UNIVERSITY OF DERBY

5CM507 Graphics

Lecture 05 Lighting and Shading

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Contents

- Lighting: computing the luminous intensity at a 3D point on a surface
  - Phong and **Blinn-Phong**
- Shading: assigning colours to 2D pixels
  - Basic Shading Models: Flat, Gouraud, **Phong**

Lighting Models

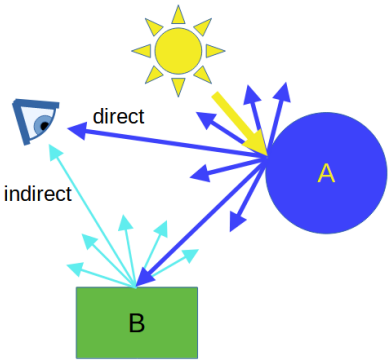
Why do we need lighting and shading

We perceive shapes through light reflected from objects

The Mousou black ink claims to absorb 99.4% of light

Light-Material Interaction

- Need to consider
  - Light sources
  - Location of viewer
  - Surface orientation
  - Material properties (colour absorption, smoothness, etc)
- Light partially absorbed and partially scattered (reflected)
  - Colour: the light reflected, the rest absorbed
  - Intensity: light direction and surface orientation
  - Scattering : smoothness of the surface

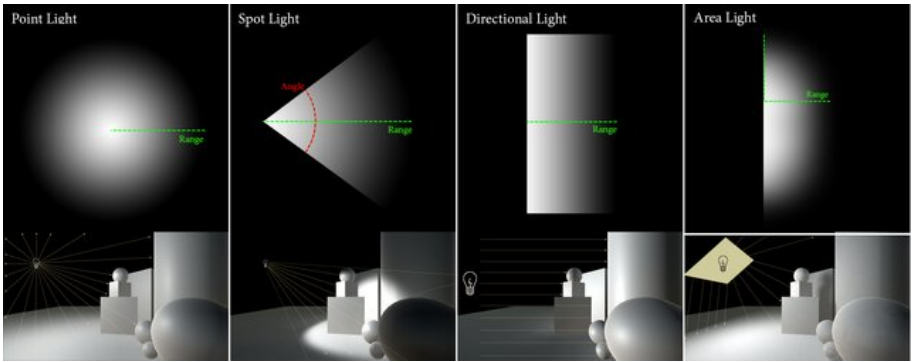


Light Sources

Basic Light Sources

Classic OpenGL : ambient, directional, point, and spotlight sources.

Modern OpenGL : no built-in lights — implemented flexibly by the user in GLSL.

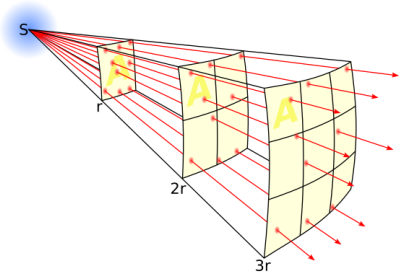


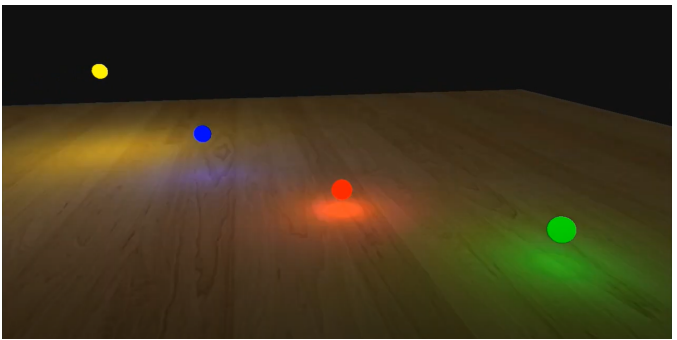
[Benjamin Kahl]

Light Attenuation - Inverse Square Falloff

Theoretic: $I \propto \frac{1}{r^2}$

In practice: $I = I_0 \frac{1}{a+bd+cd^2}$





The Basic Lighting Models: Phong and Blinn-Phong

Surface Reflection Types

Ambient : all-to-all directions

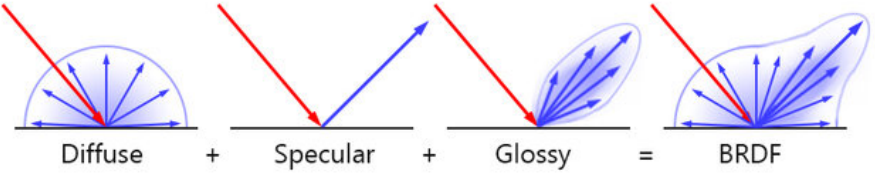
- Intensity: independent of surface normals

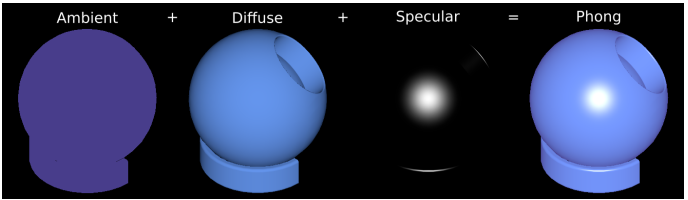
Diffuse : scattered, one-to-all directions

- Intensity: dependent on surface normals

Specular : one-to-one direction (mirror-like) or spread within a range (glossy)

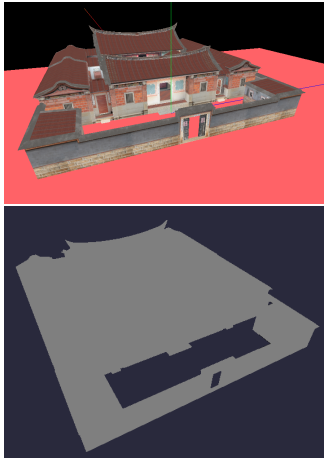
- Intensity: dependent on surface normal and viewing direction





Ambient Light

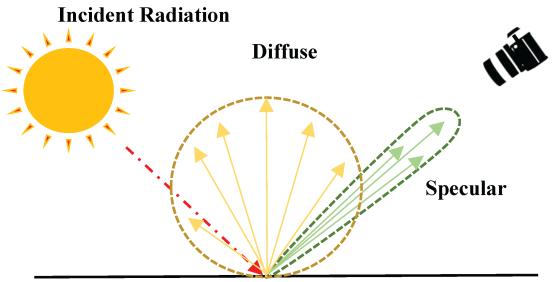
- Background light without directions
- Reflection independent of surface shapes
- Approx. of an averaged lighting
- $I_{amb} = I_a k_a$
  - k_a: reflection coefficients in (R, G, B)
  - I_a: intensity of ambient light in (R, G, B)
- Rendering: flat with outlines



Specular Reflections - the Highlight

- Most surfaces are neither ideal diffusers nor perfectly specular (ideal reflectors)
- Specular highlights : concentrated around the direction of a perfect reflection

Less diffuse makes more metallic

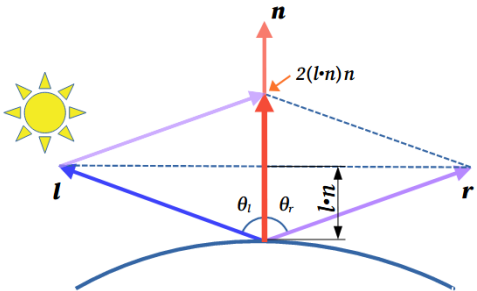


Compute the Reflection Vector r

- Vectors
  - $\boldsymbol{l}$: To incident light source
  - $\boldsymbol{v}$ Viewing direction To viewer
  - $\boldsymbol{n}$ Surface normal, unit vector
  - $\boldsymbol{r}$ Perfect reflector
- Compute r
  - $\theta_l = \theta_r$, **l**, **n**, **r** coplanar
  - l's projection on **n** : $\|l\| cos\theta_l = l \cdot n$
  - Vector addition : $\boldsymbol{r + l = 2(l \cdot n)n}$

$$\boldsymbol{r = 2(l \cdot n)n - l}$$

- GLSL `vec3 reflect(vec3 I, vec N)`

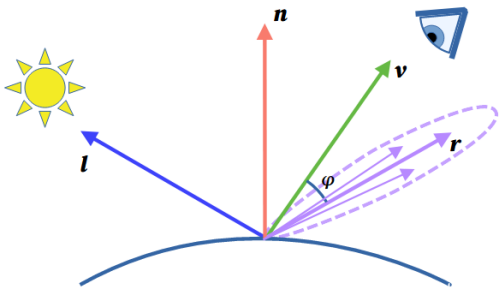


Modelling Specular Reflections

- Phong proposed using a term that dropped off as the angle between the viewer and the ideal reflection increased

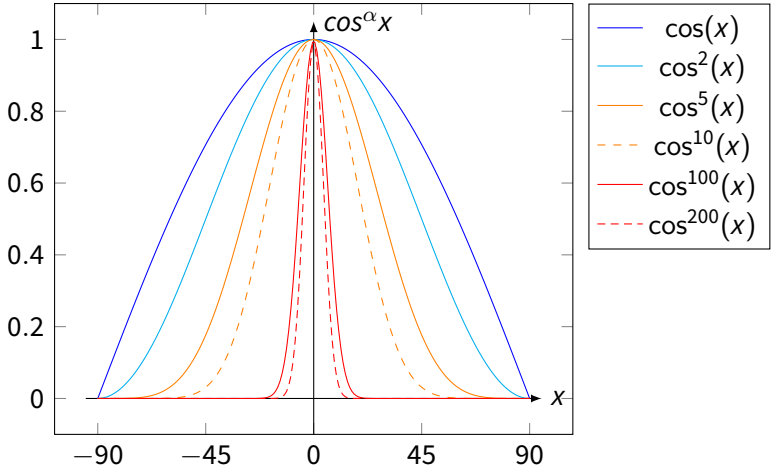
$$I_s = k_s I_i \cos^{\alpha}(\phi)$$

- $\boldsymbol{I_s}$: specular light intensity
- k_s : absorption coefficient
- $\boldsymbol{I_i}$: incoming light intensity
- $\cos\phi = \frac{r \cdot v}{\|r \cdot v\|}$
- α : shininess coefficient



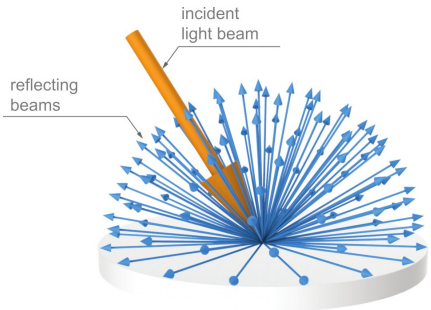
The Shininess Coefficient

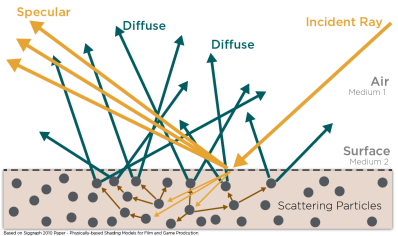
- Values of a between 100 and 200 correspond to metals
- Values between 5 and 10 give surface that look like plastic



Diffuse Reflection

- Perfect diffuse : scattered EQUALLY in all directions
- Dull, matt surfaces such as paper, bricks, carpet, etc.



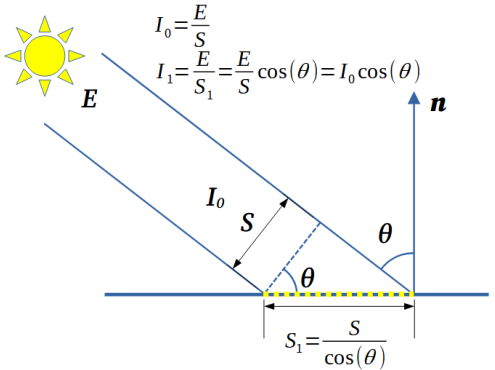


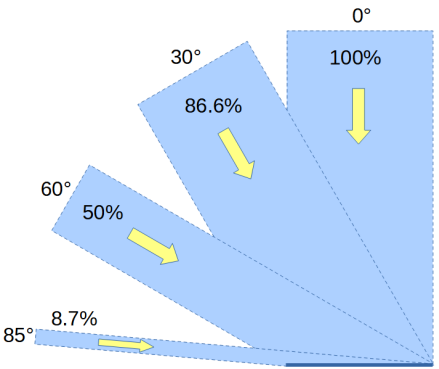
Diffuse Light Intensity: Lambert's Reflectance Model

the Cosine Law

Received incident light intensity on the surface:

$$I_{surf} = I_0 \cos\theta \quad \left(\cos\theta = \frac{\boldsymbol{l}\cdot\boldsymbol{n}}{\|\boldsymbol{l}\cdot\boldsymbol{n}\|} \right)$$

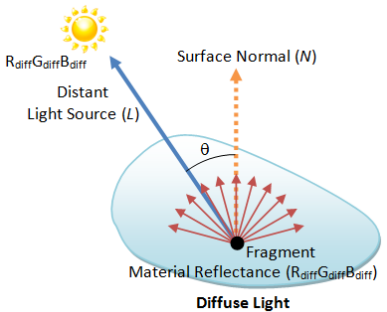




The Diffuse Light

The incident light is scattered equally in all directions

- $I_d = k_d I_{surf} = I_i k_d \cos\theta = I_i k_d (n \cdot l)$
- I_d: resulting diffuse intensity
- I_i, incoming light intensity in (R,G,B)
- k_d (diffuse) surface reflectance coefficient in (R,G,B) [0,1]
- θ: angle between normal and light direction

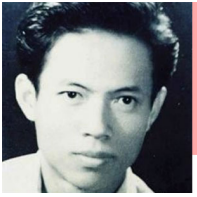


Phong Model : Ambient + Diffuse + Specular

$$\boldsymbol{I_a} k_a + \sum_p \frac{\boldsymbol{I}}{A(d_p)} \left(k_d \left(\boldsymbol{n} \cdot \boldsymbol{l_p} \right) + k_s \left(\boldsymbol{r_p} \cdot \boldsymbol{v} \right)^{\alpha} \right)$$

$$I_{incoming} \propto \frac{1}{r^2}$$

Attenuation function $A(d) = \mathrm{a} + \mathrm{b}\boldsymbol{d} + \mathrm{c}\boldsymbol{d^2}$



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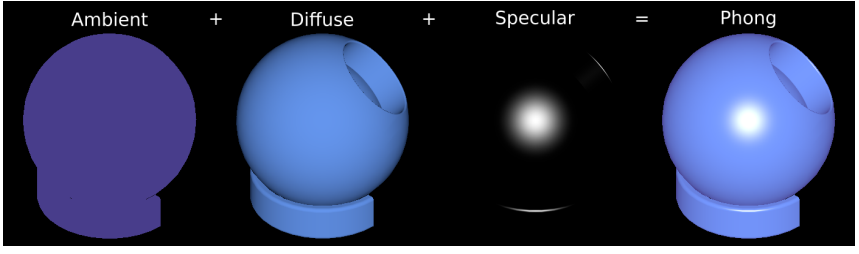
Bùi Tường Phong
裴祥風

Phong shading



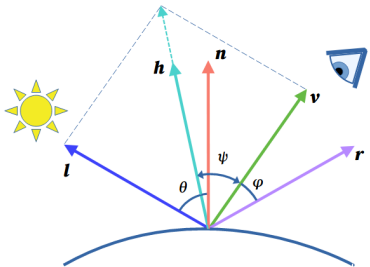
Blinn-Phong Model (Jim Blinn, 1977)

The Default Model We Use

- Change in the specular term
- Phong model: The specular term requires $\boldsymbol{r}$ for each vertex.
- Blinn-Phong model: use the halfway vector $\boldsymbol{h}$ halfway between $\boldsymbol{l}$ and $\boldsymbol{v}$

$$\boldsymbol{h} = \frac{(\boldsymbol{l}+\boldsymbol{v})}{\|\boldsymbol{l}+\boldsymbol{v}\|}$$

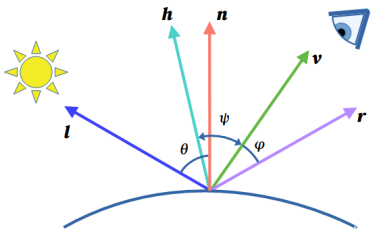
- Halfway vector represents normal of microfacets that would lead to mirror reflection to the eye
- Use cosine of angle between the half vector and the normal : $(\boldsymbol{v}\cdot\boldsymbol{r})^{\alpha} \Rightarrow (\boldsymbol{n}\cdot\boldsymbol{h})^{\beta}$ (β : shininess)
- The larger the angle between microfacet orientation and normal, the less likely



Complete Blinn-Phong Model

$$\boldsymbol{I_a} k_a + \sum_p \frac{\boldsymbol{I}}{A(d_p)} \left(k_d \left(\boldsymbol{l_p} \cdot \boldsymbol{n} \right) + k_s \left(\boldsymbol{h} \cdot \boldsymbol{n} \right)^{\beta} \right)$$

- All colours, reflection coefficients have separate values for R,G,B
- Usually, $k_a = k_d$ coefficient
- For metals, $k_s = k_d$
  - Highlight is colour of material
- For plastics, specular coefficient = (x,x,x)
  - Highlight is colour of light
- Each k has three r, g, b components



Vertex Shader for Both Phong and Blinn-Phong

```
// vertex shader for both Phong and Blinn-Phong models
#version 410

in layout(location=0) vec3 pos;
in layout(location=1) vec3 aNormal;

// M V P matrices
uniform mat4 model;
uniform mat4 view;
uniform mat4 projection;

out vec3 normal;
out vec3 fragPos;
```

```
void main() {
    // homogeneous coordinate
    gl_Position = projection * view * model * vec4(pos, 1.0);

    // colour_vert = colour_in;
    fragPos = vec3(model * vec4(pos, 1.0));

    // convert mat4 normal to mat3
    mat3 normalMatrix = mat3(model);

    // only correct for rigid body transforms
    normal = normalMatrix * aNormal;
}
```

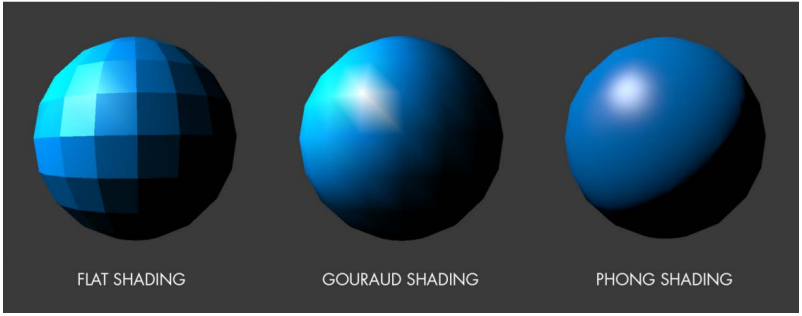
Phong and Blinn-Phong in Fragment Shaders

```
// fragment shader
#version 410
out vec4 FragColor;

vec3 fragPos;
vec3 normal;
// vec2 texCoords;

uniform sampler2D floorTexture;
uniform vec3 lightPos;
uniform vec3 viewPos;
uniform bool blinn;

void main()
{
    // specify a colour for our lab
    vec3 color = vec(1.0, 0.0 0.0);

    // or use a colour from a texture
    // vec3 color = texture(floorTexture, fs_in.TexCoords).rgb;

    // ambient
    vec3 ambient = 0.05 * color;
    // diffuse
    vec3 lightDir = normalize(lightPos - fragPos);
    vec3 normal = normalize(normal);

    float diff = max(dot(lightDir, normal), 0.0);
    vec3 diffuse = diff * color;
    // specular
    vec3 viewDir = normalize(viewPos - fragPos);
    vec3 reflectDir = reflect(-lightDir, normal);
    float spec = 0.0;
    if(blinn) {
        vec3 halfwayDir = normalize(lightDir + viewDir);
        spec = pow(max(dot(normal, halfwayDir), 0.0), 32.0);
    }
    else {
        vec3 reflectDir = reflect(-lightDir, normal);
        spec = pow(max(dot(viewDir, reflectDir), 0.0), 8.0);
    }
    // assuming bright white light colour
    vec3 specular = vec3(0.3) * spec;

    // The final combined colour
    fragColor = vec4(ambient + diffuse + specular, 1.0);
}
```

Shading in OpenGL

OpenGL Shading Models

- Flat shading: one normal, one colour per polygon
- Gouraud shading: vertex normals, interpolated colours per pixel
- Phong shading: interpolated normals per pixel



Flat Shading Implementation

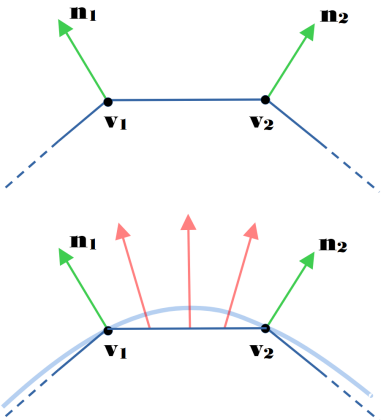
- Each polygon shares the same normal vector
- All pixels in the same polygon are coloured by the same color
- Intensity discontinuities at polygon edges

```
#version 410 // vertex shader
in layout(location=0) vec3 pos;
in layout(location=1) vec3 aNormal;

uniform mat4 model;
uniform mat4 view;
uniform mat4 projection;

out flat vec3 normal;
out vec3 fragPos;

void main() {
    gl_Position = projection * view * model * vec4(pos, 1.0);
    fragPos = vec3(model * vec4(pos, 1.0));
    mat3 normalMatrix = mat3(model);

    // only for rigid body transforms
    normal = normalMatrix * aNormal;
}
```

```
#version 410 // fragment shader
out vec4 colour_out;
in vec3 fragPos;
in flat vec3 normal;

uniform vec3 lightPos;

void main() {
    vec3 colour = vec3(1.0, 0.0, 0.0); // colour set manually

    vec3 ambient = 0.05 * colour; // 1. ambient

    vec3 lightDir = normalize(lightPos - fragPos);
    vec3 norm = normalize(normal);
    float diff = max(dot(lightDir, normal), 0.0);
    vec3 diffuse = diff * colour; // 2. diffuse

    colour_out = vec4(ambient + diffuse, 1.0);
}
```

Phong Shading (also by Bui Tuong Phong)

- Per-pixel shading
- Interpolating the normal vectors at the vertices (again using barycentric coordinates)
- Applying illumination at each pixel



Interpolation of normals

Summary

- Basic Lighting Models : Ambient + Diffuse + Specular
  - Phong - reflection vector : $\boldsymbol{I_a} k_a + \sum_p \frac{\boldsymbol{I}}{\mathrm{a+b}\boldsymbol{d}+\mathrm{c}\boldsymbol{d^2}} \left(k_d \left(\boldsymbol{n} \cdot \boldsymbol{l_p}\right) + k_s \left(\boldsymbol{r_p} \cdot \boldsymbol{v}\right)^{\alpha}\right)$
  - Blinn-Phong - half vector : $\boldsymbol{I_a} k_a + \sum_p \frac{\boldsymbol{I}}{\mathrm{a+b}\boldsymbol{d}+\mathrm{c}\boldsymbol{d^2}} \left(k_d \left(\boldsymbol{l_p} \cdot \boldsymbol{n}\right) + k_s \left(\boldsymbol{h} \cdot \boldsymbol{n}\right)^{\beta}\right)$
- Phong shading: pixel-based, interpolation of vertex normals, normal per vertex

Pursuit of photorealism in games