# 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, 6:30-9:30 PM PST, in class, in person***

# TA Session This Friday

- *Team project proposals*
- *Assignment #3*
- *Gouraud and Phong shadings*

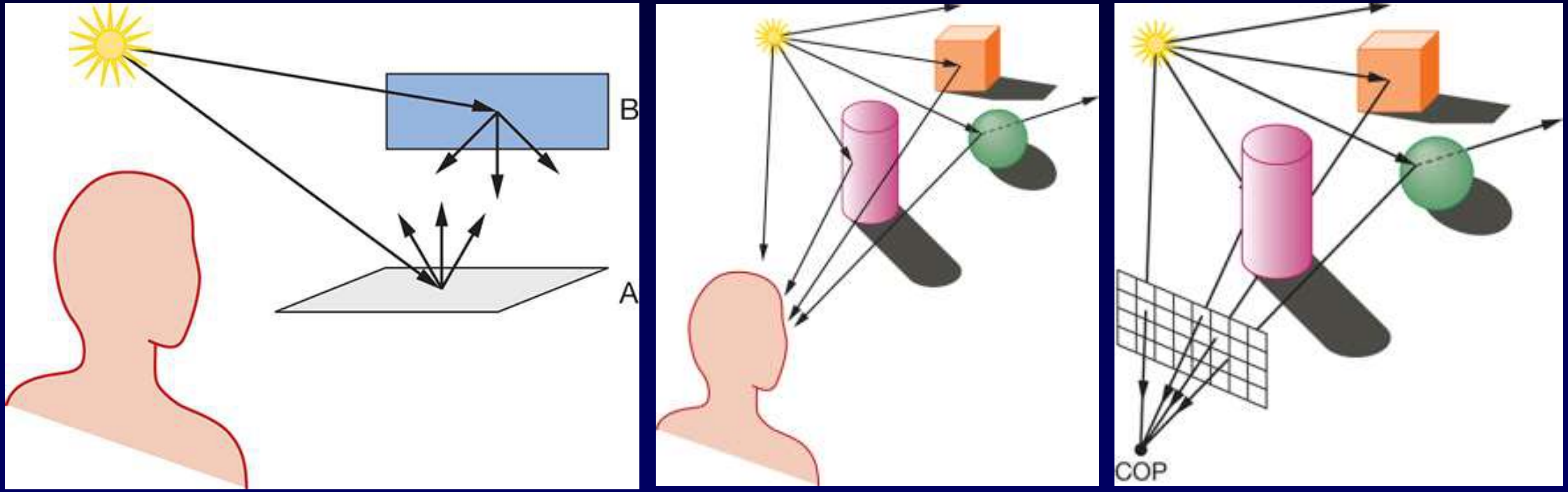
# Last Lecture Recap

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

# Next Up

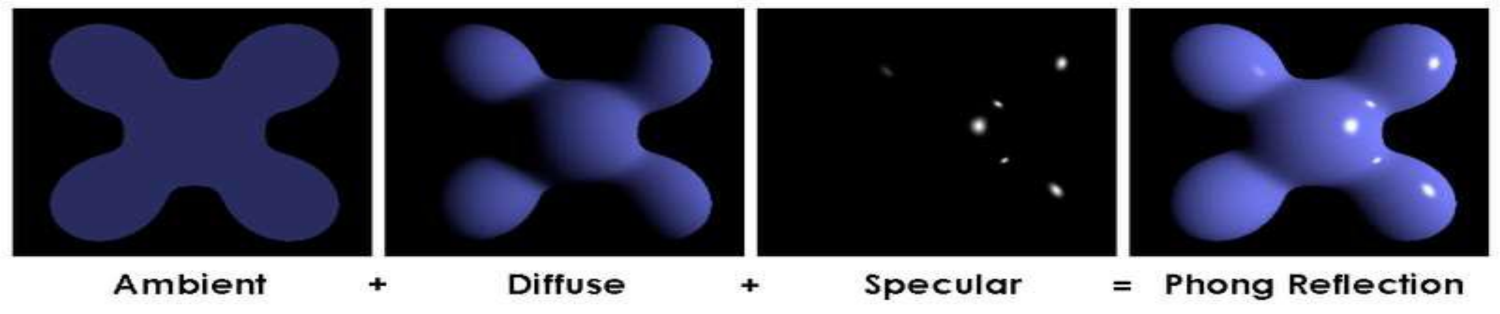
- ***Lighting/Illumination Models***
  - Ambient
  - Diffuse
  - Specular
- ***Barycentric Coordinates, Bilinear Interpolations***
- ***Flat and Smooth Shading***
- ***Shadow Algorithms***
  - 2-pass z-buffer algorithm
- ***Hidden Surface Removal***
  - Ray casting

# Global Illumination



# Lighting/Illumination

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



# 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

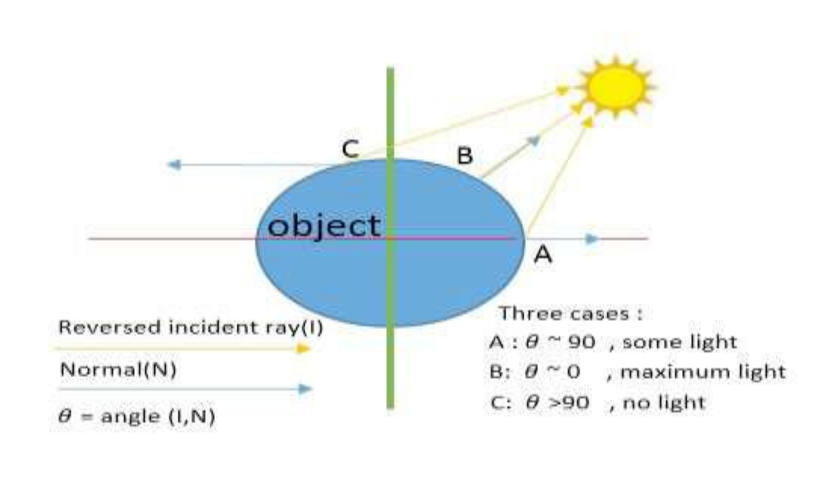
- ***Properties***
  - Background light
  - Unrealistic
  - Works as a good approximation of scattered light
  - Does NOT depend on position/orientation of light, object or eye
  - Only depends on object and light's material property
  - $k_a$ = ambient reflection coefficient, values [0..1], may be different 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 ($\theta$)*
  - $k_d$ = 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***
  - θ < 90º ⇒ some light based on angle θ
  - θ = 0º ⇒ max light
  - θ > 90º ⇒ 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 $\frac{1}{c_1 + c_2 * d + c_3 * d^2}$; $f_{att} = \min(f_{att}, 1)$

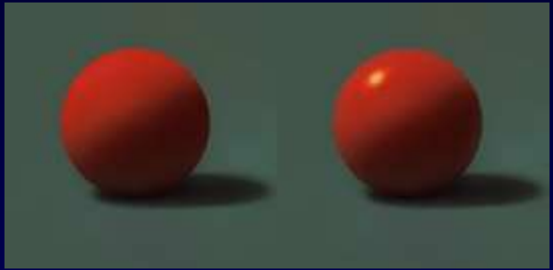


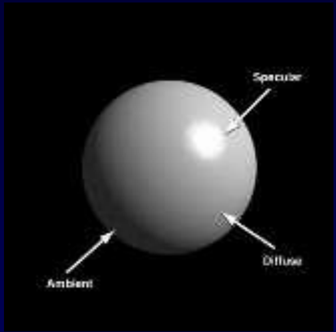
# Diffuse Lighting (Contd.)

- ***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

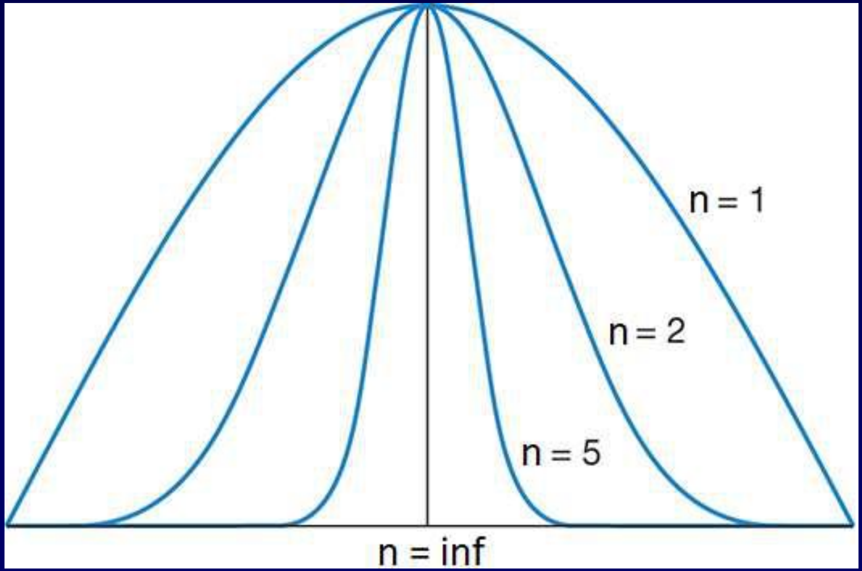
- ***Properties***
  - Shiny surfaces
  - Color of light, not object
  - Does depend on position of light, object and eye
  - Light reflects **unequally** in different directions (e.g., perfect reflector: mirror)
  - For non-perfect reflectors
  - $k_s$ = specular reflection coefficient, values [0..1],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





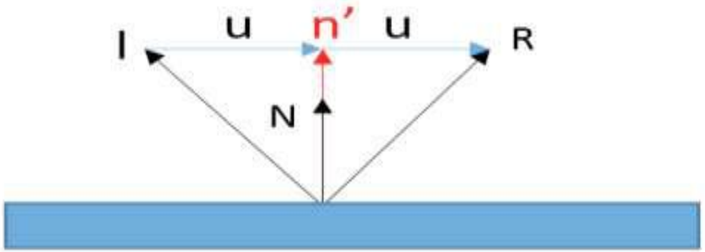
# Specular Lighting (Contd.)

- ***Specular Term: Smoothness Exponent Effect***
  - Exponentiating a term that has values < 1 draws it closer to 0
  - Higher exponent ⇒ smaller region where point light's reflection is considered aligned with the viewer ⇒ 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.)

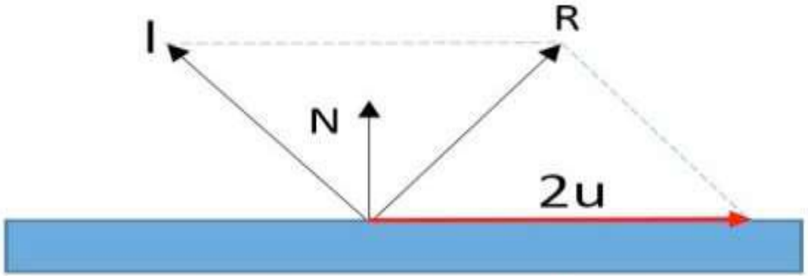
- ***Calculating R Vector: reflection of point light source***




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

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

$$\vec{u} = \vec{n'} - \vec{I}$$

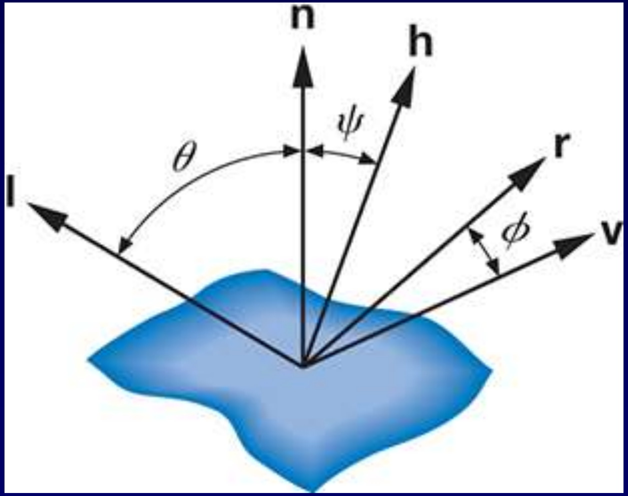



$$\vec{R} = \vec{I} + 2\vec{u} = \vec{I} + 2(\vec{n'} - \vec{I})$$

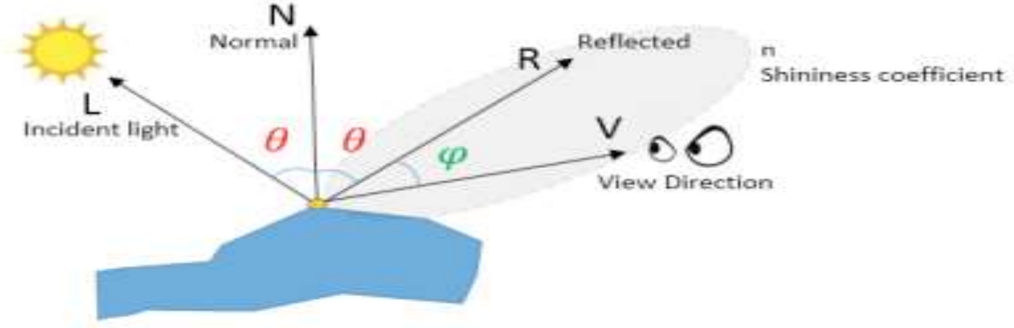
$$\vec{R} = 2(\vec{N} \cdot \vec{I})\,\vec{N} - \vec{I}$$

# Specular Lighting (Contd.)

- ***Halfway Vector: Alternate Formulation of R·V***
  - Halfway vector (H) between L and V = normalize(L + V)
  - Replace $(R \cdot V)^n$ with $(H \cdot N)^n = \cos^n\psi$
  - This alternate is referred to as Blinn-Phong illumination



# Final Light Equation




I = emissive + ambient + diffuse + specular

emissive = $k_e$

ambient = $k_a * ambientColor$

diffuse $= k_d * lightColor * \cos(\theta)$

$= k_d * lightColor$ * max(0,N · L)

specular = $k_s * lightColor * \cos(\varphi)^n$

$= k_s * lightColor$ * max(0,R · 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 $\frac{t}{n - nt + t}$
- ***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 |