Shading in OpenGL

Objectives

- Introduce the OpenGL shading functions
- Discuss polygonal shading
  - Flat
  - Smooth
  - Gouraud

Steps in OpenGL shading

1. Enable shading and select model
2. Specify normals
3. Specify material properties
4. Specify lights

Normals

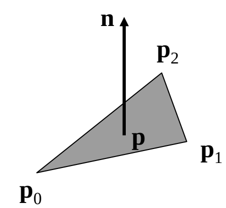
- In OpenGL the normal vector is part of the state
- Set by `glNormal*()`
  - `glNormal3f(x, y, z);`
  - `glNormal3fv(p);`
- Usually we want to set the normal to have unit length so cosine calculations are correct
  - Length can be affected by transformations
  - Note that scaling does not preserved length
  - `glEnable(GL_NORMALIZE)` allows for autonormalization at a performance penalty

Normal for Triangle

plane $\mathbf{n} \cdot (\mathbf{p} - \mathbf{p}_0) = 0$

$\mathbf{n} = (\mathbf{p}_2 - \mathbf{p}_0) \times (\mathbf{p}_1 - \mathbf{p}_0)$

normalize $\mathbf{n} \leftarrow \mathbf{n} / |\mathbf{n}|$



Note that right-hand rule determines outward face

Enabling Shading

- Shading calculations are enabled by
  - `glEnable(GL_LIGHTING)`
  - Once lighting is enabled, glColor() ignored
- Must enable each light source individually
  - `glEnable(GL_LIGHTi)` i=0,1…..
- Can choose light model parameters
  - `glLightModeli(parameter, GL_TRUE)`
    - `GL_LIGHT_MODEL_LOCAL_VIEWER` do not use simplifying distant viewer assumption in calculation
    - `GL_LIGHT_MODEL_TWO_SIDED` shades both sides of polygons independently

Defining a Point Light Source

- For each light source, we can set an RGB for the diffuse, specular, and ambient parts, and the position

```
GL float diffuse0[]={1.0, 0.0, 0.0, 1.0};
GL float ambient0[]={0.1, 0.1, 0.1, 1.0};
GL float specular0[]={1.0, 1.0, 1.0, 1.0};
Glfloat light0_pos[]={1.0, 2.0, 3,0, 1.0};

glEnable(GL_LIGHTING);
glEnable(GL_LIGHT0);
glLightv(GL_LIGHT0, GL_POSITION, light0_pos);
glLightv(GL_LIGHT0, GL_AMBIENT, ambient0);
glLightv(GL_LIGHT0, GL_DIFFUSE, diffuse0);
glLightv(GL_LIGHT0, GL_SPECULAR, specular0);
```

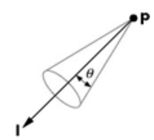

Distance and Direction

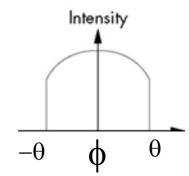
- The source colors are specified in RGBA
- The position is given in homogeneous coordinates
  - If w =1.0, we are specifying a finite location
  - If w =0.0, we are specifying a parallel source with the given direction vector
- The coefficients in the distance terms are by default a=1.0 (constant terms), b=c=0.0 (linear and quadratic terms). Change by

```
a= 0.80;
glLightf(GL_LIGHT0, GLCONSTANT_ATTENUATION, a);
```


Spotlights

- Use `glLightv` to set
  - Direction `GL_SPOT_DIRECTION`
  - Cutoff `GL_SPOT_CUTOFF`
  - Attenuation `GL_SPOT_EXPONENT`
    - Proportional to $\cos^{\alpha}\phi$





Global Ambient Light

- Ambient light depends on color of light sources
  - A red light in a white room will cause a red ambient term that disappears when the light is turned off
- OpenGL allows a global ambient term that is often helpful
  - **`glLightModelfv(GL_LIGHT_MODEL_AMBIENT, global_ambient)`**

Moving Light Sources

- Light sources are geometric objects whose positions or directions are affected by the model-view matrix
- Depending on where we place the position (direction) setting function, we can
  - Move the light source(s) with the object(s)
  - Fix the object(s) and move the light source(s)
  - Fix the light source(s) and move the object(s)
  - Move the light source(s) and object(s) independently

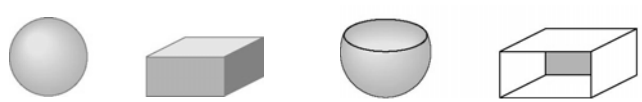
Material Properties

- Material properties are also part of the OpenGL state and match the terms in the Phong model
- Set by **`glMaterialv()`**

```
GLfloat ambient[] = {0.2, 0.2, 0.2, 1.0};
GLfloat diffuse[] = {1.0, 0.8, 0.0, 1.0};
GLfloat specular[] = {1.0, 1.0, 1.0, 1.0};
GLfloat shine = 100.0
glMaterialf(GL_FRONT, GL_AMBIENT, ambient);
glMaterialf(GL_FRONT, GL_DIFFUSE, diffuse);
glMaterialf(GL_FRONT, GL_SPECULAR, specular);
glMaterialf(GL_FRONT, GL_SHININESS, shine);
```


Front and Back Faces

- The default is shade only front faces which works correctly for convex objects
- If we set two sided lighting, OpenGL will shade both sides of a surface
- Each side can have its own properties which are set by using **`GL_FRONT`**, **`GL_BACK`**, or **`GL_FRONT_AND_BACK`** in **`glMaterialf`**



back faces not visible   back faces visible

Emissive Term

- We can simulate a light source in OpenGL by giving a material an emissive component
- This color is unaffected by any sources or transformations

```
GLfloat emission[] = 0.0, 0.3, 0.3, 1.0);
glMaterialf(GL_FRONT, GL_EMISSION, emission);
```


Transparency

- Material properties are specified as RGBA values
- The A value can be used to make the surface translucent
- The default is that all surfaces are opaque regardless of A
- Later we will enable blending and use this feature

Efficiency

- Because material properties are part of the state, if we change materials for many surfaces, we can affect performance
- We can make the code cleaner by defining a material structure and setting all materials during initialization

```
typedef struct materialStruct {
   GLfloat ambient[4];
   GLfloat diffuse[4];
   GLfloat specular[4];
   GLfloat shineness;
} MaterialStruct;
```

We can then select a material by a pointer (see 6.8), and set material properties with a function

Polygonal Shading

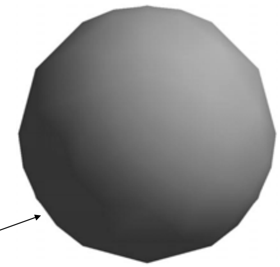
- Shading calculations are done for each vertex
  - Vertex colors become vertex shades
- By default, vertex colors are interpolated across the polygon
  - **`glShadeModel(GL_SMOOTH);`**
- If we use **`glShadeModel(GL_FLAT);`** the color at the first vertex will determine the color of the whole polygon

Polygon Normals

- Polygons have a single normal
  - Shades at the vertices as computed by the Phong model can be almost same
  - Identical for a distant viewer (default) or if there is no specular component
- Consider model of sphere
- Want different normals at each vertex even though this concept is not quite correct mathematically

Smooth Shading

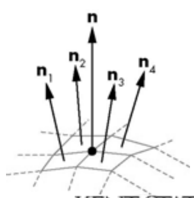
- We can set a new normal at each vertex
- Easy for sphere model
  - If centered at origin **n** = **p**
- Now smooth shading works
- Note *silhouette edge*



Mesh Shading

- The previous example is not general
- Worked because we knew the normal at each vertex analytically
- For polygonal models, Gouraud proposed we use the average of normals around a mesh vertex

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



Gouraud and Phong Shading

- Gouraud Shading
  - Find average normal at each vertex (vertex normals)
  - Apply Phong model at each vertex
  - Interpolate vertex shades across each polygon
- Phong shading
  - Find vertex normals
  - Interpolate vertex normals across edges
  - Find shades along edges
  - Interpolate edge shades across polygons

Comparison

- If the polygon mesh approximates surfaces with high curvatures, Phong shading may look smooth while Gouraud shading may show edges
- Both need data structures to represent meshes so we can obtain vertex normals
- Phong shading requires much more work than Gouraud shading
  - Previously not available in real time systems
  - Can now be implemented using programmable *fragment shading* on modern GPUs