MTAT.03.015 Computer Graphics (Fall 2013) Exercise session VII: Lighting

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Today we shall study the basics of OpenGL lighting, and the use of fragment shaders. As usual, the base code is provided in the practice07.zip archive on the course website or via the course github page. Download, unpack and open it. You will need to submit your solution as a zipped archive file.

1 OpenGL pre-3.x Lighting

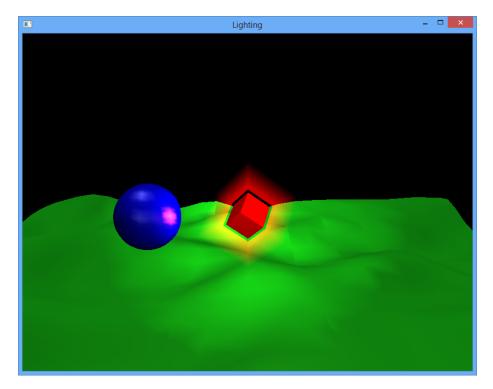
As you should remember from the lecture, OpenGL versions prior to 3.1 provide a bunch of convenient functions to implement the *per-vertex Phong lighting* model. To use it you have to do the following:

- 1. Turn on lighting computations using glEnable(GL_LIGHTING), and one or more light sources using glEnable(GL_LIGHTx),
- 2. Configure position/direction for each light source using glLightfv(GL_LIGHTx, GL_POSITION, ...). Note that it is important what coordinate frame this command is executed in, as the provided coordinates are transformed using the model-view matrix.
- 3. Configure ambient, diffuse and specular light emission parameters of the Phong model for each light source using glLightfv(GL_LIGHTx, GL_AMBIENT, ...), etc. For the ambient light it usually more reasonale to specify just a single overall ambient term via glLightModelfv(GL_LIGHT_MODEL_AMBIENT, ambient_light) rather than provide it separately for each light source (which is possible, but makes less sense).
- Configure ambient, diffuse and specular light diffusion parameters for each surface using either the glMaterial command or the combination of glEnable(GL_COLOR_MATERIAL), glColorMaterial and glColor.

Exercise 1 (1pt). Open the project 1_Lighting. The project renders three objects (the "ground", a "blue sphere" and a "flying cube"). Your goal is to add lighting to the scene as described below.

- 1. First enable lighting computations using glEnable. Once this is done, the scene will become dark. The glColor commands that were used to specify pixel color before play no role any more.
- 2. Now start adding lights one by one. First enable the ambient light using glLightModel(GL_LIGHT_MODEL_AMBIENT ..). Let the ambient light intensity be (0.1, 0.1, 0.1).
- 3. To have objects react to this light, you need to specify material parameters for them. You can usually do it by using the glMaterial function, or by enabling GL_COLOR_MATERIAL, and using glColorMaterial together with glColor. In this particular exercise you are requested to not use GL_COLOR_MATERIAL. Please, specify all material parameters using glMaterial. This will allow you to continue to the next exercise later on.
- 4. Specify the following material properties:
 - (a) **Ground**. Specular (0,0,0), Ambient & Diffuse: (0.1,1.0,0.1).
 - (b) Cube. Specular (0,0,0), Ambient & Diffuse: (1,0,0).
 - (c) **Sphere**. Specular (1,1,1), Ambient & Diffuse: (0,0,1). Specular exponent (GL_SHININESS) 20.
- 5. Now let us start adding actual light sources. First add the "sun". It will be a directional light source shining straight from above the ground with diffuse/specular intensity equal to (0.4, 0.4, 0.4).
- 6. Next, add a positional light source, located exactly at the position of the flying cube. Let the diffuse & specular intensity be (0.5,0.1,0.1). Configure attenuation for this light source to be $\frac{1}{0.1d^2}$. (Hint: see GL_CONSTANT_ATTENUATION, GL_LINEAR_ATTENUATION, GL_QUADRATIC_ATTENUATION).
- 7. Finally, add a spotlight shining from the camera position straight forward. Set the diffuse & specular intensity to (1.0, 1.0, 1.0). Set the spotlight cutoff angle (GL_SPOT_CUTOFF) to 20 degrees, and the spotlight fall-off exponent (GL_SPOT_EXPONENT) to 30.

In the end you should obtain an image like the one below.



Note that OpenGL does not do gamma correction in its lighting computations. Some graphics cards, however, can perform on-the-fly sRGB-gamma-encoding as pixels are written to the framebuffer. To switch it on, use GLUT_SRGB in your glutInitDisplayMode call and do a glEnable(GL_FRAMEBUFFER_SRGB). See whether it makes any difference¹

2 GLSL, Per-vertex and Per-fragment Lighting

Now let us try implementing the whole lighting logic manually in the shader program. We shall continue working with the 1_Lighting project.

Exercise 2 (1pt). Uncomment the line

per_vertex_lighting .use();

which is located somewhere near the end of the main function. Once you do it, the built-in OpenGL lighting computations will be disabled in favor of the shader programs lighting1_vertex.glsl and lighting1_fragment.glsl. Your task is to implement the lighting computations in the shader manually, so that the result would exactly match the GL_LIGHTING solution you configured in the previous exercise using OpenGL's (now deprecated) fixed pipeline.

 $^{^{1}\}mathrm{E.g.}$ my laptop does not react to $\mathtt{glEnable}(\mathtt{GL_FRAMEBUFFER_SRGB}).$

You should keep the fragment shader intact. The vertex shader shows the implementation of the spotlight to get you started.

Exercise 3 (0.5pt). So far we did *per-vertex shading*, i.e. performing lighting computations for each vertex and interpolating the resulting colors. The result looks nice, but you can clearly see some ugly artifacts, in particular in how grainy the "ground" is lit. Let us now do per-fragment shading.

Comment out the line per_vertex_lighting.use(); that you used in the previous exercise, and instead uncomment the next line:

```
per_fragment_lighting.use();
```

This will enable the use of the shader programs lighting2_vertex.glsl and lighting2_fragment.glsl. Your task is to modify the code in the fragment shader to implement the same lighting logic as before (but now applied to each fragment).

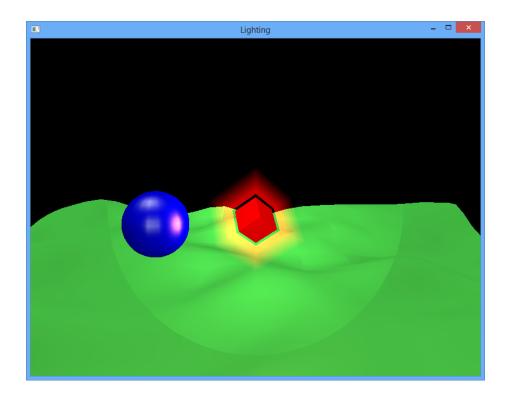
In the end, add the code line that performs gamma correction for the computed color². Recall that gamma correction means transforming the color from linear RGB colorspace to non-linear sRGB colorspace (used on the display) via the transformation:

$$\operatorname{color}_{\operatorname{sRGB}} := (\operatorname{color}_{\operatorname{RGB}})^{\frac{1}{2.2}}$$

Hint: Solving this task is all about copy-pasting the solution of your previous task to the fragment shader, fixing a couple of variable names and making sure you return the result in the gl_FragColor variable.

Below is the result you should expect to see:

²Switch off the GL_FRAMEBUFFER_SRGB extension, if you used it before.



3 Fragment Shaders

In general, a fragment shader is a very powerful concept, the application of which extends far beyond basic lighting computations. Fragment shaders are particularly well-suited for implementing hardware-accelerated raytracing techniques. You can get a good overview of what kinds of effects can be implemented in a single fragment shader by browsing the ShaderToy website³. Now, although understanding the techniques behind demos like https://www.shadertoy.com/view/lsXGWl in full detail is slightly beyond the scope of our course⁴, an easy starting point is trying to use a fragment shader to implement a simple Phonglighted orthogonal projection of a sphere.

Exercise 4* (1pt). We shall be using the "ShaderToy" website in this exercise. Open the website and click "New Shader". You will be presented with the main function of an empty fragment shader. Recall that the shader must produce the value for the gl_FragColor variable – color of the pixel located at position gl_FragCoord.

³https://www.shadertoy.com/

⁴It is not too far beyond this course, though. The main thing we shall not cover in sufficient detail eventually in the course are fractals and various "postprocessing effects". Hopefully those interested will find this information in the internet on their own.

1. Suppose we are trying to render an orthogonal projection of a sphere. Our viewport is positioned so that the sphere is centered in the window and its height is exactly half the window's height. Let us start coding our shader by determining the pixels that belong to such a sphere.

```
void main(void) {
    // Center and normalize coordinates
    vec2 uv = gl.FragCoord.xy - iResolution.xy*0.5;
    uv /= iResolution.yy*0.5;

    // Write red pixels for all points belonging to the sphere
    if (length(uv) < 0.5) {
        gl.FragColor = vec4(1, 0, 0, 1);
    }
    else {
        gl.FragColor = vec4(1, 1, 1, 1);
    }
}</pre>
```

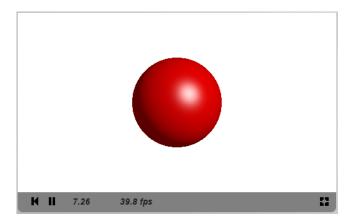
- 2. Now for every pixel that does belong to the sphere you have to implement the following:
 - (a) Compute the position of the corresponding point on the sphere in 3D. Assume that sphere is centered at (0,0,0) in camera coordinates. Hint: Every point on the sphere satisfies

$$x^2 + y^2 + z^2 = R^2.$$

- (b) Compute the normal at this point.
- (c) Assume the direction to the viewer is (0,0,1) as usual.
- (d) Assume that the sphere is illuminated by a positional light source located at (5,2,5). Compute the light direction and the reflection vectors.
- (e) Assume the sphere's diffuse color is red (1,0,0), specular is white (1,1,1), shininess is 15, ambient light is (0.1,0.1,0.1). Let the light source intensity be (0.7,0.7,0.7) for both diffuse and specular components. Assume no attenuation. Given this information and the previously computed vectors, evaluate the Phong lighting model at the corresponding point on the sphere.
- (f) Apply gamma correction.
- (g) Apply HDR, if you find it necessary.
- (h) Finally, make the light position move around the sphere in a circle. I.e. do something like

vec3 light_pos = vec3(5.0*cos(iGlobalTime), 2.0, 5.0*sin(iGlobalTime));

3. As a result you will have implemented an animated rendering of a complete sphere done fully within a fragment shader (i.e. no "standard graphics pipeline" involved). The resulting image should look more or less as follows:



4. Submit the solution to this exercise in a text file sphere.glsl added to the archive. Note in the submission comment that you solved this task.

Exercise 5* (0.5pt). Use ShaderToy to develop a fragment shader, which renders a Mandelbrot Set⁵. The baseline solution is a simple black-and-white image (this is enough to receive points), however trying to make the set nicely colored (e.g. like the picture on Wikipedia) and/or adding animation (such as a continous "zoom in" effect or the like) is quite fun and thus strongly recommended

Submit the solution in a text file mandelbrot.glsl, added to the archive. Note in the submission comment that you solved this task.

 $^{^5 {\}tt http://en.wikipedia.org/wiki/Mandelbrot_set}$