

15-462 Computer Graphics I

Lecture 8

Shading in OpenGL

Polygonal Shading

Light Source in OpenGL

Material Properties in OpenGL

Normal Vectors in OpenGL

Approximating a Sphere

[Angel 6.5-6.9]

February 14, 2002

Frank Pfenning

Carnegie Mellon University

<http://www.cs.cmu.edu/~fp/courses/graphics/>

Polygonal Shading

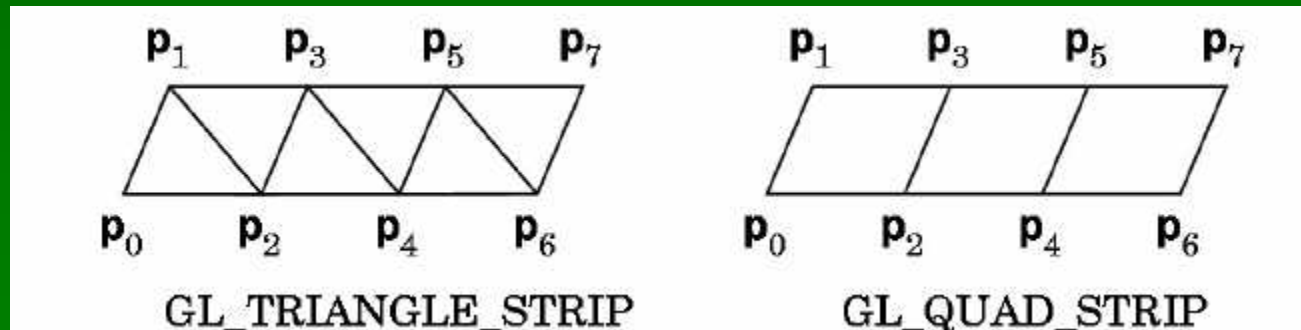
- Curved surfaces are approximated by polygons
- How do we shade?
 - Flat shading
 - Interpolative shading
 - Gouraud shading
 - Phong shading (different from Phong illumination)
- Two questions:
 - How do we determine normals at vertices?
 - How do we calculate shading at interior points?

Flat Shading

- Normal: given explicitly before vertex

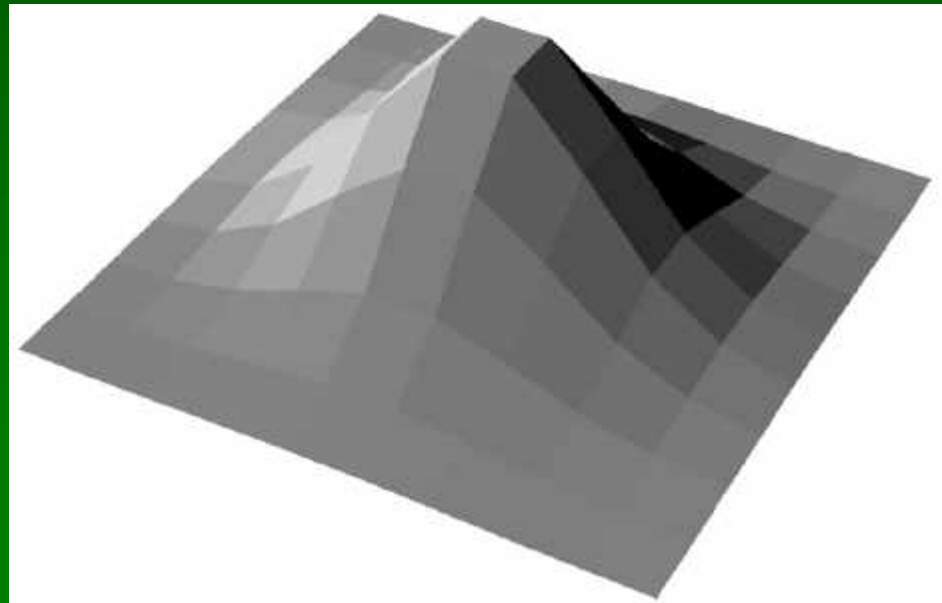
```
glNormal3f(nx, ny, nz);  
glVertex3f(x, y, z);
```

- Shading constant across polygon
- Single polygon: first vertex
- Triangle strip: Vertex $n+2$ for triangle n



Flat Shading Assessment

- Inexpensive to compute
- Appropriate for objects with flat faces
- Less pleasant for smooth surfaces



Interpolative Shading

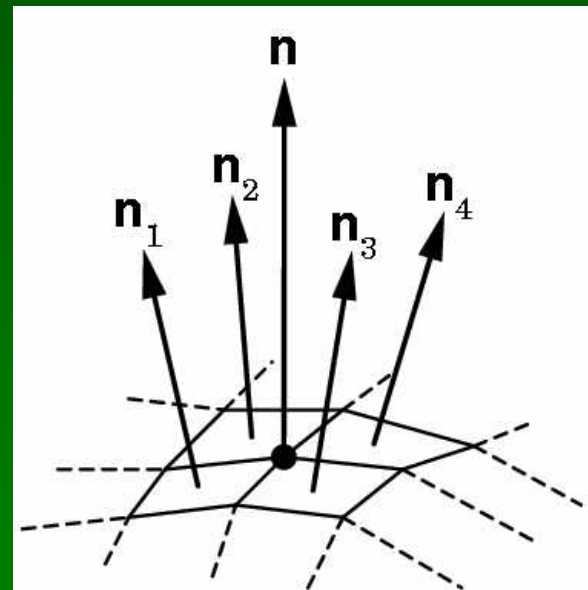
- Enable with `glShadeModel(GL_SMOOTH);`
- Calculate color at each vertex
- Interpolate color in interior
- Compute during scan conversion (rasterization)
- Much better image (see Assignment 1)
- More expensive to calculate

Gouraud Shading

- Special case of interpolative shading
- How do we calculate vertex normals?
- Gouraud: average all adjacent face normals

$$\mathbf{n} = \frac{\mathbf{n}_1 + \mathbf{n}_2 + \mathbf{n}_3 + \mathbf{n}_4}{|\mathbf{n}_1 + \mathbf{n}_2 + \mathbf{n}_3 + \mathbf{n}_4|}$$

- Requires knowledge about which faces share a vertex

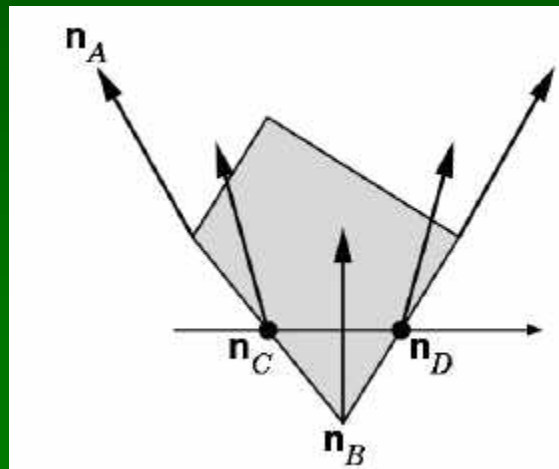


Data Structures for Gouraud Shading

- Sometimes vertex normals can be computed directly (e.g. height field with uniform mesh)
- More generally, need data structure for mesh
- Key: which polygons meet at each vertex

Phong Shading

- Interpolate **normals** rather than colors
- Significantly more expensive
- Mostly done off-line (not supported in OpenGL)



Polygonal Shading Summary

- Gouraud shading
 - Set vertex normals
 - Calculate colors at vertices
 - Interpolate colors across polygon
- Must calculate vertex normals!
- Must normalize vertex normals to unit length!

Outline

- Polygonal Shading
- **Light Sources in OpenGL**
- Material Properties in OpenGL
- Normal Vectors in OpenGL
- Example: Approximating a Sphere

Enabling Lighting and Lights

- Lighting in general must be enabled
`glEnable(GL_LIGHTING);`
- Each individual light must be enabled
`glEnable(GL_LIGHT0);`
- OpenGL supports at least 8 light sources

Global Ambient Light

- Set ambient intensity for entire scene

```
GLfloat ai[] = {0.2, 0.2, 0.2, 1.0};  
glLightModelfv(GL_LIGHT_MODEL_AMBIENT, ai);
```

- The above is default
- Also: local vs infinite viewer

```
glLightModeli(GL_LIGHT_MODEL_LOCAL_VIEWER,  
             GL_TRUE);
```

- More expensive, but sometimes more accurate

Defining a Light Source

- Use vectors {r, g, b, a} for light properties
- Beware: light source will be transformed!

```
GLfloat light_ambient[] = {0.2, 0.2, 0.2, 1.0};  
GLfloat light_diffuse[] = {1.0, 1.0, 1.0, 1.0};  
GLfloat light_specular[] = {1.0, 1.0, 1.0, 1.0};  
GLfloat light_position[] = {-1.0, 1.0, -1.0, 0.0};  
glLightfv(GL_LIGHT0, GL_AMBIENT, light_ambient);  
glLightfv(GL_LIGHT0, GL_DIFFUSE, light_diffuse);  
glLightfv(GL_LIGHT0, GL_SPECULAR, light_specular);  
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```

Point Source vs Directional Source

- Directional light given by “position” **vector**

```
GLfloat light_position[] = {-1.0, 1.0, -1.0, 0.0};  
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```

- Point source given by “position” **point**

```
GLfloat light_position[] = {-1.0, 1.0, -1.0, 1.0};  
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```

Spotlights

- Create point source as before
- Specify additional properties to create spotlight

```
GLfloat sd[] = {-1.0, -1.0, 0.0};  
glLightfv(GL_LIGHT0, GL_SPOT_DIRECTION, sd);  
glLightf(GL_LIGHT0, GL_SPOT_CUTOFF, 45.0);  
glLightf(GL_LIGHT0, GL_SPOT_EXPONENT, 2.0);
```

[Demo: Lighting Position Tutor]

Outline

- Polygonal Shading
- Light Sources in OpenGL
- **Material Properties in OpenGL**
- Normal Vectors in OpenGL
- Example: Approximating a Sphere

Defining Material Properties

- Material properties stay in effect
- Set both specular coefficients and shininess

```
GLfloat mat_d[] = {0.1, 0.5, 0.8, 1.0};
```

```
GLfloat mat_s[] = {1.0, 1.0, 1.0, 1.0};
```

```
GLfloat low_sh[] = {5.0};
```

```
glMaterialfv(GL_FRONT, GL_AMBIENT, mat_d);
```

```
glMaterialfv(GL_FRONT, GL_SPECULAR, mat_s);
```

```
glMaterialfv(GL_FRONT, GL_SHININESS, low_sh);
```

- Diffuse component is analogous

[Demo: Light material Tutor]

Color Material Mode (Answer)

- Can shortcut material properties using glColor
- Must be explicitly enabled and disabled

```
glEnable(GL_COLOR_MATERIAL);  
/* affect front face, diffuse reflection properties */  
glColorMaterial(GL_FRONT, GL_DIFFUSE);  
glColor3f(0.0, 0.0, 0.8);  
/* draw some objects here in blue */  
glColor3f(1.0, 0.0, 0.0);  
/* draw some objects here in red */  
glDisable(GL_COLOR_MATERIAL);
```

Outline

- Polygonal Shading
- Light Sources in OpenGL
- Material Properties in OpenGL
- Normal Vectors in OpenGL
- Example: Approximating a Sphere

Defining and Maintaining Normals

- Define **unit normal** before each vertex

```
glNormal3f(nx, ny, nz);  
glVertex3f(x, y, z);
```

- Length changes under some transformations
- Ask OpenGL to re-normalize (all tfms)

```
glEnable(GL_NORMALIZE);
```

- Ask OpenGL to re-scale normal

```
glEnable(GL_RESCALE_NORMAL);
```

- Works for uniform scaling (and rotate, translate)

Example: Icosahedron

- Define the vertices

```
#define X .525731112119133606  
#define Z .850650808352039932
```

```
static GLfloat vdata[12][3] = {  
    {-X, 0.0, Z}, {X, 0.0, Z}, {-X, 0.0, -Z}, {X, 0.0, -Z},  
    {0.0, Z, X}, {0.0, Z, -X}, {0.0, -Z, X}, {0.0, -Z, -X},  
    {Z, X, 0.0}, {-Z, X, 0.0}, {Z, -X, 0.0}, {-Z, -X, 0.0}  
};
```

- For simplicity, avoid the use of vertex arrays

Defining the Faces

- Index into vertex data array

```
static GLuint tindices[20][3] = {  
    {1,4,0}, {4,9,0}, {4,9,5}, {8,5,4}, {1,8,4},  
    {1,10,8}, {10,3,8}, {8,3,5}, {3,2,5}, {3,7,2},  
    {3,10,7}, {10,6,7}, {6,11,7}, {6,0,11}, {6,1,0},  
    {10,1,6}, {11,0,9}, {2,11,9}, {5,2,9}, {11,2,7}  
};
```

- Be careful about orientation!

Drawing the Icosahedron

- Normal vector calculation next

```
glBegin(GL_TRIANGLES);  
for (i = 0; i < 20; i++) {  
    icoNormVec(i);  
    glVertex3fv(&vdata[tindices[i][0]] [0]);  
    glVertex3fv(&vdata[tindices[i][1]] [0]);  
    glVertex3fv(&vdata[tindices[i][2]] [0]);  
}  
glEnd();
```

- Should be encapsulated in display list

Calculating the Normal Vectors

- Normalized cross product of any two sides

```
GLfloat d1[3], d2[3], n[3];
```

```
void icoNormVec (int i) {  
    for (k = 0; k < 3; k++) {  
        d1[k] = vdata[tindices[i][0]] [k] - vdata[tindices[i][1]] [k];  
        d2[k] = vdata[tindices[i][1]] [k] - vdata[tindices[i][2]] [k];  
    }  
    normCrossProd(d1, d2, n);  
    glNormal3fv(n);  
}
```


The Normalized Cross Product

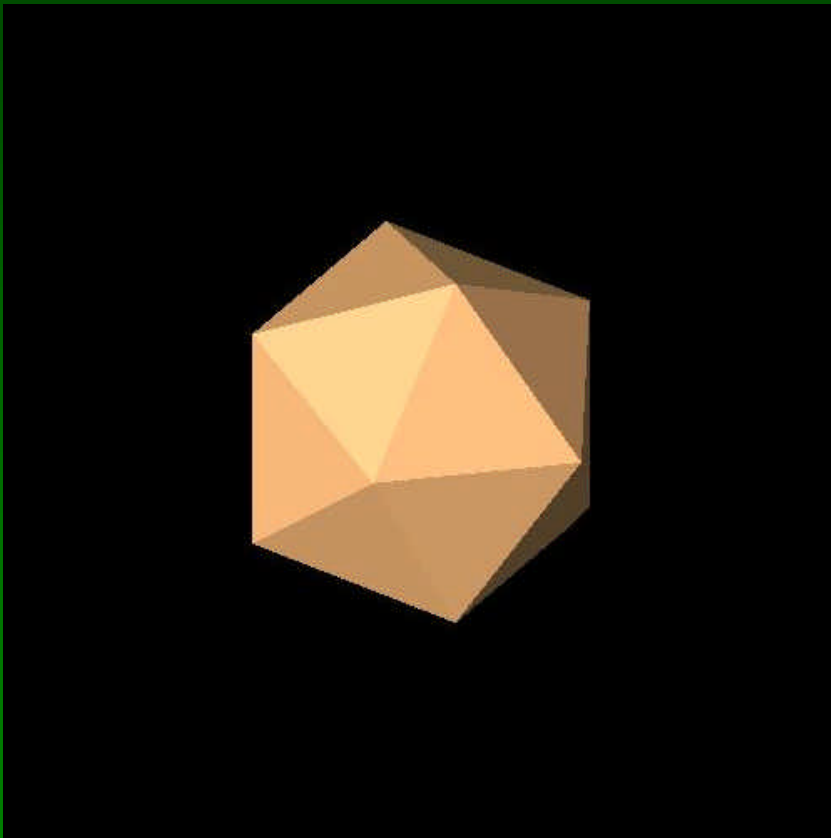
- Omit zero-check for brevity

```
void normalize(float v[3]) {  
    GLfloat d = sqrt(v[0]*v[0] + v[1]*v[1] + v[2]*v[2]);  
    v[0] /= d; v[1] /= d; v[2] /= d;  
}
```

```
void normCrossProd(float u[3], float v[3], float out[3]) {  
    out[0] = u[1]*v[2] - u[2]*v[1];  
    out[1] = u[2]*v[0] - u[0]*v[2];  
    out[2] = u[0]*v[1] - u[1]*v[0];  
    normalize(out);  
}
```

The Icosahedron

- Using simple lighting setup



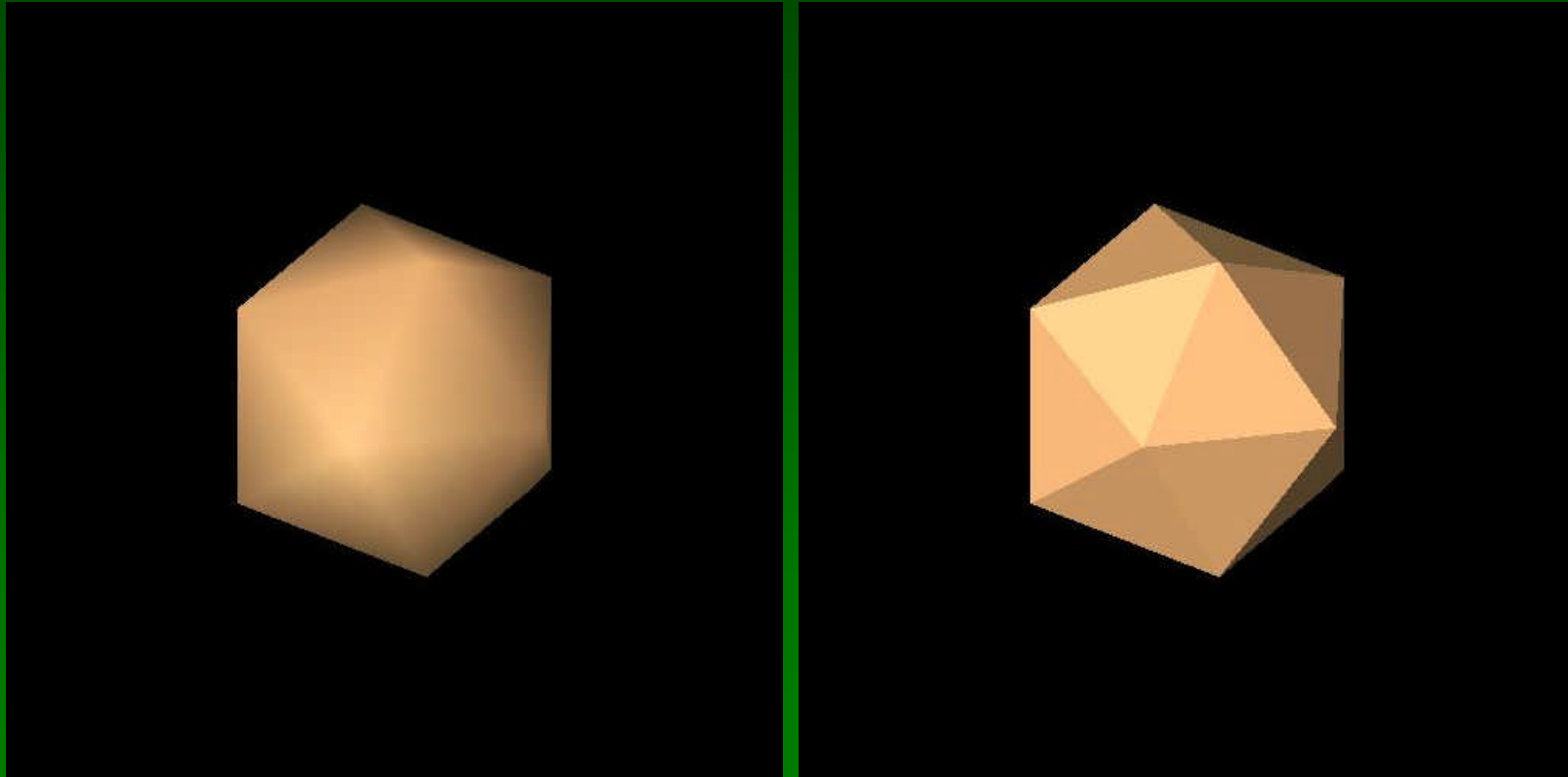
Sphere Normals

- Set up instead to use normals of sphere
- Unit sphere normal is exactly sphere point

```
glBegin(GL_TRIANGLES);  
for (i = 0; i < 20; i++) {  
    glNormal3fv(&vdata[tindices[i][0]][0]);  
    glVertex3fv(&vdata[tindices[i][0]][0]);  
    glNormal3fv(&vdata[tindices[i][1]][0]);  
    glVertex3fv(&vdata[tindices[i][1]][0]);  
    glNormal3fv(&vdata[tindices[i][2]][0]);  
    glVertex3fv(&vdata[tindices[i][2]][0]);  
}  
glEnd();
```

Icosahedron with Sphere Normals

- Interpolation vs flat shading effect

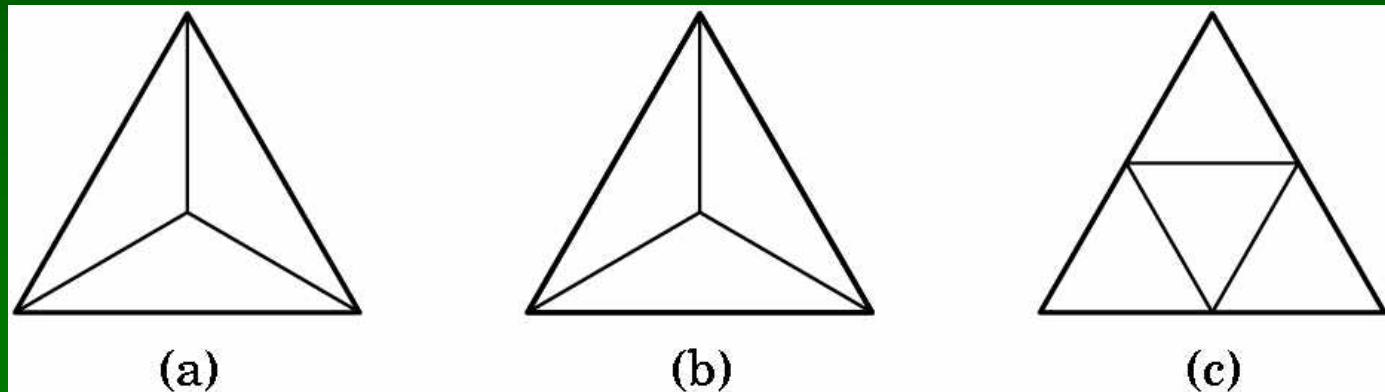


Recursive Subdivision

- General method for building approximations
- Research topic: construct a good mesh
 - Low curvature, fewer mesh points
 - High curvature, more mesh points
 - Stop subdivision based on resolution
 - Some advanced data structures for animation
 - Interaction with textures
- Here: simplest case
- Approximate sphere by subdividing icosahedron

Methods of Subdivision

- Bisecting angles
- Computing center
- Bisecting sides



- Here: bisect sides to retain regularity

Bisection of Sides

- Draw if no further subdivision requested

```
void subdivide(GLfloat v1[3], GLfloat v2[3],
              GLfloat v3[3], int depth)
{ GLfloat v12[3], v23[3], v31[3]; int i;
  if (depth == 0) { drawTriangle(v1, v2, v3); }
  for (i = 0; i < 3; i++) {
    v12[i] = (v1[i]+v2[i])/2.0;
    v23[i] = (v2[i]+v3[i])/2.0;
    v31[i] = (v3[i]+v1[i])/2.0;
  }
  ...
}
```

Extrusion of Midpoints

- Re-normalize midpoints to lie on unit sphere

```
void subdivide(GLfloat v1[3], GLfloat v2[3],  
              GLfloat v3[3], int depth)
```

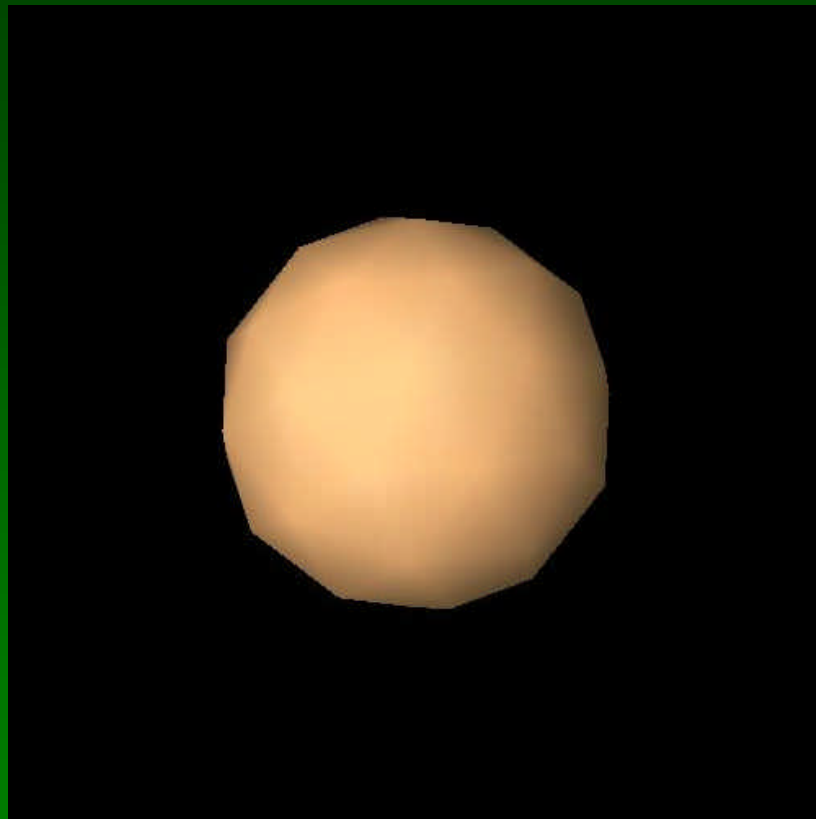
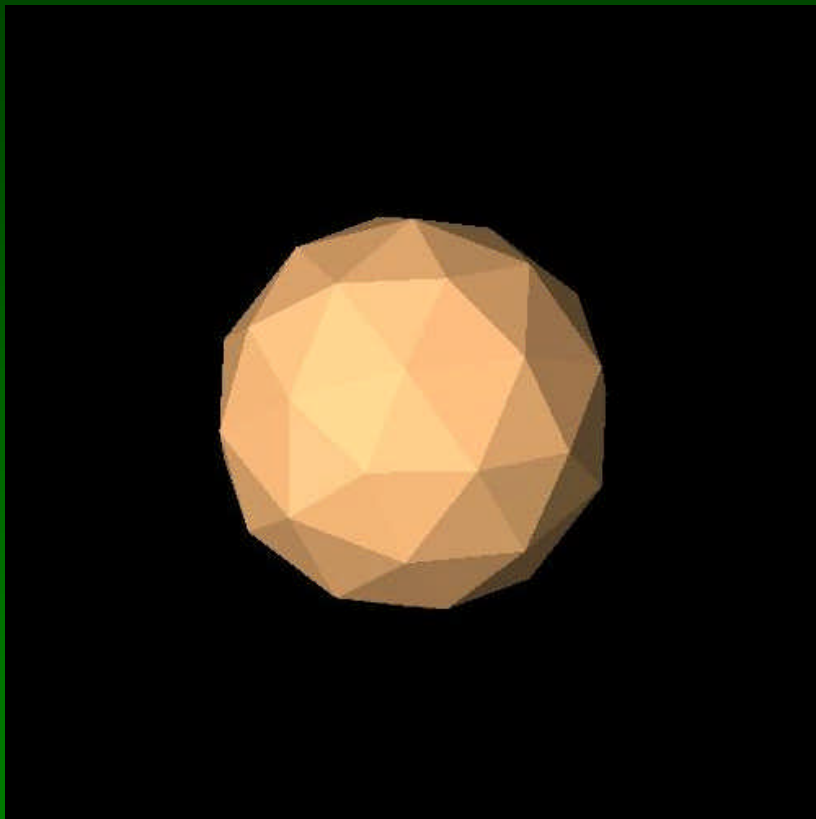
```
{ ...  
  normalize(v12);  
  normalize(v23);  
  normalize(v31);  
  subdivide(v1, v12, v31, depth-1);  
  subdivide(v2, v23, v12, depth-1);  
  subdivide(v3, v31, v23, depth-1);  
  subdivide(v12, v23, v31, depth-1);  
}
```


Start with Icosahedron

- In sample code: control depth with '+' and '-'

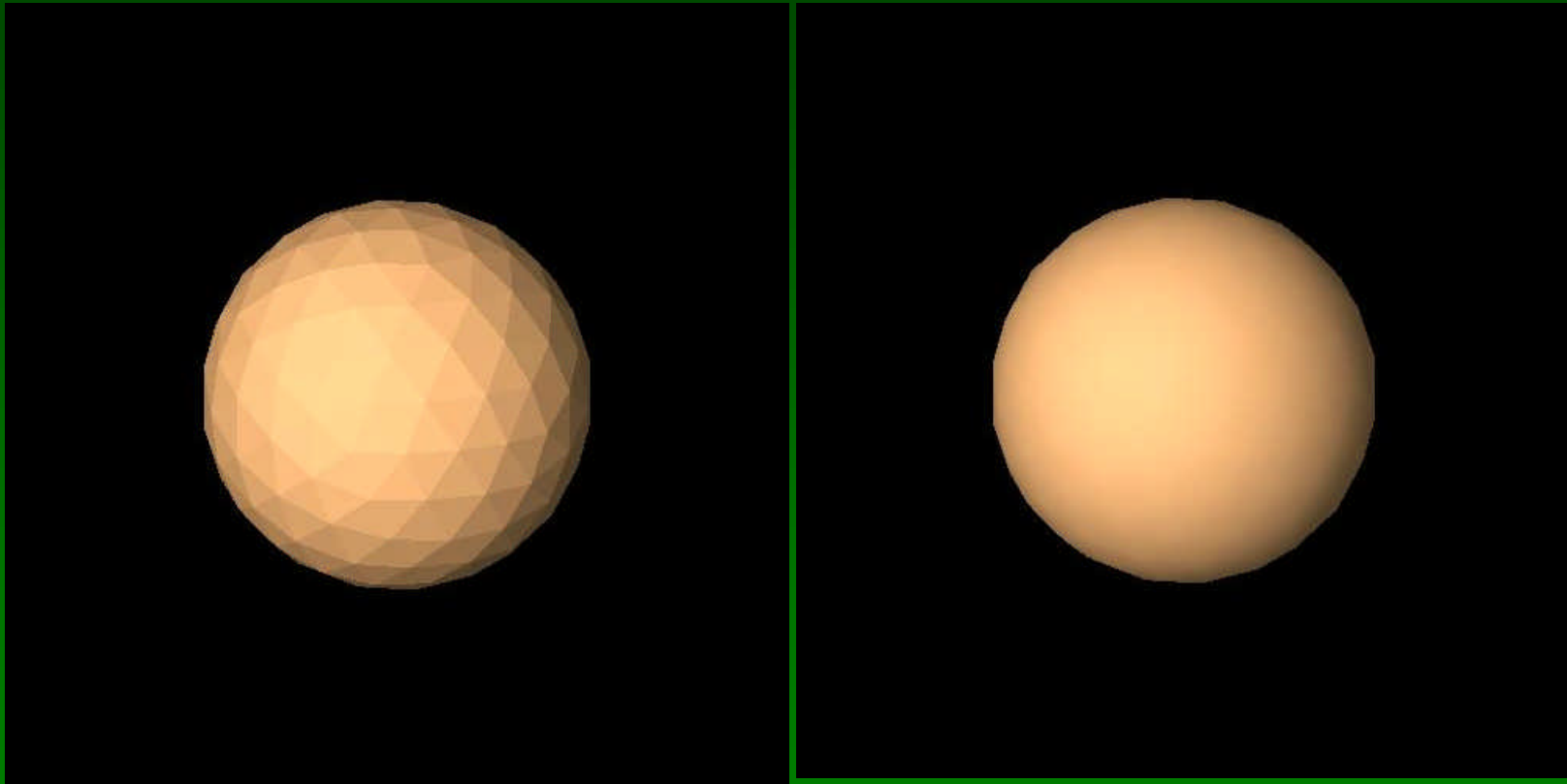
```
void display(void)
{
    ...
    for (i = 0; i < 20; i++) {
        subdivide(&vdata[tindices[i][0]][0],
                 &vdata[tindices[i][1]][0],
                 &vdata[tindices[i][2]][0],
                 depth);
    }
    glFlush();
}
```

One Subdivision



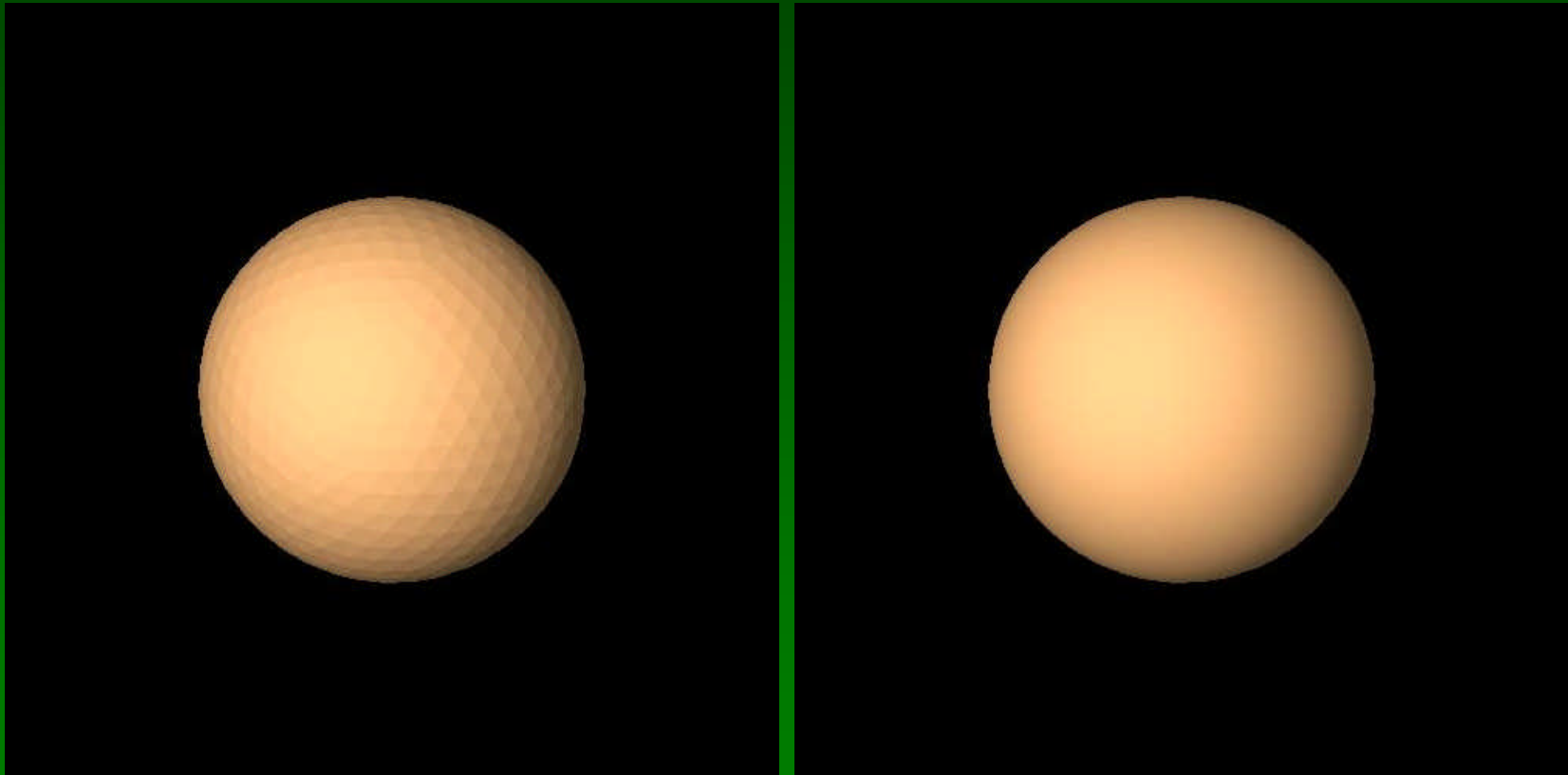
Two Subdivisions

- Each time, multiply number of faces by 4



Three Subdivisions

- Reasonable approximation to sphere



Example Lighting Properties

```
GLfloat light_ambient[]={0.2, 0.2, 0.2, 1.0};  
GLfloat light_diffuse[]={1.0, 1.0, 1.0, 1.0};  
GLfloat light_specular[]={0.0, 0.0, 0.0, 1.0};
```

```
glLightfv(GL_LIGHT0, GL_AMBIENT, light_ambient);  
glLightfv(GL_LIGHT0, GL_DIFFUSE, light_diffuse);  
glLightfv(GL_LIGHT0, GL_SPECULAR, light_specular);
```

Example Material Properties

```
GLfloat mat_specular[]={0.0, 0.0, 0.0, 1.0};
GLfloat mat_diffuse[]={0.8, 0.6, 0.4, 1.0};
GLfloat mat_ambient[]={0.8, 0.6, 0.4, 1.0};
GLfloat mat_shininess={20.0};
glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
glMaterialfv(GL_FRONT, GL_AMBIENT, mat_ambient);
glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_diffuse);
glMaterialf(GL_FRONT, GL_SHININESS, mat_shininess);

glShadeModel(GL_SMOOTH); /*enable smooth shading */
glEnable(GL_LIGHTING); /* enable lighting */
glEnable(GL_LIGHT0); /* enable light 0 */
```

Summary

- Polygonal Shading
- Light Sources in OpenGL
- Material Properties in OpenGL
- Normal Vectors in OpenGL
- Example: Approximating a Sphere

Preview

- Either
 - Basic texture mapping
 - Curves and surfaces