CS148 Summer 2025 - Lecture 5

07/08/2025

Light and Optics

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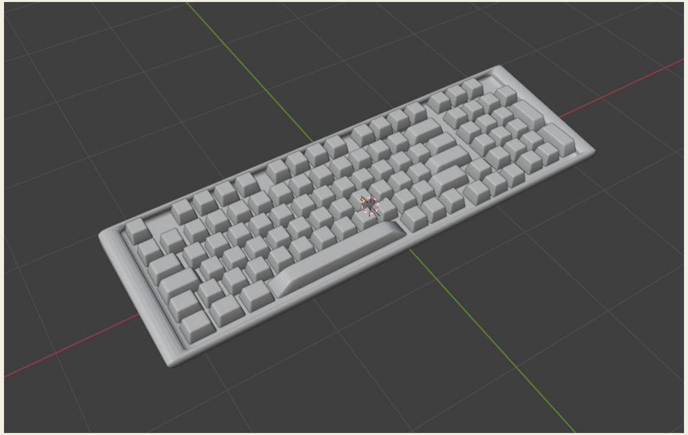
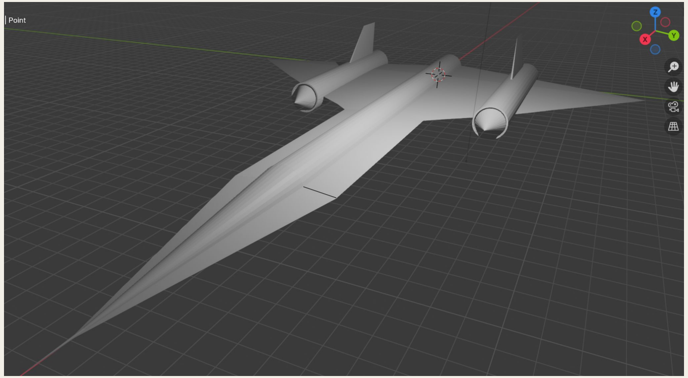
Homework 1 Student Models

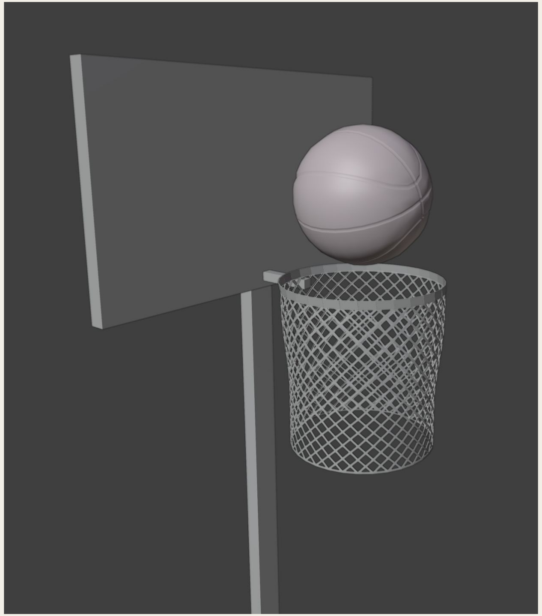


Tzu Yu



Sudharsan Sundar

Sibo Peng



Spurthi Bhat

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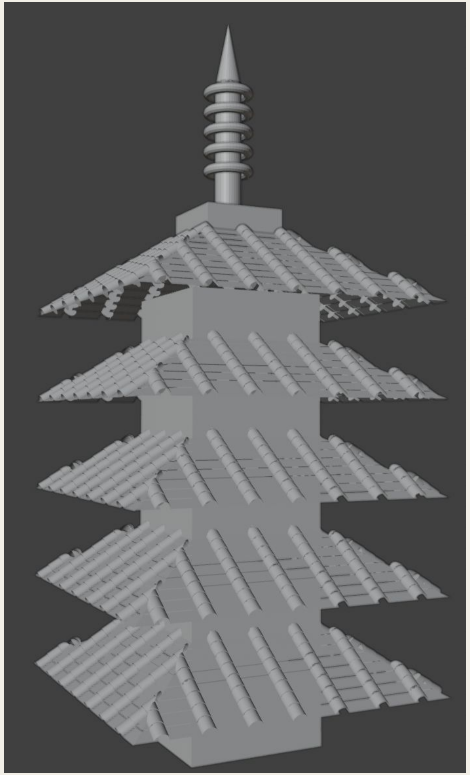
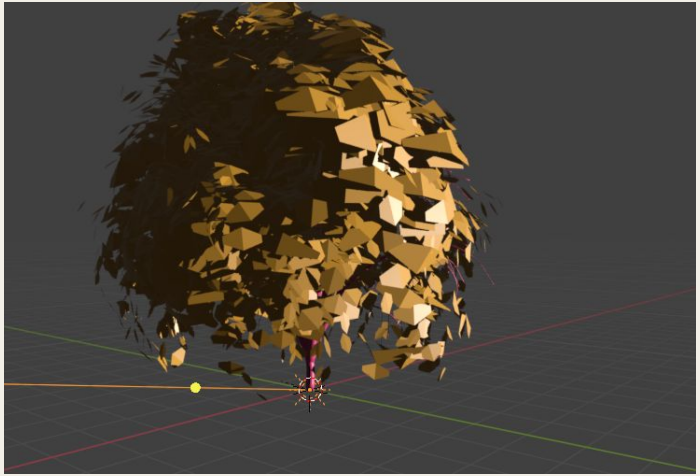


Seigo Hayami

Benjamin Zaidel

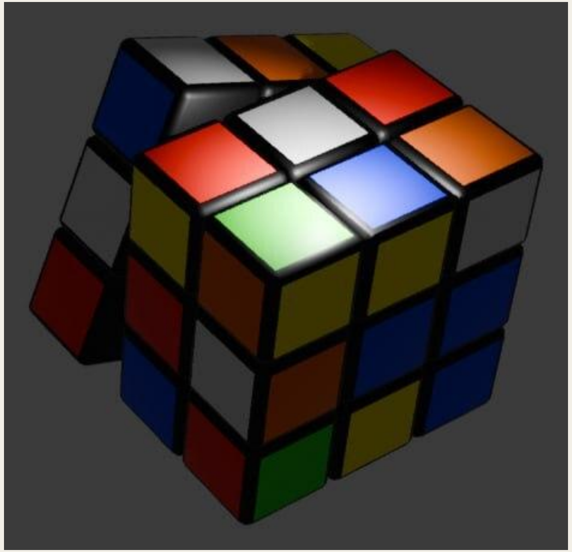


Ian Fong

Homework 1 Student Models

Felix Fan

Sisi Aarukapalli



Ray Sim

Looking Towards Ray Tracing

Rasterization (Scanline Rendering)

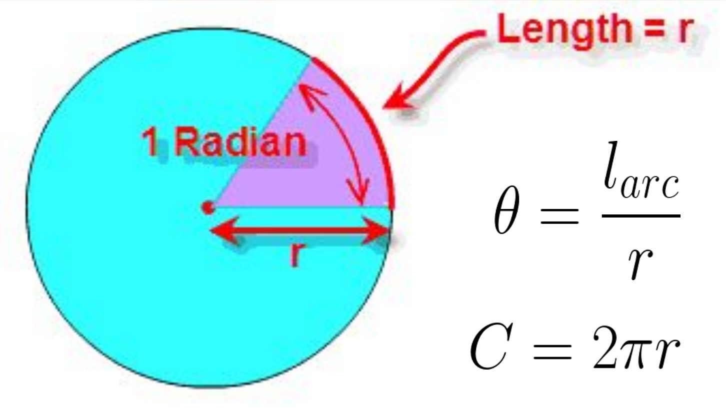
Ray Tracing

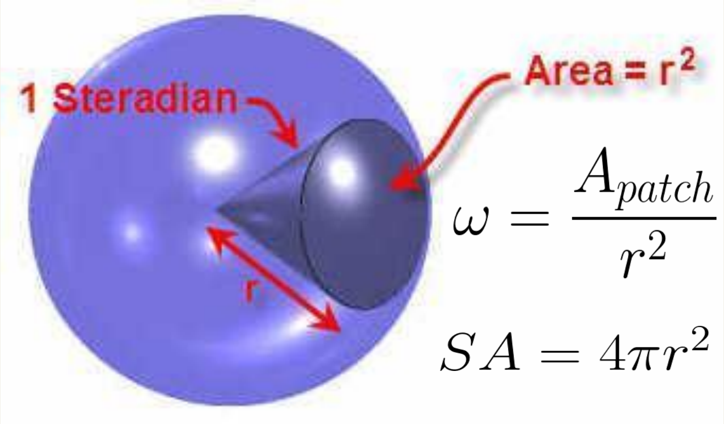
- Today’s lecture: first need to understand how we model light

Solid Angle

- A **<u>steradian</u>** is the 3D equivalent of the 2D radian
- More exactly: a steradian is a cone-like volume (called a **<u>solid angle</u>**) defined by a point and **surface area patch**

- 2π radians in a circle; 4π steradians in a sphere



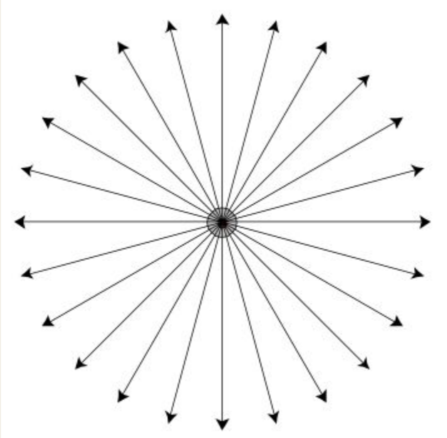


Radiant Intensity for a Light Source

- **Radiant Intensity** is the power of a light source per solid angle:

$$I(\omega) = \frac{dP}{d\omega}$$

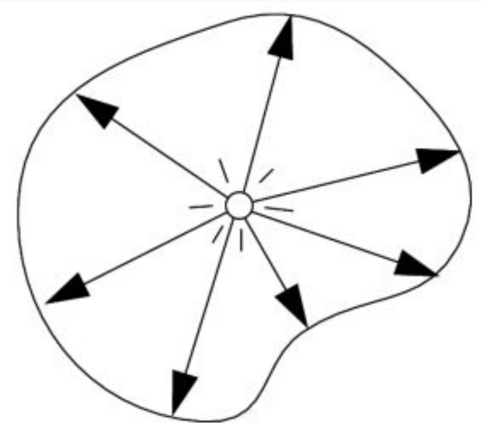
where power is measured in watts, i.e. joules (energy) per second



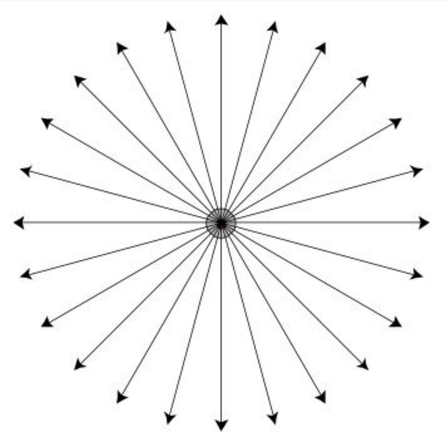
Radiant Intensity for a Light Source

- For **anisotropic** light sources, radiant intensity varies across the light, and thus needs to be a function of steradians
- For **isotropic point lights**, if we integrate $dP = I d\omega$:

$$P = \int_{sphere} I d\omega = 4\pi I$$



anisotropic light

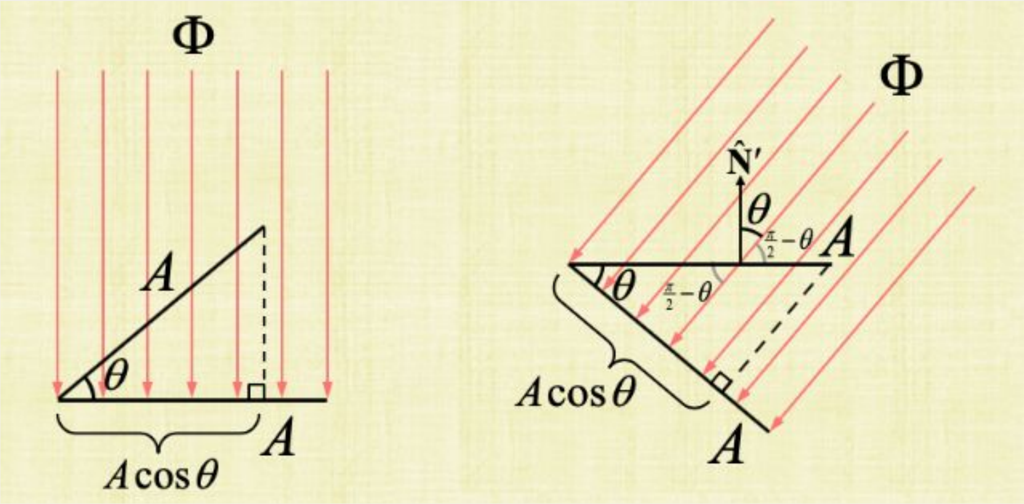


Isotropic point light

Irradiance on a Surface

- **Irradiance** is the power per unit surface area of the object that the light is hitting:

$$E = \frac{dP}{dA}$$

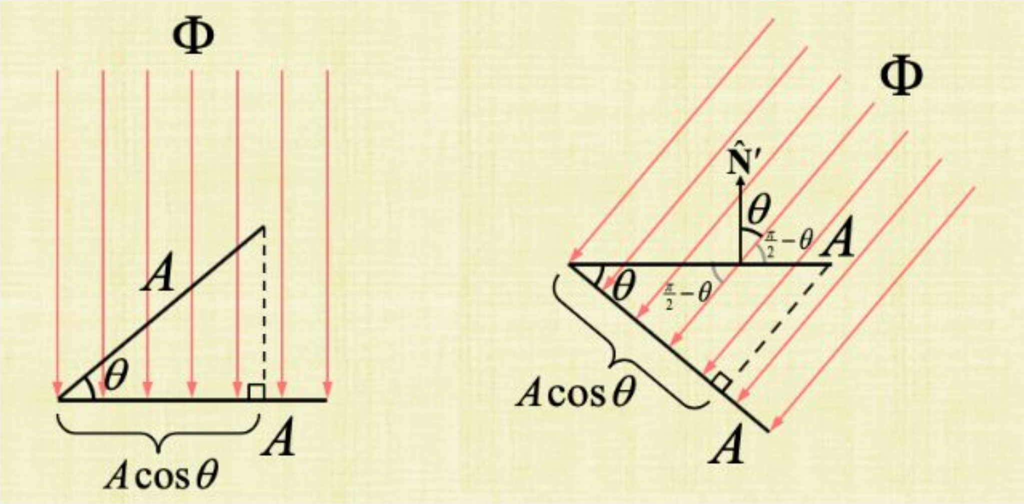


Irradiance on a Surface

- Irradiance <u>decreases as you tilt</u> the surface:

$$E = \frac{dP}{dA} \rightarrow E_{tilted} = \frac{\frac{A\cos\theta}{A}P}{A} = E\cos\theta$$

We saw this cosine appear when we talked about diffuse lighting!

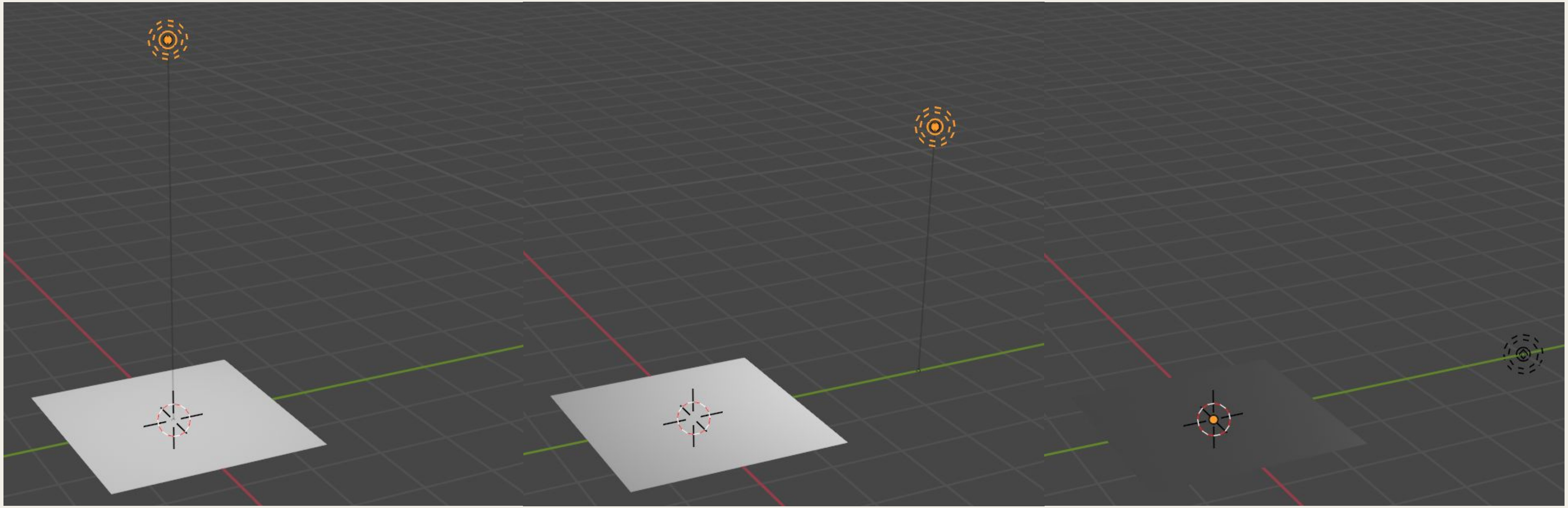


Summary

- Radiant Intensity:
    - power (coming from a light) per unit solid angle
    - measures the strength of a (point) light source
- Irradiance:
    - light power (hitting a surface) per unit surface area
    - measures how much light is hitting a surface
    - varies based on tilt angle of surface with light
    - varies based on distance from light

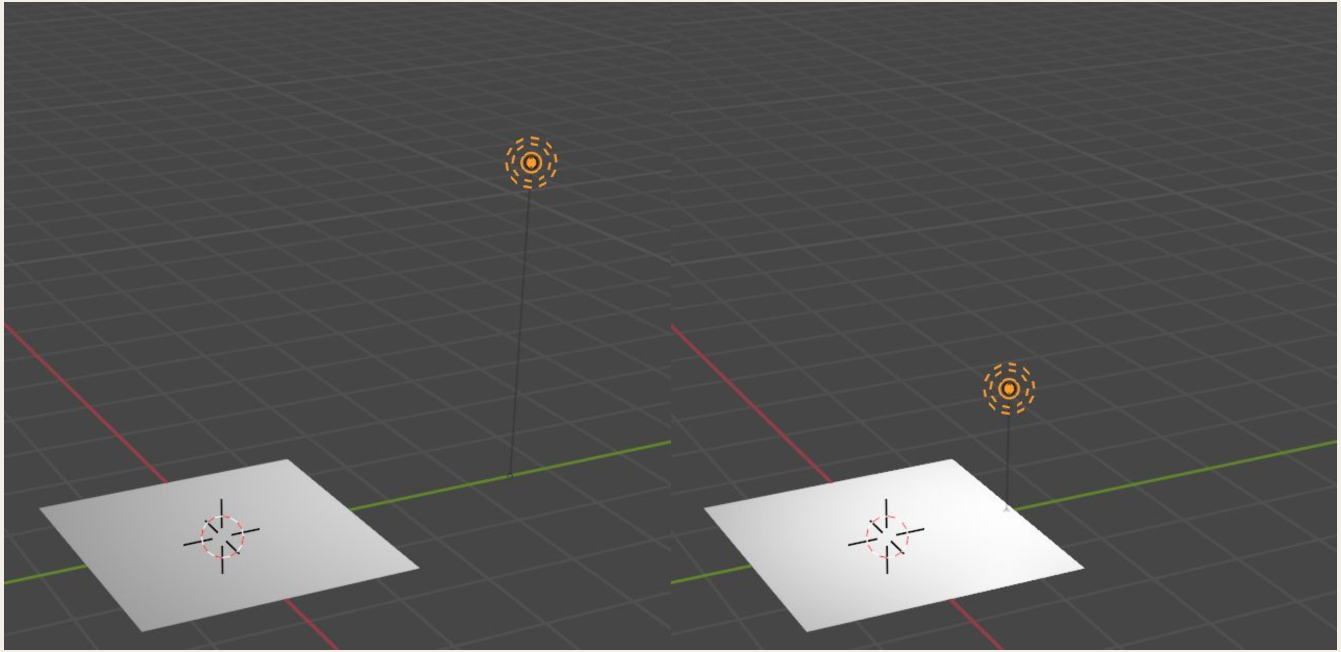
Summary

- Irradiance:
  - varies based on tilt angle of surface with light



Summary

- Irradiance:
  - varies based on distance from light



Area Lights - Radiance

- In the real world, light is emitted per unit area (not from a point)
- Think: computer screen (rectangle area), light bulb (surface patch)

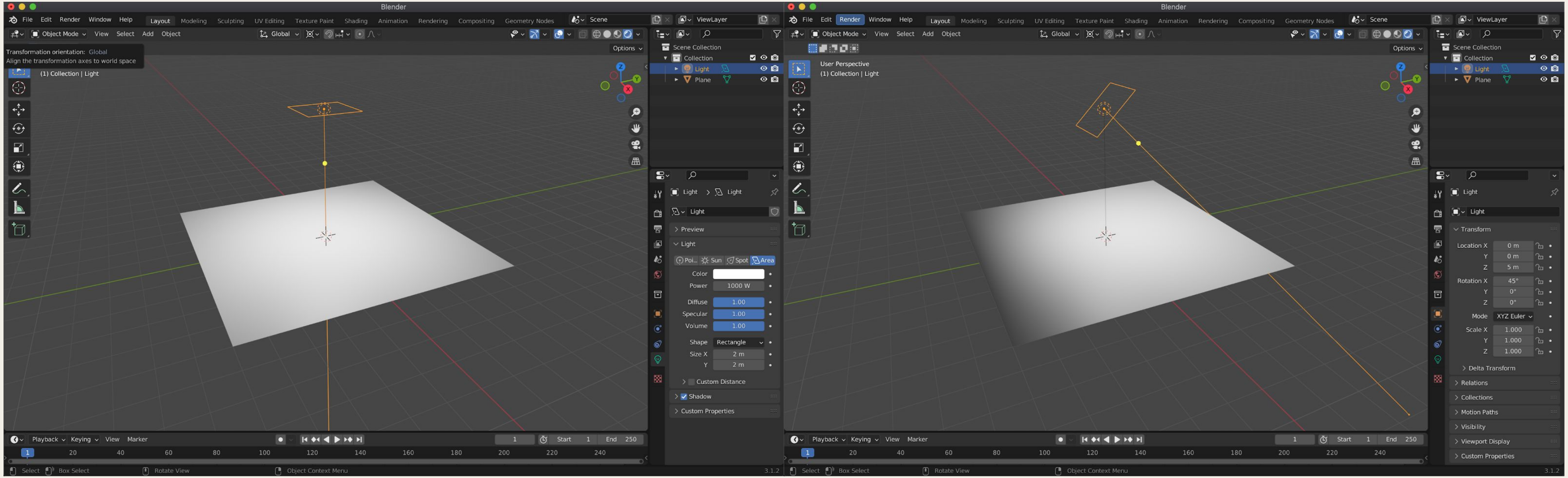
- Approximate area light by breaking it into small area chunks
- Each area chunk emits light in a solid angle direction
- Thus, define **radiance** as radiant intensity per area chunk:

$$L = \frac{dI}{dA \cos\theta}$$

Area Lights - Radiance

- Define **radiance** as radiant intensity per area chunk:

$$L = \frac{dI}{dA\cos\theta} = \left(\frac{d(dP)}{d\omega dA\cos\theta} = \frac{dE}{d\omega\cos\theta}\right)$$



Questions?

Incoming Light - Color Bleeding

- In the real world, light doesn’t come from just light sources
- Light comes from all visible objects in the world
- Each area chunk of each object acts as a source of light

- Example: the tree acts as a light shining its radiance on the car

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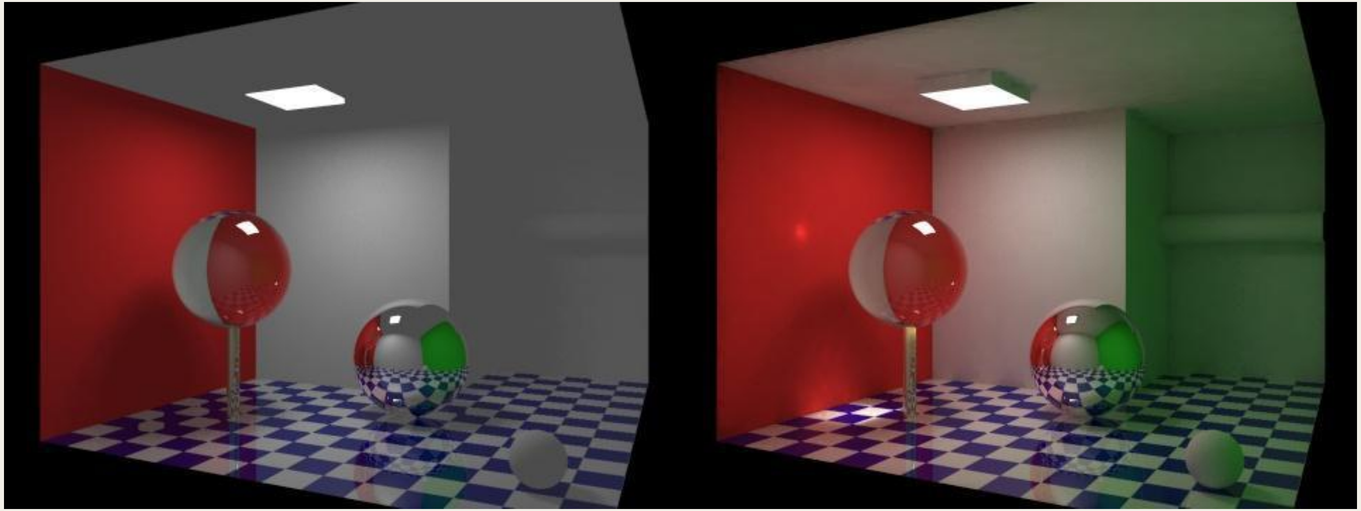


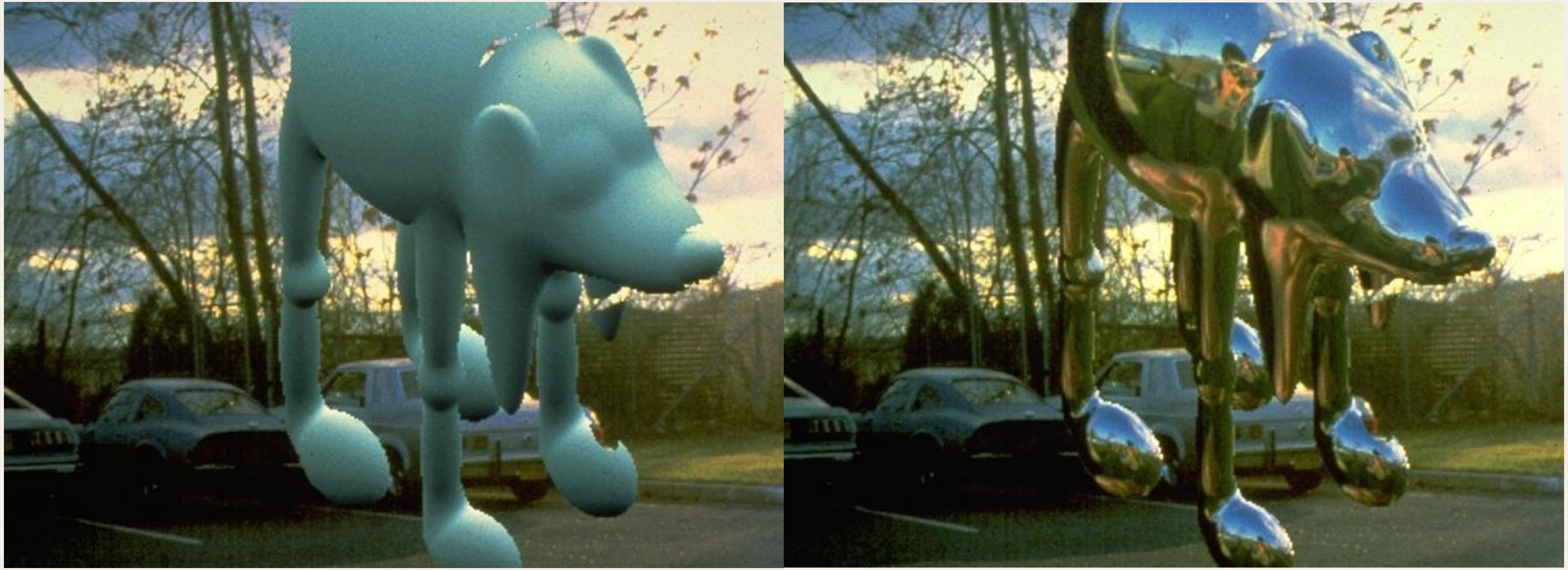
using only light from the light source | using incoming light from all directions

Measuring Incoming Light

- Use a small reflective chrome sphere (called a light probe)
- Photograph it to record the intensity of incoming light

Measuring Incoming Light

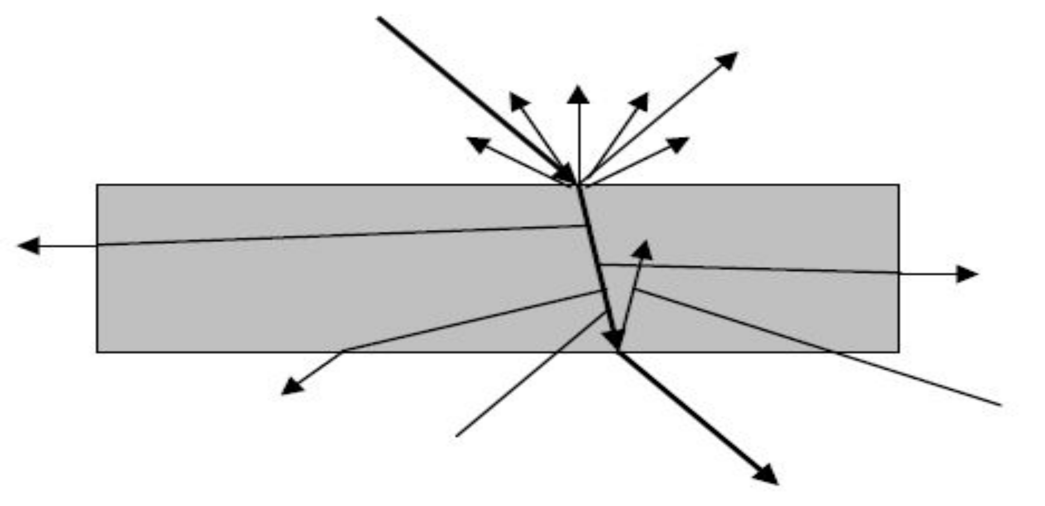
- Measuring incoming light lets us model a synthetic object in CGI and render it as though it belonged in the original scene



Questions?

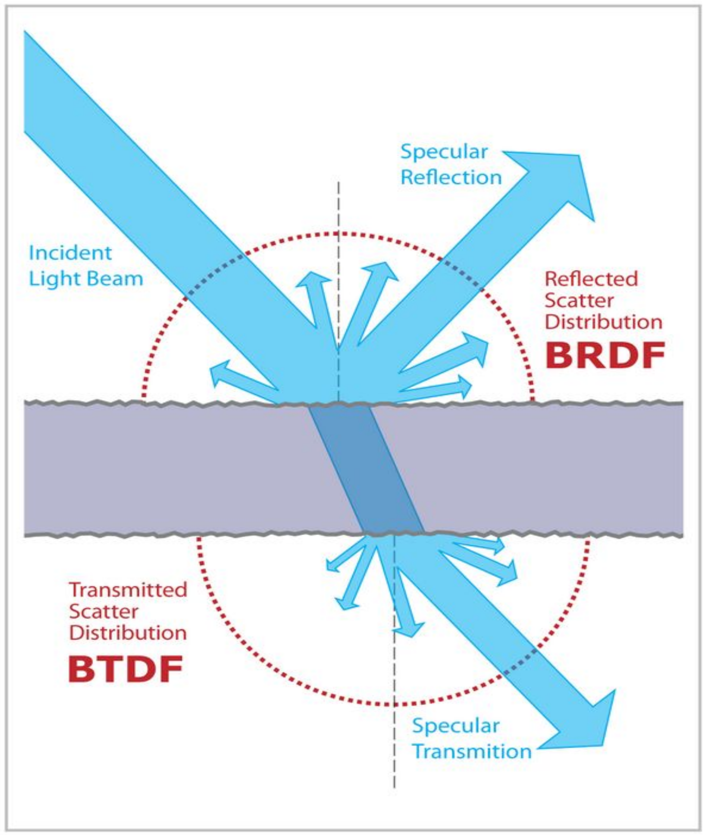
Light/Object Interaction

- Depending on the **material of the object**, when light hits it, it may be: **absorbed, reflected, or transmitted**
- Also refer to the light as **absorbed or scattered**

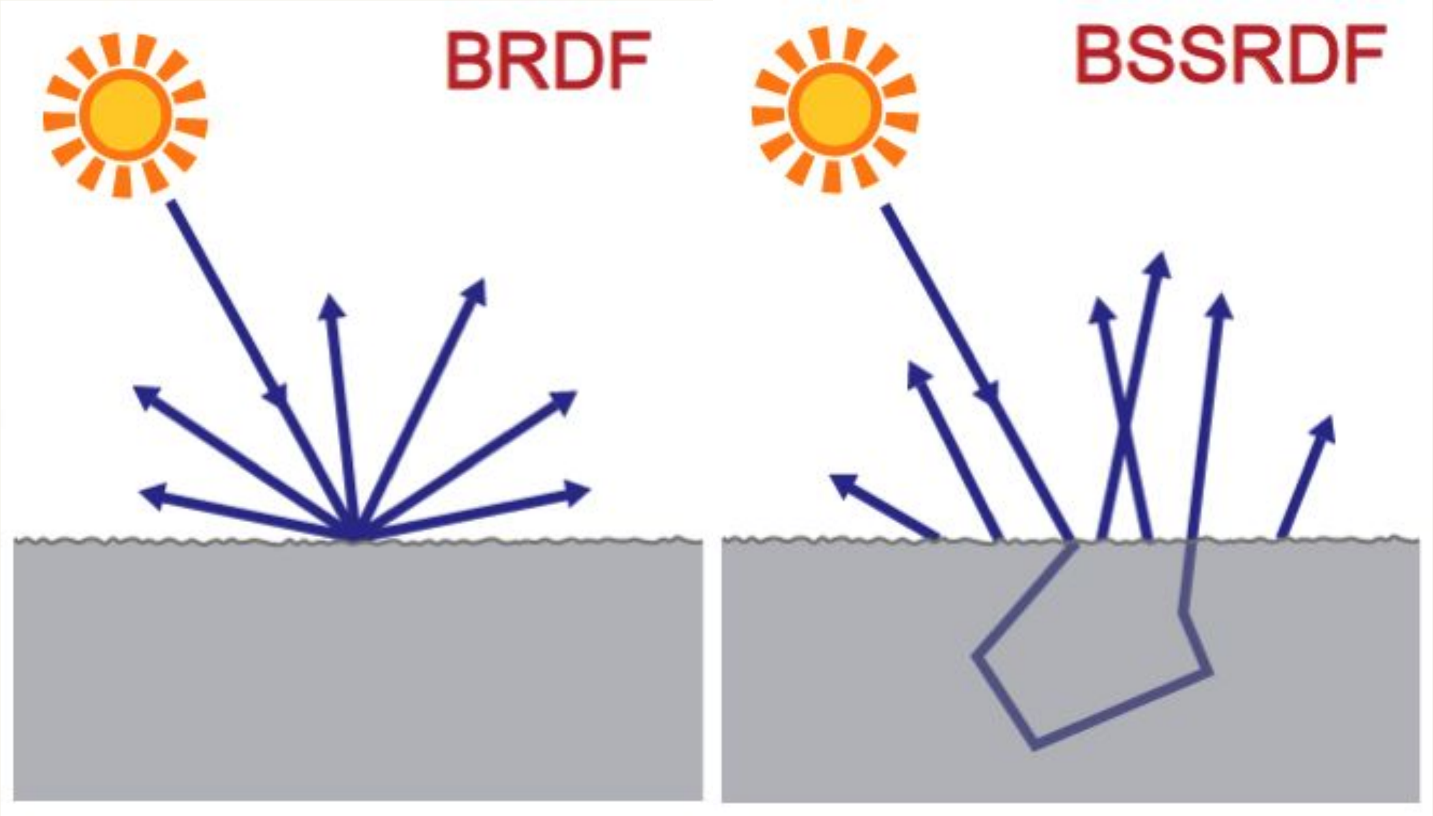


Approximations for Modeling Materials

- **BRDF**
  - Bidirectional **Reflectance** Distribution Function
- **BTDF**
  - Bidirectional **Transmittance** Distribution Function
- **BSSRDF**
  - Bidirectional Surface Scattering Reflectance Distribution Function
  - Combines reflection and transmission models



Opaque (BRDF) vs. Translucent (BSSRDF)



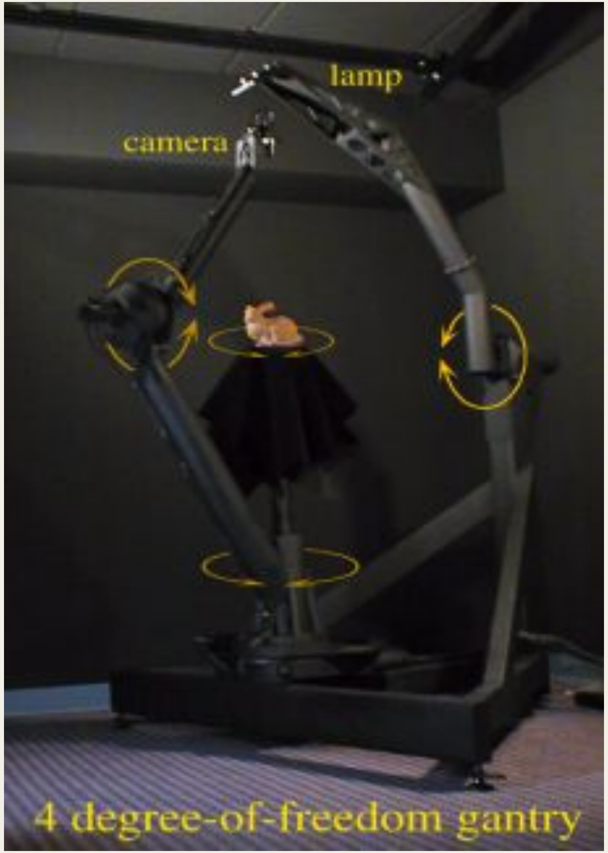
Opaque (BRDF) vs. Translucent (BSSRDF)

Opaque (BRDF) vs. Translucent (BSSRDF)

Opaque (BRDF) vs. Translucent (BSSRDF)

Measuring/Approximating Material Models

- Can measure material data for an object using a gonioreflectometer
- OR (simple) analytical models (BRDFs)
  - Blinn-Phong:
    - simplest, most general (plastic)
    - recall Phong Reflection Model!
  - Cook-Torrance:
    - better specular (metal)
  - Ward:
    - anisotropic (brushed metal, hair)
  - Oren-Nayar:
    - non-matte (concrete, plaster)



BRDF

- BRDF $(\lambda, \omega_i, \omega_o, u, v)$
  - λ wavelength: use RGB for 3 BRDFs, 1 for each color component
  - $\omega_i(\theta_i, \phi_i), \omega_o(\theta_o, \phi_o)$ are the incoming / outgoing light directions, solid angles parameterized using spherical coordinates
  - (u, v) are the coordinates on the object surface (textures later!)

- Thus, we have 3 functions, 1 for each color component, each a function of 4 variables:

$$BRDF_R(\omega_i, \omega_o), BRDF_G(\omega_i, \omega_o), BRDF_B(\omega_i, \omega_o)$$

$$BRDF_R(\theta_i, \phi_i, \theta_o, \phi_o), BRDF_G(\theta_i, \phi_i, \theta_o, \phi_o), BRDF_B(\theta_i, \phi_i, \theta_o, \phi_o)$$

BRDF

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- Relates the incoming light that hits a surface patch (irradiance) to the outgoing light emitted from the surface patch (radiance)

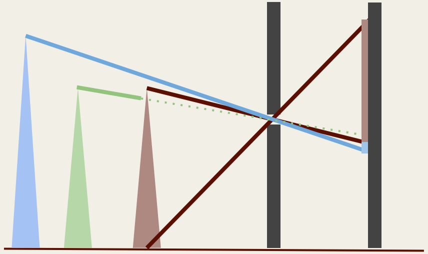
$$BRDF(\omega_i, \omega_o) = \frac{dL_o(\omega_o)}{dE_i(\omega_i)}$$

Questions?

Lighting Equation

- Putting it all together –
- Given a point on an object, we have:
  - light from incoming directions ω_i hitting the point
  - for each incoming direction ω_i, light reflects outwards with ω_o
  - BRDF models how much light gets reflected in each outward direction ω_o given an incoming direction ω_i

- We render from the perspective of the camera
- Need to figure out which of the outgoing light reaches the pixels on our camera film plane

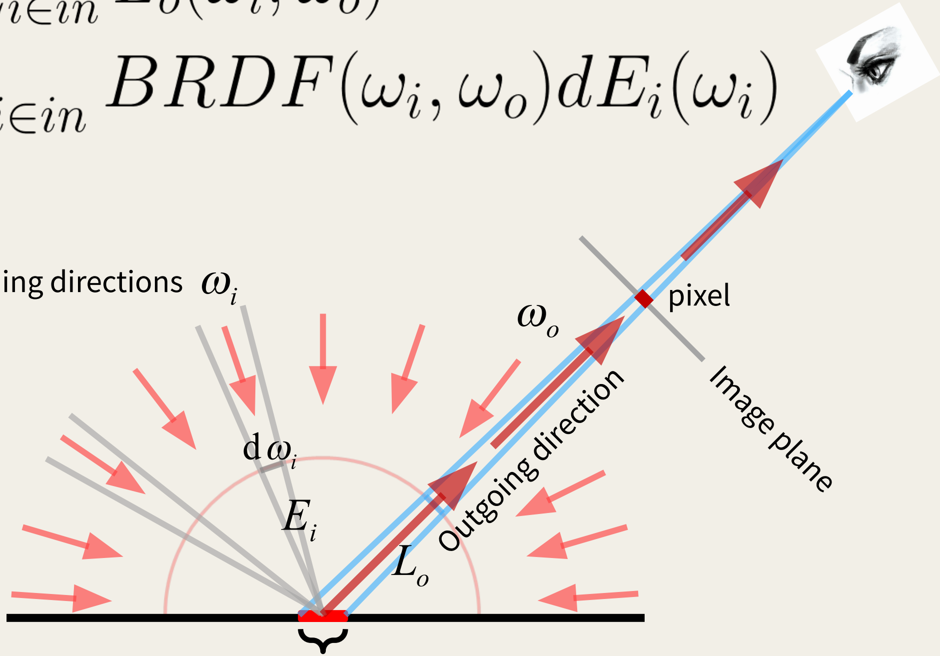


Lighting Equation

- More precisely:

$$L_o(\omega_o) = \sum_{i \in in} L_o(\omega_i, \omega_o)$$

$$L_o(\omega_o) = \int_{i \in in} BRDF(\omega_i, \omega_o) dE_i(\omega_i)$$



Lighting Equation

- Our equation relates incoming irradiance to outgoing radiance

$$L_o(\omega_o) = \int_{i \in in} BRDF(\omega_i, \omega_o) dE_i(\omega_i)$$

- But recall:

$$L = \frac{dI}{dA \cos\theta} = \left(\frac{d(dP)}{d\omega dA \cos\theta} = \frac{dE}{d\omega \cos\theta} \right)$$

- So we can write: $dE = L d\omega \cos\theta$
- Thus, to simplify the equation, we write the **lighting equation** as:

$$L_o(\omega_o) = \int_{i \in in} BRDF(\omega_i, \omega_o) L_i \cos\theta_i d\omega_i$$

Lighting Equation

$$L_o(\omega_o) = \int_{i \in in} BRDF(\omega_i, \omega_o) L_i \cos\theta_i d\omega_i$$

- To summarize:
  - The BRDF is a function that models the material of our object
    - Example: Phong model computes ambient, diffuse, specular components to model the color that the object reflects
  - The result of the BRDF is scaled by the incoming radiance
    - Example: If our light is red, then even if the BRDF computes e.g. blue, we would still multiply the blue by a factor of red
  - The incoming radiance is scaled by a cosine term
    - Radiance depends on the tilt of the object and the tilt of the (area) light
- For each (for loop!) incoming light direction on a point on our surface, compute the above, then sum (integrate) them all up

Questions?