Render an Earth Model

Final Project of Computer Graphics

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1 Introduction

In this project, there are mainly two steps to carry on. The first step is sphere tessellation using triangle mesh to tessellate a sphere, while the second step is texture mapping. Adopt bump mapping to adjust sphere with an elevation earth map and implement the texture mapping of the earth model with an earth map. Then this project uses Phong illumination model, which includes three parts: global ambient reflection, per-light diffuse reflection, and per- light specular reflection, to simulate the realistic directional light. At last, it uses night light map to make the rendered surface more realistic.

2 Related Technologies

2.1 Sphere Tessellation Algorithms

A tessellation of a flat surface is the process of tilling a plane with one or more geometric shapes, called tiles, without any overlaps or any gaps. Iterative sphere tessellation algorithms begins with triangle-based platonic solids and during each time, one triangle splits into four triangles. This process makes it closer to a real sphere step by step and it will be completed repeatedly for several times to get close to the wanted result. To make sphere tessellation algorithms more efficient, the triangle mesh generated by tessellation approach should contain as few vertices as possible. This means when multiple triangles share the same vertex, only one copy of the vertex shall exist in the vertex list. Figure 1 shows the process of sphere tessellation.

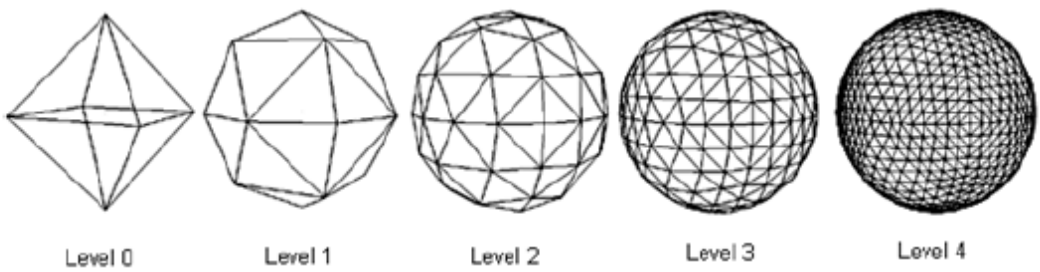


Figure 1: Process of Sphere Tessellation

2.2 Texture Mapping and Displacement Mapping with Images

Displacement Mapping gives an actual displacement for each geometric position along the local surface normal. A displacement map stores the displacement of each point with an array. However, it slows down the editor due to the large amount of additional geometry. Therefore, it is usually used for large-scale surface changes. An effect occurs where the actual geometric position of points over the textured surface are displaced. Figure 2 shows displacement mapping.

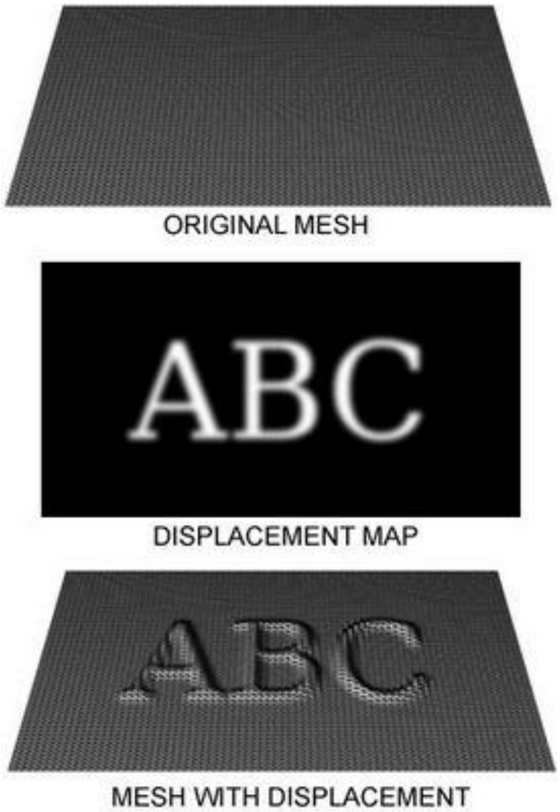


Figure 2: Displacement Mapping

2.2 Phong Illumination Model

The Phong illumination model is an empiric of the local illumination of points on a surface, and Bui Tuong Phong firstly developed this theory in his PhD dissertation in 1973. It represents the sum of the three components: ambient, diffuse and specular. Ambient can be modeled by multiplying the intensity of the light source by the surface reflectivity: I = $I_a k_a$, where I_a is the intensity of ambient light and k_a is the ambient coefficient of surface. Diffuse is the intensity of the light being reflected, and it is calculated by the angle between the surface normal and the vector defining the light source. The equation is $I_d = I_p(L \cdot N)k_d$, where I_p is the intensity of point light and $k_d$is the diffuse – reflection coefficient. The third component, specular, models the reflectivity of the light like a mirror in a scene. The intensity of specular is calculated by this equation: $I_s = I_p\,(R \cdot V)^n k_s$, where n is the specular exponent which determines the falloff rate and k_d is the specular-reflection coefficient of each component.

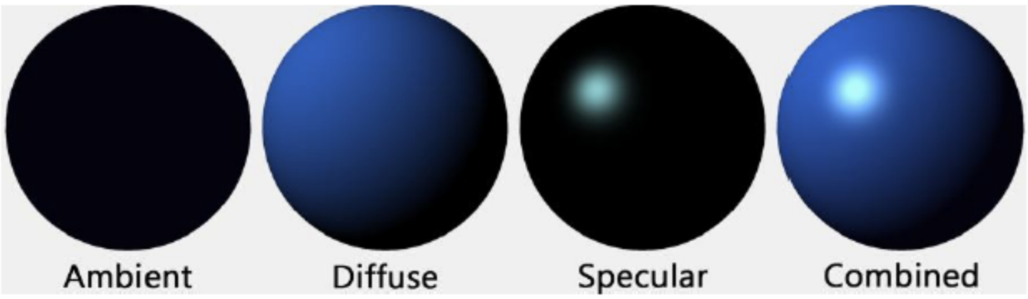


Figure 3: Effect of Each Component

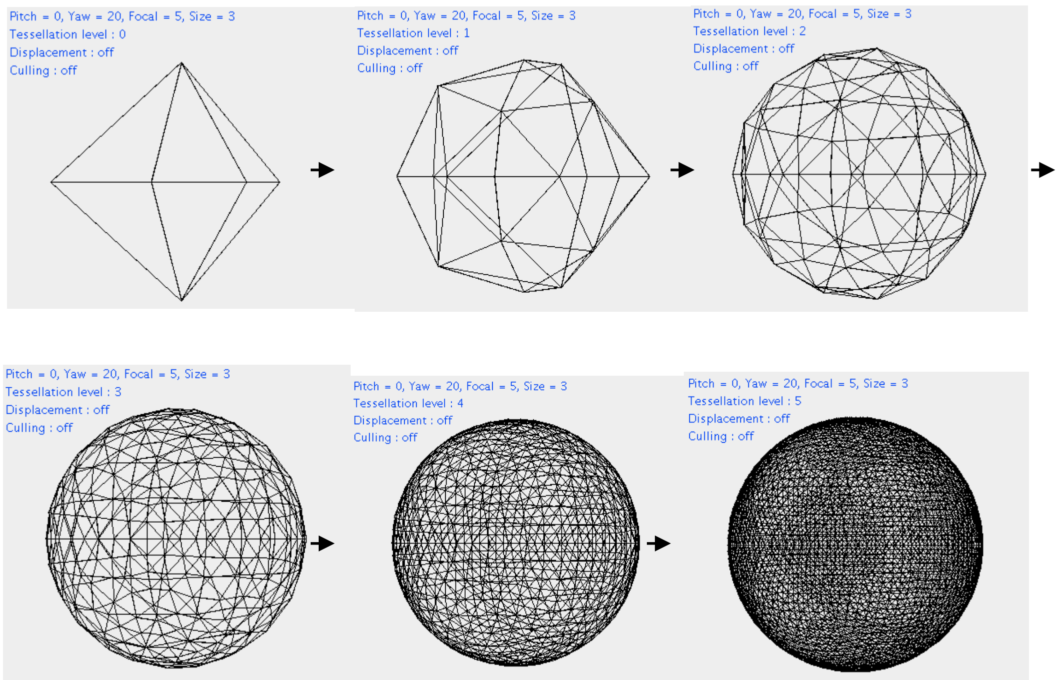
3 Implementation

3.1 Implementation of Earth Model

To implement the earth model, firstly, a sphere has to be modeled by tessellation algorithm. During this implementation, an octahedron mesh is created. Each time the implementation is completed, one triangle splits into four triangles. Pseudo code for octahedron mesh is shown as below.

```
vertices = new Vertex[6];
vertices[0] = new Vertex(center.x, center.y, center.z+radius);
vertices[1] = new Vertex(center.x+radius, center.y, center.z);
vertices[2] = new Vertex(center.x, center.y+radius, center.z);
vertices[3] = new Vertex(center.x-radius, center.y, center.z);
vertices[4] = new Vertex(center.x, center.y-radius, center.z);
vertices[5] = new Vertex(center.x, center.y, center.z-radius);
```

To tessellate this sphere, the center is set at (0, 0, 0) and the radius length is 2. During this process, each triangle splits into four small triangles. The tessellated sphere process is shown as below.



This is the procedure of sphere tessellation. Besides, back-face culling is used to detect whether polygons are visible in a particular scene or not. In this project, it is determined by calculating the inner product of the vector V from the camera to the point P and its normal vector N. If $V \cdot N > 0$, the polygons is back facing. Otherwise, it is front facing.

Earth elevation map makes the earth more realistic by computing the longitude and latitude of each vertex based on its 3D coordinates. Code to get elevation information is shown as below.

```
private Vertex displace(Vertex from){
    double theta = Math.acos(from.y / sphere.radius) * 180 / Math.PI;
    double psi = Math.acos(from.x / Math.sqrt(from.x * from.x + from.z * from.z)) * 180 / Math.PI;
    if(from.z < 0)
        psi = 360 - psi;
    int y_img = (int)(theta * image.getHeight()) / 180;
    int x_img = (int)(psi * image.getWidth()) / 360;
    x_img = x_img >= image.getWidth() ? x_img - image.getWidth() : x_img;
    y_img = y_img >= image.getHeight() ? y_img - image.getHeight() : y_img;

    int attitude = new Color(image.getRGB(x_img, y_img)).getRed();

    double newR = sphere.radius * (1 + 1.0 * attitude / 255 / 8);
    return new Vertex(newR * from.x / sphere.radius + sphere.center.x,
            newR * from.y / sphere.radius + sphere.center.x,
            newR * from.z / sphere.radius + sphere.center.x
            );
}
```

This next step is to implement earth texture mapping. Figure 5 shows the process of earth texture mapping. U and V denote the axes in 2D texture while X, Y and Z denote the axes of 3D object in model space.

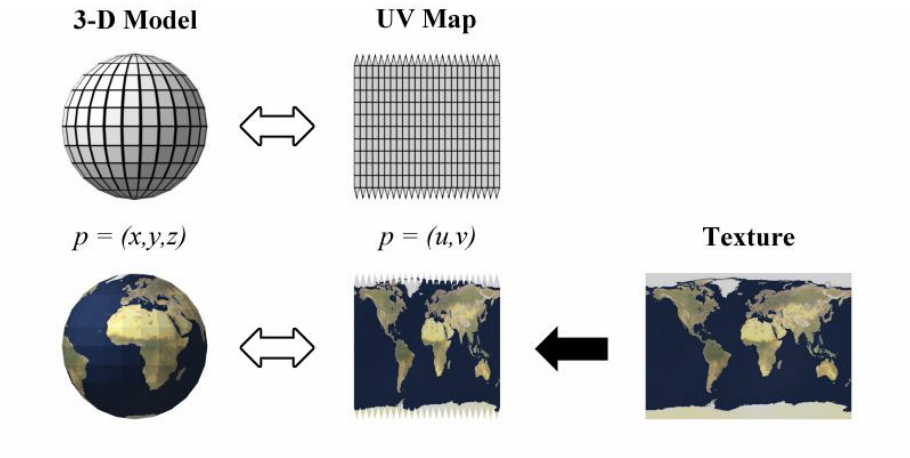


Figure 5: Earth Texture Mapping

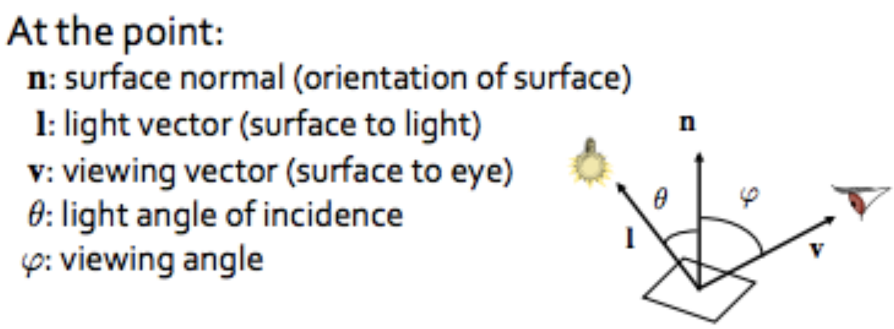
U-V coordination is calculated at each point on the earth sphere. The calculation of U-V coordination in the range of [0, 1] is as follow:

$$u = \mathrm{atan2}(z, x) \,/\, (2 \times \pi) + 0.5$$

$$v = \mathrm{asin}\left(\frac{y}{r}\right) / (\pi) + 0.5$$

3.2 Implementation of Phong Illumination Model

To simulate sun light, the directional light is supposed to be set for implementation of illumination. A directional light source emits light over a large area in a single direction. It is equivalent to a point light source which is infinitely far away. Set the vertex source at (2, 2, 7) and the intensity is (4, 4, 4). Then the light effects achieve Phong Illumination. During this process, the following parameters are necessary:



This project uses approximate color as sum of two components. The one is ideal diffuse component and the other one is a glossy specular component. Since a combination of both specular and diffuse material represents the most real surfaces, the amount of diffuse reflected light is computed by the negative dot product of the unit-vector light direction and surface normal. To value the specular component, both vertex source and the surface of the earth must be considered. Besides, it is also necessary to take into account the location of the viewer. To determine the shading of a point on the surface of the earth, the distance between the viewer and the direct ray reflection must considered. Then the brightness of the point is determined. The effect of phong illumination model is shown as follow:

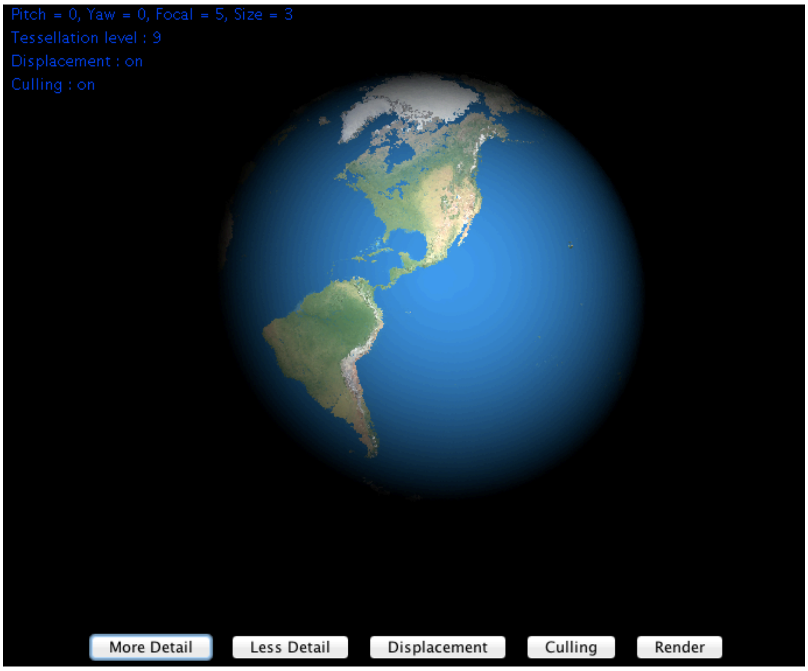


Figure 6: Phong Illumination Model Effects

From this figure, it is obvious that there is already a shading effect on the earth model. Night light map implementation makes it more realistic and the effect is enhanced. 'If' statement is used in this part to add a judgment condition in the code.

If the lighting of RGB color from the directional light is less than 5, that part will be implemented by light night map.

The effect is shown as follow:

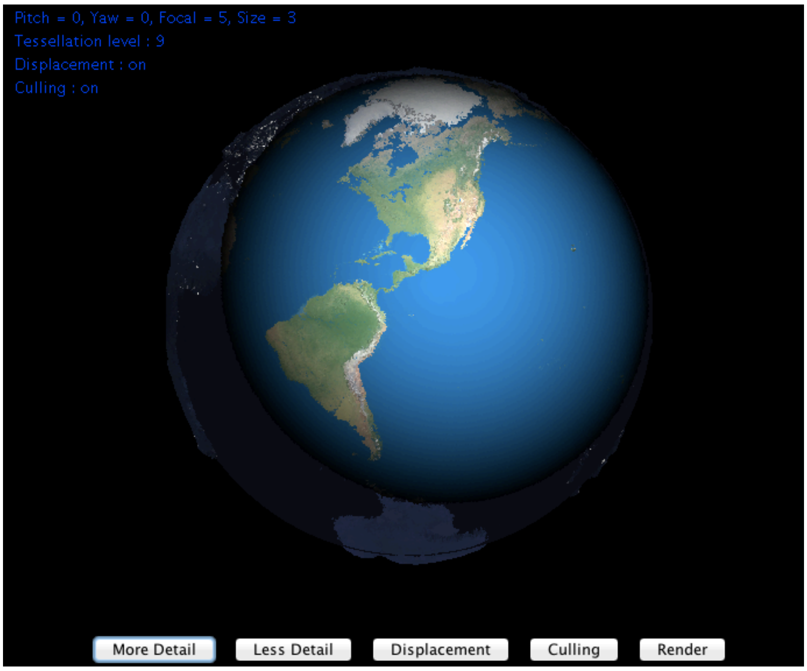


Figure 7: Implementation of Night Light Map

Hence, the implementation of this earth model is basically achieved. Furthermore, 3D viewing system can be set up by rotating the earth model by mouse. Besides, arrow keys ← and → allow users to zoom in and out this earth model and arrow keys ↑ and ↓ allow users to change the focal point.

Reference

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