Using Shaders for Lighting
Lighting Definitions

- **Ambient** = Light intensity that is “everywhere”
- **Diffuse** = Light intensity proportional to \( \cos(\Theta) \)
- **Specular** = Light intensity proportional to \( \cos^S(\Phi) \)
- **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

**Per-vertex lighting** = Compute A-D-S using each vertex normal and then interpolate the sum over the entire polygon

**Per-fragment lighting** = Interpolate the vertex normals across the entire polygon and 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: $K_s \cdot \cos^n \phi$
Computer Graphics

Ambient-only

Diffuse-only

Specular-only

ADS – Shininess=50

ADS – Shininess=1000

ADS – Shininess=1000 -- Flat
A-D-S Lighting with Flat Interpolation

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

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

\[
\text{vec3 ambient} = \text{Color.rgb}; \\
\text{diffuse} = \max( \text{dot}(L, N), 0. ) \times \text{Color.rgb}; \\
\text{vec3 R} = \text{normalize}( \text{reflect}( -L, N ) ); \\
\text{vec3 spec} = \text{LightColor} \times \text{pow}( \max( \text{dot}( R, E), 0. ), \text{Shininess} ); \\
\]

Vertex Shader

Fragment Shader

\[
\text{gl_FragColor} = \text{Ka} \times \text{ambient} + \text{Kd} \times \text{diffuse} + \text{Ks} \times \text{spec}; \\
\]

Flat-rasterize ambient, diffuse, specular
What you see depends on the light color and the material color

\[ E_R = L_R \times M_R \]
\[ E_G = L_G \times M_G \]
\[ E_B = L_B \times M_B \]
A-D-S Lighting with Smooth Interpolation

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

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

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

Vertex Shader

Fragment Shader

gl_FragColor.rgb = Ka*ambient + Kd*diffuse + Ks*spec;

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 );
Smooth-rasterize ambient, diffuse, spec
A-D-S Lighting with Normal Interpolation

Note: The normal is interpolated throughout the facet. The light intensity is computed at each fragment. This avoids Mach Banding and makes the bright spot circular. You can only do this in a shader.

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 );
gl_FragColor.rgb = Ka*ambient + Kd*diffuse + Ks*spec;
```

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

Normal interpolation
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.

\begin{align*}
\text{vec3 ambient} &= \text{Color.rgb;}
\text{diffuse} &= \text{max( dot(L,N), 0. ) * Color.rgb;}
\text{vec3 R} &= \text{normalize( reflect( -L, N ) );}
\text{vec3 spec} &= \text{LightColor * pow( max( dot( R, E ), 0. ), Shininess );}
\text{vec3 refcolor} &= \text{textureCube( ReflectUnit, R ).rgb;}
\text{gl_FragColor.rgb} &= \text{Ka*ambient + Kd*diffuse + Ks*spec + Kr*refcolor.rgb;}
\end{align*}

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

Smooth-rasterize N, L, E
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**

```glsl
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;
```

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

    Nf = normalize( uNormalMatrix * aNormal ); // 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 = uModelViewProjectionMatrix * aVertex;
}
#version 330 compatibility

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

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

out vec4 fFragColor;

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;

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