Lighting & Shading

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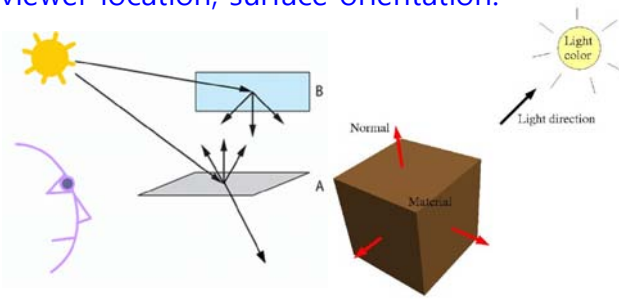
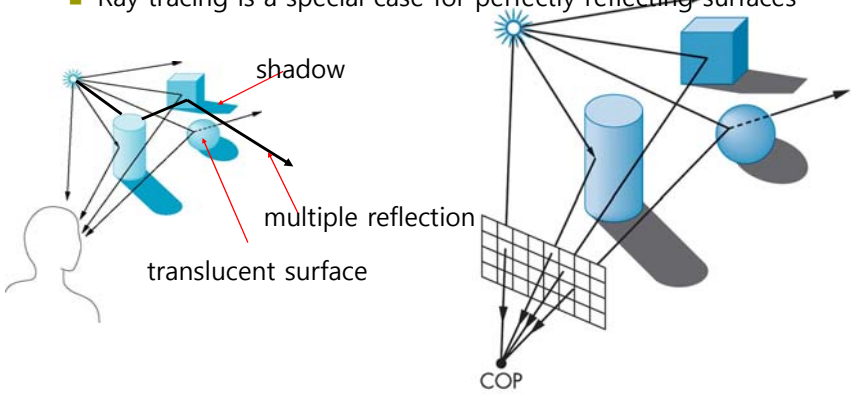
Lighting

- Light starts at the lighting source
- The light strike on the surface, it
  - Absorption
  - Reflection
  - Transmission or Refraction
- Shading is determined by light source color, material properties, viewer location, surface orientation.



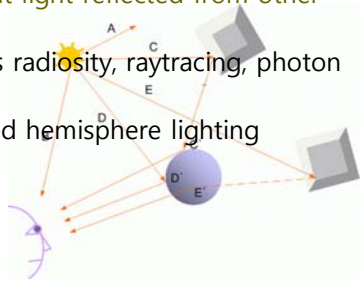
Lighting Model

- The infinite scattering and absorption of light can be described by the rendering equation
  - Cannot be solved in general
  - Ray tracing is a special case for perfectly reflecting surfaces



Lighting Model

- Direct Illumination Model
  - Light model that deals with the light that points on the surface of an object receive directly from all light sources in the scene
  - It is mainly used in traditional real-time rendering because of low computation
  - Phong reflection model
- Global Illumination Model
  - Light model that considers incident light reflected from other objects
  - Global illumination model includes radiosity, raytracing, photon mapping, etc
  - Real-time GPU programming-based hemisphere lighting

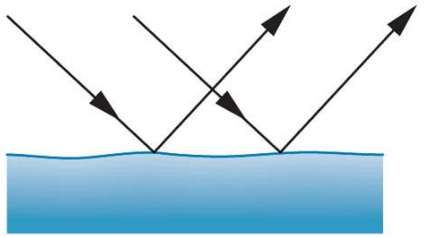


Light-Material Interactions

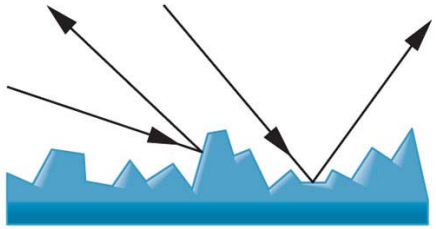
- Specular surface
  - The smoother a surface, the more reflected light is concentrated in the direction a perfect mirror would **reflected** the light.
- Diffuse surface
  - A very rough surface scatters light in all directions.
- Translucent surface
  - In a translucent surface, some light penetrates the surface and exist to other locations on the object **(refraction)**

Light-Material Interactions

- Perfectly Specular surface
  = very smooth surface



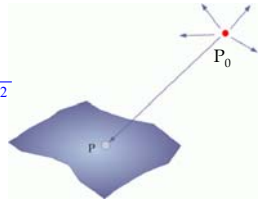
- Perfectly Diffuse surface
  = very rough surface



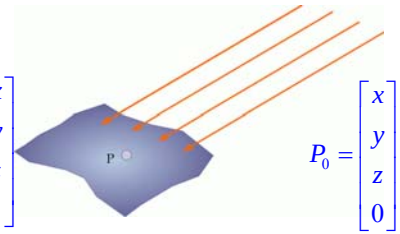
Light Source

- Point Light Source
  - Light that spreads around a point
  - The brightness is attenuated in proportion to the square of the distance from the surface.
- Directional Light Source
  - Light travels in a certain direction toward the object surface.
  - The direction of light is important rather than the distance.

$$I(P) \propto \frac{I(P_0)}{|P - P_0|^2}$$



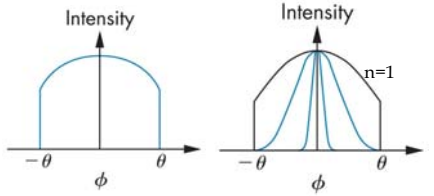
$$P_0 = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

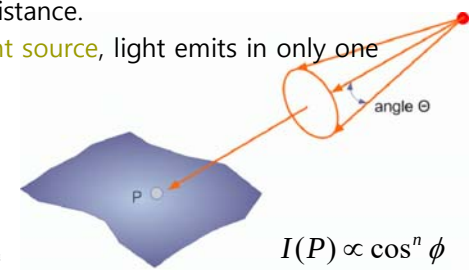


$$P_0 = \begin{bmatrix} x \\ y \\ z \\ 0 \end{bmatrix}$$

Light Source

- Spot Light Source
  - A special form of a point light source that emits in a certain range like a cone.
  - It is necessary to set the location of the light source and the direction and range of the lighting.
  - If θ=180 degrees, it becomes a point light source.
  - Similar to a point light source, light proceeds radially and the light source is at a finite distance.
  - Similar to a directional light source, light emits in only one direction.

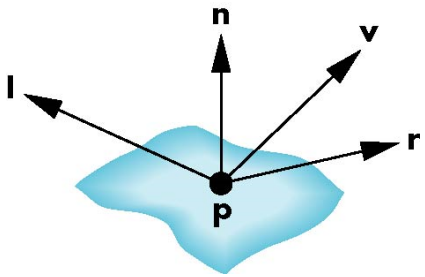




$$I(P) \propto \cos^n \phi$$

Lighting Model

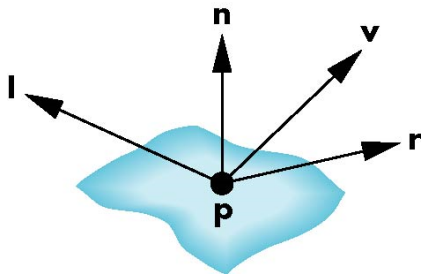
- Phong Reflection Model
- The light-material interaction
  - Ambient reflection
  - Diffuse reflection
  - Specular reflection
- Uses 4 vectors
  - Source (P)
  - Viewer (V)
  - Normal (N)
  - Perfect reflector (R)



Angle of Incidence

- Angle of Incidence
  - The angle between the light source vector and the normal vector

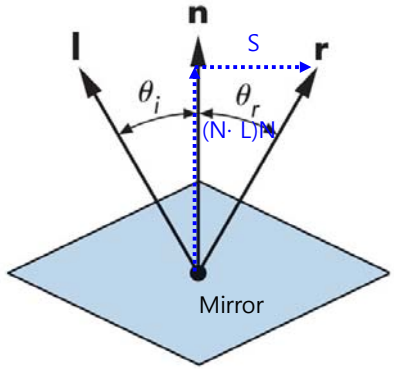
$$N \cdot L = \|N\|\|L\| \cos\theta = (1)(1)\cos\theta = \cos\theta$$



Angle of Reflection

- Angle of Reflection
  - The angle of incident and the angle of reflection are the same.

$$\theta_i = \theta_r$$
$$R = (N \cdot L)N + S$$
$$L = (N \cdot L)N - S$$
$$\Rightarrow S = (N \cdot L)N - L$$
$$\Rightarrow R = 2(L \cdot N)N - L$$

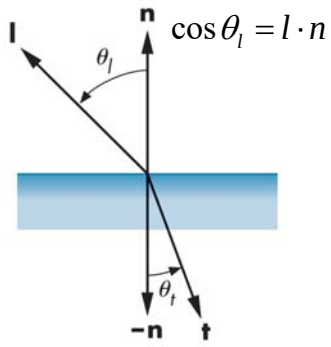


Projecting L onto N = $(L \cdot N)N$ when $\|N\| = 1$

Indices of Refraction

- Refraction
  - η_l, η_t = the indices of refraction of two materials
- Snell's law:

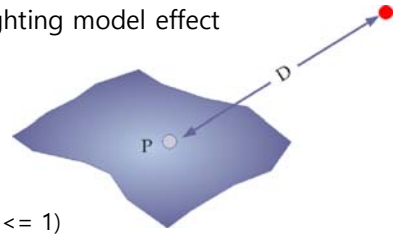
$$\frac{\sin\theta_l}{\sin\theta_t} = \frac{\eta_t}{\eta_l} = \eta$$
$$\cos\theta_t = \sqrt{1 - \frac{1}{\eta^2}\left(1 - \cos^2\theta_l\right)}$$
$$\eta = \eta_t / \eta_l$$
$$T = -\frac{1}{\eta}L - \left(\cos\theta_t - \frac{1}{\eta}\cos\theta_l\right)N$$



Perfect light transmission

Ambient Reflection

- Ambient reflection gives brightness to the surface not directly exposed to the light source
- It is difficult to track all light paths
  - It give constant brightness for each face
  - Approximation of global lighting model effect

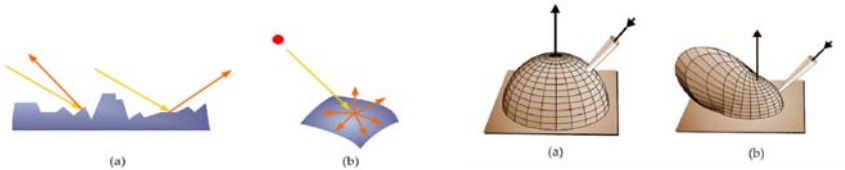


$$Ambient\ Reflection = K_a I_a$$

I_a: ambient light intensity
K_a: ambient light coefficient ($0 <= K_a <= 1$)

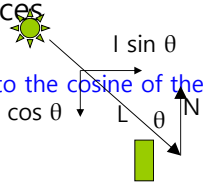
Diffuse Reflection

- Light scatter equally in all directions
- Perfect diffuser and Directional diffuser
  - Directional diffuser
    - If there is a viewpoint in the direction of diffusion, the object should be brighter.
  - Perfect diffuser
    - Assume a perfect diffuser to simplify computer graphics processing of the local lighting model.



Diffuse Reflection

- Depends on the direction of object faces
  - Lambertian Law
    - Surface brightness is directly proportional to the cosine of the angle of incidence



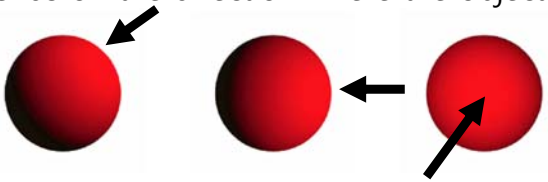
$$Diffuse\ Reflection \propto \cos\theta$$

$$Diffuse\ Reflection = K_d I_d \cos\theta = K_d I_d (N \bullet L)$$

I_d: diffuse light intensity
K_d: diffuse light coefficient

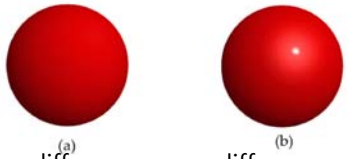
Light vector
Surface normal vector

- Brightness depends on the direction where the object is facing
  - 3D effect



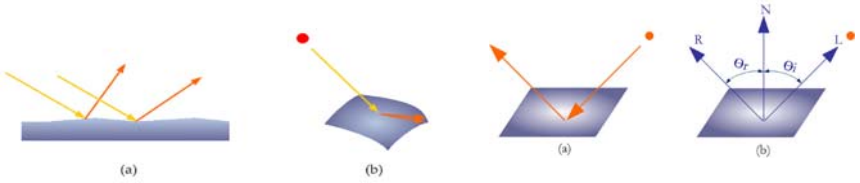
Specular Reflection

- Specular light is a light reflected off a smooth surface.
  - Specular reflection
  - The color of the light source, not the color of the object



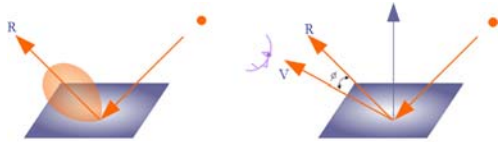
diffuse diffuse + specular

  - Specular light is visible when the viewpoint is in the exact opposite direction.

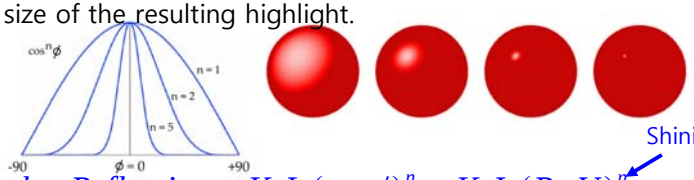


Specular Reflection

- Actual lobe looks like



- Phong reflection model
  - Adjusts the speed at which the intensity of reflected light decreases as the viewpoint direction deviates from the specular reflection direction through the shininess coefficient. Determine the size of the resulting highlight.

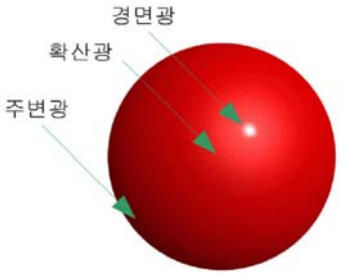


Shininess

$$Specular\ Reflection = K_s I_s (\cos\phi)^n = K_s I_s (R \bullet V)^n$$

Reflection vector, View vector

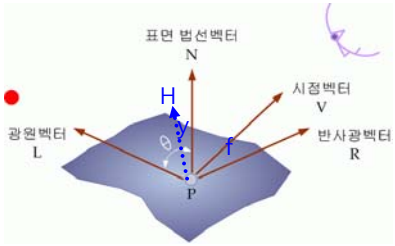
Direct Illumination Model



$$I = K_a I_a + K_d I_d (N \bullet L) + K_s I_s (R \bullet V)^n$$

Ambient reflection | Diffuse reflection | Specular reflection

Halfway Vector [Blinn]



$$H = \frac{L+V}{\|L+V\|}$$

Shininess

$$Specular\ Reflection = K_s I_s (\cos\psi)^n = K_s I_s (N \bullet H)^n$$

Normal vector, Halfway vector

$where\ 2\psi = \phi$

$When\ N \bullet L > 0, H = 1$

$When\ N \bullet L \le 0, H = 0$

Light Attenuation

- Adjust the brightness intensity according to the distance between the light source and the object

$$I = K_a I_a + f_{att}(d)\{K_d I_d (N \bullet L) + K_s I_s (N \bullet H)^n\}$$

$$f_{att}(d) = \frac{1}{d^2}$$

$$f_{att}(d) = \frac{1}{k_0 + k_1 d + k_2 d^2}$$

$$f_{att}(d) = \min\left(\frac{1}{k_0 + k_1 d + k_2 d^2}, 1\right)$$

Multiple Light Sources

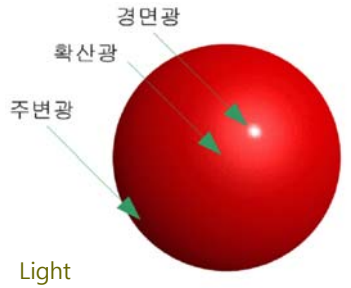
- Multiple light sources

$$I = K_a I_a + \sum_{i=0}^{m-1} f_{att}(d)\{K_d I_d (N \bullet L) + K_s I_s (N \bullet H)^n\}$$

- Emissive illumination $I_e = E$
  - Certain objects not only reflect light but also emit light, which is called emissive lighting. Simply add the color of the emitted light.

$$I = K_a I_a + \sum_{i=0}^{m-1} f_{att}(d)\{K_d I_d (N \bullet L) + K_s I_s (N \bullet H)^n\} + E$$

Direct Illumination Model



Multiple lights — Light attenuation

$$I = K_a I_a + \sum_{i=0}^{m-1} f_{att}(d)\{K_d I_d (N \bullet L) + K_s I_s (N \bullet H)^n\} + E$$

Ambient reflection — Diffuse reflection — Specular reflection — Emissive light

OpenGL uses the modified Phong model (Blinn model) with Halfway vector.

Shading

- Shading refers to shading or surface rendering, which is done during the raster process by giving the color of an object surface.
- Flat shading
  - Draws the entire given polygon with the same color
- Gouraud shading
  - Interpolates vertex color
- Phong shading
  - The normal vector of the vertex instead of the color of the vertex is not provided by interpolated OpenGL.

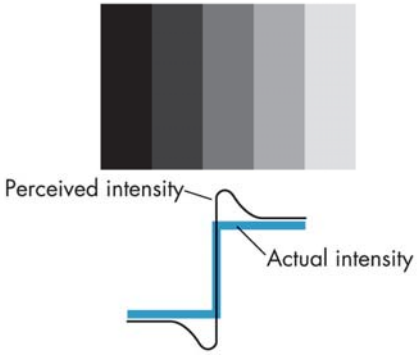
Flat Shading

- Flat shading draw the entire given polygon with the same color. Fast and simple.
- Constant shading, Facet shading
- The centroid is obtained by averaging the positions of the polygon vertices constituting the polygon.
- The lighting model is applied based on the normal vector, light source, and view vector at the center point, and as a result, the color fills all the inside of the plane.

glShadeModel (GL_FLAT);

Mach Band Effect in Flat Shading

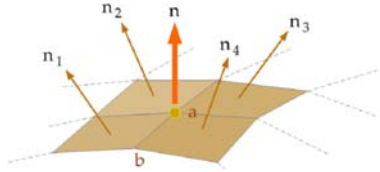
- Mach Band Effect
  - A dark and light band is formed by contrasting the intensity near the boundary line.
  - Borders become more distinct than necessary
  - Optical illusion



Gouraud Shading

- Fills the inside of a polygon with different colors.
- Interpolating vertex color
  - Requires the normal vector of the vertex, which is calculated by averaging the normal vectors of the adjacent surface.
  - Linear interpolation of inner surface color from vertex color.
- Does not take specular light into account
  - This is because the actual vertex normal vector and the approximate calculated normal vector do not completely coincide.

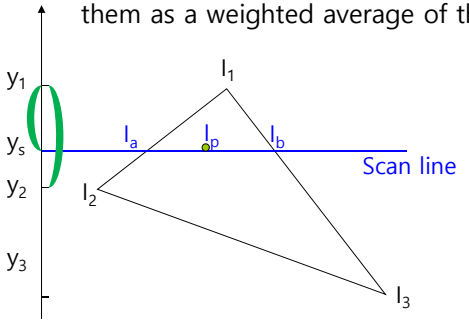
glShadeModel (GL_SMOOTH);



$$n = \frac{n_1 + n_2 + n_3 + n_4}{|n_1 + n_2 + n_3 + n_4|}$$

Gouraud Shading

- Gouraud shading interpolates color
  - Using the brightness intensity of the starting point and the ending point, and it calculates the brightness intensity between them as a weighted average of the two.



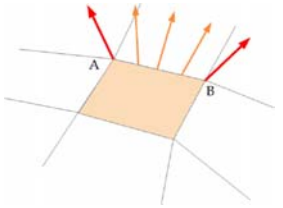
$$I_a = I_1 - (I_1 - I_2)\frac{y_1 - y_s}{y_1 - y_2}$$

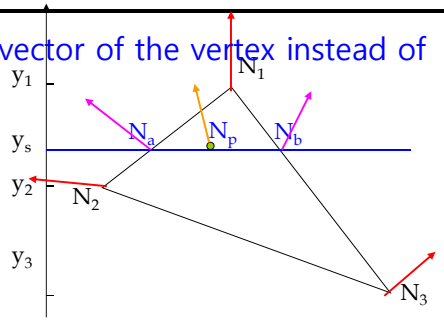
$$I_b = I_1 - (I_1 - I_3)\frac{y_1 - y_s}{y_1 - y_3}$$

$$I_p = I_b - (I_b - I_a)\frac{x_b - x_p}{x_b - x_a}$$

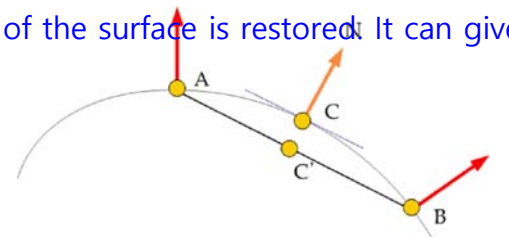
Phong Shading

- Interpolate the normal vector of the vertex instead of the color of the vertex

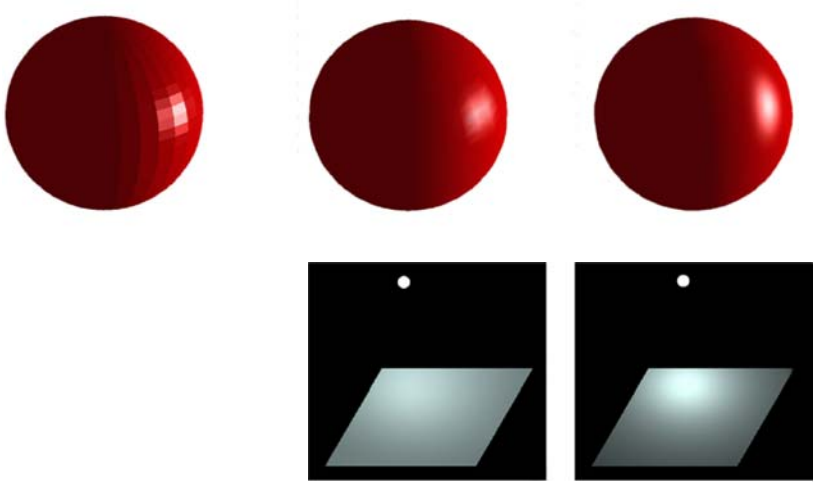




- The slope of the surface is restored. It can give specular light.

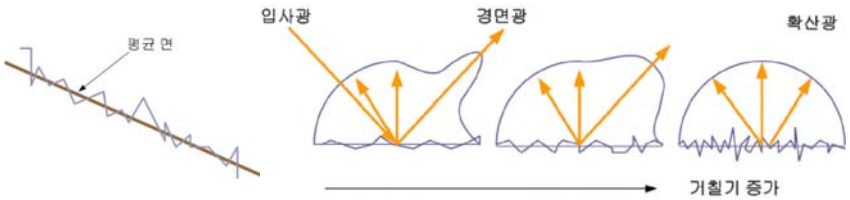


Flat, Gouraud, and Phong Shading



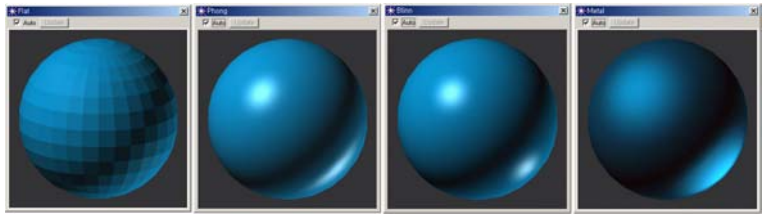
Microfacet Model

- Modeling the roughness of the surface
  - Based on the direction of the average plane
  - Controls the curvature or shape of microsurfaces using a parameter called surface roughness



Microfacet Model

- Flat, Phong, Blinn, Cook-Torrance Shading



- Blinn
  - Similar to Phong. The specular light component spreads more gently.
- Cook-Torrance (Metal shading)
  - Advantageous for subtle specular light on metal surfaces
  - Phong model: plastic material $I_{specular} = K_s I_s (\hat{N} \cdot \hat{H})^{\beta}$