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 6, 2003

Frank Pfenning
Carnegie Mellon University

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

Polygonal Shading

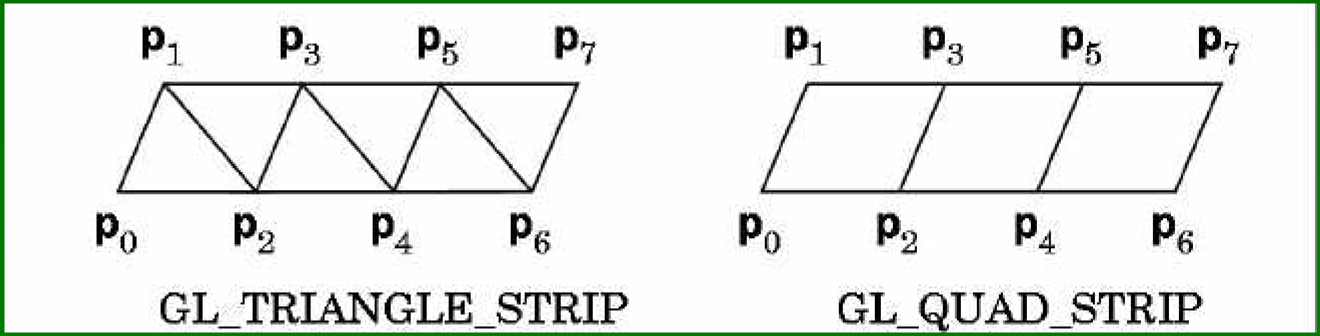
- Curved surfaces are approximated by polygons
- How do we shade?
  - Flat shading
  - Interpolative shading
  - Gouraud shading
  - Phong shading (different from Phong illumination)
- Two questions:
  - How do we determine normals at vertices?
  - How do we calculate shading at interior points?

Flat Shading

- Normal: given explicitly before vertex

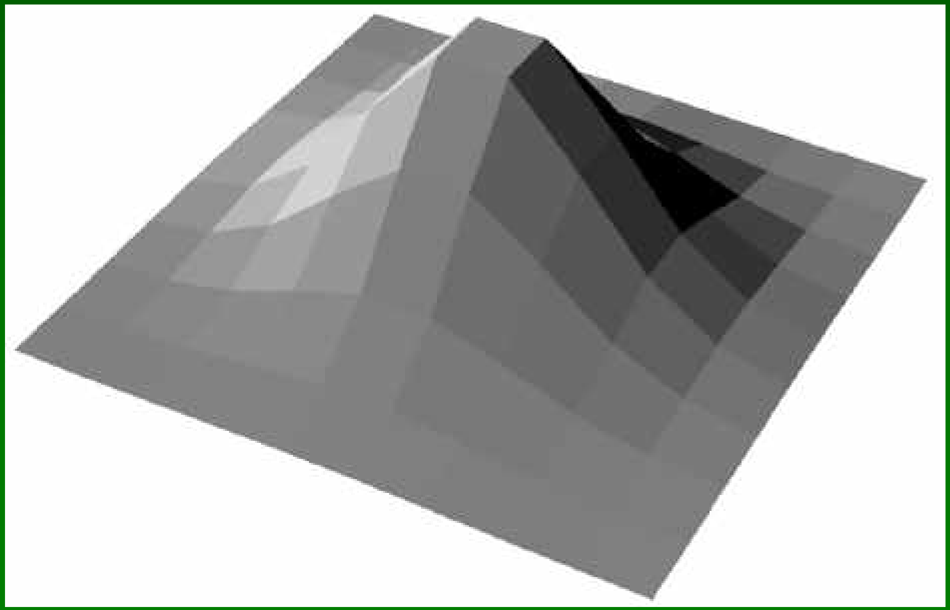
```
glNormal3f(nx, ny, nz);
glVertex3f(x, y, z);
```

- 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

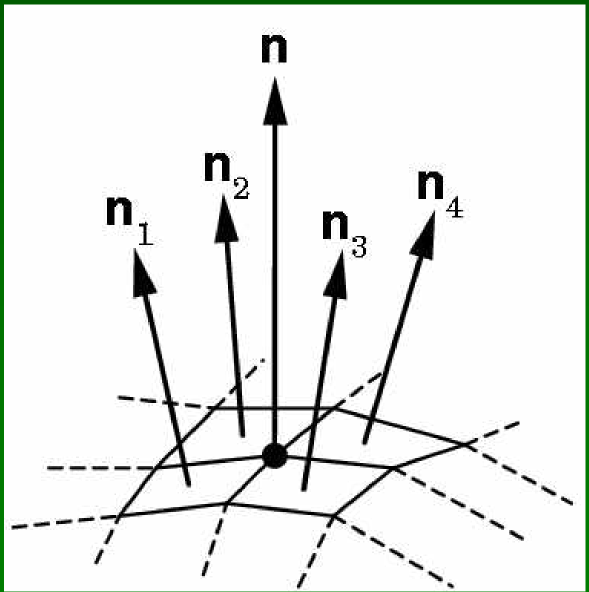
- Enable with glShadeModel(GL_SMOOTH);
- Calculate color at each vertex
- Interpolate color in interior
- Compute during scan conversion (rasterization)
- Much better image (see Assignment 1)
- More expensive to calculate

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

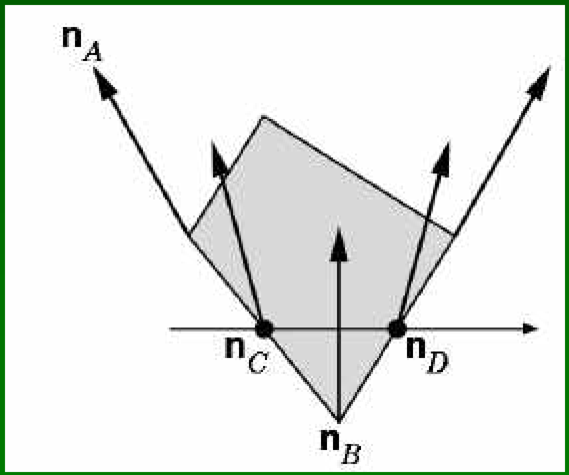


Data Structures for Gouraud Shading

- 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)



Phong Shading Results

Michael Gold, Nvidia

Single pass Phong Lighting Gouraud Shading	Two pass Phong Lighting, Gouraud Shading	Two pass Phong Lighting, Phong Shading

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

- 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

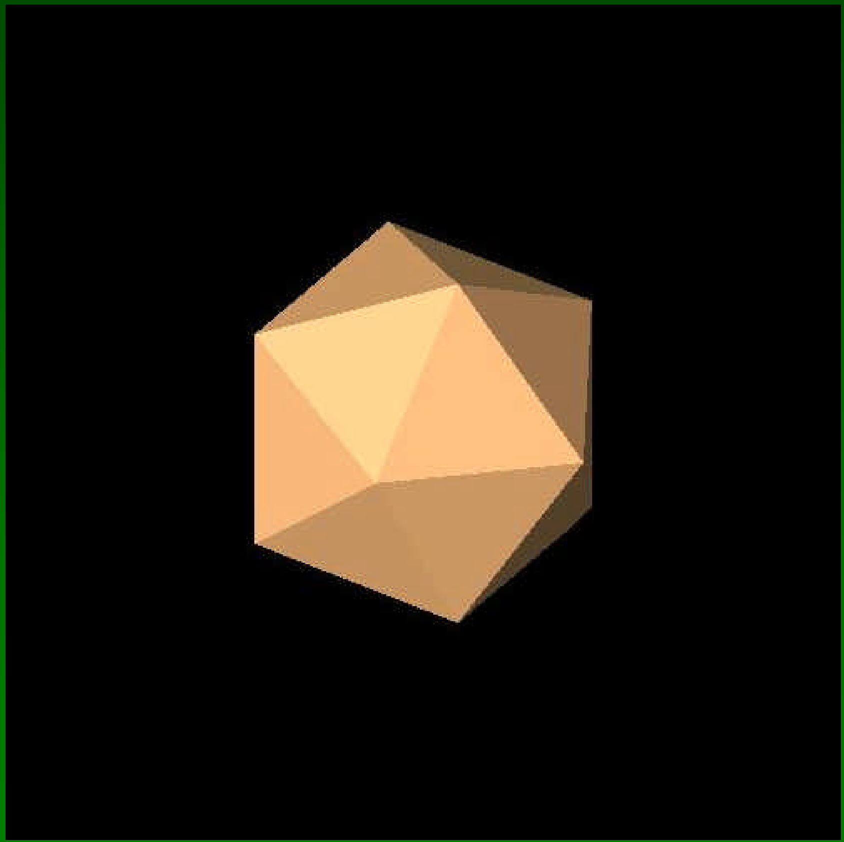
- Omit zero-check for brevity

```
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



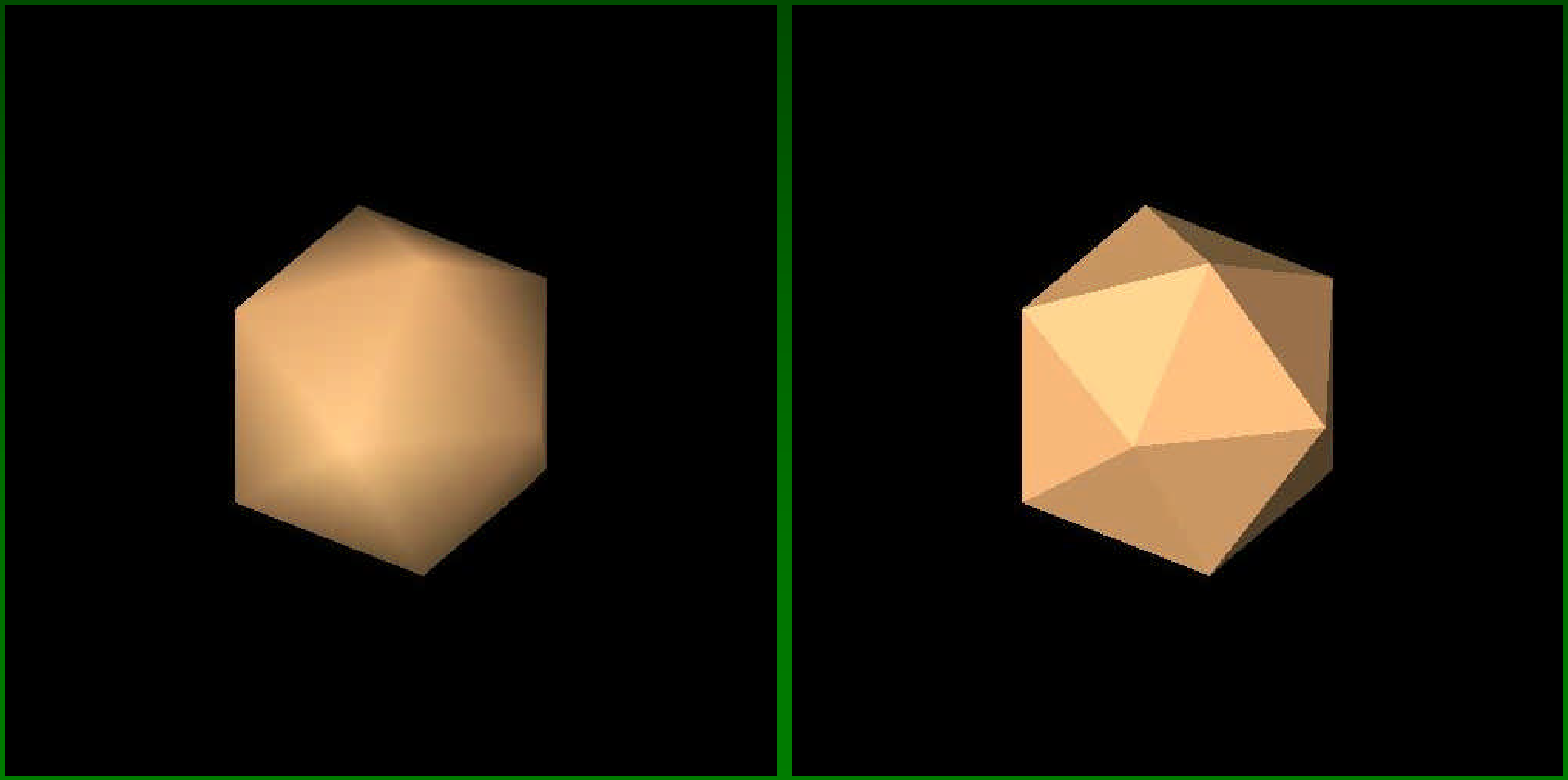
Sphere Normals

- 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

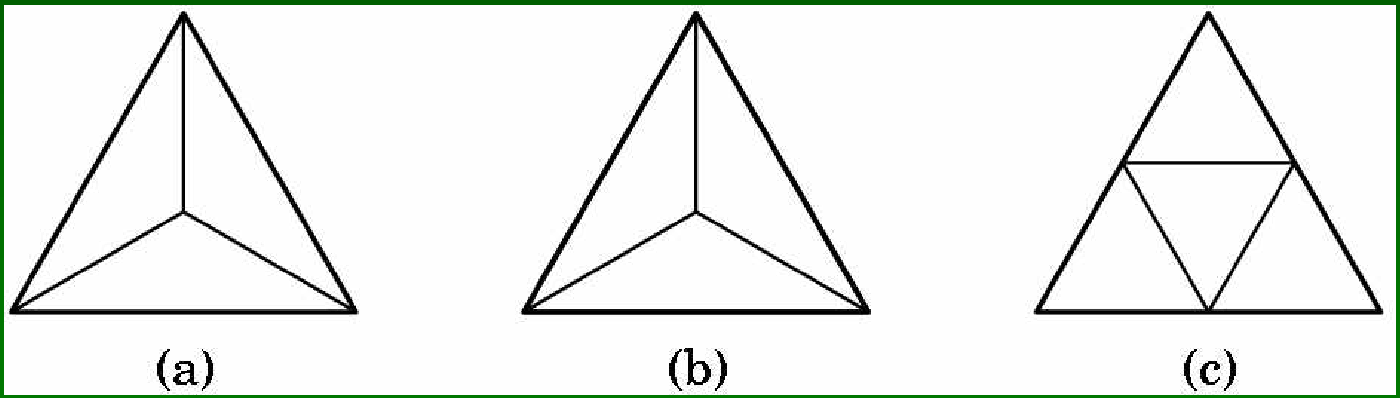


Recursive Subdivision

- 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

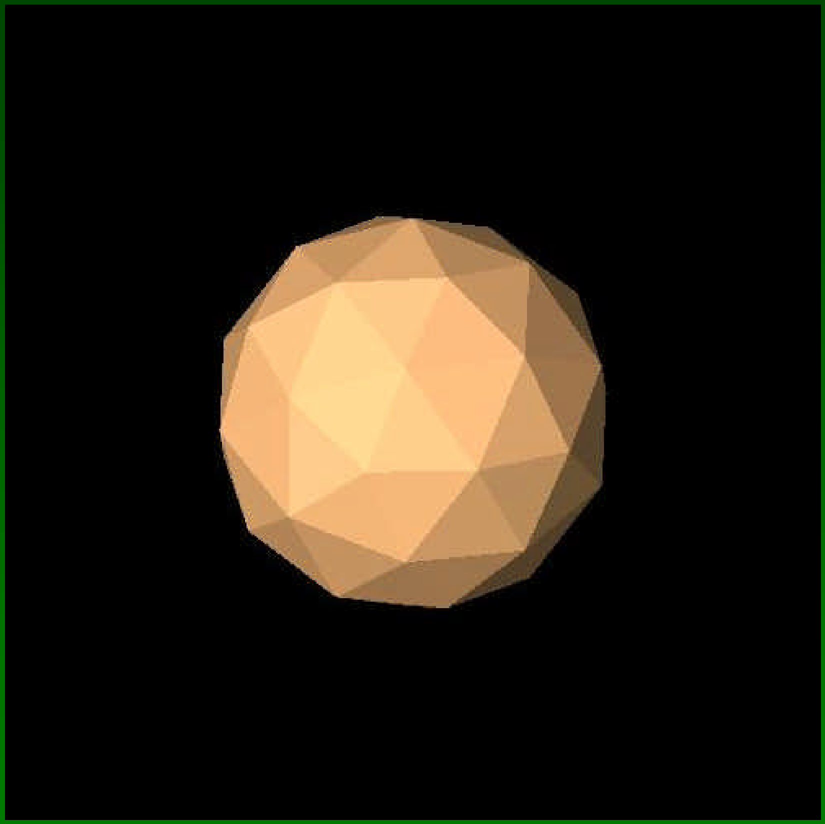
```
void subdivide(GLfloat v1[3], GLfloat v2[3],
               GLfloat v3[3], int depth)
{ ...
  normalize(v12);
  normalize(v23);
  normalize(v31);
  subdivide(v1, v12, v31, depth-1);
  subdivide(v2, v23, v12, depth-1);
  subdivide(v3, v31, v23, depth-1);
  subdivide(v12, v23, v31, depth-1);
}
```

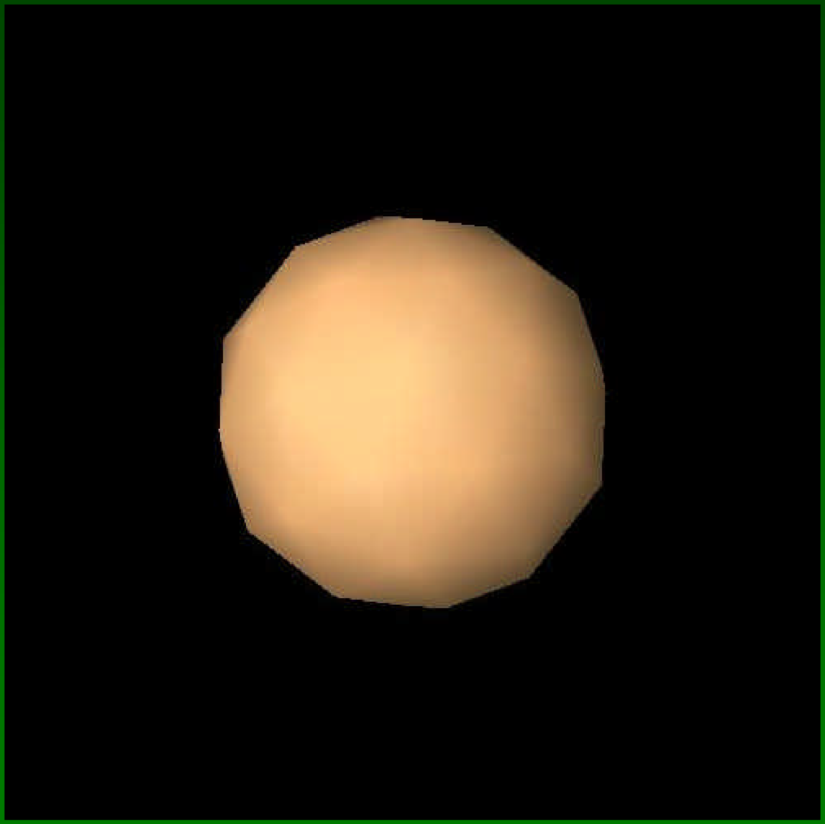
Start with Icosahedron

- 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();
}
```

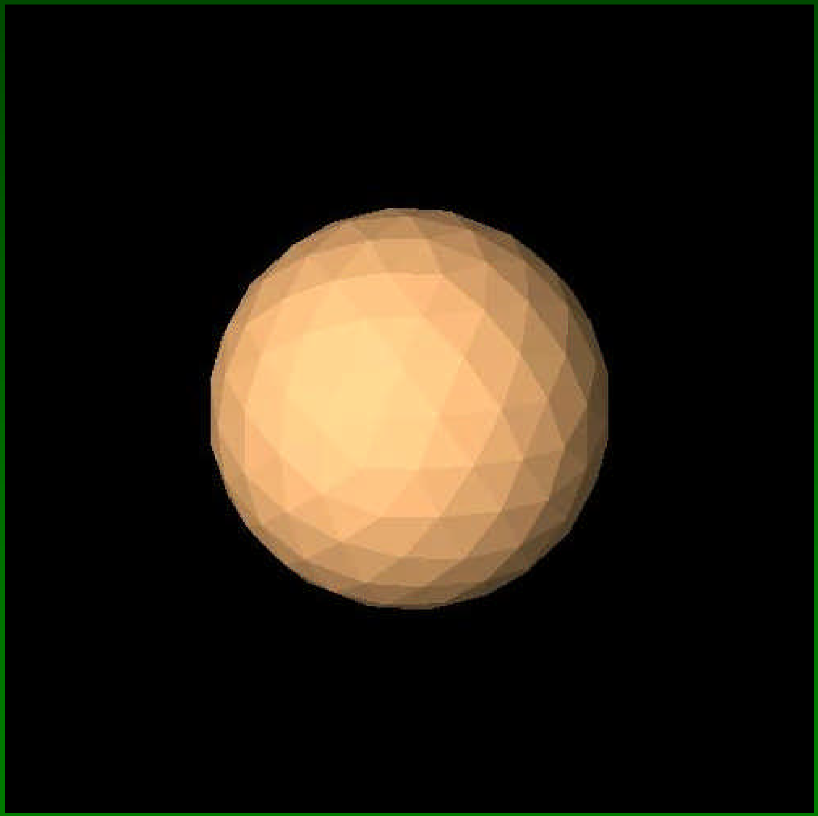
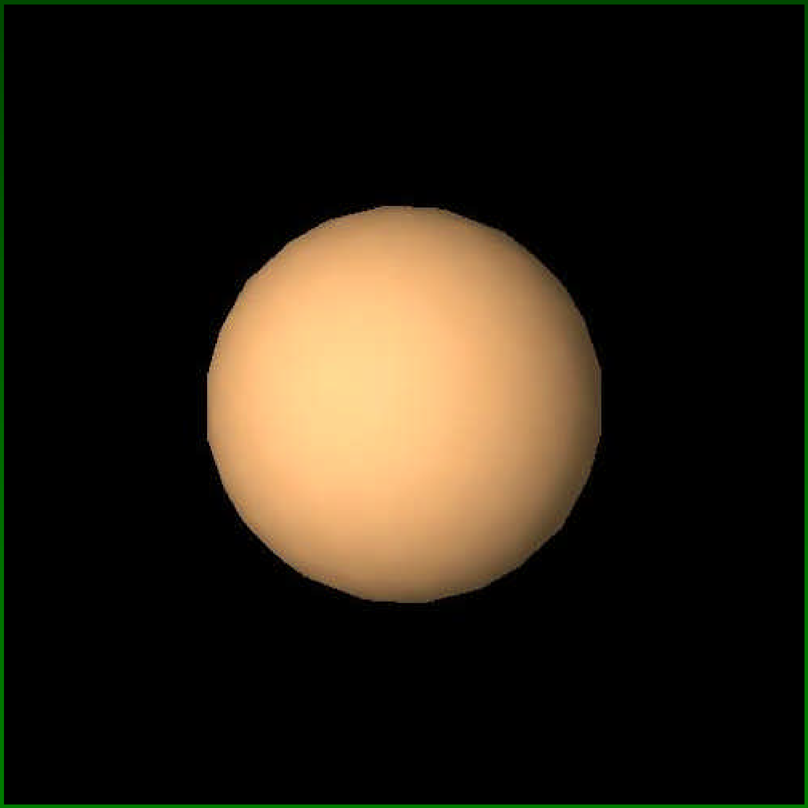
One Subdivision





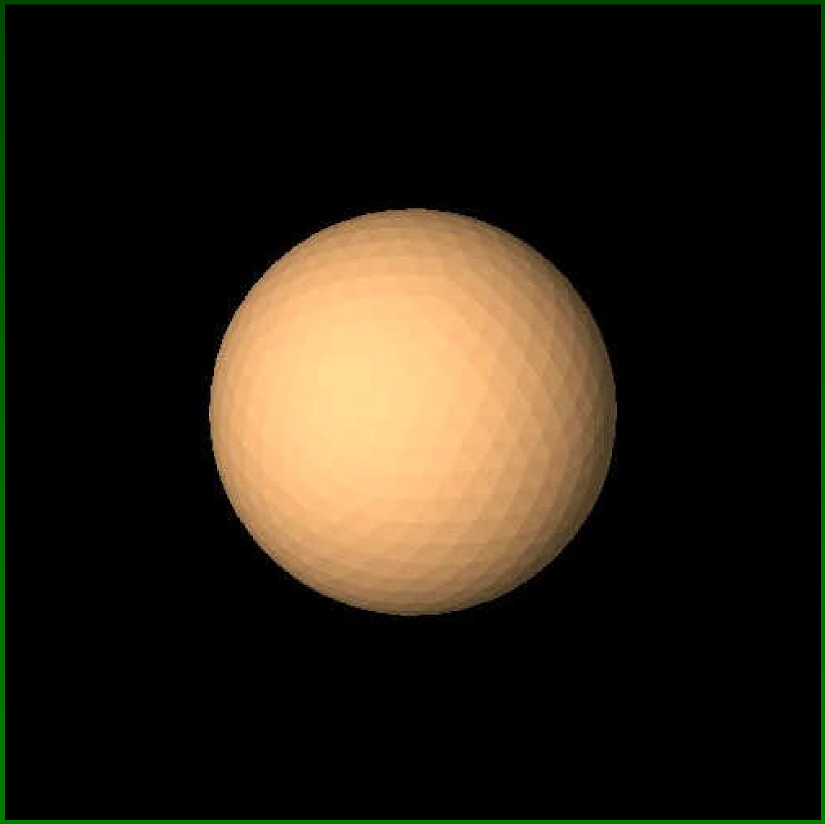
Two Subdivisions

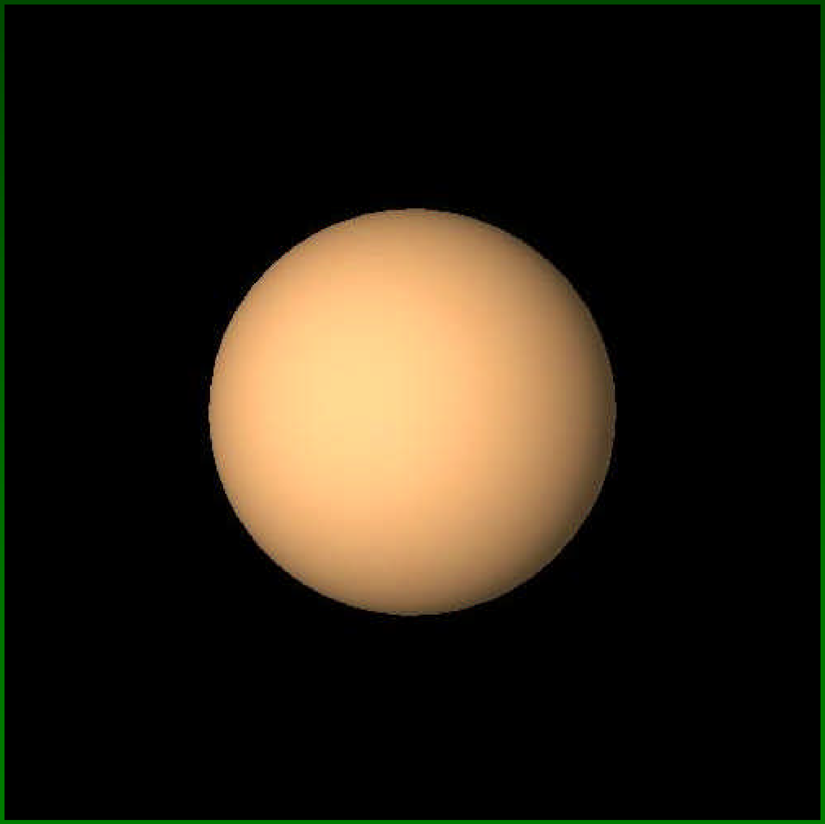
- Each time, multiply number of faces by 4

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