CS 4204 Computer Graphics

OpenGL shading and blending

Yong Cao

Virginia Tech

Objectives

Introduce the OpenGL shading functions

Discuss polygonal shading

- Flat
- Smooth
- Gouraud

Discuss blending in OpenGL

Steps in OpenGL shading

- *Enable shading and select model*
- *Specify normals*
- *Specify material properties*
- *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

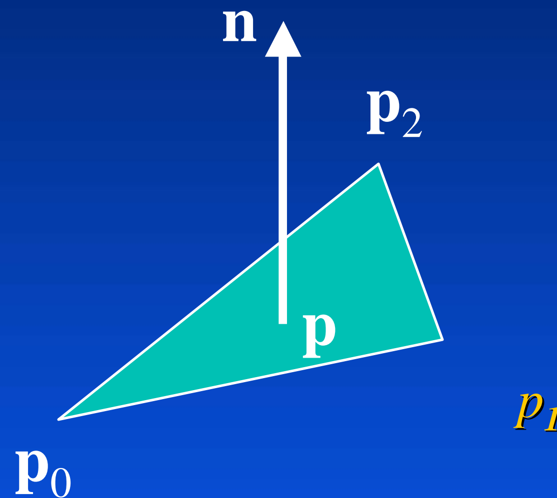
- Length can be affected by transformations
- Note that scaling does not preserved length
- `glEnable(GL_NORMALIZE)` allows for autonormalization at a performance penalty

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 RGBA for the diffuse, specular, and ambient components, and for the position

```
GL float diffuse0[]={1.0, 0.0, 0.0, 1.0};
GL float ambient0[]={1.0, 0.0, 0.0, 1.0};
GL float specular0[]={1.0, 0.0, 0.0, 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

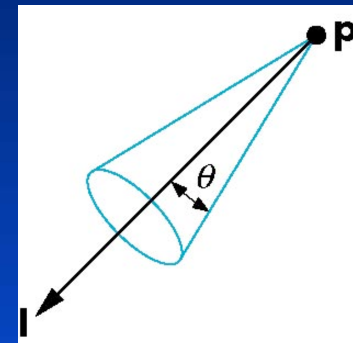
The coefficients in the distance terms are by default a=1.0 (constant terms), b=c=0.0 (linear and quadratic terms). Change by

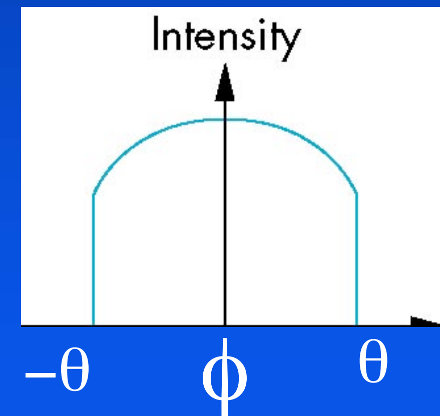
```
a= 0.80;
glLightf(GL_LIGHT0, GLCONSTANT_ATTENUATION, a);
```

Spotlights

Use `glLightv` ***to set***

- Direction `GL_SPOT_DIRECTION`
- Cutoff `GL_SPOT_CUTOFF` θ
- Attenuation `GL_SPOT_EXPONENT`
  - *Proportional to* $\cos^{\alpha}\phi$





$-\theta$ ϕ θ

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 also allows a global ambient term that is often helpful for testing

- `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 modified Phong model

Set by `glMaterialv()`

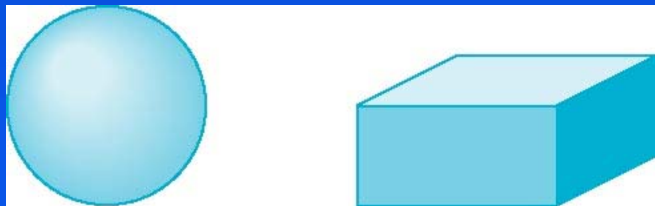
```
GLfloat ambient[] = {0.2, 0.2, 0.2, 1.0};
GLfloat diffuse[] = {1.0, 0.8, 0.0, 1.0};
GLfloat specular[] = {1.0, 1.0, 1.0, 1.0};
GLfloat shine = 100.0
glMaterialf(GL_FRONT, GL_AMBIENT, ambient);
glMaterialf(GL_FRONT, GL_DIFFUSE, diffuse);
glMaterialf(GL_FRONT, GL_SPECULAR, specular);
glMaterialf(GL_FRONT,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

Front and Back Faces

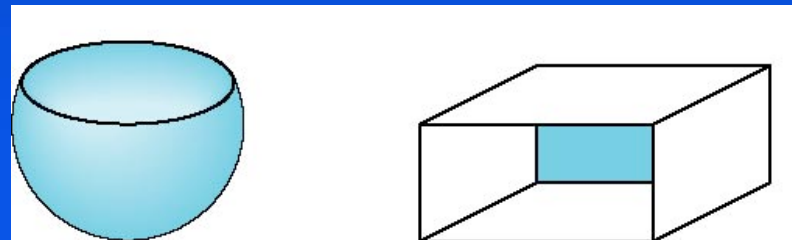
The default is shade only front faces which works correctly for convex objects

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 component 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*

Polygonal Shading

Shading calculations are done for each vertex

- Vertex colors become vertex shades

By default, vertex shades are interpolated across the polygon

- `glShadeModel(GL_SMOOTH);`

If we use *`glShadeModel(GL_FLAT);`* ***the color at the first vertex will determine the shade 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 normal at each vertex*

Smooth Shading

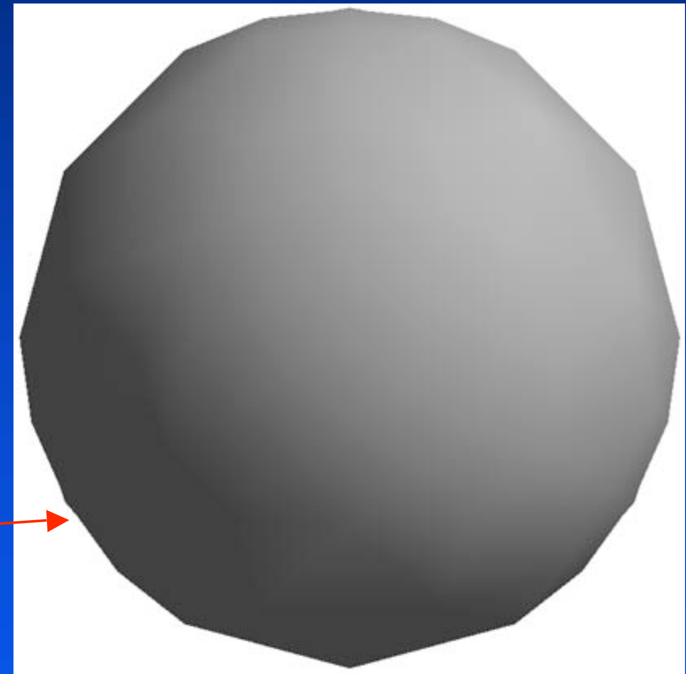
We can set a new normal at each vertex

Easy for sphere model

- If centered at origin $\mathbf{n} = \mathbf{p}$

Now smooth shading works

Note silhouette edge

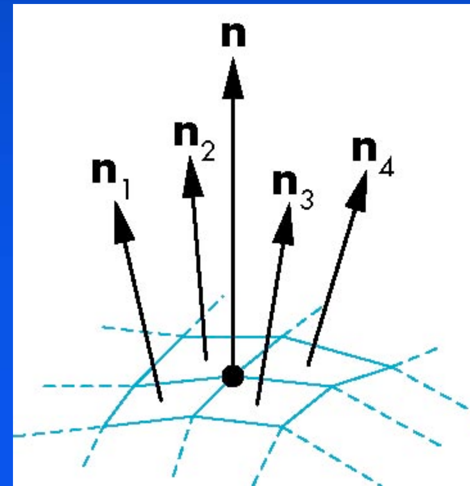


Mesh Shading

The previous example is not general because we knew the normal at each vertex analytically

For polygonal models, Gouraud proposed we use the average of the normals around a mesh vertex

$$\mathbf{n} = (\mathbf{n}_1+\mathbf{n}_2+\mathbf{n}_3+\mathbf{n}_4) / |\mathbf{n}_1+\mathbf{n}_2+\mathbf{n}_3+\mathbf{n}_4|$$



Gouraud and Phong Shading

Gouraud Shading

- Find average normal at each vertex (vertex normals)
- Apply modified Phong model at each vertex
- Interpolate vertex shades across each polygon

Phong shading

- Find vertex normals
- Interpolate vertex normals across edges
- Interpolate edge normals across polygon
- Apply modified Phong model at each fragment

Comparison

If the polygon mesh approximates surfaces with a high curvatures, Phong shading may look smooth while Gouraud shading may show edges

Phong shading requires much more work than Gouraud shading

- Until recently not available in real time systems
- Now can be done using fragment shaders (see Chapter 9)

Both need data structures to represent meshes so we can obtain vertex normals

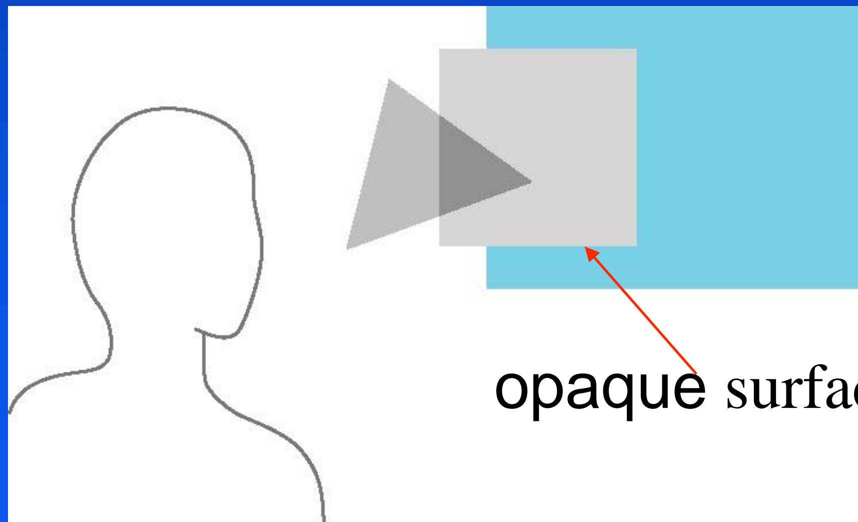
Opacity and Transparency

Opaque surfaces permit no light to pass through

Transparent surfaces permit all light to pass

Translucent surfaces pass some light

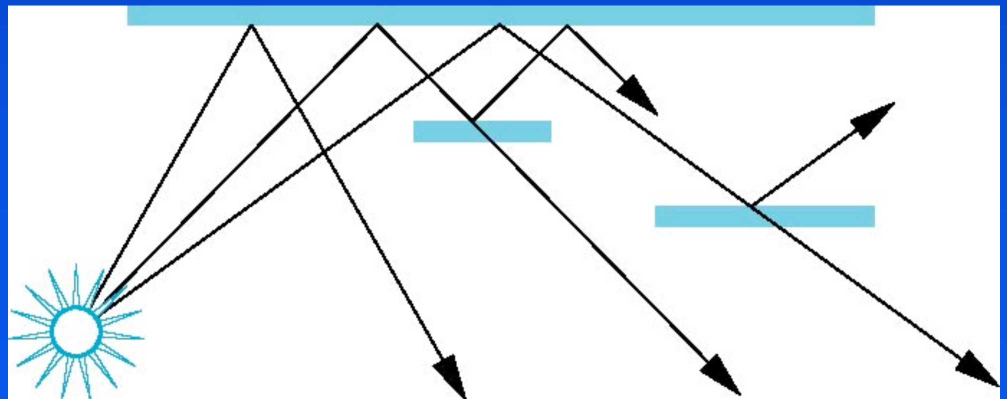
$$\text{translucency} = 1 - \text{opacity}\ (\alpha)$$



Physical Models

Dealing with translucency in a physically correct manner is difficult due to

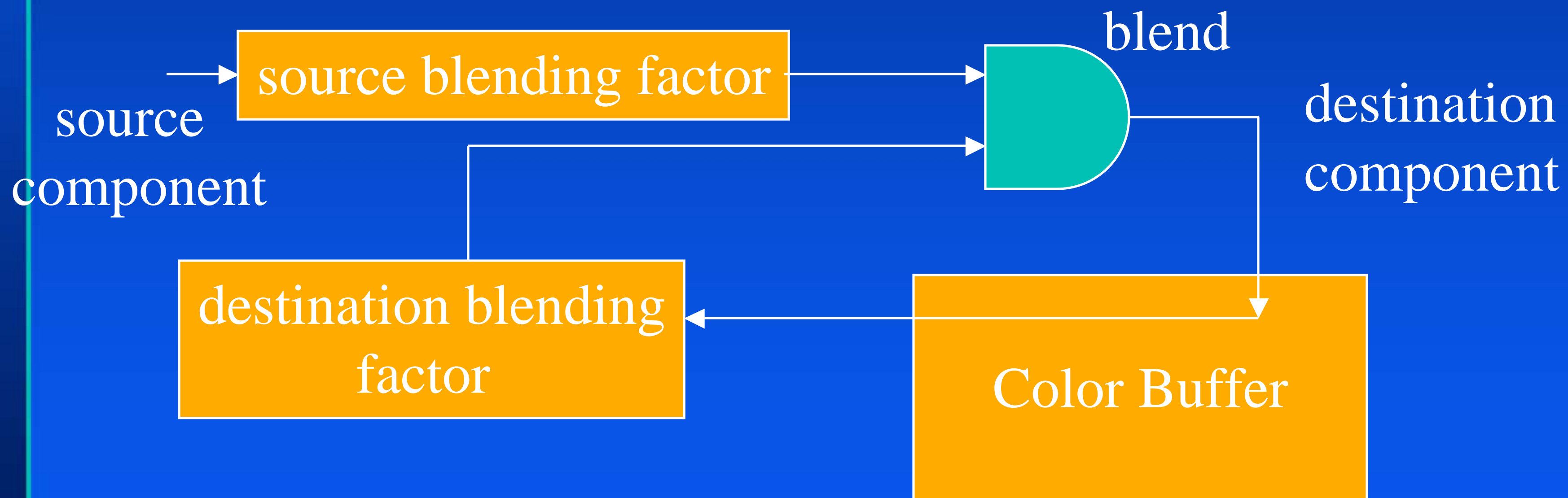
- the complexity of the internal interactions of light and matter
- Using a pipeline renderer



Writing Model

Use A component of RGBA (or RGBα) color to store opacity

During rendering we can expand our writing model to use RGBA values



Blending Equation

We can define source and destination blending factors for each RGBA component

$$s = [s_r, s_g, s_b, s_\alpha]$$

$$d = [d_r, d_g, d_b, d_\alpha]$$

Suppose that the source and destination colors are

$$b = [b_r, b_g, b_b, b_\alpha]$$

$$c = [c_r, c_g, c_b, c_\alpha]$$

Blend as

$$c' = [b_r s_r + c_r d_r, b_g s_g + c_g d_g, b_b s_b + c_b d_b, b_\alpha s_\alpha + c_\alpha d_\alpha]$$

OpenGL Blending and Compositing

Must enable blending and pick source and destination factors

```
glEnable(GL_BLEND)
glBlendFunc(source_factor,
  destination_factor)
```

Only certain factors supported

- **GL_ZERO, GL_ONE**
- **GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA**
- **GL_DST_ALPHA, GL_ONE_MINUS_DST_ALPHA**
- See Redbook for complete list

Example

- ***Suppose that we start with the opaque background color $(R_0, G_0, B_0, 1)$***
  - This color becomes the initial destination color
- ***We now want to blend in a translucent polygon with color $(R_1, G_1, B_1, \alpha_1)$***
- ***Select*** `GL_SRC_ALPHA` ***and*** `GL_ONE_MINUS_SRC_ALPHA` ***as the source and destination blending factors***
- $R'_1 = \alpha_1 R_1 + (1 - \alpha_1) R_0, \ldots\ldots$
- ***Note this formula is correct if polygon is either opaque or transparent***

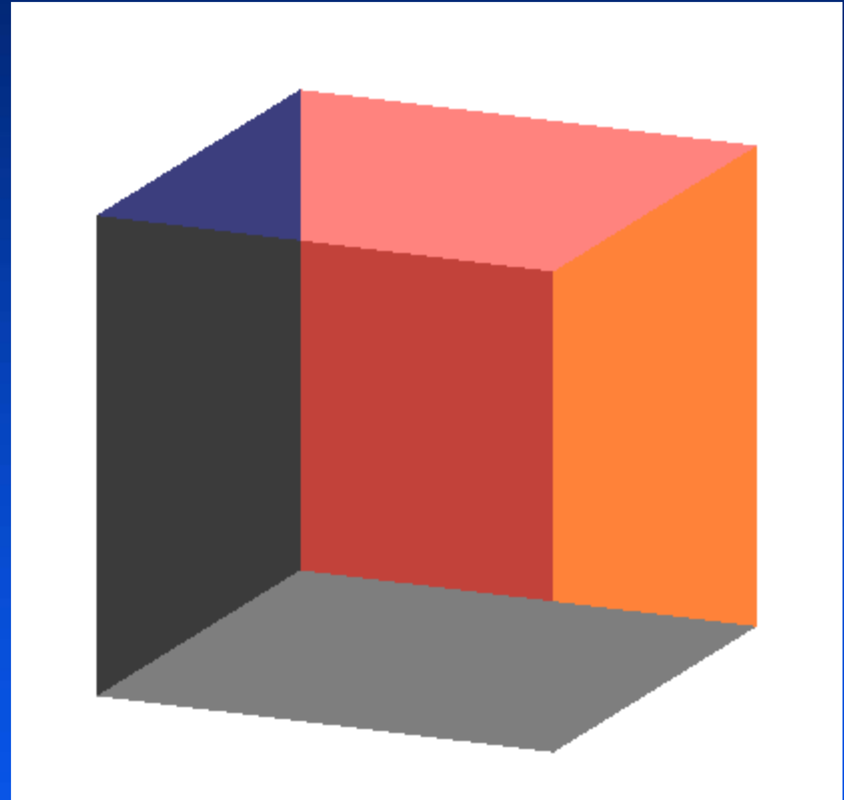
Clamping and Accuracy

- ***All the components (RGBA) are clamped and stay in the range (0,1)***
- ***However, in a typical system, RGBA values are only stored to 8 bits***
  - Can easily loose accuracy if we add many components together
  - Example: add together n images
    - *Divide all color components by n to avoid clamping*
    - *Blend with source factor = 1, destination factor = 1*
    - *But division by n loses bits*

Order Dependency

Is this image correct?

- Probably not
- Polygons are rendered in the order they pass down the pipeline
- Blending functions are order dependent



Opaque and Translucent Polygons

- *Suppose that we have a group of polygons some of which are opaque and some translucent*
- *How do we use hidden-surface removal?*
- *Opaque polygons block all polygons behind them and affect the depth buffer*
- *Translucent polygons should not affect depth buffer*
  - Render with `glDepthMask(GL_FALSE)` which makes depth buffer read-only
- *Sort polygons first to remove order dependency*