Computer Graphics (CS 543)
Lecture 6 (Part 2): Lighting, Shading and Materials (Part 2)

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Modified Phong Model

\[ I = k_d I_d \ l \cdot n + k_s I_s (\mathbf{v} \cdot \mathbf{r})^\alpha + k_a I_a \]
\[ I = k_d I_d \ l \cdot n + k_s I_s (\mathbf{n} \cdot \mathbf{h})^\beta + k_a I_a \]

- Blinn proposed using **halfway vector**, more efficient
- \( h \) is normalized vector halfway between \( l \) and \( v \)

\[ h = (l + v) / |l + v| \]
Example

Modified Phong model gives similar results as original Phong
Computation of Vectors

- To calculate lighting at vertex $P$
  Need $\mathbf{l}$, $\mathbf{n}$, $\mathbf{r}$ and $\mathbf{v}$ vectors at vertex $P$

- User specifies:
  - Light position
  - Viewer (camera) position
  - Vertex (mesh position)

- $\mathbf{l}$: Light position – vertex position
- $\mathbf{v}$: Viewer position – vertex position

- Normalize all vectors!
Specifying a Point Light Source

- For each light source component, set RGBA and position
- alpha = transparency

```cpp
vec4 diffuse0 = vec4(1.0, 0.0, 0.0, 1.0);
vec4 ambient0 = vec4(1.0, 0.0, 0.0, 1.0);
vec4 specular0 = vec4(1.0, 0.0, 0.0, 1.0);
vec4 light0_pos = vec4(1.0, 2.0, 3.0, 1.0);
```
Distance and Direction

- Position is in homogeneous coordinates
  - If $w = 1.0$, we are specifying a finite $(x, y, z)$ location
  - If $w = 0.0$, light at infinity
    $(x/w = \infty \text{ if } w = 0)$

```
vec4 light0_pos = vec4(1.0, 2.0, 3.0, 1.0);
```
Recall: Mirror Direction Vector $r$

- Can compute $r$ from $l$ and $n$
- $l$, $n$ and $r$ are co-planar
- What about determining vertex normal $n$?

$$r = 2 \left( l \cdot n \right) n - l$$
Finding Normal, $n$

- Normal calculation in application, passed to vertex shader

![Diagram showing normal calculation and its flow to vertex shader]
Recall: Newell Method for Normal Vectors

- Formulae: Normal $N = (m_x, m_y, m_z)$

\[
\begin{align*}
m_x &= \sum_{i=0}^{N-1} \left( y_i - y_{\text{next}(i)} \right) \left( z_i + z_{\text{next}(i)} \right) \\
m_y &= \sum_{i=0}^{N-1} \left( z_i - z_{\text{next}(i)} \right) \left( x_i + x_{\text{next}(i)} \right) \\
m_z &= \sum_{i=0}^{N-1} \left( x_i - x_{\text{next}(i)} \right) \left( y_i + y_{\text{next}(i)} \right)
\end{align*}
\]
OpenGL shading

- Need
  - Normals
  - material properties
  - Lights
- State-based shading functions now deprecated
  - (glNormal, glMaterial, glLight) deprecated
- 2 options:
  - Compute lighting in application
  - or send attributes to shaders
Material Properties

- Need to specify material properties of scene objects
- Material properties also has ambient, diffuse, specular
- Material properties specified as RGBA + reflectivities
- w component gives opacity (transparency)
- **Default?** all surfaces are opaque

```cpp
vec4 ambient = vec4(0.2, 0.2, 0.2, 1.0);
vec4 diffuse = vec4(1.0, 0.8, 0.0, 1.0);
vec4 specular = vec4(1.0, 1.0, 1.0, 1.0);
GLfloat shine = 100.0
```
Recall: CTM Matrix passed into Shader

- **Recall:** CTM matrix concatenated in application
  
  ```
  mat4 ctm = ctm * LookAt(vec4 eye, vec4 at, vec4 up);
  ```

- CTM matrix passed in contains object transform + Camera

- Connected to matrix `ModelView` in shader

```bash
in vec4 vPosition;
Uniform mat4 ModelView;
main( )
{
    // Transform vertex position into eye coordinates
    vec3 pos = (ModelView * vPosition).xyz;
    ...........
}
```

OpenGL Application Builds **CTM**

CTM passed in vertex Shader
Computation of Vectors

- CTM transforms vertex position into eye coordinates
  - Eye coordinates? Object, light distances measured from eye
- Normalize all vectors! (magnitude = 1)
- GLSL has a **normalize** function
- **Note:** vector lengths affected by scaling

```c
// Transform vertex position into eye coordinates
vec3 pos = (ModelView * vPosition).xyz;

vec3 L = normalize(LightPosition.xyz - pos);    // light vector
vec3 E = normalize(-pos);                        // view vector
vec3 H = normalize(L + E);                      // Halfway vector
```
Spotlights

- Derive from point source
  - **Direction I** (of lobe center)
  - **Cutoff**: No light outside $\theta$
  - **Attenuation**: Proportional to $\cos^{\alpha \phi}$
Recall: Lighting Calculated Per Vertex

- Phong model (ambient+diffuse+specular) calculated at each vertex to determine vertex color
- Per vertex calculation? Usually done in vertex shader
// vertex shader
in vec4 vPosition;
in vec3 vNormal;
out vec4 color;  //vertex shade

// light and material properties
uniform vec4 AmbientProduct, DiffuseProduct, SpecularProduct;
uniform mat4 ModelView;
uniform mat4 Projection;
uniform vec4 LightPosition;
uniform float Shininess;

Ambient, diffuse, specular (light * reflectivity) specified by user

\[ k_d I_d \]

\[ k_a I_a \]

\[ k_s I_s \]

exponent of specular term
void main( )
{
    // Transform vertex position into eye coordinates
    vec3 pos = (ModelView * vPosition).xyz;

    vec3 L = normalize( LightPosition.xyz - pos );
    vec3 E = normalize( -pos );
    vec3 H = normalize( L + E ); // halfway Vector

    // Transform vertex normal into eye coordinates
    vec3 N = normalize( ModelView*vec4(vNormal, 0.0) ).xyz;
Per-Vertex Lighting Shaders III

// Compute terms in the illumination equation
vec4 ambient = AmbientProduct;  // $k_a I_a$

float cos_theta = max( dot(L, N), 0.0 );
vec4  diffuse = cos_theta * DiffuseProduct;  // $k_d I_d \cdot n$

float cos_phi = pow( max(dot(N, H), 0.0), Shininess );
vec4  specular = cos_phi * SpecularProduct;  // $k_s I_s (n \cdot h)^\beta$

if( dot(L, N) < 0.0 )  specular = vec4(0.0, 0.0, 0.0, 1.0);

gl_Position = Projection * ModelView * vPosition;

color = ambient + diffuse + specular;
color.a = 1.0;

}  

$I = k_d I_d \cdot n + k_s I_s (n \cdot h)^\beta + k_a I_a$
**Shading?**

- After triangle is rasterized/drawn
  - Per-vertex lighting calculation means we know color of pixels coinciding with vertices (red dots)
- Shading determines color of interior surface pixels

\[
I = k_d I_d \cdot n + k_s I_s (n \cdot h)^\beta + k_a I_a
\]
Shading?

- Two types of shading
  - Assume linear change => interpolate (Smooth shading)
  - No interpolation (Flat shading)

\[
I = k_d I_d \cdot n + k_s I_s (n \cdot h)^\beta + k_a I_a
\]

Lighting calculation at vertices (in vertex shader)
Flat Shading

- compute lighting once for each face, assign color to whole face
Flat shading

- Only use face normal for all vertices in face and material property to compute color for face
- Benefit: Fast!
- Used when:
  - Polygon is small enough
  - Light source is far away (why?)
  - Eye is very far away (why?)
- Previous OpenGL command: `glShadeModel(GL_FLAT)` deprecated!
Mach Band Effect

- Flat shading suffers from “mach band effect”
- Mach band effect – human eyes accentuate the discontinuity at the boundary
Smooth shading

- Fix mach band effect – remove edge discontinuity
- Compute lighting for more points on each face
- 2 popular methods:
  - Gouraud shading
  - Phong shading

Flat shading   ➔   Smooth shading
Gouraud Shading

- Lighting calculated for each polygon vertex
- Colors are interpolated for interior pixels
- Interpolation? Assume linear change from one vertex color to another
- Gouraud shading (interpolation) is OpenGL default
Per-Vertex Lighting Shaders IV

// in vertex shader, we declared color as out, set it

    color = ambient + diffuse + specular;
    color.a = 1.0;
}

// in fragment shader (in vec4 color;

void main()
{
    gl_FragColor = color;
}
Flat Shading Implementation

- Default is **smooth shading**
- Colors set in vertex shader interpolated
- **Flat shading?** Prevent color interpolation
- In vertex shader, add keyword `flat` to output `color`

```glsl
flat out vec4 color;  //vertex shade

......

color = ambient + diffuse + specular;
color.a = 1.0;
```
Flat Shading Implementation

- Also, in fragment shader, add keyword `flat` to color received from vertex shader

```glsl
flat in vec4 color;

void main()
{
    gl_FragColor = color;
}
```
References