Foundations of Computer Graphics
Online Lecture 7: OpenGL Shading

Motivation

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Motivation for Lecture

- Lecture deals with lighting (DEMO for HW 2)
- Briefly explain shaders used for mytest3
  - Do this before explaining code fully so you can start HW 2
  - Primarily explain with reference to source code

Demo for mytest3

- Lighting on teapot
- Blue, red highlights
- Diffuse shading
- Texture on floor
- Update as we move

Importance of Lighting

- Important to bring out 3D appearance
- Important for correct shading under lights
- The way shading is done also important
  - Flat: Entire face has single color (normal) from one vertex
  - Gouraud or smooth: Colors at each vertex, interpolate

Brief primer on Color

- Red, Green, Blue primary colors
  - Can be thought of as vertices of a color cube
  - R+G = Yellow, B+G = Cyan, B+R = Magenta,
  - R+G+B = White
  - Each color channel (R,G,B) treated separately
- RGBA 32 bit mode (8 bits per channel) often used
  - A is for alpha for transparency if you need it
- Colors normalized to 0 to 1 range in OpenGL
  - Often represented as 0 to 255 in terms of pixel intensities

Outline

- Gouraud and Phong shading (vertex vs fragment)
- Types of lighting, materials and shading
  - Lights: Point and Directional
  - Shading: Ambient, Diffuse, Emissive, Specular
- Fragment shader for mytest3
  - HW 2 requires a more general version of this
- Source code in display routine
**Vertex vs Fragment Shaders**

- Can use vertex or fragment shaders for lighting
- Vertex computations interpolated by rasterizing
  - **Gouraud (smooth) shading**, as in mytest1
  - Flat shading: no interpolation (single color of polygon)
- Either compute colors at vertices, interpolate
  - This is standard in old-style OpenGL
  - Can be implemented with vertex shaders
- Or interpolate normals etc. at vertices
- And then shade at each pixel in fragment shader
  - **Phong shading** (different from Phong illumination)
  - More accurate

**Foundations of Computer Graphics**

*Online Lecture 7: OpenGL Shading*

*Gouraud and Phong Shading*

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**Gouraud Shading – Details**

- \( I_a = I_1 \frac{(y_s - y_2)}{(y_1 - y_2)} + I_2 \frac{(y_1 - y_s)}{(y_1 - y_2)} \)
- \( I_b = I_1 \frac{(y_s - y_3)}{(y_1 - y_3)} + I_3 \frac{(y_1 - y_s)}{(y_1 - y_3)} \)
- \( I_p = I_a \frac{(x_b - x_p)}{(x_b - x_a)} + I_b \frac{(x_p - x_a)}{(x_b - x_a)} \)

*Actual implementation efficient: difference equations while scan converting*

**Gouraud and Errors**

- \( I_1 = 0 \) because \((N \cdot E)\) is negative.
- \( I_2 = 0 \) because \((N \cdot L)\) is negative.
- Any interpolation of \( I_1 \) and \( I_2 \) will be 0.

**Phong Illumination Model**

- Specular or glossy materials: highlights
  - Polished floors, glossy paint, whiteboards
  - For plastics highlight is color of light source (not object)
  - For metals, highlight depends on surface color
- Really, (blurred) reflections of light source

**2 Phongs make a Highlight**

- Phong Shading (not illumination) model.
- First interpolate the **normals**, not colors.
- The entire lighting calculation is performed for each pixel, based on the interpolated normal. (Old OpenGL doesn’t do this, but you can and will with current fragment shaders)
Simple Vertex Shader in mytest3

```cpp
// version 1.20
// Mine is an old machine. For version 1.30 or higher, do
// out vec4 color ; out vec4 mynormal ; out vec4 myvertex ;
varying vec4 color ;
varying vec3 mynormal ;
varying vec4 myvertex ;

void main () {
    gl_TexCoord[0] = gl_MultiTexCoord0 ;
    gl_Position = gl_ProjectionMatrix * gl_ModelViewMatrix * gl_Vertex ;
    color = gl_Color ;
    mynormal = gl_Normal ;
    myvertex = gl_Vertex ;
}
```

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Lighting and Shading

Rest of this lecture considers lighting
- In real world, complex lighting, materials interact
- For now some basic approximations to capture key effects in lighting and shading
- Inspired by old OpenGL fixed function pipeline
  - But remember that’s not physically based

Types of Light Sources

- Point
  - Position, Color
  - Attenuation (quadratic model) \( \text{atten} = \frac{1}{k_c + k_d d + k_d d^2} \)
  - Attenuation
- Directional (\( w=0 \), infinite far away, no attenuation)

Sources of Lighting

- Lights: Point and Directional
  - Position, Color
  - Attenuation (quadratic model) \( \text{atten} = \frac{1}{k_c + k_d d + k_d d^2} \)
  - Attenuation
    - Usually assume no attenuation (not physically correct)
    - Quadratic inverse square falloff for point sources
    - Linear falloff for line sources (tube lights). Why?
    - No falloff for distant (directional) sources. Why?

Types of Light Sources
**Material Properties**

- Need normals (to calculate how much diffuse, specular, find reflected direction and so on)
  - Usually specify at each vertex, interpolate
  - GLUT does it automatically for teapots etc
  - Can do manually for parametric surfaces
  - Average face normals for more complex shapes
- Four terms: Ambient, Diffuse, Specular, Emissive

**Emissive Term**

\[ I = E_{\text{material}} \]

Only relevant for light sources when looking directly at them
- Gotcha: must create geometry to actually see light
- Emission does not in itself affect other lighting calculations

**Ambient Term**

- Hack to simulate multiple bounces, scattering of light
- Assume light equally from all directions
- Global constant
- Never have black pixels

\[ I = \text{Ambient} \]

**Diffuse Term**

- Rough matte (technically Lambertian) surfaces
- Light reflects equally in all directions

\[ I = \sum \text{intensity}_i \times \text{diffuse}_\text{material} \times \text{atten} \times \max (L \cdot N, 0) \]

**Specular Term**

- Glossy objects, specular reflections
- Light reflects close to mirror direction
Phong Illumination Model

- Specular or glossy materials: highlights
  - Polished floors, glossy paint, whiteboards
  - For plastics, highlight is color of light source (not object)
  - For metals, highlight depends on surface color
- Really, (blurred) reflections of light source

Idea of Phong Illumination

- Simple way for view-dependent highlights
- Not physically based
- Use dot product (cosine) of eye and reflection of light direction about surface normal
- Alternatively, dot product of half angle and normal
  - Has greater physical backing. We use this form
  - Raise cosine lobe to some power to control sharpness or roughness

Phong Formula

\[ R = -L + 2(L \cdot N)N \]

Alternative: Half-Angle (Blinn-Phong)

\[ I = \sum_{i=0}^{\text{specular}} \text{intensity}_i \cdot \text{specular}_i \cdot \text{atten} \cdot [\max(N \cdot H, 0)]^{\text{power}} \]

Demo in mytest3

- What happens when we make surface less shiny?
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Fragment Shader Example (HW 2 more general)

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Fragment Shader Setup

```plaintext
# version 120
// Mine is an old machine. For version 130 or higher, do
// in vec4 color ; in vec4 mynormal ; in vec4 myvertex ;
// That is certainly more modern

attribute vec4 color ;
attribute vec3 mynormal ;
attribute vec4 myvertex ;

uniform sampler2D tex ;
uniform int istex ;
uniform int islight ; // are we lighting.
```

---

Fragment Shader Variables

```plaintext
// Assume light 0 is directional, light 1 is a point light.
// Actual light values are passed from the main OpenGL program.
uniform vec3 light0dirn ;
uniform vec4 light0color ;
uniform vec4 light1posn ;
uniform vec4 light1color ;

// Now, set the material parameters. These could be varying or
// bound to a buffer. But for now, I’ll just make them uniform.
uniform vec4 ambient ;
uniform vec4 diffuse ;
uniform vec4 specular ;
uniform float shininess ;
```

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Fragment Shader Compute Lighting

```plaintext
vec4 ComputeLight (const in vec3 direction, const in vec4 lightcolor, const in vec3 normal, const in vec3 halfvec, const in vec4 mydiffuse, const in vec4 myspecular, const in float myshininess) {
    float nDotL = dot(normal, direction)  ;
    vec4 lambert = mydiffuse * lightcolor * max (nDotL, 0.0) ;
    float nDotH = dot(normal, halfvec) ;
    vec4 phong = myspecular * lightcolor * pow (max(nDotH, 0.0), myshininess) ;
    vec4 retval = lambert + phong ;
    return retval ; }
```

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Fragment Shader Main Transforms

```plaintext
void main (void) {
    if (istex > 0) gl_FragColor = texture2D(tex, gl_TexCoord[0].st) ;
    else if (islight == 0) gl_FragColor = color ;
    else {
        // They eye is always at (0,0,0) looking down -z axis
        const vec3 eyepos = vec3(0,0,0) ;
        vec4 _mypos = gl_ModelViewMatrix * myvertex ;
        vec3 mypos = _mypos.xyz / _mypos.w ; // Dehomogenize
        vec3 eyedirn = normalize(eyepos - mypos) ;
        // Compute normal, needed for shading.
        // Simpler is vec3 normal = normalize(gl_NormalMatrix * mynormal)
        vec3 normal = normalize((gl_ModelViewMatrixInverseTranspose*vec4(mynormal,0.0)).xyz) ;
        vec4 retval = lambert + phong ;
        return retval ; }
```
Fragment Shader Main Routine

// Light 0, directional
vec3 direction0 = normalize(light0dirn) ;
vec3 half0 = normalize(direction0 + eyedirn) ;
vec4 col0 = ComputeLight(direction0, light0color, normal, half0, diffuse, specular, shininess) ;

// Light 1, point
vec3 position = light1posn.xyz / light1posn.w ;
vec3 direction1 = normalize(position - mypos) ; // no atten.
vec3 half1 = normalize(direction1 + eyedirn) ;
vec4 col1 = ComputeLight(direction1, light1color, normal, half1, diffuse, specular, shininess) ;
gl_FragColor = ambient + col0 + col1 ;
}

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Light Set Up (in display)

/* New for Demo 3; add lighting effects */
const GLfloat one[] = {1,1,1,1} ;
const GLfloat medium[] = {0.5, 0.5, 0.5, 1};
const GLfloat small[] = {0.2, 0.2, 0.2, 1};
const GLfloat high[] = {100} ;
const GLfloat zero[] = {0.0, 0.0, 0.0, 1.0} ;
const GLfloat light_specular[] = {1, 0.5, 0, 1};
const GLfloat light_specular1[] = {0, 0.5, 1, 1};
const GLfloat light_direction[] = {0.5, 0, 0, 0} ; // Dir lt
const GLfloat light_position1[] = {0, -0.5, 0, 1};
GLfloat light0[4], light1[4] ;

// Set Light and Material properties for the teapot
// Lights are transformed by current modelview matrix.
// The shader can't do this globally. So we do it manually.
transformvec(light_direction, light0) ;
transformvec(light_position1, light1) ;

Moving a Light Source

- Lights transform like other geometry
- Only modelview matrix (not projection). One of only real applications where the distinction is important
- Types of light motion
  - Stationary: set the transforms to identity before specifying it
  - Moving light: Push Matrix, move light, Pop Matrix
  - Moving light source with viewpoint (attached to camera). Can simply set light to 0 0 0 so origin wrt eye coords (make modelview matrix identity before doing this)

Modelview Light Transform

- Could also use GLM (but careful of conventions)
- New helper function to transform vector by modelview */
void transformvec (const GLfloat input[4], GLfloat output[4]) {
  GLfloat modelview[16] ; // in column major order
  glGetFloatv(GL_MODELVIEW_MATRIX, modelview) ;
  for (int i = 0 ; i < 4 ; i++) {
    output[i] = 0 ;
    for (int j = 0 ; j < 4 ; j++)
      output[i] += modelview[4*j+i] * input[j] ;
  }
}

Set up Lighting for Teapot

glUniform3fv(light0dirn, 1, light0) ;
glUniform4fv(light0color, 1, light_specular) ;
glUniform4fv(light1posn, 1, light1) ;
glUniform4fv(light1color, 1, light_specular1) ;
// glUniform4fv(light1color, 1, zero) ;
glUniform4fv(ambient,1,small) ;
glUniform4fv(diffuse,1,medium) ;
glUniform4fv(specular,1,one) ;
glUniform4fv(shininess,1,high) ;

if (DEMO > 4) glUniform1i(islight,lighting) ; // light only teapot.
Shader Mappings in init

```c
vertexshader = initshaders(GL_VERTEX_SHADER, "shaders/light.vert") ;
fragmentshader = initshaders(GL_FRAGMENT_SHADER, "shaders/light.frag") ;
shaderprogram = initprogram(vertexshader, fragmentshader) ;

// * NEW * Set up the shader parameter mappings properly for lighting.

islight = glGetUniformLocation(shaderprogram,"islight") ;
light0dirn = glGetUniformLocation(shaderprogram,"light0dirn") ;
light0color = glGetUniformLocation(shaderprogram,"light0color") ;
light1posn = glGetUniformLocation(shaderprogram,"light1posn") ;
light1color = glGetUniformLocation(shaderprogram,"light1color") ;
ambient = glGetUniformLocation(shaderprogram,"ambient") ;
diffuse = glGetUniformLocation(shaderprogram,"diffuse") ;
specular = glGetUniformLocation(shaderprogram,"specular") ;
sininess = glGetUniformLocation(shaderprogram,"sininess") ;
```