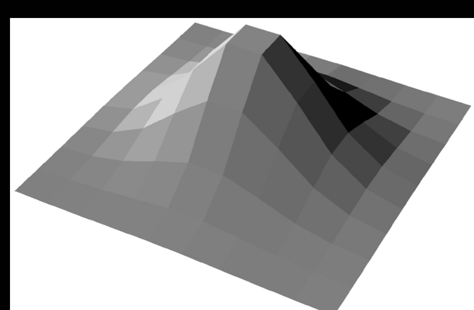
Shading in OpenGL

Polygonal Shading
Light Source in OpenGL
Material Properties in OpenGL
Normal Vectors in OpenGL
Approximating a Sphere
[Angel 6.5-6.9]

Flat Shading Assessment

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



Flat Shading and Perception

- *Lateral inhibition*: exaggerates perceived intensity
- *Mach bands*: perceived “stripes” along edges

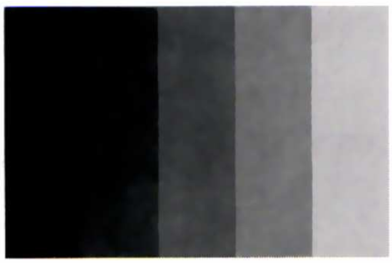


Figure 6.28 Step chart.

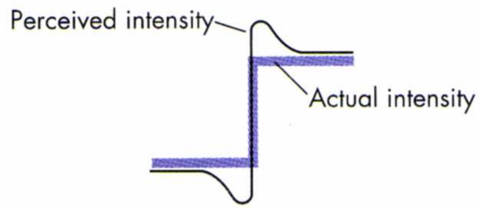
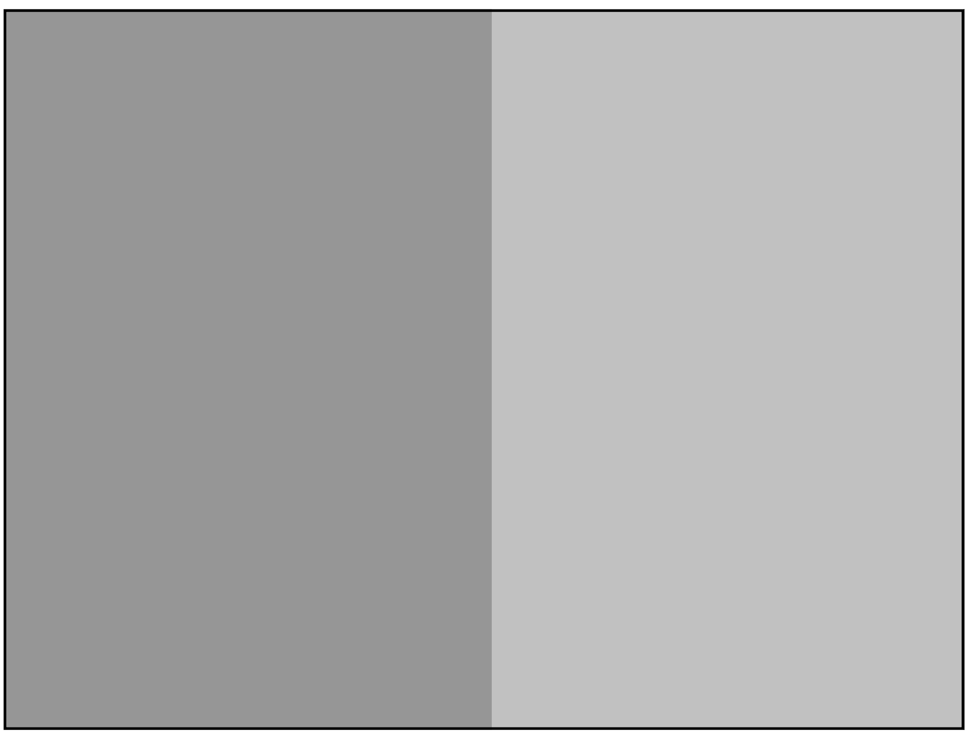
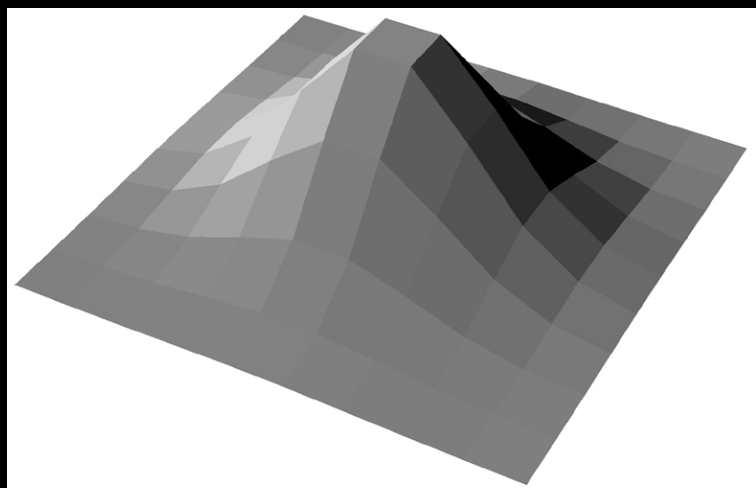


Figure 6.29 Perceived and actual intensities at an edge.





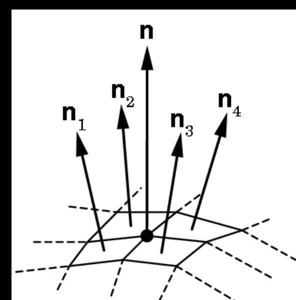
Interpolative Shading

- 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

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



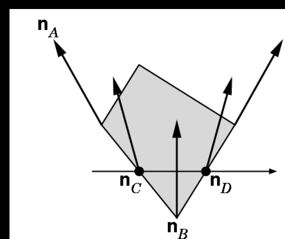
- Requires knowledge about which faces share a vertex—adjacency info

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

Phong Lighting
Gouraud Shading

Phong Lighting,
Phong Shading

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: properly light backs of polygons

```
glLightModeli(GL_LIGHT_MODEL_TWO_SIDED, GL_TRUE)
```

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);
```

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Defining Material Properties

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

```
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);
```

- Diffuse component is analogous

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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 (always works)

```
glEnable(GL_NORMALIZE);
```

- Ask OpenGL to re-scale normal (works for **uniform** scaling, rotate, translate)

```
glEnable(GL_RESCALE_NORMAL);
```

Example: Icosahedron

- Define the vertices

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

static GLfloat vdata[12][3] = {
  {-X, 0, Z}, {X, 0, Z}, {-X, 0, -Z}, {X, 0, -Z},
  {0, Z, X}, {0, Z, -X}, {0, -Z, X}, {0, -Z, -X},
  {Z, X, 0}, {-Z, X, 0}, {Z, -X, 0}, {-Z, -X, 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]]);
  glVertex3fv(&vdata[tindices[i][1]]);
  glVertex3fv(&vdata[tindices[i][2]]);
}
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

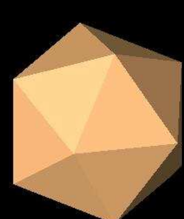
- Omit zero-check for brevity

```
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



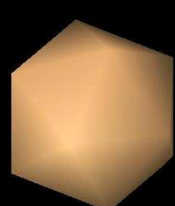
Sphere Normals

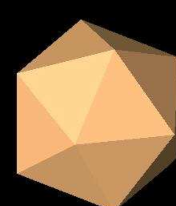
- Set up instead to use normals of sphere
- Unit sphere normal is exactly sphere point

```
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



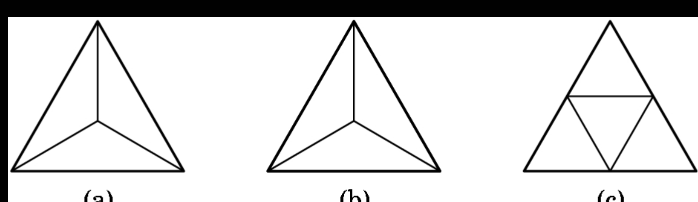


Recursive Subdivision

- 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

- (a) Bisecting angles
- (b) Computing centroid
- (c) Bisecting sides



- Here: bisect sides to retain regularity

Sphere Subdivision: 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);
      return;
  }
  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;
  }
  ...
}
```

Sphere Subdivision: Extrusion of Midpoints

- Re-normalize midpoints to lie on unit sphere

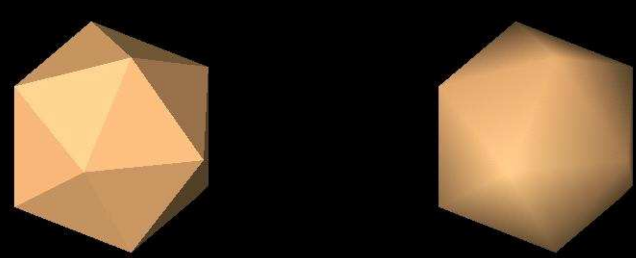
```
void subdivide(GLfloat v1[3],
               GLfloat v2[3],
               GLfloat v3[3], int depth)
{
  ...
  normalize(v12);
  normalize(v23);
  normalize(v31);
  subdivide(v1,  v12, v31, depth-1);
  subdivide(v2,  v23, v12, depth-1);
  subdivide(v3,  v31, v23, depth-1);
  subdivide(v12, v23, v31,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

Sphere Subdivision: 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();
}
```

Icosahedron Unsubdivided



One Subdivision

Two Subdivisions

- Each time, multiply number of faces by 4

Three Subdivisions

- Reasonable approximation to sphere