GUIDING THE EYE: A NON-PHOTOREALISTIC SOLUTION FOR CONTROLLING VIEWER INTEREST

A Thesis

by

PEDRO A. PIEDRA JR.

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Visualization Sciences

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Approved by:

Chair of Committee,	Frederic I. Parke
Committee Members,	Richard Davison
	Scott Schaefer
Head of Department,	Tim McLaughlin

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ABSTRACT

Guiding the Eye: A Non-photorealistic Solution for Controlling Viewer Interest.

(December 2010)

Pedro A. Piedra Jr., B.E.D., Texas A&M University

Chair of Advisory Committee: Dr. Frederic I. Parke

In film and still photography, depth of field control is often employed to control viewer interest in an image. This technique is also used in computer animation, but, in a medium where artists have near infinite control, must we rely on replicating photo-realism?

This research is a viable, non-photorealistic solution to the problem of directing viewer interest. Vision is directed by reducing superfluous visual information from parts of the image, which do not directly affect the depictive meaning of that image. This concept is applied to images and animations rendered from three-dimensional, computer-generated scenes, where detail is defined as visual information pertaining to the surface properties of a given object. A system is developed to demonstrate this concept. The system uses distance from a user-defined origin as the main mechanism to modulate detail. This solution is implemented within a modeling and shading environment to serve as a non-photorealistic, functional alternative for depth of field. This approach is conceptually based on a model of human vision, specifically, the relationship between foveal and peripheral vision, and is artistically driven by various works in the disciplines

of painting and illustration, that through the careful manipulation of detail, control interest and understanding within the image.

The resulting images and animations produced by this system provide viable evidence that detail modulation can be used to control effectively viewer interest in an image eliminating the need to use photographic techniques like depth of field.

Para minha esposa mais linda du mundo… ☺

Mom and Dad, I did it! This is for all your love and never-ending support.

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But most of all, I would like to thank the people in the trenches with me, my beautiful wifey, Leticia, Megha, Bob, and all the other Vizzers that help maintain the richness and culture of the Vizlab.

This has been a long time in the making...

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CHAPTER I

INTRODUCTION

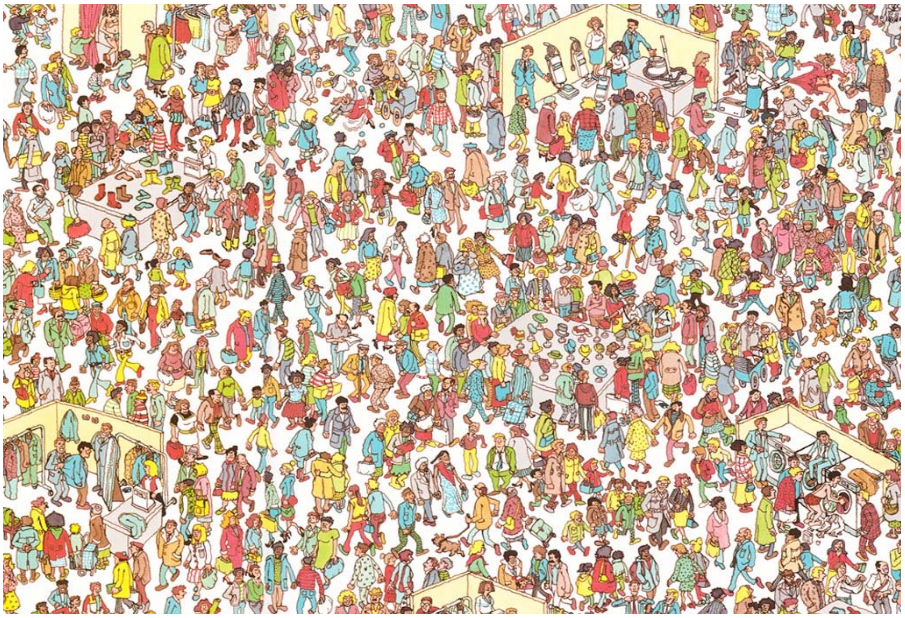

Fig. 1. Example of equally weighted visual elements.

In film and still photography, the technique of depth of field control is often employed to lead the viewer's eye to the most significant action of a shot or image. This technique is also employed in computer animation, but in a medium where artists have near infinite control of the final image, is it necessary to rely on replicating photoreal solutions for directing viewer attention? This research proposes a non-photorealistic approach for manipulating/organizing visual information in a computer-generated image

This thesis follows the style and format of *IEEE Transactions on Visualization and Computer Graphics*.

so that viewer attention is directed to targeted elements within a composition.

This research takes the approach of selectively removing detail from non-significant elements of an image to guide viewer attention to the high-detail, significant portions of the composition. This approach is informed by the understanding that the human eye has the tendency to fixate first on areas of greatest visual contrast, and be drawn less to relatively homogeneous areas of a composition [Livingstone, 2002, p. 78]. Thus by removing detail selectively from an image you create contrast between regions of high detail and low detail.

Not all images are created to adhere to this principle of contrast. Images, which lack visual contrast, are difficult to understand and cause confusion. Fig. 1 is an excellent example of an image intentionally designed to produce this effect. The image is taken from a popular children's book called "Where's Waldo". The reader is tasked with finding Waldo, the famous bespectacled protagonist, in each elaborate image. This is no trivial task. Every image element competes with the other clamoring for attention and, thus, eliminating any focal point from the image. It is the objective of the work performed in this thesis to create images, which clearly direct the attention of the viewer.

This work has a secondary motivation, to control interest in an aesthetically pleasing manner, which does not call attention to the technique used to capture attention, but instead integrates itself within the design of the imagery as has been achieved in various works in the disciplines of painting and illustration. These two objectives guide the work for this entire research.

Three areas of research helped to formulate the aforementioned concept and represent different existing solutions to the problem of controlling viewer interest in an image. The first area of discussion is the use of depth of field control in film and photography. The relationship between foveal and peripheral vision in the human eye, as well as related discussions of visual perception provide a second solution. And the principle of contrast and emphasis as applied in the field of painting and illustration provides a third approach to the problem of capturing attention. These topics will be presented in the background section and connected back to the overarching objective of this research, the development of a non-photorealistic solution for capturing viewer attention within an image.

This concept is developed and demonstrated through the creation of a system for controlling viewer interest, which is implemented within a modeling and shading environment. The interest-control system serves as a functional alternative for depth of field control in the medium of computer animation. It is implemented as a time-based, art-directable solution for producing images and animations. This system organizes a scene based on distance in scene space from an arbitrary origin. This information allows one to essentially separate an image into foreground, middle ground, and background spaces. Once scene space is divided, the user has the capability to selectively reveal surface information as defined by the surface shader associated with each object. The purpose of this organization is to simplify an image into a ranking of visual themes placing emphasis on the most important aspect of the composition through the selected removal of detail via shading.

The evaluation of the work performed in this thesis is based on the effectiveness that the produced images direct attention as opposed to an evaluation of the system designed to generate the images and animations. The criteria used to evaluate the images and animations has two components. First, does the modulation of detail achieve a clear point of emphasis in the composition? And second, does the manner in which surface properties transition from their most simple state of detail to most complex state integrate itself aesthetically within the composition?

The resulting images and animations produced by the system provide viable evidence that detail modulation can be used to effectively control viewer interest in an image, eliminating the need to use photographic techniques like depth of field. This work is a first step toward solving this challenge, but there is far more exploration needed within the realm of perception-based shading and rendering.

It is important to clarify a few key concepts and terms before further explanation is given. For the purpose of this research detail is defined as visual information pertaining to the surface properties of a given object that can be manipulated through a surface shader (e.g. color, texture, opacity). It is also necessary to make the distinction between the aesthetically driven work done in this research from the collective body of research in computer graphics on the subject of "levels of detail" (LOD), a field of research dedicated to the development of efficient scene data management algorithms to display complex scenes with particular application to real-time systems.

CHAPTER II

BACKGROUND

Fig. 2. Field of flowers.

Imagine a field of identical flowers, extending to the horizon, as in Fig. 2. All of the flowers roughly share the same physical properties, color, size, orientation, position, number of petals, with little noticeable variation separating one flower from another. Now how would you render an image of this field, if the intention is to direct attention to a specific flower or a specific group of flowers?

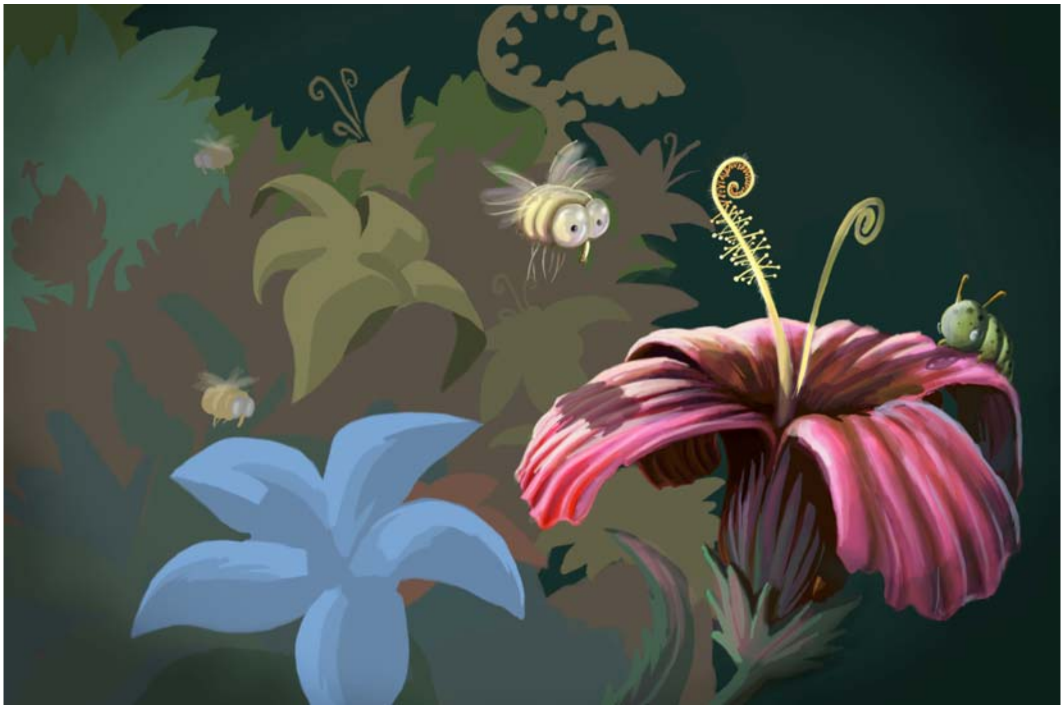

Fig. 3. Personal study illustrating the simplification of objects based on distance.

This question has been answered before in photography with the use of depth of field control and in art, as shown in various examples of painting and illustration, and even our own visual system offers a solution. What is of particular interest to this work is the degree of abstraction used to render subjects when solving this problem. “[The artist] can replicate the appearance of the physical world with the meticulous faithfulness of the *trompe l'oeil* painter, or, like Mondrian and Kandinsky, he can work with completely nonmimetic shapes, which reflect human experience by pure visual expression and spatial relations “ [Arnheim, 1974, p. 144]. This spectrum from the photoreal to the completely non-representational abstract represents the gamut of visual solutions.

How one constructs an image using this spectrum of representation was the subject of a series of illustrations that became the catalyst for this entire research. The illustrations explored the notion of using distance to determine the representation of an object. Fig. 3 is an example from this series. One can observe that the most significant portion of the composition is carefully rendered, but as scene elements recede further away from this area of significance and into perceived space, the objects are gradually reduced to simplified representations of their original form. The illustrations in this series are all composed of unique layers. Each layer represents one “level of detail” with each subsequent layer progressively simplifying rendering quality as distance increases from the area of emphasis in the image. Using distance from a specified area of a composition as the driving mechanism of object representation, allows emphasis to be established in the image, and essentially performs the same function as depth of field control in photography. The difference is that these images do not rely on focus to guide attention, instead, the distinct difference between the rendering quality, or representation of figure and ground ultimately guides the eye.

A. Photography: Depth of Field Control

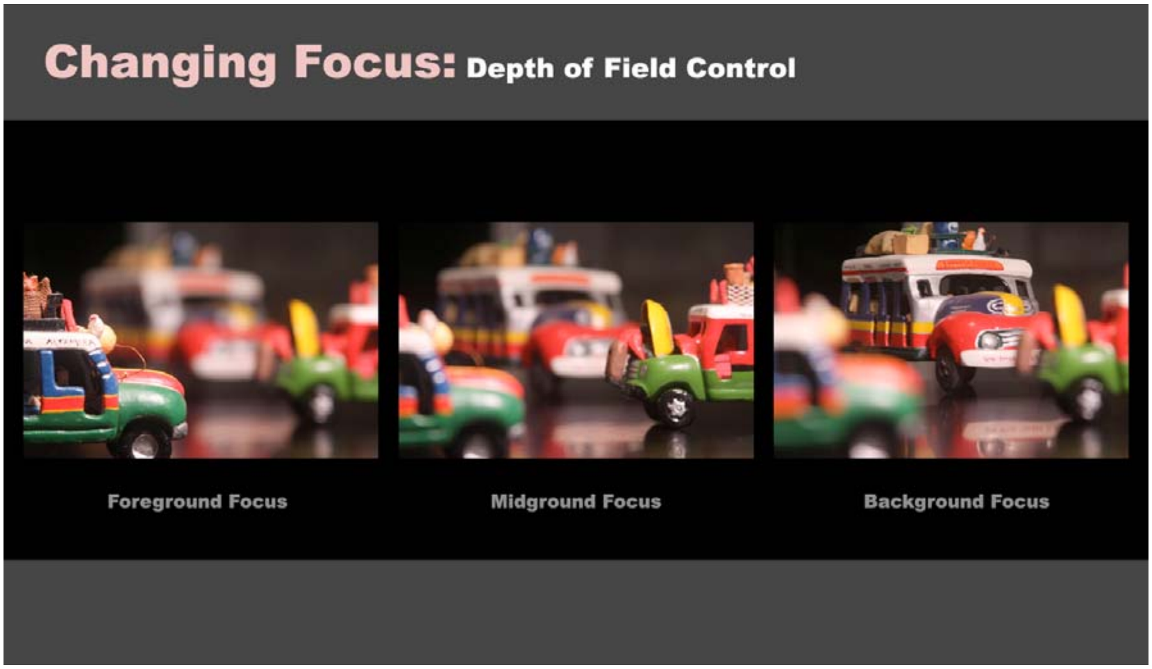

Fig. 4. Examples of shallow depth of field.

The ability to control interest in an image is an especially pertinent problem in photography. This problem becomes compounded in time-based mediums, such as film and animation. In every frame of every scene of a film, the audience is bombarded by visual information. Disparate elements combine together to form the final composition of any given shot. Elements are staged in the background, middle ground, and foreground for different effects, but at all times "the viewer's attention should always be attracted to the most significant portion of the scene" [Mascelli, 1965, p. 215]. In film this is where the central action of the scene is occurring, whether it is an actor delivering an important line, or the camera capturing the emotional reaction of another player. It is essential for story clarity that viewer attention is directed to the most important action in a scene.

In film and still photography, depth of field control is often employed to direct viewer interest in an image. This solution uses the degree to which an object is in focus to draw the eye. Fig. 4 shows examples of how depth of field control can be used to direct attention to a specific area of a composition. Three factors influence depth of field (DOF), aperture, focal length, and the camera's distance from the subject. Large apertures result in shallow DOF where only a small range of an image is in focus. Small apertures increase the DOF so that almost the entire field of view remains in complete focus. Wide angle lenses, generally considered as a lens with a focal length less than 35 mm, maintain sharp focus throughout the image. While narrow angle lenses , or telephoto lenses, which usually start at around 70 mm and above have a much more shallow range of DOF.

Computer animation also relies on DOF to guide attention within a composition. 3D modeling and rendering packages use a virtual camera model that like an actual physical camera, it also takes into account aperture, focal length, and the camera's distance from the subject to perform per-pixel calculations to achieve realistic DOF effects. But as was stated in the introduction, in a medium where artists have near infinite control of the final image, must we rely on replicating photorealism?

B. Vision: Peripheral and Foveal Vision

The world around us is always in a state of perfect focus. It is the camera which allows us to interpret and simplify reality, so that only what is of greatest importance to the photographer is emphasized or remains in focus while the complexity of the surroundings of our subject are made to disappear. DOF helps to simplify the image by this reduction of information. Our visual system performs a similar function.

Seldom are we conscious of how our eyes experience the world. We mistakenly accept our vision as an accurate facsimile of the world around us, but like our four other senses it is at the mercy of the processing which occurs in the brain. The information we receive is never a perfect replica of our world. It is informed and affected by our personal experiences and by the unique physiological makeup of our own visual system. Our eyes are not able to see everything within our field of vision at the same level of detail. The fovea, the very center/back of the retina, has the highest acuity making our vision much sharper at the center of our gaze than the rest of our visual field. Foveal vision is used for scrutinizing highly detailed objects or surfaces, whereas peripheral vision is used for organizing the spatial scene, sensing depth and motion, for seeing large objects, and for detecting areas to which we should direct our foveal vision [Livingstone, 2002, p.68]. We are seldom conscious of this limitation of our vision because our eyes are constantly darting about to the next area of interest. This fact of our vision is worth noting because it plays a vital role in how we interpret our world. Our vision organizes visual information into a hierarchy of importance that is constantly shifting. When our foveal vision fixates on a given area that area now holds the most importance, but the second our peripheral vision notes something we again shift our interest to this new area which now becomes our center of focus. Thus as we observe the world our eyes are constantly shifting to focus on the next area of significance. An excellent example of this occurs when we drive. One's attention is constantly on alert watching for absent-minded pedestrians crossing the street or other vehicles that may veer into our lane, etc. We do not take in all of this information at once, but instead we take it in piecemeal in order of importance.

The function of the visual system is to process light patterns into information useful to the organism [Livingstone, 2002, p.28]. The keyword in this statement is process. Light entering the eye is only one aspect of our visual system. Much of our vision can be attributed to the processing, which occurs in the eye and the brain "giving immense added value to the images of the eyes" [Gregory, 1997, p. 2]. Pre-processing occurs in the retina even before the information is passed onto the brain to interpret. For this reason "what we see, and what we know, can be very different" [Gregory, 1997, p. 2]. Although understanding of our visual system has advanced much since the early Greek philosophers suggested that beams of light emitted by our eyes reach out to palpate the objects that we observe, much is still not understood about the physiological process of vision, in particular what occurs in the brain. We know that light enters the eye, "optically projected from the outside world onto the screens of the retinas. The brain receives minute electrochemical pulses of various frequencies, as signals from the senses" [Gregory, 1997, p. 2], but how are these signals interpreted and given relevance by the brain? "The human eye is physically incapable of capturing a moving scene in full detail. We sense image detail in a 2° foveal region, relying on rapid eye movements, or saccades, to jump between points of interest. Our brain, then reassembles these glimpses into a coherent, but inevitably imperfect, visual percept of the environment." This loss of sight of unimportant details is known as inattentional blindness [Cater, Chalmers and Ward, 2003]. The research in this paper accepts the currently dominant view of the intelligent eye derived from the nineteenth century German psychologist Hermann von Helmholtz [Gregory, 1997, p. 5]. Its basic premise is that "sensory signals are not adequate for direct or certain perceptions; so intelligent guessing is needed for some objects" [Gregory, 1997, p. 5]. This implies that our vision is not only informed by what we see, but is given added significance by what we perceive. Perceptual factors such as, simplicity of shape, orderly grouping, clear overlapping, distinction of figure and ground, use of lighting and perspective to interpret spatial values, allows the brain to organize and better understand visual information.

C. Illustration: The Principle of Contrast and Emphasis

Fig. 5. Edgar Degas. *Woman Ironing*. c.1869. Oil on canvas. Neue Pinakothek, Munich, Germany.

The human eye's inability to scrutinize detail in all but a small portion of our field of vision is a powerful fact when applied to image-making. It is apparent from various examples of painting and illustration that artists are constantly making aesthetic decisions to lead the eye of the viewer to what her/she deems to be the most important aspect of the composition. Whether this is a conscious or unconscious decision made by the artist is not always known. But what is of note, is how often these decisions resemble the relationship between foveal and peripheral vision, where fine detail is only perceived in a small region of the field of view, in this case the canvas. An excellent example of such a work is a painting by the French artist Edgar Degas, *Woman Ironing*, Fig. 5. His use of small, careful brush strokes to render the face of a woman ironing clothes is juxtaposed by the loose, broad brush strokes used to form the woman's body and to a greater extent the middle ground and background of the painting. The distinct difference in brush strokes used to render the painting creates a hierarchy of detail, which is used to emphasize the portion of greatest significance in the composition, the woman's face. Degas uses this painting technique in an aesthetically pleasing manner that does not call attention to itself. The woman's carefully rendered face is seamlessly integrated into the imagery of the composition despite the contrast created by the varying size and coarseness of brush strokes used in the rendering of the painting.

Our vision has specific tendencies when it comes to where our eyes tend to fixate. The Russian psychologist Albert Yarbus in the 1960's conducted several experiments in which he tracked human eye movement when analyzing complex objects and images [Yarbus, 1967]. "Yarbus found that the subjects tended to look most at those parts of the picture that contained high-contrast and fine detail, as well as items of biological significance (like other humans)" [Livingstone, 2002, p. 78].

Thus, it is within the artist's control to guide an observer's eye by carefully modulating visual information within an image. Nathan Goldstein states it best in the following passage from his book, *Design and Composition*:

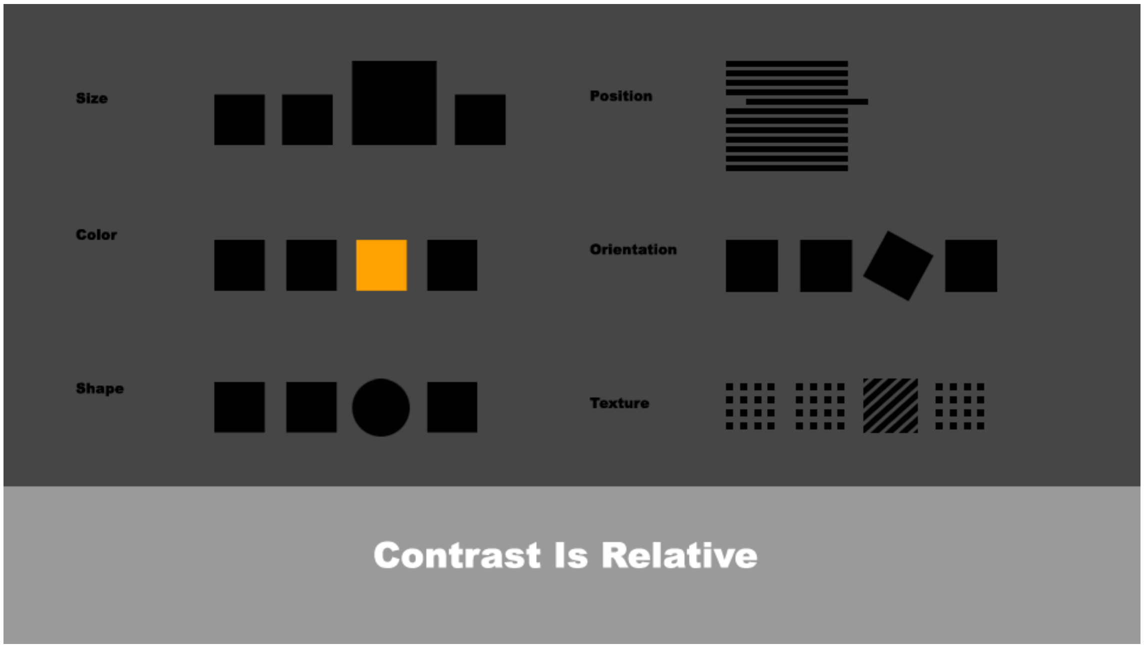

Fig. 6. Forms of contrast.

> In the best works, balance, emphasis, and simplicity all serve to establish a hierarchy of visual occurrences – a kind of ranking of visual themes in their order of importance to a work's depictive and dynamic meanings. Placing organizational themes in an order of importance not only clarifies for the viewer what is of importance in a work to the artist, but avoids the visual confusion that would result if every theme clamored equally for attention [Goldstein, 1989, p. 15].

To establish this "hierarchy of visual occurrences", artists modulate various visual properties, which serve as the fundamental tools for establishing contrast or emphasis in an image. Goldstein describes seven visual elements or properties that can be modulated to achieve contrast: line, shape, value, color, mass, space, and texture [Goldstein, 1989, p. 25]. Fig. 6 displays a series of simple examples using these properties to achieve emphasis. When these visual properties are appropriately used, an artist can achieve distinct differences between two compared effects to effectively bring out one element over another.

The effect of contrast is completely relative. “Our sense organs can function only by means of comparisons. The eye accepts a line as long when a shorter line is presented for comparison. The same line is taken as short when compared with a longer line. Color effects are similarly intensified or weakened by contrast” [Itten, 2001, p. 32]. Itten discusses the ways in which color can be used to create contrast in “the seven color contrasts”: contrast of hue, light-dark contrast, cold-warm contrast, complimentary contrast, simultaneous contrast, contrast of saturation, and contrast of extension [Itten, 2001, p. 32]. The role of color in directing or misdirecting attention has been observed in many predator-prey relationships in nature. Countershading, an adaptation observed in a number of species of fish where pale colored undersides are used to reduce the contrast between themselves and their environment, exemplifies the power of color to capture attention. “Countershading compensates for the shadowing effects caused by the sun shining from above and has at least two benefits: it reduces the contrast with the background and it ‘flattens’ the animal’s perceived shape [Rock, 1990, p. 127].” So color not only plays a large role in capturing attention, but it also allows us to understand the shape or form of an object through shading, probably the most primitive mechanism used by the human visual system to recognize three-dimensional shape [Rock, 1990, p. 127]. This fact adds another important tool that can be used to guide attention in an image. By eliminating the subtle value variations which occur over a surface, we essentially lose the ability to perceive form. This reduction of visual information can be used to decrease the salience of an object relative to the environment, much in the same way that DOF control is used to decrease the interest in unimportant elements of a composition by placing them out of focus. Both approaches help to reduce the perception of form and allow attention to be drawn away from relatively unimportant areas of a composition that otherwise may compete for attention with the main subject of the image.

D. Modulating Detail

Encompassing all three of the aforementioned approaches for controlling viewer interest is the basic premise that attention is only captured when emphasis is placed on selected elements of an image or space through the omission or obscuring of unimportant details. As we have already noted, this can be achieved in a number of different ways, but what essentially links each of these approaches is the notion of presenting a “selected reduction of reality”. The world around us is constantly in a state of perfect focus, yet each of these solutions in some ways reduces undesired visual information from reality, so that only the most important elements of an image are conveyed to the viewer. “This means only that the better picture is one that omits unnecessary detail and chooses telling characteristics, but also that the relevant facts must be unambiguously conveyed to the eye" [Arnheim, 1974, p. 157]. This selected

Fig.7. Personal study demonstrating the directed removal of detail.

removal of detail from an image or space may allow for faster human processing of an image or environment and may even add greater meaning and understanding of the presented information.

This research proposes that an image should be organized into a hierarchy of visual information that favors the presence of fine detail in the main subject of an image and selectively reduces detail from less important areas. With detail being defined as visual information that describes the surface of a given object. This method of crafting images may simplify the overall image processing which occurs in the eye and brain by limiting visual information in relatively unimportant areas of an image and by increasing the amount of information used to describe the surface of important elements. Images are organized to have an area of increased localized detail in the area of greatest importance with secondary and tertiary image elements becoming simplified in gradations that correspond with their position in space relative to the area of importance. This use of relative position or distance from a central area of focus to drive the reduction of detail helps to further organize an image into foreground, middle ground, and background spaces. Fig. 7 is a study illustration which I created to demonstrate this approach towards detail. Our attention is led to the bird perched on a protruding stem of a bamboo plant. Localized detail present on the bird and nearby stems and leaves, in addition to a subtle use of warm hues on the bird's face, are used to separate these elements from the comparatively simple brush strokes and cooler green hue which form the middle ground and background elements of the composition. The purpose of this organization is to create "a kind of ranking of visual themes in their order of importance to a work's depictive and dynamic meanings" [Goldstein, 1989, p. 15].

The work performed in this thesis provides a non-photorealistic solution for controlling viewer interest within rendered 3D environments. Related computer graphics research has explored this topic before. Early work in this area primarily focused on solving this problem in two-dimensional space. DeCarlo and Santella's 2002 research, *Stylization and Abstraction of Photographs*, presented a system, which transformed photographs into simplified line-drawings formed by large patches of constant color and bold line-work, retaining detail in only the “meaningful elements” of the image. The system identified the meaningful elements of the photograph by “using a model of human perception and a record of a user's eye movements” taken during the observation of the given photo [DeCarlo and Santella, 2002]. This research similarly takes the approach of selectively removing detail from non-significant image elements to guide viewer attention to the high-detail, depictively significant portion of the image, but unlike DeCarlo and Santella's work, our system relies on the user to determine which areas of the image are meaningful. Our system is designed as an art-directable tool, which allows the user to determine how and where detail is modulated to create emphasis in a composition.

Another major difference of this research from others in the area of perceptual rendering is that this work is aesthetically driven and seeks novel stylization within the medium of computer animation. Much research in this area has focused on using perceptual rendering methods for non-artistic purposes. Cater, Chalmers and Ward applied the understanding of inattentional blindness, the inability to perceive features in a visual scene when the observer is not attending to them, to develop a system that accelerates the rendering of animated sequences [Cater, Chalmers and Ward, 2003]. McNamara's research on *subtle gaze direction* exploits the lack of acuity in our peripheral vision to involuntarily draw a viewer's gaze to specific image locations using subtle luminanace or warm-cool modulations. Her work is solely concerned with how to unobtrusively capture viewer attention with particular application towards large scale display systems and perceptually adaptive rendering [McNamara, Bailey and Grimm, 2008]. Our research, on the other hand, takes the understanding of the relationship between foveal and peripheral vision and inattentional blindness to inform artistic decisions that determine how visual information is modulated in an image or animated sequence.

The work in this research has particular application towards storytelling in computer animation. The system developed in this research to control viewer interest is designed to serve as a functional alternative to depth of field control. A similarly conceptualized system is presented in the research, *Directing Gaze in 3D Models with Stylized Focus*, but the work is predominantly applied to architectural visualization [Cole, DeCarlo, Finkelstein, Kin, Morley, and Santella, 2006]. Also their system uses a more limited set of properties, relying on color saturation, contrast, line density, and line sharpness to establish emphasis in an image. Our system uses, hue, saturation, value, specular light, occlusion, and a few other shading properties to control viewer interest in a scene. And our system allows the user to have much more control of the final image by allowing the user to specify how shading properties are modulated through each of the five levels of detail that make up scene space in our system. In a computer animation production pipeline it is of utmost importance to have flexible solutions that empower artists, and for this reason our system is designed so that the user can specify how every surface shader property is modulated in a scene.

CHAPTER III

METHODOLOGY: INTEREST-CONTROL SYSTEM

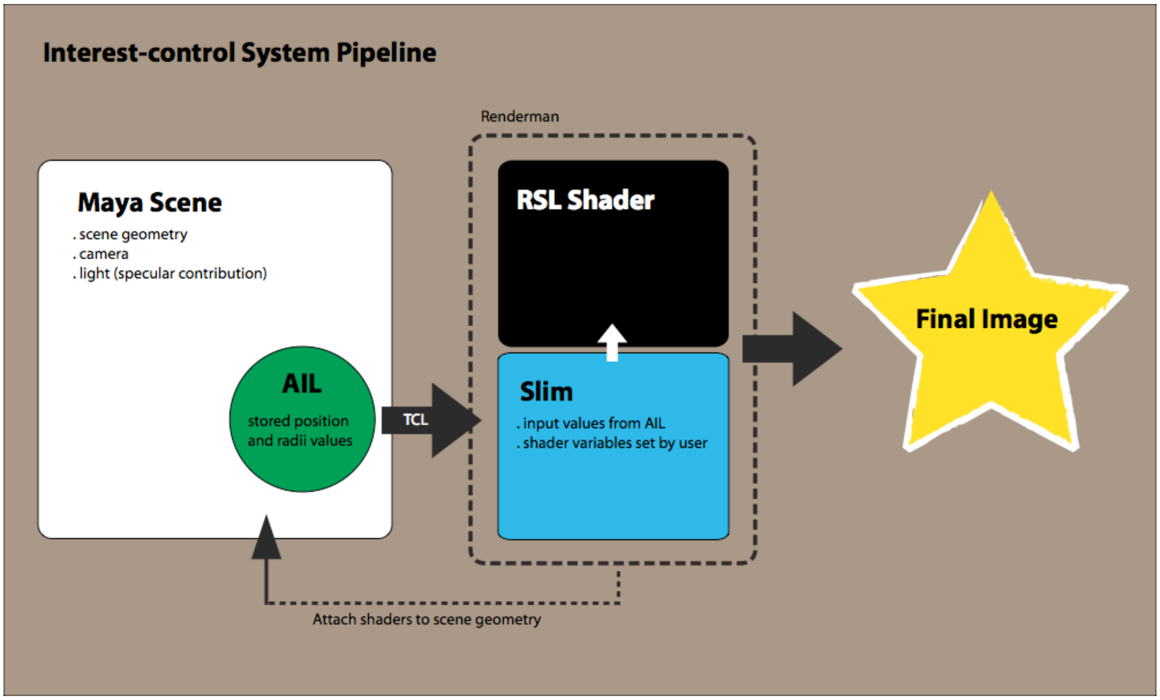

Fig. 8. Diagram of Interest-control system.

The following discussion presents the modeling and shading pipeline that was used to generate the images and animations created to evaluate this thesis work. The pipeline is called the Interest-control System. It is implemented in Maya and Renderman. Fig. 8 shows a diagram of the basic workflow for this system.

The Interest-control System is a non-photorealistic solution for controlling viewer interest in an image. The system modulates surface shader information, color and opacity, based on distance from an arbitrary origin. The modulation of this information establishes the area of focus in the image.

The interest-control system functions by dividing scene space into five distinct volumes. Four concentric spheres of increasing size make up the first four divisions; the fifth division of space is defined as the volume outside of the concentric spheres. A mechanism for locating the shared center point of the volumes, and for calculating the radius of each sphere is provided. These values are used by the shader to locate a shading point within one of the five volumes. Each volume has a user-designated set of shading properties. Once a point is found to be in a volume the appropriate surface properties are passed on to the shading point. A visual manifestation of the divided space is provided for the user as a guide to determine the area of interest in a given scene. The user is able to position the guide and control the size of each volume independent from the others allowing the user to essentially fit the guide to any scene.

The interest-control system is implemented in Maya and Renderman. Two major components comprise this system, the Area of Interest Locator (AIL) which functions as the visual guide within the Maya scene environment and a custom-written, RSL (Renderman Shading Language) shader, which sets the surface properties, associated with each of the five volumes. The following sections will elaborate upon the specifics of the implementation of this system and the relationship between AIL and the custom RSL shader.

A. Area of Interest Locator (AIL)

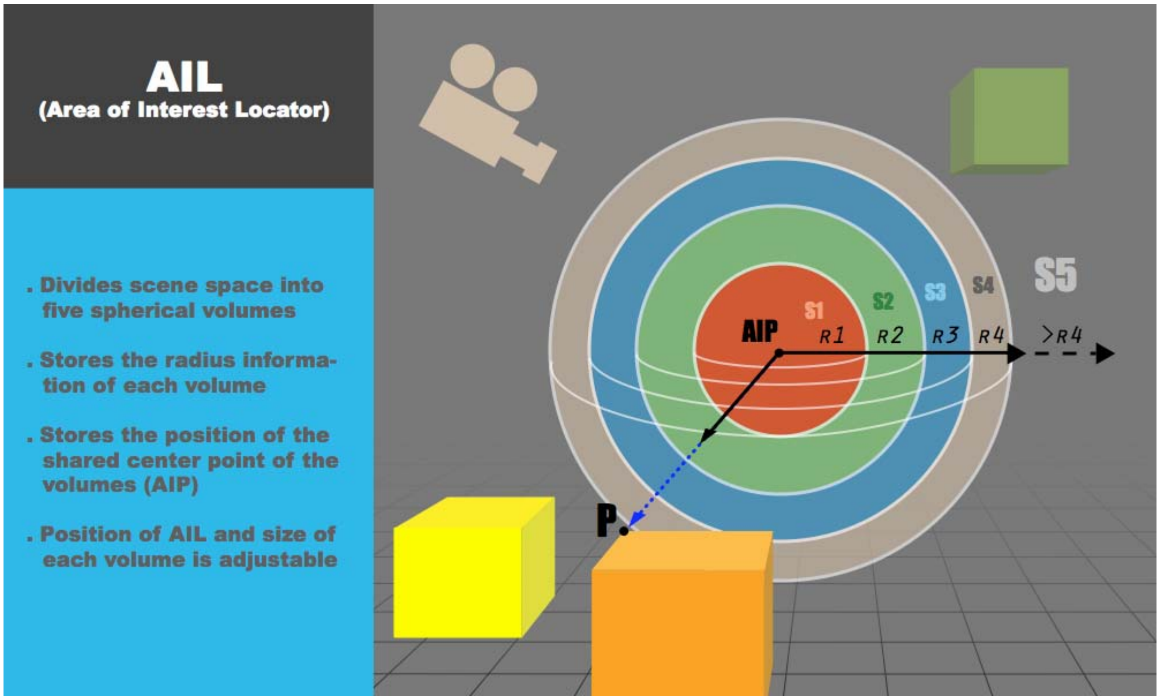

Fig.9. Diagram of Area of Interest Locator (AIL).

AIL serves as the visual guide that divides scene space into five volumes within the Maya scene environment. It is a camera-independent, non-renderable object comprised of a series of four, semi-transparent, concentric spheres, which the user places within a given scene to determine where the area of interest will be in a scene. Fig. 9 is a diagram which depicts how an AIL object is used in a simple scene.

AIL serves two main functions; one, to communicate its three-dimensional position in space and the radii values, R1, R2, R3, and R4 to the shader; second, to serve as a visual guide within the Maya environment for the user to locate the area of interest in a composition. Each sphere is given a unique color for readability. The red center volume is designed to have the greatest emphasis in the scene with each radiating sphere diminishing in importance. AIL can be positioned anywhere in a scene to control interest at the discretion of the user. Animating its position allows the user to change the area of interest in a continuous image sequence. The resulting shift of visual emphasis in the scene attempts to replicate the functionality of depth of field control in traditional cinematography by increasing the salience of targeted objects relative to the rest of the scene environment. Rack focus, a commonly practiced technique in cinematography where focus in a shot is inverted over the duration of a sequence from a subject in the foreground to a subject in the background, or vice versa, can essentially be replicated with the proper translation of AIL. AIL is camera-independent, and as such, animating the position of AIL can potentially have the adverse affect of being visually distracting as surface properties animate across objects in a scene. The user also has controls to independently adjust the size of the individual spheres, which make up the AIL object. These values are keyable and have led to interesting visual results in early tests of the system. Further discussion will be given to the visual results attained from animating the AIL object and its component volumes, as well as, possible applications of this capability in the evaluation section of this paper.

AIL is broken into five distinct volumes, S1, S2, S3, S4, and S5 as shown in Fig.9. AIL stores the three-dimensional position of the shared center point of the concentric spheres and the associated radius value of each volume, R1, R2, R3, and R4, respectively. The user within the Maya scene environment determines these values. By default each sequential radius is larger than the previous by a power of two, but as stated before the user has controls to independently adjust the volume of each sphere. Only the first volume, S1, is a complete sphere. This volume is designed to be the area of interest in a given scene. Scene objects within this volume should have the highest degree of salience relative to the environment. Volumes S2, S3, S4, and S5 can be calculated by $Sn = Sn - Sn\text{-}1$. The fifth volume, S5, is comprised of the area outside of the radiating spheres and is the only volume with no radius value associated with it. Each volume corresponds to an area of influence controlled within the shader. The shader assigns a unique set of shading properties to each of these volumes. A more detailed explanation of the function of each volume and its implementation in the shader will be given in the following section.

One last notable aspect of AIL is the ability to have multiple AIL objects in a single scene. Scene objects are attached to AIL through Tcl (Tool Command Language) code passed to the shader. Since each AIL has a unique name, if desired a user can import multiple AIL objects and assign them to different objects in a scene. Each AIL works independent of the other, and no object can be assigned to more than one AIL. This aspect of the shading system should be used with some degree of caution. Each AIL adds another level of complexity to a scene and can become increasingly cumbersome to manage if not used carefully. This will be elaborated upon in the Evaluation section.

B. Area of Interest Shader

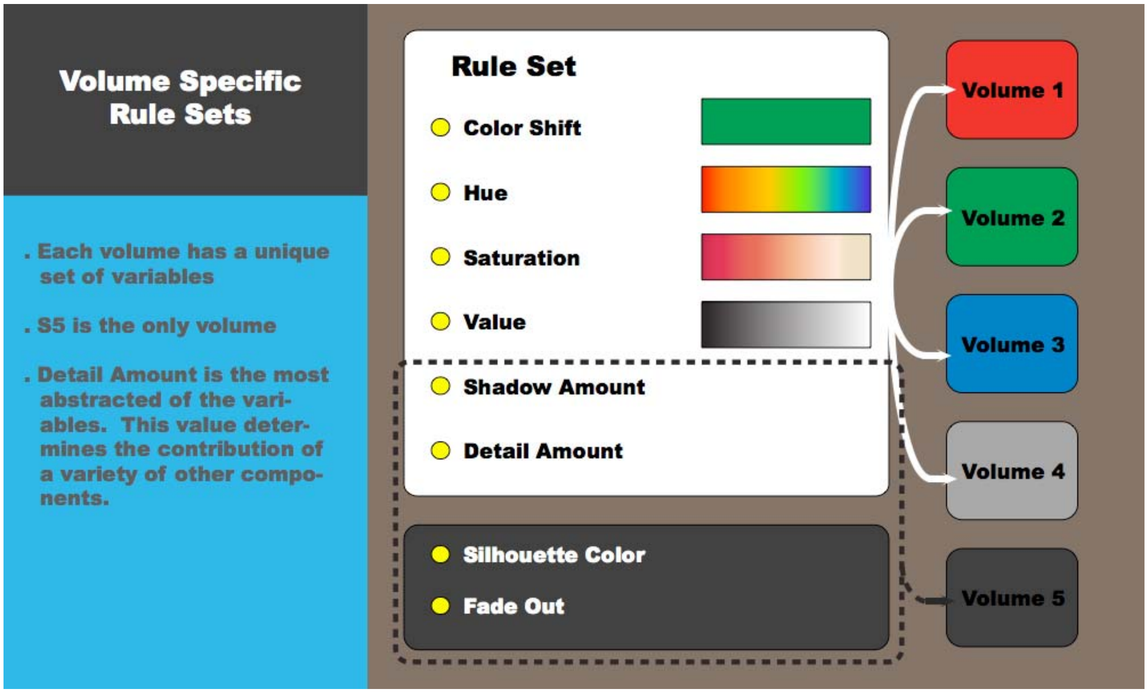

Fig.10. Diagram of volume specific variables.

The area of interest shader is a standard Renderman surface shader. The shader is written in the Renderman Shading Language and uses the Slim interface to expose shader variables to the user. Its sole function is to determine the final color and opacity for a given shading point. What makes this shader unique is that it uses distance as the mechanism to determine final color and opacity, and here lies the connection between AIL and our shader. The shader uses the values stored in AIL as the inputs to calculate distance. The stored AIP coordinate is used as the origin of our system. The distance of a shading point from this origin, and the stored radii values are used to resolve the volume in which the shading point is located. Once the volume is established a unique set of rules associated with that volume are used to calculate final color and opacity of the shading point. The details of how this shader is organized, and how rule sets are used to determine final color and opacity are explained in the following paragraphs.

The shader is organized into a series of five filters that correspond to the five volumes that divide scene space, S1, S2, S3, S4, and S5, respectively. Each of these filters has a set of variables associated with it that control various surface properties built into the shader. These variables make up the rule set for each volume, as is shown in Fig. 10. A filter is triggered when the distance of a shading point from the AIP, an arbitrary origin set by the user in the Maya scene environment, is found to be within the bounds of one of the five volumes that make up scene space. Once a shading point is found to be within a specific volume the rule set for that volume is applied to the shading point to calculate final color and opacity. The shader does not automatically generate the rules set for each volume. Instead they are set by the user through the Slim interface. The user assigns appropriate values for each of the variables and these values are used to calculate the contribution of various shading components. For the purposes of this thesis work, color, occlusion, specular light, a faked subsurface scattering function, a faked shadow function, and a shader controlled rim light make up the components that determine final color. The equation for final color, Fig. 11, is shown below.

Final Color = (((DiffuseColor + Rim + FakeSubsurfaceScatter)*Opacity*Shadow) + Specular)*Occlusion;

Fig. 11. Equation used to calculate final color.

The approach used for the design of our area of interest shader was a system of layering of detail. With the idea that layers of detail information could be systematically “peeled” away at the discretion of the user in order to establish visual hierarchies in a scene.

The following paragraphs describe in more detail the individual components, which are used to determine final color and opacity.

The base layer that contributes to final color, *Ctex*, is broken up into four contributing components, hue, saturation, value, and color shift. Color shift and hue take color inputs, and saturation and value require float inputs from zero to one. The function that calculates *Ctex* requires a color texture map, if none is provided a constant color is assigned instead. Fig. 12 shows the texture map inputs used for the butterfly model. The function multiplies the input color by the color shift component and then transforms this new color from RGB space to HSV space. With the color in HSV space the user can

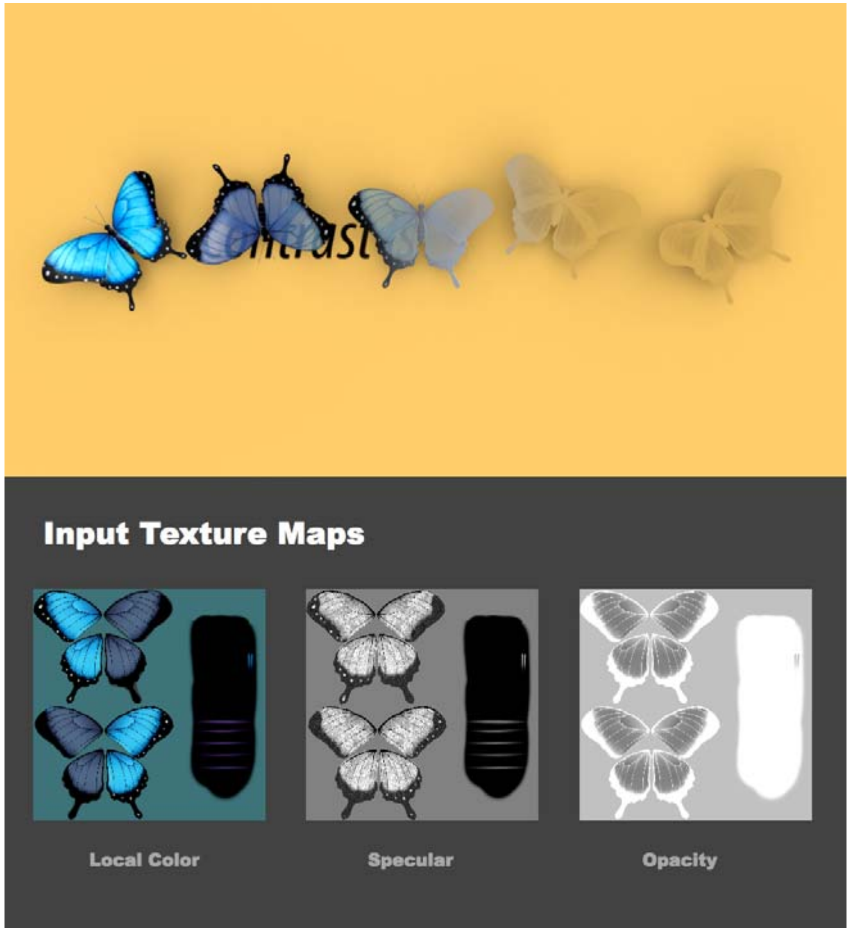

Fig.12. Texture map inputs used for the butterfly model.

individually control the hue, saturation, and value component. Each boundary can be blended by a smoothstep function.

Shadows are calculated using a modified occlusion function with a narrow cone angle. A locator placed in the Maya scene environment controls the direction of the shadows by calculating a vector from the shading point to the locator. This is a very unorthodox method for creating shadows, and inherently can produce undesired results.

Although this approach is not ideal for a normal cg production pipeline it was ideal for the purposes of this research. This approach for calculating shadows allows this color information to be filtered through the shader, thus allowing its value to be modified by distance like the other surface properties modulated in this system.

CtR is a rim light contribution. This layer of detail helps separate objects of emphasis from the background. By adding or removing this value greatly changes the relative contrast of objects being affected by this value.

CtL is calculated by a function, which initially was designed to determine the light contribution that occurred in each volume. The standard light components, ambient, diffuse, and specular were all taken into account. The resulting images that were produced when all light components were introduced were less effective in creating emphasis. This added layer of information had the tendency to overwhelm the base color layer from the Ctex value. Because of this I decided to limit this functions purpose to calculating the specular contribution that occurs for a shading point. Specular light is essential in perception. It tells us how rough or smooth a surface is and thus provides another important level of visual information that can easily be modified through this shader.

As a way of adding another layer of detail a faked subsurface scattering function was created. It uses a texture map as the color input. Maps need to be painted carefully to achieve the desired effect. This function is a modified version of the rim function. The only difference is that it takes a texture map as the color input and it is non-directional. Once again logistics prevented me from implementing a real subsurface scattering function. One, the version of Renderman that I was using throughout my research did not proved such a function, and two, like displacement the calculation time required would have been prohibitive and would have forced me to exclude the calculations.

There is also a standard occlusion function that calculates *Occ*. This value was mainly introduced to improve shaping in forms that was lost due to the lack of lighting information that resulted when the light contribution function was reduced to only have a specular component. There is an opacity function, but it is not regulated by distance like all the other functions in the shader.

All five volumes have a nearly identical set of six variables. Only the fifth volume, S5, is handled slightly differently than the others. S1, S2, S3, and S4 each have a variable set composed of a color shift variable, a hue variable, a saturation variable, a value variable, a shadow amount variable, and a detail amount variable. These variables give the user the control to emphasize or deemphasize objects by minimizing or maximizing the effect of the shader component controlled by the variable. With the exception of color shift and hue all of the variables take float inputs from zero to one. Color shift and hue take color inputs. The volume S5 does not have any of the color inputs used by the other volumes. It has a set of four variables, shadow amount and detail amount which exist in all volumes and two other variables unique to this volume, silhouette which is a color input that replaces whatever color information is assigned to the object and fade out which is used to transition the silhouette color to whatever background color has been set for the scene. It instead uses a variable called silhouette, which is simply a color input that is assigned to all objects within this volume with the idea that objects in this space are reduced nearly to a silhouette. The user can add detail to objects in this volume by increasing the detail amount or shadow amount. It also has the variables shadow amount and detail amount, and another unique variable called fade out.

Detail Amount is the most abstracted of the variables. Detail amount takes a float input with valid values ranging from zero to one. This variable is a scale factor that controls the contribution amount of four functions, which contribute to the final color for a shading point. These functions calculate the specular light contribution, fake rim light contribution, fake subsurface scattering contribution, and occlusion contribution to the final color of a shading point. This variable has been abstracted from the user to control a large set of functions for two reasons. The first reason is to minimize the number of variables exposed to the user, and secondly, because the functions controlled by this variable each have a global setting that can be adjusted.

By it self the shader and AIL do not automatically insure that interest will be controlled within an image output from this system. The area of interest shader is dependent on the user to establish the appropriate settings to best create a selective area of emphasis within a scene. The only automation designed in this system comes from the shader knowing when to apply the appropriate set of values to a given shading point based on its distance from the AIP. Once values are assigned by the user to the volume-specific variables iterations can be made relatively quickly on an image to find the best settings for selectively establishing emphasis.

CHAPTER IV

EVALUATION

The goal of this research is to demonstrate that careful modulation of detail can direct viewer attention within an image or animation eliminating the need to rely on photographic techniques like depth of field. Because of this goal, the evaluation of this work is predominantly focused on the images produced by the interest-control system as opposed to an evaluation of the system itself.

The criteria used to evaluate the animations produced for this work has two components. First, does the modulation of detail achieve a clear point of emphasis in the composition? And second, does the manner in which surface properties transition from their most detailed state to least detailed state integrate itself aesthetically within the composition? The first question assesses the degree to which targeted object(s) contrast from the rest of the scene. As is stated in the Background section, emphasis can only be achieved when distinct differences between two compared effects brings out one element over another. The second question looks at the subjective visual quality of using the selected removal of detail to establish emphasis in an image as opposed to using a traditional, photographic technique like depth of field. The main concern is that this method may prove distracting to viewers if an object shifts from different levels of detail during an animation.

The following section is an informal discussion and evaluation of three test animations produced for this research using the interest-control system discussed in the methodology section of this paper. These test animations were performed after several studies had been done to explore the final implementation of the interest-control system, and reflect the final state of the system used in this research.

A. Test 1: Contrast Is Emphasis

This test was designed to evaluate the effect of having objects move into the space of a stationary Area of Interest Locator (AIL), as well as to assess the effect of translating AIL over several stationary objects. Both tasks test the effectiveness of the interest-control system at establishing a selected area of emphasis and the aesthetic quality of having objects shift between different levels of detail as emphasis shifts from one side of a composition to the other.

This test uses a stationary camera. All the geometry in the scene are linked to one AIL object. The significance of this statement is that objects must be assigned to an AIL object in order to be affected by the interest-control system. Objects can only be affected by one AIL, but multiple AIL objects can be used in the same scene if desired by the user as was used for Test2. Also for this test the area of interest surface shader is set so that the S1 volume of AIL has the highest level of detail. Each subsequent volume loses visual information and falls to silhouette in the S5 volume.

The shot begins with a butterfly entering the frame from screen right and landing screen left upon a ground plane with the words “Contrast is” printed across the surface. AIL is located in the scene so that the butterfly flies into the S1 volume, thus placing the

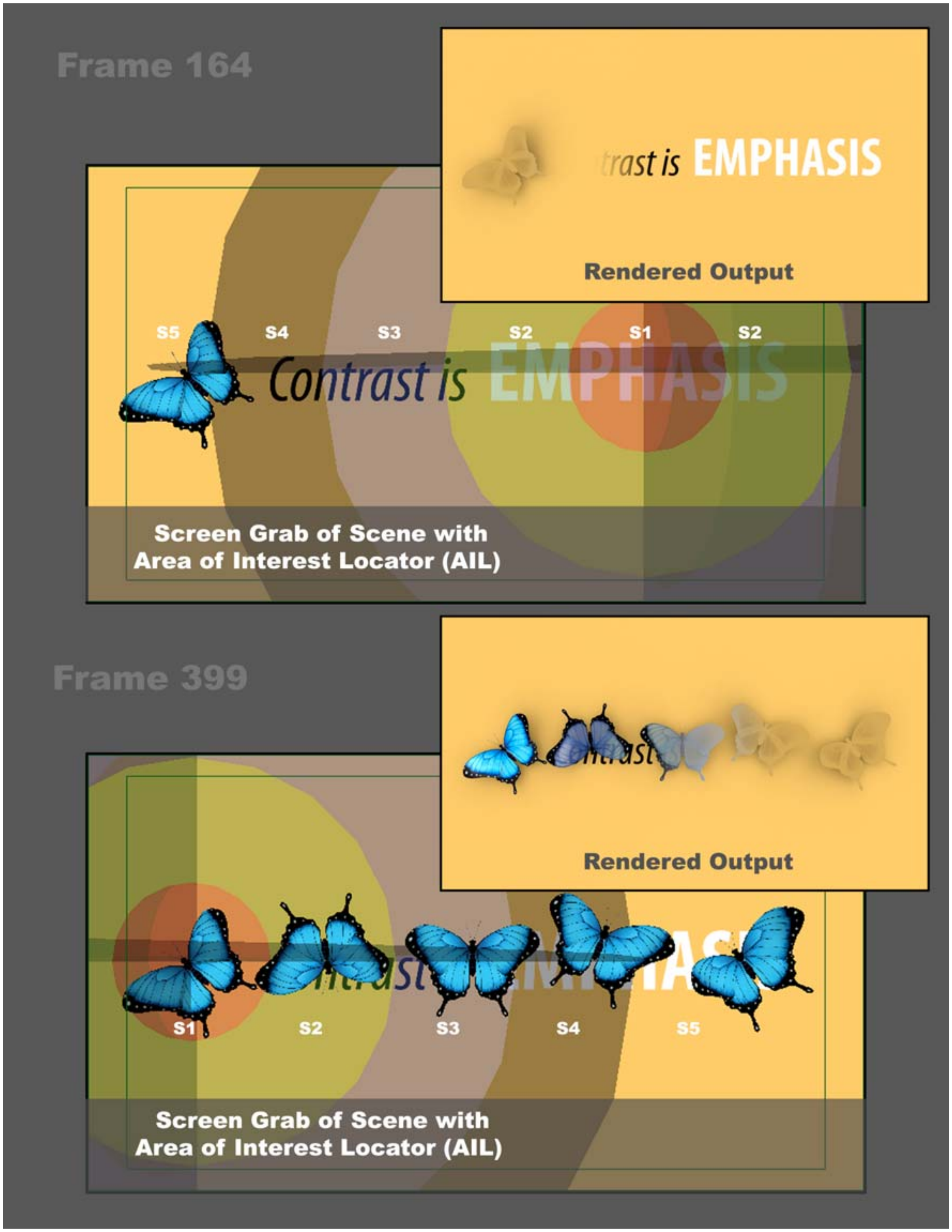

Fig. 13. Comparison of rendered images to screen grabs.

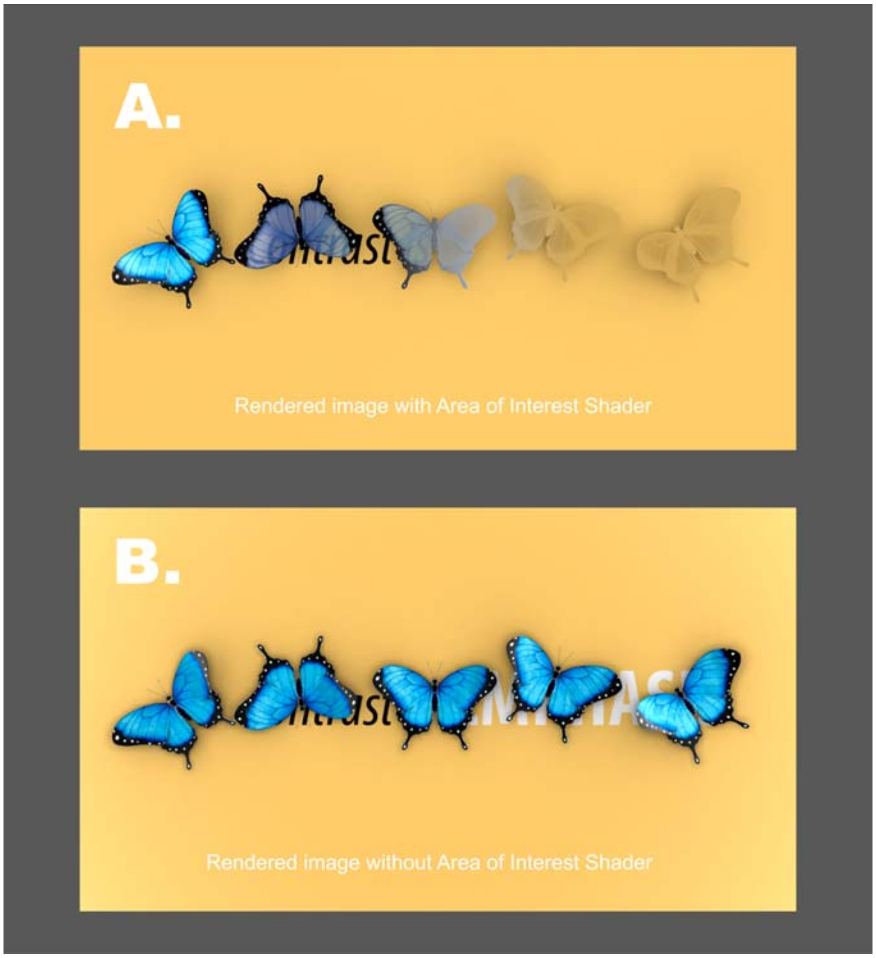

Fig. 14. A. Rendered output using the interest-control system to modulate detail. B. Same image using normal rendering methods.

emphasis of the composition screen left. The AIL object is then translated screen right revealing the word “EMPHASIS”. The butterfly is now located in volume S5, the lowest state of complexity, as is shown above in frame 164 of Fig. 13. Four more butterflies land on the ground plane. As each butterfly enters the frame and lands on the ground they pass through different volumes. With all of the butterflies on the ground plane AIL is once again translated back to screen left, so that the emphasis shifts across each butterfly until it reaches the last butterfly as shown in frame 399, Fig. 14, A.

This animation test clearly demonstrates the potential of using detail to control viewer interest in an image. Fig. 14, above, shows a comparison of frame 399 taken from the animation sequence. Image A shows the resulting image using the interest-control system to modulate detail, and image B shows the same frame rendered without modulating detail. Image A clearly places emphasis on the butterfly that is most screen left. Every aspect of its surface is used to create contrast between itself and the surrounding environment. The other butterflies simplify and essentially blend into the background the further you move screen right. While image B gives the viewer no focal point. All of the objects in the scene hold the same amount of visual weight.

B. Test 2: Functional Rack Focus

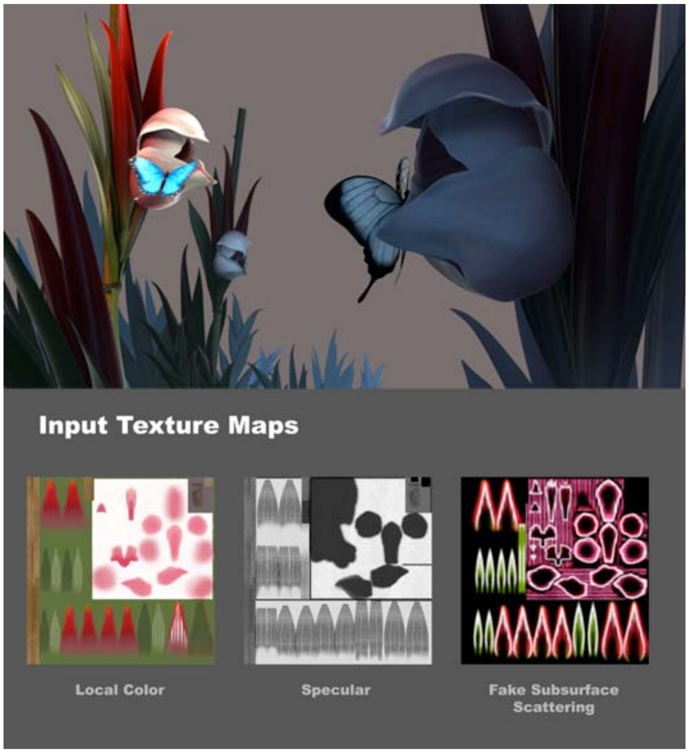

Fig. 15. Input texture maps used for the flower model.

The purpose of this sequence was to attempt to recreate the functionality of a traditional rack focus. A rack focus is a technique used in traditional cinematography where the attention of a viewer is shifted by changing the focus of the lens from a subject in the foreground to a subject in the background, or vice versa. This task assesses the effectiveness of the interest-control system at establishing a selected area of emphasis and shifting it to another part of the composition. The aesthetic quality of the image as emphasis shifts in the composition will also be appraised.

This sequence used a held camera. Two AIL were needed for the sequence. One was attached to the background and middle ground geometry and the other was attached to the foreground geometry. This setup allows the user to control the two areas of the composition independently of the other. Once again the area of interest shader is set so that the S1 volume has the highest level of detail with each subsequent volume decreasing in detail. Another aspect of this sequence that should be noted is that only two original models are used for this shot, the butterfly and flower. All of the background foliage uses the same model and textures that are used for the flowers. To avoid repetition and to achieve a greater a sense of complexity in the scene, the flower heads and stems are removed from the background foliage. Fig. 15 shows the input texture maps used for the model of the flower.

The sequence begins with a butterfly entering the frame screen left and landing upon a flower in the middle ground of the composition. The flower is located within the S1 and S2 volumes of the first AIL. The butterfly enters the S1 volume when it lands upon the flower. The emphasis in the image as frame 036 in Fig. 16 shows is on the flower and butterfly in the middle ground, both the background and foreground elements are nearly reduced to silhouettes. The focus is then shifted to the foreground flower.

Fig. 16. Still images from Test 2 animation.

The first AIL is animated so that the radius of S1 and S2 is set to zero as the second AIL attached to the foreground flower is animated so that the volume of S1 encompasses the foreground flower. The middle ground flower is now reduced in detail placing the emphasis of the composition on the foreground flower as can be seen in frame 199 of the previous figure.

This test demonstrates that it is possible to shift the emphasis in the image in a manner that mimics the functionality of a rack focus. The success of the aesthetic quality in which this shift occurs is a bit more questionable. The image seems to dissolve as the shift occurs. Fig. 16, above, shows a few key frames from the sequence that show this “dissolving”.

C. Test 3: Moving Camera through a Complex Space

The purpose of this test was to evaluate the interest-control system with a camera moving through a complex environment. The most challenging aspect of this test deals with the approach used to blend the five different levels of detail. This once again is really an appraisal of the aesthetic value of this solution. Is it distracting? Does it distract from the primary goal of this work, which is to lead the audience's eye to a user-defined region of the composition?

In this test the camera moves through a forest scene following the flight path of a butterfly. Throughout the animation there is one AIL object constrained and attached to the butterfly, and another AIL object attached to the forest environment. The AIL object attached to the butterfly is set so that the butterfly is always in full detail. The AIL object attached to the set insures that the highest detail occurs in the foreground of the set relative to the camera as the background shifts into silhouette, but as can be observed in Fig. 17, above, your eye is also drawn to the background because of the value contrast of the background and foreground. This was not the intended affect because the

Fig. 17. Still frame from Test 3.

background of the set now competes visually with the butterfly. This occurred because of the properties which I set for the shader associated with the trees. I increased the value too much for the S5 seeing that although it loses all texture information and becomes just a flat color its value contrast ends up drawing the attention of the viewer. This example illustrates that the Interest-control System developed for this research is completely dependent on the user to determine appropriate settings for the shader to function effectively in its purpose of directing viewer attention.

In the end, the resulting images from the interest-control system did increase the relative salience of user-targeted scene elements when appropriate settings were used for the Area of Interest Shader. The targeted objects became salient relative to their environment. However, the aesthetic quality in which objects shift from one state of detail to another was not as successful.

CHAPTER V

CONCLUSIONS AND FUTURE WORK

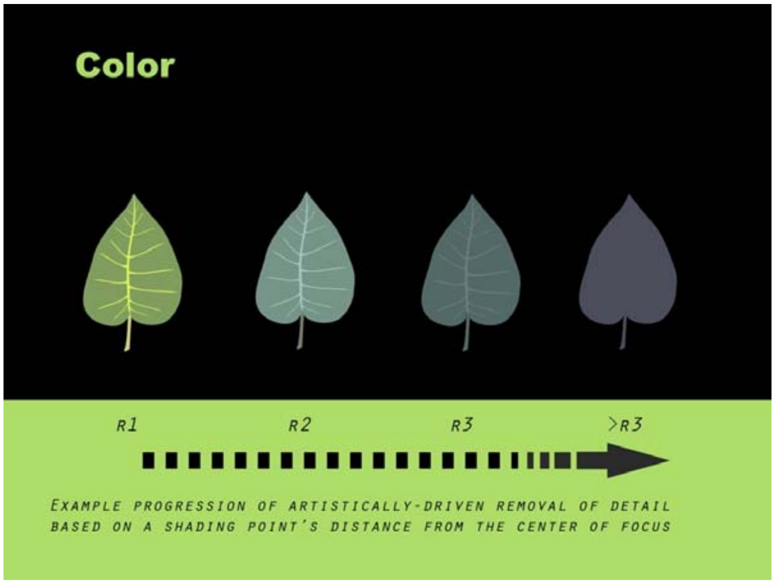

Fig. 18. Study image created to understand how to modulate local color based on distance from an arbitrary origin.

The following is a discussion of the ideas and paths that were taken and abandoned during this work, as well as, a general reflection of this thesis research as a whole and future areas of development to which this work can be applied.

A. Conclusions

There were two major goals for this work. One, to cogently present the argument that the medium of computer animation should not rely only on photoreal techniques to direct viewer interest in an image or animation. And second, to present a viable, non-photorealistic solution to this problem that would control viewer interest by selectively removing detail from secondary and tertiary image elements as a means of reducing superfluous visual information from parts of an image which did not directly affect the depictive meaning of that image. This second goal required the development of an interest-control system implemented within a modeling and shading environment that could produce such images and animations.

The design of this system evolved throughout the term of this research. The final implementation of the Interest-control System essentially used just one variable, local surface color, as the only variable being modulated to direct viewer interest. At the inception of this research this was not so. Three variables, local surface color, light, specifically, the surface reaction to light, and texture defined as the three-dimensional displacement of a surface, were going to be modulated to determine the amount of detail exposed for the surface of a given object. However, in the actual implementation of the Interest-control System the modulation of local color became the predominant variable used for establishing the different levels of detail within a scene. Fig. 18 shows an example study illustration of how this idea could be used to reduce local color information. A specular contribution was calculated to help determine the final color output from the Area of Interest Shader, as is shown in C., Fig. 19, but that was the only light calculation that made its way into the Interest-control System. These test images lead me to significantly reduce the impact of light on the final color calculated by the Area of Interest Shader. The final implementation of the Interest-control system only

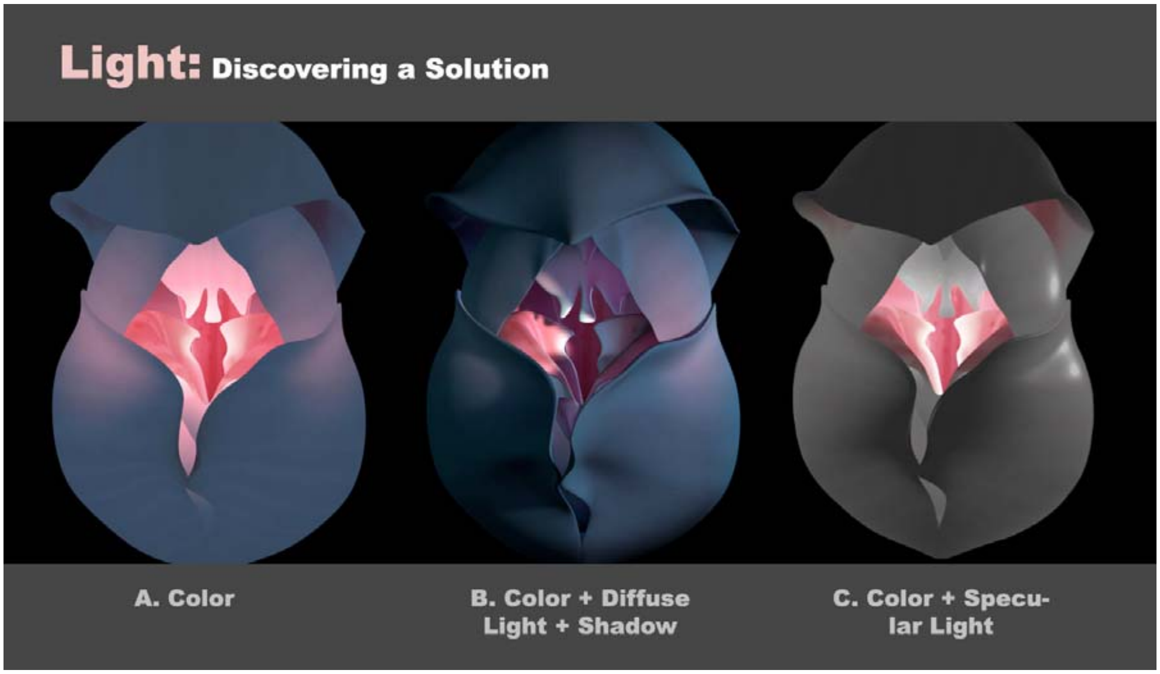

Fig. 19. Test renders used to explore how light would factor into final color calculations.

takes into account the specular light contribution when determining final color. Several factors contributed to this divergence in implementation. One, it is difficult to conceptually separate color from light when designing rules to modulate these two properties. In reality color cannot be expressed without the presence of light. Although this is not necessarily true in the world of computer graphics it became apparent that there was too much overlap between these two variables. Secondly, texture, or more accurately displacement, became too expensive to use as a component for modulating surface detail. Displacement calculations took an exorbitant amount of time, making testing of this component nearly impossible for complicated scenes. Since my main goal for this thesis work was to present a novel concept for controlling viewer interest, displacement was reluctantly eliminated from the final implementation of the Interest-control System. Another separate issue that was encountered with texture deals with the semantics of the word texture as applied in computer graphics versus the field of painting or illustration. At times I would think of texture as the three-dimensional surface quality of an object, ie., soft, bumpy, rough, and at other times I was really referring to repeated pattern versus areas of large flat color. And, in that sense once again texture is really talking about color. So in the end color became almost exclusively the variable that was modulated to selectively create emphasis in an image or animation. The above image, Fig. 19, and Fig. 20, on the following page, convinced me of this approach. By layering all extra visual information on top of my color, I felt like I was getting the most effective results with the most amount of control. And, I would not add a feature if it was not possible to add as input into the area of interest shader. For this reason I did not add shadows into my equation until much later, when I came up with an alternative method for calculating shadows by using an occlusion function with a narrow cone angle that would base its calculations from the position of a Maya locator. This effectively acted as a single directional light source in my scene that could be modulated through my shader since it used a Renderman occlusion function to generate the shadows.

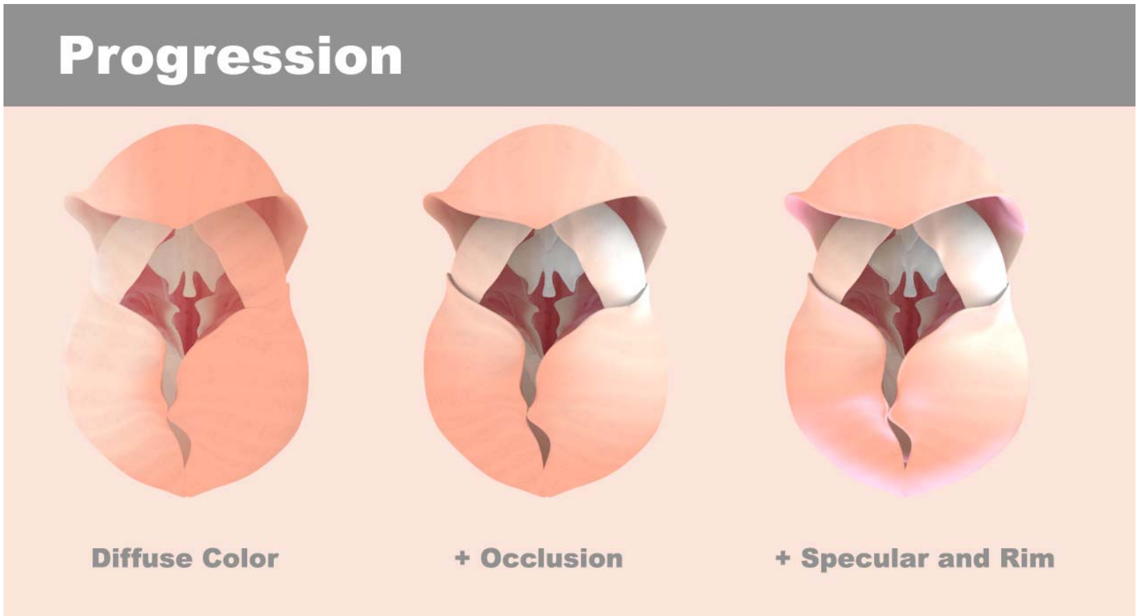

Fig. 20. Renders showing the layering of the various components used to calculate final color.

Another tangential result of this work that came about during the development of the Area of Interest Shader was the drastic reduction in lighting setup complexity for scenes. In all of my test animations each shot used only one Maya spot light to determine the specular contribution in each scene. This allows me to drive the entire color scheme of a scene almost exclusively through my shader and reduces the amount of work necessary to create a visually interesting image which at the same time has a clear area of interest. This system essentially drastically reduces the role of light in any production. Initially, I intended to control light contributions of diffuse, specular, ambient and other components based on distance as was done with my color manipulation. My early results proved visually weak because they would overpower the work I had done with my color pass as is shown in Fig.19, B. Another problem is that oftentimes my color pass would play the role of light. I have steered away from using any lights in my scene, with the exception of generating specular highlights. All other light is faked in the shader. Part of the reasoning behind this is to reduce the necessity to set up complex lighting schemes for a given scene and allow the shader to primarily drive all coloration and semblances of light.

I also moved away from my original idea of painting four unique texture maps that would correspond to each of the five spherical volumes. The major reason for this change of design was efficiency and usability of system. The notion of having unique textures, although potentially interesting from an artistic point of view, when actually implemented is quite cumbersome. It requires an inordinate amount of work by an artist to design unique maps for color, displacement, specularity, etc. I simplified the design by only allowing inputs for one unique map for each surface property. These texture maps are then manipulated through a series of controls designed to allow the artist to control interest in an image. I do think there is the possibility of adding a second local color map for added value to the image without much more effort by the artist.

Narrative filmmaking is an immensely complex task, and in the world of computer animation, where every pixel of every frame is meticulously crafted, it is essential to direct audience attention to the most important portion of the frame. The presented work is a first step toward answering this visual challenge, but far more exploration is warranted within the realm of perception-based shading and rendering.

B. Future Work

Fig. 21. Early illustration that shows how form could be used for abstraction.

It is never explicitly stated throughout the discussion in this paper, but the true motivation for this entire body of work comes from a sincere desire to explore “novel/interesting” aesthetic approaches for the medium of computer animation. As a result of this desire an idea occurred to me that I had originally played with sub-consciously in some drawings I had created; what if objects abstracted as they moved into the distance. This simple idea was the first seed of this research and evolved into what is written in these pages today. There is so much more I would like to explore within the realm of this research. But for know this will suffice. The following paragraphs represent ideas that would be worthwhile augmentations of the research I have presented thus far.

The overall aesthetic goal that was envisioned at the outset of this research was far more ambitious than what was eventually accomplished. The scope of the work was reduced to maintain the feasibility of the final implementation, but the ideas that were initially formulated remain valid for future endeavors into related research.

The use of form or geometry as a tool for abstraction of complex visual information was explored in many of the early illustrations created as a part of this research. Unfortunately, this idea was abandoned due to the complexity involved in its actual implementation. But the idea to use form remains a very powerful tool for directing attention. In these illustrations, form acted as a visual complement to surface detail reduction. As objects recede into the background, as in Fig. 21, the form of objects simplify and surface information becomes reduced. This differs from the final implementation of the interest-control system, which relies almost exclusively on the modulation of local surface color as the variable modulated to selectively emphasize a composition. This idea has been explored before in computer graphics, but it has never been motivated as a means to produce aesthetically novel images as is suggested here and in Fig. 21. Kim and Varshney's research, *Persuading Visual Attention through Geometry*, aimed simply to demonstrate that geometry can be modified to achieve saliency [Kim and Varshney, 2008]. However, what I am suggesting is the potential of abstracting geometry to achieve artistically compelling images that also control viewer interest.

Fig. 22. Example of color reversal in shadows. Production Design by Frederick Gardner; Art Direction by Scott Fassett.

Using shadows as an additional way to filter shading information can provide another added level of complexity and interest to an image. Objects located in shadow could have detail modulated differently than objects located in light. Fig. 22 illustrates the use of color reversal in shadowed areas of the image. The value relationship between the line work and the mass color of objects reverses in areas of the composition cast in shadow. This can be observed on the telephone pole and the grout of the background wall where in shadow the line work used to describe the texture of the pole is lighter in value than the mass color, but when in light the value relationship reverses so that the line work is now darker in value than the mass color of the pole. While this value change does not necessarily lend itself to the major theme of this research it does introduce the idea that areas cast in shadow can be handled differently than areas in light. This concept potentially adds another level of complexity and sophistication to the final image. Areas cast in shadow could automatically have less detail by using a constant color and excluding other visual information such as displacement and certain light components.

Movement provides another powerful tool to control interest in time-based work. The idea to use movement to capture attention revealed itself during the process of this research. Rudolph Arnheim in his book, *Art and Visual Perception,* states succinctly, “motion is the strongest visual appeal to attention”. This statement seems validated by the strong and automatic response to motion that is evidenced in animal and man. In terms of survival, a change in one's environment often requires reaction. Vision has developed as an instrument of survival, as such, it is keyed to the detection of motion [Arnheim, 1974, p. 372]. This notion of using movement to capture attention can also be regulated in the same fashion that detail was modulated in work performed for this research. Movement could potentially be amplified or subdued based on the distance of the object from an arbitrary origin, thus, focusing attention to the object that displays greatest motion. Of course, this idea would not be appropriate for character animation. It is meant more for background or ambient animation, such as, the rustling leaves of trees, or flocking birds off in the distance of a scenic landscape.

Each of these ideas for future work seeks to uncover an alternative methodology for handling the medium of computer animation that moves away from photorealism into a realm that looks to painting and illustration, visual perception, and fields outside of computer graphics for inspiration. In a medium where the artist has near infinite control of the final image produced, is it necessary to create facsimiles of reality? I hope that this research provokes further exploration into non-photorealistic interpretations of our world through this relatively new and powerful medium, computer animation.

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