Aesthetic Primitives of Images for Visualization

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Abstract

Images play an important role in visualization. As users are more willing to adopt a product if it evokes pleasurable feelings the aesthetic appeal of interfaces becomes more important. Thus, there is a growing need to generate also images which appear aesthetically to the user. Starting with the modularities of the human visual system, we derive six dimensions of visual aesthetics. For each dimension we explore, inspired by principles of the visual arts and insights of cognitive neuroscience, which pecularities of the dimensions are particularly adequate for an aesthetic impression. Accompanied by a fair number of image examples, these considerations result in an easy to understand guideline for computer scientists and interface designers how to deal with images in terms of aesthetics.

1. Introduction

The roles of images[1] in visualization are manifold. Stone et al. [1] 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 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. For example, in web design images are utilized mainly for two different purposes. They can have the function to attract the user and may be used as anticipation of the overall topic of the website. On the other hand, small thumbnails promote interaction. In e-learning images usually are the support of the information, that should be conveyed by the course. Other examples of interfaces from several applications of augmented reality (geovisualization, navigation, maintenance and repair, and a museum guide) where images are the key components of the visualization, are shown in figures 1 and 2. The left picture of figure 1 shows an image of the environment which is augmented by data indicating a possible path for a vehicle. 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. The right part of figure 1 shows an example for maintenance instructions for an engine. The previous statements hold true for this example, as well. The last example is given in figure 2. A virtual guide for the Guggenheim Museum Bilbao refers the visitor to architectural features of the building or gives explanations of exhibits. Two screenshots from the user interface are shown. In the context of information visualization and human-computer interaction topics such as the importance of aesthetic qualities of graphical elements of user interfaces [2] or the aesthetics of interaction [3] have frequently been addressed. Also the relation between visual and verbal information in presentations has been dealt with [4]. What is underrepresented in the literature is the role of image aesthetics in visualization. This paper is an attempt to fill this gap. To identify aesthetic dimensions that, on the one hand, allow for the evaluation of the aesthetic qualities of an image and, on the other hand, enable an interface designer to adapt her tools to the needs of the

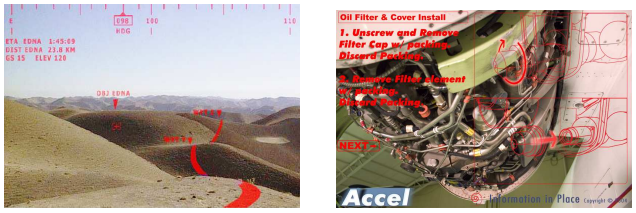

Figure 1. Images as key components of visualization: navigation and maintenance.

[1]The term "images" is used here in the sense of pictures, i.e., photographs or drawings. It does not denote diagrams or charts.

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Figure 2. Images as key components of visualization: museum guide (project AMIRE of C-LAB, Paderborn, Germany).

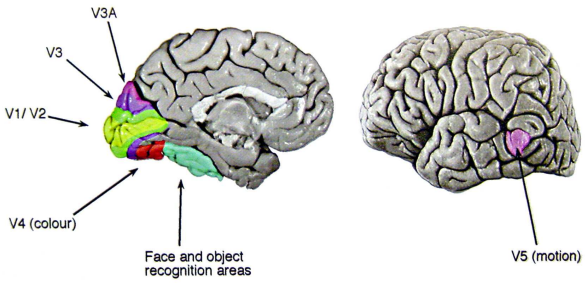

Figure 3. Cortical areas of the human visual system dedicated to different visual modularities. (Images taken from [9].)

user, we have to start at the user, i.e., the human, and have to know basics about human visual information processing. In section 2 we summarize results from cognitive neuroscience, 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 give us clues to define *dimensions of visual aesthetics*. These dimensions are the starting point for section 3 where we investigate for each dimension (e.g., *spatial organization*) which specific characteristics (e.g., *the golden mean*) would best evoke an aesthetic experience. These characteristics we call *aesthetic primitives*.

2. Dimensions of visual aesthetics

We start with an overview of the human visual system in subsection 2.1 and draw the conclusion in subsection 2.2 that the basic dimensions that constitute an aesthetic experience can directly be derived from the modularity of our visual system.

2.1. 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 3 shows a human brain from the medial side with some of these areas. From the retina the visual information is carried along the *optic pathway* to the *primary visual cortex* (V1) at the back of the brain. Signals carrying information on *color*, *motion*, *form*, and *depth* are transported to V1 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. 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 (right part of figure 3). *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 intersting 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 [5]. The human fusiform gyrus (in the left part of figure 3 marked by the turquoise color) is important for the perception of faces. The functional specialization of the human visual system and the independence of its modules is 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* [6]. It also has been shown in a behavioral study that *motion* perception is sensitive to luminance, but not to *color* cues [7].

2.2. Correlation to the aesthetic experience

The above mentioned modules of the visual system (color, form, motion, body parts) and other not mentioned ones (such as *depth* and *spatial organization*) are also attributes that have been important for the formal aspects of visual arts, and thus for aesthetics. 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 [8, 9]. Neuroscience studies revealed that the judgement of a painting as beautiful or ugly correlates with specific brain structures, principally the orbito-frontal cortex [10]. But Zeki suggests that there is not one visual aes-


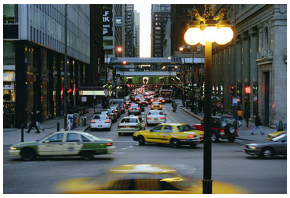

Figure 4. Only a Few Strong Colors and Complementary Contrast.



Figure 5. Monochrom coloration and color circle by Goethe.

thetic "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 [9]. It is intersting to study patients with brain lesions in different parts of the visual system. A patient of Sacks suffered from achromatopsia due to a damage to area V4, which is dedicated to color processing [11]. 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 - *aesthetic primitives* - of the modularities provoke a stronger aesthetic impression than others [8]. He came to the conclusion that a property of a stimulus is intrinsically interesting if it resonates with mechanisms of the visual system. Aesthetic primitives isolate or exaggerate one of the processes of the human visual system by evoking maximal responses of those cells in the brain dedicated to that special attribute. They are aesthetically moving because they blend with our brains. Summarizing, we suggest the basic dimensions of visual aesthetics to be exactly the different modularities of the human visual system. The most important of them are *color*, *form*, *spatial organization*, *motion*, *depth*, and the *human body*.

3. Aesthetic primitives of vision

Having identified the main dimensions of visual aesthetics, we will consider the question now, which pecularities of these dimensions are capable of evoking an aesthetic sensation. Those pecularities we will call *aesthetic primitives*. Many books have been filled with principles of lay-out 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 [12] as it summarizes the basic principles of aesthetic composition and is still a reference for photographers and artists. For each primitive described in this section we give an example, mostly in from of a photograph[2], but the described principles hold true for all kinds of images.

3.1. Color

Color is a modularity of the visual system, which just in the context of beauty is an important means to evoke aesthetic experiences. We examine three properties of color and its distribution in an image, which are known to appeal to our aesthetic sense.

Only a few strong colors. Less is more. Two to three strong colors usually are the maximum for an image still to be pleasant to the eyes. 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 was mentioned in subsection 2.2.) In principle, color in an image should correlate with its content [12]. If color is not the salient feature of an object depicted in the image, as it holds true, e.g., for a butterfly, the visual system of the observer is overcharged and an aesthetic impression is missed. An example is shown in the left image of figure 4. The orange color of the turbans of the musicians is the dominant property of them in this image. Thus, they are depicted in such a way that the orange color is also the dominant property of the whole image. All other colors are subordinate or even non-colors. Also the right image of figure 4 gets by with only a few strong colors, the yellow of the taxis and the red rear lights of the cars. An exaggeration of this rule is *monochromaticity*, the deliberate choice of only one main color. Quite aesthetic results can be achieved if only a small range of colors adjacent in the color circle (see below) are chosen, e.g., only red, brown, and orange tones in a picture of autumn foliage. The left images of figure 5 show an example of this principle, where only a brown tone is used. Such a subtle monochrom coloration allows for the accentuation of important elements which come to the fore (such as the bench and the person in these examples).

Complementary contrast. Complementary colors are pairs of colors that are in some way opposites of each other.

[2]If not otherwise stated all photographs are taken from [13].

Figure 6. Exploitation of the dynamic range.

Figure 7. Clarity and simplicity of form.

The traditional set of complementary pairs in art are red and green, blue and orange, and yellow and purple. They face each other in the color circle, as, e.g., advocated by Goethe [14] (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. The most beautiful effect often is achieved if the complementary colors are the only strong colors. The hindu picture of figure 4 with the dominant orange of the turbans 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 phenomenons, the simultaneous and the sucessive 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.

Exploitation of the dynamic range. Exploitation of the dynamic range concerns the distribution of tonal values in an image. 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. 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 [15]. 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. To come back to aesthetics, one can say that an image looks pleasing to the eye if the display medium (print or 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. The histogram of an image can serve as an indicator for an advantageous distribution. An overall Gaussian shape which covers the whole range of gray level values 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* [16]. 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. Another technique worth mentioning is high dynamic range imaging [17]. As a field primarily evolved in computer graphics, it provides a set of methods to generate an image of high dynamic range, e.g., 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.

3.2. Form

Form provides the source of information necessary for basic survival function such as navigation, recognition of prey, predators, and mates, as well as for high level behaviors such as reading. But the shape of objects does not only allocate essential information on the world surrounding us, it is also a source of aesthetic sensation.

Clarity of form. When we speak of form in the context of elements constituting an image we usually mean lines

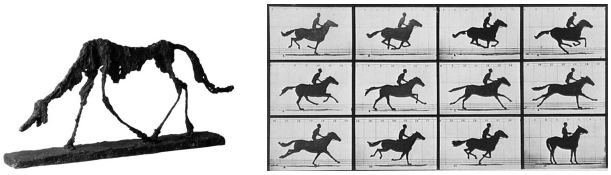

Figure 8. Animal silhouettes: statue of a dog by Alberto Giacometti ("Le Chien", 1951) and "The Horse in Motion" by Eadweard Muybridge (taken from [18]).

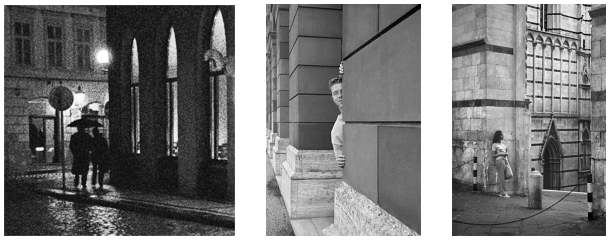

Figure 9. Silhouettes of other objects, clarity of spatial organization, and golden mean.

Figure 10. Human silhouettes. Photographs by G. Peters ("Dark Days - Venice", 2006).

and surfaces. Lines can actually be present by the contrast gradient or color changes or they can emerge through our perception. 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. 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 of the left image of figure 7 are constituted only by straight lines (verticals, horizontals, and diagonals), those of the right image of the same figure by straight and curved lines and concentric ovals. The few and overall shapes of these images are consistent, simple, and clearly recognizable. This is what Feininger means when he speaks of clarity and simplicitiy of form [12]. Curved lines seem to appear beautiful if they obey a continuous function (yet in the mathematical sense) and take a uniform course within the image as a whole.

Silhouettes. Feininger explicitly lists silhouettes as components of aesthetic images ("outlines which are typical for an object, vigorous and unusual; clear silhouettes" [12]). 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 [19], rather than by their three-dimensionality. Giacometti was a master in reducing objects to their characteristic outlines. The left part of figure 8 shows an example. Another prominent example is the series of photographs of moving humans and animals by Muybridge (right part of figure 8). 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 beeing beautiful, also the silhouettes of other objects can be aesthetic elements of an image, such as the couple under the umbrella in the left image of figure 9 or the bench in the left image of figure 5. 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 distinctable 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. Apparently, human silouettes can evoke a sense of beauty even if they are depicted in a blurry fashion (see figure 10).

3.3. Spatial organization

Not only the shapes of the elements constituting an image are of importance for its aesthetic appearance, but also their mutual spatial relations in the two-dimensional surface of the image play a major role for the aesthetics of an image as a whole. Analogously to the form primitive *clarity* in the last subsection, we will here comment on the aesthetic primitive *clarity of spatial organization*. Other aesthetic primitives of spatial organization are the *golden mean*, *texture and pattern*, and *rhythm, repetition, and variation*.

Clarity of spatial organization. Feininger argued that clarity and simplicity of spatial organization is the silver bullet for an aesthetic image [12]. Too many objects in a single image cause confusion and derangement. An image should not be overloaded by details, as well. The middle image of figure 9 shows an example which demonstrates the power of spatial organization. The attention of the viewer is focussed on the person in the center, although the visible parts of the boy occupy only a very small portion in the image. This ef-

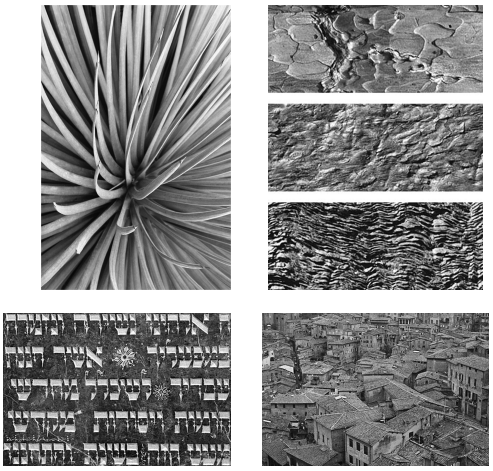

Figure 11. Texture and pattern.

fect 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 neither can be omitted nor can 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 humans are more inclined to examine lighter parts of an image rather than darker parts, an image should have its lighter parts in the upper left, its darker parts in the lower right, just as exemplified by the pictures of figure 7.

Golden mean. The golden mean denominates a particular ratio of an asymmetric line division. Whereas symmetry appears rather statical and boring, divisions in accordance with the golden mean are considered as beeing 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: $\phi = a/b = b/(a + b)$. The only positive solution is $\phi = (\sqrt{5} - 1)/2 \approx 3/5 \approx 0.618$, which is the geometric definition of the golden mean. It has the continued fraction expansion $\phi = 1/(1 + 1/(1 + \ldots))$ and the best rational approximations to ϕ are given by the convergents of this infinite continued fraction, arrived at by cutting it off at different levels in the expansion: $1/1, 1/2, 2/3, 3/5, \ldots$ Thus, the convergents of the golden mean are the ratios of successive Fibonacci numbers [20]. Therefore, a division of a line, surface, or volume in the ratio of about $3 : 5$ appears harmonic. From antiquity until today ϕ has constantly been present in art. Even acient Chinese paintings show the golden mean in an accuracy of three decimal places. 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. Figure 9 shows an image constructed according to the rule of the golden mean. The woman is placed approximately in the golden mean. The majority of the images in this article obey this construction rule, in particular the left images of figure 5.

Texture and pattern. *Texture* denotes the structural characteristics of a surface. The number of the different dimensions of texture is still discussed, but is probably five or larger. For example in a classical study [21] texture was classified into coarseness, contrast, directionality, linelikeness, 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, or checked patterns). Nature is full of patterns. Sand dunes, tree branches, and snowflakes 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. 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* [22]. For Feininger [12] "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 figure 11. The images on the left are made up of fairly regular patterns, those on the right 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 beeing effective because of patterns are given in figure 13, and maybe even the images of figure 7 work partly because of their pattern character.

Rhythm, repetition, and variation. Many visual patterns are strongly related to repeated shapes or objects. These copies can occur in regular spatial distances or they can be arranged arbitrarily. Patterns of largest relevance for animals are those of medium entropy. Regarding aesthetics conditions are similar. Perfect symmetry in images as well as chaos (or noise) are not ranked beautiful. Figure 12 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 7 and contribute to their aesthetic appeal. As pure repetition often is said to be monotonous another principle of art consists in *variation*, which means an instance of change in present stuctures. This is usually applied to increase the visual interest. Figure 13 shows variations over a theme, namely stripe patterns in animal fur. Another ex-

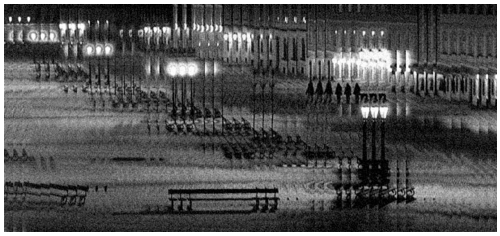

Figure 12. Repetition.

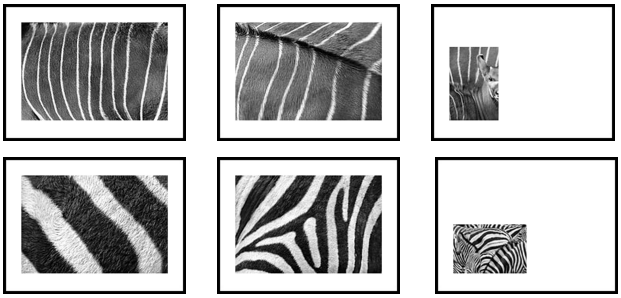

Figure 13. Rhythm and variation. Photographs by G. Peters ("Streifzüge", 2000).

ample is given in figure 11. Variation of the overall stripe pattern is realized here in the lower left image by the details of the different letters. *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. There are several types of visual rhythm [23]. These include[3]: **Regular rhythms:** $ab\ ab\ldots$ is the most common type. Another example is $abbb\ abbb\ldots$ The picture in figure 12 exploits the schema $aaa\ bbb\ ccc\ldots$ **Alternating rhythms:** for example: $aba\ cdc\ aba\ efe\ aba\ldots$ **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: $ab\ aabb\ aaabbb\ldots$ The left image of figure 7 displays a progressive rhythm. In figure 13 the effect of visual rhythm is even more evident: in the upper left image the viewer's gaze is led horizontally from the left to the right by the arrangement of the vertical stripes, whereas in the middel picture of the same row it is directed more smoothly and diagonally from the upper left to the lower right.

[3]In the following examples, let the letters a, b, etc. stand for visual elements of any sort.

Figure 14. Blur. Upper row: motion blur, lower row: panning blur.

3.4. Motion

Motion inherently is an aesthetic cue because it 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 [24]. 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 2.1. 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. We will concentrate here on two of the most expressive motion symbols, *blur* and the depiction of *distinct motion phases*.

Blur. Blur is an indicator for movement. Feininger defines it as "unsharpness in one direction", namely the direction of the moving object [12]. The stronger the blur, the stronger the impression of speed. In photography[4] 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 beeing of homogeneous luminance. The upper row of figure 14 shows two examples of motion blur. Note the high contrast changes in the blurred regions. The same holds true for the images in the lower row. Here the blur was induced by a

[4]It is irrelevant whether the image was generated with a camera, whether it was painted, or created with computer graphic techniques. What counts is the visual impression obtained by the described techniques.

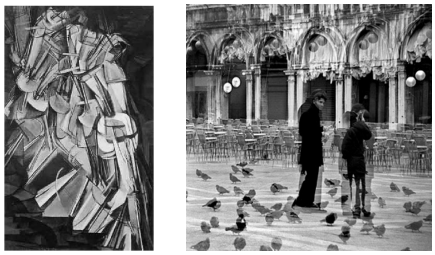

Figure 15. Distinct motion phases. Left: Marcel Duchamp's "Nude Descending a Staircase", 1911-12, right: double exposure indicating slight movement.

panning of the camera. In the left image it was panned with the walking woman, thus she is depicted almost sharply. In the right image the camera was panned with the right car. Again, in both images the blurred regions exhibit high contrasts, which is essential to evoke an aesthetic impression.

Distinct motion phases. Another technique to illustrate movement in images is the depiction of a number of distinct motion phases simultaneously in a single image. 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. Duchamp practised this principle in his famous painting pictured in figure 15. In photography distinct motion phases are usually obtained by multiple exposures of a object (right image of figure 15).

3.5. Depth

As the image plane is two-dimensional, the three-dimensional world 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. 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 [23]. We concentrate here on the depiction of *linear perspective*, the contrast between *sharpness and unsharpness*, and between *light and shadow*.

Linear perspective. The invention of linear perspective dates to the early 1400s, with Filippo Brunelleschi's experiments in perspective painting. 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 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

Figure 16. Linear perspective.

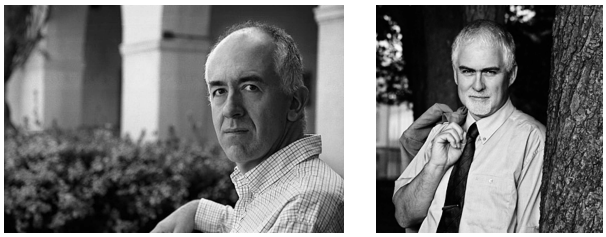

Figure 17. Sharpness and unsharpness.

imaginary horizontal line representing the eye level [23]. Examples for images composed in linear perspective, each with its vanishing point in the center, are given in figure 16.

Sharpness and unsharpness. In contrast to blur, which is unsharpness in one direction, unsharpness here is more generally defined by an absence of high frequency content. The visual impression of the contrast between sharp and unsharp parts of an image can act quite aesthetic on the viewer. This can be exploited for the purpose of focussing attention to the important image elements. The most common application of this principle can be found in potrait 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 (figure 17).

Light and shadow. How the shape of a three-dimensional object may be recovered from shading in a two-dimensional image is still the subject of a large field of research in machine vision, called *shape from shading* [25]. Different illumination conditions cause different shadings of the objects we perceive. Somehow our brain is able to suggest the from 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, 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. This principle is employed, e.g., in the pictures of figure 18.

3.6. Human body

As already mentioned in subsection 2.1 the human body and its parts such as hands and heads take up a special position in visual information processing, which reflects the

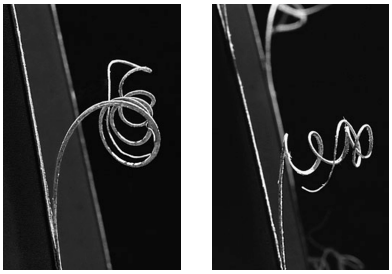

Figure 18. Light and shadow.

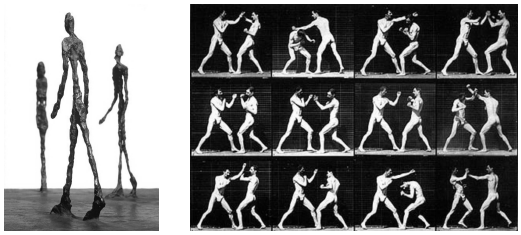

Figure 19. Human body. Left: part of a sculpture by Alberto Giacometti (”Le Place”, 1948-49), right: photographs by Eadweard Muybridge (taken from [18]).

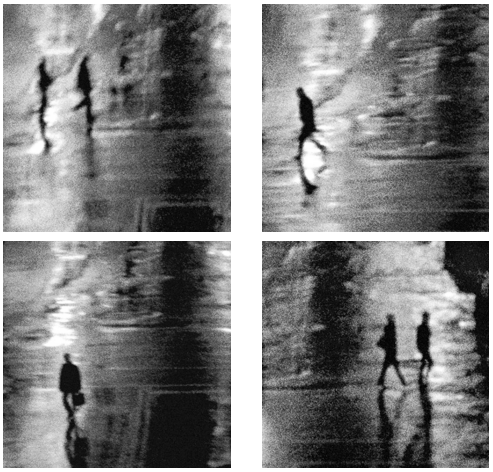

Figure 20. Silhouettes of the human body. Photographs by G. Peters (”Dark Days - New York”, 2006).

importance of these visual stimuli for our survival. Also in our aesthetic sensation it seems to be worth to be regarded as a separate category. A concept which is important in this context is that of the *principal axes* of an object.

Principal axes. Principal axes are axes of symmetry or elongation around which the local parts of objects are grouped in order to constitute their global form. If an object is enlarged, shrunk, or rotated around its principal axis the relationship between the parts and the principal axis remains constant across all variations. Principal axes are considered as aesthetic primitives [8]. 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 the animals [26]. They are easily recognizable altough 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 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 statues is the fact that they almost only consist of their *principal axes*. Giacometti reduces the body to its basic shape, and thus we recognize the concept of a human at once (left image of figure 19). 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.” [19]. Other examples are given again by a motion study of Muybridge in figure 19, this time boxing men, and the shapes of humans in figure 20, which illustrate both, the aesthetic primitive of silhouettes dealt with in subsection 3.2, as well as the beauty of the human body defined by its principal axes. It seems that the human body does not appear beautiful arbitrarily, but because its shape, especially in the exaggerated version of principal axes, corresponds to the simplifications and transformations our visual system performs to analyze and represent it.

4 Summary

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. Motivated by the modularity of the human visual system we have identified six dimensions of visual aesthetics. For each dimension we explored the conditions and properties that enhance the clarity or vividness of the visual presentation. These *aesthetic primitives* 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. We did

not address here the question how more than one of these primitives can be combined in a single image. Also exceptions to the rules stated in section 3 have not been subject of our considerations. Clearly, not all aesthetic images obey the stated rules of image composition. Of course, there are exceptions and often just famous works of art break these basic rules. But to keep control over the process of generating appealing images it is necessary to break the rules *consciously* rather than randomly or just by exploration. And for that purpose interface designers have to be aware of the basic aesthetic primitives. Summarizing, we list here, in striking terms, the directives for image composition for the six identified dimensions of visual aesthetics. These directives should not be adhered to too seriously but rather be regarded as rules of thumb. **Color:** use a few strong colors only; often complementary contrasts are effective; exploit the dynamic range **Form:** forms should be clear and simple; silhouettes are aesthetic **Spatial organization:** spatial organization of image elements should be clear and simple; apply the rule of the golden mean; attain a wholistic impression by textures and patterns; apply variations to patterns and take care for the visual rhythm induced by repetition of elements **Motion:** express motion by blur of high contrast; distinct motion phases are aesthetically appealing **Depth:** illustrate linear perspective; exploit the contrast between sharpness and unsharpness; the distribution of light and shadow may evoke the impression of depth **Human body:** let the pricipal axes of the human body be clearly visible.

References

[1] Stone, D., Jarett, C., Woodfoffe, M. and Minocha, S.: User Interface Design and Evaluation. Morgan Kaufmann Publishers/Elsevier, 2005.

[2] Tufte, E.: Envisioning Information. Gra. Press, 1990.

[3] Norman, D.: Emotion and Design: Attractive Things Work Better. Interact. Magazine, ix(4), 36-42, 2002.

[4] Ware, C.: Information Visualization: Perception for Design. Morgan Kaufman, 2004.

[5] Perrett, D. I., Rolls, E. T., and Caan, W.: Three Stages in the Classification of Body Movements by Visual Neurons. In: Images and Understanding, 94–107, Cambridge University Press, 1990.

[6] Moutoussis, K. and Zeki, S.: A Direct Demonstration of Perceptual Asynchrony in Vision. Proc. R. Soc. Lond. B., 264, 393–397, 1997.

[7] Ramachandran, V. S. and Gregory, R. L.: Does Colour Provide an Input to Human Motion Perception? Nature 275, 55–56, 1978.

[8] Latto, R.: The Brain of the Beholder. in: The Artful Eye, 66–94, Oxford University Press, 1995.

[9] Zeki, S.: Inner Vision. Oxford University Press, 1999.

[10] Kawabata, H. and Zeki, S.: Neural Correlates of Beauty. Journal of Neurophysiology, 91(4), 1699–1705, American Physiological Society, 2004.

[11] Sacks, O. and Wasserman, R.: The Painter who became Color Blind. NY Rev. Books, 34, 25–33, 1987.

[12] Feininger, A.: Die hohe Schule der Fotografie. ECON Düsseldorf und Wien, 1961.

[13] Peters, G.: www.eyeszeit.net, 2007.

[14] Goethe, J. W. v.: Zur Farbenlehre. Tübingen, 1810.

[15] McHugh, S. T.: Cambridge in Color. www.cambridgeincolour.com, 2007.

[16] Adams, A.: The Negative. New York Graphic Society, Little, Brown, and Company, 1981.

[17] Reinhard, E., Ward, G., Pattanaik, S., and Debevec, P.: High Dynamic Range Imaging: Acquisition, Display, and Image-Based Lighting. Morgan Kaufmann, 2005.

[18] Muybridge, E.: Animal Locomotion. Philadelphia, 1887.

[19] Sartre, J.-P.: The Search for the Absolute. in: Exhibition of Sculptures, Paintings, Drawings [by Alberto Giacometti], New York: Pierre Matisse Gallery, 1948.

[20] Cartwright, J., Gonzalez, D., Piro, O., and Stanzial, D.: Aesthetics, Dynamics, and Musical Scales: A Golden Connection. J. New Mus. Res. (31), pp. 51-58, 2002.

[21] Tamura, H., Mori, S., and Yamawaki, T.: Textural Features Corresponding to Visual Perception. IEEE Trans. Sys., Man, Cybern., 8(6), pp. 460–472, 1978.

[22] Gilovich, T., Vallone, R., and Tversky, A.: The hot hand in basketball: On the misperception of random sequences. Cog. Psy., vol. 17, pp. 295-314, 1985.

[23] Delahunt, M. R.: Rhythm. ArtLex Art Dictionary, http://www.artlex.com, February 17, 2007.

[24] Calder, A.: Temoignages Pour l'Art Abstrait. in: Alvard, J., Gindertael, R., eds., Ed. Art d'aujourd'hui, 1952.

[25] Zhang, R., Tsai, P.-S., Cryer, J. E., and Shah, M.: Shape from Shading: A Survey. IEEE Trans. on PAMI, 21(8), 1999.

[26] Marr, D. and Nishihara, H. K.: Representation and Recognition of the Spatial Organization of Three-Dimensional Shapes. Proc. R. Soc. of London, B, vol. 200, pp. 269–294, 1978.