RAMACHANDRAN AND HIRSTEIN'S NEUROLOGICAL THEORIES OF AESTHETIC FOR COMPUTER GRAPHICS

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CONTENTS

One way of looking at the history of computer science is to examine the type of communication the computers of the day allowed. In the 70's and 80's human computer interaction was the basis for research. In the 90's the focus of research shifted to networking or computer to computer interaction. In the new millennium we are starting to look into human to human interaction via a computer. Humans communicate using three basic methods: via the spoken word, in writing, or using images. This text deals with communication between human minds via computer generated images. Because our goal is communication, we not only want a viewer to see a picture, we want them to understand an image. As the saying goes, ”A picture is worth a thousand words, but an image is worth a thousand pictures.”

Images are a logical choice for interpersonal communication because they utilize the highest bandwidth input to the brain, the eyes. While written language also uses the eyes for input, it adds further levels of abstraction which tend to slow and confuse the communication process. The purpose of this text is to educate the reader in some methods for enhancing the communication content of the images they create using computer graphics.

The article “Neurological Theories of Aesthetic” [28] by Vilayanur S. Ramachandran and William Hirstein lists what the authors call the eight laws of art. The authors argue that artists either consciously or unconsciously deploy these eight laws of art to optimally excite the visual areas of the brain. They also suggest that the first three rules are primary were as the last five serve to support the first three. These theories of Ramachandran and Hirstein explain many familiar experiences, such as why a cartoon squiggle can evoke a well-known face more quickly than a full color photograph. Their theories address three questions:

1. What are the rules of art that make something visually pleasing?
2. What form do these rules have and why did the rules evolve?
3. What brain mechanisms are involved?

Previous theories of art have looked at one or two of these questions, but never all three together. One problem with Ramachandran and Hirstein's analysis, which authors make clear, is that art is a diverse enterprise that may not be amenable to a simple treatment. In addition, these “laws” may not form a complete set of artistic principles. Ramachandran and Hirstein make no mention of the power of the center emphasized by Rudolph Arnheim [4], the widely recognized principle of balance in composition [7], or of the dynamic interplay of visual forces emphasized by Wassily Kandinsky.

Searching for a universal rule underlying the artistic experience is not a new quest [19]. During the 1920's and 1930's the mathematician G.D. Birkhoff attempted to reduce aesthetics to mathematics by defining the aesthetic beauty of an object to be the ratio of its symmetry to its complexity [8, 9]. Although Birkhoff's work is regarded as a failure, it can be said that his attempt advanced our knowledge of the difficulty of quantify beauty. In the field of computer graphics a number of works on visual communication and creating images based on the human visual system exist. Feiner and Seligmann [17, 31] borrowed principles from technical illustration. Kawai et al. [23] automated the creation of pleasing lighting. Both He et al. [21] and Karp and Feiner [22] examined how animation sequences are developed. Kowalski et al. [24] have explored user guided composition.

Ramachandran and Hirstein cite studies by other researchers in perceptual psychology as evidence for their eight laws. However, the true strength of Ramachandran and Hirstein's work is the experimental program that they propose for directly validating their observations [19]. They propose an experimental methodology, involving physiological measurements such as galvanic skin response, to explore the human experience of creating and viewing works of art. Such projects are currently being carried out. In one such study Robert L. Solso presented the results of a preliminary study of an accomplished artist as he drew a portrait while in an functional magnetic resonance imaging (fMRI) machine [32]. In addition countless studies involving visual stimulation, including works of art, and measured response have been reported in the medical and psychophysical literature [11, 16, 18, 13].

In this text Ramachandran and Hirstein's eight laws of art are refined to focus on images created using computer graphics. In addition this text expands the work of Ramachandran and Hirstein by including information from "Cognition and the Visual Arts", by Robert L. Solso [33], "Perception and Imaging" by Richard D. Zakia [42], and "Inner Vision" by Samir Zeki [43]. The eight laws are listed below, and each is expanded upon in a separate section of the text.

1. The Peak Shift Principle – Exaggerated elements are attractive.

2. Grouping and Binding – Perceptual grouping and binding makes objects stand out from the background.

3. Isolation of a Single Visual Module – Isolating a single visual cue helps to focus attention.

4. Problem Solving – Perceptual "problem solving" is reinforcing.

5. Contrast Extraction – Contrast is reinforcing.

6. Symmetry – Symmetry is attractive.

7. Generic Viewpoint – Unique vantage points are suspect.

8. Use of Metaphor – Visual puns and metaphors enhance art.

0.1 The Peak Shift Principle

Ramachandran and Hirstein define the peak shift effect as the use of supernormal stimuli to excite areas in the brain more strongly than natural stimuli. The peak shift effect is a well-known principle in animal learning [20]. For example, if a rat is taught to discriminate a square from a rectangle and rewarded for the rectangle, it will soon learn to respond more frequently to the rectangle. Moreover, if the rat is trained with a prototype rectangle of aspect ratio 3:2, it will respond even more positively to a longer thinner rectangle of aspect ratio 4:1. This result implies that what the rat is learning to value is not a particular rectangle but a rule: rectangles are better than squares. So the greater the ratio between the long and the short sides, i.e. the less square-like it is, the better the rectangle is in the rats eyes. This is the peak shift effect. Ramachandran argues that this principle holds the key for understanding the evocativeness of much of visual art.

Caricatures of human faces are a well studied example of the peak shift effect in human visual perception. Caricatures constitute a powerful medium to express and exaggerate distinctive features of human faces. Caricatures are usually created by skilled artists who use lines to represent facial features. The skill of the artist lies in knowing which facial features are essential and which are incidental. For facial caricatures the usual assumption is that the feature shift for a particular face should be to enhance its difference from an average face [12, 29].

It could be argued that line drawings as well as caricatures derived from such drawings form impoverished environments when compared with their photographic counterparts. Within such impoverished environments, many studies have shown that caricatures can be recognized faster than line drawings that accurately portray someone's face (these are called veridical line drawings) [6, 12, 29, 34]. Similarly, line-drawn caricatures tend to be learned faster in learning tasks than veridical line drawings [34]. This is known as the super portrait effect. Examples of faces shown as photographs, line art, and caricatures are shown in Figure 0.1.

Ramachandran and Hirstein explain that the peak shift effect can occur in any visual modality. The human responses to color, motion, form, highlight, outline, and depth are all susceptible to

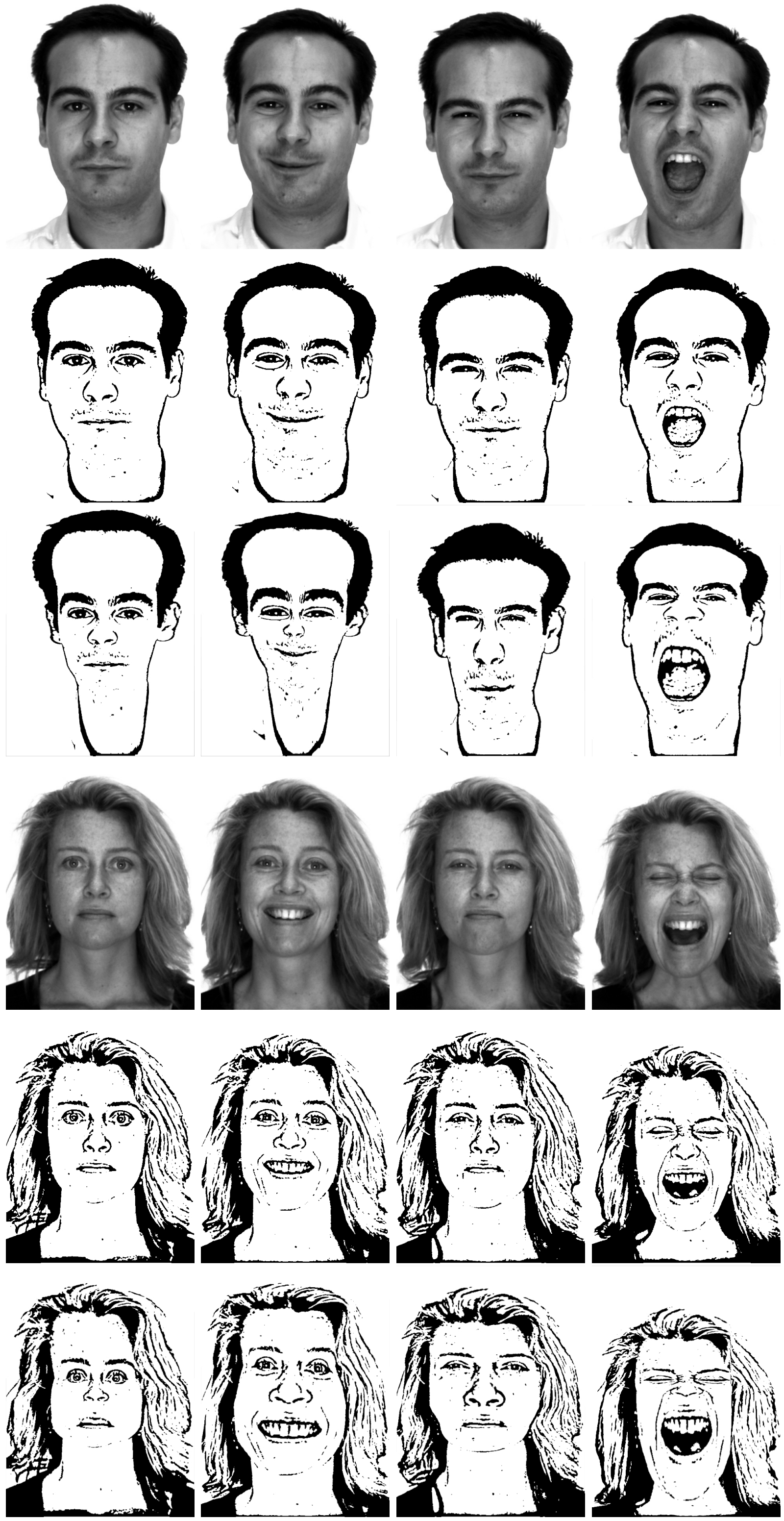

Figure 0.1. *Examples of photographs, black-and-white line art and black-and-white line art caricatures of human faces. The line art is an example of a single mode, "edge lines", of human faces. The caricatures are an example of a peak shift in the "edge lines" mode. The images with differing facial expressions are courtesy of Aleix Martinez of Purdue University. The entire face database is online [25].*

Figure 0.2. *Left and Center: Vangogh's "Irises, Saint-Remy" and "The Cafe Terrace on the Place du Forum, Arles, at Night" are examples of peak shift in color space. Color images of these works are available online [1]. Right: Rodin's "Burghers of Calais" is an example of peak shift in form (Image courtesy of The Marion Koogler McNay Art Museum [36]).*

peak shift effects. An example of a peak shift in color space is shown in the paintings of Van Gough as seen in Figure 0.2. Rodin's "Burghers of Calais" is an example of peak shift in form. Rodin exaggerates the details of each of the figures in order to create emotional impact.

The key fact concerning the peak shift phenomena is that the reward stimulus and the non-reward stimulus must be close in order for the peak shift stimulus to exist. For example, if a rat is trained to respond to a tone at 1000Hz and not to respond to a tone at 500Hz no peak shift will be observed. However, if the rat is trained to respond to a tone at 1000Hz and not to respond to a tone at 950Hz a peak shift stimulus will be observed at approximately 1010Hz. Some researchers believe that due to this fact, peak shift may not be responsible for an individuals response to art, but may explain quite a bit about art history and the fashion industry. For example in fashion the shorting of skirts and widening of mens ties during the 60's may be an example of peak shift phenomena over time.

0.2 Perceptual Grouping and Binding

The second principle suggested by Ramachandran and Hirstein is grouping and binding. When we look at a collection of discrete entities we often perceive the collection as organized into subsets. When our mind recognizes differing subsets as a unit, that unit becomes bound in our mind and is perceived as different from the surrounding collection from then on. Ramachandran and Hirstein explain that visual areas of the brain may have evolved specifically to extract correlations in different visual modalities and that this process is facilitated and reinforced by direct connections from these brain areas to limbic structures (pleasure centers).

0.2.1 Perceptual Grouping

Perceptual grouping was first considered by the gestalt psychologist Max Wertheimer [40] who investigated what our mind does versus what our mind might have done. Wertheimer explored the way elements in a visual scene are typically perceptually grouped into units. He constructed simple examples consisting of sets of dots. The purpose of these examples is to illustrate factors that influence the grouping of elements into units. Wertheimer suggested grouping factors that influence how elements are organized. The fact that perceptual grouping tendencies are genetic, not learned, is suggested by the cross-cultural effectiveness of sleight-of-hand magic and camouflage both of which work by subverting Wertheimer's grouping factors. Visual examples of Wertheimer's grouping factors are shown in Figures [3-8] and listed below:

1. Similarity – Items that are the same are grouped together.
2. Proximity – Items that are physically close are grouped.
3. Common Fate – Items that move together are grouped.
4. Continuity – Items that form or are joined by a line are grouped.
5. Closure – Items that form closed regions of space are grouped.
6. Past Experience – Items are interpreted based on surrounding items.

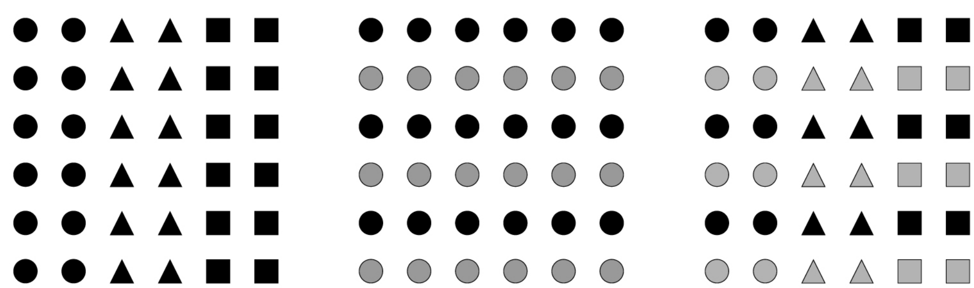

Figure 0.3. *Left: An example of grouping by similarity of shape. Center: An example of grouping by similarity of color. Right: An example of grouping by similarity overwhelming the perception of grouping by shape.*

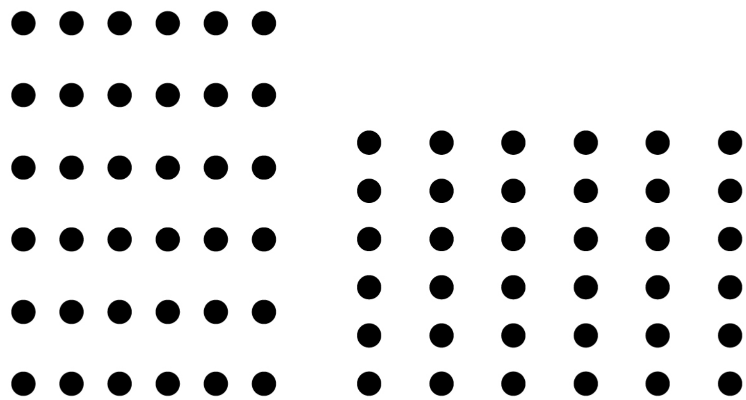

Figure 0.4. *Examples of grouping by proximity. The matrix of dots on the left is perceived as being composed of rows while the matrix of dots on the right is perceived as being composed of columns.*

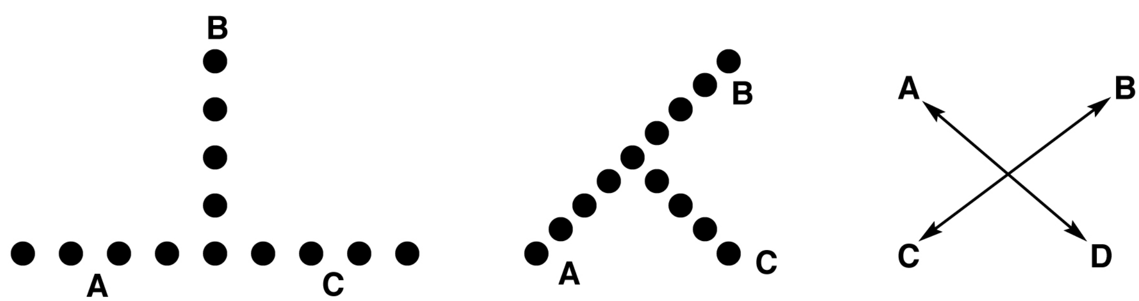

Figure 0.5. *Left and Center: Examples of grouping by continuity. Most observers perceive these figures as composed of two line segments instead of three separate segments. Right: An example of another aspect of grouping by continuity. Observers group this scene into two sets A, D and C, B because of the lines joining the letters.*

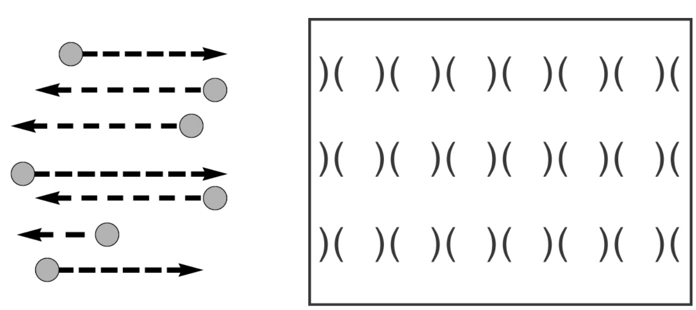

Figure 0.6. *Left: An example of grouping by common fate. Items moving on similar paths are grouped into units. Right: These parentheses could be grouped by proximity to produce hourglass shaped figures, however most observers find that grouping the parentheses as closed regions is more pleasing.*

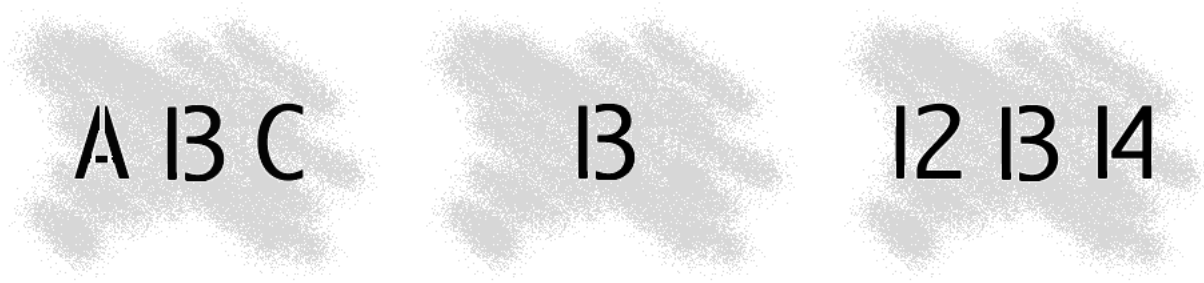

Figure 0.7. *An example of grouping by experience. On the left the center figure is observed to be the letter B. On the right the center figure is viewed as the number 13. In the center the figure is shown on its own. Images courtesy of Professor Charles Schmidt, Rutgers University [30].*

Interaction between perceptual grouping factors is far from simple for three reasons: First, the appearance of parts is determined by wholes. Second, judgments about similarity and proximity are always comparative. Third, one grouping factor can override another. For example grouping by color can overcome grouping by shape as shown in Figure 0.3.

Artists have been explicitly using these rules in their work for some time. For example Paul Klee used gestalt grouping diagrams in his paintings in the 1930s [35]. Later generations of artists learned of Wertheimer's laws of visual organization from two books on art and design education: "Language of Vision" by Gyorgy Kepes, a graphic designer who taught at the New Bauhaus in Chicago; and "Art and Visual Perception: A Psychology of the Creative Eye" by Rudolf Arnheim at Harvard University. Anthony A. Apodaca and Larry Gritz include a chapter on how gestalt grouping and binding can be facilitated using computer graphics in their book "Advanced Renderman Creating CGI for Motion Pictures" [2].

0.2.2 Perceptual Binding

Perceptual binding is illustrated in the examples shown in Figure 0.8. In the first example, the "dog image" is initially observed as a field of random spots. However once the dog grouping is interpreted by your visual system the subset of "dog spots" is linked in your mind and it becomes nearly impossible to perceive the image as a random field of spots again. The discovery of the dog and the linking of the dog spot group generates a pleasant sensation. Artists understand the pleasure given by such effects and are masters of producing the "aha" sensation in a viewer. In the second example, the "old-young woman image" the lines can either be perceptually grouped and interpreted as the face of a young woman or an old woman. However, the visual system will not allow both interpretations to be held at the same time. In the third example the image is initially ambiguous. When the page is rotated the grouping of figure and ground becomes

Figure 0.8. *Left: This image is initially observed to be a random field of dots. However, once the dog is perceived the "dog spots" are grouped together which is experienced as a pleasing effect. Ramachandran and Hirstein believe that this pleasing effect may be due to stimulation of the limbic system by the temporal lobe cortex of the brain. Center: The "old-young woman" image can only be bound in a single phase (old or young) by most viewers. Right: The object of the third example is initially ambiguous, by turning the page the grouping of figure and ground becomes apparent. (After Solso [33])*

apparent. Binding most likely serves to aid in the detection of predators and prey and is therefore an evolutionary advantage.

0.3 Isolation of a Single Module

The third principle of Ramachandran and Hirstein is the need to isolate a visual modality before applying the peak shift stimulus. They believe that by providing only a single visual module the attention of the observer is more easily focused onto the peak shifted stimulus. The ability of the visual to isolate a visual modality can explain the effectiveness of outline drawings or sketches.

The neurophysiologist Semir Zeki [43] has provided evidence that the brain does indeed process visual information into separate modalities in his quest for a "theory of aesthetics based on an understanding of the workings of the brain." Zeki has shown that movement, color and form are processed using different methods by different areas of the brain. In relating his work to the understanding of works of art, Zeki states,"artists are neurologists, studying the brain with techniques that are unique to them and reaching interesting but unspecified conclusions about the organization of the brain." Zeki's most compelling argument is: Artists who are especially interested in property X have found ingenious ways to partially isolate property X from property Y, using methods which have a clear basis in known neuroanatomy.

In order to understand this idea consider kinetic art and fauvism. Kinetic art refers to painted

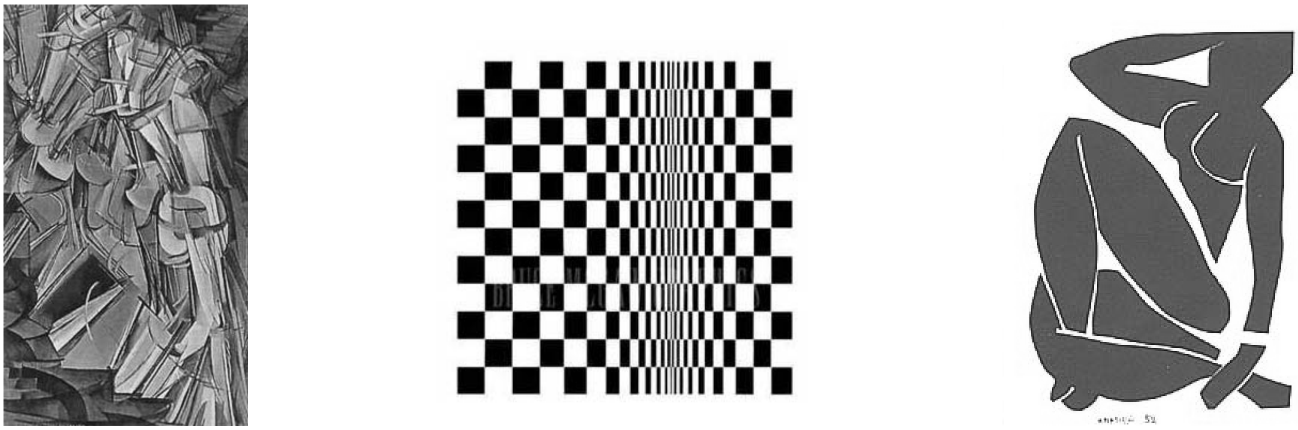

Figure 0.9. *Left: Marcel Duchamp's "Nude Descending a Staircase, No. 2" is a painted example of kinetic art. Center: Bridget Riley's "Movement in Squares" is an example of an artist creating the illusion of motion were none exits. Right: The "Blue Nude 3" of Henri Matisse is an example of fauvism. Color images of these works are available online [1].*

or sculptured works that include motion as a significant dimension. Fauvism is a style of painting that flourished in France at the beginning of the 20th century. The Fauves used pure brilliant colors and applied their paint straight form the tubes in an aggressive, direct manner. The Fauves painted directly from nature, but their works contain a strong expressive reaction to the subjects they painted. In the case of kinetic art, Zeki's property X is movement and property Y is color, while in the case of fauvism, property X is color and property Y is form. Examples of kinetic art and fauvism are shown in Figure 0.9.

An important fact about vision is the massive feedback from higher to lower centers, including the retina. This suggests that vision, far from being a passive reception of "what's out there", is an active search for "what's important". With the search is based on the viewers expectations and prior experience. Work by Zeki has shown that there is significant feedback among the areas of the brain associated with visual processing. The most basic insight to be gained from his work is that a great deal of parallel distributed processing is needed in order to create perceptual constancy and that most visual processing is unconscious. It seems likely that we will see further insights into the neural bases of visual phenomena as the result of continuing experiments in brain imaging. A complete description of neural workings of the vision centers of the brain is beyond the scope of this text. Interested readers are directed to Zeki's book "Inner Vision".

0.4 Problem Solving

Perceptual problem solving refers to the pleasure the brain takes in deciphering ambiguous scenes. Ramachandran and Hirstein argue that under the right conditions ambiguity itself can be a source of pleasure. For example the Mona Lisa's smile.

Perceptual problem solving also explains how the symbolic representation of an images subject may be given added significance. Perceptual problem solving is a constructive process based on the interplay between features of which the pattern is composed (bottom-up processes) and knowledge-based perceptual hypotheses (top-down processes). At a low level, patterns and forms are visually bound. Then at a higher level of visual analysis, recognized patterns and forms may summon a chain of associations. The mental effort that a viewer puts forth in extracting meaning from an image increases the emotional response that the viewer will have toward that image. Abstraction in the image requires the viewer to make a perceptual effort to extract the theme of the image. This effort on the part of the viewer forms an essential component of the viewing experience. This effect can be taken advantage of by an artist to produce more compelling images through the use of abstraction and symbolism.

0.5 Contrast Extraction

Contrast occurs between dissimilar features that are physically close together. Nearly any object in an image can be contrasted to any other object in the scene based on one of its aspects: color, size, shape, font, texture, etc. Ramachandran and Hirstein suggest that the visual system allocates attention to contrasting regions due to the fact that information generally resides in regions of change. This makes regions of an image which contain higher contrast more interesting and therefore more pleasing. Three simple examples of visual contrast are shown in Figure 0.10.

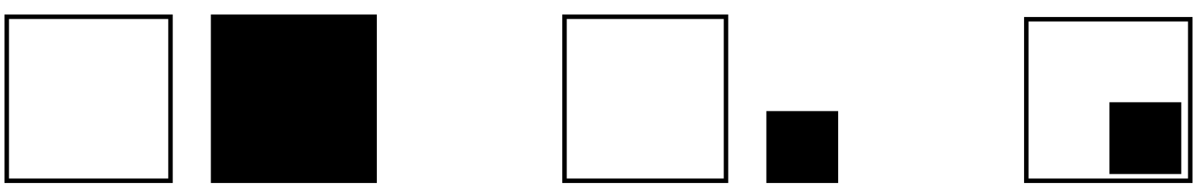

Figure 0.10. *Left: An example of intensity contrast between the two squares. Center: An example of size contrast between the two squares. Right: An example of position contrast between the two squares (inside versus outside).*

0.6 Symmetry

Symmetry establishes a ridiculous and wonderful cousinship between objects, phenomena and theories outwardly unrelated: terrestrial magnetism, woman's veils, polarized light, natural selection, the theory of groups, structure of space, vase designs, quantum physics, scarabs, flower petals, X-ray interference patterns, cell division in sea urchins, equilibrium positions of crystals, Romanesque cathedrals, snowflakes, music, the theory of relativity...

–Herman Weil

That symmetry is an important visual cue can be seen in the recurrence of symmetric patterns and designs throughout human history. Virtually all elements of the constructed environment from architecture and art to furniture and transportation contain at least one axis of symmetry. Symmetry is a special case of the gestalt grouping principle of similarity and it can been argued that symmetry is a useful cue for discriminating living organisms from inanimate objects. It has been shown that both humans and animals prefer bilateral symmetry when choosing a mate [37].

0.7 Generic Viewpoint

Psychologists have studied viewers' preferences for one viewpoint over another for particular objects. A viewpoint that is preferred by most viewers is called a *canonical viewpoint*. Palmer et al. [27] found that canonical viewpoints are off-axis, while Verfaillie [39] discovered that a three-quarter view of a familiar object is preferred.

A thorough investigation of canonical views was recently carried out by Blantz et al. [10]. They found three predictors of whether a view is canonical: the significance of visible features for a given observer, the stability of the view with respect to small transformations, and the extent to which features are occluded.

Significant features for an observer may include the facial portion of a head, the handle of a tool, or the seat of a chair. In viewing objects, Blantz et al. found that people preferred views which expressed the manner in which an object was seen in its environment, i.e. chairs are viewed

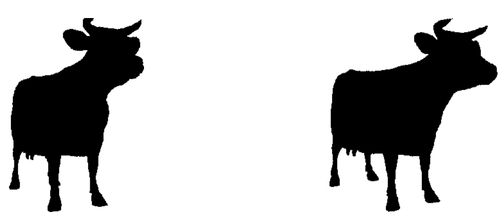

Figure 0.11. *Left: an "accidental" view where one of the cows hind legs ends up directly behind a front leg. Right: the same cow from a slightly perturbed viewing direction.*

from above, while airplanes may be viewed from above or below. They also found a distinct lack of “handedness” when humans choose preferred views. For example, when viewing a teapot a right handed viewer did not mind if the handle was placed on the left side of the image.

Image stability means that the viewpoint can be moved with little or no change in the resulting image. Many psychology researchers have shown that objects in a scene which share an edge will confuse a viewer [5, 7, 28]. For example the viewpoint that produces the “three legged cow” in Figure 0.11 is never picked as a canonical view.

When subjects in the Blantz et al. study were given the ability to choose the viewpoint for an object, it was discovered that the subjects performed an internal optimization to find a viewpoint that showed the smallest number of occlusions. This occurred for both familiar objects and artificial geometric constructs. For instance, when choosing a viewpoint for a teapot the subjects always choose a viewpoint that shows both the handle and the spout. This result agrees with Edelman et al. [15] who showed that canonical views for “nonsense” objects may also exist.

Artists have their own heuristics for choosing view directions that are consistent with the psychology results: pick an off-axis view from a natural eye height. Direct $45°$ angles are avoided. Another rule is to have the projections of front/side/top of the object to have relative areas of 4/2/1 on the canvas [3, 33] (often expressed as 55%/30%/15%). The front and side dimensions can be exchanged depending on the object.

0.8 Use of Metaphor

A metaphor expresses one thing in terms of another to suggest a likeness or analogy between them. An example of an illustrative metaphor is ”the atom is like a solar system.” The atom has a nucleus just as the sun is the solar system’s nucleus. The atom has electrons whirling around that nucleus just as the sun has planets circling around it [14]. This metaphor draws a visual analogy between something we have a metal image of (the solar system) and something we may not (the structure of an atom).

Visual metaphors surround us and provide the most prevalent mode of sharing knowledge. Nearly every television and magazine advertisement is composed of a modern visual metaphor. A favorite visual metaphor used to signify “speed” is time-lapse photography of traffic at night. Anti-depressant drug companies run adds with images of “the sun coming out”. Cultural metaphors form a common visual lexicon which can be used to emphasize the subject of an image or enhance the emotional response to an image.

0.9 Conclusion

Ramachandran and Hirstein's article, "Neurological Theories of Aesthetic" provides a useful framework for enhancing the communication content of computer generated images. Ramachandran and Hirstein present a series of rules which use evolutionary developed mechanisms of the human visual system for the perception of images. These rules allow the creator of an image to guide the attention of a viewer into a more in-depth reaction to the subject of the image.

Ramachandran and Hirstein's work has opened the door to a new frontier research into how the human visual system processes the information contained in works of art. The knowledge gained in this research will give credence to, or debunk the artistic rules of thumb currently used to judge the communication content of images. This work may also allow scientists to answer fundamental philosophical questions about the nature of art. Questions such as; "What is the difference between viewing a landscape and viewing a painting of a landscape?", can at least be answered in terms of how the brain responds to these very different stimuli.

Ramachandran and Hirstein have also drawn a fire-storm of commentary from critics in both the scientific and artistic communities. It seems that everyone either loves "Neurological Theories of Aesthetic" or hates it, but no one is indifferent. Examples of comments include:

"Perception may seem to some to be a phenomenological experience inaccessible to scientific rigor, but the efforts of generations of perceptual psychologists have shown that many aspects of perception are governed by a body of lawful relationships no less tractable than those of quantum physics, for example. The extension of such relationships to the subtleties of aesthetics is another kettle of slippery fish taken up by Ramachandran and Hirstein in a thought-provoking article in the Journal of Consciousness Studies."

–Christopher W. Tyler, "Is Art Lawful?" [38].

"I will demonstrate that Ramachandran and Hirstein confuse arousal (in a certain technical sense) with beauty, with the disastrous result of excluding most of what is usually taken to distinguish high art from its lower forms, such as advertising, industrial design, and pornography."
–Donnya Wheelwell, "Against the Reduction of Art to Galvanic Skin Response" [41], Donnya Wheelwell is the nom de guerre of a science professional who wishes to remain anonymous to avoid the scorn of her colleagues.

"Unfortunately, the flaw which undermines Ramachandran and Hirstein's attempts is a confusion regarding what constitutes an experience of beauty. They conflate pleasurable responses of a sexually titillating nature and other agreeably sensuous pleasures with the pleasurable response evoked by beauty."

–Jennifer Anne McMahon "Perceptual Principles as the Basis for Genuine Judgments of Beauty" [26].

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