CS174A Lecture 11

Announcements & Reminders

- *11/08/22: Team project proposals due, initial version*

- *11/09/22: A3 due*

- *11/10/22: Midway demo, online zoom*

- *11/20/22: A4 due*

- *11/22/22: Team project proposals due, final version*

- *11/29/22: Prof Demetri's talk*

- *12/02/22 (Discussion Sessions): Team project presentations*

- *12/06/22: Final Exam, 6:30-8:30 PM PST, in class, in person*

TA Session This Friday

- *Team project proposals*

- *Assignment #3*

- *Gouraud and Phong shadings*

Last Lecture Recap

- *Hidden Surface Removal*
  - Painter's algorithm
  - Z-buffer algorithm
  - Scanline z-buffer algorithm
  - Properties, advantages, disadvantages of each
  - Efficiency considerations

Next Up

- *Lighting/Illumination Models*
  - Ambient
  - Diffuse
  - Specular
- *Barycentric Coordinates, Bilinear Interpolations*
- *Flat and Smooth Shading*
- *Shadow Algorithms*
  - 2-pass z-buffer algorithm
- *Hidden Surface Removal*
  - Ray casting

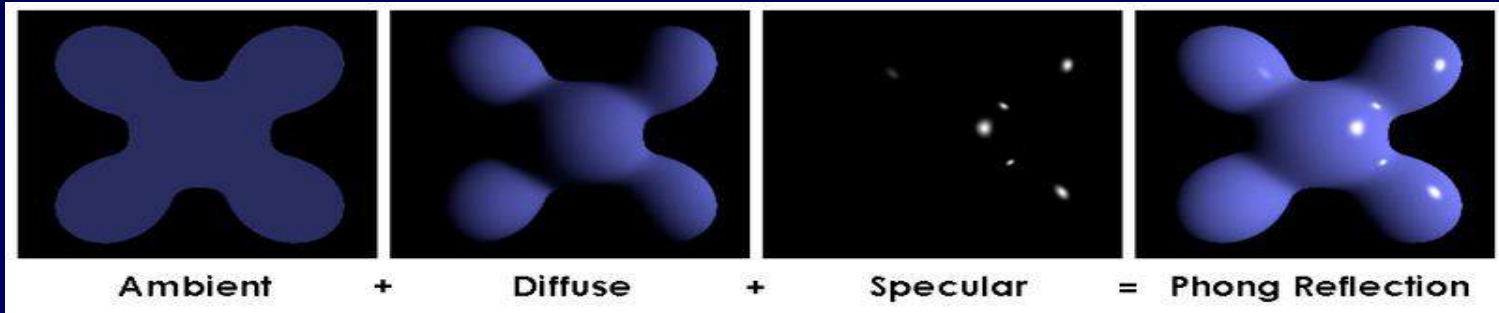# Global Illumination
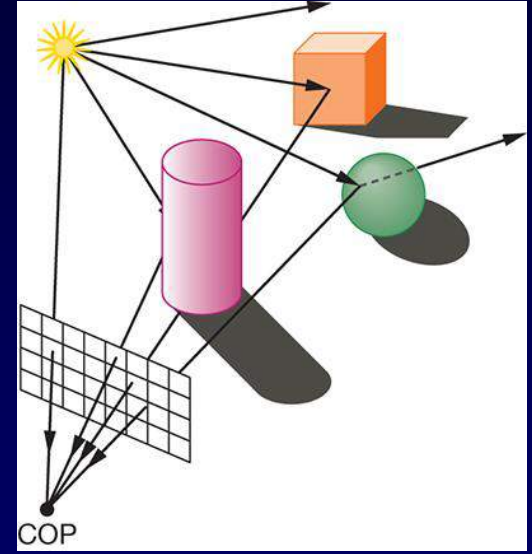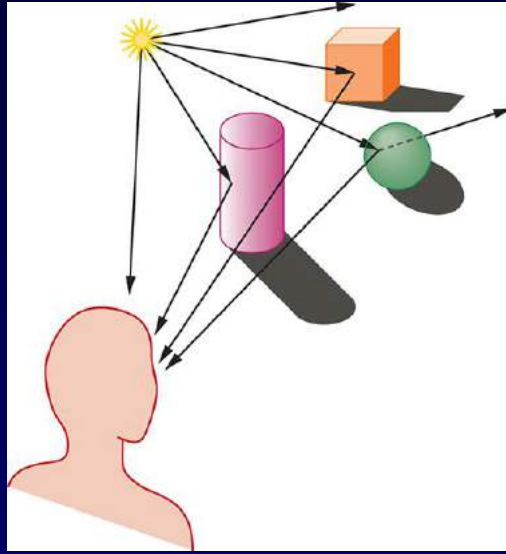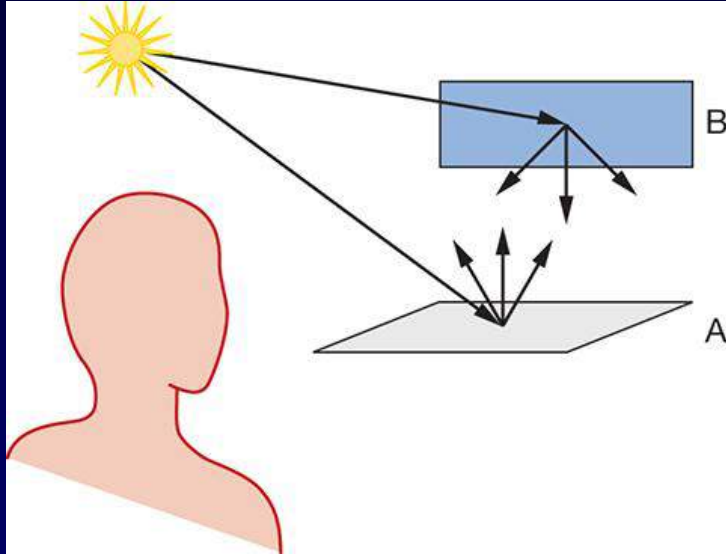
Lighting/Illumination

- *Types of Lighting*
    - Ambient
    - Diffuse
    - Specular

Ambient + Diffuse + Specular = Phong Reflection

Lighting/Illumination

- *Geometric Properties*

    - **Object**: position, orientation (normal)

    - **Light**: position, direction, point vs. spot vs. area

    - **Eye**: position, orientation

- *Material Properties*

    - **Object**: color, reflectivity, shininess, bumpiness, translucency

    - **Light**: color

    - **Eye**: filter, color blindness

Ambient Lighting

- *Properties*
  - Background light
  - Unrealistic
  - Works as a good approximation of scattered light
  - Does NOT depend on position/orientation of light, object or eye
  - Only depends on object and light's material property
  - k_a = ambient reflection coefficient, values [0..1], may be different for R, G, B
  - I_a = intensity of ambient light source, values [0..1], different for R, G, B
  - **Ambient light reflected off object = $k_a * I_a$**

Diffuse Lighting

- *Properties*
  - Point light source
  - Lambertian (or diffuse) reflection for dull, matte surfaces
  - Surfaces look equally bright from all directions
  - Reflect light **equally** in all directions
  - Lambert's Law: *amount of light reflected from a differential unit area dA toward a viewer is $\propto$ the cosine of the angle between the incident light and the normal (θ)*
  - k_d = diffuse reflection coefficient, values [0..1]
  - I_p = intensity of point light source, values [0..1]
  - **Diffuse light reflected off object = $k_d * I_p * \cos\theta = k_d * I_p * (N \cdot L)$**
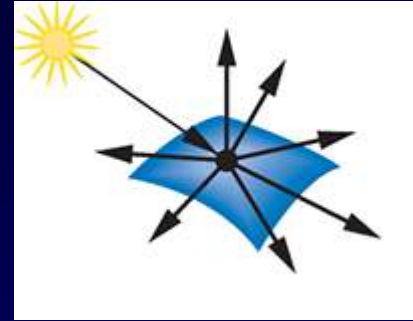
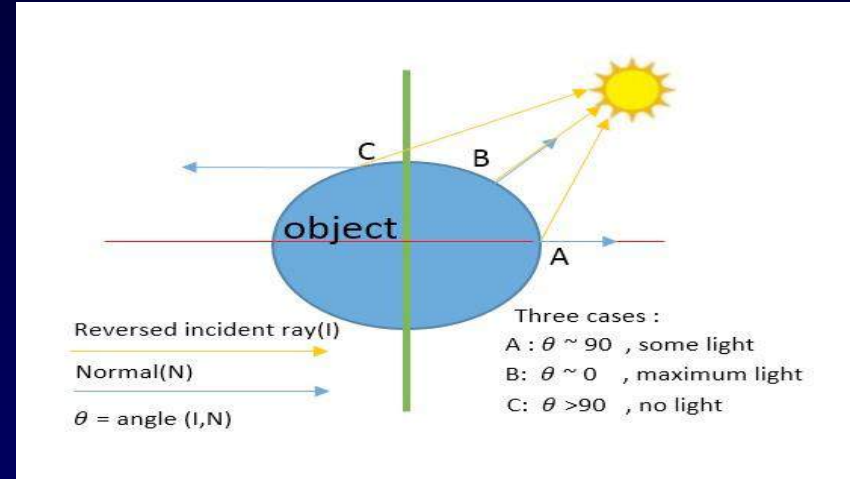# Diffuse Lighting (Contd.)

- *Incident angle θ*
  - $\theta < 90^\circ \Rightarrow$ some light based on angle θ
  - $\theta = 0^\circ \Rightarrow$ max light
  - $\theta > 90^\circ \Rightarrow$ self occlusion

- *Directional light source*
  - A light at sufficient distance from object (e.g., sun)
  - L remains the same for entire scene
  - N remains the same for entire polygon
  - Therefore, N·L = constant on poly; L = constant everywhere

- *Attenuated light source*
  - Diffuse light reflected off object = $f_{att} * k_d * I_p * \cos\theta = f_{att} * k_d * I_p * (N \cdot L)$
  - $f_{att} = \frac{1}{d^2}$ or $\frac{1}{c_1 + c_2 * d + c_3 * d^2}$; $f_{att} = \min(f_{att}, 1)$

Reversed incident ray(I)
Normal(N)
θ = angle (I,N)

Three cases :
A : $\theta \sim 90$, some light
B: $\theta \sim 0$, maximum light
C: $\theta > 90$, no light

Diffuse Lighting (Contd.)

- ***Colored Light and Objects***
  - Object's Diffuse Color ($O_{d\lambda}$): O_{dR}, O_{dG}, O_{dB}
  - $I_\lambda = [k_{a\lambda} * I_{a\lambda} + f_{att} * k_{d\lambda} * I_{p\lambda} * (N{\cdot}L)] * O_{d\lambda}$

- ***Atmospheric Attenuation or Blending***
  - Depth cueing or fog (fog color = $I_{dc\lambda}$)
  - $I'_\lambda = s_o * I_\lambda + (1 - s_o) * I_{dc\lambda}$
  - $s_o = s_b$ when $z > z_b$
  - $s_o = s_f$ when $z < z_f$
  - $s_o = s_f + \frac{(s_b - s_f)}{(z_b - z_f)}(z - zf)$
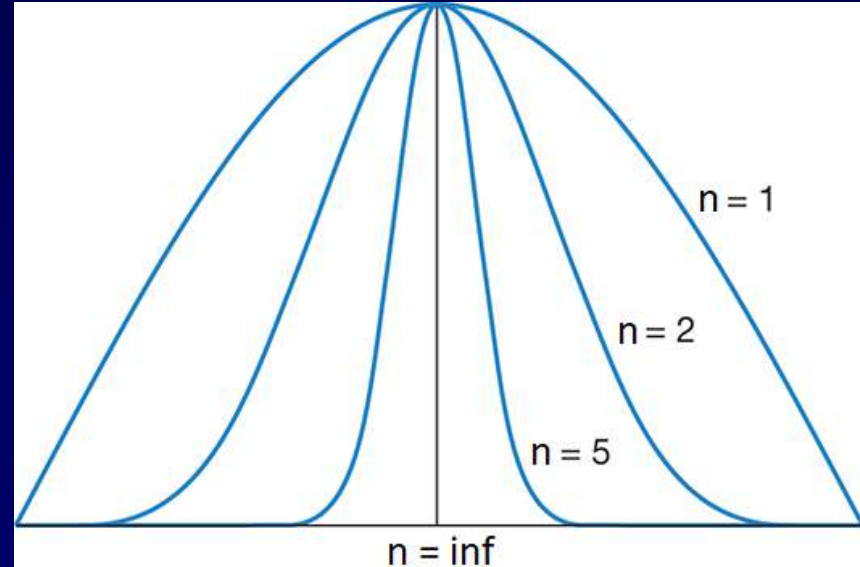
Specular Lighting

- *Properties*
  - Shiny surfaces
  - Color of light, not object
  - Does depend on position of light, object and eye
  - Light reflects **unequally** in different directions (e.g., perfect reflector: mirror)
  - For non-perfect reflectors
  - k_s = specular reflection coefficient, values [0..1], may be different for R, G, B
  - n = material's specular reflection exponent, values [1..100s], perfect reflector n = ∞
  - **Specular light reflected off object = $f_{att} * k_s * I_p * \cos^n\phi = f_{att} * k_s * I_p * (R \cdot V)^n$**
  - $I_\lambda = k_{a\lambda} * I_{a\lambda} * O_{d\lambda} + f_{att} * k_{d\lambda} * I_{p\lambda} * (N \cdot L) * O_{d\lambda} + f_{att} * k_{s\lambda} * I_{p\lambda} * (R \cdot V)^n$
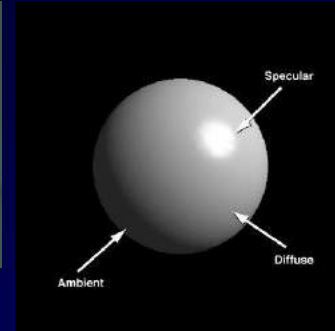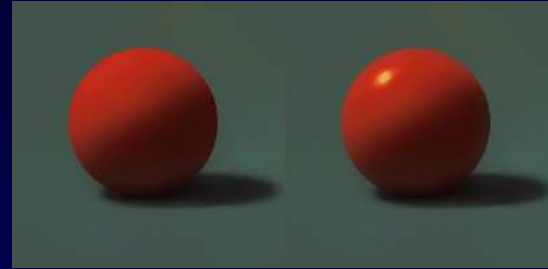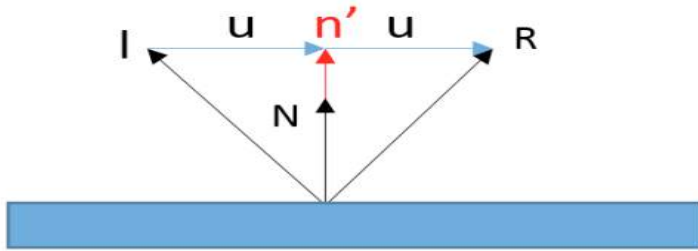
Specular Lighting (Contd.)

- *Specular Term: Smoothness Exponent Effect*
  - Exponentiating a term that has values < 1 draws it closer to 0
  - Higher exponent $\Rightarrow$ smaller region where point light's reflection is considered aligned with the viewer $\Rightarrow$ smaller shiny spot
  - -ve values of $\cos\varphi$ is clamped to 0
    $= \max(0, (R \cdot V)^n)$
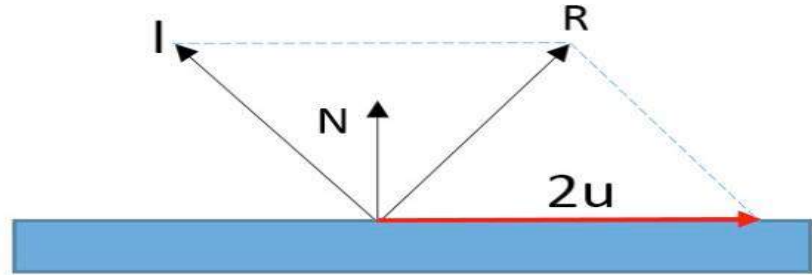 - Max specular reflection when $\varphi = 0$

Specular Lighting (Contd.)

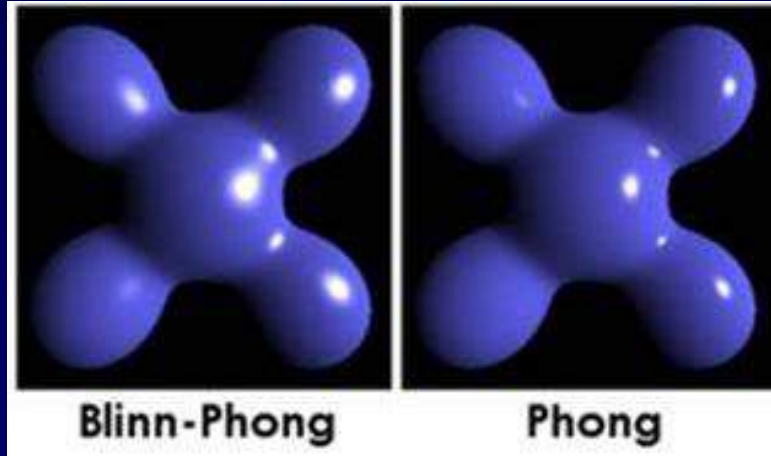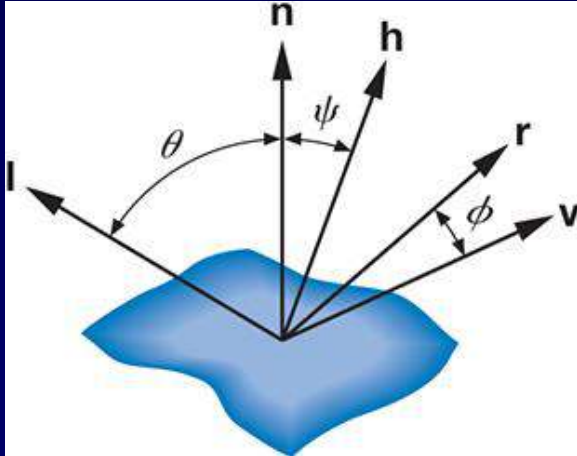- *Calculating R Vector: reflection of point light source*

The $\vec{n'}$ is the projection of $\vec{I}$ on $\vec{N}$

$\vec{n'} = (\vec{N} \cdot \vec{I})\,\vec{N}$, with $\|\vec{N}\|^2 = 1$
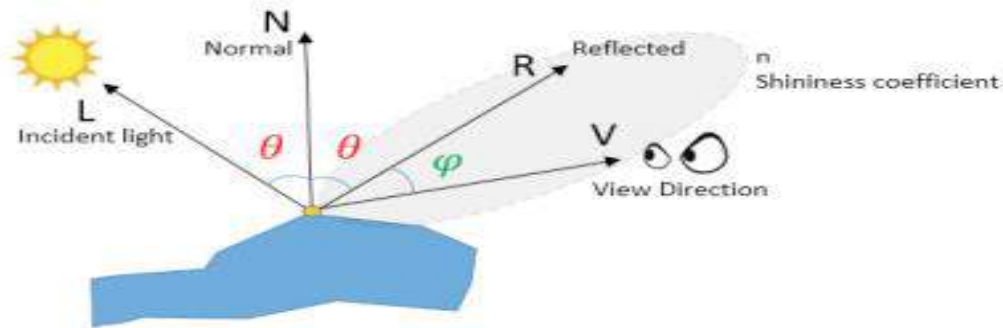
$\vec{u} = \vec{n'} - \vec{I}$

$\vec{R} = \vec{I} + 2\vec{u} = \vec{I} + 2(\vec{n'} - \vec{I})$

$\vec{R} = 2(\vec{N} \cdot \vec{I})\,\vec{N} - \vec{I}$

Specular Lighting (Contd.)

- **_Halfway Vector: Alternate Formulation of R·V_**

  - Halfway vector (H) between L and V = normalize(L + V)

  - Replace $(R·V)^n$ with $(H·N)^n = \cos^n \psi$ ($\psi = \theta/2$)

  - This alternate is referred to as Blinn-Phong illumination

Blinn-Phong   Phong

Final Light Equation

I = emissive + ambient + diffuse + specular

$$emissive = k_e$$
$$ambient = k_a * ambientColor$$
$$diffuse \quad = k_d * lightColor * \cos(\theta)$$
$$\qquad\qquad = k_d * lightColor * \max(0, N \cdot L)$$
$$specular = k_s * lightColor * \cos(\varphi)^n$$
$$\qquad\qquad = k_s * lightColor * \max(0, R \cdot V)^n$$

Lighting: Misc Improvements

- ***Multiple Light Sources***
  - Sum the light terms over all light sources
- ***Clamping***
  - x = max(0,x) and min(x,1)
  - x = normalize(x) wrt to max value of color in entire image
- ***Fast Alternative to Phong Illumination***
  - t = R·V or H·N
  - Instead of t^n, do $\dfrac{t}{n - nt + t}$
- ***Spot Lights***
  - Smooth spot silhouette

Type of Lights: Summary

Type	Location	Direction
Ambient	No	No
Point	Yes	No
Directional	No	Yes
Spot	Yes	Yes + Spot Angle