5.2 Shading in OpenGL

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Outline

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

Defining and Maintaining Normals

- Define unit normal before each vertex

```
glNormal3f(nx, ny, nz);
glVertex3f(x1, y1, z1);
glVertex3f(x2, y2, z2);
glVertex3f(x3, y3, z3);
```

```
glNormal3f(nx1, ny1, nz1);
glVertex3f(x1, y1, z1);
glNormal3f(nx2, ny2, nz2);
glVertex3f(x2, y2, z2);
glNormal3f(nx3, ny3, nz3);
glVertex3f(x3, y3, z3);
```

same normal
for all vertices

different normals

Normalization

- Length of normals changes under some modelview transformations (but not under translations and rotations)

- Ask OpenGL to automatically re-normalize

```
glEnable(GL_NORMALIZE);
```

- Faster alternative (works only with translate, rotate and ***uniform*** scaling)

```
glEnable(GL_RESCALE_NORMAL);
```

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Enabling Lighting and Lights

- Lighting "master switch" must be enabled:

```
glEnable(GL_LIGHTING);
```

- Each individual light must be enabled:

```
glEnable(GL_LIGHT0);
```

- OpenGL supports at least 8 light sources

What Determines Vertex Color in OpenGL

Is OpenGL lighting enabled?

NO

Color determined by glColor3f(...)

Ignored:

- normals
- lights
- material properties

YES

Color determined by Phong lighting which uses:

- normals
- lights
- material properties

See also: http://www.sjbaker.org/steve/omniv/opengl_lighting.html

Reminder: Phong Lighting

- Light components for each color:
  - Ambient (L_a), diffuse (L_d), specular (L_s)

- Material coefficients for each color:
  - Ambient (k_a), diffuse (k_d), specular (k_s)

- Distance q for surface point from light source

$$I = \frac{1}{a + bq + cq^2}\left(k_d L_d (l \cdot n) + k_s L_s (r \cdot v)^{\alpha}\right) + k_a L_a$$

l = unit vector to light
n = surface normal
$r = l$ reflected about n
v = vector to viewer

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);
```

- Local viewer: Correct specular highlights

  More expensive, but sometimes more accurate

- Non-local viewer: Assumes camera is far from object

  Approximate, but faster (this is default)

Defining a Light Source

- Use vectors {r, g, b, a} for light properties
- Beware: light positions will be transformed by the modelview matrix

```
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);
```

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Defining Material Properties

```
GLfloat mat_a[] = {0.1, 0.5, 0.8, 1.0};
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_a);
glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_d);
glMaterialfv(GL_FRONT, GL_SPECULAR, mat_s);
glMaterialfv(GL_FRONT, GL_SHININESS, low_sh);
```

OpenGL is a state machine:
material properties stay in effect until changed.

Color Material Mode

- Alternative way to specify material properties
- Uses glColor
- Must be explicitly enabled and disabled

```
glEnable(GL_COLOR_MATERIAL);
/* affect all faces, diffuse reflection properties */
glColorMaterial(GL_FRONT_AND_BACK, 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);
```

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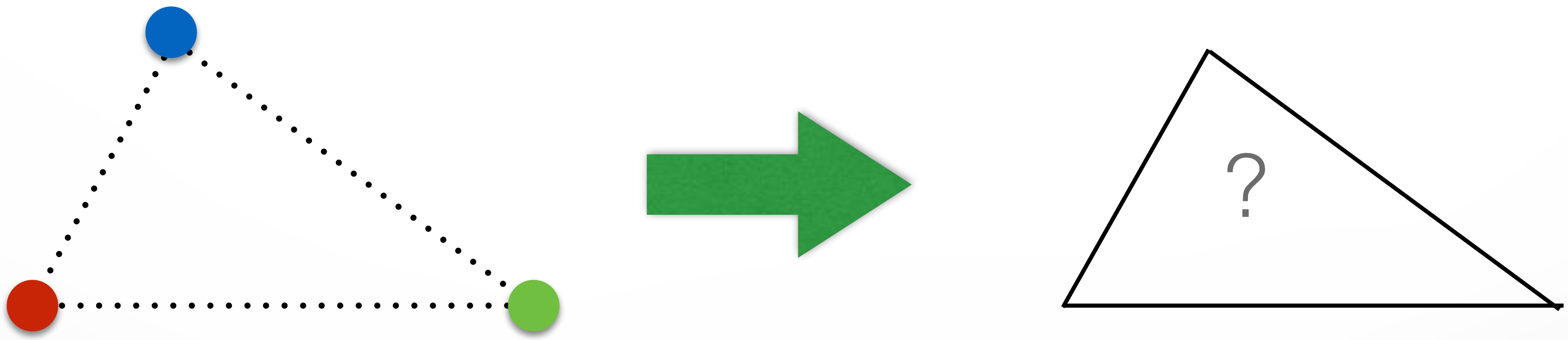
Polygonal Shading

- Now we know vertex colors
  - either via OpenGL lighting,
  - or by setting directly via glColor3f if lighting disabled

- How do we shade the interior of the triangle ?



Polygonal Shading

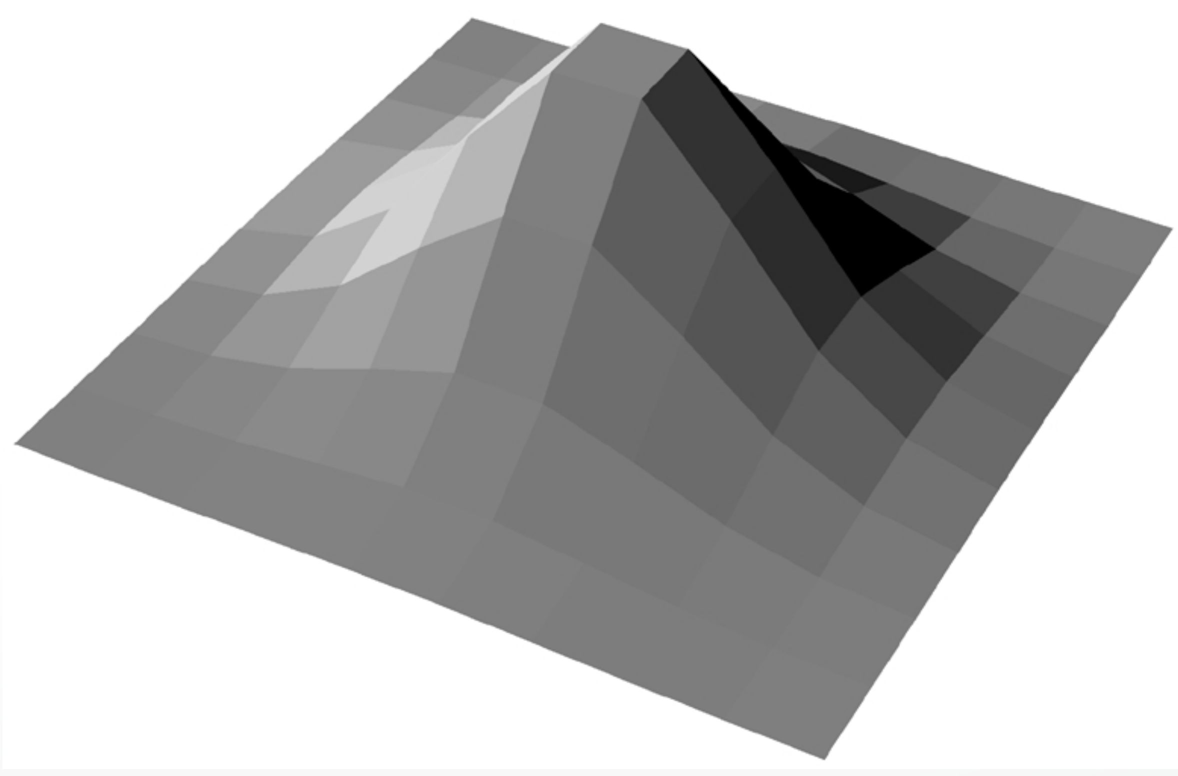
- Curved surfaces are approximated by polygons
- How do we shade?
  - Flat shading
  - Interpolative shading
  - Gouraud shading
  - Phong shading (different from Phong illumination!)

Flat Shading

- Enable with glShadeModel(GL_FLAT);
- Shading constant across polygon
- Color of last vertex determines interior color
- Only suitable for *very* small polygons

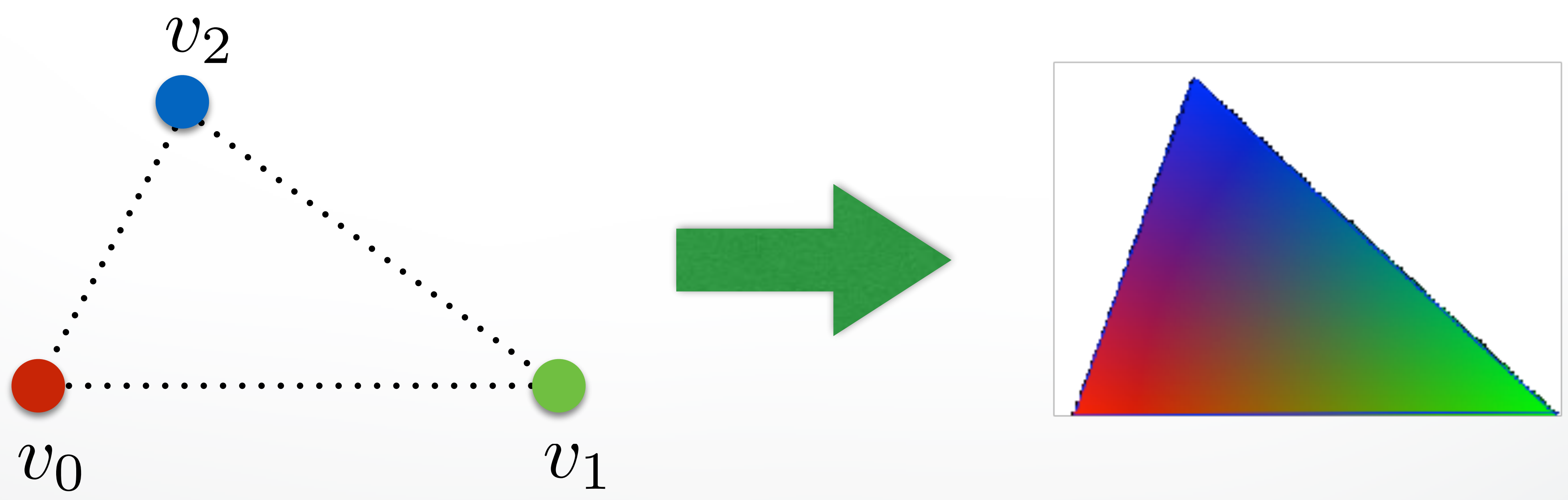
Flat Shading Assessment

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



Interpolative Shading

- Enable with glShadeModel(GL_SMOOTH);
- Interpolate color in interior
- Computed during scan conversion (rasterization)
- Much better than flat shading
- More expensive to calculate
  (but not a problem for modern graphics cards)

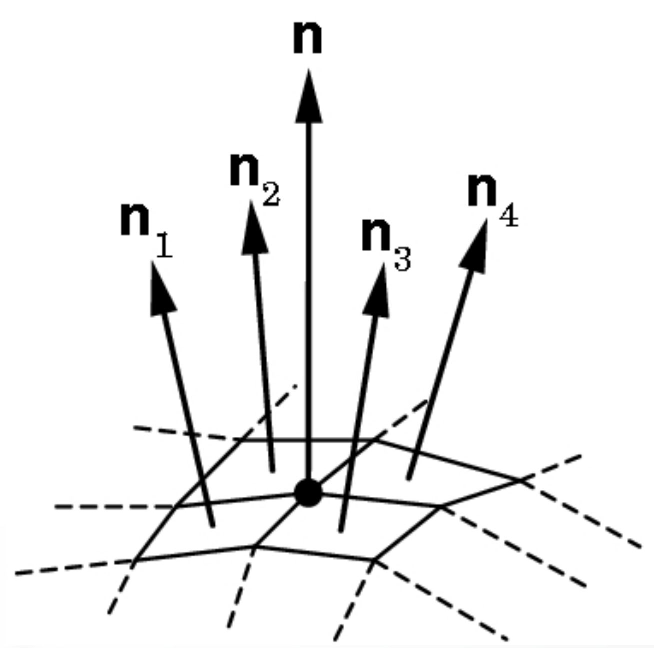


Gouraud Shading

- Invented by Henri Gouraud, Univ. of Utah, 1971
- Special case of interpolative shading
- How do we calculate vertex normals for a polygonal surface? Gouraud:
  1. average all adjacent face normals

$$n = \frac{n_1 + n_2 + n_3 + n_4}{|n_1 + n_2 + n_3 + n_4|}$$

  2. use *n* for Phong lighting
  3. interpolate vertex colors into the interior



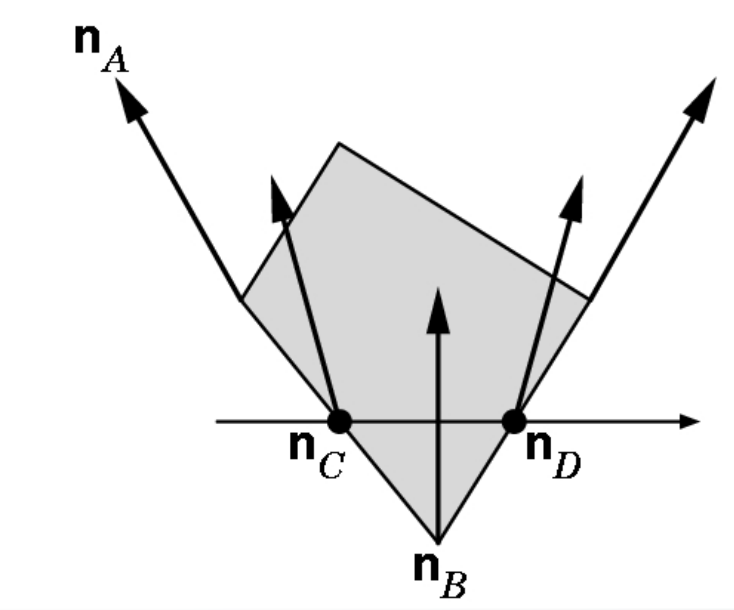
- Requires knowledge about which faces share a vertex

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 ("per-pixel lighting")

- Invented by Bui Tuong Phong, Univ. of Utah, 1973
- *At each pixel* (as opposed to at each vertex) :
  1. Interpolate *normals* (rather than colors)
  2. Apply Phong lighting to the interpolated normal
- Significantly more expensive
- Done off-line or in GPU shaders
  (not supported in OpenGL directly)

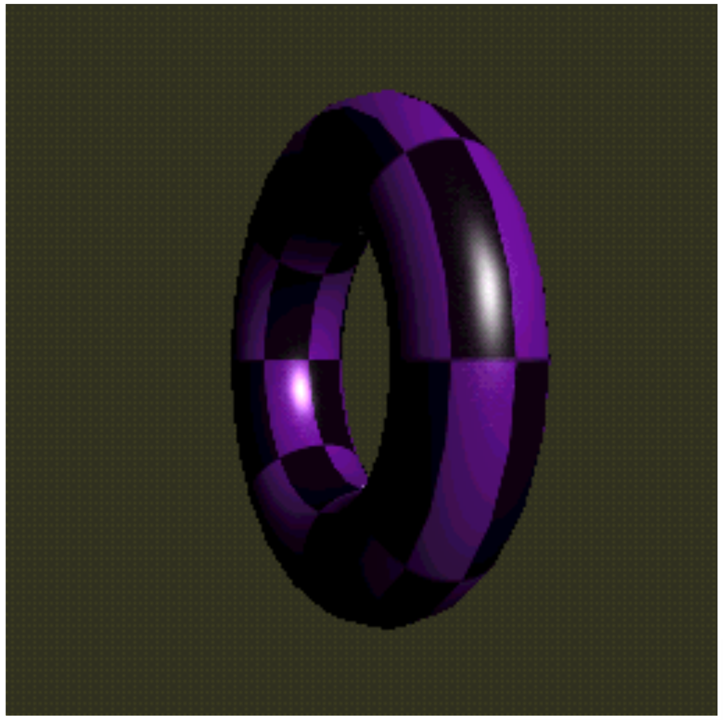


Phong Shading Results

Michael Gold, Nvidia

Single light
Phong Lighting
Gouraud Shading

Two lights
Phong Lighting
Gouraud Shading



Two lights
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!

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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, this example avoids 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

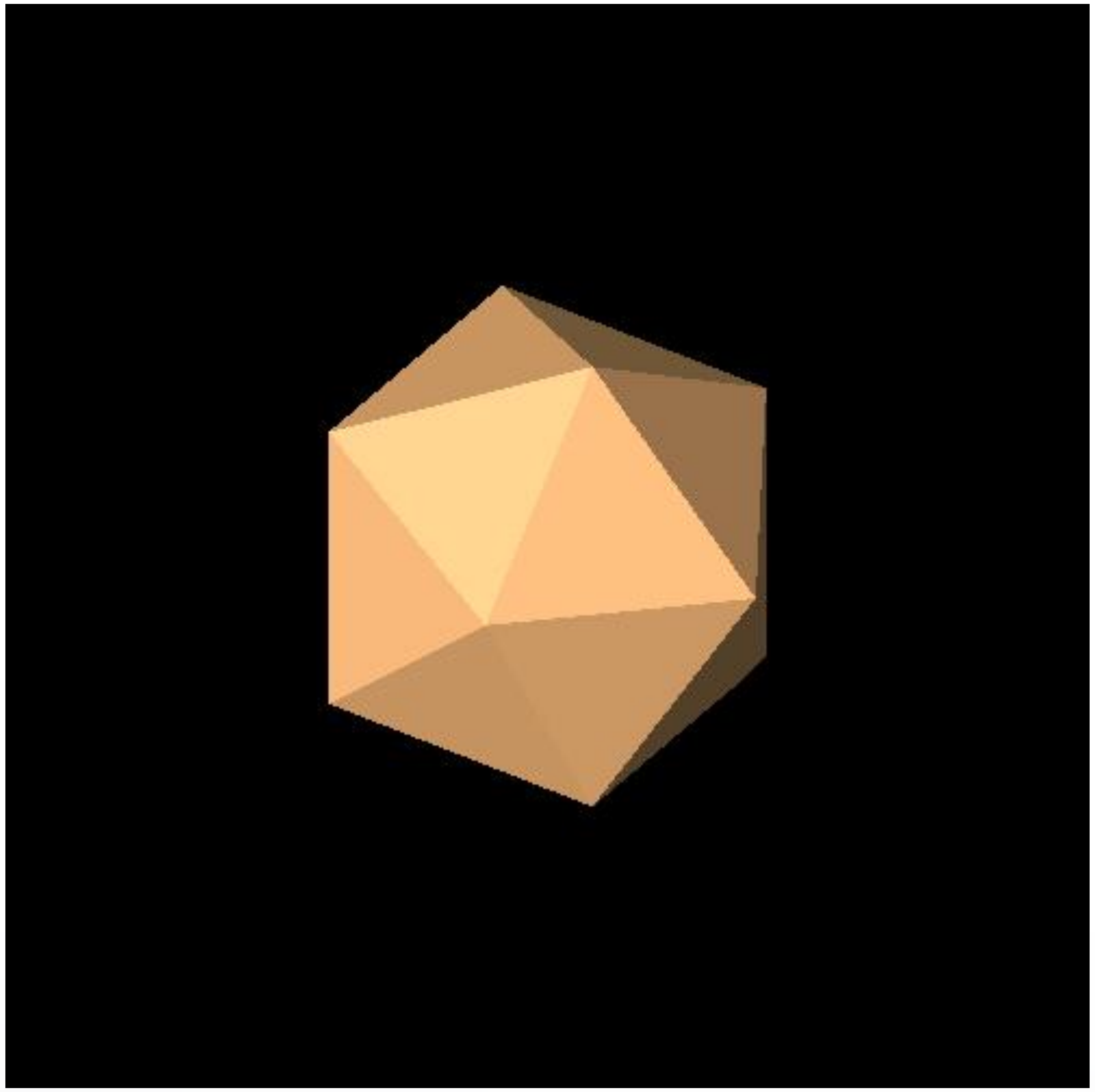
- Omit zero-check for brevity

```
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

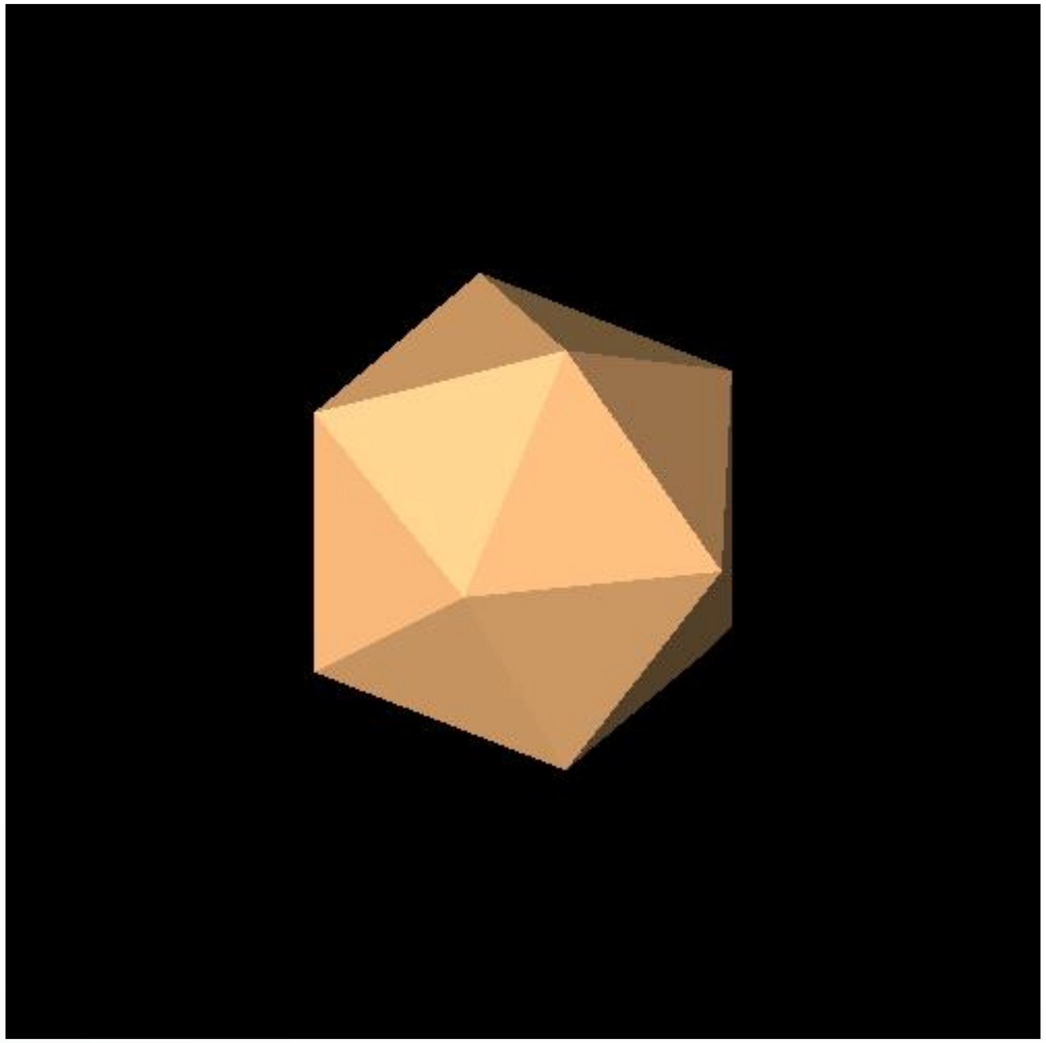


Sphere Normals

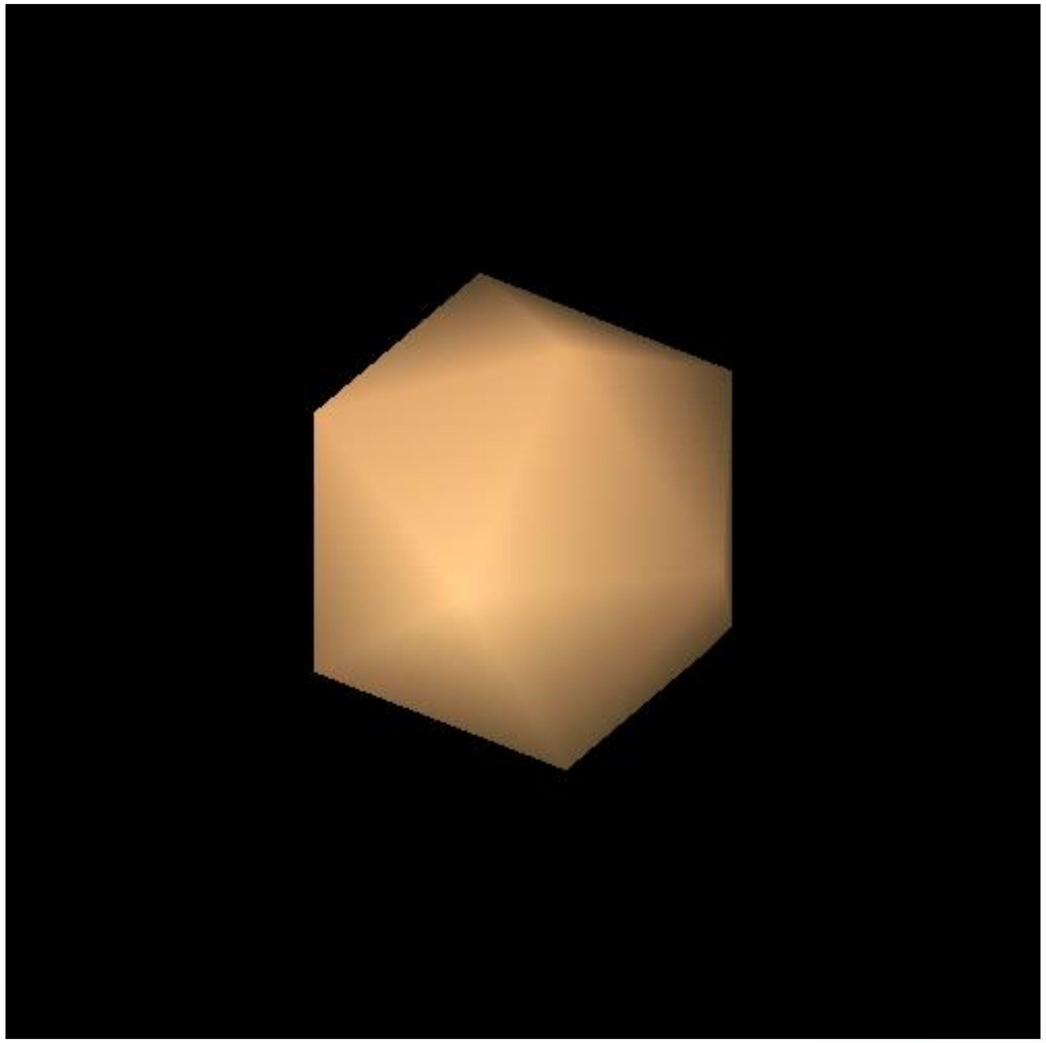
- Set up instead to use normals of sphere
- Unit sphere normal is exactly sphere point

```
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



flat shading



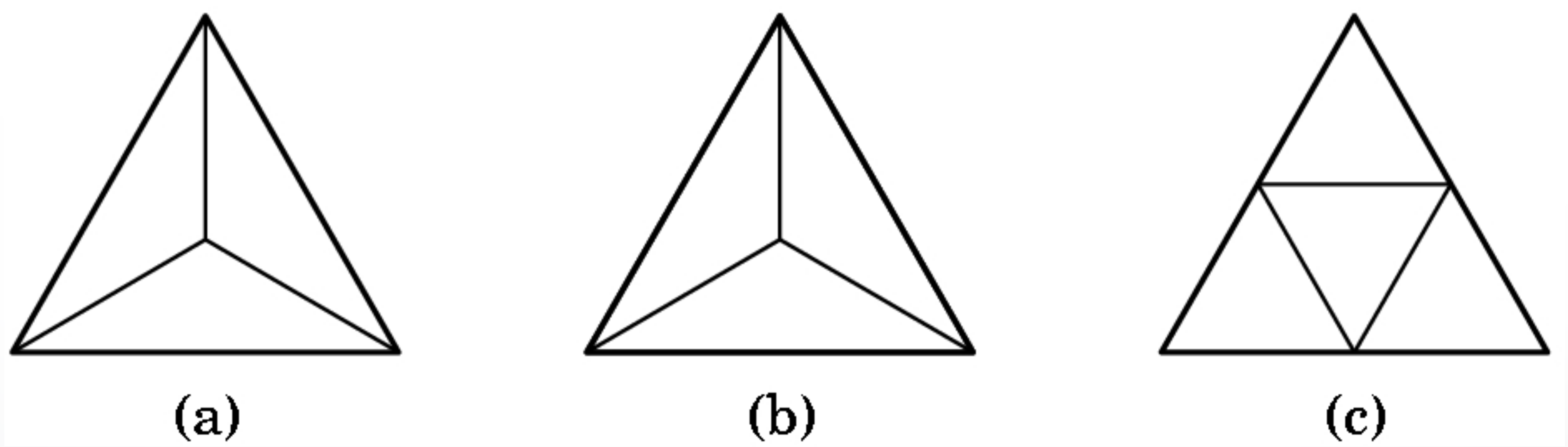
interpolation

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

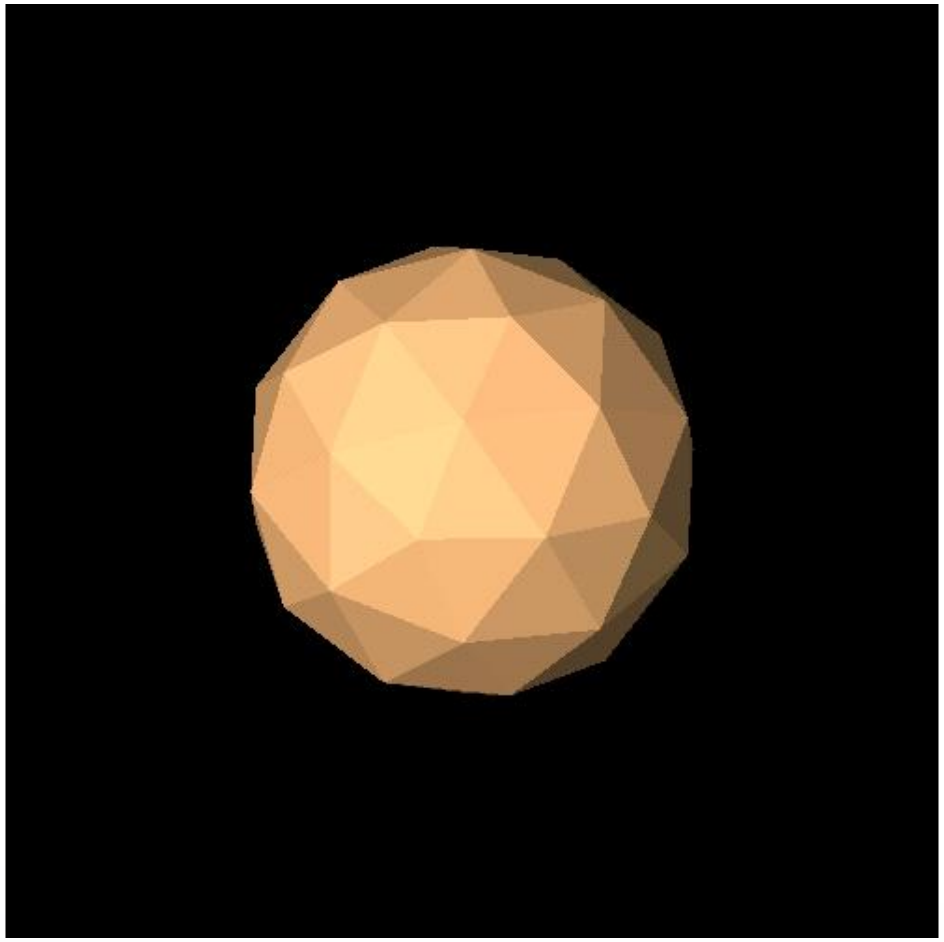
```
void subdivide(GLfloat v1[3], GLfloat v2[3],
               GLfloat v3[3], int depth)
{ ...
  normalize(v12);
  normalize(v23);
  normalize(v31);
  subdivide(v1, v12, v31, depth-1);
  subdivide(v2, v23, v12, depth-1);
  subdivide(v3, v31, v23, depth-1);
  subdivide(v12, v23, v31, depth-1);
}
```

Start with Icosahedron

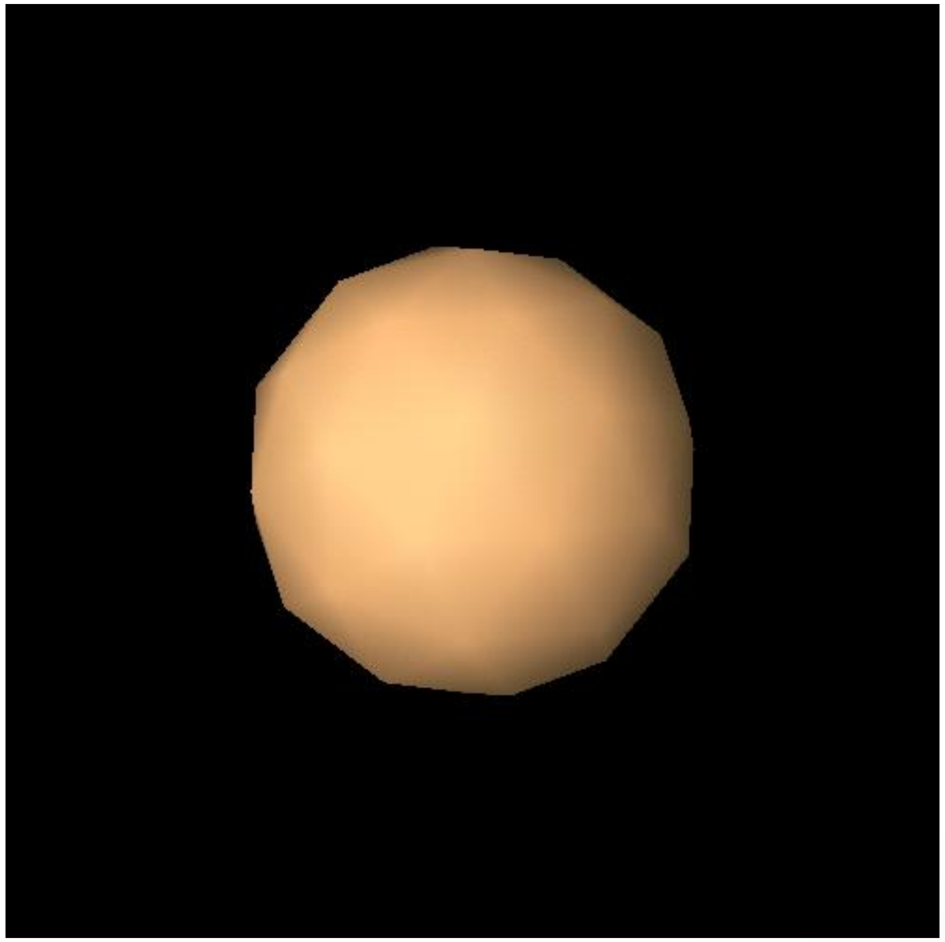
- In sample code: control depth with ‘+’ and ‘-’

```
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



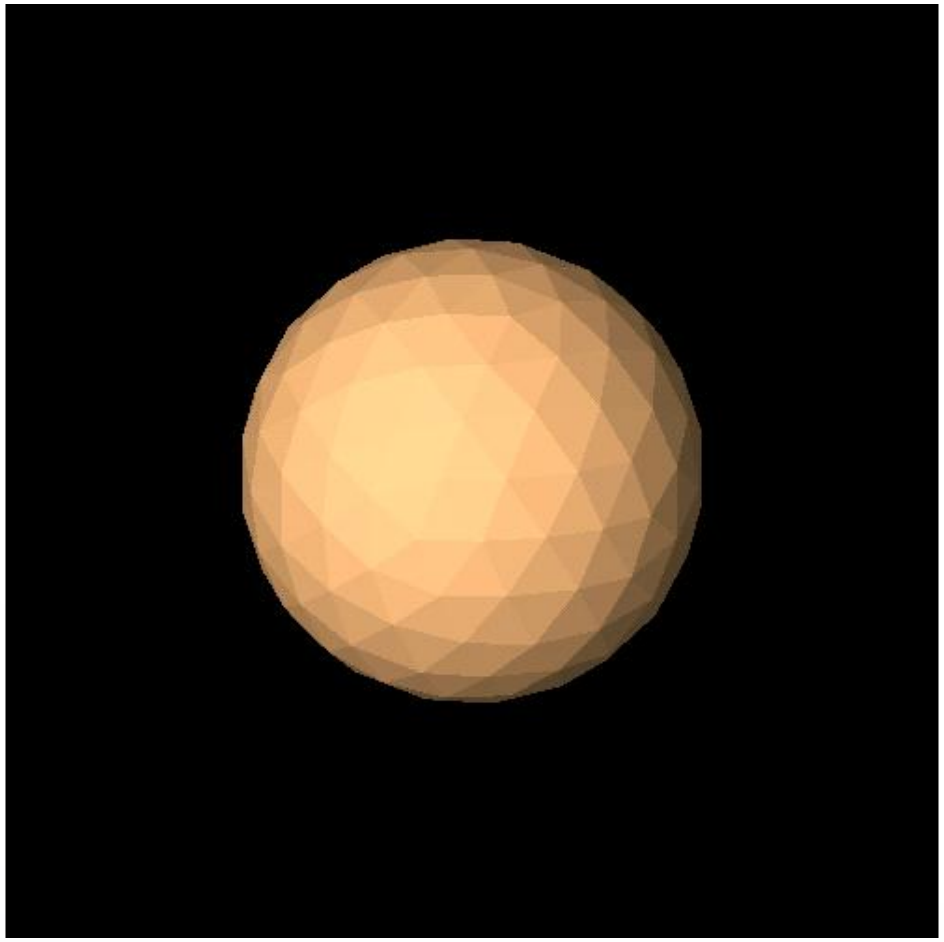
flat shading



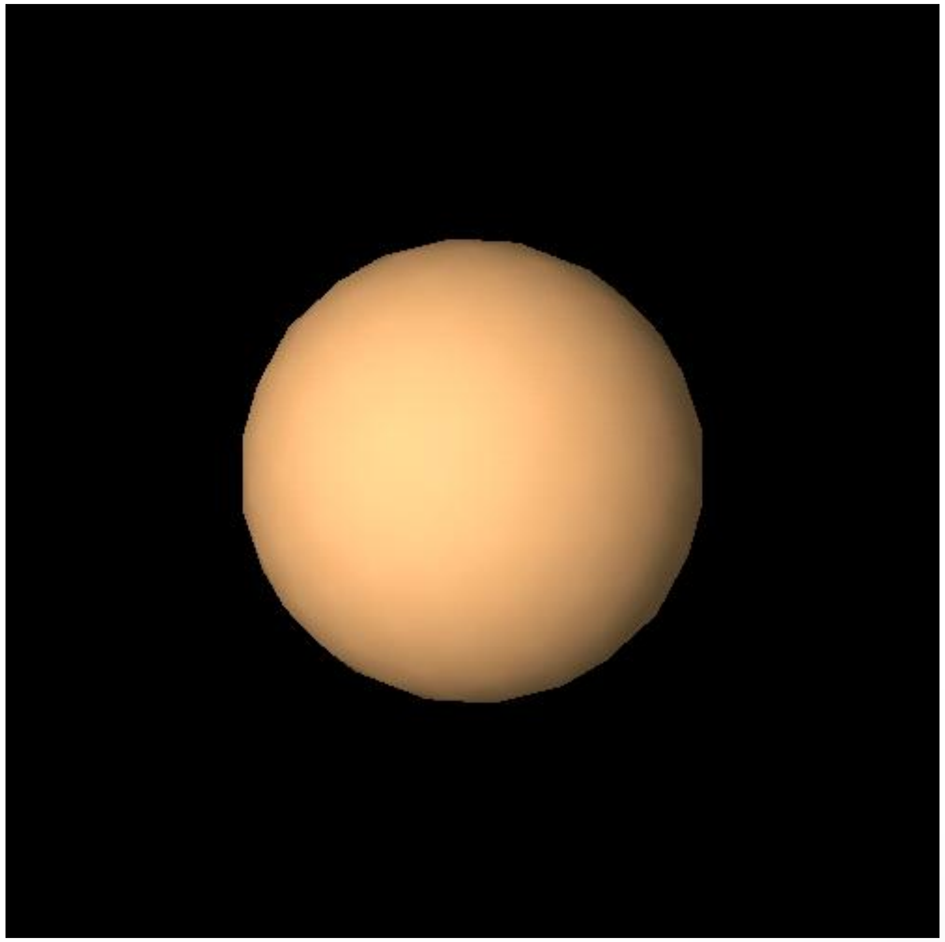
interpolation

Two Subdivision

- Each time, multiply number of faces by 4



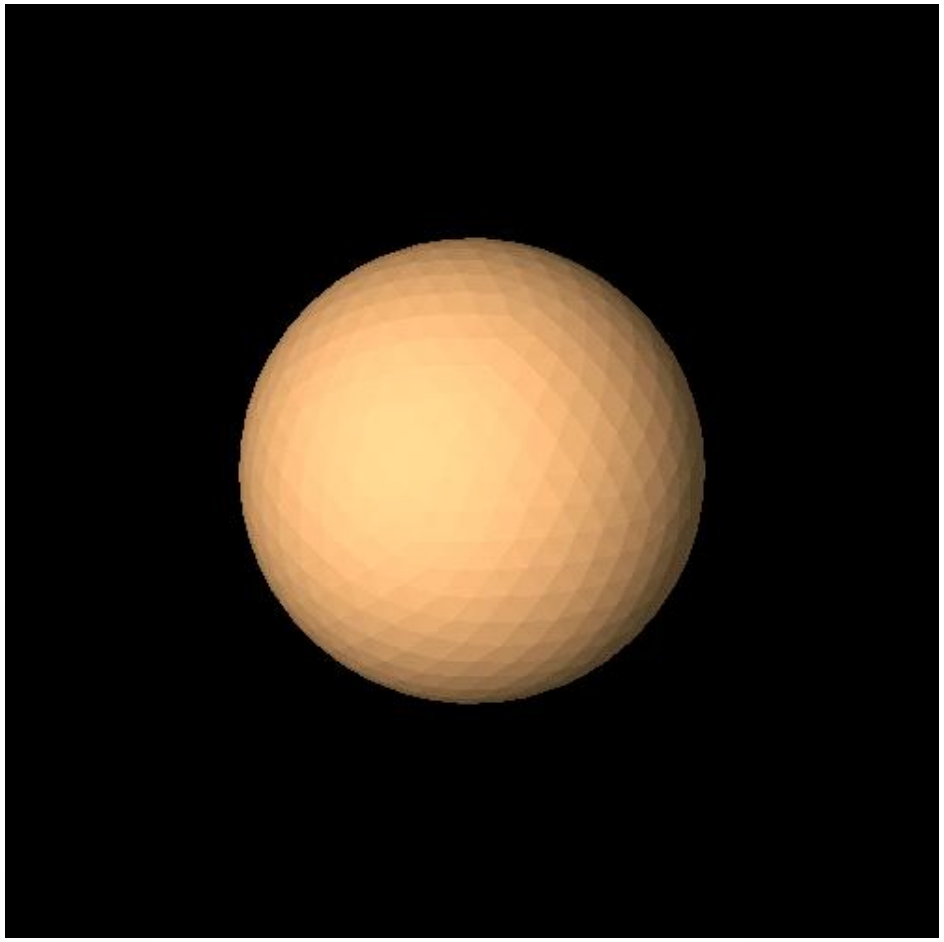
flat shading



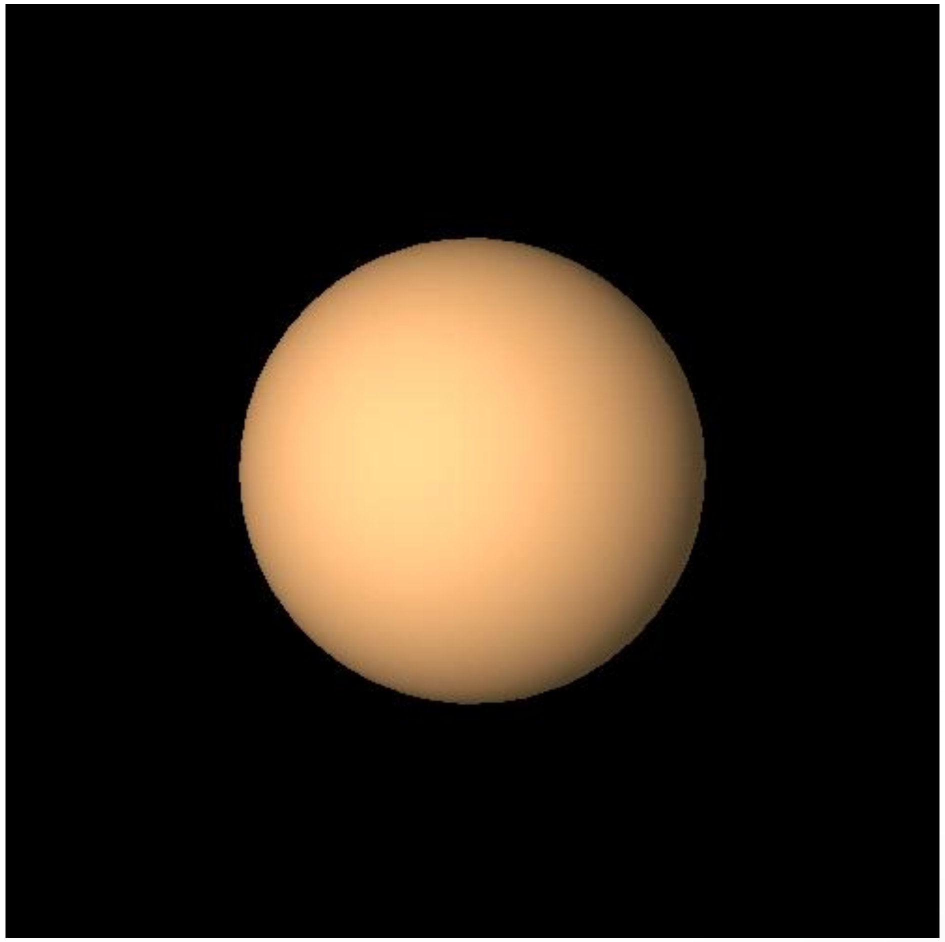
interpolation

Three Subdivision

- Reasonable approximation to sphere



flat shading



interpolation

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 */
```

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