Basic Principles of Surface Reflectance

Thanks to Shree Nayar, Ravi Ramamoorthi, Pat Hanrahan

Surface Appearance

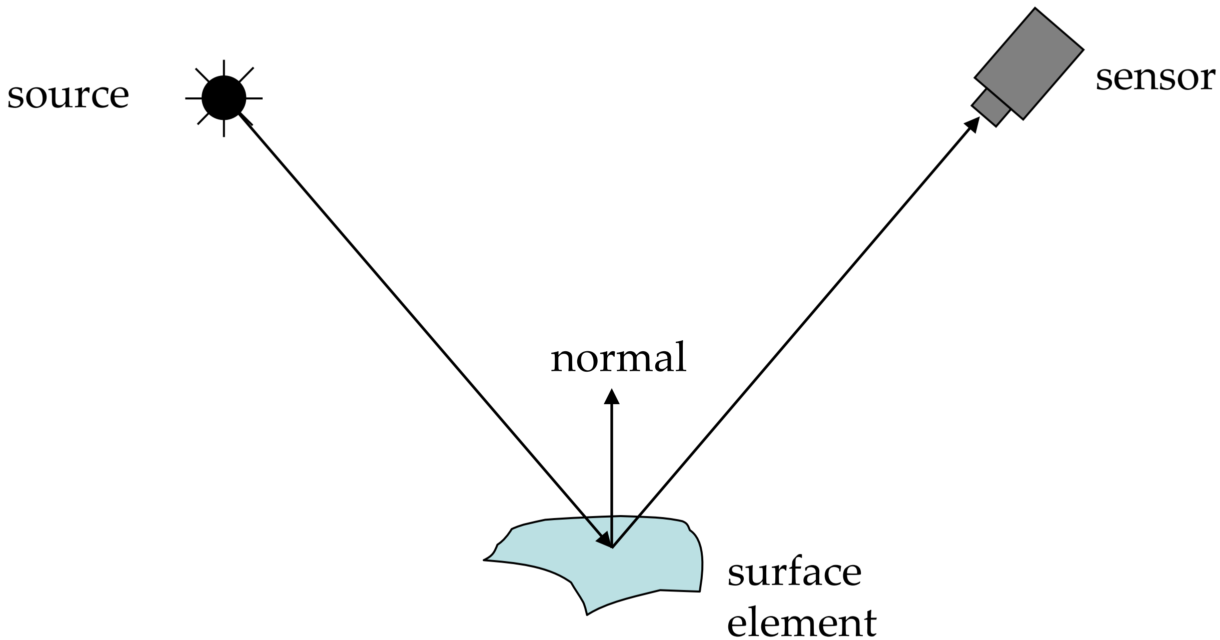
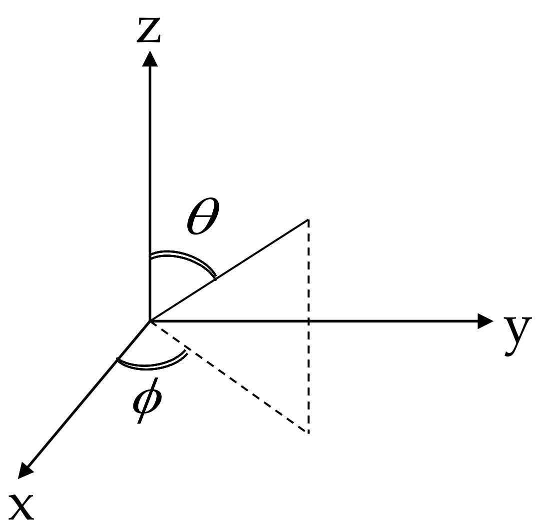
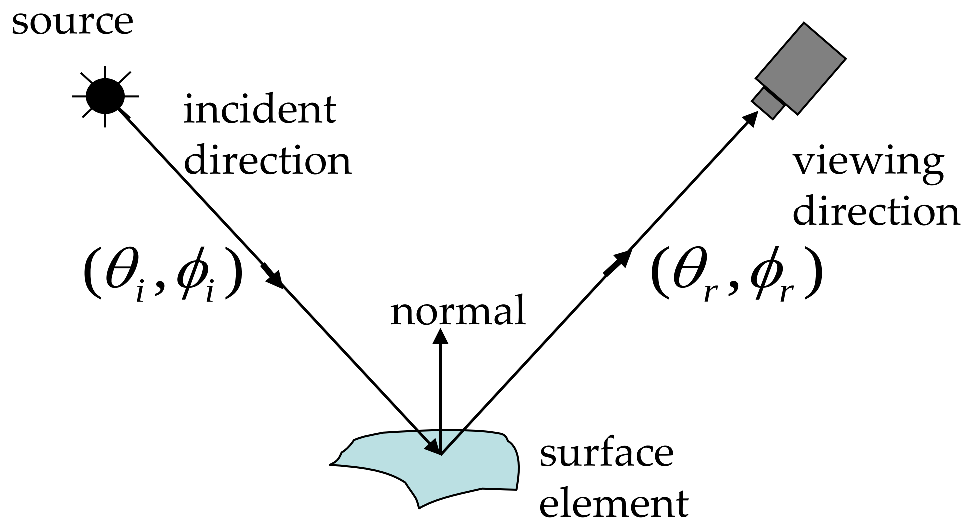


Image intensities = f (normal, surface reflectance, illumination)

Surface Reflection depends on both the viewing and illumination direction.

BRDF: Bidirectional Reflectance Distribution Function



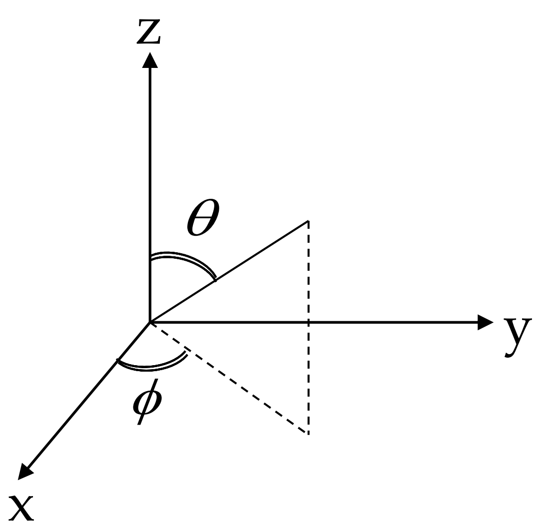


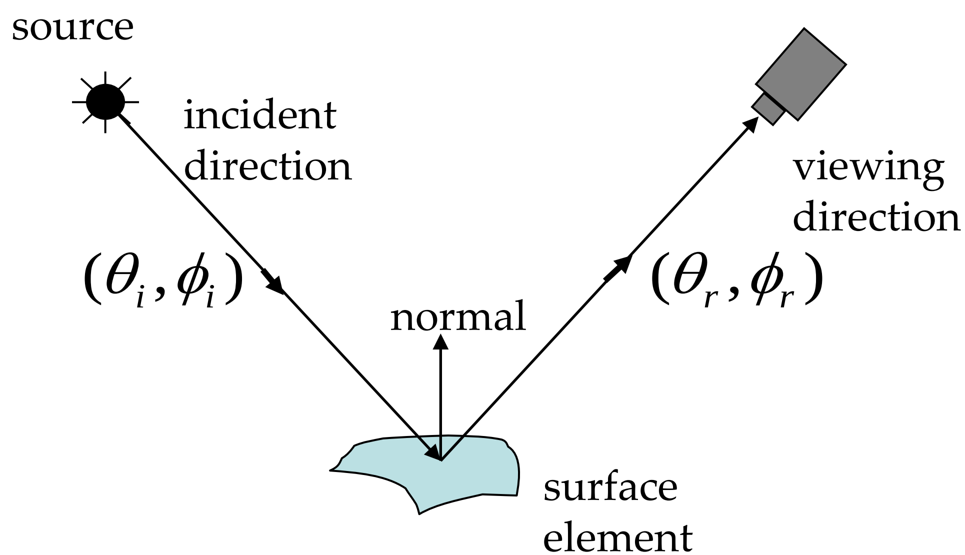
$E^{surface}(\theta_i, \phi_i)$ Irradiance at Surface in direction (θ_i, ϕ_i)

$L^{surface}(\theta_r, \phi_r)$ Radiance of Surface in direction (θ_r, ϕ_r)

$$\text{BRDF}: f(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{L^{surface}(\theta_r, \phi_r)}{E^{surface}(\theta_i, \phi_i)}$$

Important Properties of BRDFs





- Rotational Symmetry:

  Appearance does not change when surface is rotated about the normal.

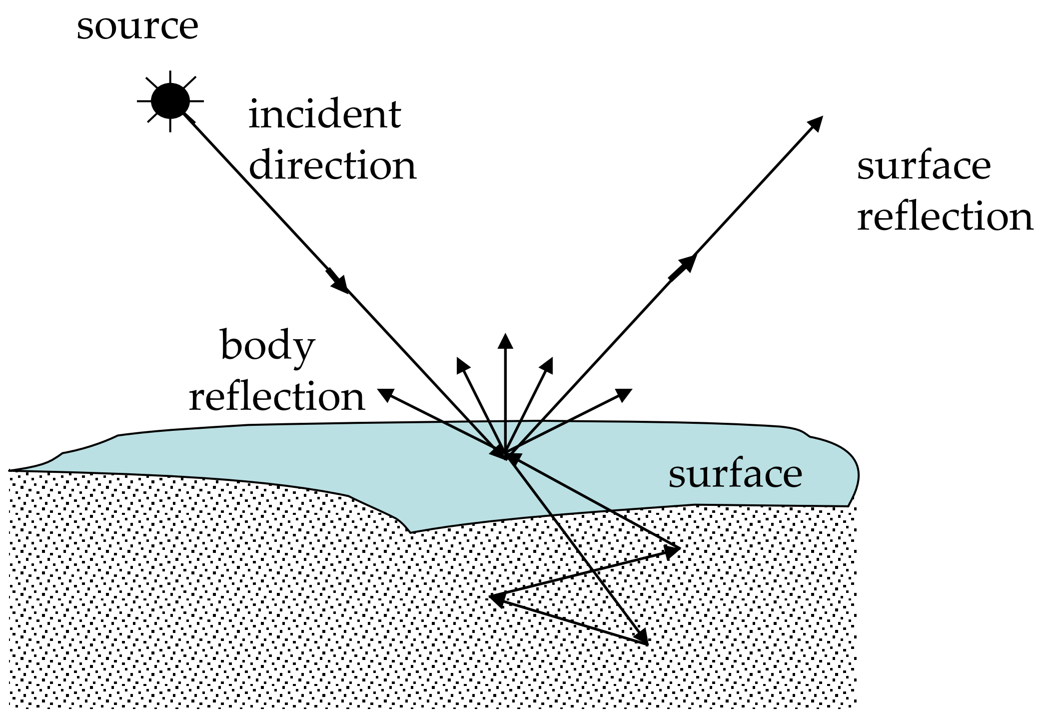
  BRDF is only a function of 3 variables : $f(\theta_i, \theta_r, \phi_i - \phi_r)$

- Helmholtz Reciprocity: (follows from 2^{nd} Law of Thermodynamics)

  Appearance does not change when source and viewing directions are swapped.

$$f(\theta_i, \phi_i; \theta_r, \phi_r) \quad = \quad f(\theta_r, \phi_r; \theta_i, \phi_i)$$

Mechanisms of Surface Reflection



Body Reflection:

Diffuse Reflection
Matte Appearance
Non-Homogeneous Medium
Clay, paper, etc

Surface Reflection:

Specular Reflection
Glossy Appearance
Highlights
Dominant for Metals

Image Intensity = Body Reflection + Surface Reflection

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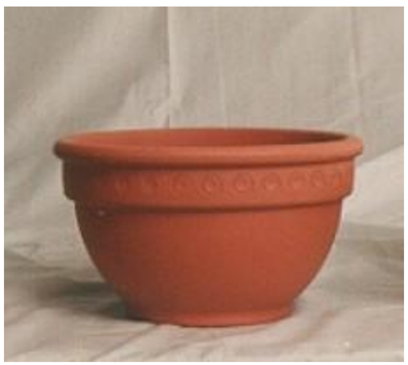

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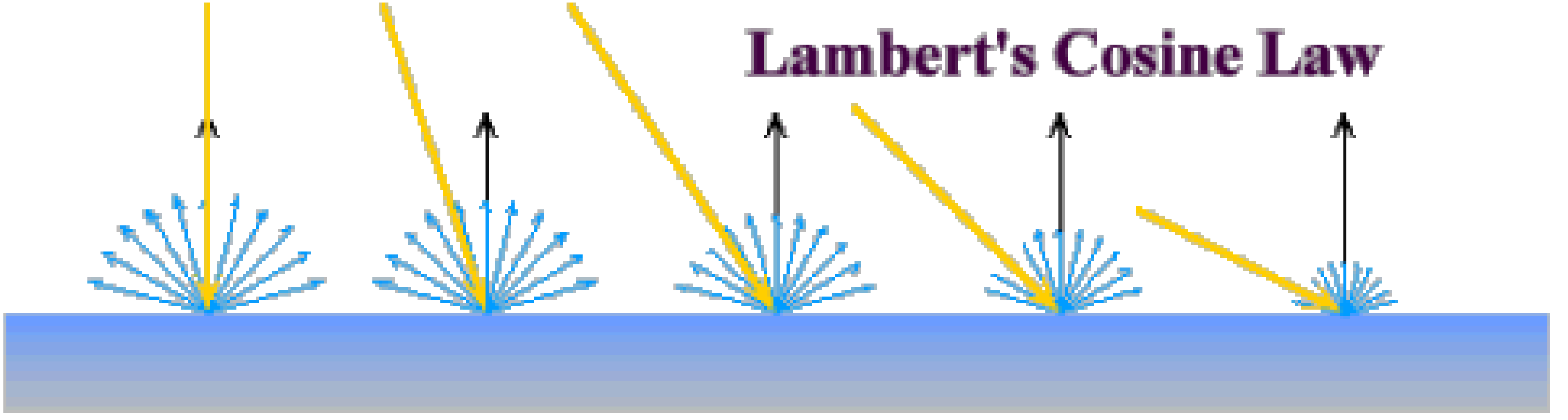
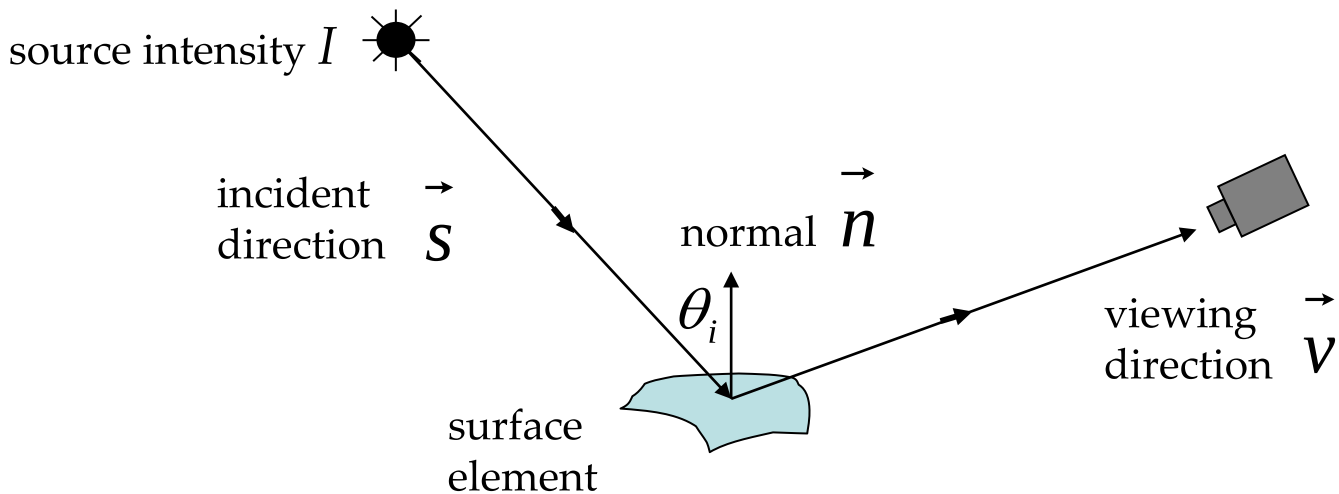
Specular Reflection
Glossy Appearance
Highlights
Dominant for Metals

Many materials exhibit both Reflections:

Diffuse Reflection and Lambertian BRDF



Diffuse Reflection and Lambertian BRDF



- Surface appears equally bright from ALL directions! (independent of $\vec{v}$)

- Lambertian BRDF is simply a constant : $f(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{\rho_d}{\pi}$ (albedo: ρ_d)

- Surface Radiance : $L = \frac{\rho_d}{\pi} I \cos\theta_i = \frac{\rho_d}{\pi} I \; \vec{n} \cdot \vec{s}$ (source intensity: I)

- Commonly used in Vision and Graphics!

Rendered Sphere with Lambertian BRDF

- Edges are dark (N.S = 0) when lit head-on
- See shading effects clearly.

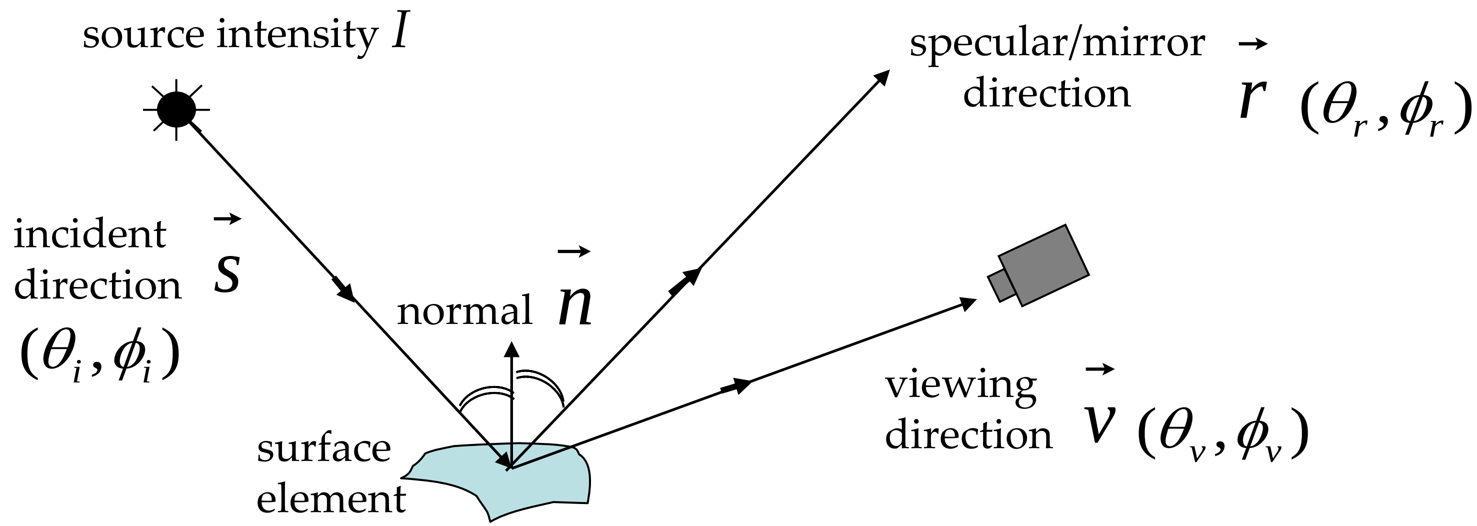
White-out Conditions from an Overcast Sky

CAN'T perceive the shape of the snow covered terrain!

CAN perceive shape in regions lit by the street lamp!!

WHY?

Specular Reflection and Mirror BRDF



- Very smooth surface.
- All incident light energy reflected in a SINGLE direction. (only when $\vec{v} = \vec{r}$)
- Mirror BRDF is simply a double-delta function :

specular albedo

$$f(\theta_i, \phi_i; \theta_v, \phi_v) = \rho_s\ \delta(\theta_i - \theta_v)\ \delta(\phi_i + \pi - \phi_v)$$

- Surface Radiance : $L = I\ \rho_s\ \delta(\theta_i - \theta_v)\ \delta(\phi_i + \pi - \phi_v)$

Glossy Surfaces

- Delta Function too harsh a BRDF model
  (valid only for highly polished mirrors and metals).

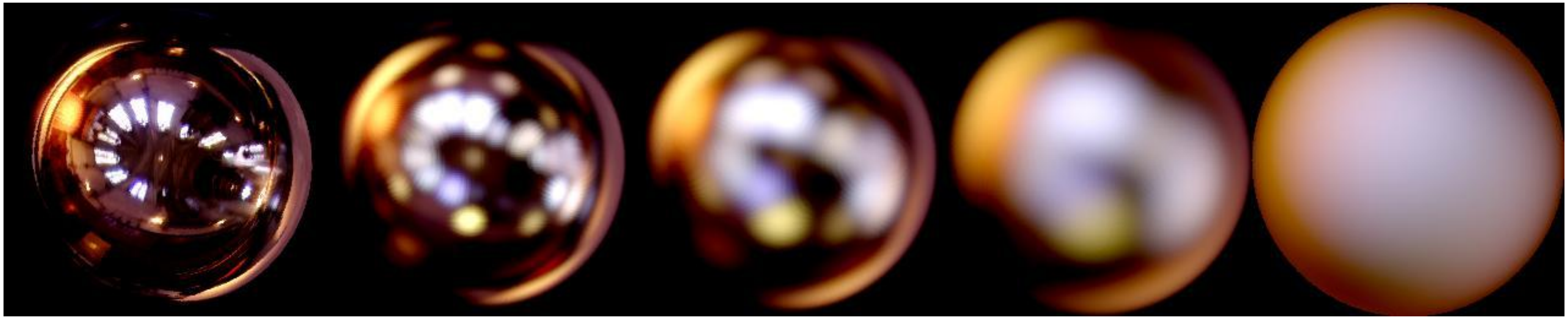
- Many glossy surfaces show broader highlights in addition to mirror reflection.


- Surfaces are not perfectly smooth – they show micro-surface geometry (roughness).

- Example Models : Phong model

  Torrance Sparrow model

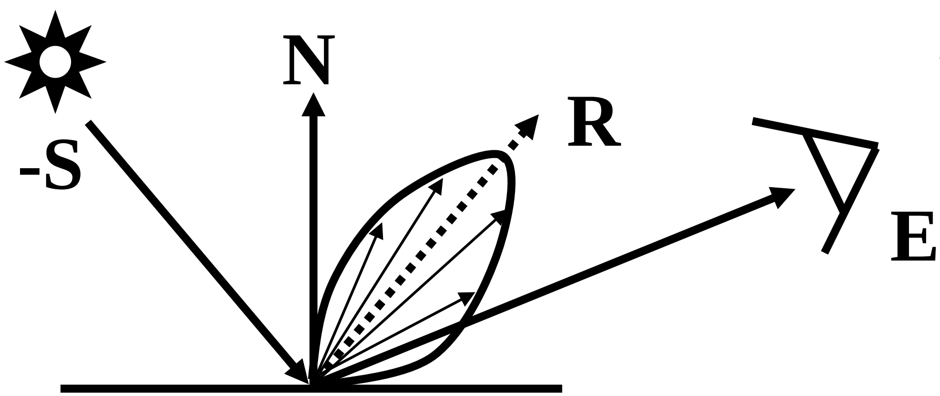
Blurred Highlights and Surface Roughness

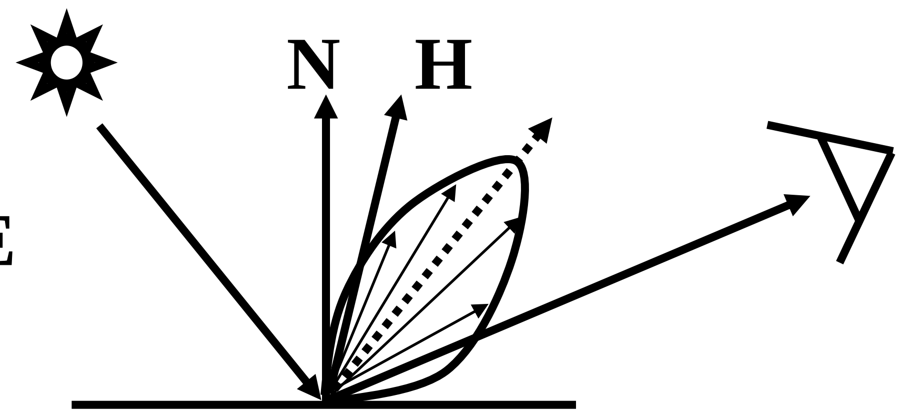


Roughness

Phong Model: An Empirical Approximation

- How to model the angular falloff of highlights:





$$L = I\ \rho_s\ (R.E)^{n_{shiny}}$$

$$R = -S + 2(N.S)N$$

Phong Model

$$L = I\ \rho_s\ (N.H)^{n_{shiny}}$$

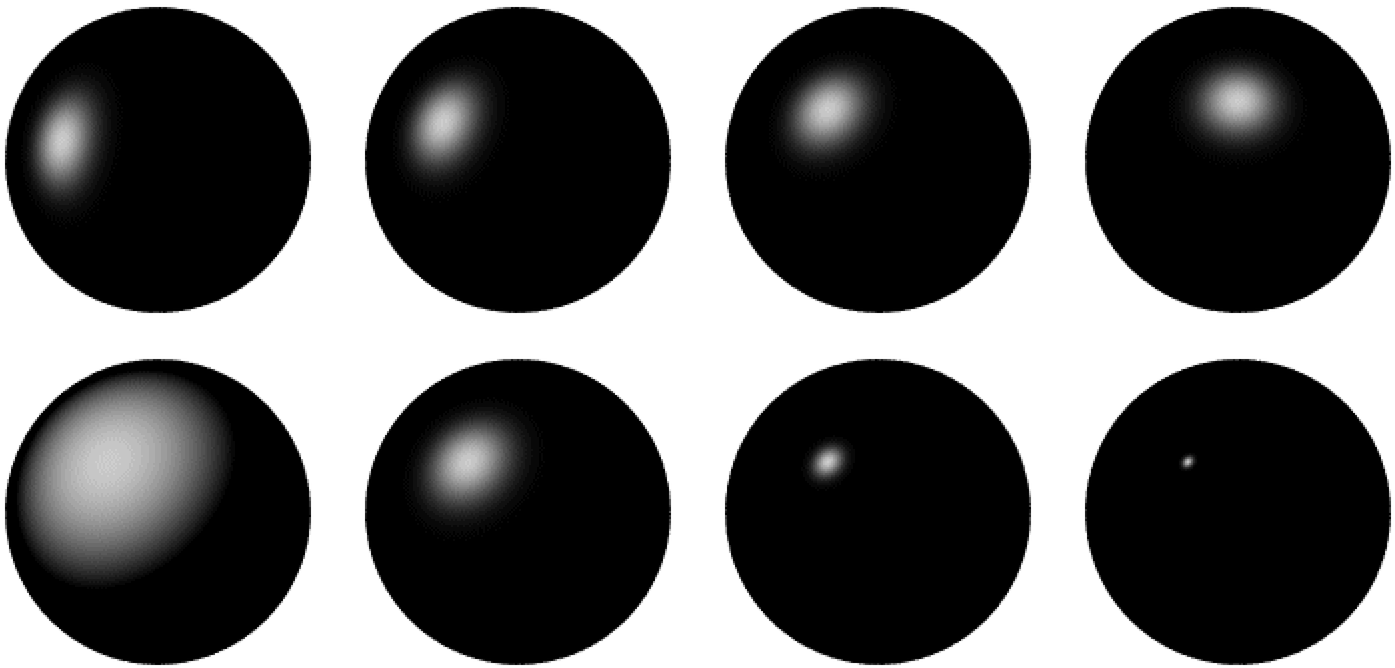
$$H = (E + S)/2$$

Blinn-Phong Model

- Sort of works, easy to compute
- But not physically based (no energy conservation and reciprocity).
- Very commonly used in computer graphics.

Phong Examples

- These spheres illustrate the Phong model as *lighting direction* and n_{shiny} are varied:

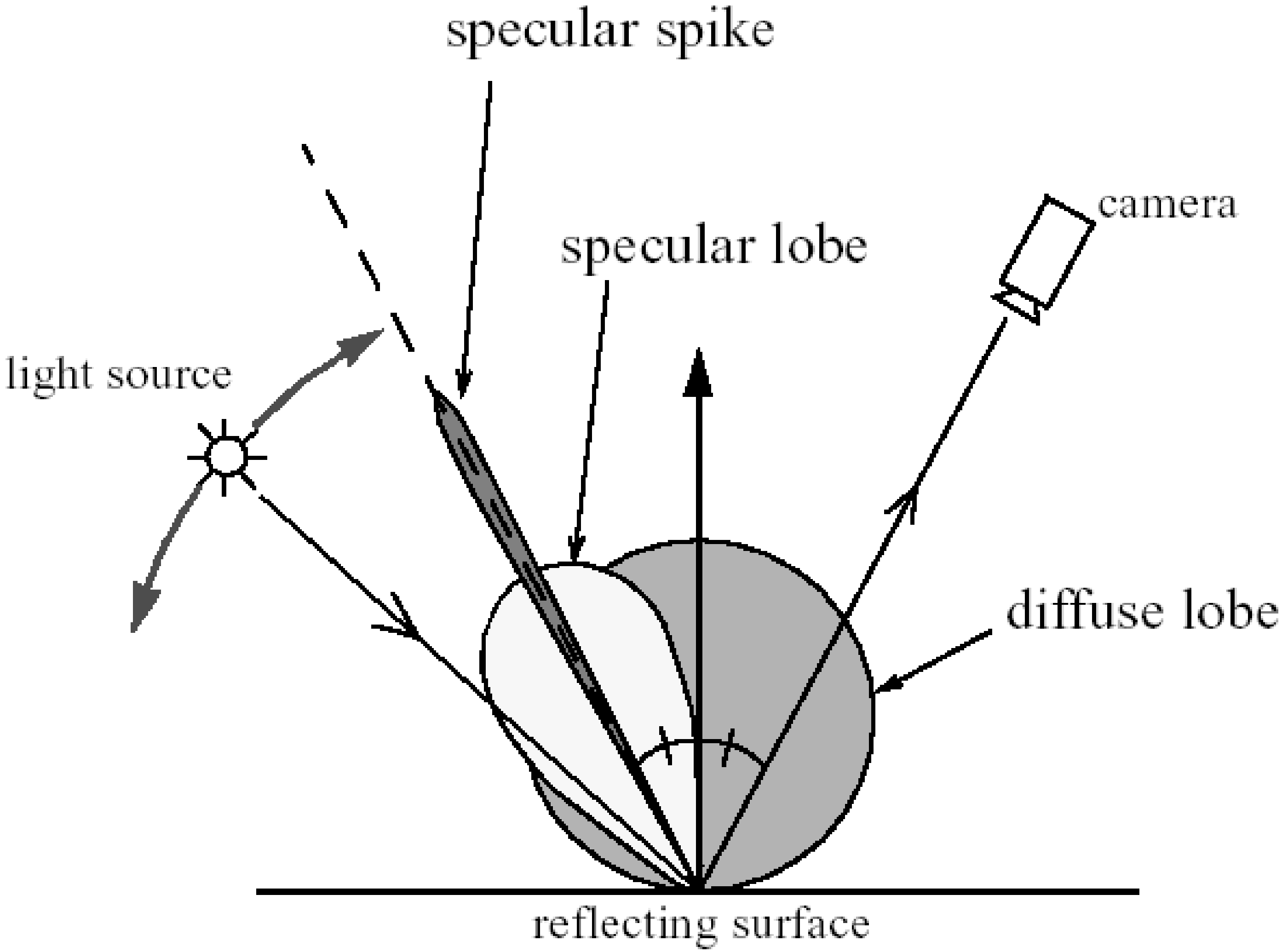


Those Were the Days

- "In trying to improve the quality of the synthetic images, we do not expect to be able to display the object exactly as it would appear in reality, with texture, overcast shadows, etc. We hope only to display an image that approximates the real object closely enough to provide a certain degree of realism."

  – Bui Tuong Phong, 1975

All components of Surface Reflection



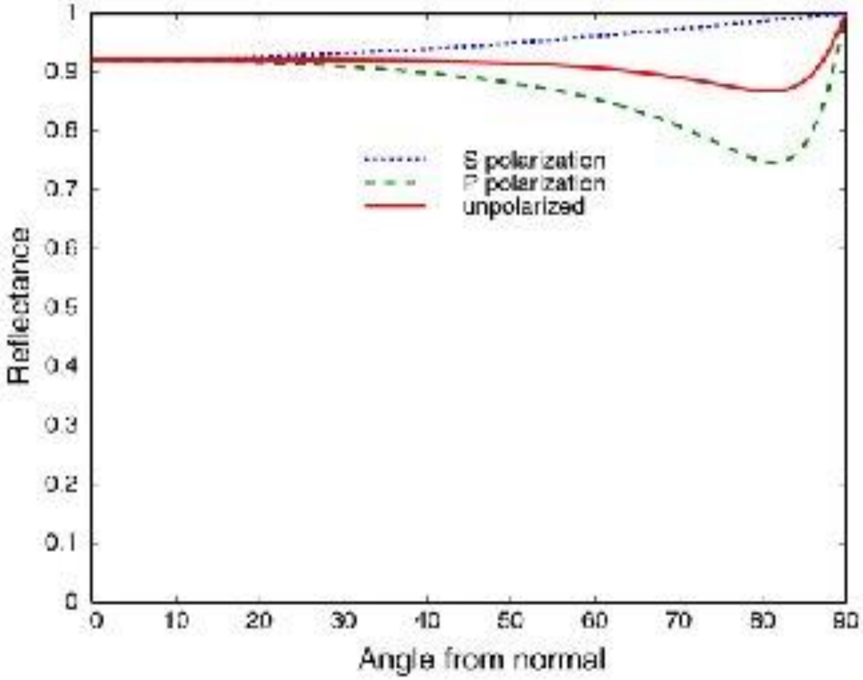
Experiment

Reflections from a shiny floor

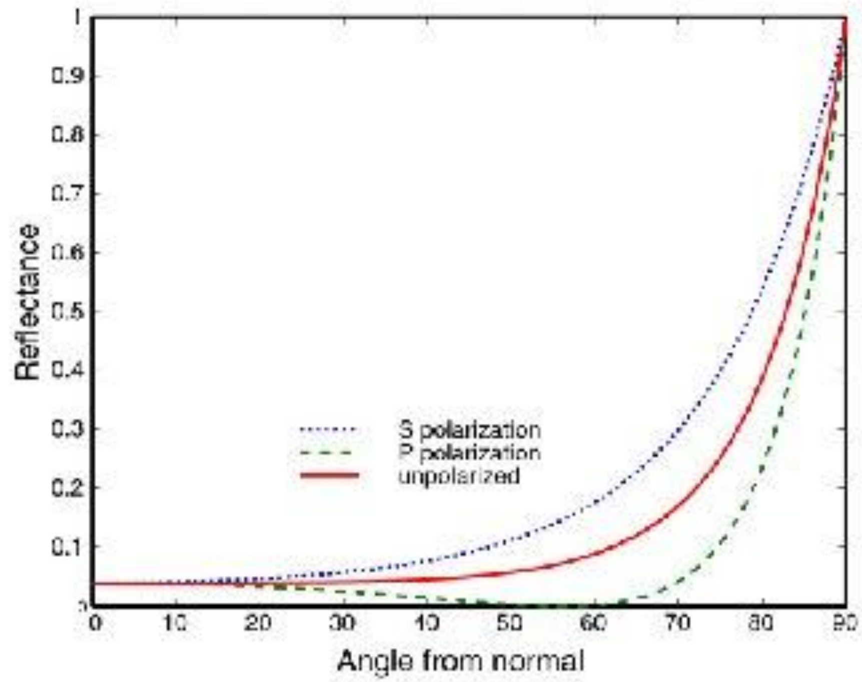
From Lafortune, Foo, Torrance, Greenberg, SIGGRAPH 97

Fresnel Reflectance

Metal (Aluminum)



Dielectric (N=1.5)

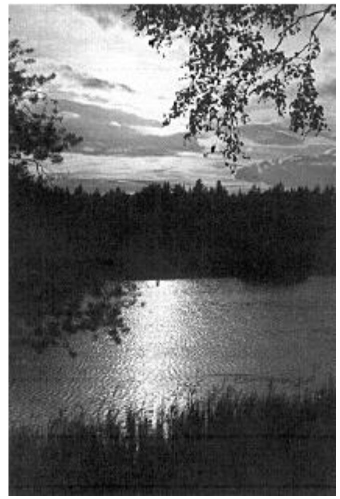


Gold F(0)=0.82
Silver F(0)=0.95

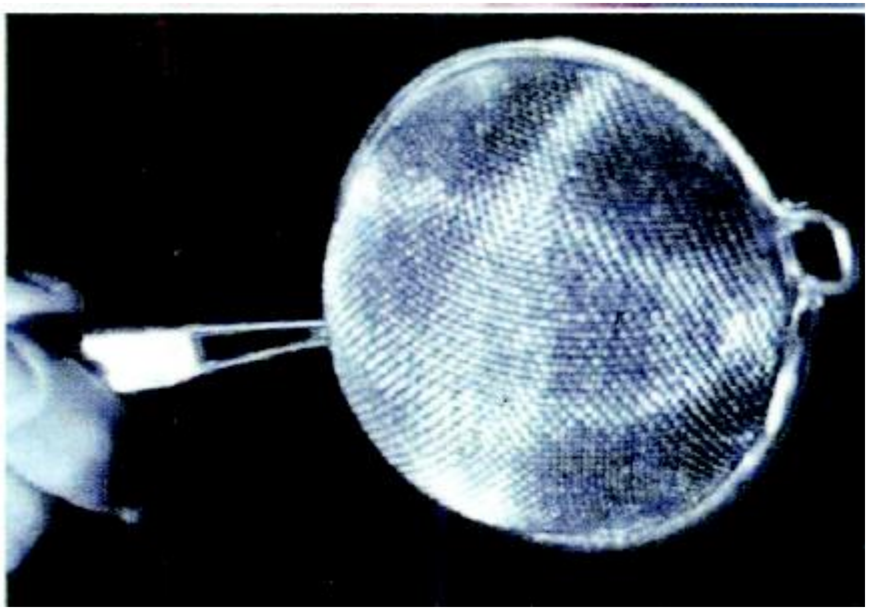
Glass n=1.5 F(0)=0.04
Diamond n=2.4 F(0)=0.15

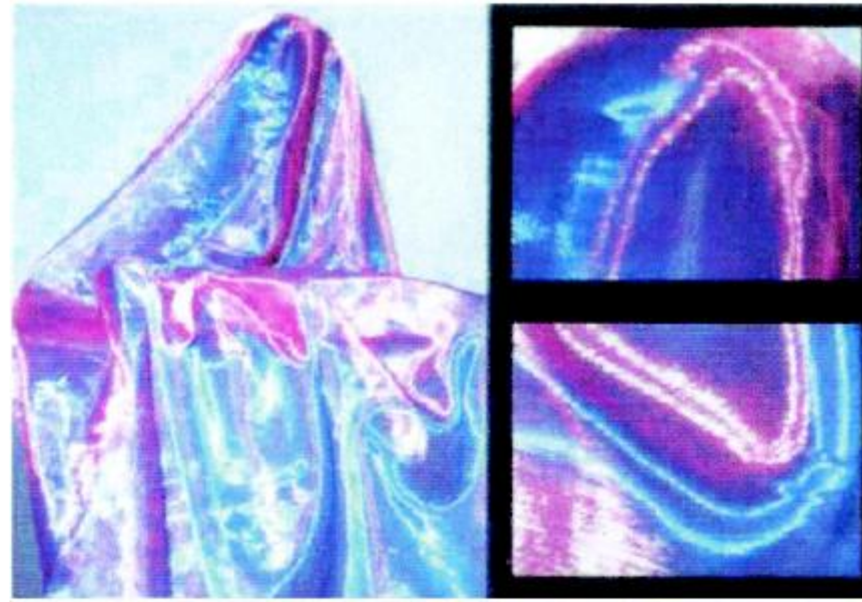
Schlick Approximation $F(\theta) = F(0) + (1 - F(0))(1 - \cos\theta)^5$

Reflections on water surfaces - Glittering



Split off-specular Reflections in Woven Surfaces



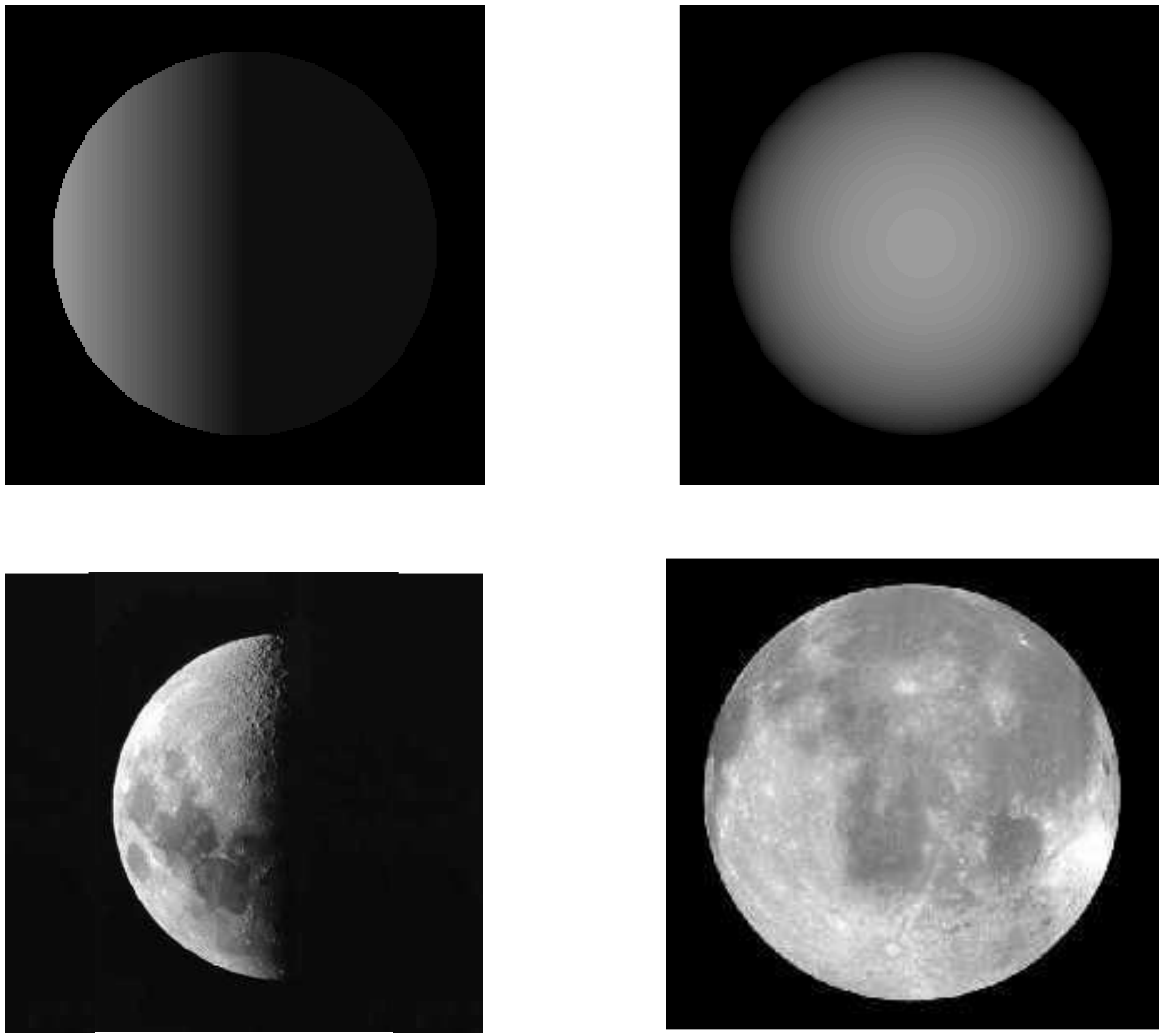


Why does the Full Moon have a flat appearance?

- The moon appears matte (or diffuse)

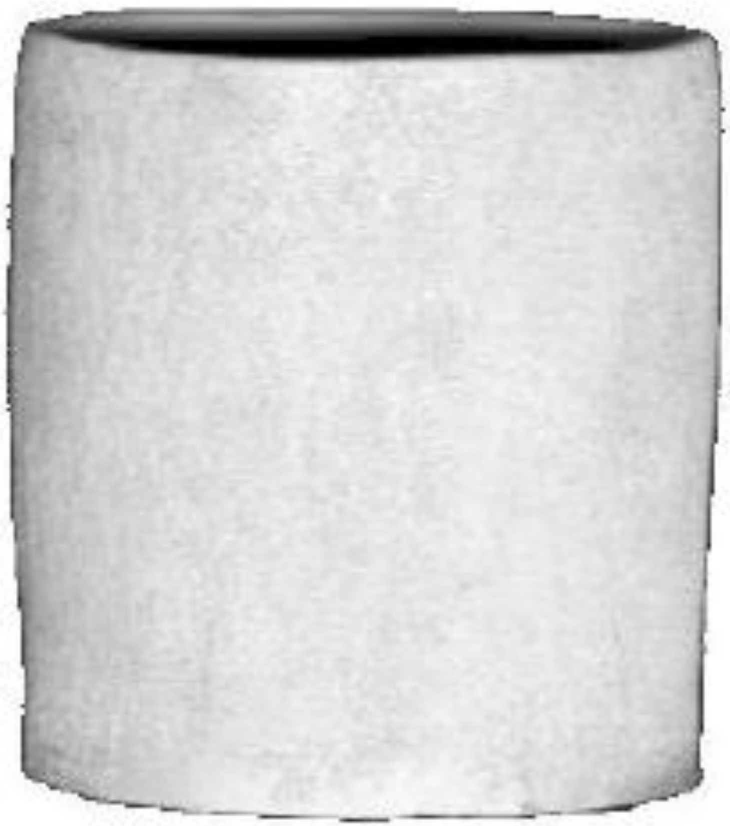
- But still, edges of the moon look bright (not close to zero) when illuminated by earth's radiance.

Why does the Full Moon have a flat appearance?



Lambertian Spheres and Moon Photos illuminated similarly

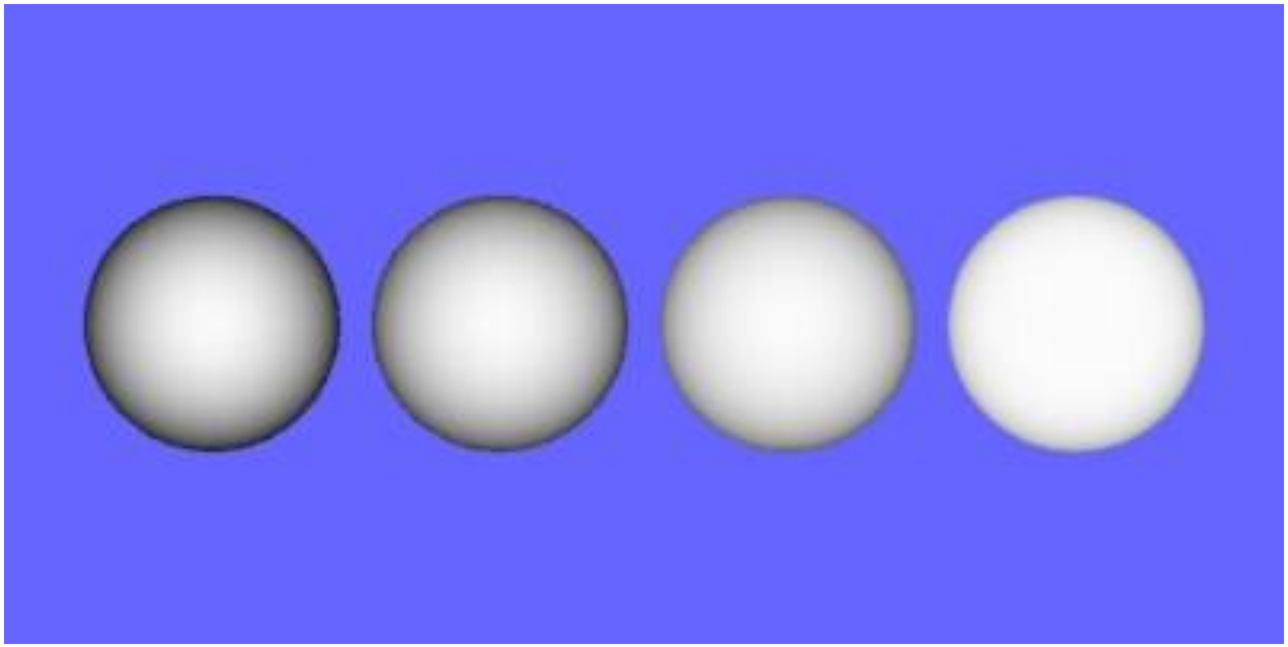
Surface Roughness Causes Flat Appearance



Actual Vase

Lambertian Vase

Surface Roughness Causes Flat Appearance



Increasing surface roughness →

Lambertian model

Valid for only SMOOTH MATTE surfaces.

Bad for ROUGH MATTE surfaces.

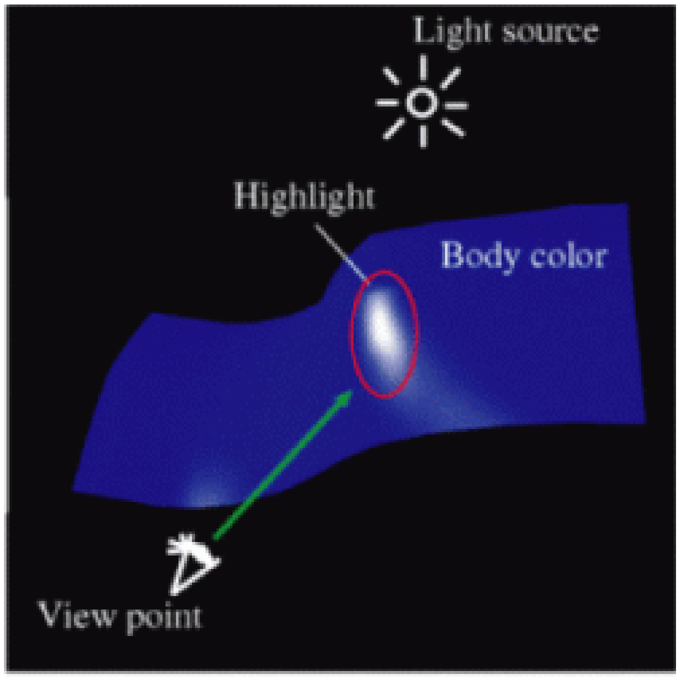
Oren-Nayar Model – Main Points

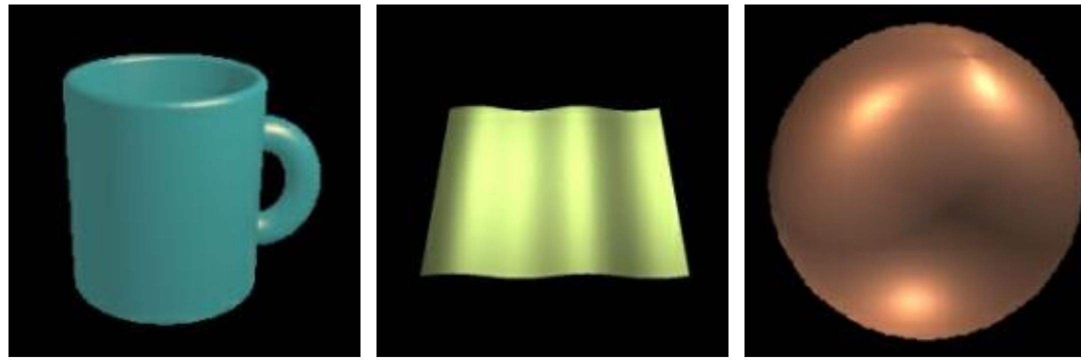
- Physically Based Model for Diffuse Reflection.
- Based on Geometric Optics.
- Explains view dependent appearance in Matte Surfaces
- Take into account partial interreflections.
- Roughness represented like in Torrance-Sparrow Model
- Lambertian model is simply an extreme case with roughness equal to zero.

A Simple Reflection Model - Dichromatic Reflection

Observed Image Color = a x Body Color + b x Specular Reflection Color

Klinker-Shafer-Kanade 1988





Does not specify any specific model for
Diffuse/specular reflection