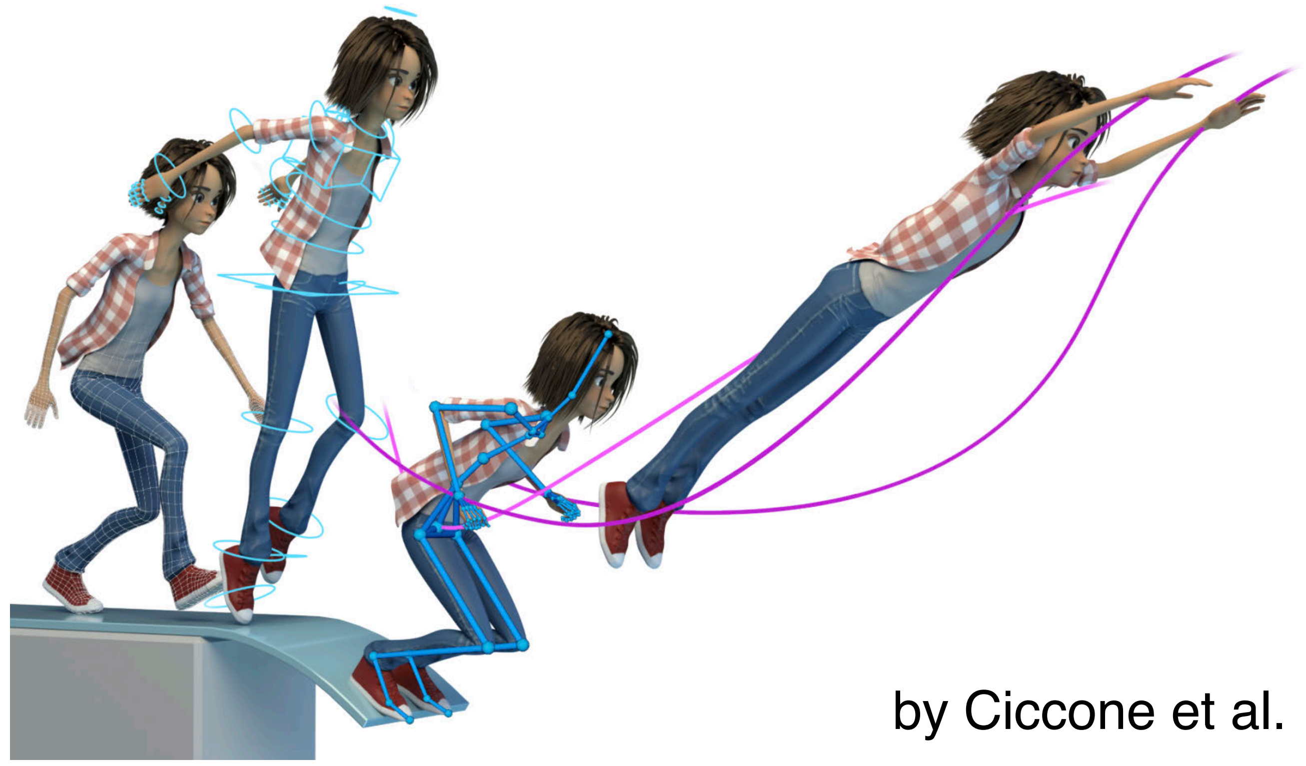
Computer Graphics

Lighting Models


by Fang et al.

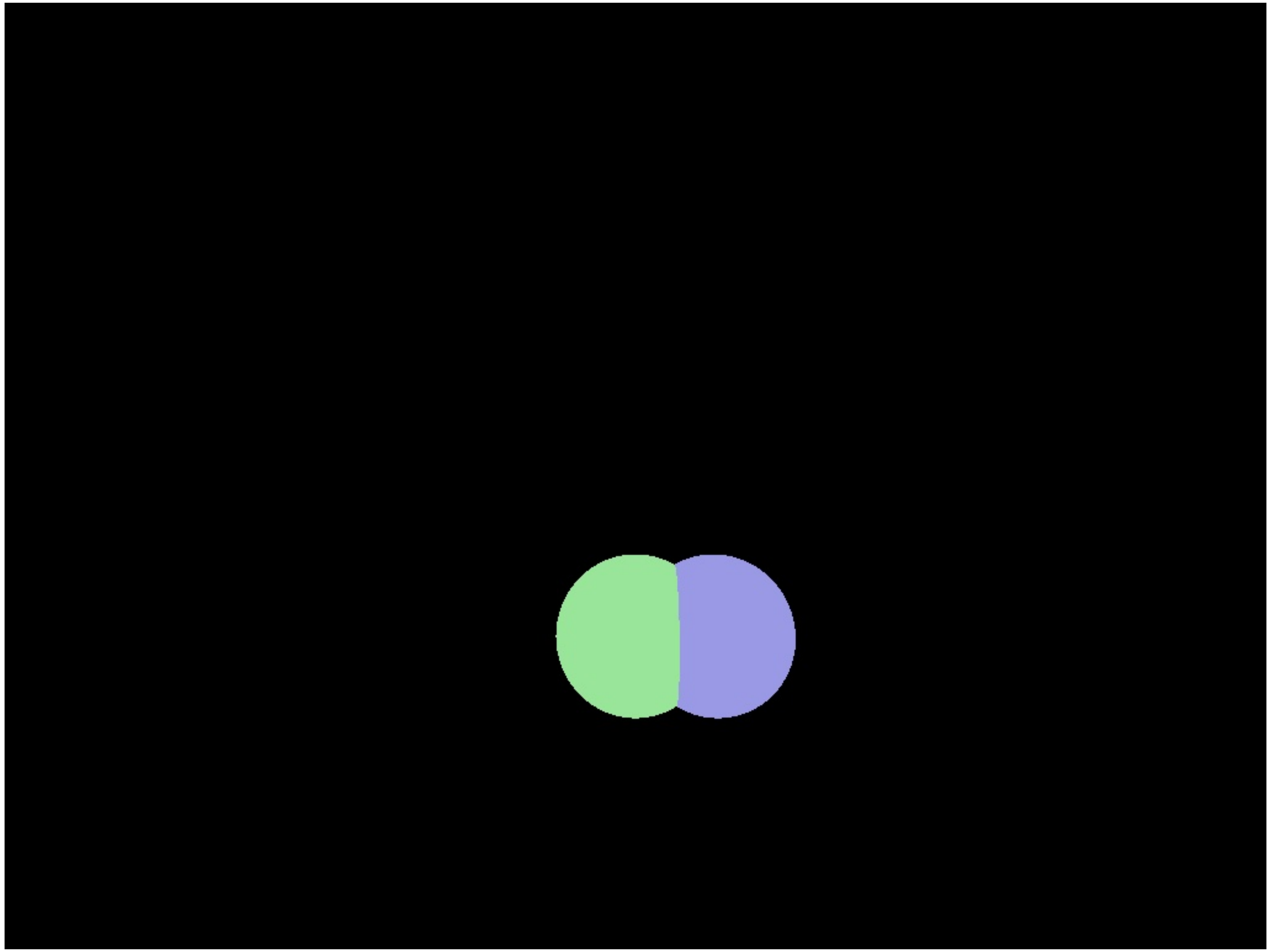

by Ciccone et al.


by Křivánek et al.

Prof. Piotr Didyk

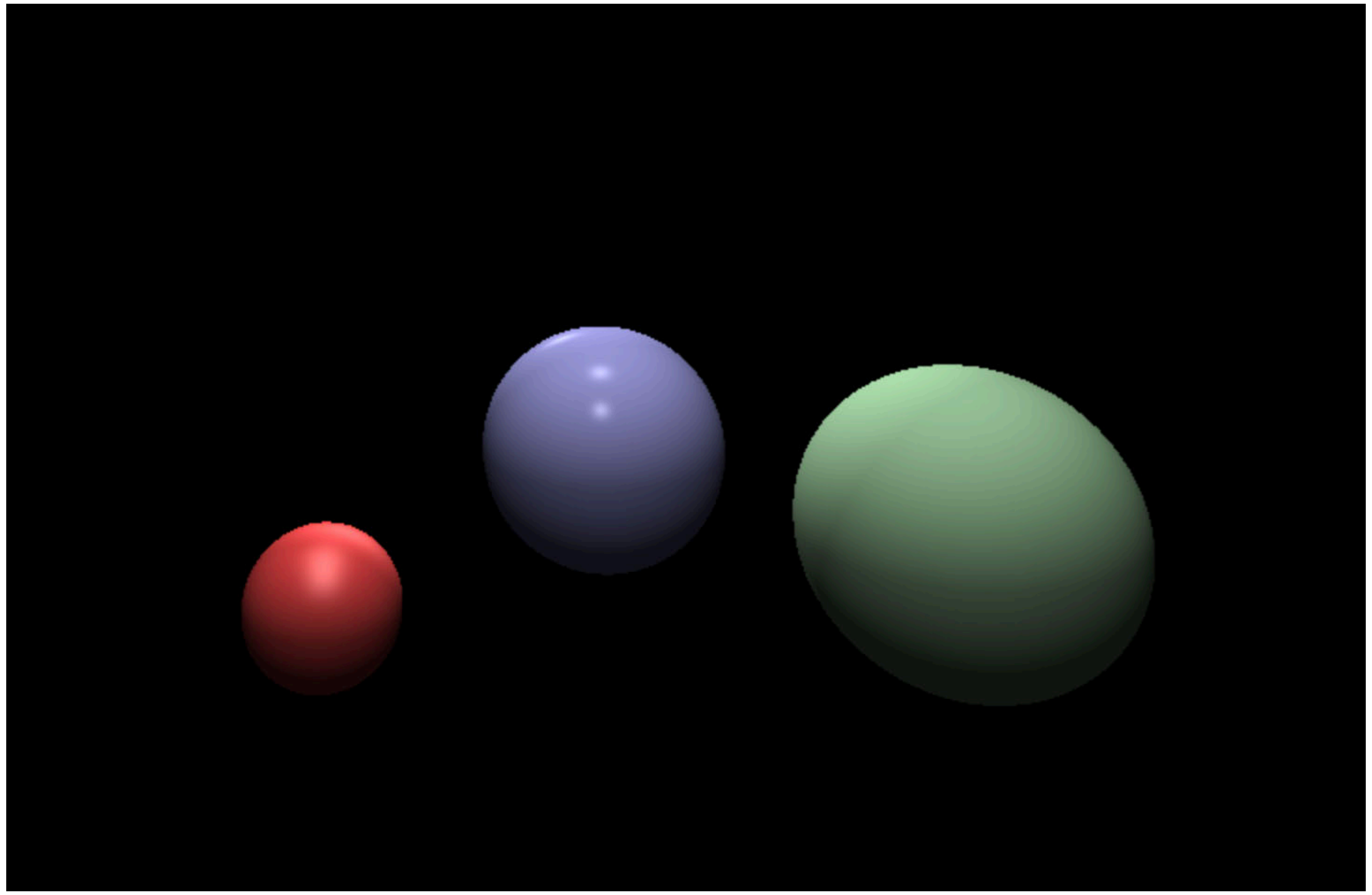
Faculty of Informatics
Università della Svizzera italiana

Last Assignment



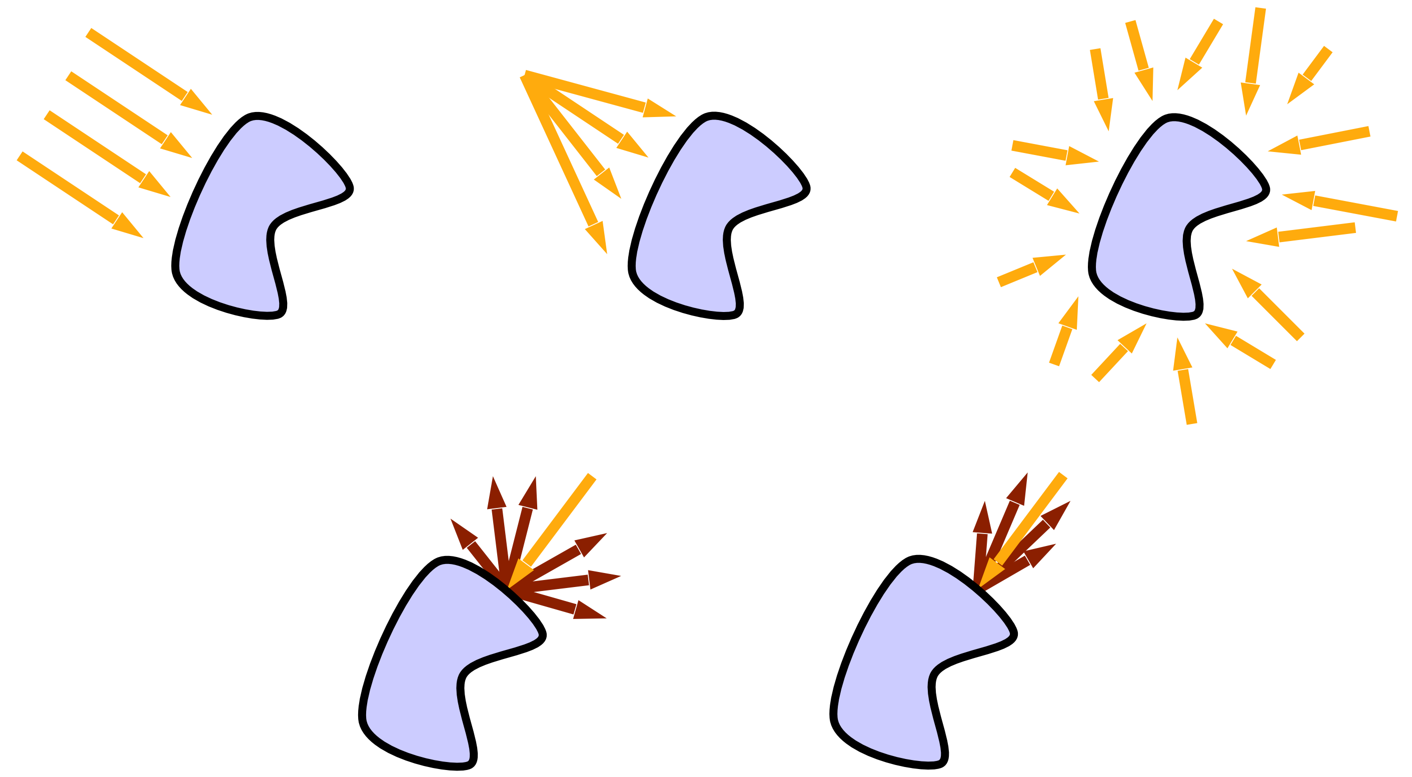
Plan for Today

- Adding light into the scene
- How to model reflections:
    - Diffuse reflection
    - Specular reflection
    - Ambient illumination
- Different light sources
- Distance attenuation
- Generalization: BRDF



Reflection (or Lighting) Models

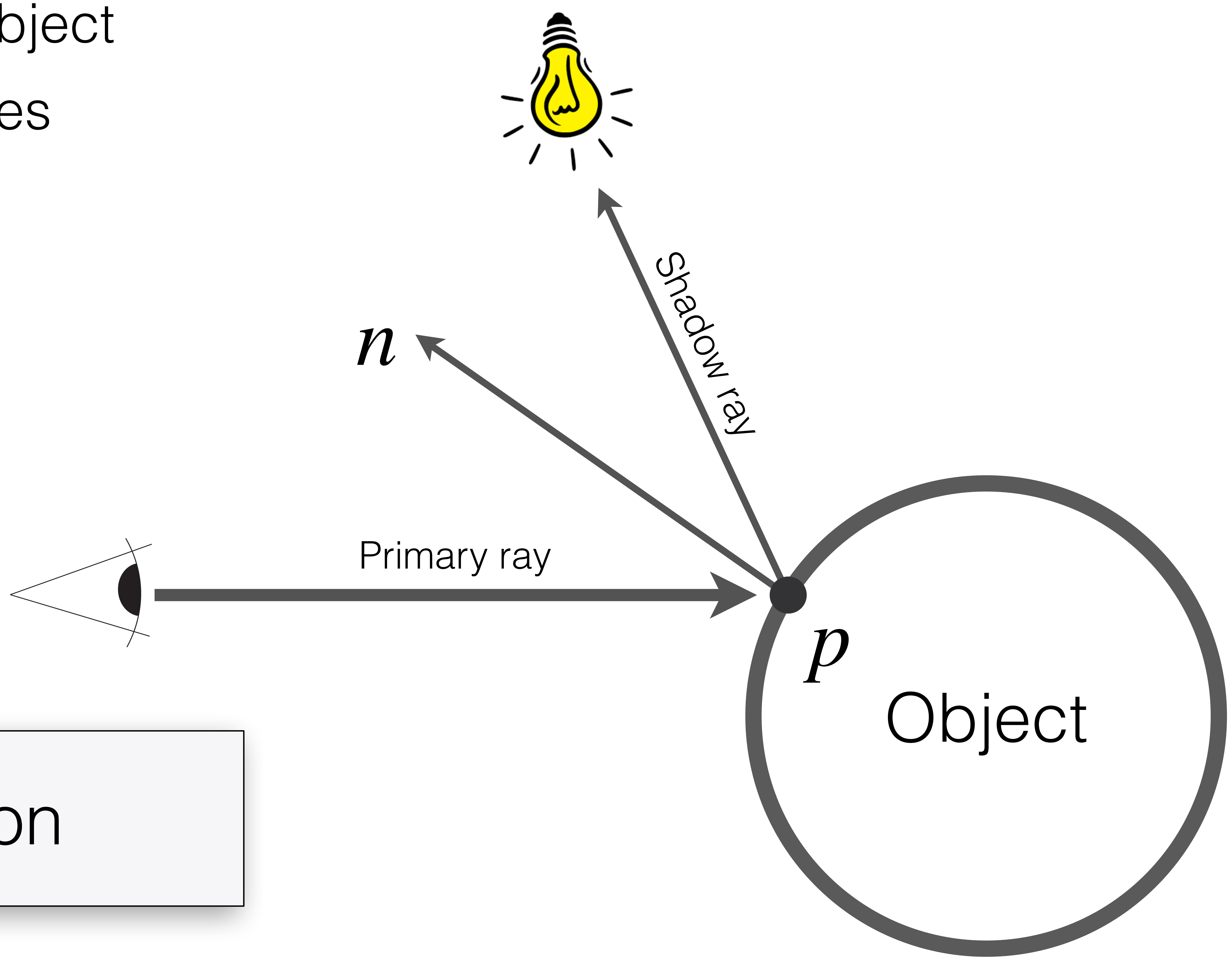
- Rule for computing color values on an object's surface
  - Based on the laws of physic (radiometry, photometry)
  - Models the effect of:
    - light sources (position, intensity, colour)
    - object surface (geometry, reflection properties)



- Very simple, local models for real time applications
  - Only primary light exchange between light source and object
  - No secondary effects (light exchange between objects)

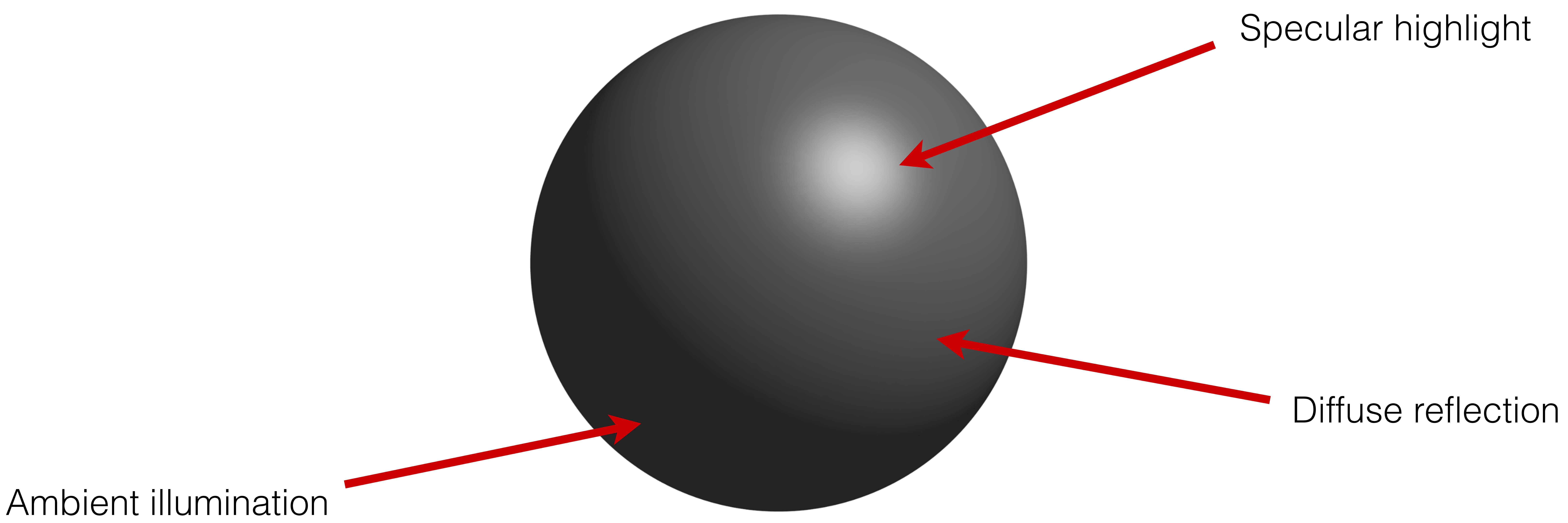
Illumination Factors

- Intensity depends on:
  - Color and reflective properties of the object
  - Position and intensity of the light sources
  - Position of the viewer
  - Normal ($\boldsymbol{n}$) of the surface at point $\boldsymbol{p}$
  - Distance from $\boldsymbol{p}$ to the light source



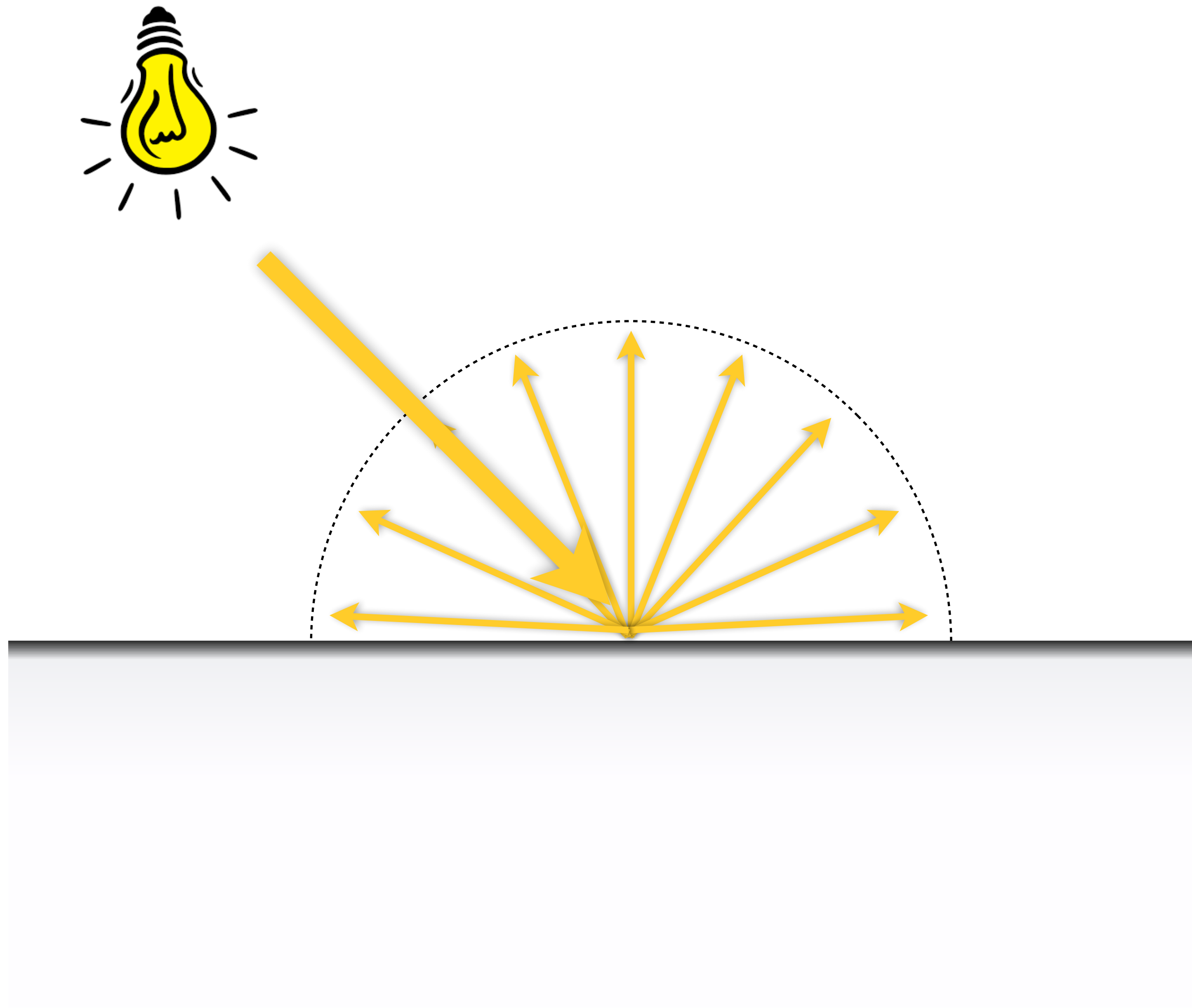
Let's build some better intuition

Components of Simple (Phong) Lighting Model



Diffuse Reflection

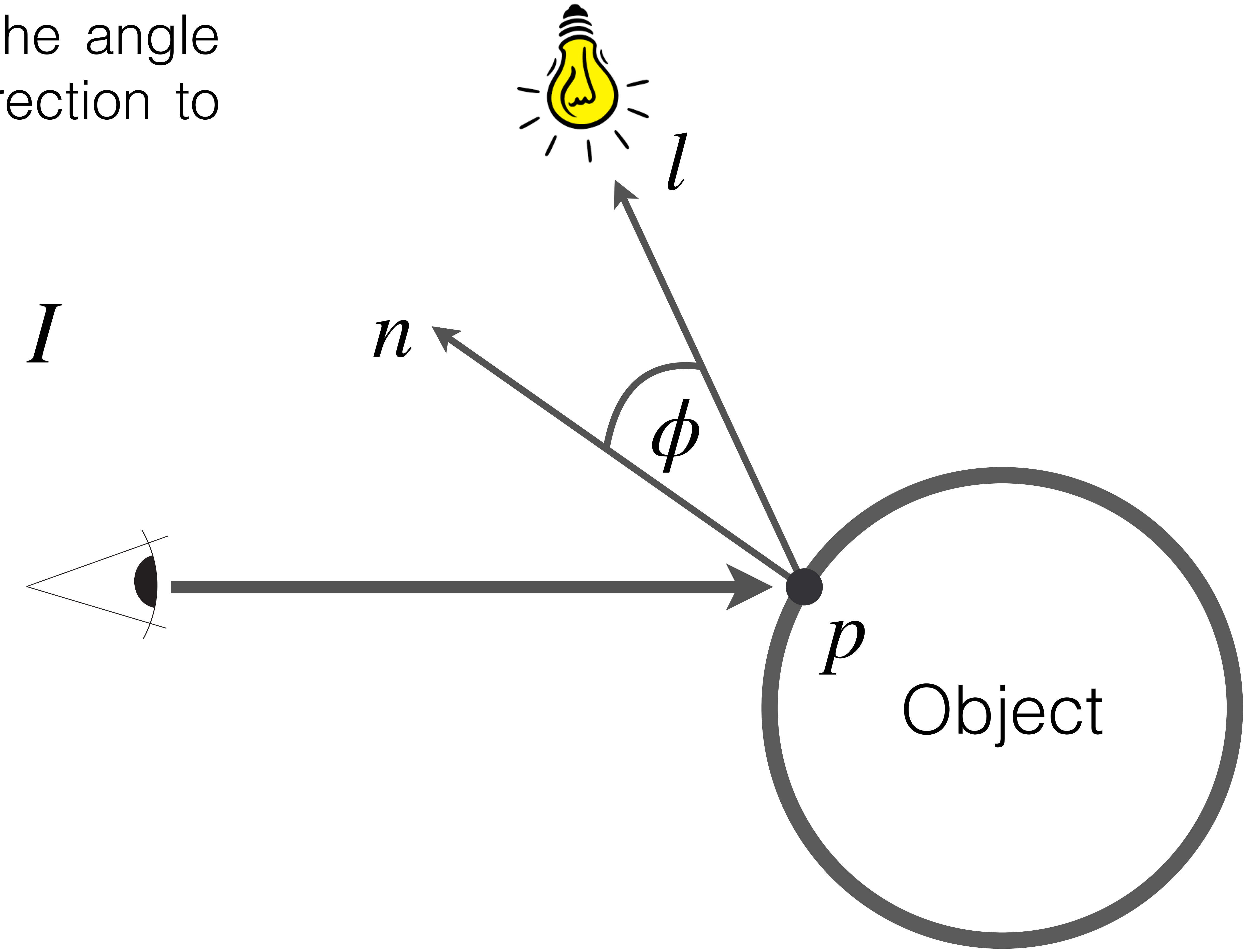
- Simulation of “matte” surfaces (Lambertian surface)
  - Incoming light is reflected evenly in all directions
  - Material-dependent reflection constant $\rho_d \leq 1$
- Examples: paper, dry stone, unfinished wood
- Intensity:
  - Does not dependent on the viewpoint
  - It does depend on the light direction and the normal



Lambert's Cosine Law

The intensity I_d of a surface coming from the diffuse reflection is proportional to the cosine of the angle between the surface normal n and the direction to the light source l.

$$I_d = \rho_d \cdot \cos\phi \cdot I = \rho_d \cdot \langle n, l \rangle \cdot I$$

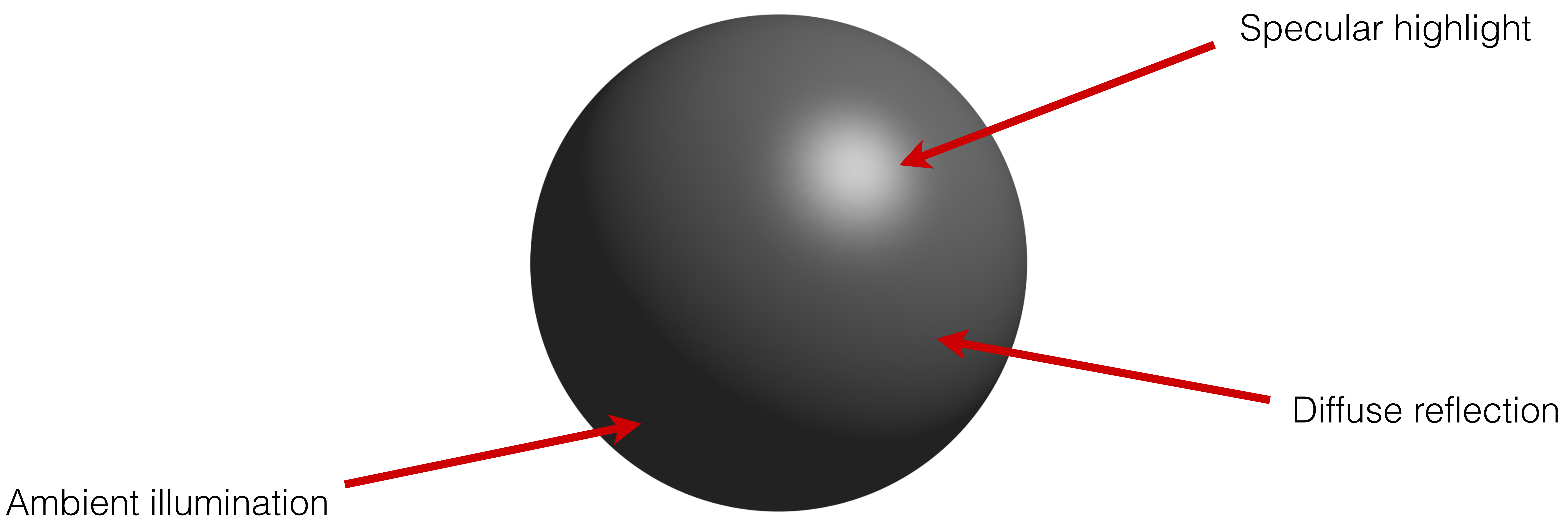


I — light intensity
ρ_d — diffuse coefficient of the surface

Assumption: $\|n\| = \|l\| = 1$

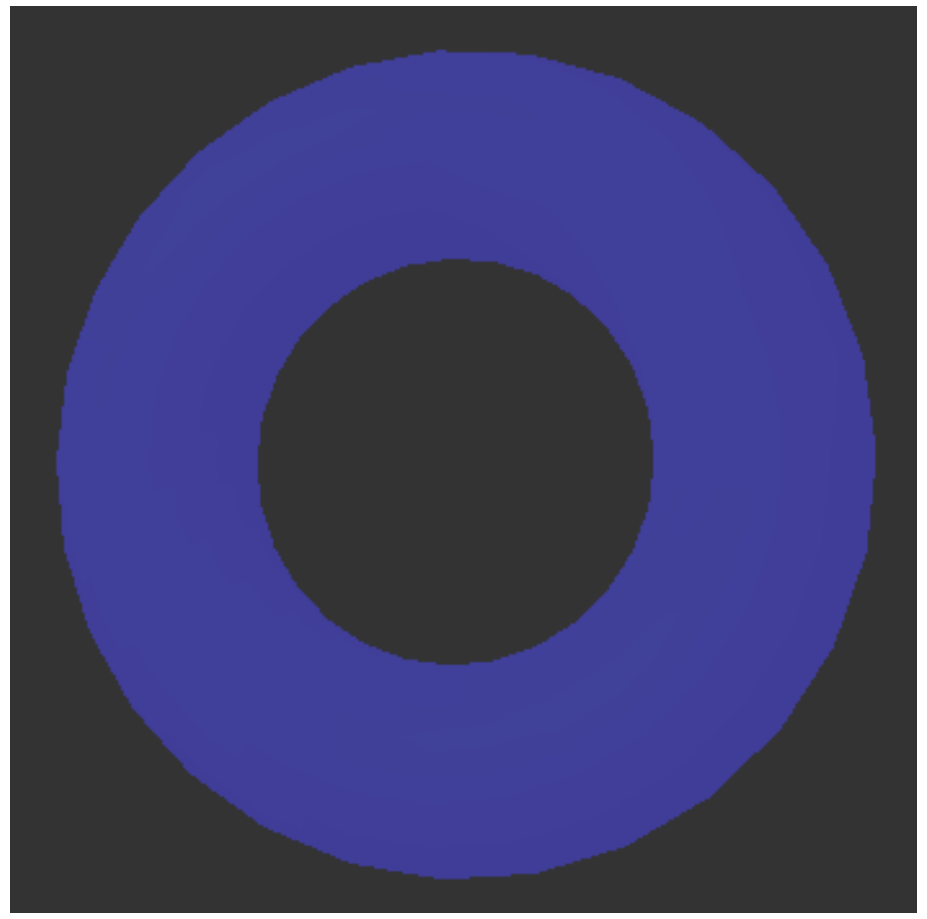
Important: What if $\langle n, l \rangle \leq 0$?

Components of Simple (Phong) Lighting Model

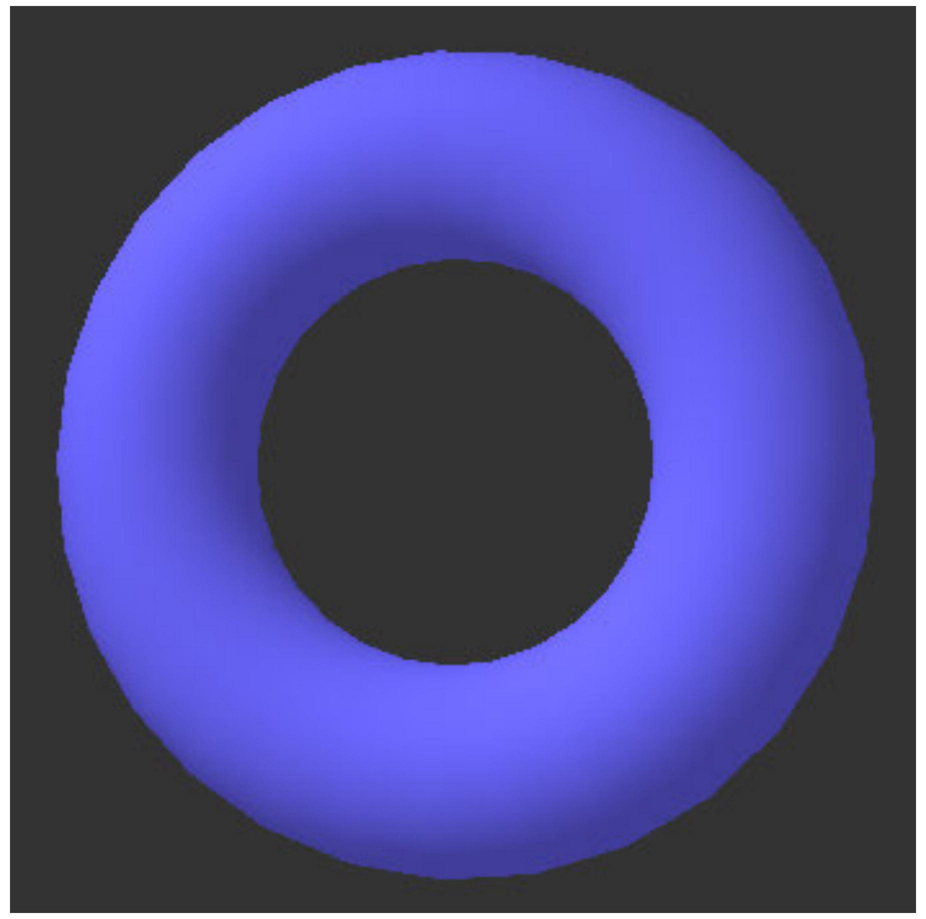


Ambient Illumination

- So far, surfaces that do not face the light source are black
- Ambient illumination simulates indirect lighting:
  - Effect of multiple inter-reflections of light between all objects
  - Isotropic and independent of light source and viewpoint
- Global, scene constant I_a
- Material-dependent:
  - reflection constant $\rho_a \leq 1$
- Ambient term: $\rho_a \cdot I_a$

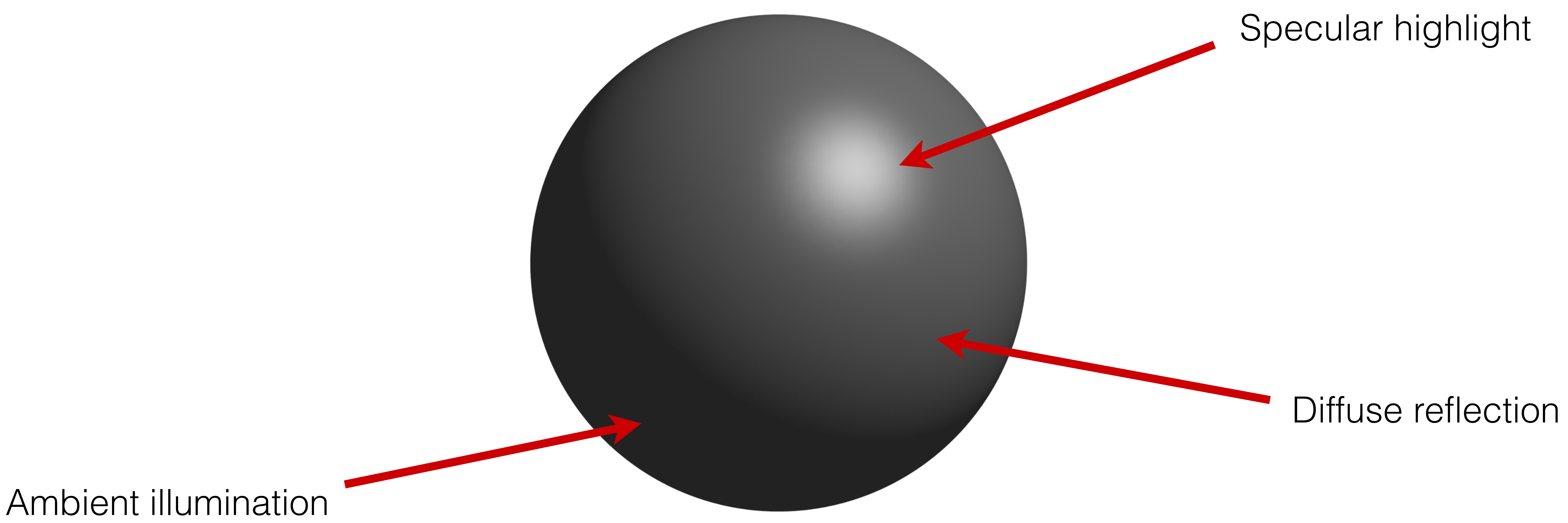


ambient only



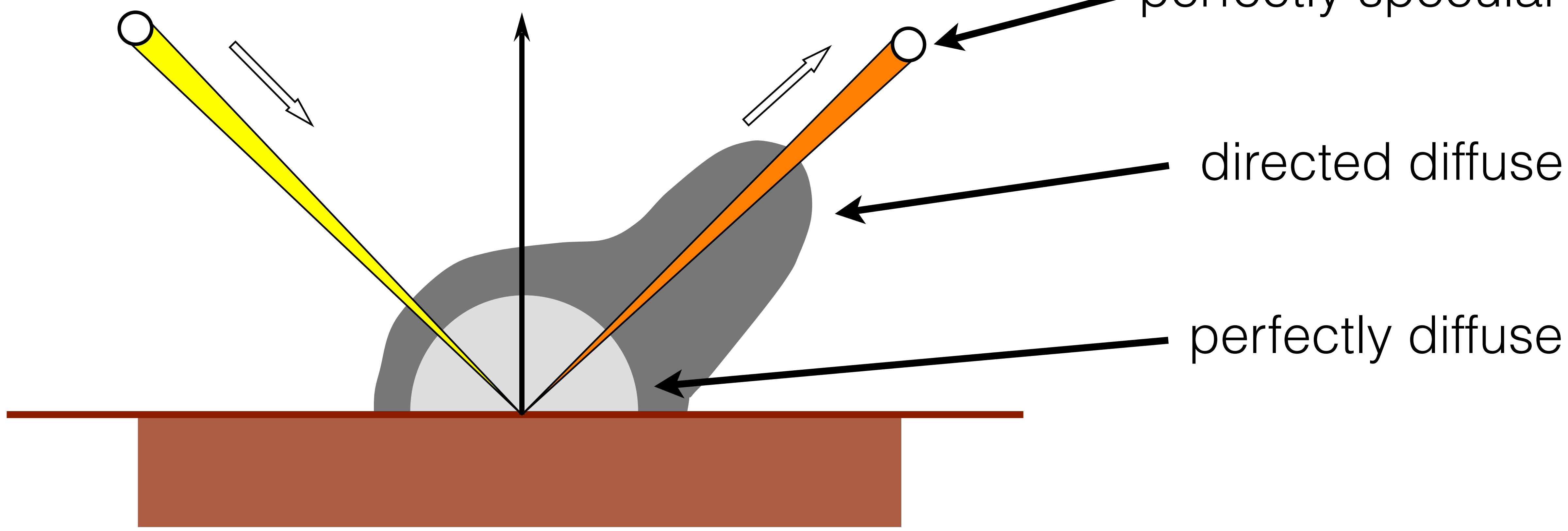
diffuse + ambient

Components of Simple (Phong) Lighting Model



Specular Reflection

- Simulates shiny surfaces
- Incoming light is reflected in exactly one, reflection direction
- In practice: directed diffuse reflection
  - maximal intensity in the direction of the perfect reflection



Specular Reflection

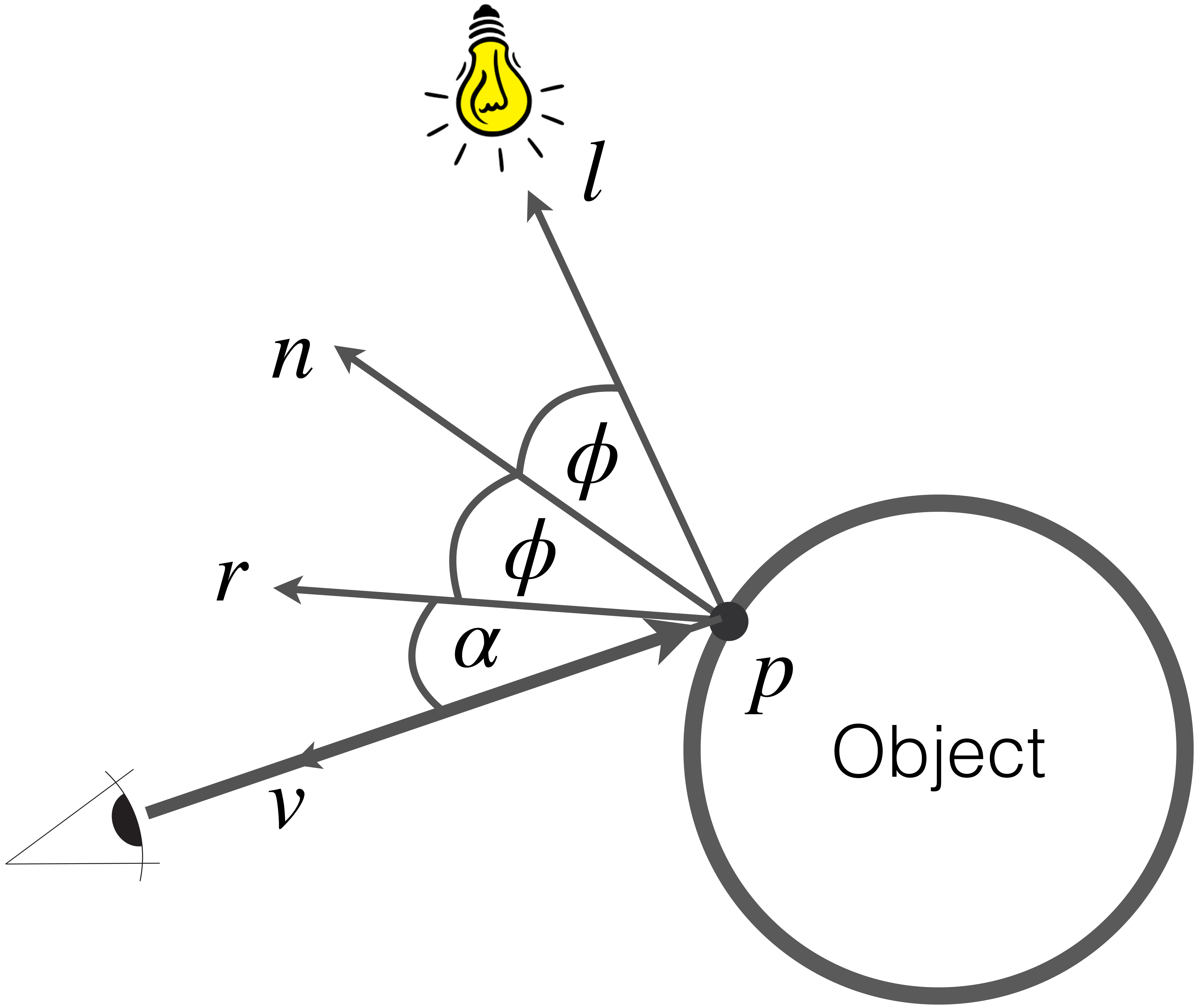
- Reflected light vector:

$$r = 2n \cdot \langle n, l \rangle - l$$

- Specular term:

$$I_s = \rho_s \cdot (\cos\alpha)^k \cdot I$$

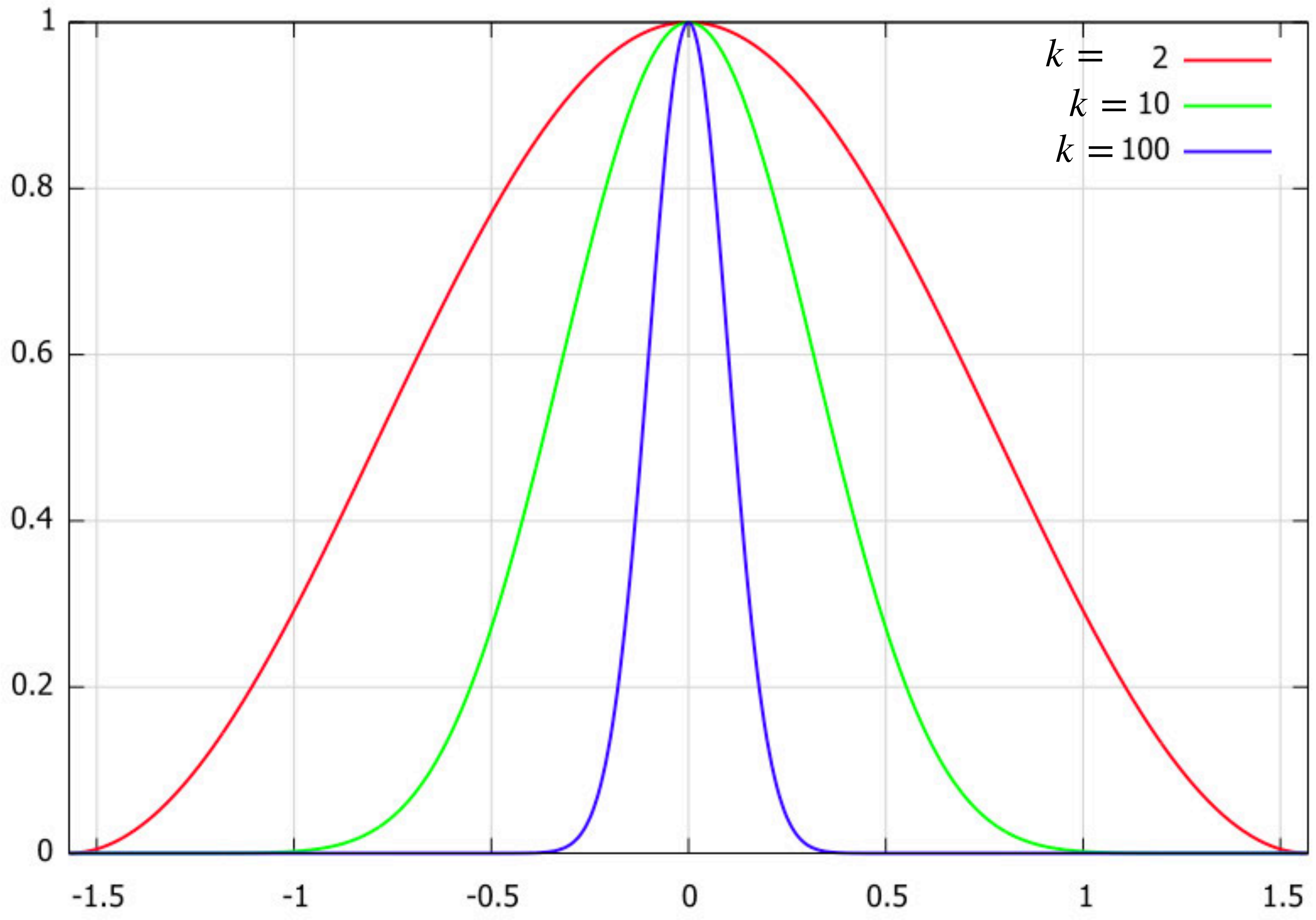
k — shininess ≥ 1
ρ_s — specular coefficient of the surface



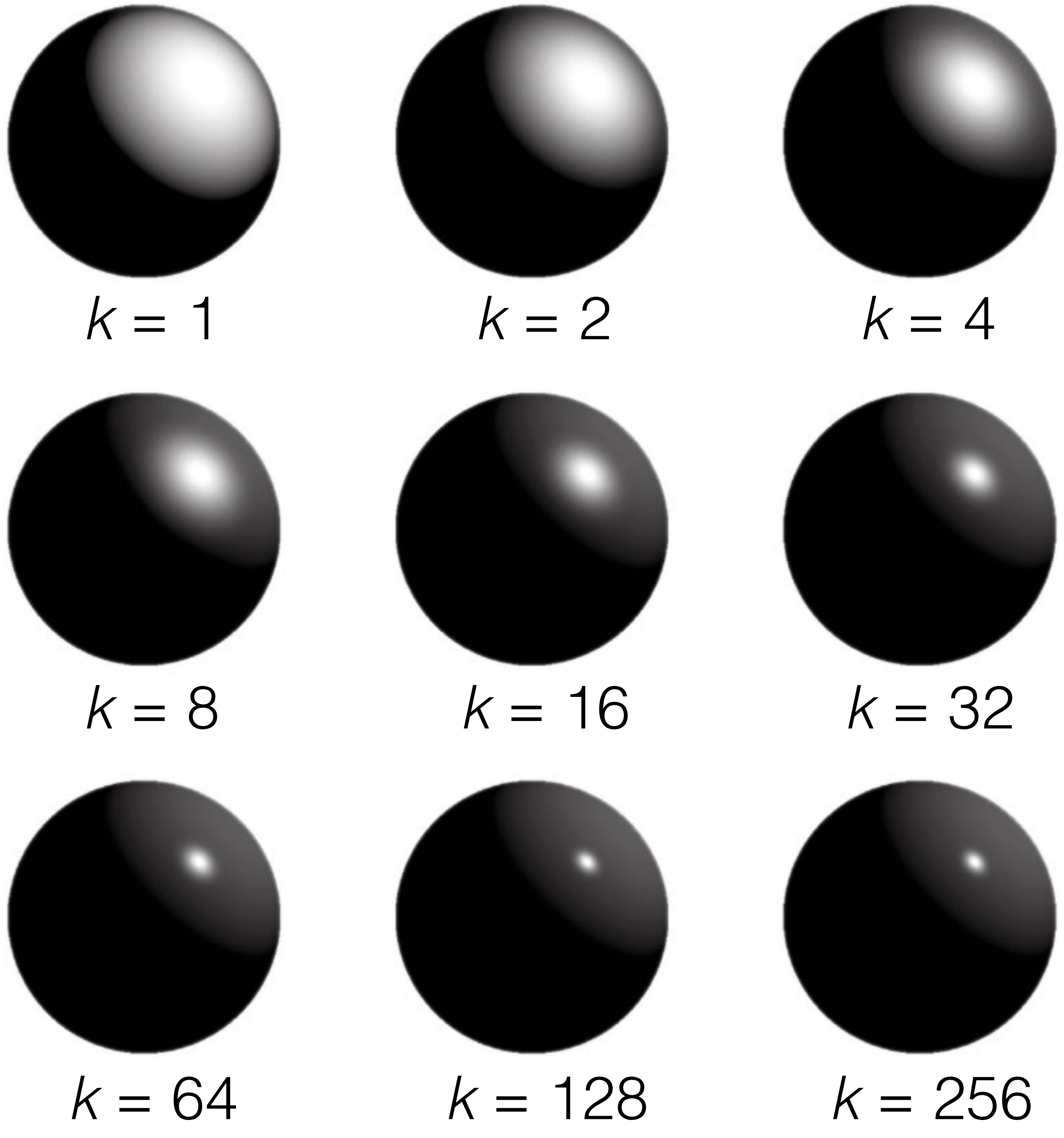
Specular Reflection

- Exponent k controls the highlight characteristic

$(\cos\alpha)^k$

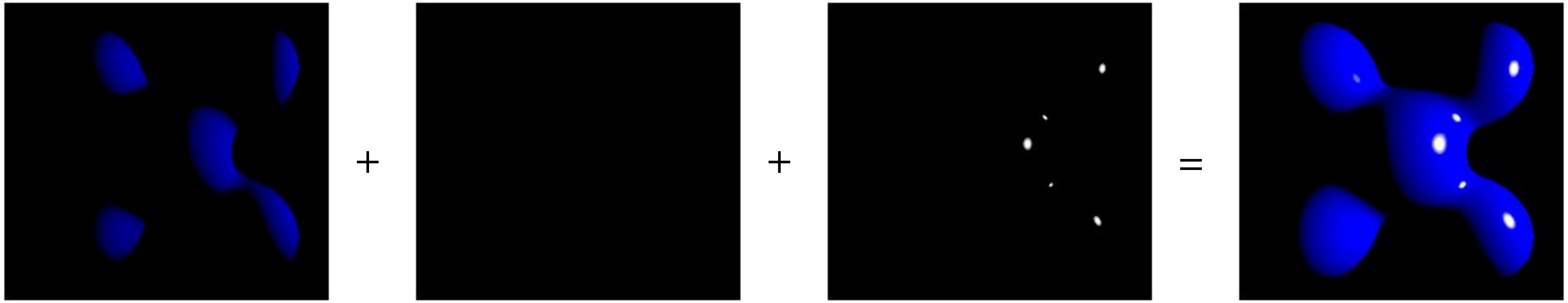


α



Phong Lighting Model

- Superposition of ambient, diffuse, and specular terms for each light source:



diffuse + ambient + specular = Phong lighting

Phong Lighting Model

- Superposition of <u>ambient</u>, <u>diffuse</u>, and <u>specular</u> terms for each light source:

$$I = I_e + \rho_a \cdot I_a + \sum_{j=1}^{n} \left(\rho_d \cdot \cos \phi_j + \rho_s \cdot \cos^k \alpha_j \right) \cdot I_j$$

  - n light sources with intensities I_j
  - self-emitting intensity I_e
  - reflection constants (surface properties): ρ_a , ρ_d , ρ_s
  - <u>shininess</u>: k (no physical meaning)

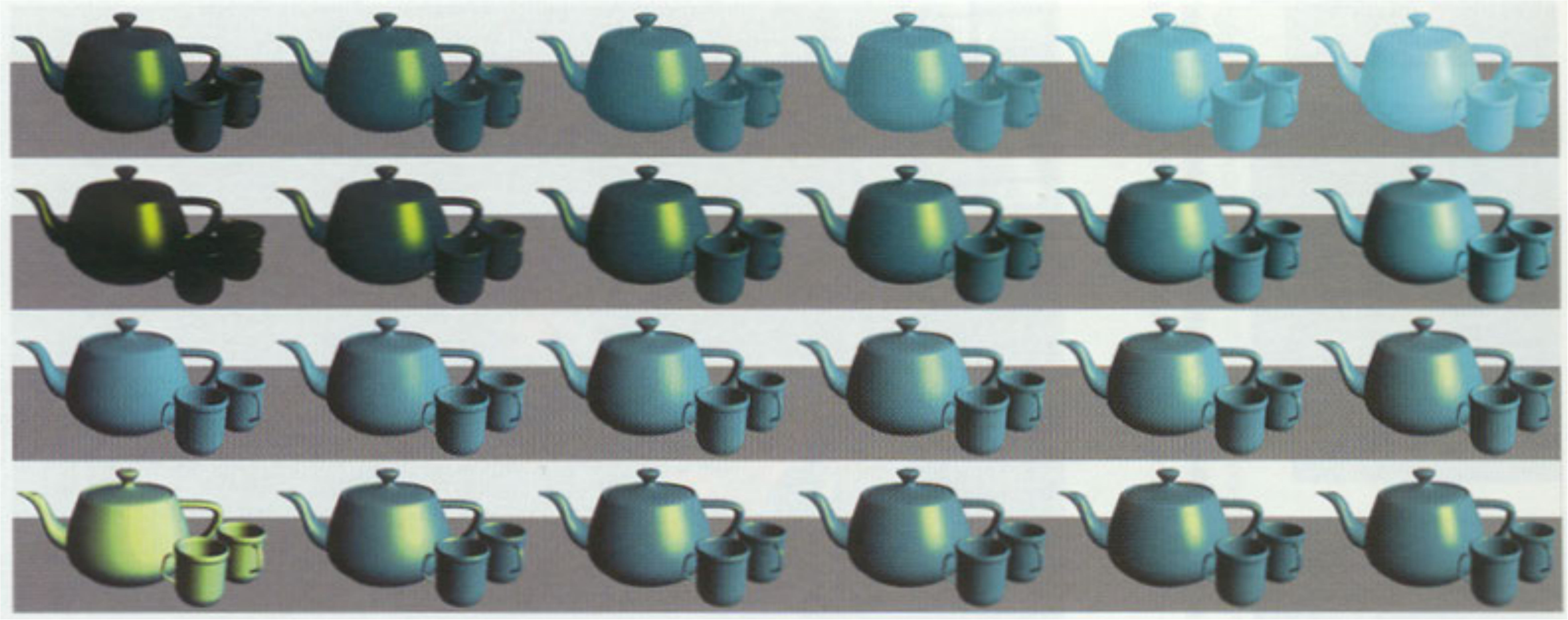
Effect of Parameters

ρ_a

ρ_d

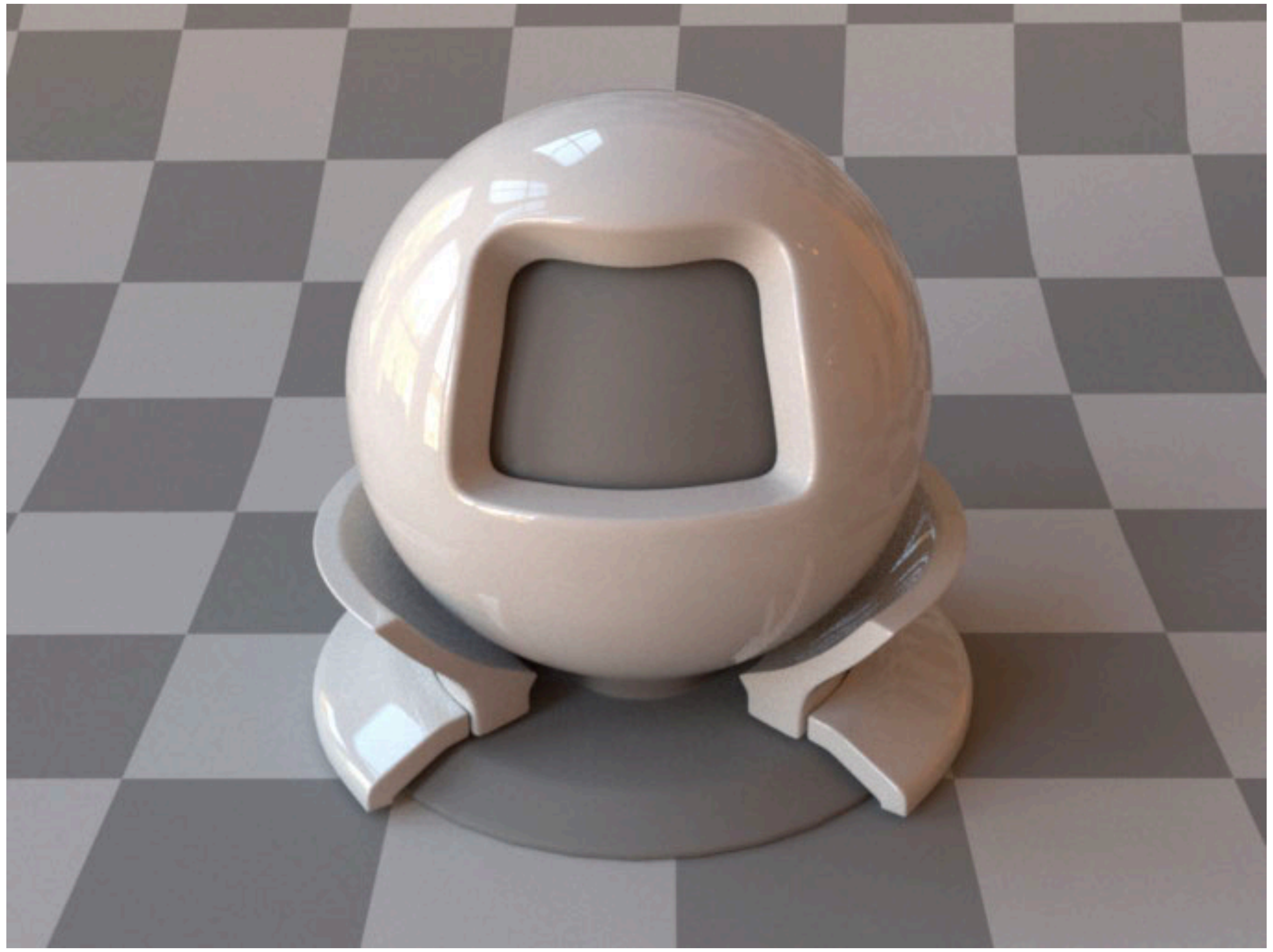
ρ_s

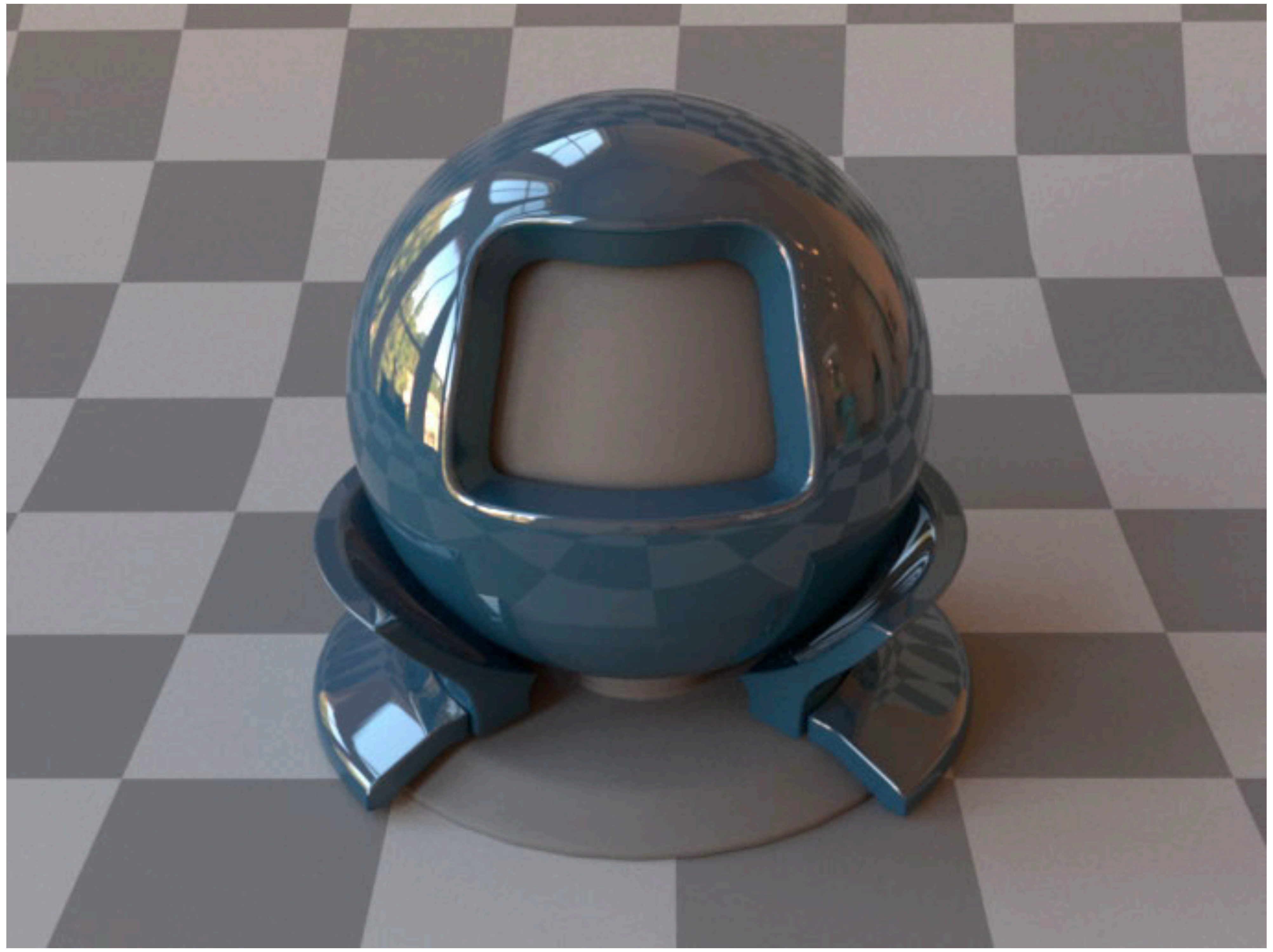
k



Plastics

- Dielectrics (e.g., plastics) do not color the reflection of light source

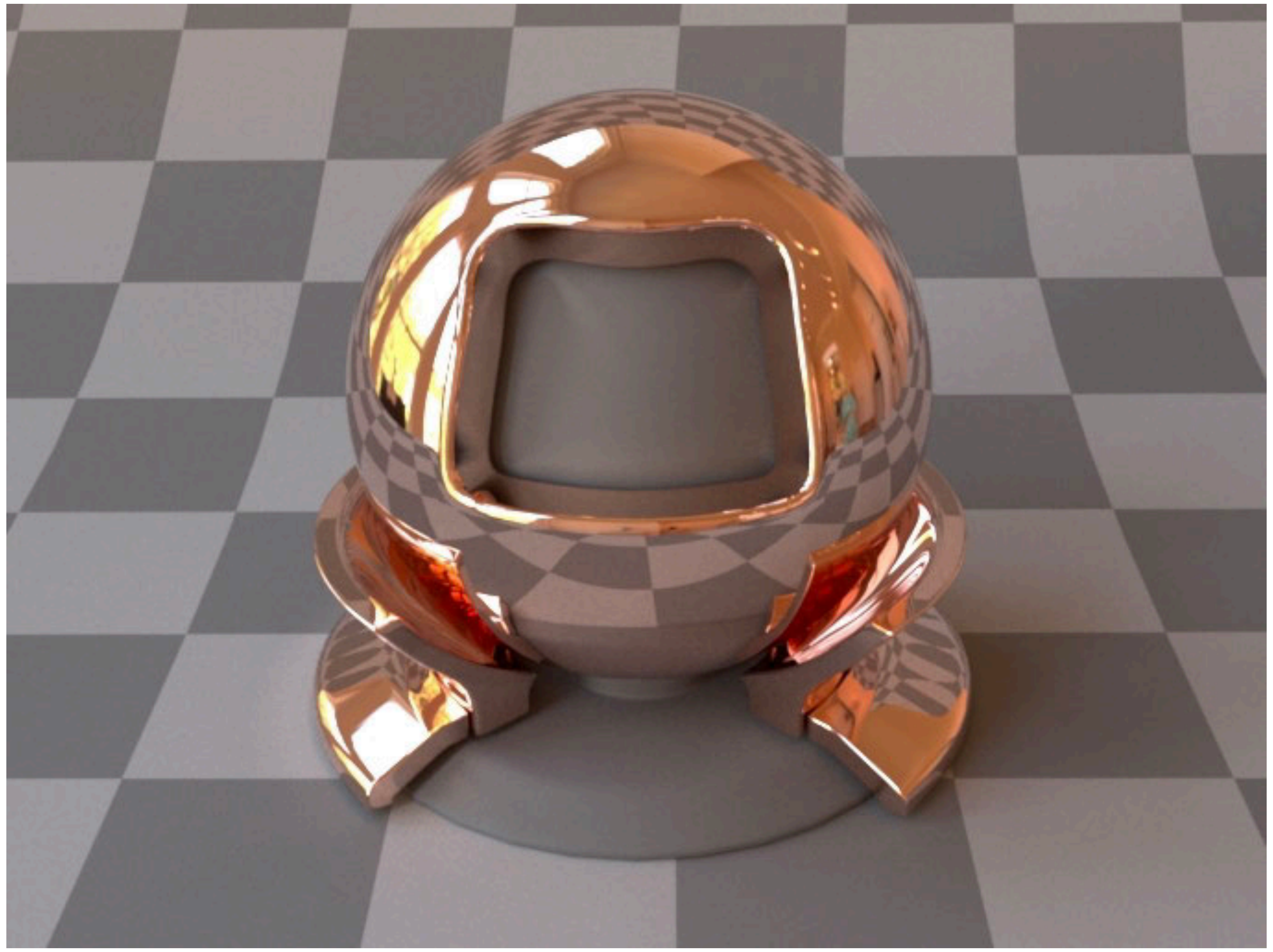




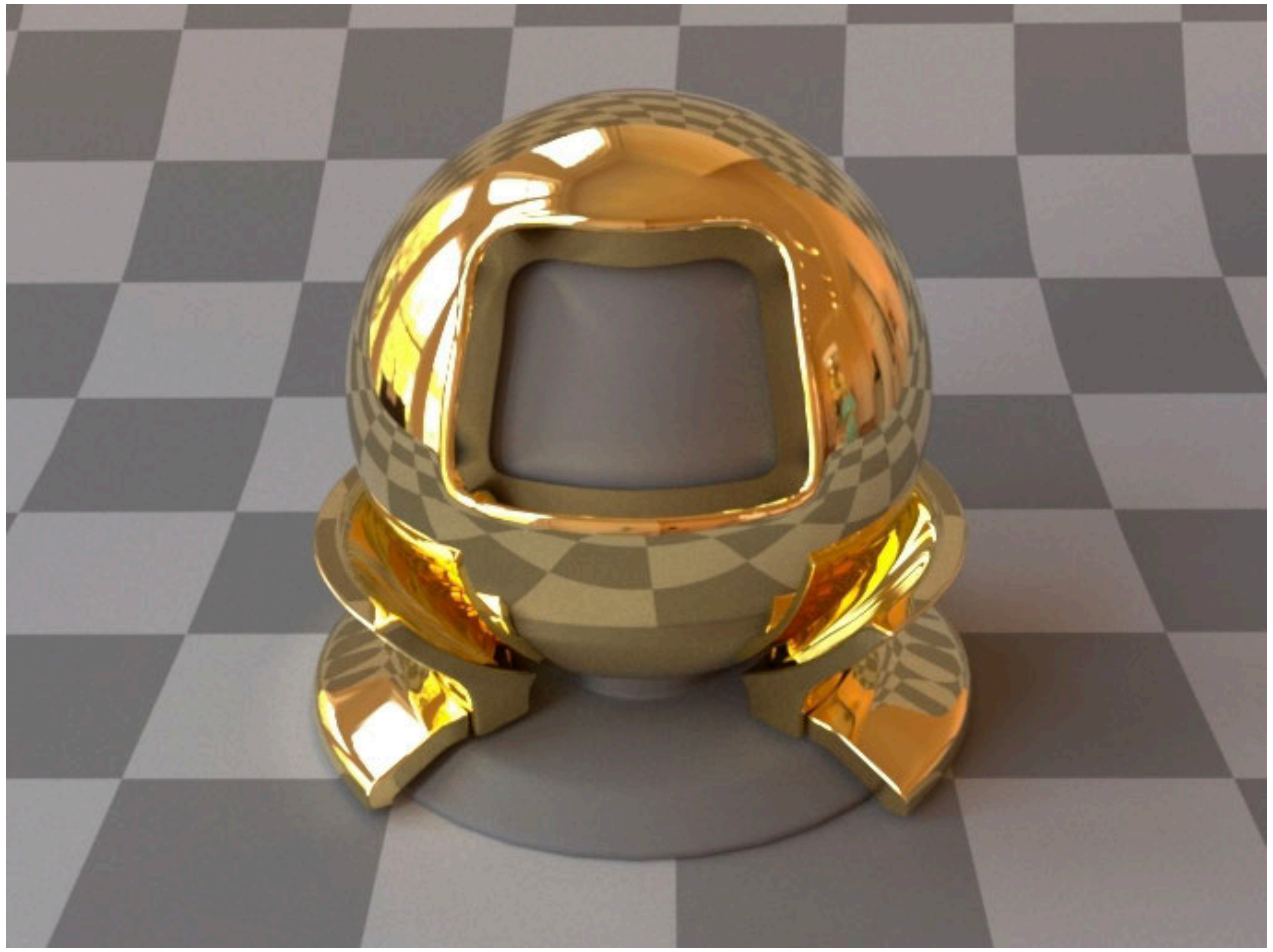
http://www.mitsuba-renderer.org/docs.html

Metals

- Conductors (metals) do color the reflections



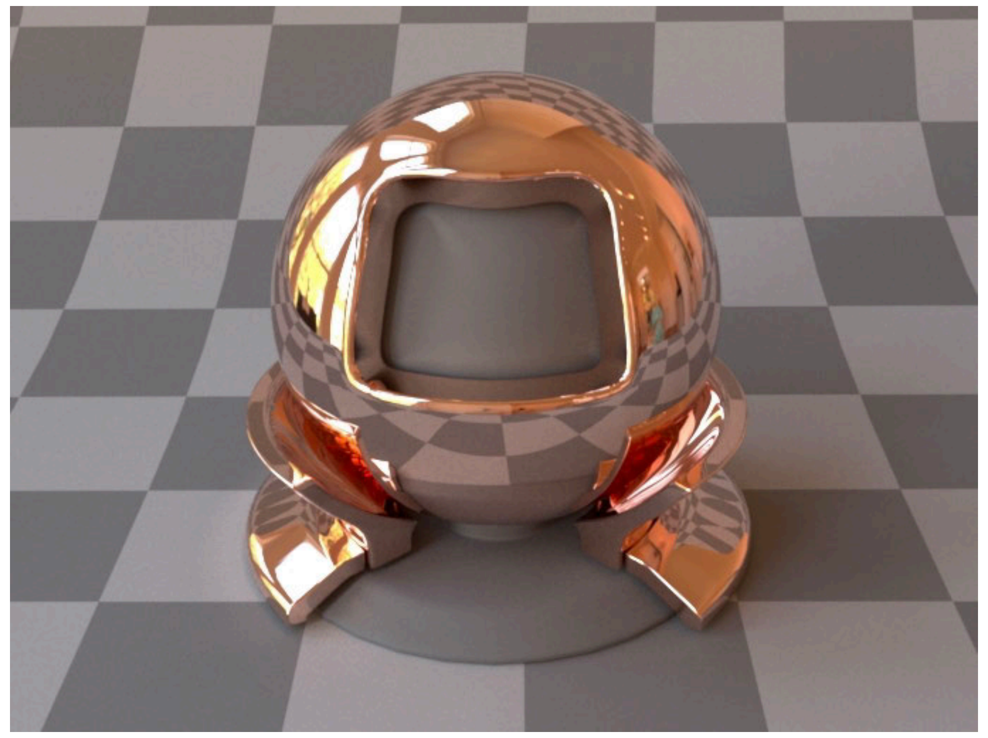
Copper

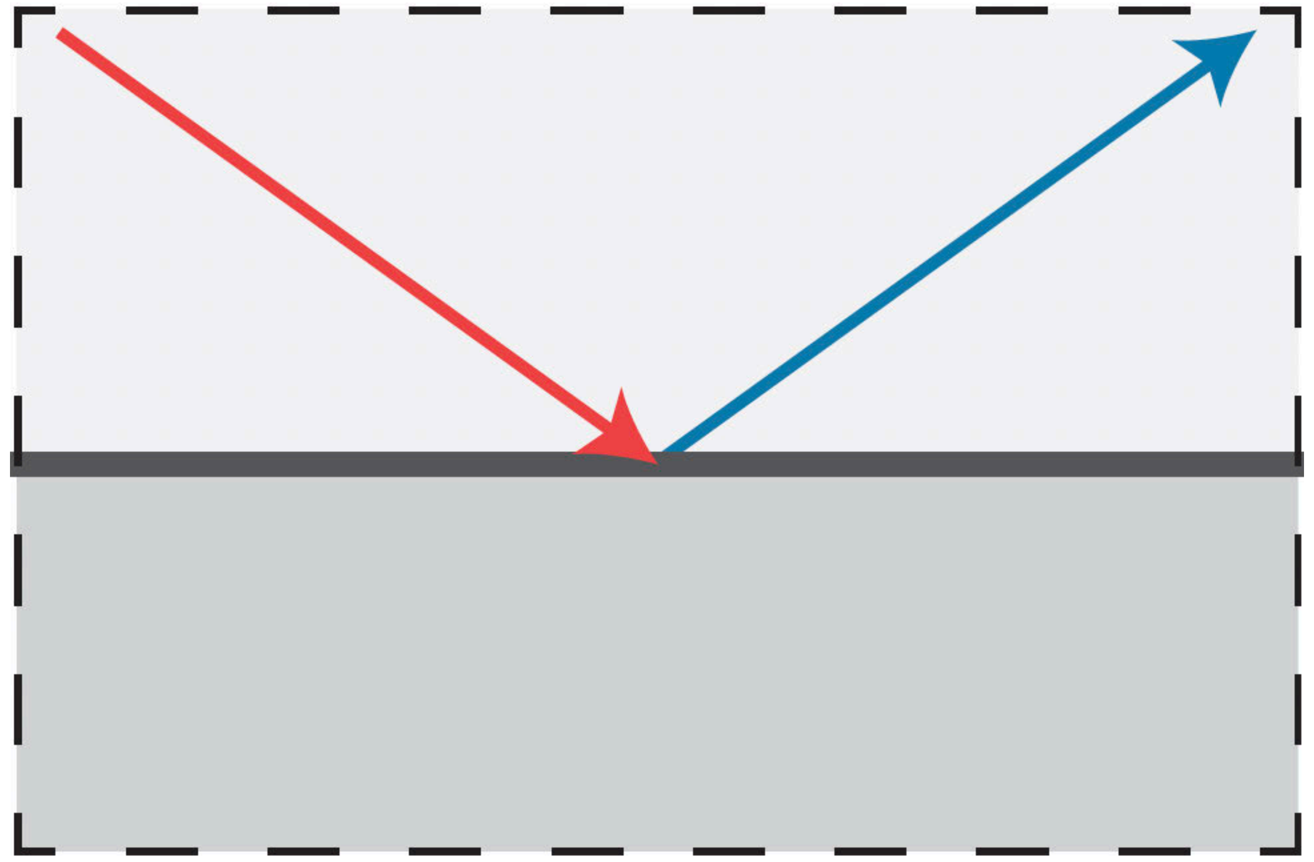


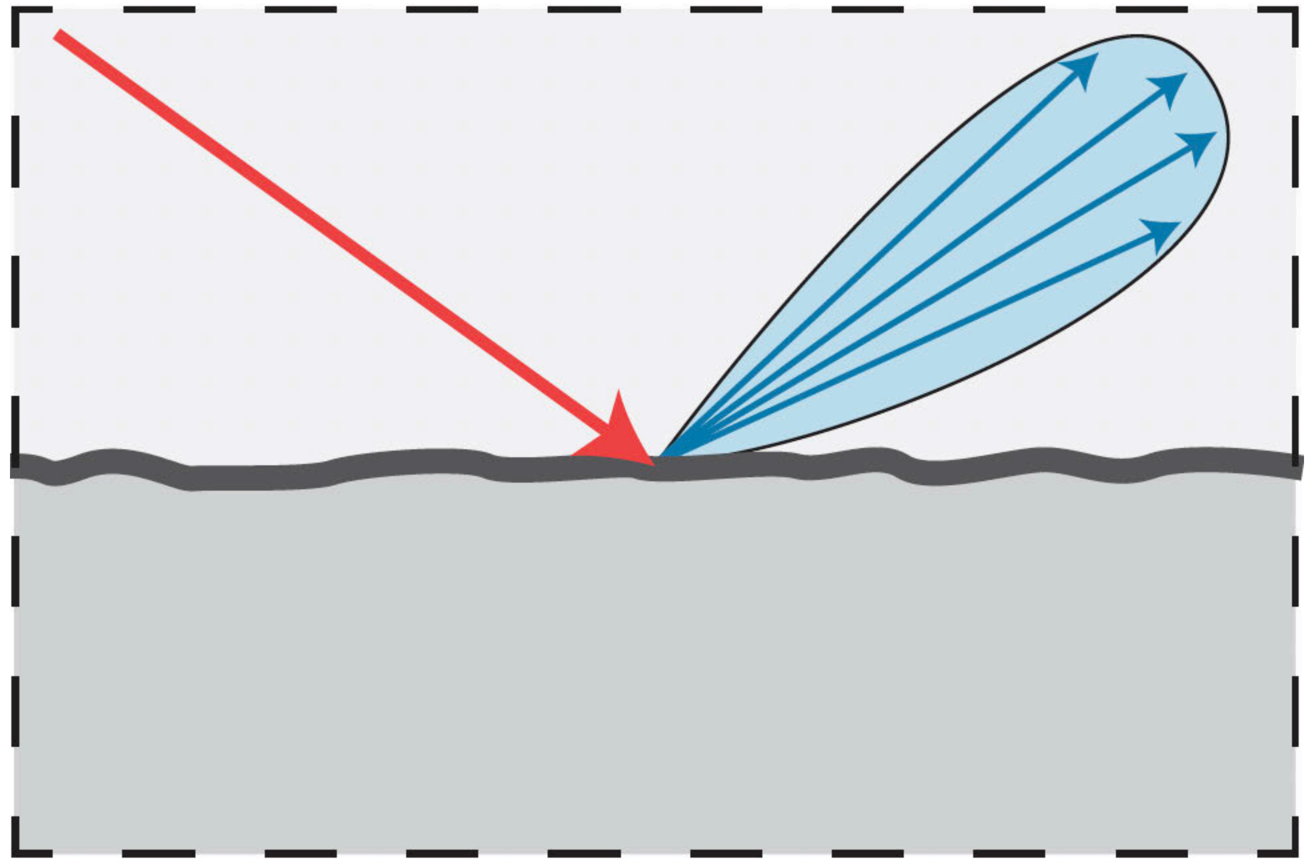
Gold

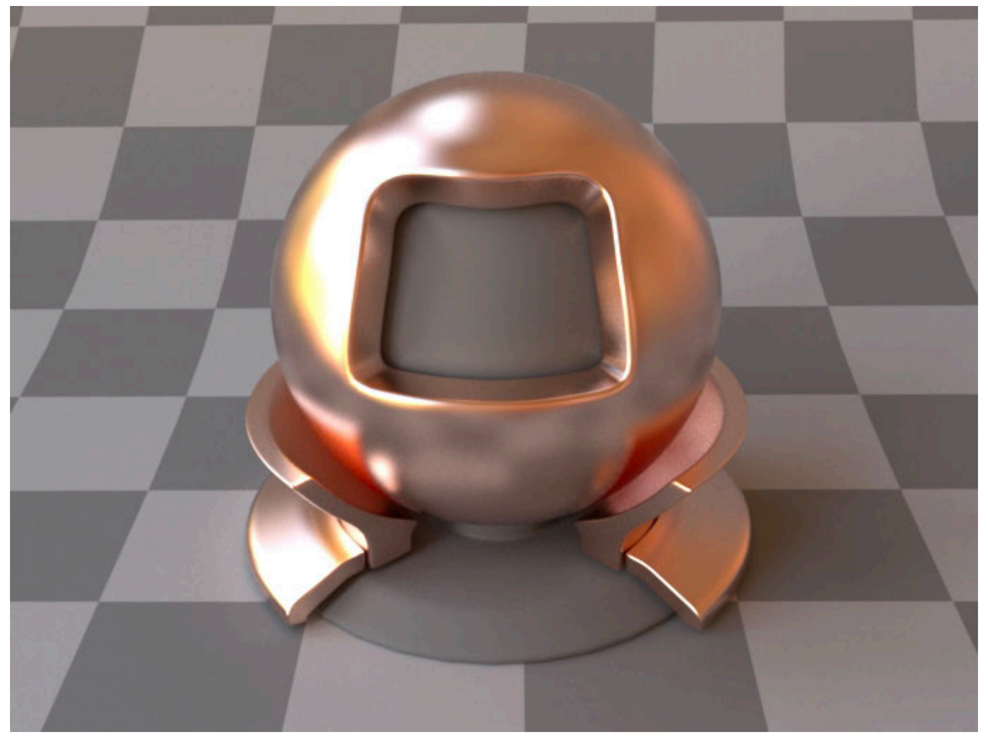
http://www.mitsuba-renderer.org/docs.html

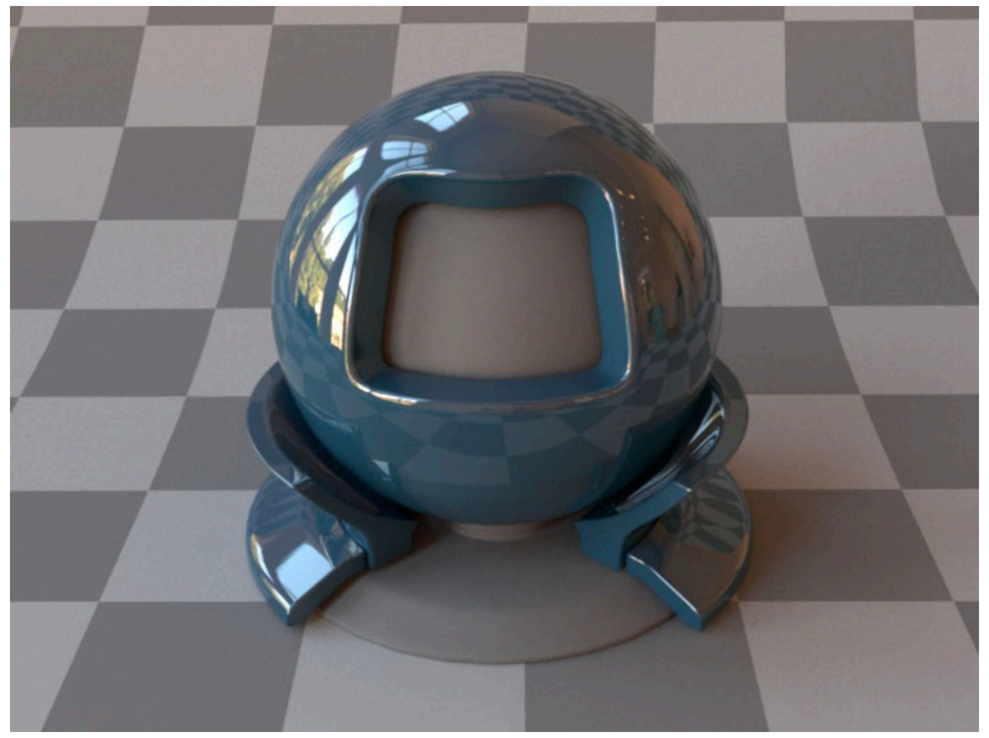
Plastics vs. Metals

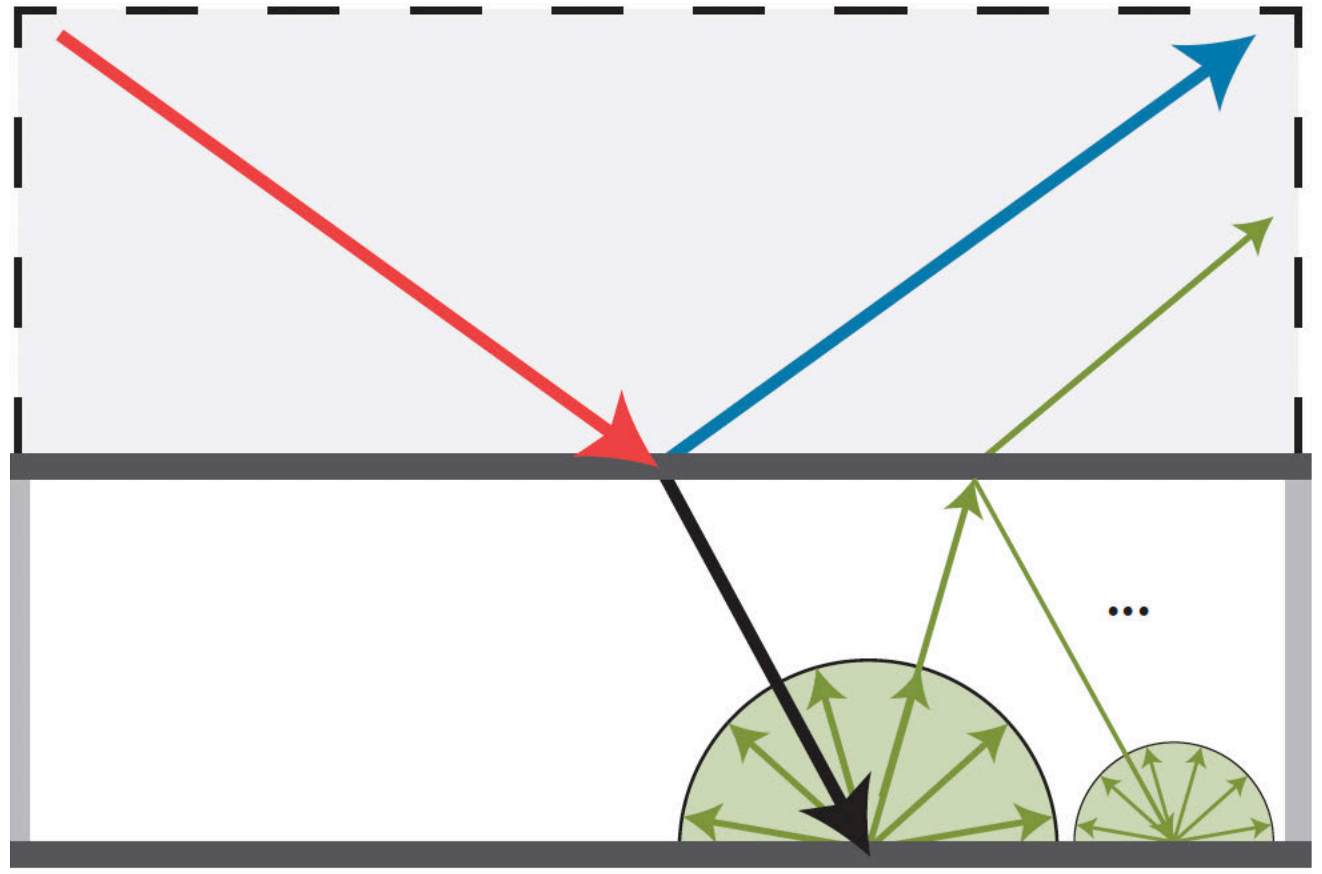


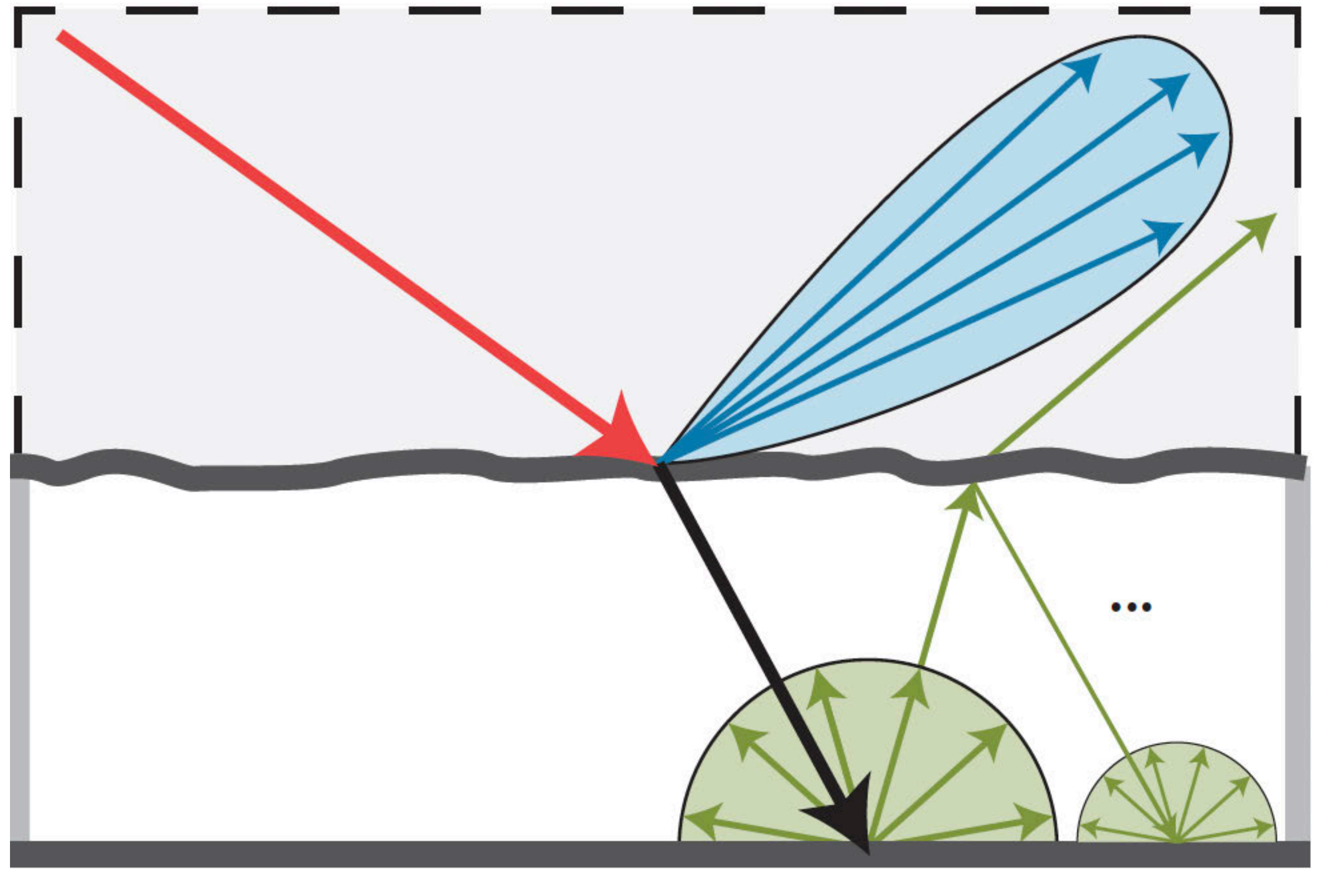


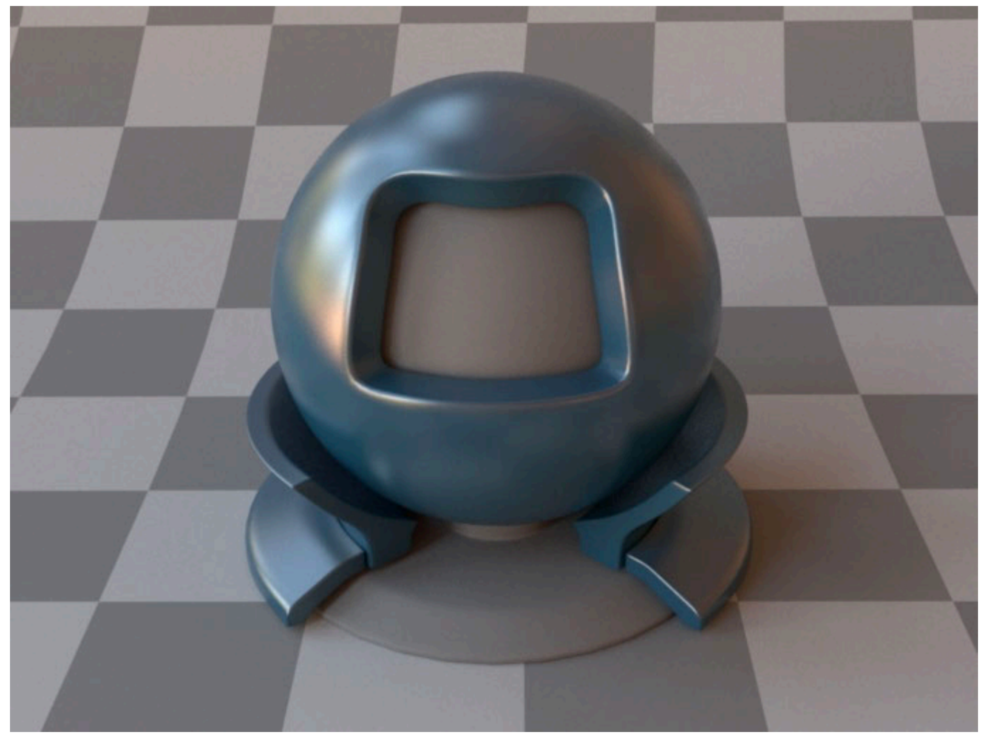












http://www.mitsuba-renderer.org/docs.html

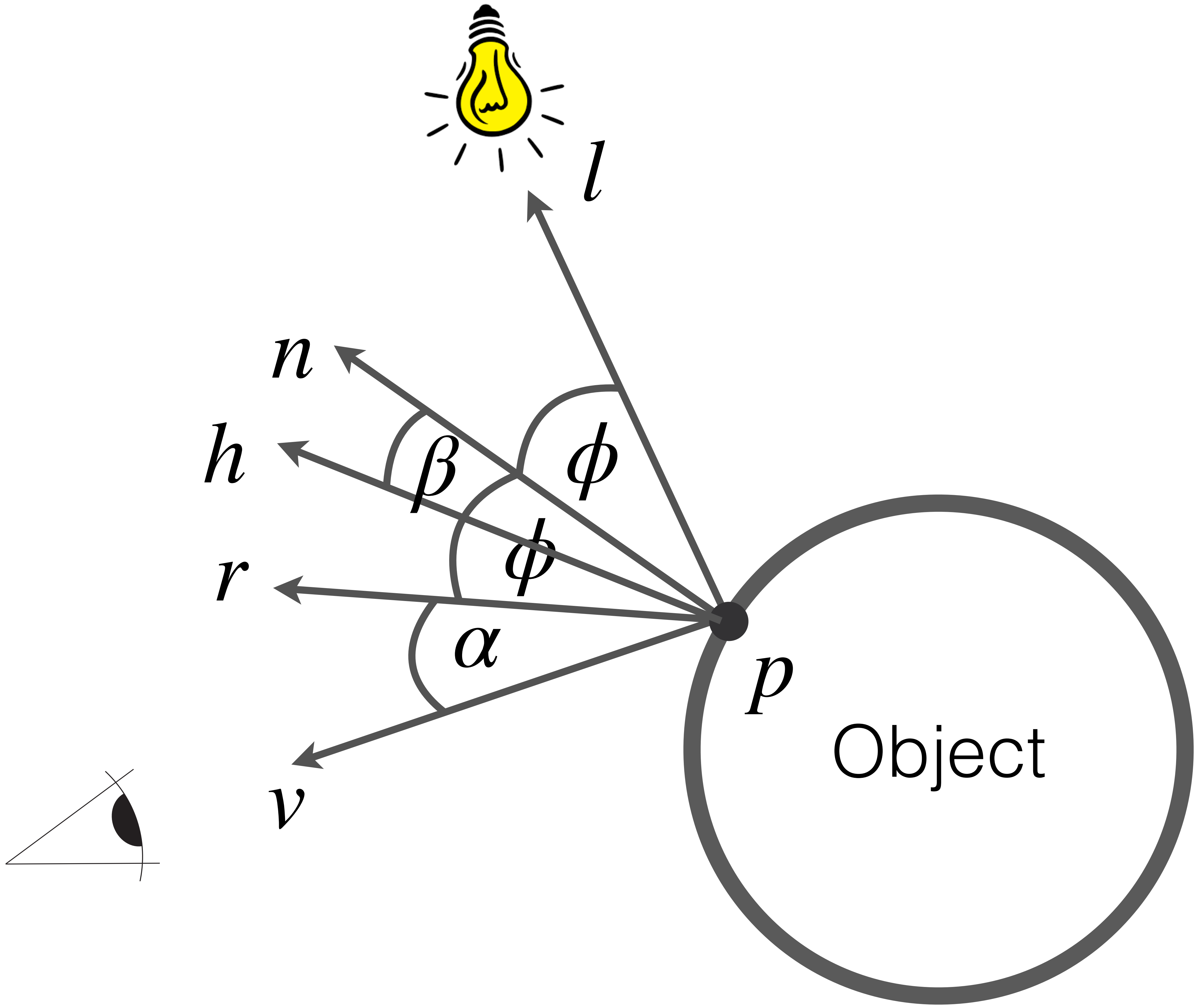
Specular Reflection (Blinn-Phong)

- Requires computing r and $\langle r, v \rangle$
- Instead we can use half vector:

$$h = \frac{1}{2}\left(l + v\right)$$

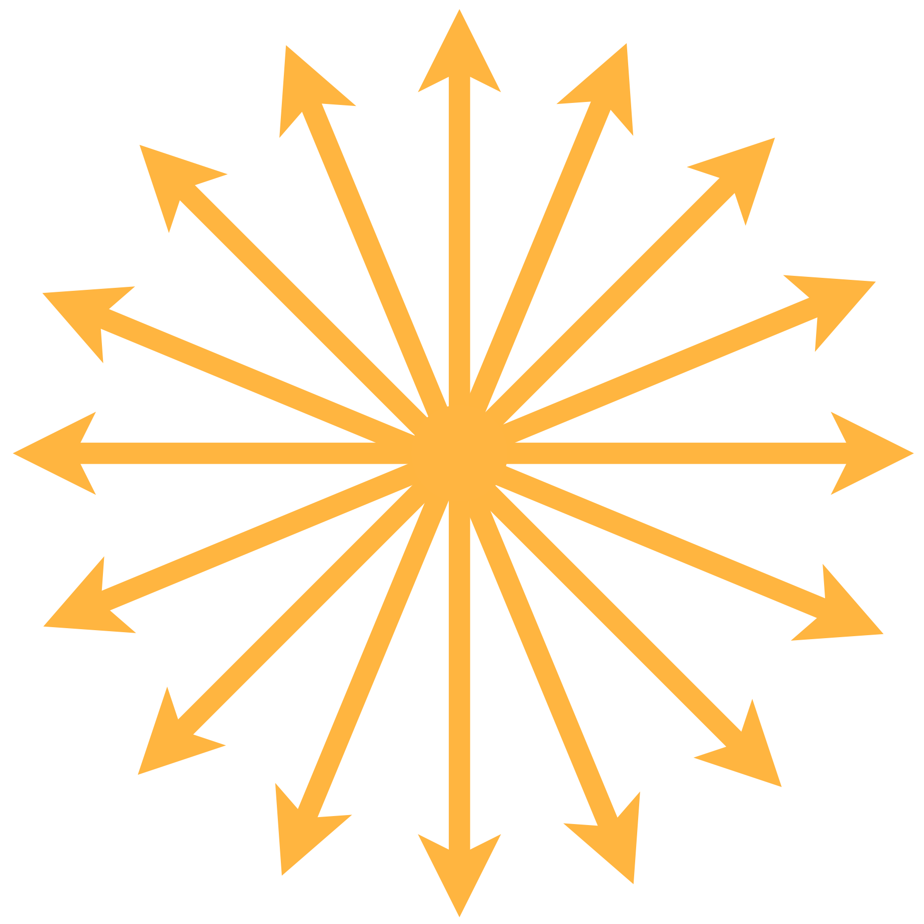
- $\beta \approx \alpha/2$, more precisely:
    - $\beta = \alpha/2$ when v, l, n, r are coplanar
    - $\beta \geq \alpha/2$ otherwise
- Since $\cos\alpha \approx \cos^4\beta$:

$$I_s = \rho_s \cdot (\cos\beta)^{4k} \cdot I$$

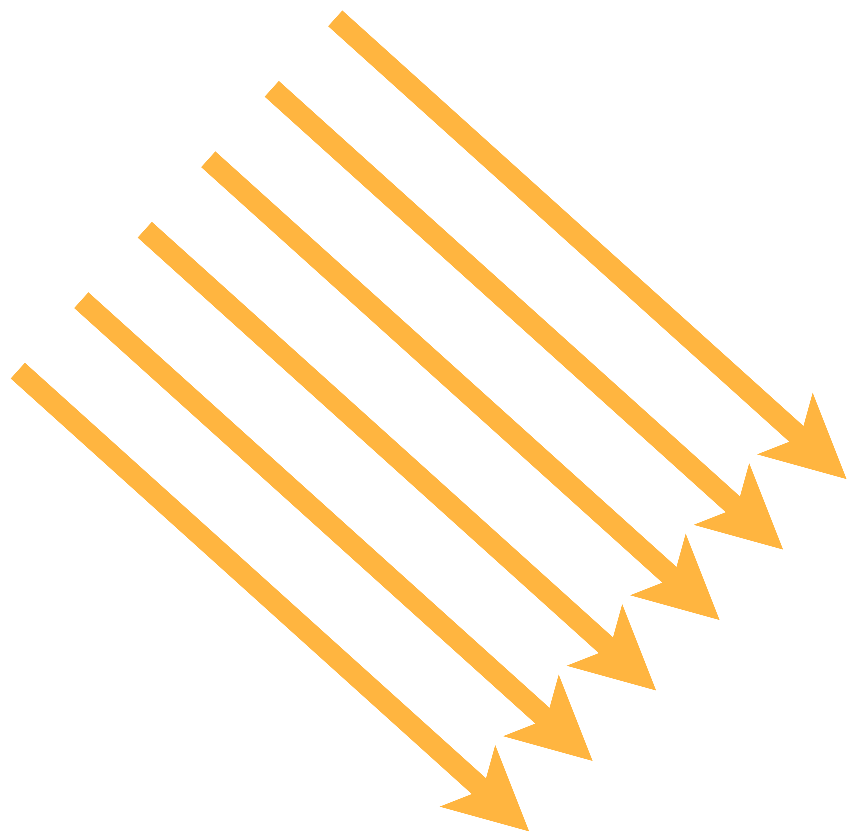


Point Light Sources

- So far: point light sources:
  - with intensity I
  - Specified by position
  - Radiate evenly (isotropic) in all directions

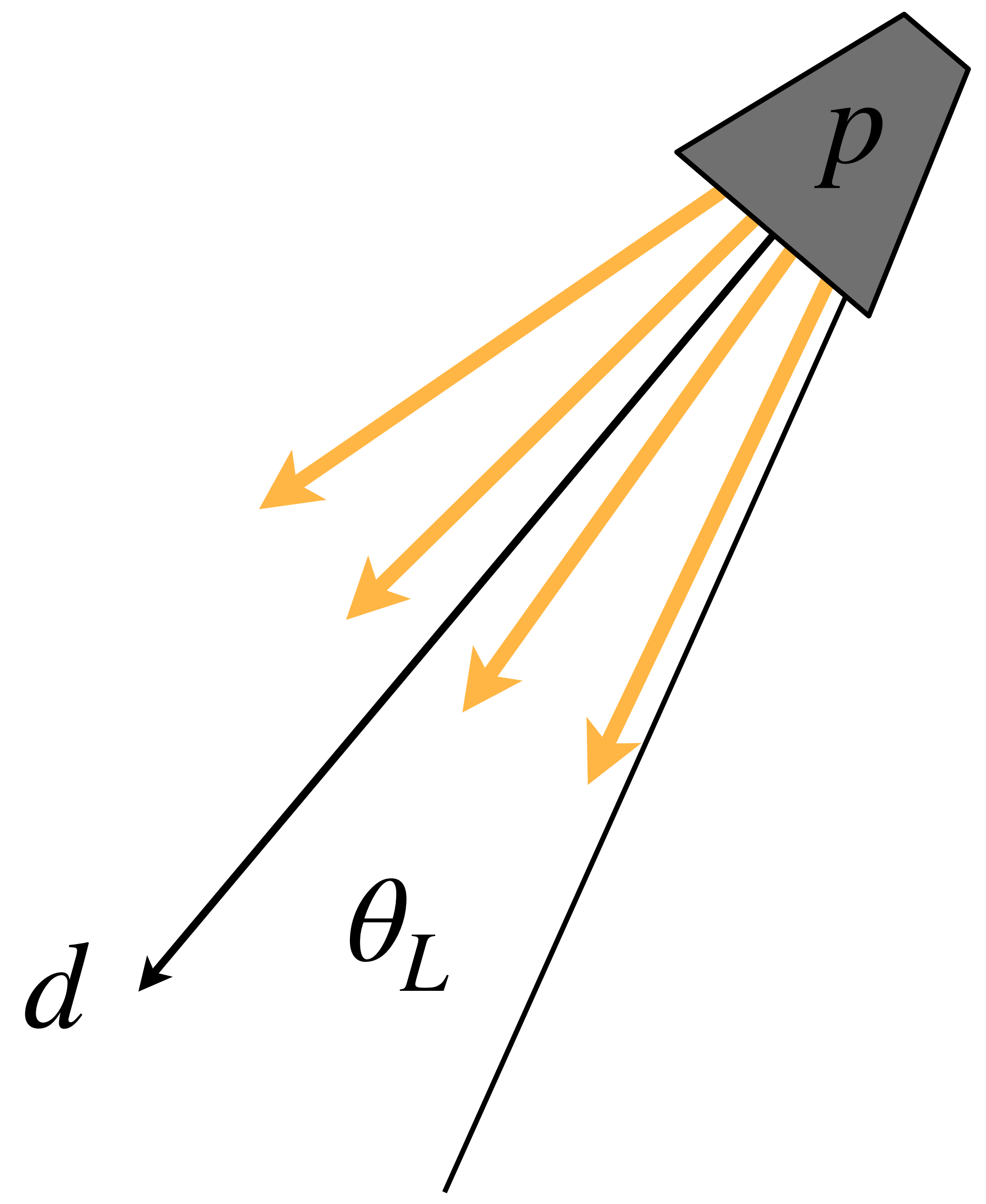


- Special case: directional light source
  - Point light source in ∞
  - Specified by direction

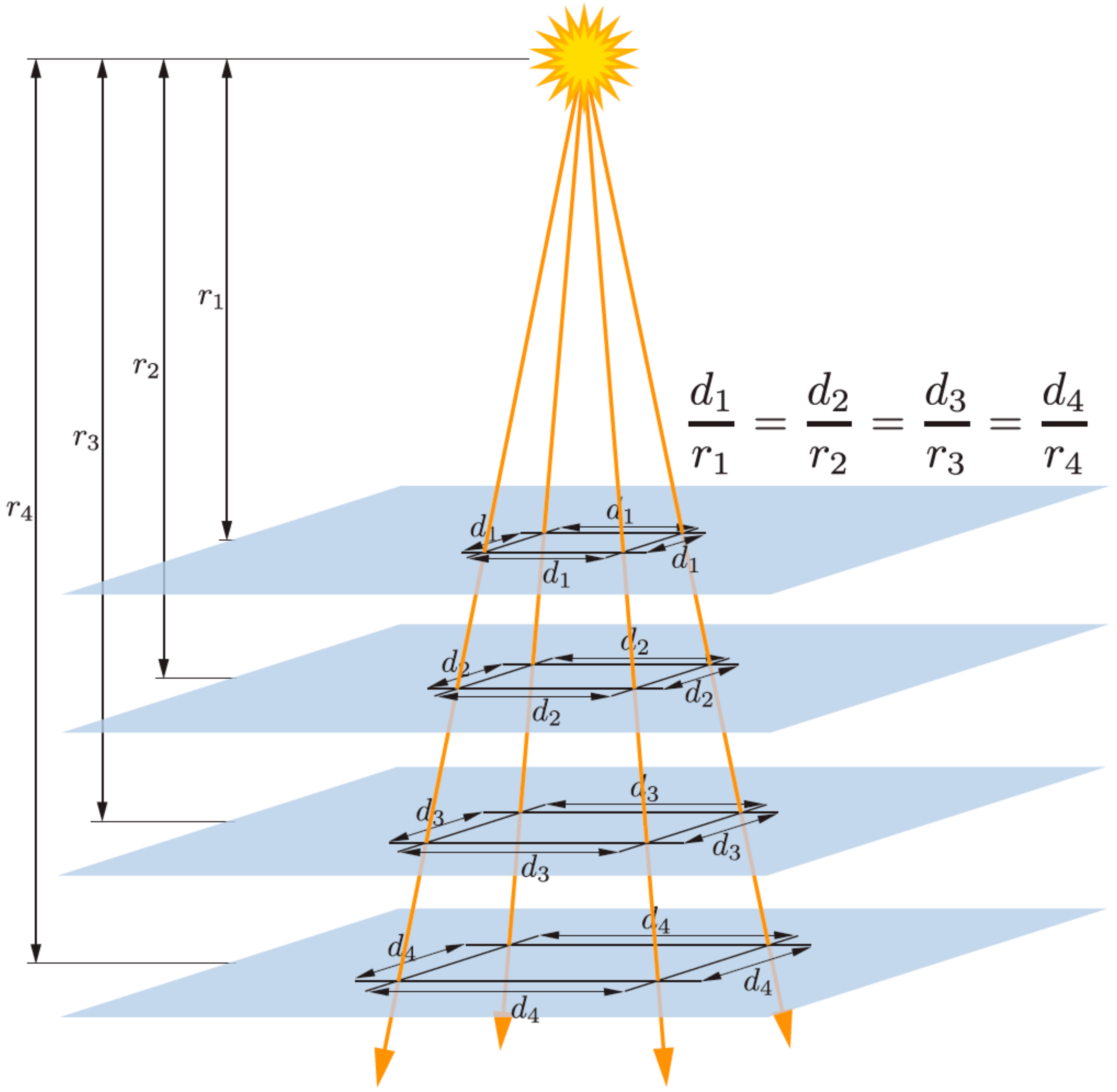


Spot Light Sources

- Preferred direction of radiation
- Generates a light cone
- Specified by its position p, direction d and opening angle θ_L
- Maximal intensity in direction d
- Otherwise decreasing intensity:
  (similar to specular reflection)
  - $I'(\theta) = \cos^k \theta \cdot I$
  - $I'(\theta) = 0$ if $\theta > \theta_L$



Distance Attenuation



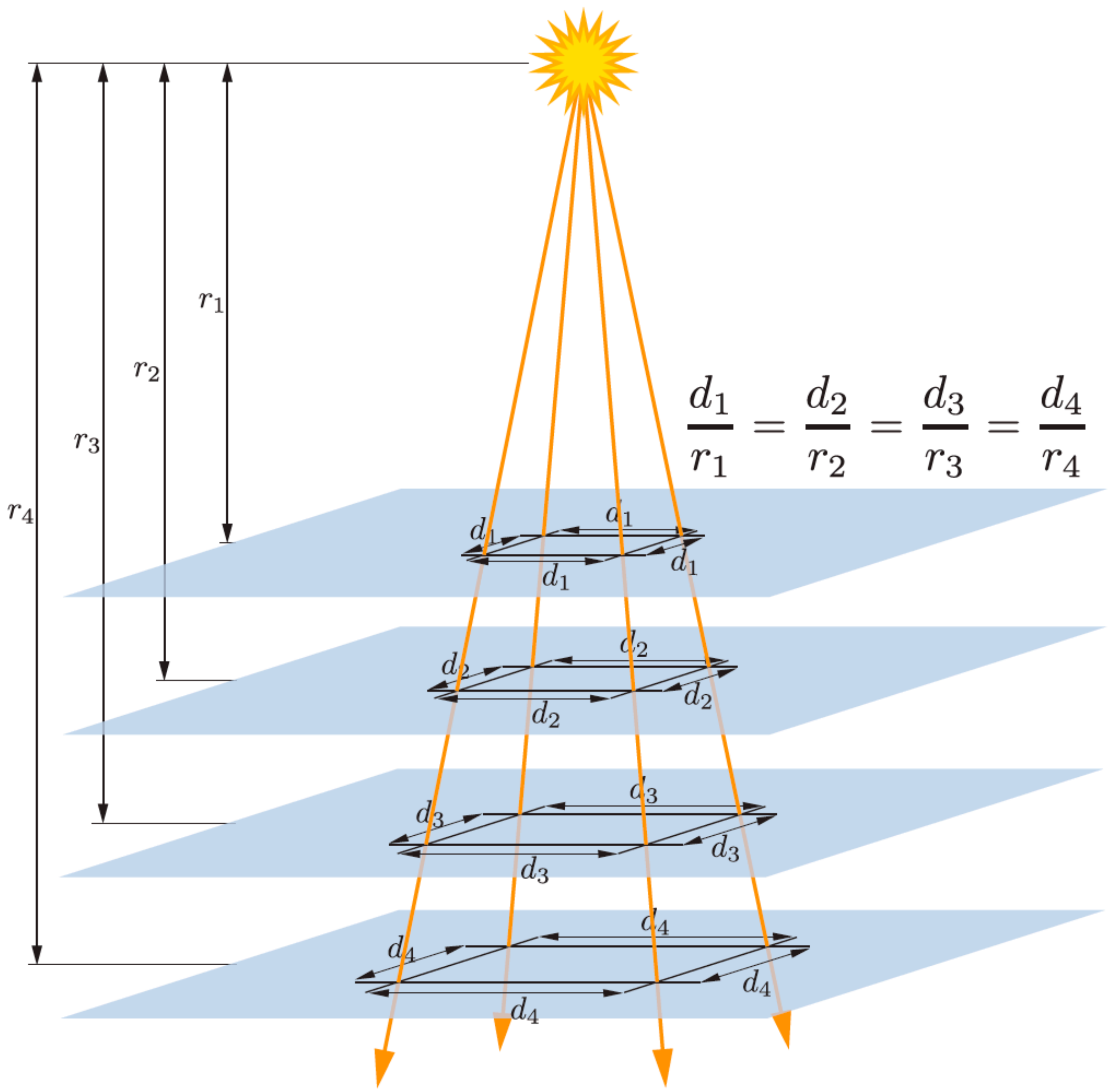
$$\frac{d_1}{r_1} = \frac{d_2}{r_2} = \frac{d_3}{r_3} = \frac{d_4}{r_4}$$

Distance Attenuation

- Light intensity attenuation is proportional to r^2
- Do you see why there is no attenuation for directional light?

$$\text{att}(r) = \frac{1}{r^2}$$

Problem with distances close to 0!

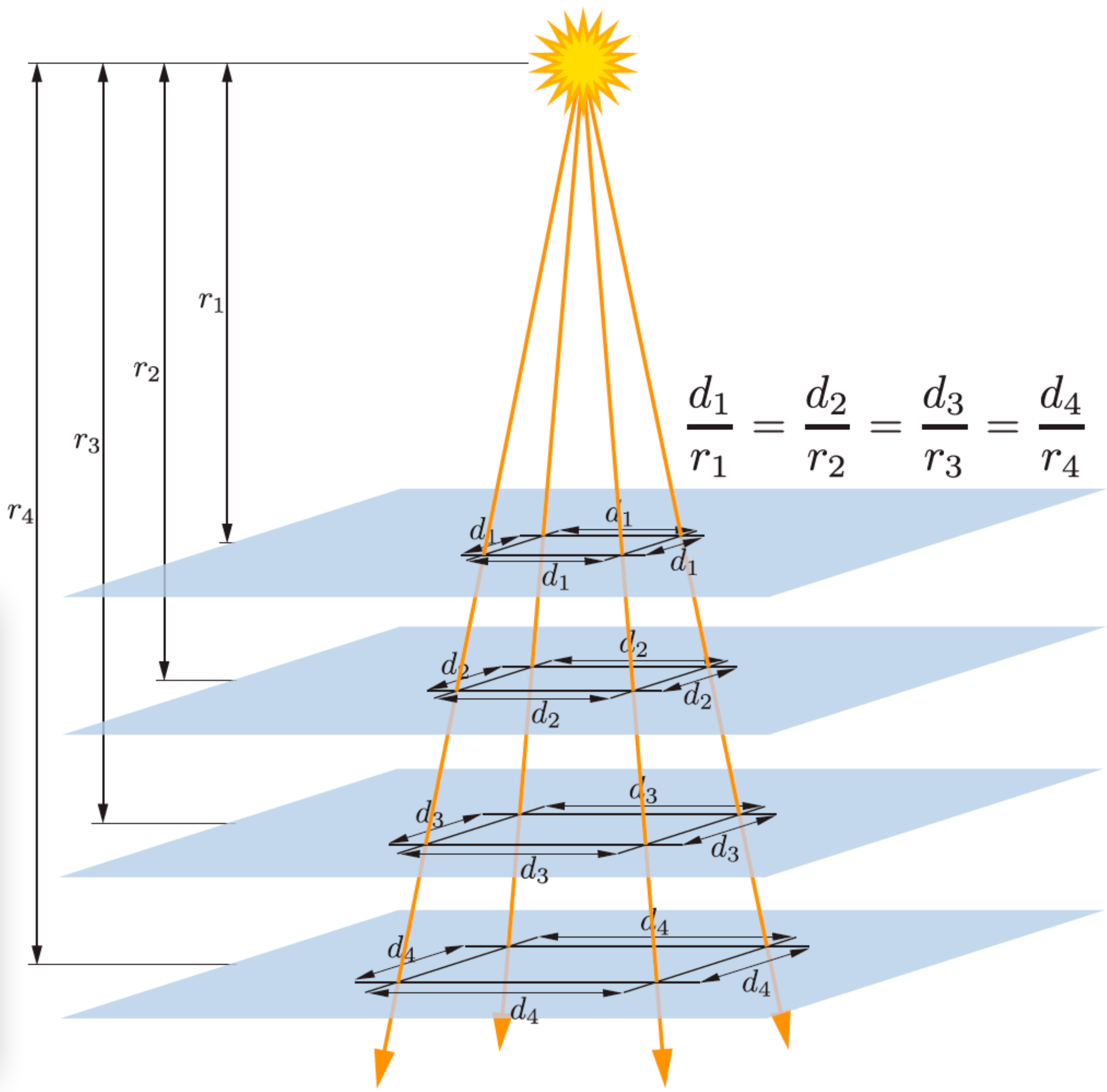


Distance Attenuation

- Light intensity attenuation is proportional to r^2
- Do you see why there is no attenuation for directional light?

$$\text{att}(r) = \frac{1}{\max(r, r_{\min})^2} \qquad \text{att}(r) = \frac{1}{a_1 + a_2 r + a_3 r^2}$$

$r_{\min}$, a_1, a_2, a_3 — extra parameters

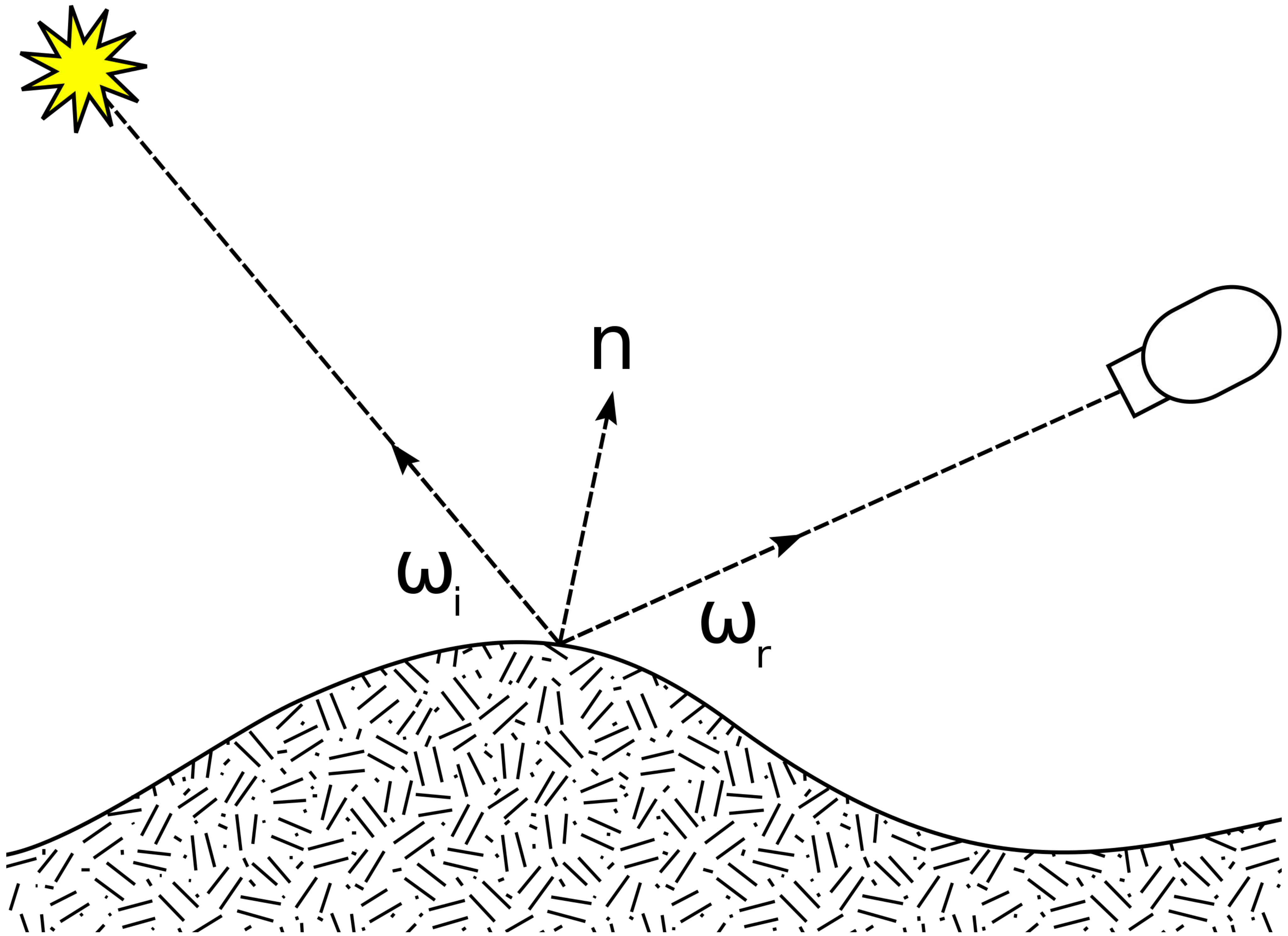


Extended Phong model:

$$I = I_e + \rho_a \cdot I_a + \sum_{j=1}^{n} \left(\rho_d \cdot \cos \phi_j + \rho_s \cdot \cos^k \alpha_j \right) \cdot I_j \cdot \text{att}(d)$$

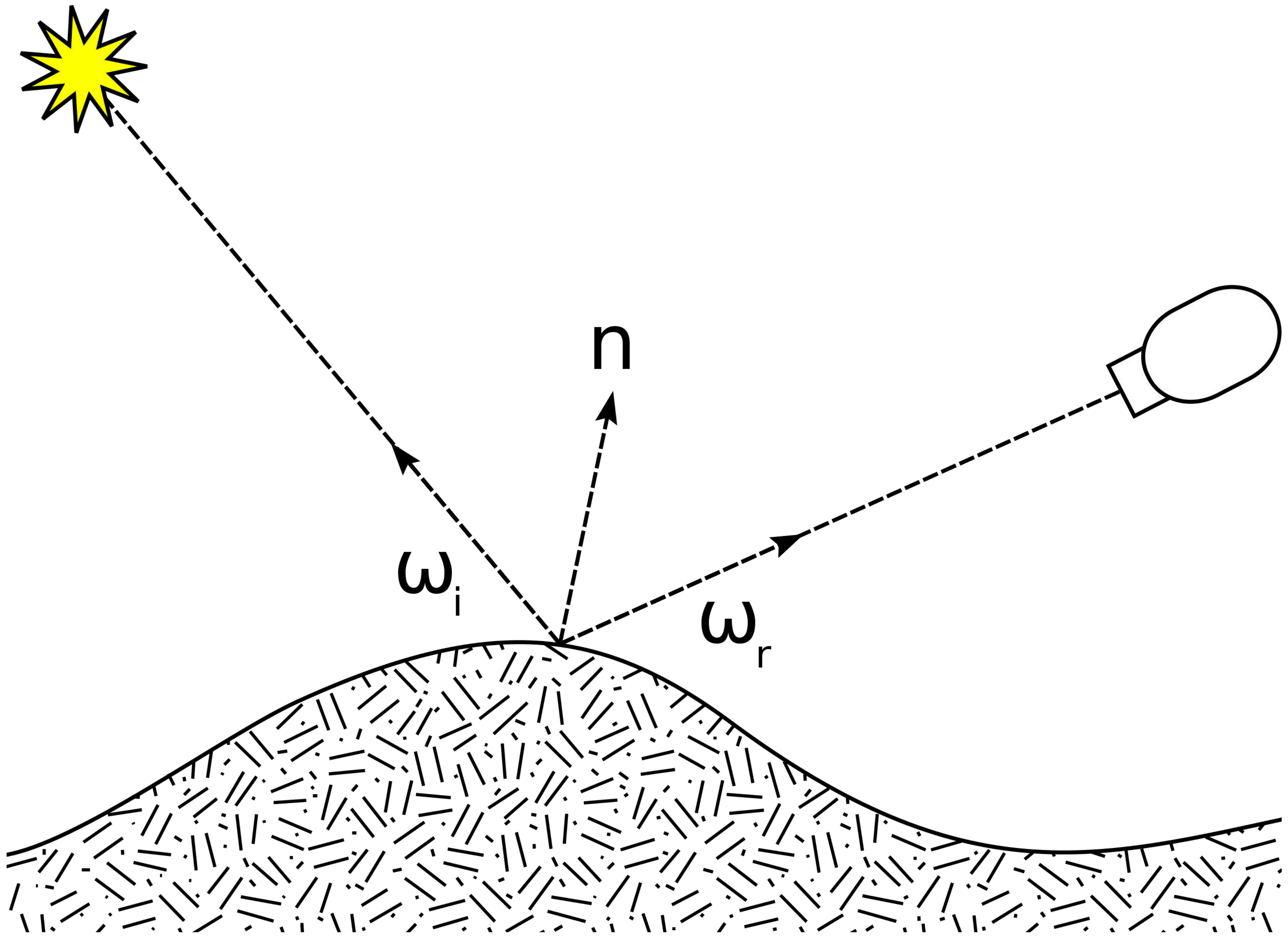
Beyond Simple Models

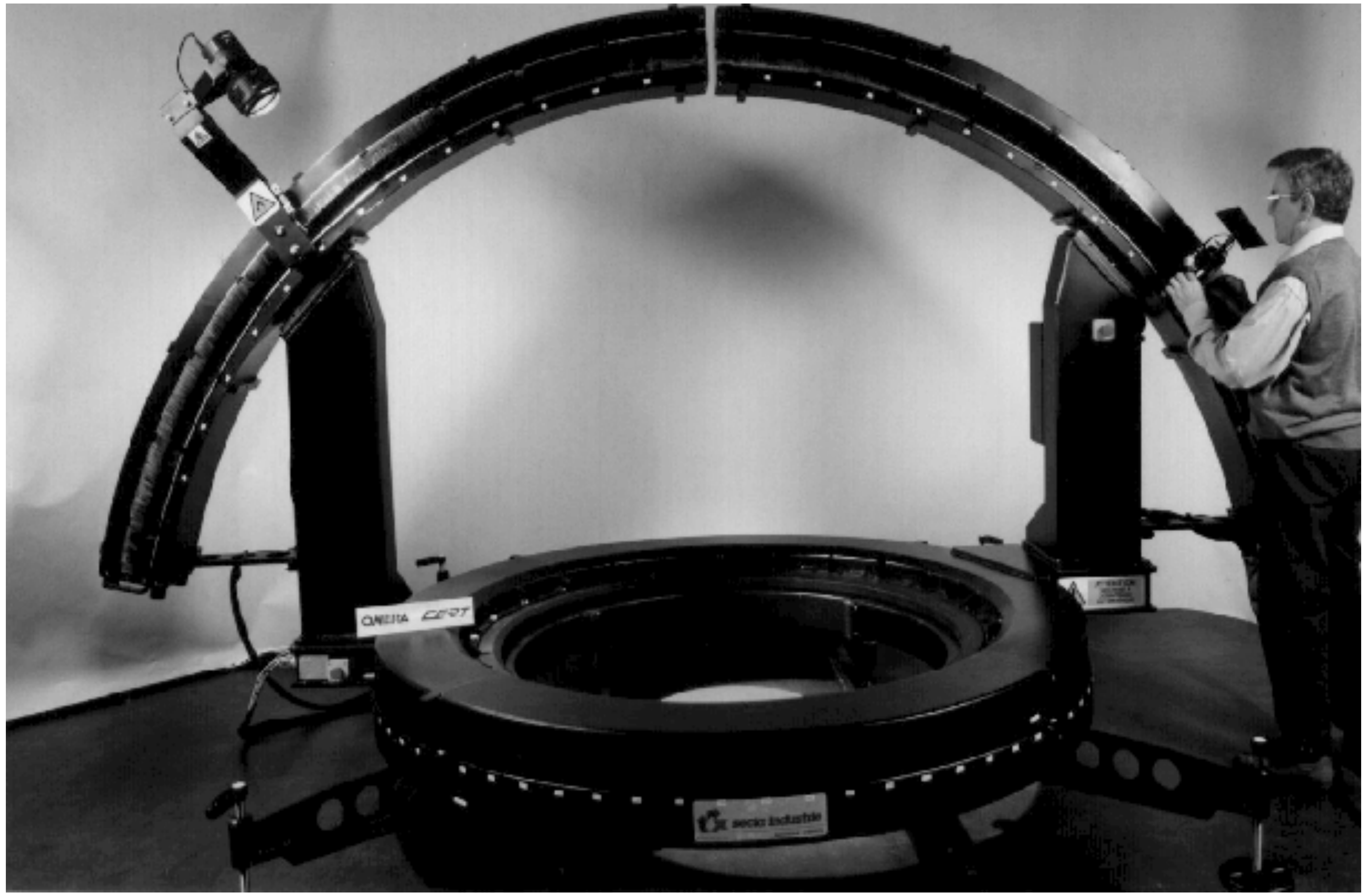
- Bidirectional Reflectance Distribution Function (BRDF)



Beyond Simple Models

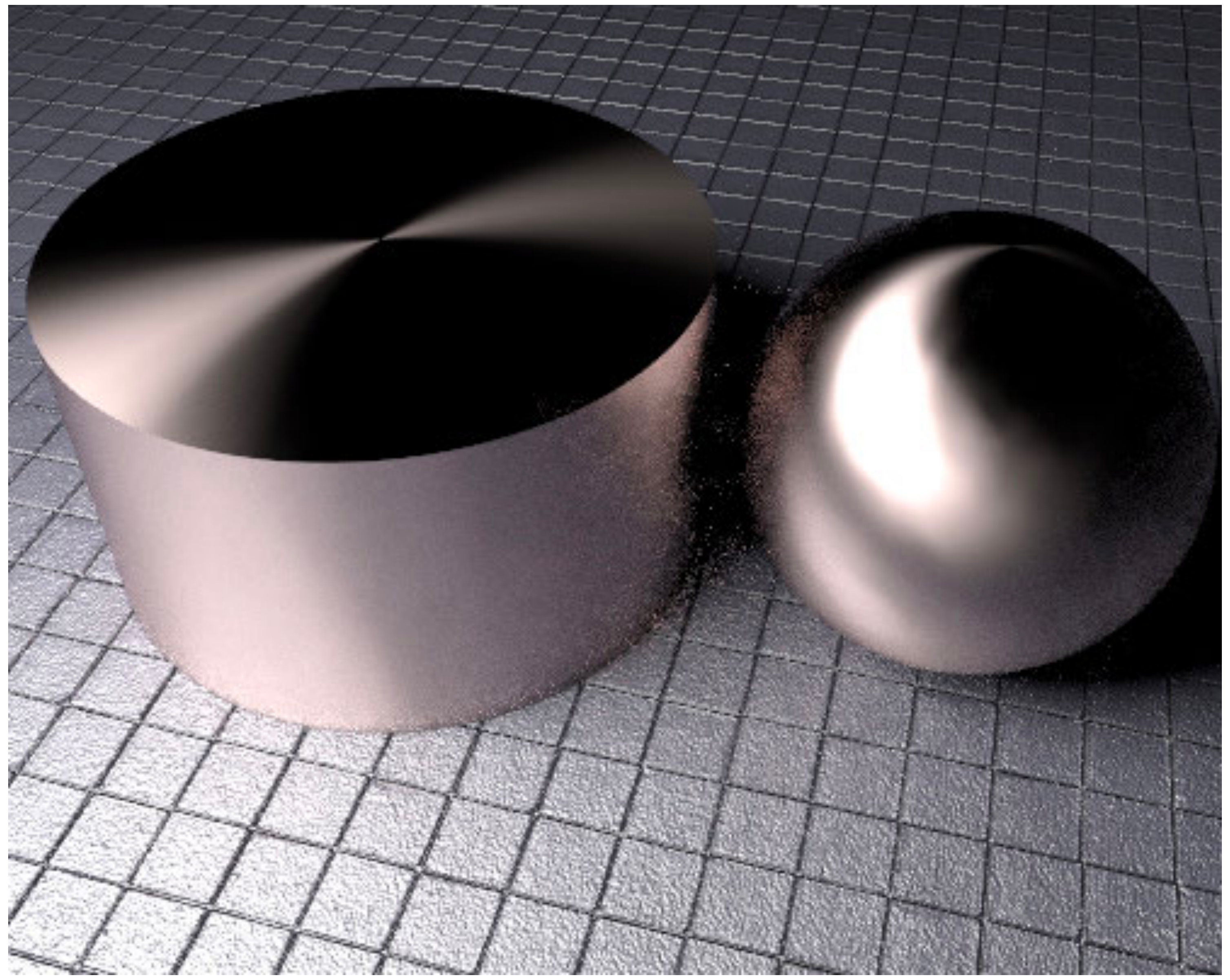
- Bidirectional Reflectance Distribution Function (BRDF)

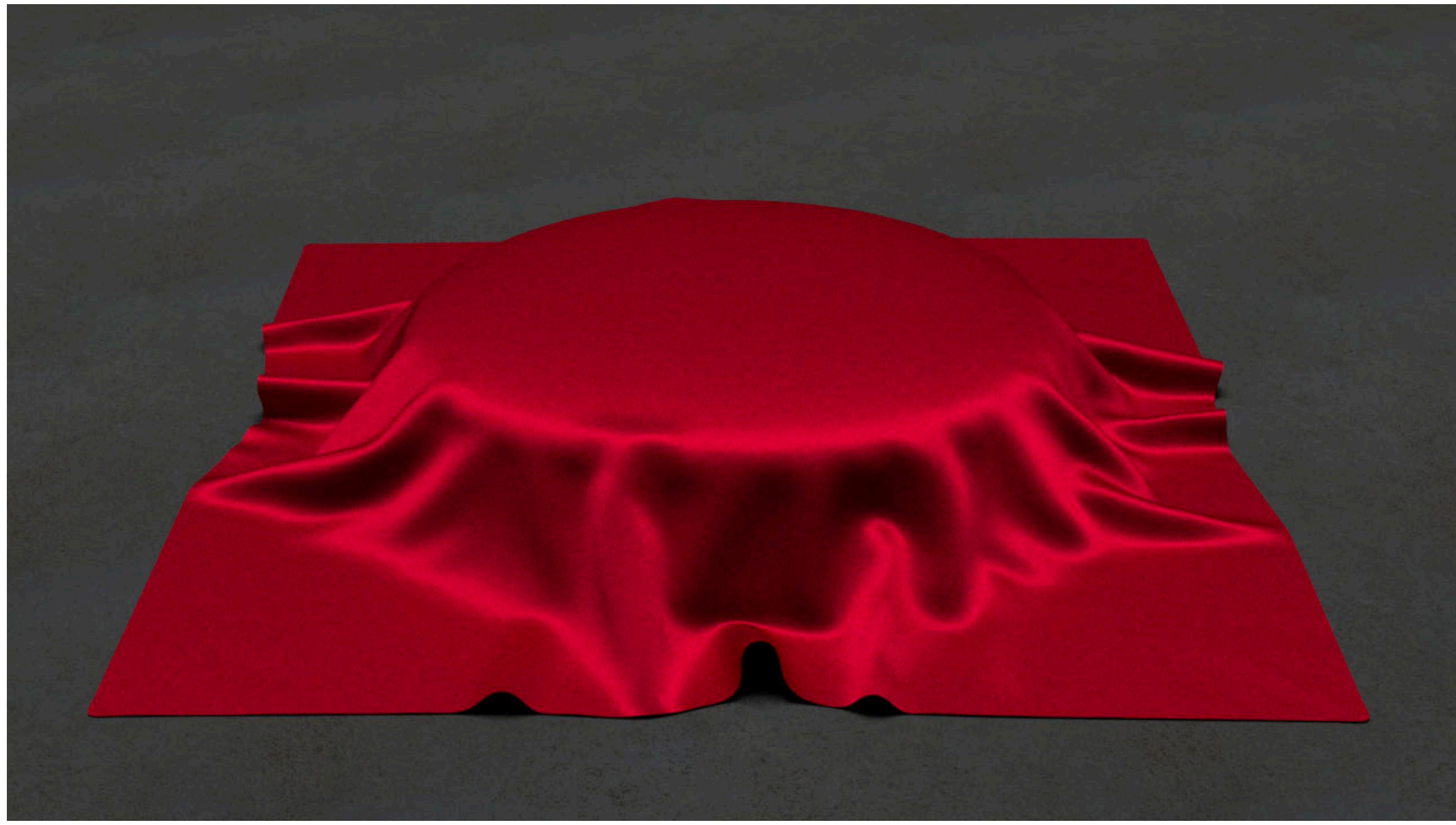




Beyond Simple Models

- Phong model allow obtaining plastic-like look
- More complex models (not too difficult):
  - Cook–Torrance model
  - Ward model
  - …





Summary

- Intensity depends on:
  - Position and intensity of the light sources
  - Position of the viewer
  - Position and normal of the surface point p
  - Several parameters (reflections constants, etc.)
  - Angles and distances
- When computing illumination:
  - Direction vectors have to be normalized
  - Handle the case when cosines are negative
  - Each color channel can be treated independently, lights may have color!

Questions?