AC 2007-571: COMPUTER-BASED NON-PHOTOREALISTIC RENDERING

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Computer-Based Non-Photorealistic Rendering

Abstract

Computer-Based Non-Photorealistic Rendering is a rather elaborate term for a set of 3D rendering techniques that focus on nonrealistic, or stylized, output. Specifically for this paper, the style is a type of concept sketching, done with a computer rather than markers and pens and other traditional tools. This paper will give an overview and show examples of some of the non-photorealistic rendering capabilities available with Maya. This curious set of tools and techniques gives you the ability to create the look and feel of pen, marker, and other traditional media concept drawings with the changeability, flexibility, and creative control offered by a 3D computer-based tool. The tools will also leverage your existing 3D capabilities of moveable cameras, lighting setups, animation, overnight renders, etc. to create multiple views and looks that can require significant amounts of rework for the traditional artist. The paper will compare computer-based versions of architectural drawings with professional artist renderings of the same project.

Introduction

Non-photorealistic rendering (NPR) is a way to give visual form to an idea without generating the amount of detail required in a photorealistic render. This can be required in the concept and funding stages of many projects where you need to show something but the details of the project are not yet complete. Using your existing modeling and texturing skills, you can generate this type of imagery in a 3D program.

There are an extremely flexible and not overly difficult set of tools for generating NPR renderings available in Maya. Using these tools and your existing 3D skills, you can generate a range of different looks and styles from your 3D program that can rival traditional artists' concept sketches. These are a very enjoyable set of tools to work with as they are fairly easy to learn, open to lots of different styles and workflows, and fast to render. And in comparison to other rendering techniques, they are straightforward to teach as they aren't overly dependent on other aspects of the scene (lighting, topology, UV maps, etc.).

Some of the tools were developed for 2D cartoon-style renders, but they adapt well for other uses. This paper will primarily focus on architectural renderings, but the same concepts and practices will work well in other areas of visualization.¹

Why do NPR

Most of our rendering techniques are aimed at producing photorealistic results. The use of global illumination, HDRI image-based lighting, ambient occlusion, and other advanced techniques are all aimed at increasing the realism of a 3D render. Renders that are perceived to be low quality are lacking in the aspects that we consider necessary for realistic renders: shadows, reflections, sophisticated shading, etc. So why to do a render that is specifically intended to be non-photorealistic?

Non-photorealistic renderings are commonly used today as architectural drawings done with traditional media such as watercolor, oil, and markers. These drawings can suggest detail without going through the tedious work of creating all of that detail in a modeling application. These drawings can also leave some areas empty and let the viewer's imagination take over at filling in any missing detail. This type of render can generate a feeling of being more immersed from the viewer since they are filling some of the details themselves rather than having the whole project visualized to the last detail for them.² Studies have shown that NPR renders can improve understanding and discussion between architects and clients.³ Rendering these pictures at a level that would be considered photo-realistic is tremendously difficult and time intensive and not always necessary to convey an idea. While these types of renderings aren't photorealistic, they can still be very accurate.

Photorealism is not the only standard in 3D renderings and NPR doesn't necessarily mean low-quality photorealism. The interpretation of non-photorealistic rendering that I'm using here is that the rendering is intentionally non-photorealistic. We've all seen renderings that we'd describe as not being photo real, even though that was clearly the attempt by the artist. In this paper I'm going to deal specifically with renders that intentionally non-photorealistic. The stylistic intent was to produce a render that left the viewer with the impression that it was done traditionally.

The 3D Look

Renders produced by a 3D rendering application have some traits that are hallmarks of computer involvement. Some of the most noticeable are unnaturally crisp and sharp edges, large areas of a perfectly flat color, perfectly straight lines, visibly repeated textures, uniformly soft depth-mapped shadows, and faceting. In Figure 1, the same information is presented four times, with the first three being done by hand, and the last being computer generated. All four present the same information, but the fourth image has perfectly straight lines, flat shading, and crisp edges, visually indicating that it's computer generated.

One of the most obvious traits of a computer rendering is that every texture and all shading are stuck on geometry surfaces. As you can see in Figure 1, this is completely not the case in traditional renderings. The shading is free to violate the surface and in some cases you are able to see through the surface (to the shadow). Emulating this is one of the challenges of getting away from the computer-generated look.

Figure 1

A Brief Look at the Tools

I'm going to use some of Maya's 3D tools for this paper to generate the renders. There are tools available here, and in other software as well, that are used primarily for cartoon rendering and special effects. At the simplest level, these cartoon rendering tools provide for outlines and banded fills for objects. However, these tools can also be used to generate renders that have a more traditional media feel to them. The reason to take a fresh look at using these tools for rendering in this way is that you can capitalize on the strengths of a 3D system while getting results that don't automatically make the viewer assume that there's a computer behind the image. This has the advantage over a traditional artist doing watercolor renderings, say, since you can achieve a similar look with your 3D system and quickly produce renders of a scene from different points of view. Or change the lighting to simulate a different time of day.

The first tool is the Toon Outline. This tool has fairly sophisticated controls for adding outlines to geometry. The outlines can be around the profile of the geometry only, or can include every polygonal edge, at the user's discretion. This is very much an alternative way to do a wireframe render. But there are possibilities here far beyond just a wireframe render by using some of the available attributes and textures. Line thickness, opacity, and offset from the geometry surface are some of the attributes of our outlines that can be textured. These attributes are key for distancing the render from the overly perfect quality of a computer-produced 3D render.

Figure 2

In Figure 2 you can see examples of the Toon outlines: (a) a simple contour, (b) wireframe lines, (c) contour with textured thickness, (d) thick contour with textured thickness and opacity, and (e) multiple outlines on each object (you can add as many as you want).

The second tool is the Paint Effects brushes. The Toon Outlines and the Paint Effects strokes can also be used in conjunction with each other. For instance, the Toon Outline tool can be used to specify how exactly the outline around the geometry should work (as in Figure 2), and it can be displayed by a Paint Effects stroke (as in Figure 3), such as oil paint or marker. In this way, you can have your traditional rendering tools, such as markers or colored pencils, or any number of very abstract brushes, following the contours of your 3D geometry. By texture mapping the offset (or how close the outline comes to precisely following the contours of the geometry), you can add an amount of randomness to further add an element of a hand drawn render to your 3D render. In Figure 3 you can see a selection of Paint Effects strokes as the outlines.

Figure 3

These Paint Effects tools are rather specific to Maya and are a curious blend of 2D paint brushes and 3D geometry. There is a large library of brushes that can be used to paint 2D images and it is easy to customize and make your own. These same brushes also can be used to create 3D geometry. For example, you could use a Paint Effects brush to paint a stroke on a 2D canvas that looks like oil paint, and you can use the same brush to paint a stroke on a plane, or on the surface of any geometry, in 3D. You could then animate a camera a view this oil paint stroke and view in from any angle in 3D. In Figure 4, I've painted strokes on the surface of the sphere and cube. Since these strokes have a 3D volume to them, they extend off the surface, past the Toon outline.

Figure 4

The third tool is really not a tool at all, but a creative use of shader networks to simulate how traditional artists show surface properties.

Trees

Trees are a good example of an object that does well with NPR rendering. To make a tree look photorealistic, you are probably going to need some specialty software or model libraries. Even with these extra tools, you are going to end up generating an object that has a huge amount of polygons, and is going to increase your computational time significantly, both in rendering time and slowed interaction with your scene. If you are rendering just a still image, you can get away with using flat image planes texture mapped with images of trees, but this standard work-around is transparent to the viewer once the camera starts to move.

Additionally, it's totally likely that you'll have a lot of trees in a scene. Where a completely urban scene might only have a few token ornamental trees in front of a building, a building in the suburbs could very conceivably be in a heavily treed environment. Taking that one high-polygon tree that is already a drain on system resources and multiplying it to create a wooded environment is computationally prohibitive.

Look at the trees in the portion of a traditionally rendered image shown in Figure 5. It would be difficult to count the number of trees in this traditional render as they all blend in to one another. There are a few individual trees, but primarily there are clumps of three to huge forested areas. I think it's self-evident that any sort of high polygon per tree solution here is going to be problematic in regards to having the system resources to pull it off.

Figure 5

A NPR tree is going to compare well against a photo real tree in terms of render time, complexity, polygonal lightness, and being aesthetically less distracting from your subject (assuming the subject isn't the tree itself). In this example our base polygonal tree is only 215 polygons. This is our base shape. Our additional Toon Outlines and Paint Effects strokes are based upon this shape, or painted directly on to this shape.

Figure 6

You can see the progression of the Toon line in Figure 6. The original, default, outline is very much a product of a computer. Even though it's tracing a rough outline of a type of tree, the uniform thickness and uniform density or opacity, along with the exact straightness of the lines identify the render as computer-produced. It's not that this couldn't be produced by hand, rather that it's unlikely. The crease lines, or interior wireframe lines, are added to show a bit of volume beyond just the outline. As the lines are textured for thickness, offset from the base geometry, and opacity, the impression of being hand drawn increases. The texturing for these attributes is a

simple fractal noise that can be scaled and adjusted to suit your render. The style of your outline will, in some part, determine how the viewer feels about your object.³

I've put a shader on the geometry that uses the facing angle to determine transparency. This leaves the center of the tree shape, or those areas that have normals facing the camera, transparent, while the areas whose normals face tangent to the camera are more opaque. This type of shader travels with the camera in that edges that are opaque because they face off at a tangent from the camera will be completely transparent when they face at the camera directly.

I've also added two Paint Effects strokes to the tree (Figure 7). The first stroke paints with transparent circles with a random range of hues, opacity, saturation, and size. This stroke is painted all around the surface of the geometry and exists in three dimensional space, not just a painted texture on a 2D plane. The second stroke is similar to the first in that it uses a random range of hues, opacity, saturation, and size, but it's realized as a set of thin lines rather than circles. It also is painted in three dimensions over the surface of the geometry of the tree. Both of these strokes have a brush width so that even though the strokes follow the geometry surface, the size of the brush allows the circles and thin lines to occupy space above and below the surface.

Since the shader and the brushes all take up 3D space, the tree will have volume. When a camera animates around the tree, you will be able to see the parallax from the different circles and thin lines of the brushes in addition to the shaded geometry. The Toon outline is primarily a 2D type of function in this case, but it will change as the contours change.

Figure 7

When they are all put together, you have a sample of a NPR tree that renders quickly and suggests that it was done with traditional media. All of the elements blend together in the final example so that you don't see the individual circles, too many of the individual lines, or the shader. If I duplicate this tree 100 times, randomize their size, rotate and position just a bit, I have a very convincing patch of forest that renders in less than a minute at 1K resolution. (see Figures 8 and 9).

Figure 8

Figure 9

Hybrid Renders

Renders can also be in multiple styles. In Figure 10, you can see that the central tower, our subject, is textured and rendered as realistically as possible, while everything else in the scene is abstract. It shows the tower in its environment of trees, other buildings, uneven ground, but treats those as just as reference objects so you can put the tower in the proper context. All of the environmental objects in the scene can be modeled, textured, and rendered in a fraction of the time it would take to make the whole thing photorealistic. As long as they are placed correctly, and are of the appropriate scale, they can represent existing buildings, without the necessary modeling detail and texturing work that would go into bringing them up to the same level as the central tower.

Figure 10

In this case, the buildings in the distance are just outlined with transparent lines that overextend a bit. This isn't a wireframe render, but rather a profile render. You aren't seeing any internal structure lines, just the outside contour of the geometry. The closer building at the end of the walkway has a bit more detail. In both cases, the lines are kept more uniform and regular with very little texturing to show that these are linear, man-made objects. This amount of detail is enough to suggest there are buildings of different types and sizes back there, without the necessary detail and specifics of their architecture. The trees are the same trees from the previous example, and have the heavily textured lines since they are organic, non-linear and non-man-made objects. The ground lines are only slightly textured since render tests showed that this could get very distracting if it was too abstract.

Case Study –Using NPR

The following set of images shows the results of putting these techniques into application. In Figure 11 you can see the original watercolor artist's rendering, and Figure 12 shows the 3D render of the same scene (the framing is slightly different due to HD video aspect). The rationale for redoing this image as a 3D render was so that it could be animated to provide a better idea of what the final project should look like.

All of colors in the original are muted, the shadows are not strong, lots of colors bleed into each other, and there are outlines around many of the various objects. This is clearly not designed to be a photorealistic render. It is, however, accurate. It delivers the same information as the original drawing, and it can be animated.

Figure 11

Figure 12

Below are some close up views of different areas on the picture that relate to what was discussed previously. The original watercolor is on the left, and the corresponding 3D render is on the right.

Figure 13

Figure 14

In Figure 14 above, all of the distant trees are done with 2 Paint Effects strokes. It's a modification of the existing strokes for the closer trees in that one of the strokes paints soft green circles, and the other paints short firm lines. The two together suggest a lot of distant trees with just a very small amount of geometry to hold the strokes in 3D space. The coloring is very similar to the more defined, closer trees, so they blend together.

Final Thoughts

Using these tools in this way puts you somewhere on the spectrum between being an accurate engineer, and a temperamental artist. If your artistic sensibilities are serving you well, we've seen that you can create whole forests, buildings and environments with a very minimal investment in modeling and texturing. These environments can suggest a great complexity, while being technically uncomplicated. But like any similar tool, if your artistic sensibilities are not serving you well, you can have an odd-looking mess, even if it is uncomplicated. Relative to everything else in 3D, these tools are mostly straightforward and easy to learn. The render times are also quite reasonable and give you fast feedback as you work.

There are any number of different styles that are within reach using these tools. Some can look like traditional media, and some can be more abstract and nontraditional. The variety of styles is truly unlimited.

Related Reading

F. Anastacio and M.C. Sousa and F. Samavati and J. Jorge. Modeling Plant Structures Using Concept Sketches. Proc. of the 4th International Symposium on Non-Photorealistic Animation and Rendering (NPAR), 2006.

Adrien Bousseau, Matt Kaplan, Joelle Thollot and Francois X. Sillion. Interactive watercolor rendering with temporal coherence and abstraction. The 4th International Symposium on Non-Photorealistic Animation and Rendering. 2006

Bibliography

1. Mario Costa Sousa, Amy Ashurst Gooch, Bruce Gooch. Illustrative Scientific Visualization Framework. Computational Aesthetics in Graphics, Visualization and Imaging. 2005.
2. Adam Lake, Carl Marshall, Mark Harris, Marc Blackstein. Stylized Rendering Techniques For Scalable Real-Time 3D Animation. Proceedings of the 1st international symposium on Non-photorealistic animation and rendering. 2000.
3. Nick Halper, Mara Mellin, Christoph S. Herrmann, Volker Linneweber, and Thomas Strothotte. Towards an Understanding of the Psychology of Non-Photorealistic Rendering. In Jochen Schneider, Thomas Strothotte, and Winfried Marotzki, editors, Proc. Workshop Computational Visualistics, Media Informatics and Virtual Communities (April 4-5, 2003), pages 67-78, Wiesbaden, 2003.