Using Shaders for Lighting

Lighting Definitions

N = Normal
L = Light vector
E = Eye vector
R = Light reflection vector
ER = Eye reflection vector
Color = LightColor * MaterialColor

Ambient = Light intensity that is “everywhere”
Diffuse = Light intensity proportional to \( \cos(\Theta) \)
Specular = Light intensity proportional to \( \cos^2(\Phi) \)
A-D-S = Lighting model that includes Ambient, Diffuse, and Specular

Flat Interpolation = Use a single polygon normal to compute one A-D-S for the entire polygon
Smooth Interpolation = Use a normal at each vertex to compute one A-D-S for at each vertex

Per-vertex lighting = Compute A-D-S using each vertex normal and then interpolate the summed intensity over the entire polygon
Per-fragment lighting = Interpolate the vertex normals across the entire polygon and then compute A-D-S at each fragment

CubeMap Reflection = Using the Eye Reflection Vector (ER) to look-up the reflection of a “wall texture”
A-D-S Lighting

**Ambient:** $K_a$

**Diffuse:** $K_d \cdot \cos\theta$

**Specular:** $K_s \cdot \cos^k\phi$
A-D-S Lighting with Flat Interpolation

Each polygon has a single lighting value applied to every pixel within it.

N = Normal
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Color = LightColor * MaterialColor

Vertex Shader

Fragment Shader

White Light

Green Light

What you see depends on the light color and the material color

\[
\begin{align*}
E_R &= L_R \times M_R \\
E_G &= L_G \times M_G \\
E_B &= L_B \times M_B \\
\end{align*}
\]
A-D-S Lighting with Smooth Interpolation

Note: The light intensity is computed at each vertex and interpolated throughout the polygon. This creates artifacts such as Mach Banding and the fact that the bright spot is not ‘jagged’.

You can do this in stock OpenGL or in a shader.

\[
\begin{align*}
N &= \text{Normal} \\
L &= \text{Light vector} \\
E &= \text{Eye vector} \\
R &= \text{Light reflection vector} \\
ER &= \text{Eye reflection vector} \\
\text{Color} &= \text{LightColor} \times \text{MaterialColor}
\end{align*}
\]

**Vertex Shader**

\[
\begin{align*}
\text{vec3 ambient} &= \text{Color.rgb} \\
\text{diffuse} &= \max(\text{dot}(L,N), 0.) \times \text{Color.rgb} \\
\text{vec3 R} &= \text{normalize} \left( \text{reflect} \left( -L, N \right) \right) \\
\text{vec3 spec} &= \text{LightColor} \times \text{pow} \left( \max(\text{dot}(R, E), 0.), \text{Shininess} \right)
\end{align*}
\]

**Fragment Shader**

\[
\begin{align*}
gl\_\text{FragColor.rgb} &= K_a\text{ambient} + K_d\text{diffuse} + K_s\text{spec};
\end{align*}
\]

A-D-S Lighting with Normal Interpolation

The normal is interpolated throughout the polygon. The light intensity is computed at each fragment. This avoids Mach Banding and makes the bright spot smooth.

You can only do this in a shader.

\[
\begin{align*}
N &= \text{Normal} \\
L &= \text{Light vector} \\
E &= \text{Eye vector} \\
R &= \text{Light reflection vector} \\
ER &= \text{Eye reflection vector} \\
\text{Color} &= \text{LightColor} \times \text{MaterialColor}
\end{align*}
\]

**Vertex Shader**

\[
\begin{align*}
\text{vec3 ambient} &= \text{Color.rgb} \\
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\end{align*}
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**Fragment Shader**

\[
\begin{align*}
gl\_\text{FragColor.rgb} &= K_a\text{ambient} + K_d\text{diffuse} + K_s\text{spec};
\end{align*}
\]
The Difference Between Per-Vertex Lighting and Per-Fragment Lighting

Per-vertex

Per-fragment

The Difference Between Per-Vertex Lighting and Per-Fragment Lighting

Per-vertex

Per-fragment
A-D-S Lighting with Normal Interpolation and a CubeMap Reflection

Note: A cube map reflection is blended in, given a stronger impression that the surface is shiny.

N = Normal
L = Light vector
E = Eye vector
R = Light reflection vector
ER = Eye reflection vector
Color = LightColor * MaterialColor

Fragment Shader

vec3 ambient = Color.rgb;
diffuse = max( dot(L,N), 0. ) * Color.rgb;
vec3 R = normalize( reflect( -L, N ) );
vec3 spec = LightColor * pow( max( dot( R, E ), 0. ), Shininess );
vec3 refcolor = textureCube( ReflectUnit, R ).rgb;
gl_FragColor.rgb = Ka*ambient + Kd*diffuse + Ks*spec + Kr*refcolor.rgb;
A-D-S Anisotropic Lighting with Normal Interpolation

Note: The bright spot is not circular because the material has different properties in different directions. Materials such as fur, hair, and brushed metal behave this way.


Fragment Shader

vec3 ambient = Color.rgb;
float dl = dot(T, L);
vec3 diffuse = sqrt(1 - dl*dl) * Color.rgb;
float de = dot(T, E);
vec3 spec = LightColor * pow( dl * de + sqrt(1 - dl*dl) * sqrt(1 - de*de), Shininess);
gl_FragColor.rgb = Ka*ambient + Kd*diffuse + Ks*spec;

Summary

Flat

Normal

Anisotropic

Smooth

Reflection
#version 330 compatibility

uniform float uLightX, uLightY, uLightZ;

flat out vec3 vNf;
out vec3 vNs;
flat out vec3 vLf;
out vec3 vLs;
flat out vec3 vEf;
out vec3 vEs;

vec3 eyeLightPosition = vec3( uLightX, uLightY, uLightZ );

void
main( )
{
    vec4 ECposition = gl_ModelViewMatrix * gl_Vertex;
    Nf = normalize( gl_NormalMatrix * gl_Normal ); // surface normal vector
    Ns = Nf;
    Lf = eyeLightPosition - ECposition.xyz; // vector from the point
    Ls = Lf; // to the light position
    Ef = vec3( 0., 0., 0.) - ECposition.xyz; // vector from the point
    Es = Ef ; // to the eye position
    gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}

#version 330 compatibility

uniform float uKa, uKd, uKs;
uniform vec4 uColor;
uniform vec4 uSpecularColor;
uniform float uShininess;
uniform bool uFlat;

flat in vec3 vNf;
in vec3v Ns;
flat in vec3 vLf;
in vec3v Ls;
flat in vec3 vEf;
in vec3v vEs;

void
main( )
{
    vec3 Normal;
    vec3 Light;
    vec3 Eye;

    if( uFlat )
    {
        Normal = normalize(vNf);
        Light = normalize(vLf);
        Eye = normalize(vEf);
    }
    else
    {
        Normal = normalize(vNs);
        Light = normalize(vLs);
        Eye = normalize(vEs);
    }
vec4 ambient = uKa * uColor;

float d = max(dot(Normal,Light), 0.);
vec4 diffuse = uKd * d * uColor;

float s = 0.;
if( dot(Normal,Light) > 0. ) // only do specular if the light can see the point
{
    vec3 ref = normalize(2. * Normal * dot(Normal,Light) - Light);
    s = pow( max(dot(Eye,ref), 0.), uShininess );
}

vec4 specular = uKs * s * uSpecularColor;

gl_FragColor = vec4(ambient.rgb + diffuse.rgb + specular.rgb, 1.);