are dominant; the only strong color is the green color of the lawn. Thus the rule to use only a small number of strong colors is fulfilled. Monochromaticity is given inherently in Figure 30b as the portrait is a black and white photograph.

Wallraf-Richartz-Museum: In Figure 31a also only one strong color appears, namely the blue color of the sky. The rest of this image has gray and almost black tonality, giving the image an almost graphical appearance. The images of Figure 31b display monochrome values; the color is even repeated between both images, establishing a relationship between them. Thus, here the single images also correspond in the con-

Figure 30. Website of the Josef Albers Museum Quadrat Bottrop, Germany. a) Main webpage, b) Subordinate webpage. Screenshots from 2011-02-02 (© 2011, www.quadrat-bottrop.de, used with permission).

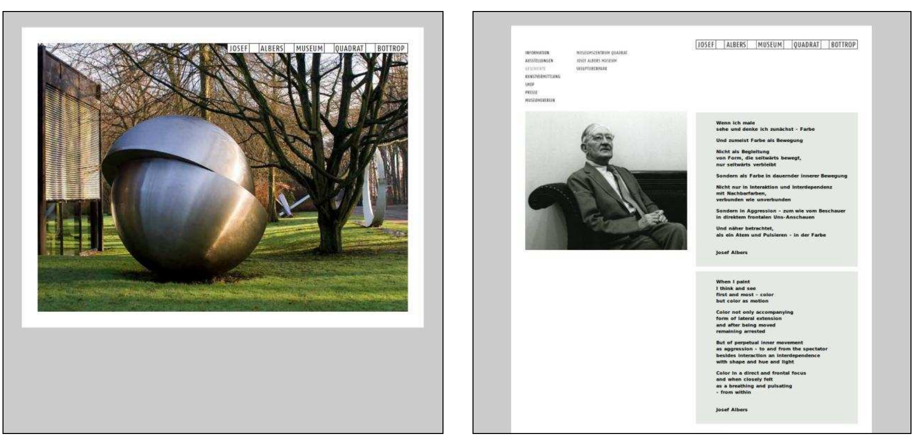


Figure 31. Website of the Wallraf-Richartz-Museum, Cologne, Germany. a) Main webpage, b) Subordinate webpage. Screenshots from 2011-02-02. (© 2011, www.wallraf.museum, used with permission).

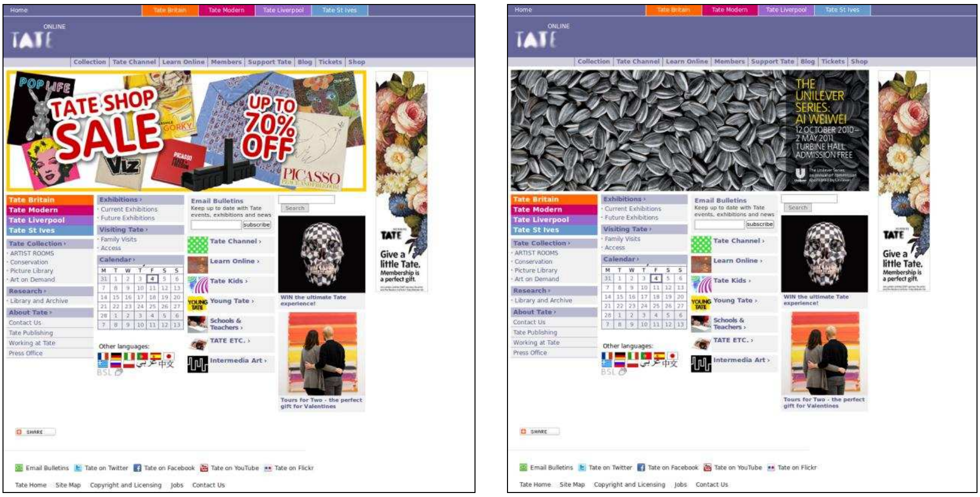
Figure 32. Website of Deutsches Museum, Berlin, Germany. a) Main webpage, b) Subordinate webpage. Screenshots from 2011-02-02. (© 2011, Deutsches Museum, www.deutsches-museum.de, used with permission).

text of the interface, yielding a consistent overall impression of the webpage.

Deutsches Museum: Many strong colors (red, turquoise, yellow, pink) are visible in the four center images of Figure 32a. The main image of Figure 32b is a collage in form of a panorama that slowly runs through from right to left. Many colors appear in this panorama and a design matching between the tones of the single components of the collage is not recognizable.

Tate: Both Figures, 33a and 33b, are variations of the main webpage of Tate, in the sense that the main image cycles through a total number of six images. For both of these screenshots we refer to this large

Figure 33. Website of Tate, London, UK. a) Main webpage, b) Variation of the main webpage. Screenshots from www.tate.org.uk, 2011-02-04 (© Copyright Tate, 2011, used with permission).



main image, only. For the main image of Figure 33a holds, as for Figure 32a, that many strong colors are visible in this collage, even red letters are superimposed (Note that this is not the website of the Tate Online Shop but the main webpage of Tate). In contrast, the image of Figure 33b displays unobtrusive shades of gray in the black and white photograph.

As the exploitation of the dynamic range is a minimal requirement for an image, and as these museums are top ranking museums, this criterion is met for all images of the four discussed websites.

2.7.2. Form

Josef Albers Museum: The dominant form of the photograph of Figure 30a is the spherical sculpture, which is a very simple form. The visible elements of the portrait (Figure 30b) are given by the person, one straight, and one curved boundary of the sofa, which are very clear and simple forms, as well.

Wallraf-Richartz-Museum: Even more simple than the photograph of the sculpture (Figure 30a) appears the image of Figure 31a. With its strong contrast between light and shadow it takes almost an abstract effect. Also the photographs of Figure 31b, especially the upper one, display clearly visible forms with the nested rectangles of the alley through the exhibition halls.

Deutsches Museum: Whereas in the images of the Figures 30 and 31 simple and clearly visible forms – spheres (with curves) and cuboids (with verticals and diagonals) - catch the eye, almost no such simple forms can be detected in the images of the website shown in Figure 32. For each of the four center images of Figure 32a it is difficult to say at a glance what they depict. Only at a closer look one can recognize a section of a close-up view of a jukebox, the front view of a classic car, a boy in front of an airplane, and a comic-strip character. Also the main image of Figure 32b, i.e., the collage of several exhibits, is not composed with simplicity in mind.

Tate: For the main image of Figure 33a the same holds true. Again in contrast to this image, the image of Figure 33b consist of rather simple forms, i.e., the ellipses that are made of the shapes of the sunflower seeds.

2.7.3. Spatial Organization

Josef Albers Museum: The photograph of the sculpture in the garden (Figure 30a) as well as the portrait of Josef Albers (Figure 30b) are composed in a clear and simple way. The sculpture is placed in the golden mean, and the spatial arrangement of the portrait ensures that possible superfluous and disturbing forms are excluded from the image.

Wallraf-Richartz-Museum: The image of Figure 31a is also composed according to the rule of the golden mean. It appears almost like a pattern with repetitions and variations, even more when viewed from a distance or with slightly slitted eyes. There is also rhythm in this image; the eye is drawn from the upper left to the lower right. Rhythm is also induced in the upper image of Figure 31b by the repetition of the nested frames of the passage way.

Deutsches Museum: In the images of Figure 32 none of the designing principles for the arrangement of image components, as proposed earlier in this section, can be recognized.

Tate: The same holds true for the main image of Figure 33a. But again, the photograph of Figure 33b, where the organizing principle consists in the completely homogeneous distribution of the texture in the image plane, appears well-organized.

2.7.4. Motion

Classical means of motion cannot be detected in any image of any of the four websites. Only the images of Figure 32 and 33a at least convey less stability than those of Figures 30 and 31 by showing more clutter or, e.g., by the skewed diagonals of the jukebox image. If motion was intended it could have been communicated more compelling, though.

2.7.5. Depth

Josef Albers Museum: The distribution of light and shadow on the sphere in Figure 30a brings out its three-dimensional shape very well.

Wallraf-Richartz-Museum: The central perspective is able to convey an impression of depth in the image of Figure 31a and even more in the upper image of Figure 31b. Another stylistic device used to create the impression of depth in Figure 31a is the distribution of light and shadow.

Deutsches Museum: In the images of Figure 33, depth is hardly conveyed. Considering the main image of Figure 33b, one can say that for the different components of the collage different viewing angles of the objects have been chosen. The white rodent, for example, is viewed from above, whereas the ship is viewed from the side. This impedes a unified perspective of the panorama and thus prevents the emergence of the impression of depth. Also the distribution of light and shadow is disadvantageous. The light comes from different angles for different components. For example, the ship is lit from right behind, whereas the man is lit from the right front. Another factor that deranges the impression of depth is the inconsistent adoption of sharpness and unsharpness. As an example it can be mentioned that the fur of the rodent is depicted sharply, whereas the ship is displayed in a more unsharp manner.

Tate: Also the main image of Figure 33a does not convey the impression of depth. In Figure 33a this has obviously not been intended, because the collage is mostly an overlay of several two-dimensional things such as books or pictures. In Figure 33b the absence of depth is not a disadvantage because of the inherently two-dimensional character of the photograph.

2.7.6. Human Body

To complete the list of aesthetic categories, the lower image of Figure 31b demonstrates very well the power of the visibility of the principal axes of the human body. The woman can be recognized at once although she takes only a small part of the image. She is in the exact position of this image. Especially, she does not have one of the paintings in her background, but she stands with the homogenous surface of the walls in her back, thus the shape of her body is clearly visible.

2.7.7. Summary

A good indicator for a clear and simple structure of an image is the fact that it does not lose anything when viewed from a larger distance. Then clear forms and a simple structure remain visible as in the examples of the Josef Albers Museum and the Wallraf-Richartz-Museum. On the other hand, one has to take into account that these four museums probably intend to address a different public. Certainly the target audience of the Deutsches Museum is a more infantine one than for example that of the Josef Albers Museum. So, maybe it is just consequent not to obey the classic aesthetic rules of image design. By the way, the overall layout (which is not the subject of this article) of the webpages of the Deutsches Museum is quite simple and well arranged. As mentioned earlier, to assess the usability of an interface as a whole, a deeper analysis of more parameters than just the aesthetics of images has to be carried out. The role of the interface as a whole has to be considered in such an analysis as well as the target audience of an interface. The webpages of the Deutsches Museum probably can hold as an example for the fact that an interface still can be usable quite well and still can be attractive for a special target group even if the images, if considered individually, are not designed according to the rules presented in this article. To make firm statements on the usability of the whole interface, further analysis of the role of the interface as a whole would be necessary which is not the scope of this article.

Summarizing, one can say that for the more aesthetic images (in the sense of aesthetics as defined in this article), i.e., those of the webpages of the Josef Albers Museum, the Wallraf-Richartz-Museum, and the second variation of the Tate's main webpage, not only a few of the earlier defined criterions for an aesthetic appeal of an image are met, but usually many of them. For example, the image of Figure 31a displays only one strong color, it consists of simple rectangular forms, the spatial organization of the image elements is clear and simple, the repetition and variations of the rectangular forms create a rhythm in the image, and the distribution of light and shadow conveys the impression of depth. The presence of one design principle seldom comes alone, and so does their absence in the less convincing examples.

3. FOUNDATIONS OF THE PROPOSED CRITERIA IN THE HUMAN VISUAL SYSTEM

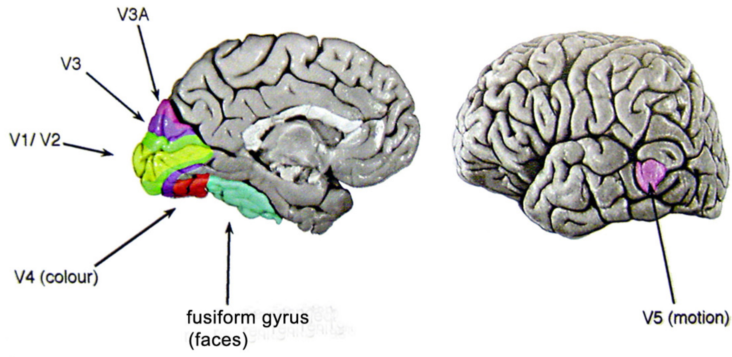
In this section we start with an overview of the human visual system in subsection 3.1 and draw the conclusion in subsection 3.2 that the basic categories of visual aesthetics introduced in Section 2 can directly be derived from the modularity of our visual system.

3.1. Modularity of the Human Visual System

The human visual system is organized as a parallel, modular system. It processes different attributes of a visual scene, such as color and motion, in different, specialized subdivisions of the brain. These cortical areas are dedicated to the analysis of a single property of the visual scene, only. The left part of Figure 34 shows a human brain from the medial side with some of these areas.

From the retina in the eyes the visual information is carried along the major visual pathway, called *optic pathway*, to the *primary visual cortex* (V1) at the back of the brain. Signals carrying information on, e.g., *color*, *motion*, *form*, and *depth* are transported to V1

Figure 34. Cortical areas of the human visual system dedicated to different visual modularities (Adapted from Zeki, 1999)



and are collected into specialized compartments in V1. Both, directly and via an intermediate area called V2, V1 sends this information further on to other specialized areas. For example, a colored stimulus leads to an activation in V1 and in a complex of areas called V4. Analogously, a moving visual pattern activates V1 and an area called V5 located on the outside surface of the hemispheres (see right part of Figure 34). Form is processed in several parts spread out over the cortex. There are cells in V1 that respond to oriented lines, but also cells in other areas such as V2 and V3 respond selectively to orientation. Another interesting modularity that has its own representation in the brain is the body and parts of it, such as faces and hands. In the monkey temporal cortex cells have been identified which are responsive to different body posture and movement (Perrett et al., 1990) .The human fusiform gyrus (in the left part of Figure 34 marked by the turquoise color), for example, is important for the perception of faces. The functional specialization of the human visual system and the independence of its modules are also reflected by the fact that the brain needs different amounts of time to perceive color, form, and motion. Color is perceived before form which is perceived before motion. The difference between color and motion perception is about 60-80 milliseconds (Moutoussis, 1997). In addition, motion perception is sensitive to luminance, but not to color cues, which has been shown in a behavioral study (Ramachandran et al., 1978).

3.2. Foundations of the Proposed Criteria in the Visual System

We speak of the aesthetics of color or the aesthetics of portrait painting, as if there are also different categories of aesthetics. These categories seem to correspond to the modules of visual perception (Latto, 1995; Zeki, 1999). The above mentioned modules of the human visual system (color, form, motion, body parts) and other not mentioned ones such as *depth* and *spatial organization* of objects are also attributes that have been important for the formal aspects of visual arts, and thus for aesthetics. Neuroscience studies revealed that the judgment of a painting as beautiful or ugly correlates with specific brain structures, principally the orbito-frontal cortex (Kawabata & Zeki, 2004). But Zeki suggests that there is not one visual aesthetic “sense” only but many, each tied to a different specialized processing system. Different attributes of the formal aspect of art excite different groups of cells in the brain, thus there is also a functional specialization in aesthetics (Zeki, 1999). It is interesting to study patients with brain lesions in different parts of the visual system. A patient of Oliver Sacks suffered from achromatopsia due to damage to area V4, which is dedicated to color processing

(Sacks et al., 1987). This patient was an artist and before his attack he had a preference for the colorful paintings of the Impressionists. However, the deterioration of V4 changed the aesthetic quality of these works for him, as he could not perceive color anymore. Also his own paintings became grayish and dirty, but his form vision was not impaired, so he still could sketch objects and enjoy the aesthetic quality of forms. Latto posed the question as to why some features - the aesthetic criteria in our context - of the modularities are more effective, i.e., provoke a stronger aesthetic impression, than others (Latto, 1995). He came to the conclusion that a property of a stimulus is intrinsically interesting if it resonates with mechanisms of the visual system. To be more concrete, the more effective features isolate or exaggerate one of the processes of the human visual system, e.g., by evoking maximal responses of those cells in the brain dedicated to that special attribute. This effect can occur at any level in the visual system, e.g., lines and edges are low-level, human shapes are high-level aesthetically effective features. They are aesthetically moving not because they reflect properties of the world but because they blend with our brains.

Summarizing, we suggest that the categories of visual aesthetics proposed in Section 2, i.e., *color*, *form*, *spatial organization*, *motion*, *depth*, and the *human body*, correspond to the different modularities of the human visual system.

4. CONCLUSION

We proposed a well-defined system of criteria for the aesthetic design of images for human-computer interfaces. In the context of human-computer interaction users are more willing to adopt a product if it evokes pleasurable feelings. In addition, the acceptance of an application has severe implications for its safety. Disregarded for a long time, the aesthetic appeal of interfaces recently becomes more important. In this article we addressed only one element of interfaces, namely images. The best content of an image does not reach the recipient, if the image is designed poorly and thus appears confusing or ugly.

We have proposed six categories of visual aesthetics. For each category we explored the conditions and properties that enhance the clarity or vividness of the visual presentation. These *aesthetic criteria* are, on the one hand, presented in the form of a quick guide for interface designers for the creation of images in interfaces and, on the other hand, they can be used for the assessment of the usability of given interfaces. In addition, the proposed criteria are justified in an interdisciplinary fashion by the way how sensory information is processed by our visual system, as well as by approved practices of artists.

Summarizing, the contributions of this article are the following. It gives a *concise* compilation of a set of aesthetic rules for images to be used in interfaces (in contrast to probably already existing, but circumlocutory descriptions in the literature of visual arts). These rules are justified not only artistically (by the fact that artists apply them since a long time), but for the first time in this context also *scientifically* (by drawing parallels to principles of visual information processing by the human brain). These rules are discussed in the context of interface design. By publishing them in a computer science context the benefit consists in the circulation of knowledge maybe well-known in the arts and design community but maybe little-known in the computer science community. Thus, there is reasonable hope that this article is able to promote development in an *interdisciplinary* manner.

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