NON-PHOTOREALISTIC RENDERING

Many of the modeling and rendering techniques described in previous readings attempt to create images and animations that appear realistic, that is, indistinguishable from an actual photograph or film of a live scene. Procedural modeling and texture mapping add visual details, sophisticated shading algorithms attempt to model subtle shading such as penumbras and diffuse inter-reflections, and motion capture tries to make movement appear natural. Arguably, a great deal of progress has been made in this area over the history of computer graphics, and given an arbitrary image, it can be difficult to tell if it is real or computer generated. Computer generated characters and effects are integrated into film so well that they appear as if they truly exist. As improvements are made to algorithms and processing power, this trend will continue.

There are instances, however, in which the goal of rendering is not to appear photo-realistic, but rather to express a style. For example, it may be desirable to create an image that appears as if it was painted by a particular artist with similar brush strokes, colors, and expressiveness. No one would mistake a Picasso-like image for a photograph. Or, an artist may want to create a specific effect that does not match reality, but expresses their own artistic style. Another example is using computers to create animations that model traditional hand-drawn cartoons with similar appearance and movement. The computer can be used to save thousands of hours in manually drawing and painting individual cels, while producing a similar result. Another purpose for stylistic rendering that has been proposed is for augmented reality applications. When combining computer generated images with real objects, it may be useful for the user to easily differentiate between real and artificial objects. All of these examples may incorporate some aspects of modeling, hidden surface calculation, and shading, but may do so with different approaches to create the desired effect.

This reading will present some common examples of non-photorealistic (NPR) rendering techniques.

Toon Shading

When the NPR goal is to make a rendering look as if it is a hand-drawn cartoon, it is useful to review how a traditional cartoon image is drawn, as shown in Figure 1. First the outline of the figure is drawn in black ink (usually). Silhouette edges, creases, and other edges to be emphasized are drawn. The lines may be inspired by a physical object or photograph, or may come totally from the imagination of the creator. Once inked, the image is colored, possibly by a different artist. The shade of the color may be uniform over the area which results in a flat shaded appearance, as the majority of Figure 1 demonstrates. Or, slight variations in shade can be used as a visual effect as seen in the nose and end of the tail in Figure 1. It is not hard to imagine using fill algorithms to perform the shading function on the computer, given the outlines. To mimic this cartoon effect when rendering an image, a special shading technique called a toon shader is used.
Figure 1. Hand drawn cartoon figure.

Figure 2 is an example of a toon shaded robot. In both images, a 3D model of a robot is used, and the hidden surface problem is solved for the particular viewpoint. The differences are the outline of the object and the shading at each point. In the plastic shaded image, a standard lighting model is used that creates specular and diffuse shading at each point similar to reality. Note that shadows are present which indicates a ray tracing algorithm was likely used. The silhouettes of the object transition from one surface to the next. In the toon shaded image on the right, a black ink outline surrounds the objects and primary edges in the scene, and individual pixel shades are mapped to a small number of color values giving it the flat appearance. The shadow still exists.

Figure 2. Example of toon shading of a robot.
Inking the edges of objects can be accomplished in different ways. One simple approach is to remove all polygons facing towards a viewer leaving only the rear facing ones. Make them slightly larger and fill them in with black. Then draw the front polygons on top of them leaving a black edge where a front polygon meets a backward facing polygon. Figure 3 shows this approach applied to the Utah teapot. In the first image, back facing polygons are slightly enlarged and drawn in black. In the middle image, front facing polygons are rendered in front. Finally, normally shaded values are quantized to a smaller number of shades to give the banding effect in the rightmost image.

![Figure 3. Inking edges of teapot.](image)

Another approach to inking is to first render the image and then apply some type of edge detection image processing filter to find edges. These edges can be enhanced and saved as a texture map that can be reapplied to the rendered image to add edges on top of the scene. Figure 4 shows Lena being “tooned” using this technique. The middle image is the result of applying an edge detection filter. The parameters for the filter have to be carefully chosen to produce the desired level of detail in the edges. Too sensitive of a filter will create more detailed edges than an artist would draw for a cartoon. Too insensitive of a filter will result in missing or broken lines. Post processing of the edges may be necessary to darken them, clean them up, and connect broken lines. Finally, the color level of the original image is reduced to give the flat shaded appearance, and the processed edges are layered on top of the final image to give the inked appearance. In film, a similar technique called rotoscoping applies these same techniques frame by frame.

![Figure 4. Lena: original picture, detected edges, edges added to reduced color image.](image)
Emulating Painting and Drawing

Another application for NPR is to try and replicate physical painting or drawing styles, sometimes called *painterly rendering*. Three general approaches can be used: user generated strokes, totally automated, and interactive systems. In a painting system, the user supplies the strokes, and the system makes the color and texture that appears on the screen appear as a specific painting style such as oil, water color, or pen and ink. Many systems, such as the open source Gimp, use different types of brushes to create different effects. Figure 5 shows some of the effects that can be achieved.

![Figure 5. Different brush types in Gimp: oil, water color, and pen and ink.](image)

In the totally automated approach, the final result is generated from a 3D model or an existing photograph or image. The computer generates the strokes or effects automatically based on the input image or model, and the user-supplied parameters. This can be applied to existing images, whether a photograph or computer generated image, as a post-processing filter. Applications such as Photoshop and Gimp offer a wide range of artistic filters to set styles, brush strokes, and effects, some of which are shown in Figure 6.

![Figure 6. Some artistic filters in Gimp.](image)

Different approaches have been used to achieve similar effects for 3D models as part of the rendering process. Researchers at the University of Washington investigated how pen and ink drawings are drawn and attempted to define parameters that could be specified to control the output appearance of a drawing program. Level of detail and stroke textures, density, and orientations can all be specified as part of the system. Figure 7 shows some of the results. Stippling (or pointillism) and cross-hatching are
other examples of pen and ink techniques that have been used in rendering 3D models. Figure 8 shows examples of these. Other line drawing approaches have been documented in the literature as well. Google in conjunction with Princeton offers a free NPR line drawing program called dpix that renders 3D models as stylized line drawings (http://code.google.com/p/dpix/). Figure 9 shows line drawings using the dpix software.

Figure 7. Computer generated pen and ink drawings from the University of Washington.

Figure 8. Computer generated images with stippling and cross-hatching.

Figure 9. Line drawings from 3D models using Princeton/Google’s dpix.
For simulating paint strokes, a particle-based approach was developed by Barbara Meier that places particles on the modeled surface. The particles are used to create brush strokes or effects that emulate the desired outcome. Figure 10 shows an example of this technique.

![Haystacks painting](image1)

Figure 10. Haystacks by Barbara Meier showing particle based painterly rendering.

Sometimes a drawing or painting style to be emulated is specific to a particular artist. Figure 11 shows the results of research at Brown University to create 3D models that could be rendered to appear like Dr Seuss illustrations. Other famous artist styles such as Rembrandt, Monet, and Van Gogh have been similarly been copied to create artist-emulated images.

![Dr Seuss illustration](image2)

Figure 11. Emulating Dr Seuss drawings.

The third general approach combines the first two using an existing image or model for the basic shape and color, and interacting with the user to apply the brush strokes and effects to get the desired results.
Such systems interact with the user to determine the types of strokes, such as pencil cross-hatched or oil paint brush, the orientation of the strokes, and the density of the strokes. A user has a set of tools to modify these parameters across the image in real time to fine tune the final result. The Princeton WYSIWYG NPR system is an example of using user interaction to achieve impressive images. The system draws stroke based information directly on 3D models and provides a wide variety of brush styles. It allows the user to interactively place individual marks on the image along with view dependent orientations. Figure 12 shows some sample images from the system.

Figure 12. Images created with interactive NPR system (WYSIWYG NPR) from Princeton.
LAGNIAPPE – Non-photorealistic Rendering in Feature Animations

The 37th film in the Walt Disney animated classics was Tarzan, produced in 1999 based on the classical story by Edgar Rice Burroughs. Tarzan was the most expensive Disney animated film ever produced with an estimated production cost of $150 million. The animated feature preceded Disney’s economic slump in the 2000’s, and was a huge financial success with $171,091,819 in domestic gross and $448,191,819 worldwide, outperforming its animated predecessors, Mulan and Hercules.

One of the unique aspects of Tarzan was its use of an innovative NPR system known as Deep Canvas. The system was created by the production team as a 3D painting system to create sweeping background panoramas. The system recorded brush strokes in 3D and created backgrounds that appeared as paintings. The system was so effective, it was awarded a Technical Achievement Award by the Academy of Motion Picture Arts and Sciences in 2003. The system was used in later animations, Atlantis: The Lost Empire and Treasure Planet.

Looking to continue the use of painting-like animations, Disney is producing an animation based on the story of Rapunzel due for theatrical release in 2010 under the title Tangled. Supposedly, the title and story line was changed to appeal more to boys than the original story of the imprisoned princess. Director Glen Keane states of the NPR techniques that he is trying to make the computer "bend its knee to the artist" instead of having the computer dictate the artistic style and look of the film. By making the computer become as "pliable as the pencil," Keane’s vision of a "three dimensional drawing" seems within reach, with the artist controlling the technology. It will be Disney’s 50th animated film.