Lighting and Shading (Part I)

Computer Graphics

Yu-Ting Wu

Outline

- Overview
- Lights
- Materials

(Part I)

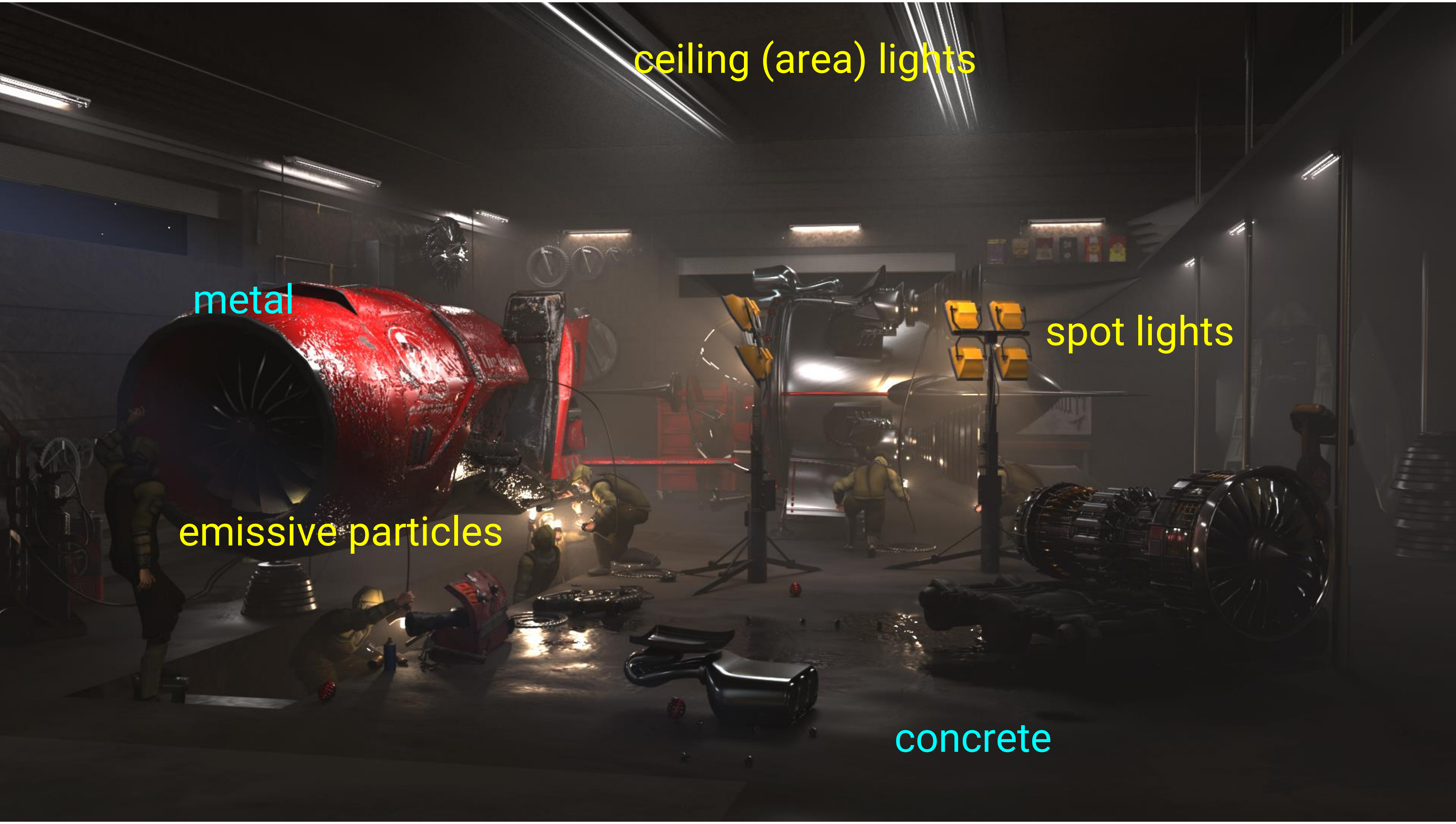
- Material file format
- OpenGL implementation

(Part II)

Outline

- **Overview**
- Lights
- Materials
- Material file format
- OpenGL implementation

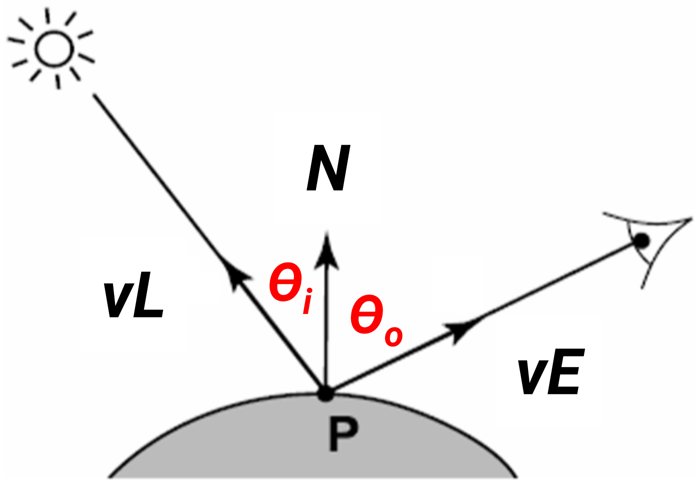
Shading: Materials and Lighting



Shading: Materials and Lighting (cont.)

Shading

- Shading refers to the process of altering the color of an object/surface/polygon in the 3D scene
- In physically-based rendering, shading tries to approximate the **local behavior** of lights on the object's surface, based on things like
  - Surface orientation (normal) ***N***
  - Lighting direction ***vL*** (and θ_i)
  - Viewing direction ***vE*** (and θ_o)
  - Material properties
  - Participating media
  - etc.



Lambertian Cosine Law

- Illumination on an oblique surface is less than on a normal one
- Generally, illumination falls off as **cosθ**

$$A = A' \cos\theta$$

$$E = \frac{\Phi}{A'} = \frac{\Phi \cos\theta}{A}$$

Outline

- Overview
- **Lights**
- Materials
- Material file format
- OpenGL implementation

Lights in Computer Graphics

- Point light
- Spot light
- Area light

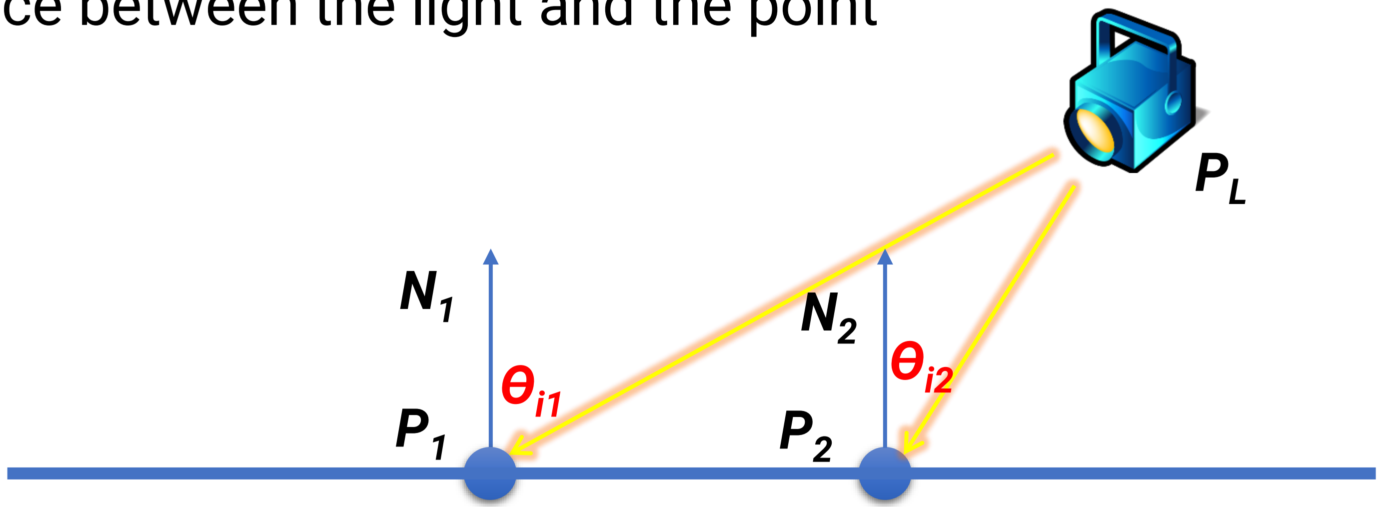
} local lights

- Directional light
- Environment light

} distant lights

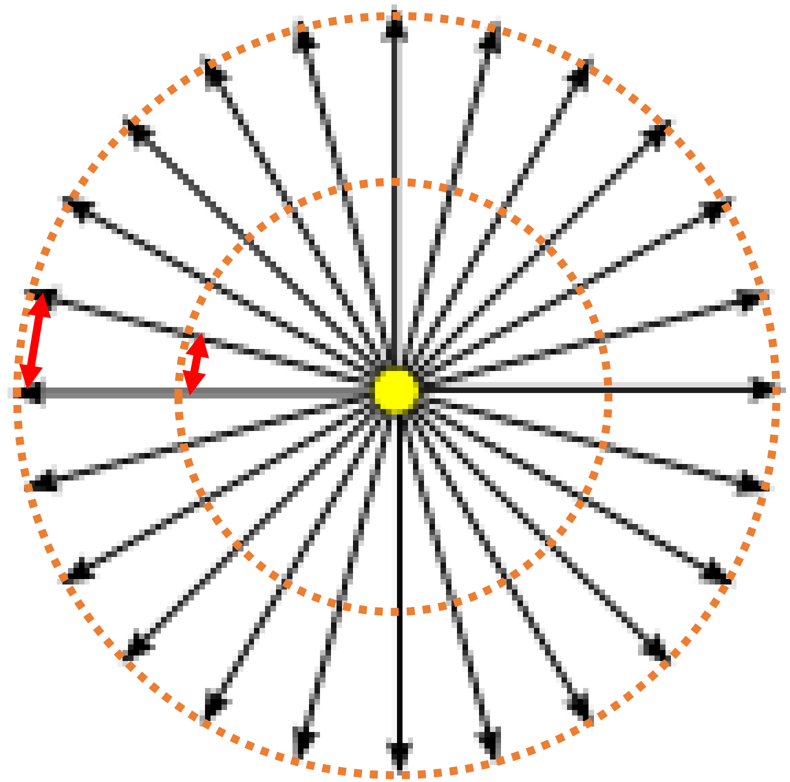
Local Light

- The distance between a light and a surface is **NOT** long enough compared to the scene scale
- The position of light needs to be considered during shading
  - **Lighting direction vL = $|P_L - P|$**
  - **Lighting attenuation** is proportional to the square of the distance between the light and the point



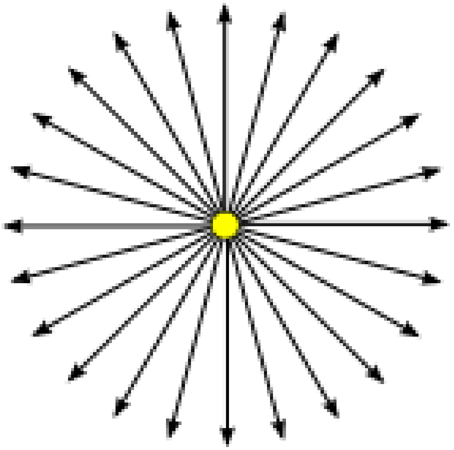
Local Light Attenuation

- The length of the side of a receiver patch is proportional to its distance from the light
- As a result, the average energy per unit area is proportional to the **square of the distance** from the light



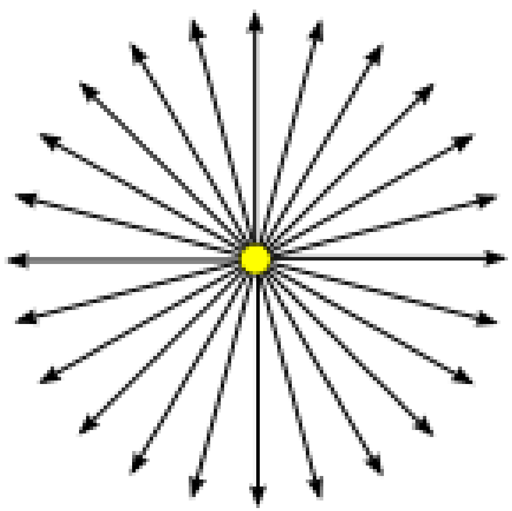
Point Light

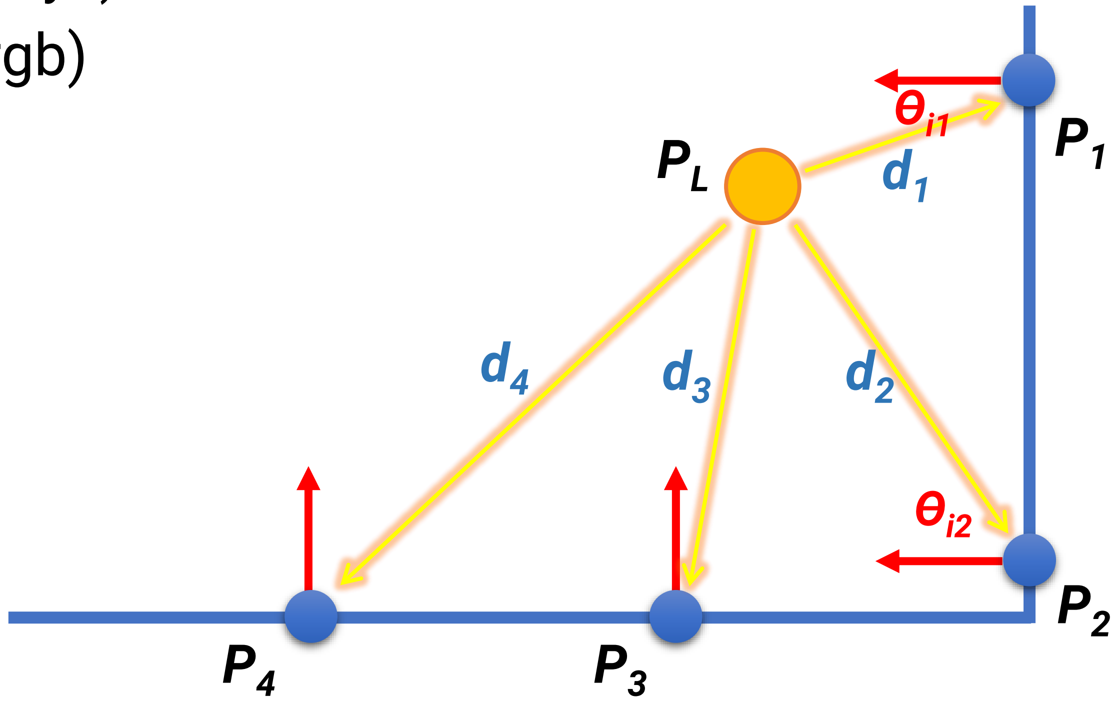

A scene illuminated by a point light



Point Light (cont.)

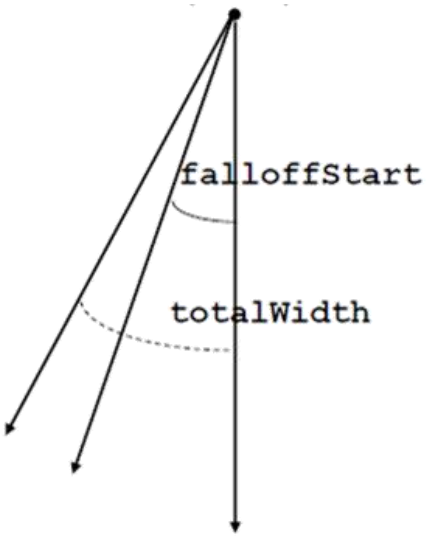
- An isotropic point light source that emits the same amount of light in all directions
- Described by
  - Light position (**P**$_L$, xyz)
  - Light intensity (**I**, rgb)





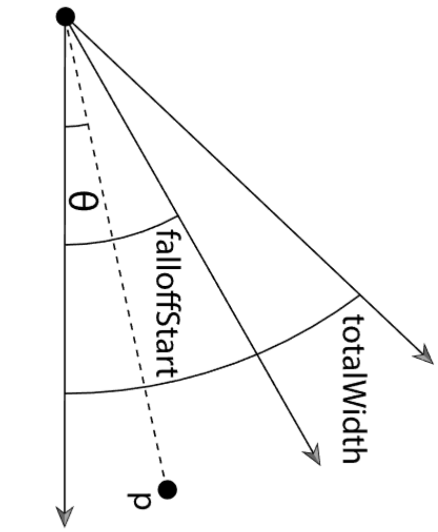
Spot Light

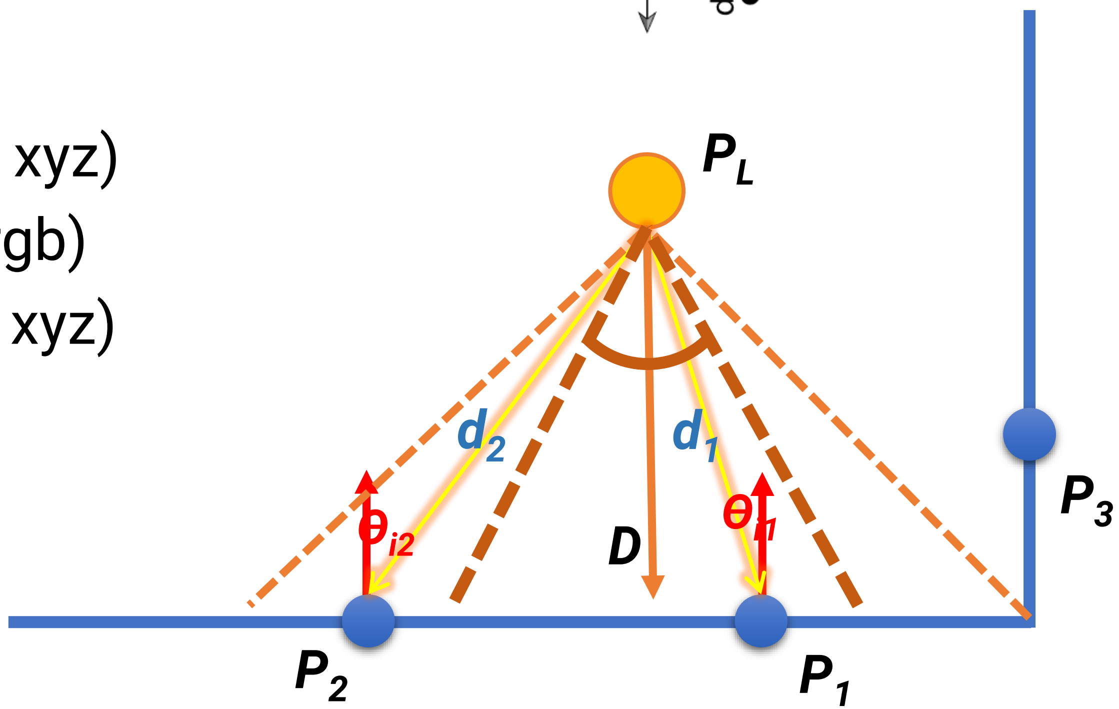
A scene illuminated by a spot light



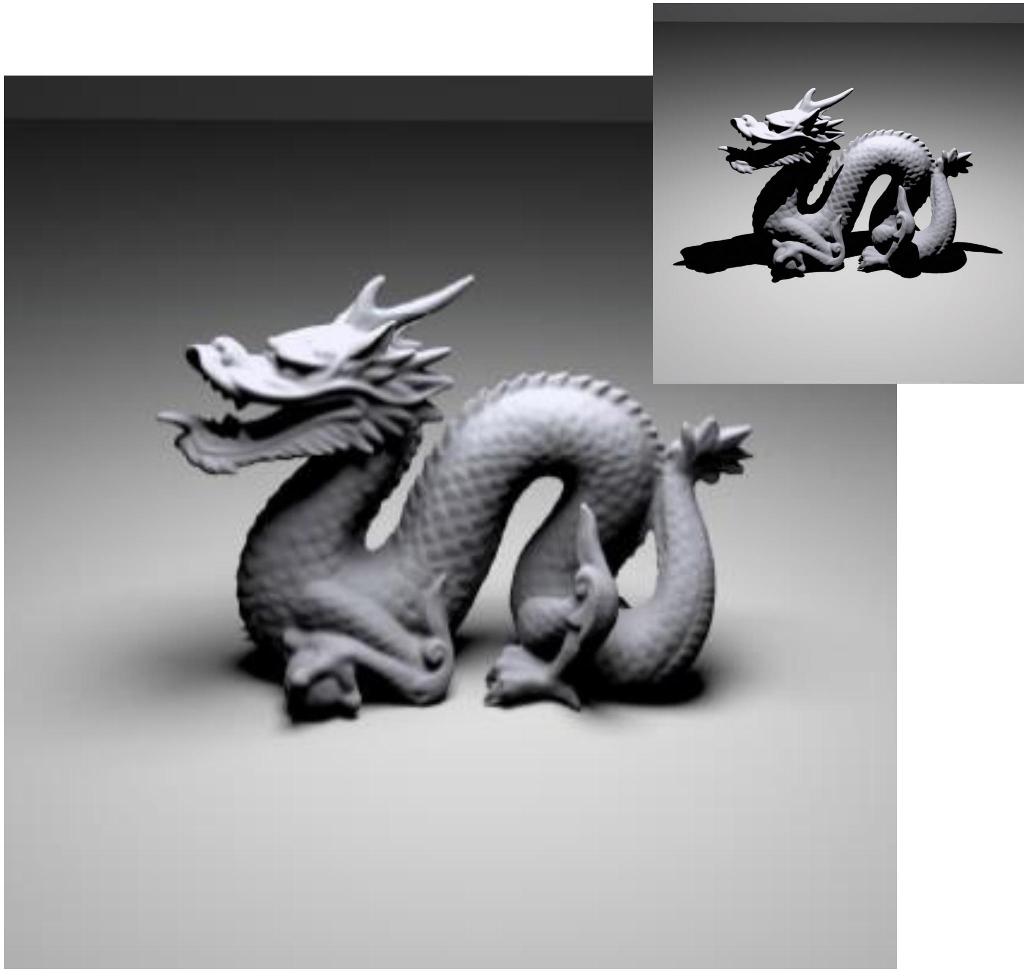
Spot Light (cont.)

- A handy variation on point lights
- Rather than shining illumination in all directions, it emits light in a cone of directions from its position
- Described by
  - Light position (**P**$_L$, xyz)
  - Light intensity (**I**, rgb)
  - Light direction (**D**, xyz)
  - TotalWidth
  - FalloffStart

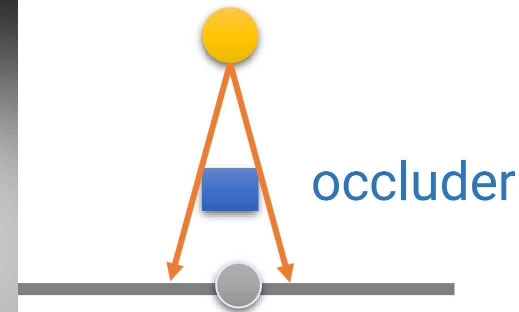




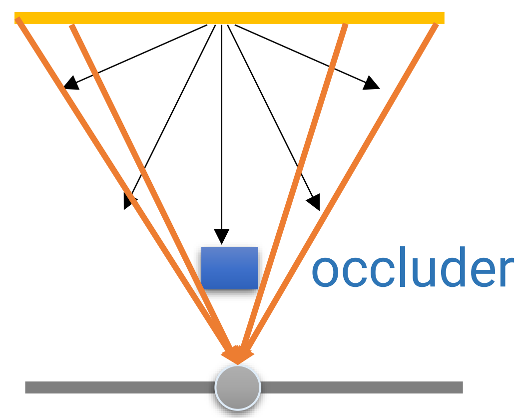
Area Light



A scene illuminated by an area light



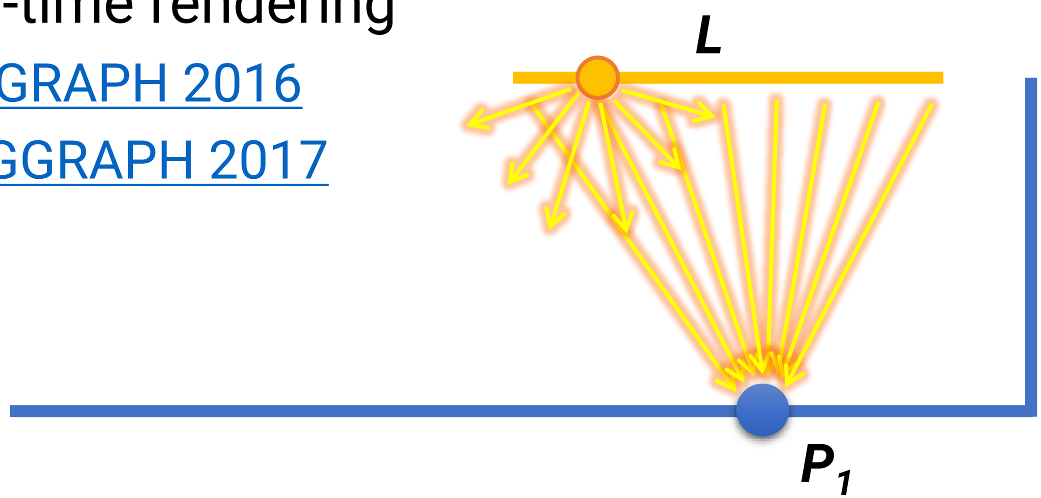
point light



area light

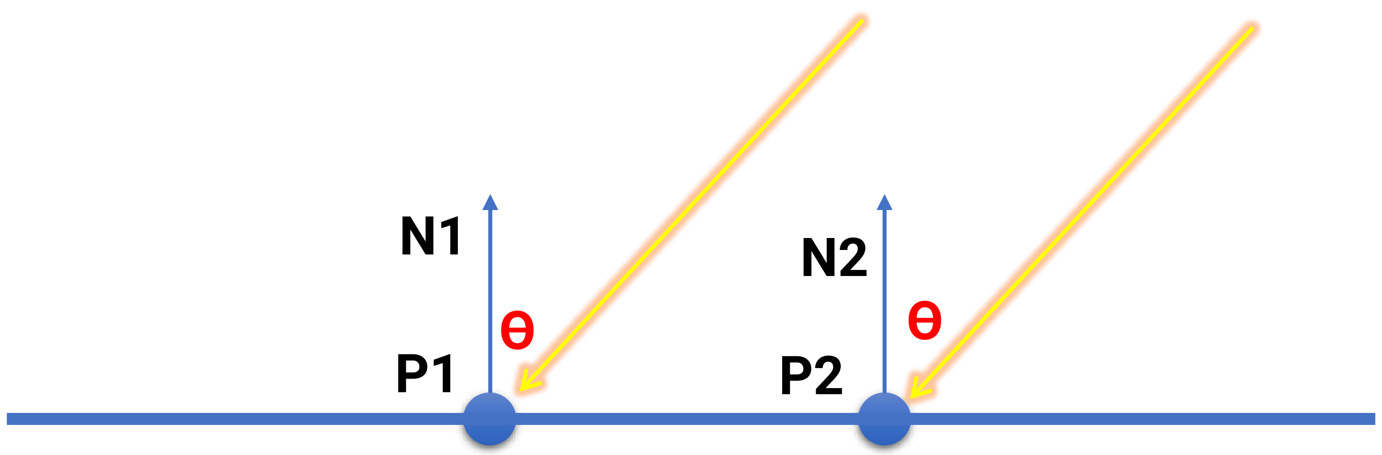
Area Light (cont.)

- Defined by one or more **shapes** that emit light from their surface, with some directional distribution of energy at each point on the surface
- Require **integration** of lighting contribution across the light surface
  - In offline rendering, usually estimated by sampling
  - Expensive for real-time rendering
    - Heitz et al., SIGGRAPH 2016
    - Dupuy et al., SIGGRAPH 2017



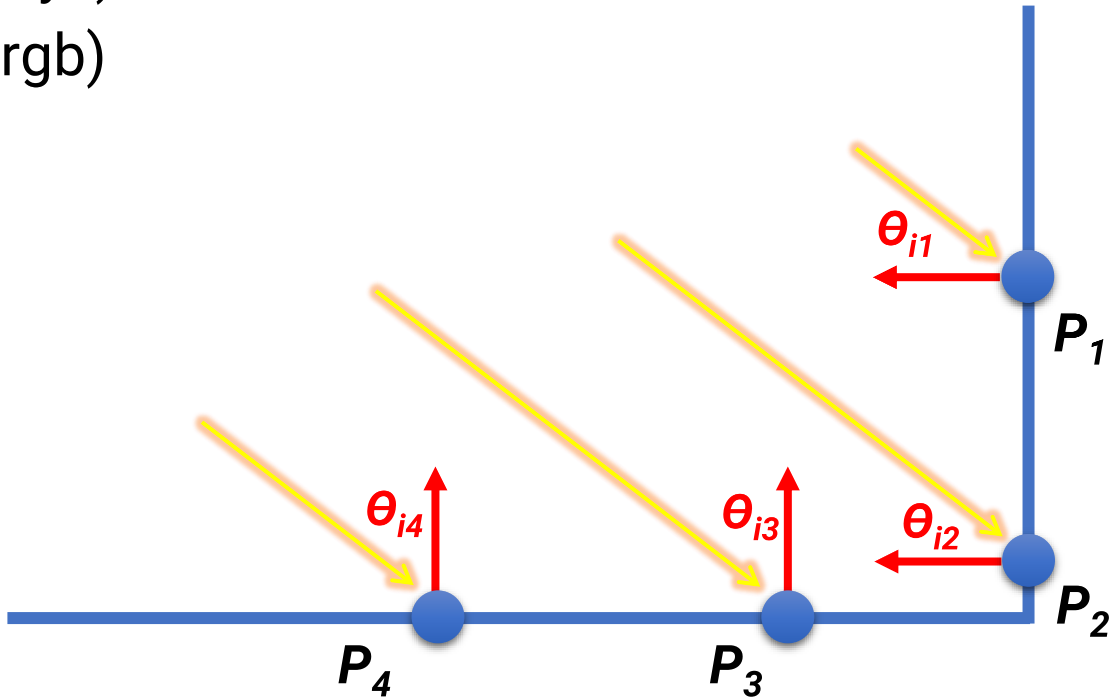
Distant Light

- The distance between a light and a surface is long enough compared to the scene scale and **can be ignored**
  - **Lighting direction** is **fixed**
  - **No lighting attenuation**
- **Directional light (sun)** is the most common distant light



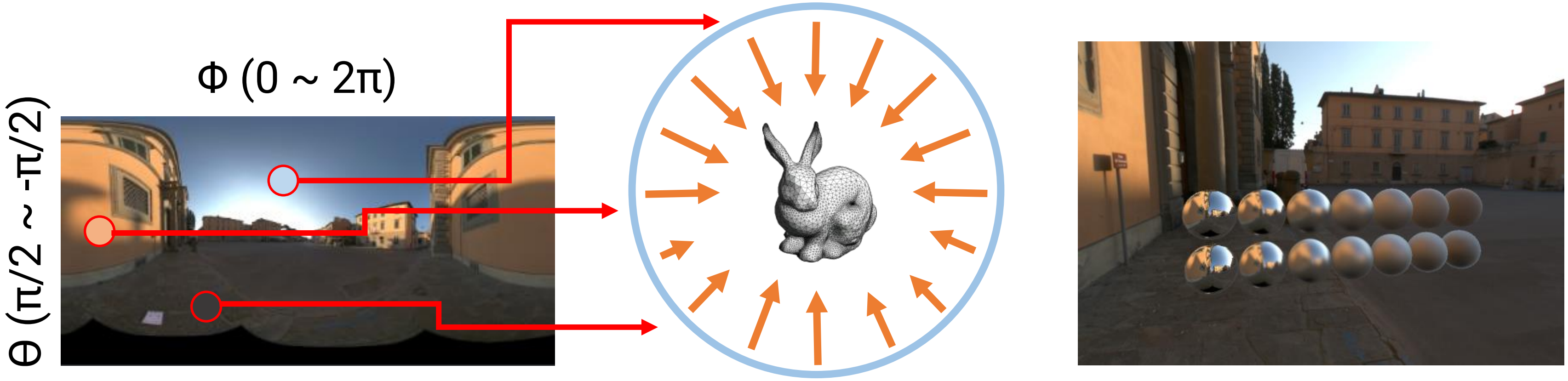
Directional Light

- Describes an emitter that deposits illumination from the **same direction** at every point in space
- Described by
  - Light direction (**D**, xyz)
  - Light radiance (**L**, rgb)



Environment Light

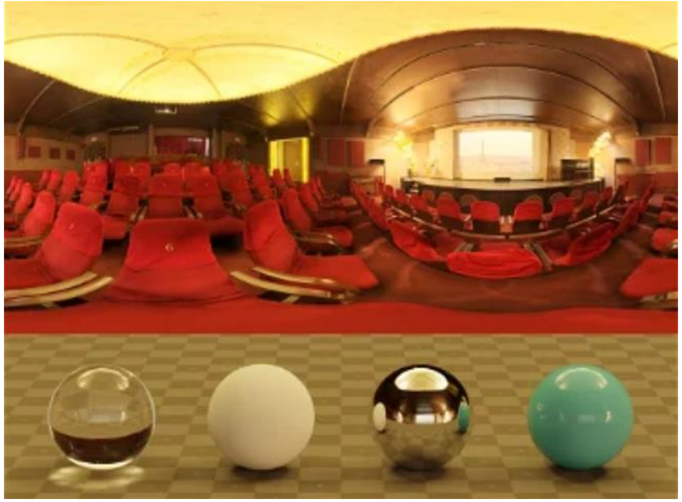
- Use a **texture** (cube map or longitude-latitude image) to represent a **spherical energy distribution**
  - Each texel maps to a spherical direction, considered as a directional light
  - The whole map illuminates the scene from a virtual sphere at an infinite distance
- Also called **image-based lighting (IBL)**

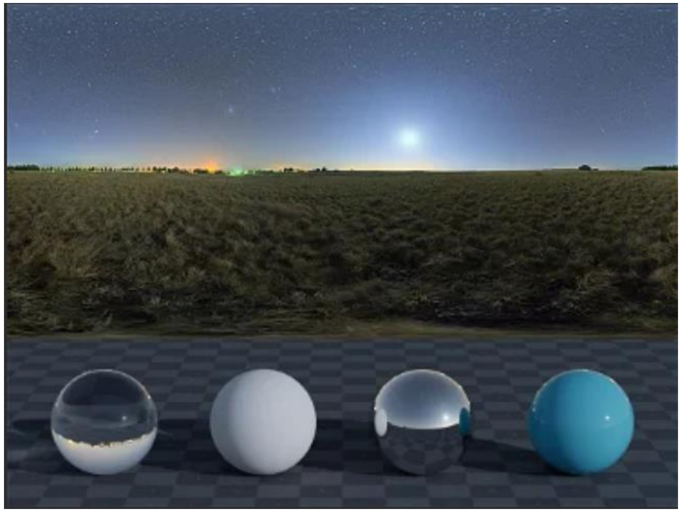


Environment Light (cont.)

- Widely used in digital visual effects and film production

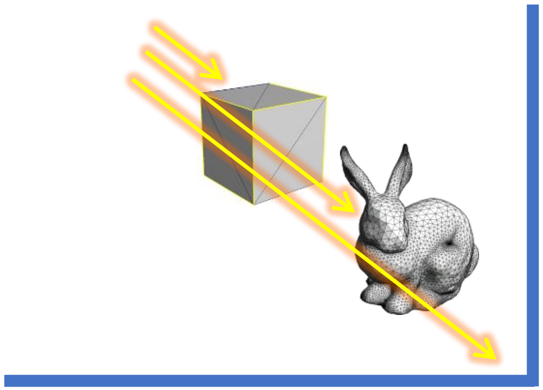
Environment Light (cont.)

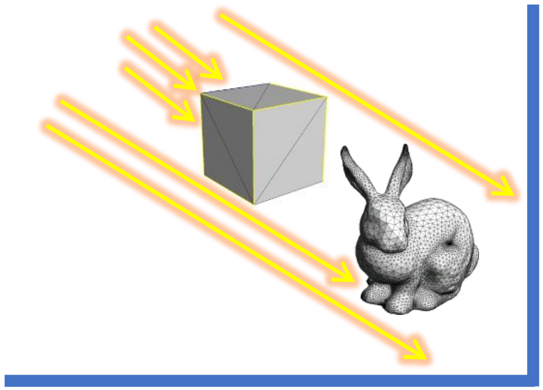


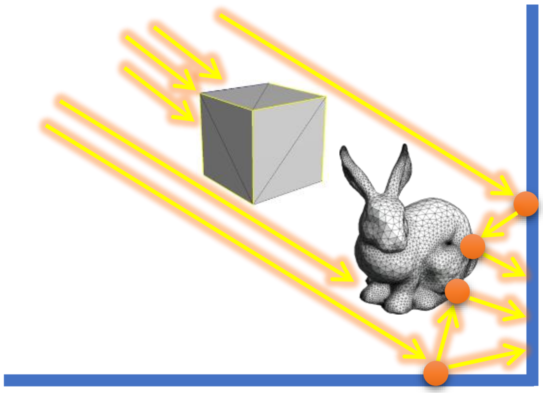



Local, Direct, and Global Illumination

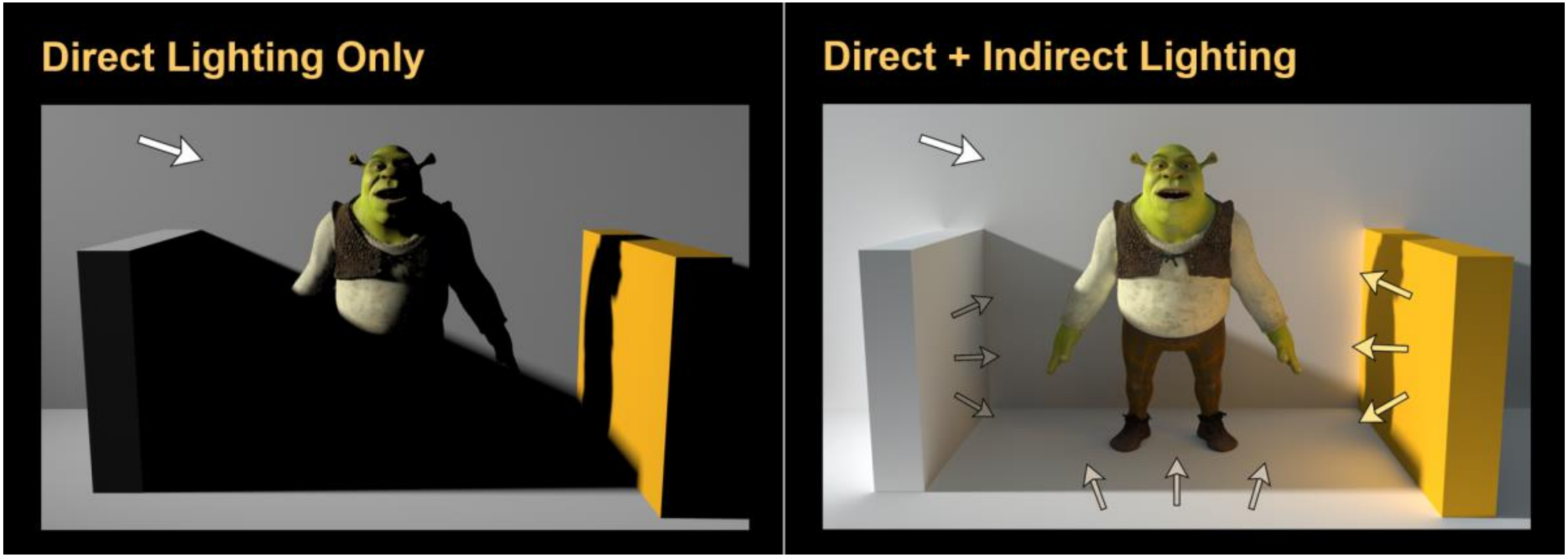
- Direct illumination considers only the **direct** contribution of lights
- Local illumination can be considered as direct lighting **without occlusion** (all lights are fully visible, no shadows)
- Global illumination includes **multi-bounce** illumination reflected from other surfaces (need **recursive** computation!)


local illumination


direct illumination


global illumination

Local, Direct, and Global Illumination (cont.)

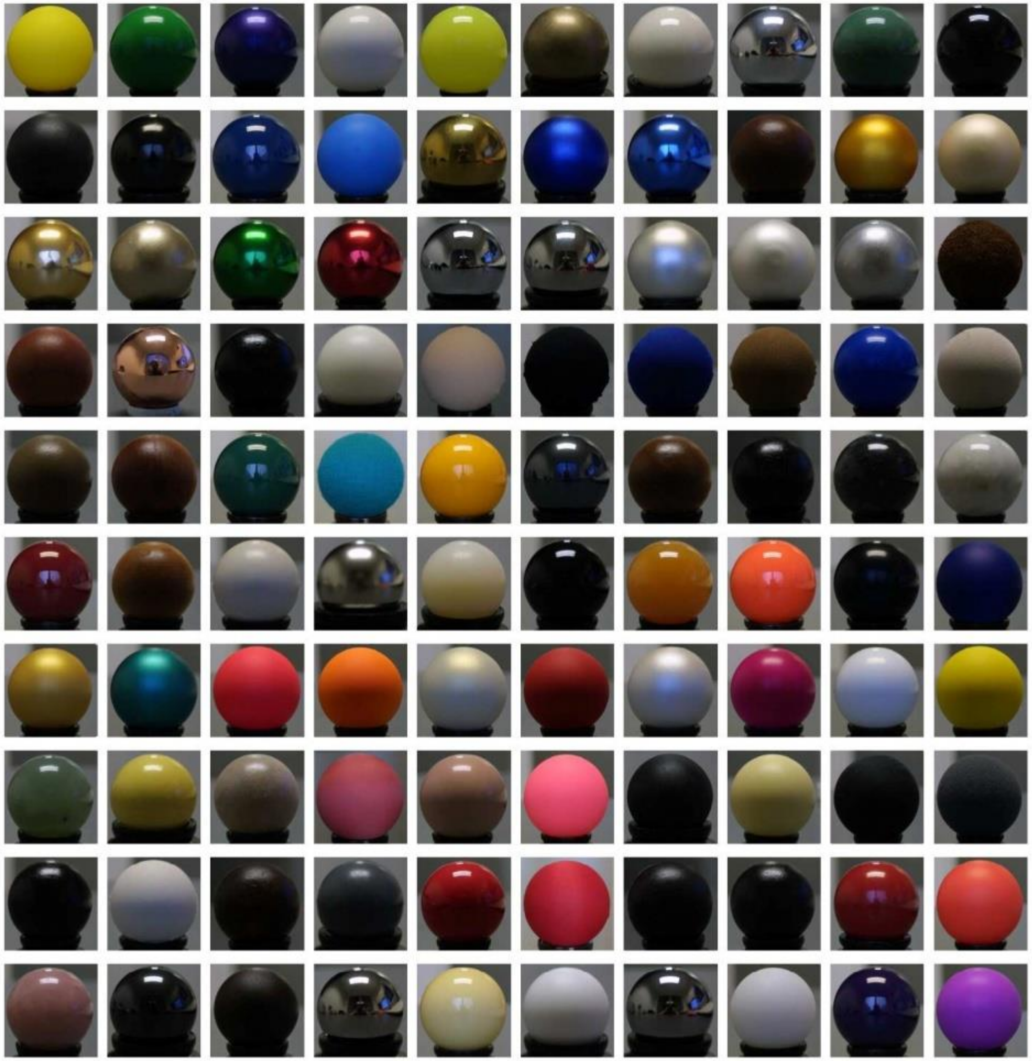


Comparison of direct and global illumination

Outline

- Overview
- Lights
- **Materials**
- Material file format
- OpenGL implementation

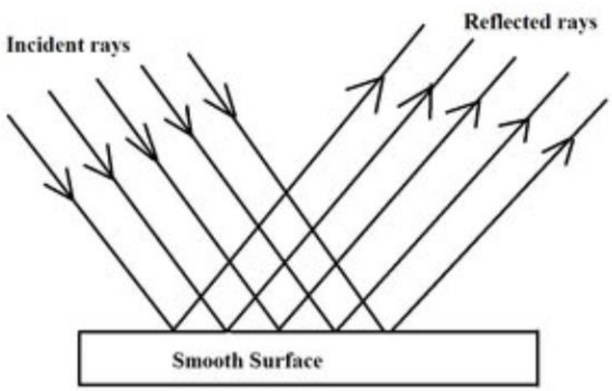
Materials

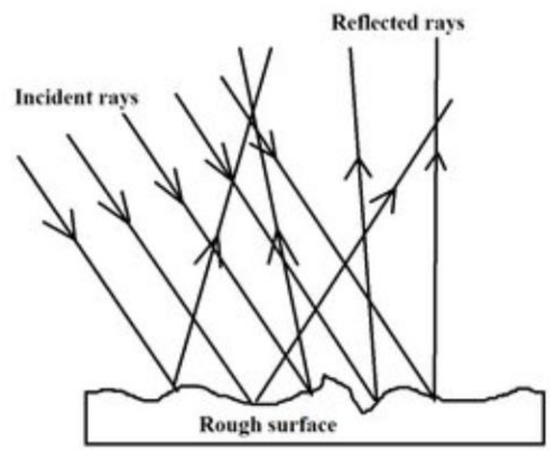


Materials (cont.)

- Highly related to surface types
- The **smoother** a surface, the more reflected light is concentrated in the direction a **perfect mirror** would reflect the light

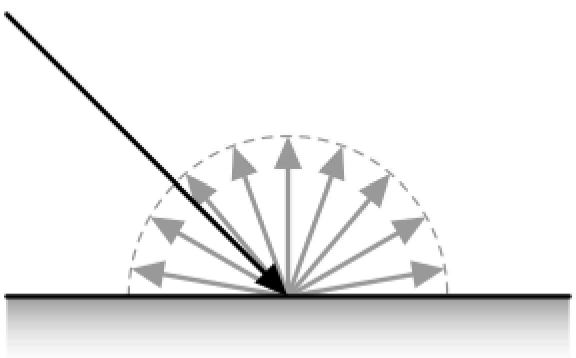




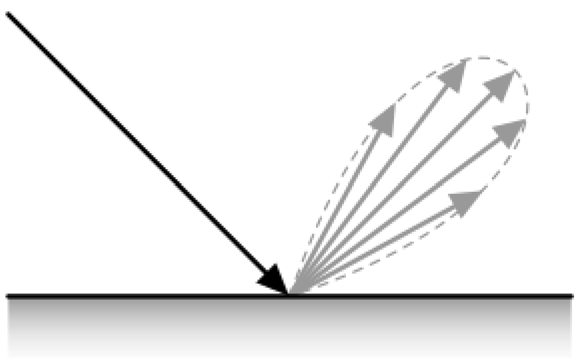


Materials (cont.)

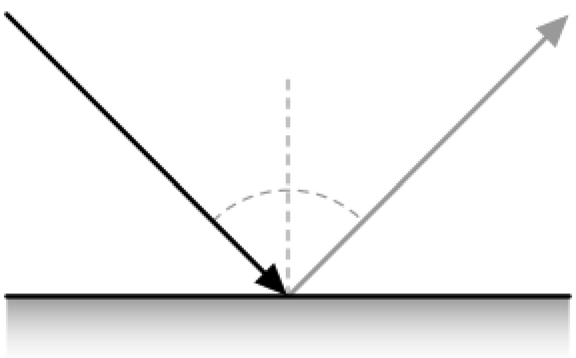
- Highly related to surface types
- The **smoother** a surface, the more reflected light is concentrated in the direction a **perfect mirror** would reflect the light



diffuse



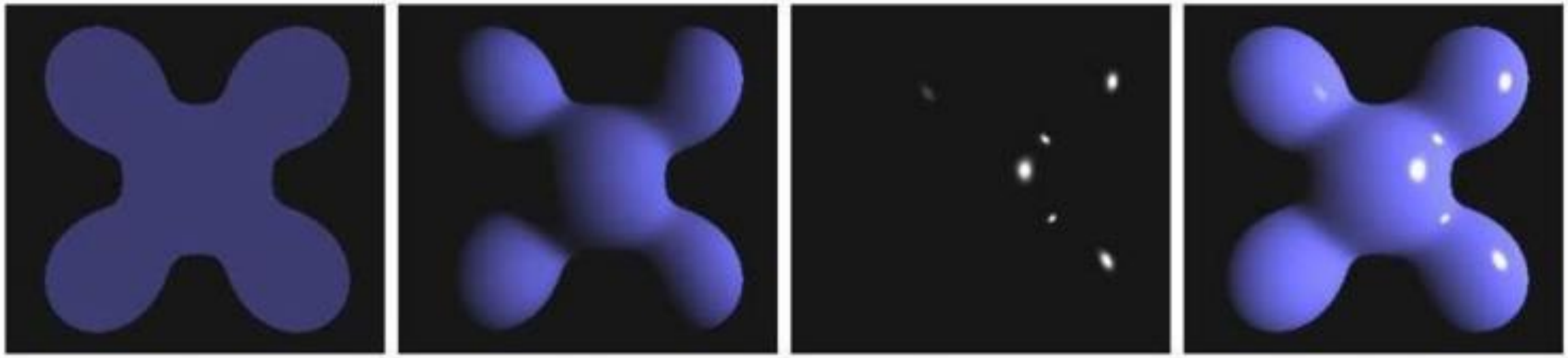
glossy



specular

Phong Lighting Model

- **Diffuse reflection**
  - Light goes everywhere; colored by object color
- **Specular reflection**
  - Happens only near mirror configuration; usually white
- **Ambient reflection**
  - Constant accounted for global illumination (cheap hack)



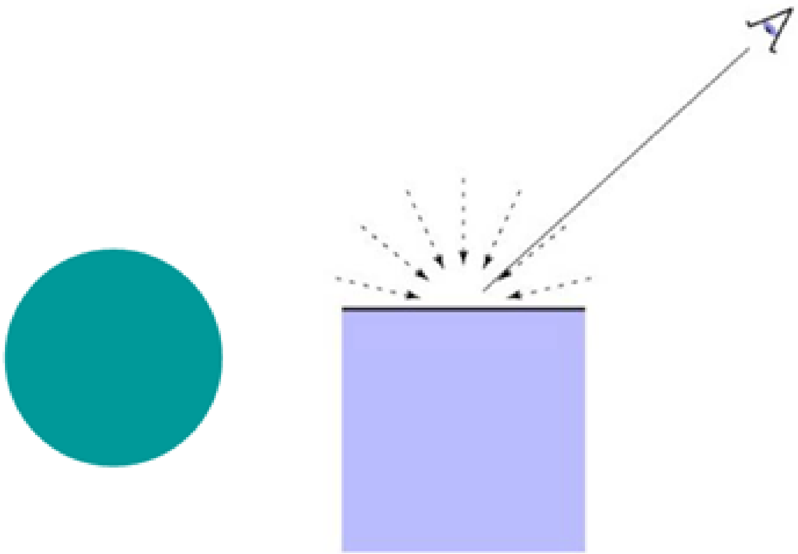
ambient diffuse specular

Ambient Shading

- Add constant color to account for disregarded illumination and fill black shadows

Ambient Shading (cont.)

- Add constant color to account for disregarded illumination and fill black shadows



(R, G, B)
the **intensity** of ambient light

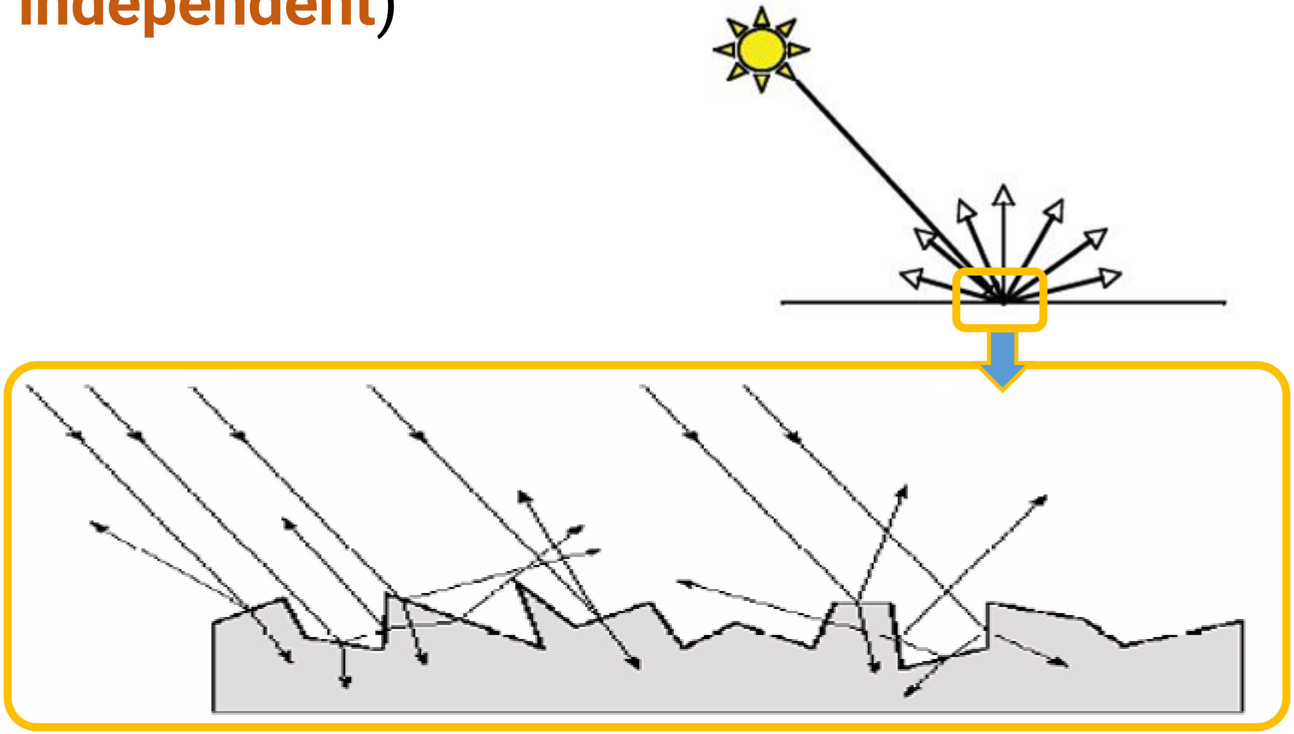
$$L_a = k_a \cdot I_a$$

ambient coefficient
(R, G, B)

reflected ambient light
(R, G, B)

Diffuse Shading

- Assume light reflects **equally in all directions**
  - The surface is rough with lots of tiny microfacets
- Therefore, the surface looks the same color from all views (**view independent**)

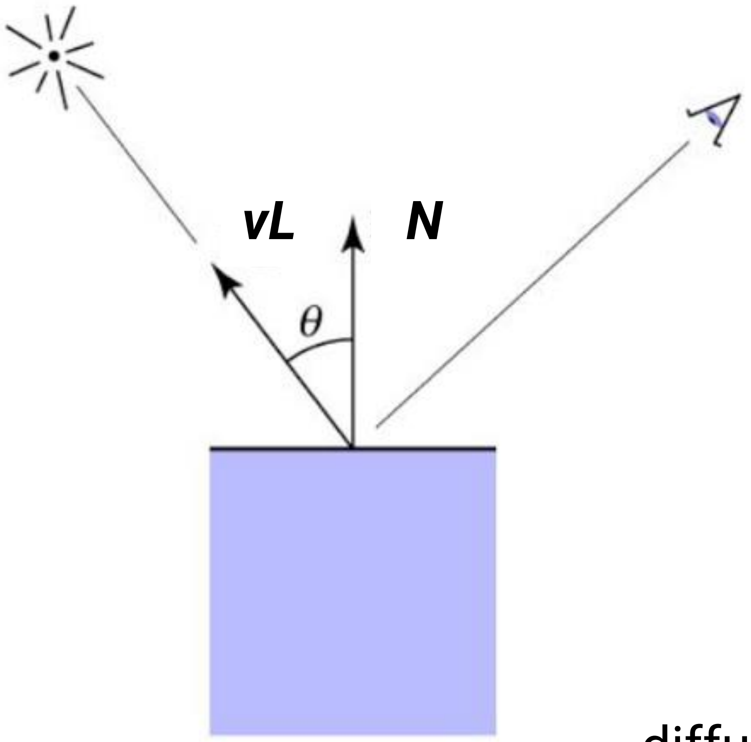


Diffuse Shading (cont.)

- Assume light reflects **equally in all directions**
  - The surface is rough with lots of tiny microfacets
- Therefore, the surface looks the same color from all views (**view independent**)

Diffuse Shading (cont.)

- Applies to diffuse or matte surface



(R, G, B)
illumination from source

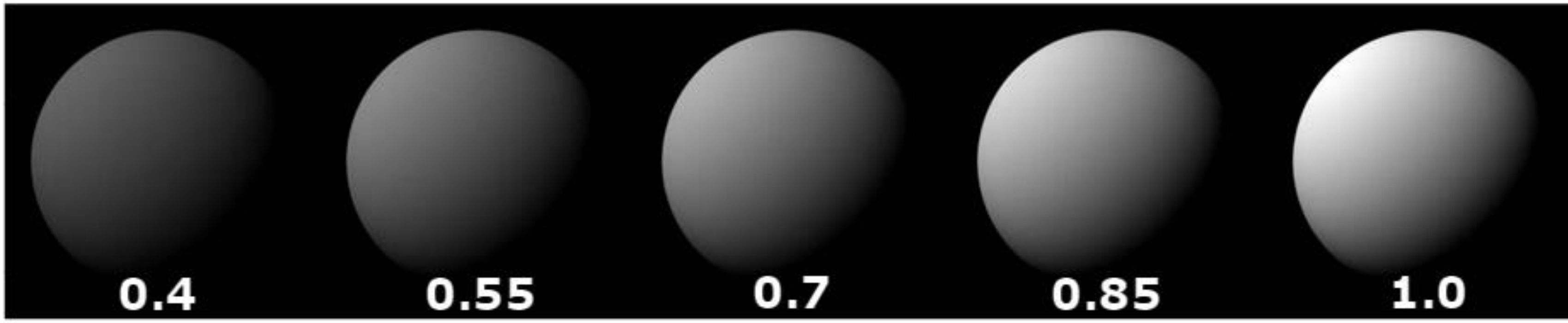
$$L_d = k_d \cdot I \cdot \max(0, N \cdot vL)$$

Lambertian law
(scalar)

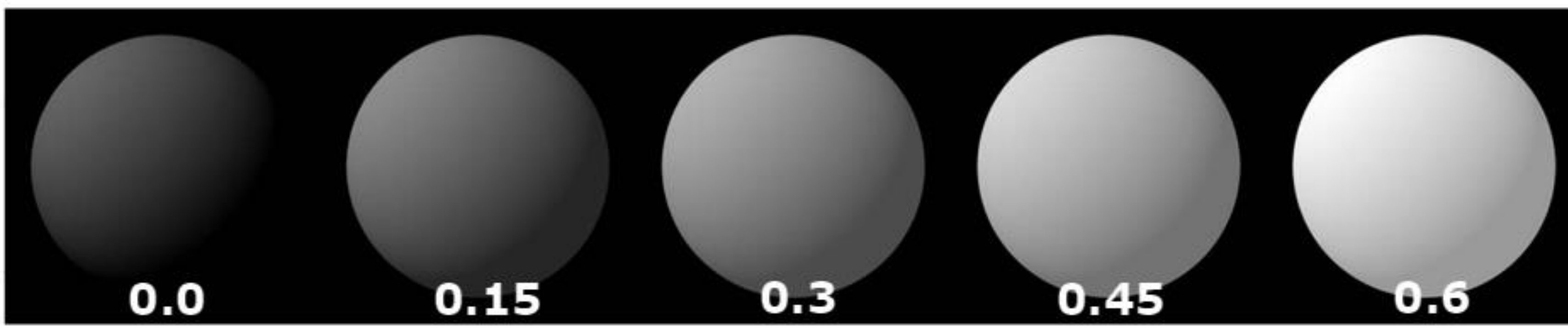
diffuse coefficient
(R, G, B)

diffusely reflected light
(R, G, B)

Diffuse Shading (cont.)



diffuse-reflection model with different k_d



ambient and diffuse-reflection model with different k_a

$I_a = 1.0 \qquad k_d = 0.4$

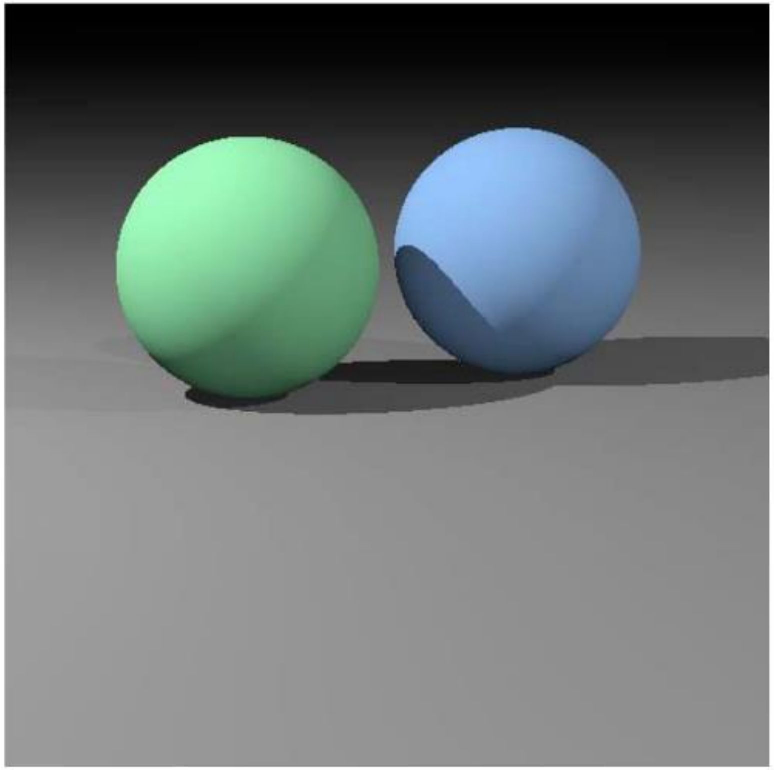
Diffuse Shading (cont.)

- For color objects, apply the formula for each color channel separately
- Light can also be non-white

Example:
white light: (0.9, 0.9, 0.9)
yellow light: (0.8, 0.8, 0.2)

$$L_d = \boxed{k_d} \cdot \boxed{I} \cdot \max(0, N \cdot vL)$$

Example:
green ball: (0.2, 0.7, 0.2)
blue ball: (0.2, 0.2, 0.7)

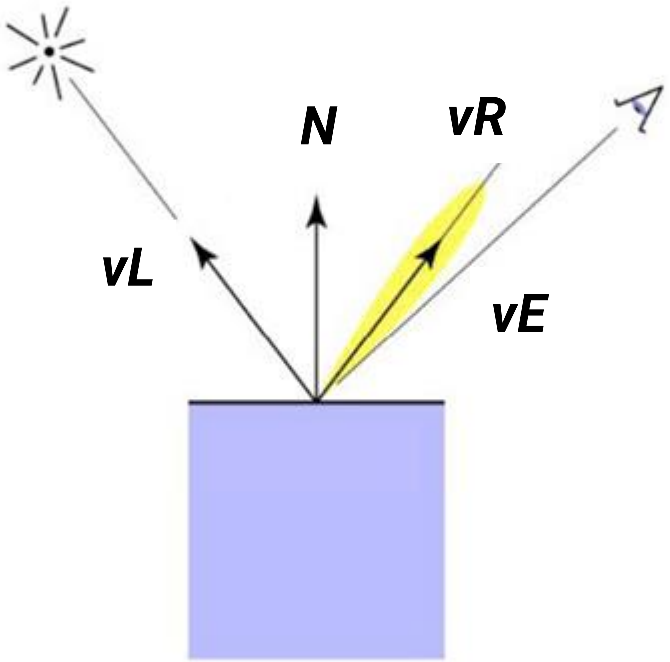


Specular Shading

- Some surfaces have highlights, mirror-like reflection
- **View direction dependent**
- Especially obvious for smooth shiny surfaces

Specular Shading (cont.)

- **Phong specular model [1975]**



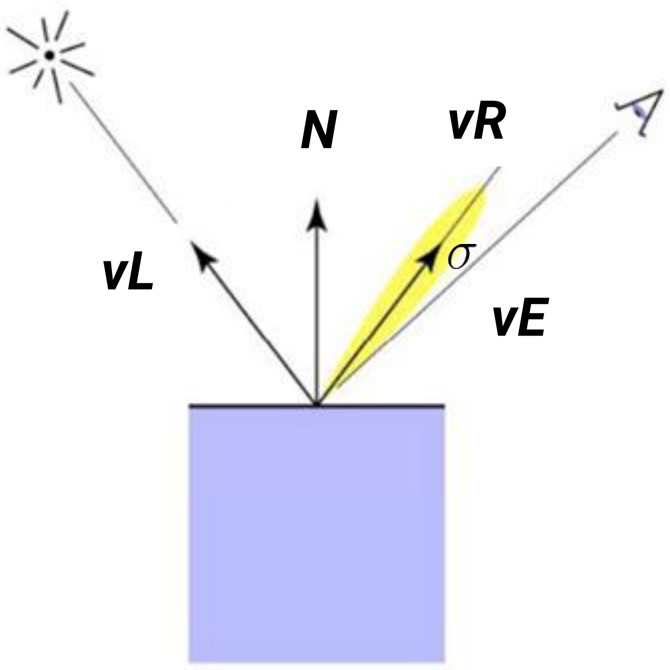
$$vR = vL + 2((N \cdot vL)N - vL)$$
$$= 2(N \cdot vL)N - vL$$

perfectly reflected direction

(you can find the proof here)

Specular Shading (cont.)

- **Phong specular model [1975]**
  - Fall off gradually from the perfect reflection direction



$$vR = vL + 2((N \cdot vL)N - vL)$$
$$= 2(N \cdot vL)N - vL$$

(scalar)
specular exponent

(R, G, B)

$$L_s = k_s \cdot I \cdot \max(0, \cos\sigma)^{n}$$
$$= k_s \cdot I \cdot \max(0, vE \cdot vR)^n$$

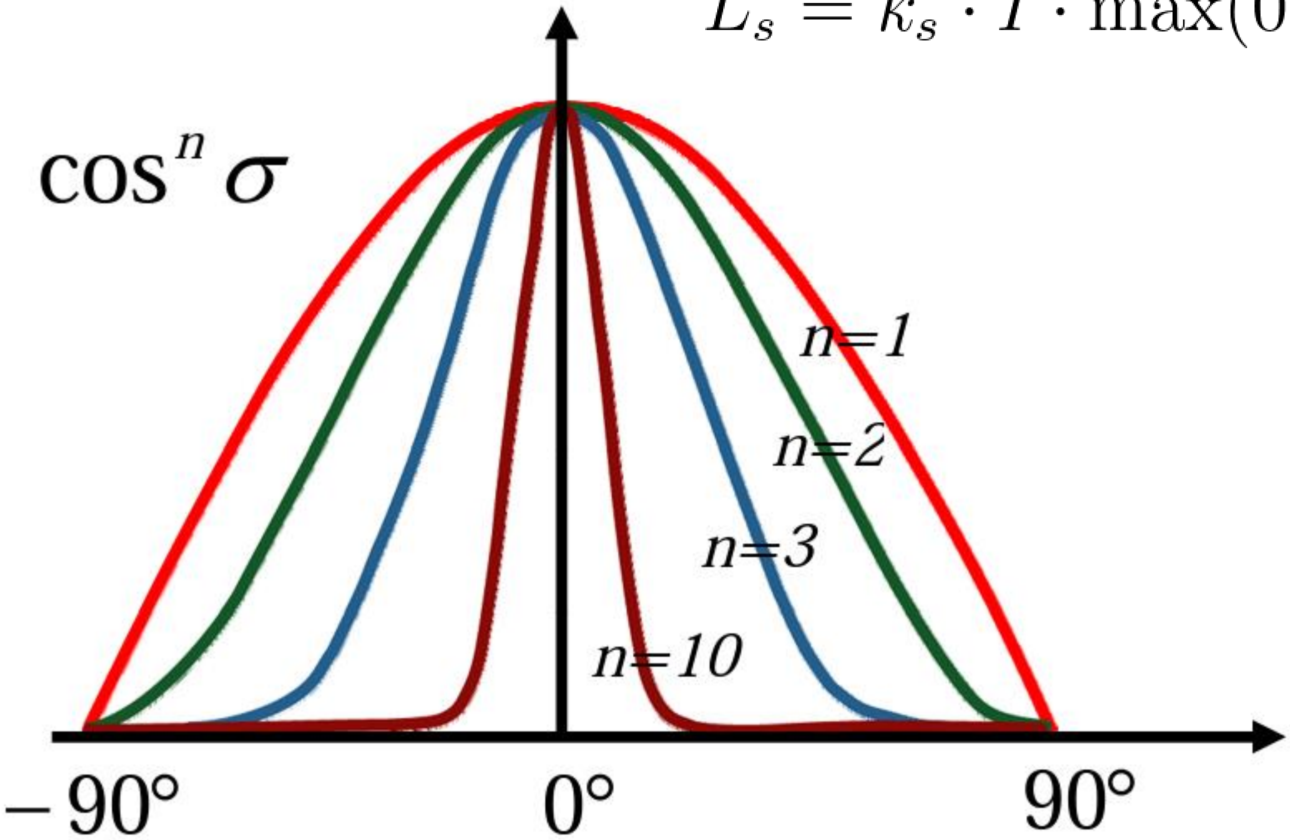
specular coefficient (R, G, B)

specularly reflected light (R, G, B)

Specular Shading (cont.)

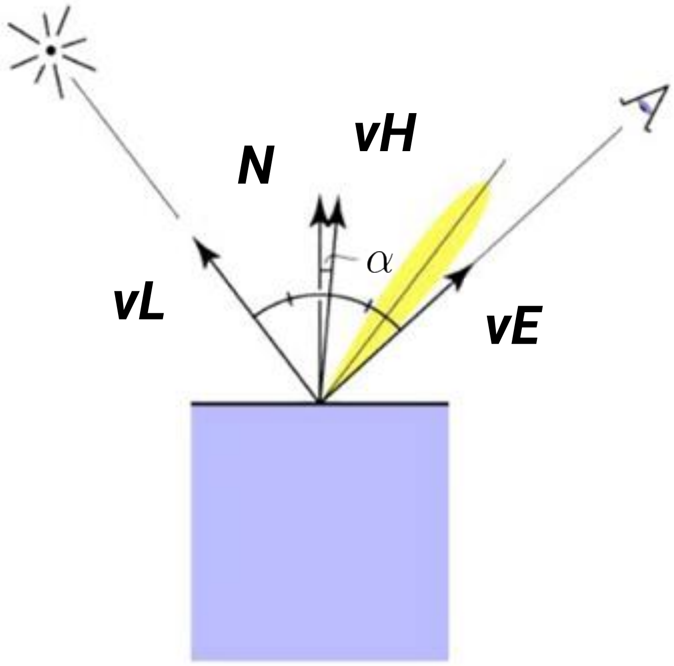
- Increase *n* narrows the lobe

$$L_s = k_s \cdot I \cdot \max(0, \cos\sigma)^n$$



Phong specular Variant: Blinn-Phong

- Rather than computing reflection directly, just compare to normal bisection property
- One can prove $\cos^n(\sigma) = \cos^{4n}(\alpha)$

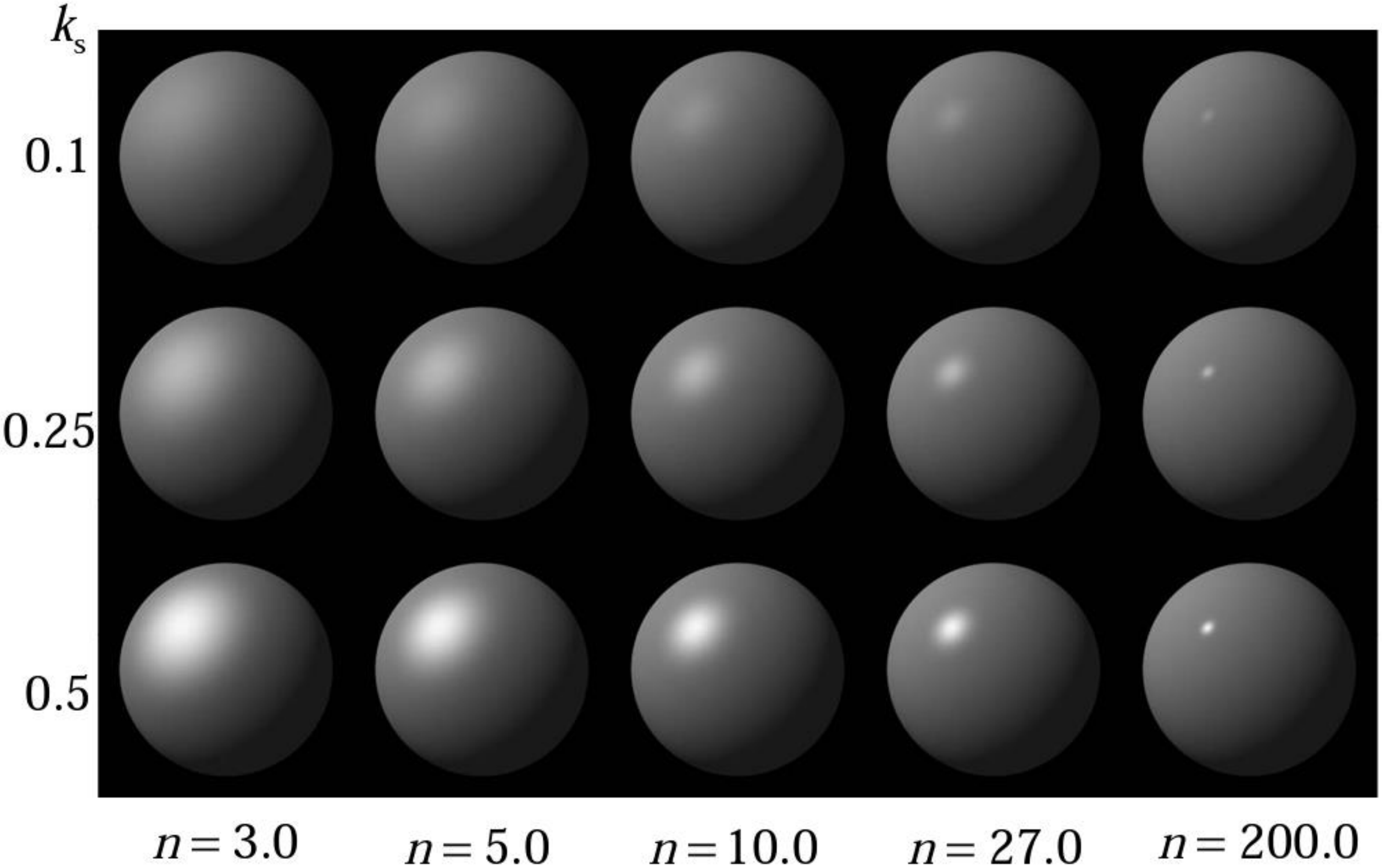


half vector

$$vH = \text{bisector}(vL, vE)$$
$$= \frac{(vL + vE)}{\|vL + vE\|}$$

$$L_s = k_s \cdot I \cdot \max(0, \cos\alpha)^n$$
$$= k_s \cdot I \cdot \max(0, N \cdot vH)^n$$

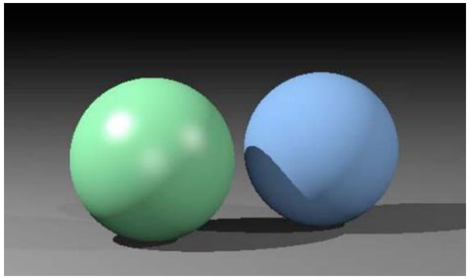
Specular Shading (cont.)



Complete Phong Lighting Model

- Compute the contribution from a light to a point by including **ambient**, **diffuse**, and **specular** components

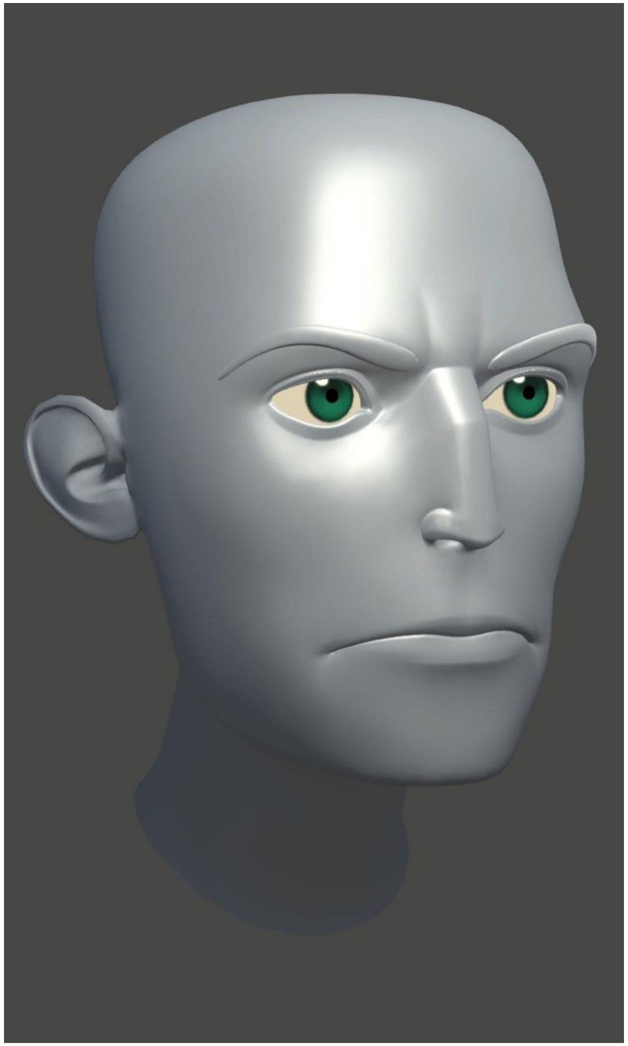
$$\begin{aligned} L &= L_a + L_d + L_s \\ &= k_a \cdot I_a + I(k_d \cdot \max(0, N \cdot vL) + k_s \cdot \max(0, N \cdot vH)^n) \end{aligned}$$



- If there are ***s*** lights, just sum over all the lights because the lighting is **linear**

$$L = k_a \cdot I_a + \sum_i^s (I_i(k_d \cdot \max(0, N \cdot vL_i) + k_s \cdot \max(0, N \cdot vH_i)^n))$$

Some Results with Phong Lighting Model




END OF PRESENTATION
ANY QUESTIONS?