

## Computer Graphics

CSE 167 [Win 19], Lecture 7: OpenGL Shading

Ravi Ramamoorthi

<http://viscomp.ucsd.edu/classes/cse167/wi19>

## To Do

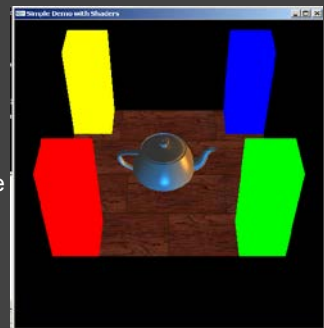
- This week's lectures have all info for HW 2
- Start EARLY (milestone due Monday Feb 4)

## Methodology 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
- More formal look at lighting and shading possible
  - Will be discussed in more detail if you take CSE 163

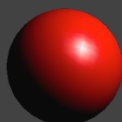
## Demo for mytest3

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



## Importance of Lighting

- Important to bring out 3D appearance (compare teapot now to in previous demo)
- 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



glShadeModel(GL\_FLAT) [old] glShadeModel(GL\_SMOOTH) [old]

## Brief primer on Color

- Red, Green, Blue primary colors
  - Can be thought of as vertices of a color cube
  - $R+G = \text{Yellow}$ ,  $B+G = \text{Cyan}$ ,  $B+R = \text{Magenta}$ ,  $R+G+B = \text{White}$
  - 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
- Also, color index mode (not so important)

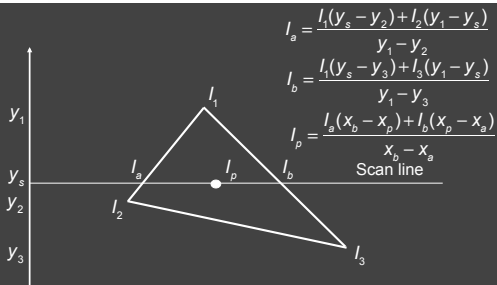
## Outline

- *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
- Wireframe: `glPolygonMode (GL_FRONT, GL_LINE)`
  - Also, polygon offsets to superimpose wireframe
  - Hidden line elimination? (polygons in black...)

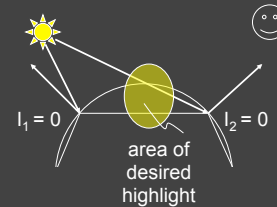
## Gouraud Shading – Details



Actual implementation efficient: difference equations while scan converting

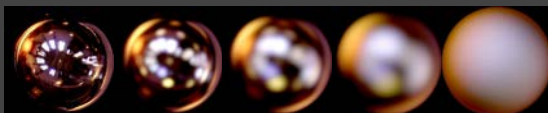
## Gouraud and Errors

- $I_1 = 0$  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

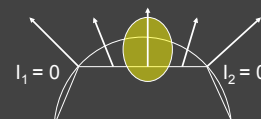
- Specular or glossy materials: highlights
  - Polished floors, glossy paint, whiteboards
  - For plastics highlight is color of light source (not object)
  - For metals, highlight depends on surface color
- Really, (blurred) reflections of light source



Roughness →

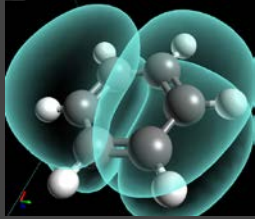
## 2 Phongs make a Highlight

- Besides the Phong Illumination or Reflectance model, there is a Phong Shading model.
- Phong Shading: Instead of interpolating the intensities between vertices, interpolate the **normals**.
- 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*)



## Examples and Color Plates

See OpenGL color plates (earlier eds) and glsl book



<http://blog.cryos.net/categories/15-Avogadro/P3.html>  
[http://blenderartists.org/forum/showthread.php?11430-Games-amp-Tutorials-\(updated-Jan-5-2011\)](http://blenderartists.org/forum/showthread.php?11430-Games-amp-Tutorials-(updated-Jan-5-2011))

## Simple Vertex Shader in mytest3

```
#version 330 core // Do not use any version older than 330!

// Inputs
layout (location = 0) in vec3 position;
layout (location = 1) in vec3 normal;
layout (location = 2) in vec2 texCoords;

// Extra outputs, if any
out vec4 myvertex;
out vec3 mynormal;
out vec2 texcoord;

// Uniform variables
uniform mat4 projection;
uniform mat4 modelview;
uniform int istex ;
```

## Simple Vertex Shader in mytest3

```
void main() {
    gl_Position = projection * modelview * vec4(position, 1.0f);
    mynormal = mat3(transpose(inverse(modelview))) * normal ;
    myvertex = modelview * vec4(position, 1.0f) ;
    texcoord = vec2 (0.0, 0.0); // Default value just to prevent errors
    if (istex != 0){
        texcoord = texCoords;
    }
}
```

## 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

## Lighting and Shading

- Rest of this lecture considers lighting
- In real world, complex lighting, materials interact
- We study this more formally in CSE 163
- 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)  $atten = \frac{1}{k_c + k_l d + k_q d^2}$
- 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?
- Directional ( $w=0$ , infinite far away, no attenuation)
- Spotlights (not considered in homework)
  - Spot exponent
  - Spot cutoff

## Material Properties

- Need normals (to calculate how much diffuse, specular, find reflected direction and so on)
  - Usually specify at each vertex, interpolate
  - GLUT used to do it automatically for teapots etc (we provide meshes with normals instead for you in hw 2)
  - Can do manually for parametric surfaces
  - Average face normals for more complex shapes
- Four terms: Ambient, Diffuse, Specular, Emissive

## Emissive Term



$$I = \text{Emission}_{\text{material}}$$

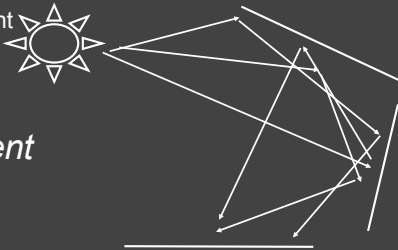
- Only relevant for light sources when looking directly at them
- Gotcha: must create geometry to actually see light
  - Emission does not in itself affect other lighting calculations

## Ambient Term

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

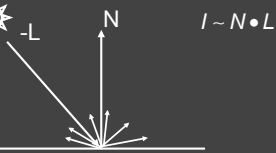


$$I = \text{Ambient}$$



## Diffuse Term

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

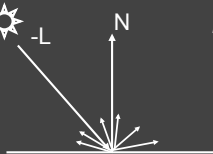


## Diffuse Term

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



$$I = \sum_{i=0}^n \text{intensity}_{\text{light } i} * \text{diffuse}_{\text{material}} * \text{atten}_i * [\max(L \cdot N, 0)]$$



## 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

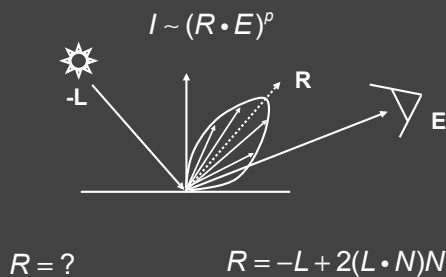


Roughness →

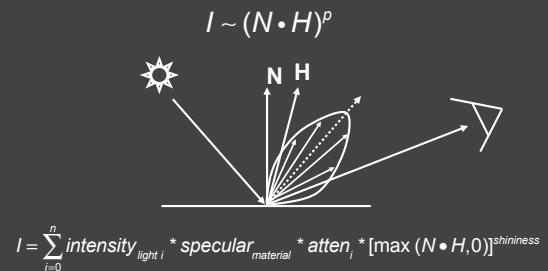
## Idea of Phong Illumination

- Find a simple way to create highlights that are view-dependent and happen at about the right place
- 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



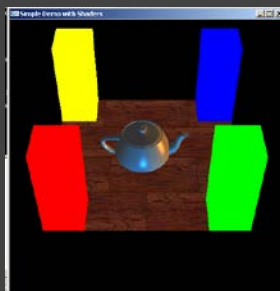
## Alternative: Half-Angle (Blinn-Phong)



- Diffuse and specular components for most materials

## Demo in mytest3

- What happens when we make surface less shiny?



## 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

## Fragment Shader Setup

```
#version 330 core // Do not use any version older than 330!

// Inputs fragment shader are outputs of same name of vertex shader
in vec4 myvertex;
in vec3 mynormal;
in vec2 texcoord;

// Output the frag color
out vec4 fragColor;

uniform sampler2D tex ;
uniform int istex ;
uniform int islight ; // are we lighting.
uniform vec3 color;
```

## Fragment Shader Variables

```
// Assume light 0 is directional, light 1 is a point light.
// Actual light values are passed from the main OpenGL program.
// This could be fancier. My goal is to illustrate a simple idea.
uniform vec3 light0dirn ;
uniform vec4 light0color ;
uniform vec4 light1posn ;
uniform vec4 light1color ;

// Now, set the material parameters. These could be bound to
// a buffer. But for now, I'll just make them uniform.
// I use ambient, diffuse, specular, shininess.
// Ambient is just additive and doesn't multiply the lights.
uniform vec4 ambient ;
uniform vec4 diffuse ;
uniform vec4 specular ;
uniform float shininess ;
```

## Fragment Shader Compute Lighting

```
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 ;
}
```

## Fragment Shader Main Transforms

```
void main (void)
{
    if (istex > 0) fragColor = texture(tex, texcoord);
    else if (islight == 0) fragColor = vec4(color, 1.0f) ;
    else {
        // They eye is always at (0,0,0) looking down -z axis
        // Also compute current fragment position, direction to eye

        const vec3 eyepos = vec3(0,0,0) ;
        vec3 mypos = myvertex.xyz / myvertex.w ; // Dehomogenize
        vec3 eyedirn = normalize(eyepos - mypos) ;

        // Compute normal, needed for shading.
        vec3 normal = normalize(mynormal) ;
```

## 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 attenuation
vec3 half1 = normalize (direction1 + eyedirn) ;
vec4 col1 = ComputeLight(direction1, light1color, normal,
half1, diffuse, specular, shininess) ;

fragColor = ambient + col0 + col1 ;
}
```

## 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*

## Light Set Up (in display)

```
/* New for Demo 3; add lighting effects */
{
    const GLfloat one[] = {1,1,1,1} ;
    const GLfloat medium[] = {0.5f, 0.5f, 0.5f, 1};
    const GLfloat small[] = {0.2f, 0.2f, 0.2f, 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 so manually.
    transformvec(light_direction, light0) ;
    transformvec(light_position1, light1) ;
}
```

## Moving a Light Source

- Lights transform like other geometry
- Only modelview matrix (not projection). The only real application 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

```
/* New helper transformation function to transform vector by
modelview */
void transformvec (const GLfloat input[4], GLfloat output[4])
{
    glm::vec4 inputvec(input[0], input[1], input[2], input[3]);
    glm::vec4 outputvec = modelview * inputvec;
    output[0] = outputvec[0];
    output[1] = outputvec[1];
    output[2] = outputvec[2];
    output[3] = outputvec[3];
}
```

## Set up Lighting for Teapot

```
glUniform3fv(light0dirn, 1, light0) ;
glUniform4fv(light0color, 1, light_specular) ;
glUniform4fv(lightiposn, 1, light1) ;
glUniform4fv(lighticolor, 1, light_specular1) ;
// glUniform4fv(lighticolor, 1, zero) ;

glUniform4fv(ambient,1,small) ;
glUniform4fv(diffuse,1,medium) ;
glUniform4fv(specular,1,one) ;
glUniform1fv(shininess,1,high) ;

// Enable and Disable everything around the teapot
// Generally, we would also need to define normals etc.
// But the teapot object file already defines these for us.
if (DEMO > 4)
    glUniform1i(islight,lighting) ; // lighting only teapot.
```

## Shader Mappings in init

```
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") ;
lightiposn = glGetUniformLocation(shaderprogram,"lightiposn") ;
lighticolor = glGetUniformLocation(shaderprogram,"lighticolor") ;
ambient = glGetUniformLocation(shaderprogram,"ambient") ;
diffuse = glGetUniformLocation(shaderprogram,"diffuse") ;
specular = glGetUniformLocation(shaderprogram,"specular") ;
shininess = glGetUniformLocation(shaderprogram,"shininess") ;
```