Leonardo and Lord of the Rings: Ray Tracing in the age of Renaissance

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With the arrival of the Renaissance era (apx. 1400's-1500's), came a milestone that would forever change the techniques by which the artists of that era illustrated and depicted the world around them. Technology would now play a major role in the artistic expression of a realistic and accurate world. With the invention and refinement of scientific measurement devices, artists such as Michelangelo, Cennini and Leonardo da Vinci could validate their own perception with accurate dimensions and comparisons. Leonardo da Vinci was the master of establishing rules and techniques whereby scientific interpretation supported the Renaissance methodology. His guidelines led to more accurate representations of the world, and also allowed the artist to alter reality with the same precision and authority.

Computer graphics, as a modern addition to the traditional brush and canvas, use mathematics and programming to create, replicate and even distort our imagery much like the techniques of da Vinci helped in defining and depicting the Renaissance environment. But as they are two different eras with two distinct sets of tools, I find significant similarities and commonalties between the scientific principles and techniques used by da Vinci and the algorithms available to the computer artist. By examining the principles and techniques of painting developed by Leonardo da Vinci, and comparing them to the functions of popular computer graphics applications, I will demonstrate a strong correlation with the techniques of Renaissance art and modern computer graphics. Specifically, three concepts that serve to define our visual representation of the world; linear perspective, aerial perspective and color relationships. Techniques well defined by Leonardo da Vinci, and certainly applicable to modern computer graphic imagery, using the functionality of Maya (Alias-Wavefront) as the reference.

Linear Perspective

Renaissance theorists were some of the first to develop concepts that closely match the physiology of perception. Leon Batista Alberti (1435) described in his treatise on painting *De Pictura*, the concepts of points and lines forming geometric shapes (elementa). His approach to mathematical applications in painting corresponds with early analysis regarding linear perspective. In Book II of *De Pictura*, Alberti developed these concepts even further, approaching painting as a hierarchy and structure with these aspects of visual representation, such as in *Lunette of the Medici Villa of Poggio a Caiano* (Figure 1).

It was during the Renaissance era that science entered the world of painting. In *Paragone* (1500-5), Leonardo presented painting as a "mathematical science, based on both geometry and experience" (Zwijnenberg, 1999). He described his criteria as points, lines, surfaces and shapes; in much the same way as modern theorists describe the icons of perception. As a tool for exploring visual perception, computer graphics programs that reflect the laws and characteristics of optics and natural occurrences are becoming increasing more important.

In Maya, a popular 3D computer graphics program, PERSPECTIVE cameras have similar attributes to physical film cameras. They represent the effect of linear perspective. When an object is near the camera it appears larger than when it is far from the camera. Size relationships are independent of camera position, but globally change based on distance from the camera. Moving the camera creates a change in perspective, much like an artist changing viewpoint in a painting. The tool within computer graphics that most defies reality is the orthographic camera. It does not represent perspective, since objects appear to be the same size no matter how near or far from the camera.

Camera controls based in Maya, such as TUMBLE, DOLLY, ROLL and DEPTH OF FIELD provide all of the functionality necessary to create the same execution of linear perspective that a Renaissance artist painted on canvas. This is in its simplest mathematical form, and is based on the measurements and science of Leonardo da Vinci as well as the tools of modern technology. To deviate and distort that perspective beyond the natural variables of viewpoint, the painter would turn to the treatment of objects within that perspective, as in *The Adoration of the Magi* (Figure 2). The computer artist can selectively adjust this range of clarity in Maya with the FOCUS DISTANCE and F-STOP variables, setting the distance from camera and range from that depth that objects will be sharp. The Renaissance artist, using the same techniques for portraying depth and focus, used sharpness and definition in painting objects to selectively define distance. This was often more of a subjective decision for the Renaissance artist, as the physical laws of optics were not widely understood.

Image relationships were based on assumptions, beliefs or the "theme" of the image. When we make these distance judgments based on the artist's depiction, what I term **"contextual distance":** We are basing our perception on the relationships of the image, not on physical parameters.

Aerial Perspective

Another characteristic that I wish to consider is aerial perspective, commonly described as a hue shift based on the distance and medium. In most instances, the medium is the earth's atmosphere, hence the term "aerial", however it could also include water, fog, smoke, dust or any type of substance that falls between the observer and the subject, influencing the reflecting light. In nature, these particles affect the appearance of the atmosphere itself and the appearance of objects within the environment.

There is a basis of scientific measurement to aerial perspective much as there is in linear. With an identical color placed at various distances and heights, its brightness will be in proportion to the distances of each location from the observer. A mathematical scale by which this diminution occurs, both horizontally and vertically. For the latter, half an interval of distance below an object is equal to one interval of distance above. This is not a modern measurement using sophisticated devices, but a calculation of Leonardo da Vinci made in the early 1500's. To this date, it is still considered an accurate observation.

In *The Virgin and Child with St. Anne* (Figure 3), Leonardo da Vinci used aerial perspective to effectively establish the distance between subject and horizon. It demonstrates both horizontal and vertical use of color diminution and variation of hue intensity to emulate the effect of atmosphere. Emulating his philosophy regarding the depiction of nature, the inaccuracies of

linear perspective, and his choice of aerial perspective as a more effect methodology. "The first intention of the painter is to make a flat surface, display a body as if modeled and separated from this plane . . . this accomplishment . . . arises from light and shade" (Kemp, 1989).

With CGI, two main variables, atmosphere and environmental fog, often control the concept of aerial perspective. In much the same way as da Vinci described and measured the effects of density in both horizontal and vertical atmosphere, computer graphics uses the same mathematical algorithms. Various controls within Maya allow the artist to apply and adjust the influences of aerial perspective. SKY BRIGHTNESS is a method of applying a scaling factor to the overall sky color. This is level of luminance creates a global representation of distance for the scene. With AIR and DUST DENSITY, the amount of atmosphere is defined artistically and mathematically. DUST DENSITY will control the amount in the air, which can give a more scattered influence of light, based on the quantity of particles. One of the most interesting correlation of Renaissance theory and modern applications is found in the methodology of atmospheric layering. SKY THICKNESS and SKY RADIUS control the thickness and radius of the atmosphere, using the same concepts that da Vinci describes in his mathematical formula for atmospheric density (Figure 4). The outer radius of the sky becomes a multiple of the thickness. As a combination, radius and thickness determine the amount of atmosphere, which creates an aesthetic judgement of how much density affects the scene, including light and color. The degree of angle, based on the viewpoint, is also affected by these two variables, for as the observer looks vertically, the thickness and layers decrease. Both da Vinci's diagram and the computer graphic algorithm (Figure 5) illustrate this concept. In fact, the degree of similarity in technique given the years of difference in application is testament to the application of da Vinci's theory in computer graphics today.

VERTICAL RANGE supplies the controls to make variations in the vertical range, consistent with the observations of da Vinci's distance and density, similar to how SKY THICKNESS and SKY RADIUS control the upward depth of the atmosphere. With DEPTH RANGE, the environment fog is assigned a specific region between two distances from the camera. In this way, placement can occur within a particular depth limit or range. For artists of both eras, the ability exists to control the location of smoke or other man-made atmospheric elements within the image of the environment.

Color Reflection in Computer Graphics Imagery (CGI)

The third set of characteristics that da Vinci explored were the effects of objects upon each other, particularly in reflected and refracted color. According to Leonardo's theory, no body is ever shown wholly in its natural color. This is substantiated by two scientific observations. First is related to atmosphere, in that there is intervention by the medium between the object and the eye, as discussed in aerial perspective. Unless you are extremely close to the object, it will tend to be influenced by that which falls in-between, like the glass in a windowpane. The second observation involves an object illuminated by a direct or reflected light that possesses and transmits its own color qualities. In *The Virgin and Child with St. Anne* (Figure 3), da Vinci affected each of the women's' clothing so that it reflected the color of the other where it came into close proximity. The same is true for the blue of the Virgin's shawl and her arm covering. Subtle, but distinguishable. As well, shadows are also influenced by alternative light sources, and will tend towards the shade of the alternative source of illumination. Renaissance artists, with da Vinci being the most notable, studied and documented the effect of color reflectance as a source and influence on the surrounding objects. While probably more aesthetic than scientific in their calculations, the result was as authentic as today's methodology.

In computer graphics, this natural effect has several associated definitions. The most common technique for shadows is referred to as Ray Tracing. With ray tracing, the pathway is quantifiable and based on the shadows that are cast by the light. Several variables within Maya are available to the artist. RAY DEPTH LIMIT quantifies the maximum number of times a light ray can be reflected and still produce a shadow. This is especially useful when shadows are cast by transparent objects, such as colored glass. COLOR and EDGE SOFTNESS control the aesthetic variables related to the intensity of the effect an object has on a shadow, although not necessarily its own, while ILLUMINATED FOG SHADOW GRAININESS adds a level of grain to the shadow based on the quantity of particles in the atmosphere. Renaissance painters also employed aesthetics to blend the colors and sharpness of light and shadow to achieve similar results.

In Maya, the REFRACTIVE INDEX controls the angle of redirect that light rays bend when passing through a transparent object, and are mathematically based on the type of surface, such as glass, air or water. The REFRACTION LIMIT defines a limit for the occurrences of a refracted light ray. For example, a typical smooth drinking glass placed in front of a mirror will refract a light beam nine times, which includes the four sides of the glass (inside and out), the mirror, and back again to the observer. Each time, the light influences and refracts based on nearby objects.

Reflection is also a controllable variable within Maya. REFLECTIONS defines the maximum number of times that a light ray is reflected. This value will influence all material values, such as the specular and hue of the surface. In more simplistic terms, it adjusts the quantity of reflection within a scene in combination with the intensity and color of existing lights and objects. A direct correlation to da Vinci's principle of color reflectivity and the influence it has on surrounding bodies. As he describes it related to reflective value of an object, REFLECTIONS controls that particular variable and the amount of influence it has on the scene. While the formula is mathematical, based on intensity and distance, the computer artist often follows the laws of Hollywood, making a predominantly aesthetic judgement, as did the Renaissance painter.

Summary

What I have found is a high degree of correlation between the theories and practices of Renaissance artists and the tools and techniques of modern computer graphics applications as constructed in Maya. Especially when it comes to the scientific principles and measurements of Leonardo da Vinci, the computer graphics methodology is consistent in formulation and application to techniques developed in the 1400-1500's (Figure 6).

CGI applications of today seem to have an amazing correlation to the principles and scientific methodology that simulate the environmental conditions described in Renaissance paintings. As both Renaissance art and modern artists attempt to represent our common physical world, the approaches and techniques of both eras are extremely comparable. Deviation from the natural world comes when the laws are violated, as da Vinci did in distorting perspective, and modern Hollywood does by creating fireballs in space.

Figures/References

Figure 1: Lunette of the Medici Villa of Poggio a Caiano - Giusto Utens

Figure 2: Adoration of the Magi - Leonardo da Vinci

Figure 3: The Virgin and Child with St. Anne - Leonardo da Vinci

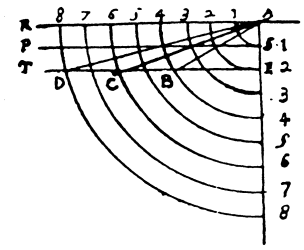

Figure 4: Color as seen through various densities of air as diagramed by Leonardo da Vinci

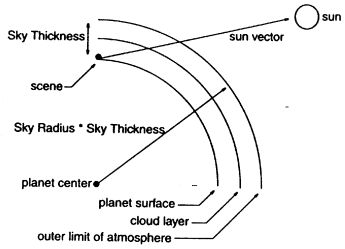

Figure 5: Computer algorithm (formula) for sky densities

A B C

Figure 6: Computer generated environment featuring aerial perspective (A), then combined with a foreground element (B) composited into environment (C).

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