CSCI 4611: Programming Interactive Graphics and Games

Assignment 5: Art Render

Handed out: Thursday, 11/8

Due: Wednesday, 11/21 11:59pm

GLSL shaders make it possible for us to create some amazing lighting effects in real-time computer graphics. These range from photorealistic lighting to artistically inspired non-photorealistic rendering, as featured in games like *The Legend of Zelda: The Wind Waker* and *Team Fortress 2*. In this assignment, you will implement a GLSL shader that can produce both realistic per-pixel lighting, "toon shading" as shown above, and a variety of other effects. You will also implement another shader that adds silhouette edges (the black outlines seen above) to complete the cartoon effect.

In this assignment, you will learn:

- How to calculate realistic and artistic per-pixel lighting in real time,
- How to modify geometry on the fly to create viewpoint-dependent effects such as silhouette edges, and
- How to implement and use your own shader programs.

Requirements

We provide support code for loading several 3D model files, rotating them on the screen using the mouse, and toggling between "Phong Shading" and "Artsy Shading". You are welcome to add to the C++ support code if you like, but in this assignment, you should only need to modify the GLSL .vert and .frag shader programs. There are 3 shader mini-programs that you need to complete:

1. Complete the phong.frag fragment shader to correctly calculate per-pixel shading using the standard (Blinn-)Phong lighting model.
2. Complete the artsy.frag fragment shader to correctly calculate the per-pixel toon shading, using the "diffuseRamp.png" and "specularRamp.png" textures to control the lighting.
3. Complete the outline.vert vertex shader to draw a black outline for the silhouette edges of the mesh, when rendering in "artsy" mode.

These correspond to "C", "B", and "A" level work respectively.

Per-Pixel Phong Shading

During the next few class sessions we'll work on some shader programs that calculate ambient, diffuse, and specular lighting using per-vertex (Gouraud) shading. Your job is to extend the concepts and programs we develop in class to implement per-pixel Phong shading with the same lighting model. You should be able to build this by extending the shaders that we discuss and develop in class.

Implement a shader program that performs all the calculations to accurately calculate the Blinn-Phong lighting model for each pixel. The lighting terms must vary per-pixel based on the normal and the light position, as well as the various material properties (such as the specular exponent). You should implement this shader following the lighting model equations discussed in class. For the specular component, you may use either the half-vector or the reflection vector method, but document your choice in the README file.

Flexible Toon Shading Using Texture Images

Once you have Phong shading working (including ambient, diffuse, and specular lighting), adapt your shader as follows. Rather than setting the final color based on the intensity of light you calculate for the Blinn-Phong model, you instead use this intensity value as a lookup into a texture and use that to compute the final color. A texture used in this way is typically called a “ramp”. With this strategy, you’ll be able to get a wide range of different lighting effects just by switching the texture you use for input.

Suppose we use the dot product in the diffuse term, $\mathbf{n} \cdot \boldsymbol{\ell}$, to look up the texture, so that if its value is -1, we pick the color from the leftmost pixel in the texture; if it is 1, we pick the color from the rightmost pixel; and similarly in between. If we use standardDiffuse.png (see below), which is zero in the left half corresponding to negative $\mathbf{n} \cdot \boldsymbol{\ell}$, and increases linearly from 0 to 1 for positive $\mathbf{n} \cdot \boldsymbol{\ell}$, then we’ll get back the standard diffuse lighting term.

standardDiffuse.png (available in the data/ directory)

But, if we use toonDiffuse.png, we’ll get something that looks like a cartoon, as if an artist were shading using just 3 colors of paint.

toonDiffuse.png (available in the data/ directory)

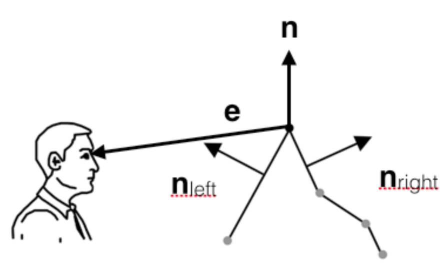
Note that this is the same type of lighting effect you see in many games, including *The Legend of Zelda: The Wind Waker* and *Team Fortress 2* (below). *Wind Waker* uses a very simplified light model. In this example, it looks like there are just 2 values used in the shading: each surface is either in bright light or dark. *Team Fortress 2* is a bit more subtle: it reduces the brightness variation in lit areas without completely flattening them out. You can read more about this in Mitchell et al.’s article “Illustrative Rendering in *Team Fortress 2*”, linked in the “Further Reading” section.

Inside your Phong shading program, you will have equations that calculate the intensity of reflected light for ambient, diffuse, and specular. For the diffuse portion, the key quantity will be $\mathbf{n} \cdot \boldsymbol{\ell}$, which should range from -1 to 1. This is the value that you want to use to lookup the lighting color to apply from the texture ramp. If the value of $\mathbf{n} \cdot \boldsymbol{\ell}$ is -1, then you want to use the color on the leftmost side of the texture, and if it is 1, then you want to use the color on the rightmost side of the texture. That means your texture coordinates for this lookup will be $(0.5(\mathbf{n} \cdot \boldsymbol{\ell}) + 0.5, 0)$, because texture coordinates only go from 0 to 1. (You could actually use any value you want for the y coordinate, since the color only varies from left to right.) After calculating these texture coordinates, you can get the color from the texture image using the GLSL built-in function texture() as discussed in class.

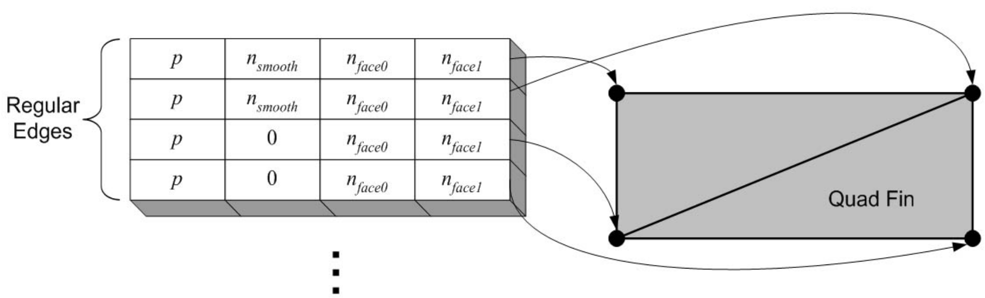
You need to add two separate texture lookups to your shader, one for the diffuse component and one for the specular component. For the specular component, we need to clamp $\mathbf{h} \cdot \mathbf{n}$ to positive values anyway before taking the exponent, so you should directly use the intensity $\max(\mathbf{h} \cdot \mathbf{n}, 0)^s$ as the texture coordinate without rescaling. Note that adding these texture lookups to your code will change the Blinn-Phong shader that you made in requirement 1.

Silhouette edges



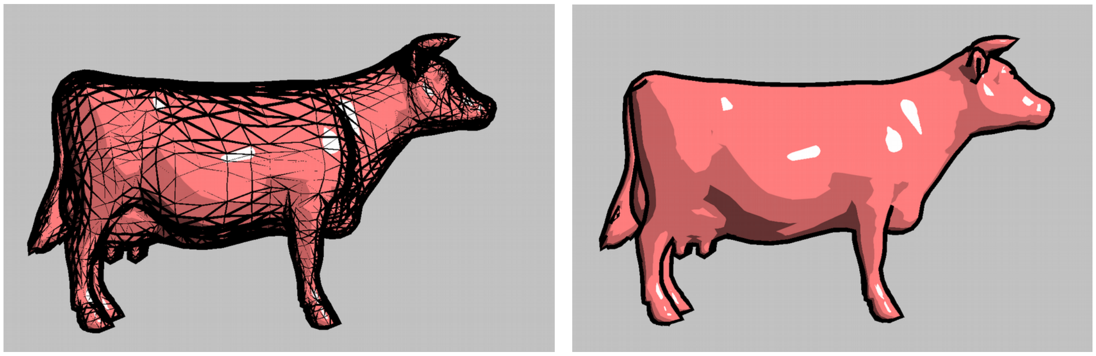
There are lots of different ways to draw silhouette contours on 3D shapes. We will use a simple method described by Card and Mitchell, linked under "Further Reading". For each edge of the triangle mesh, we check whether it lies on the silhouette, that is, on the boundary between the triangles facing towards the camera and the triangles facing away from it. If so, it is a silhouette edge, and we will draw it as a thick black line segment to create the outline of the shape.

Drawing a thick line segment takes a little bit of work in OpenGL 3 and above, since the function glLineWidth() is no longer officially supported. Instead, we will have to draw the line segment as a quadrilateral whose width is the desired thickness. Since we don't know in advance which edges will be silhouette edges and which will not, we will create a zero-width quadrilateral for *every* edge. In the vertex shader, we will check whether the vertex is part of a silhouette edge, and if so, displace it by the desired thickness. Thus, silhouette edges will be drawn as thick quadrilaterals, while all other edges will be drawn as quadrilaterals of zero width, which can't be seen.



[Card and Mitchell 2002]

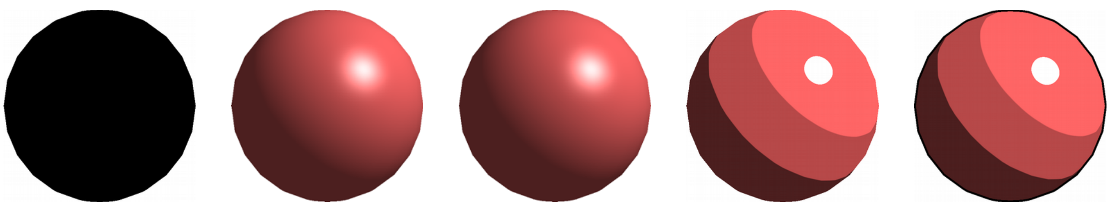
The support code provides a class EdgeMesh that stores the information needed to draw these silhouette edges. It creates a quadrilateral (4 vertices and 2 triangles) for every edge in the original mesh, as shown above. Each vertex stores its position, its displacement direction (labeled **n** in the diagram above), and the normals of the adjacent faces $\mathbf{n}_{\text{left}}$ and $\mathbf{n}_{\text{right}}$. The support code already sends all this mesh data into the outline.vert vertex shader for you, but you need to complete the shader implementation yourself. Your outline.vert vertex shader program should check each vertex for whether it lies on a silhouette edge, that is, whether $\mathbf{n}_{\text{left}} \cdot \mathbf{e}$ and $\mathbf{n}_{\text{right}} \cdot \mathbf{e}$ have different signs. If so, displace the vertex by *thickness****n** when computing the output gl_Position. The most common mistake in writing this shader is getting mixed up about coordinate spaces. Inside your shader, it is usually easiest to define the **e** vector in *eye space*, where the camera is located at (0,0,0). This means $\mathbf{n}_{\text{left}}$ and $\mathbf{n}_{\text{right}}$ should also be transformed into *eye space* (by multiplying by the normal_matrix as usual) before you calculate these dot products. However, this is not the case for **n**. When you move the vertex by *thickness****n**, you should do this before applying any other transformations to the vertex position or **n** so that the offset gets applied within the *object space* of the 3D model.



Left: cow.obj with vertices on all edges displaced.
Right: with vertices only on the silhouette edges displaced.

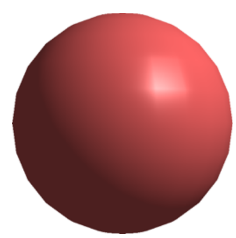
Reference Images

There is a very simple model of a sphere available in the support code. It has just 24 slices and 12 stacks and is a good model to use for testing. The results of your program on this mesh should look like the following as you progress through the assignment:



From left to right: the initial view before you implement anything; Phong shading with the standard Blinn-Phong model; ramp shading with standardDiffuse.png and standardSpecular.bmp (this is identical to the Blinn-Phong model); ramp shading with toonDiffuse.png and toonSpecular.png; and the same with silhouette edges drawn.

If you fail to normalize the fragment normal when doing Phong shading, you will get an *incorrect* result that looks like the image on the right. Note that even if your vertex normals are normalized, the rasterizer will interpolate them to fragments by averaging, and the average of two unit vectors may not itself be a unit vector!



Above and Beyond

All the assignments in the course will include great opportunities for students to go beyond the requirements of the assignment and do cool extra work. We don't offer any extra credit for this work — if you're going beyond the assignment, then chances are you are already kicking butt in the class. However, we do offer a chance to show off… While grading the assignments the TAs will identify the best 4 or 5 examples of people doing cool stuff with computer graphics. After each assignment, the selected students will get a chance to demonstrate their programs to the class!

Once you get the hang of them, shaders can be really fun! Try out some different textures and lighting effects. One interesting possible extension of our 1D ramp textures could be to use a single 2D texture that you look up using both the diffuse and specular intensities. With shaders you can also do other cool effects like adding stripes, waves, random noise, or bumps to the surface.

If your ideas for going beyond the requirements would make your code more difficult for the TAs to grade, please help them out by submitting a standard version of your assignment first through the normal website link, and then email the TAs the fancier version of your assignment.

Academic Integrity Reminder

Shaders are hard to learn and you will find tons of resources, examples, and other information online. You defeat the purpose of the assignment (and break our course rules) if you use these online resources to complete the core assignment (everything other than the "Above and Beyond" section above). To solve the core assignment you may use the online MinGfx documentation, this handout, the textbook, and the information we cover in class – that is all. AFTER you have successfully completed the core assignment, if you then wish to continue working on Wizardly extensions, then it is fine to use online resources to continue learning more about shaders and/or even implement examples that you find online. However, if you are inspired by or copy and modify code from elsewhere you must cite your sources in your README file and any additional shaders that you create. Aside from any licensing issues that may surround the code you are using, we need you to cite your sources and inspirations so that we may accurately understand how much of your wizardly work represents your own intellectual contribution.

Support Code

You should *not* need to update MinGfx in order to complete this or any future assignments.

As in past assignments, you will need to download the support code for assignment 5. This can be done with the following commands:

```
cd repo-[your x500]

git pull upstream support-code
```

After this, the a5-artrender and a5-artrender-docs should be in your dev/ directory.

Handing It In

To hand in your code, check in to the master branch of your Github repository by the deadline. Any commits past the deadline will be assessed according to the late penalties described in the syllabus.

Further Reading

Note: You don't need to read these articles to implement the assignment. They're only provided in case you're curious and want to learn more about non-photorealistic rendering.

Mitchell, Francke, and Eng, "Illustrative Rendering in Team Fortress 2", *Non-Photorealistic and Artistic Rendering* 2007. http://www.valvesoftware.com/publications/2007/NPAR07_IllustrativeRenderingInTeamFortress2.pdf

Gooch, Gooch, Shirley, and Cohen, "A Non-Photorealistic Lighting Model for Automatic Technical Illustration", *SIGGRAPH* 1998. http://www.cs.northwestern.edu/~ago820/SIG98/abstract.html

Card and Mitchell, "Non-Photorealistic Rendering with Pixel and Vertex Shaders", in *ShaderX: Vertex and Pixel Shaders Tips and Tricks*, 2002. http://developer.amd.com/wordpress/media/2012/10/ShaderX_NPR.pdf