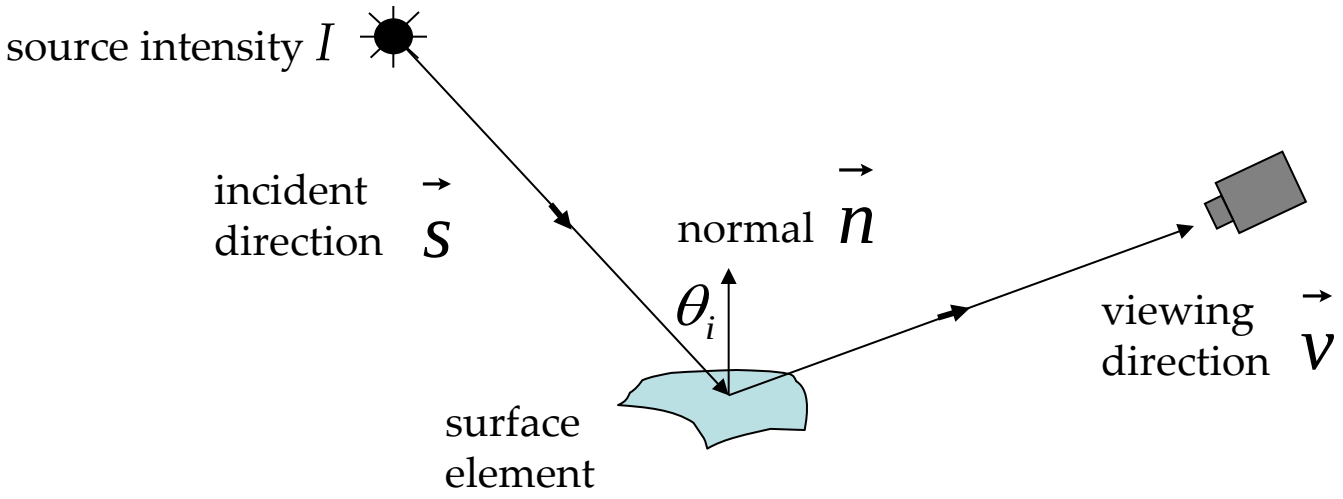
# Diffuse Reflections from Rough Surfaces

# Lecture #5

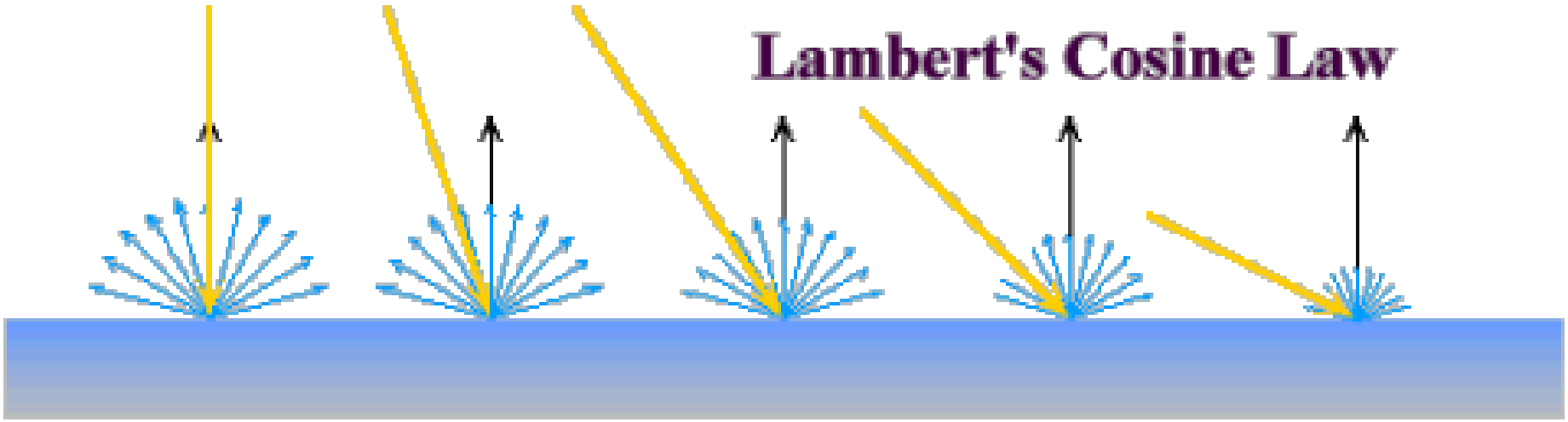
Thanks to Michael Oren, Shree Nayar, Ravi Ramamoorthi, Pat Hanrahan

# Diffuse Reflection and Lambertian BRDF - Recap



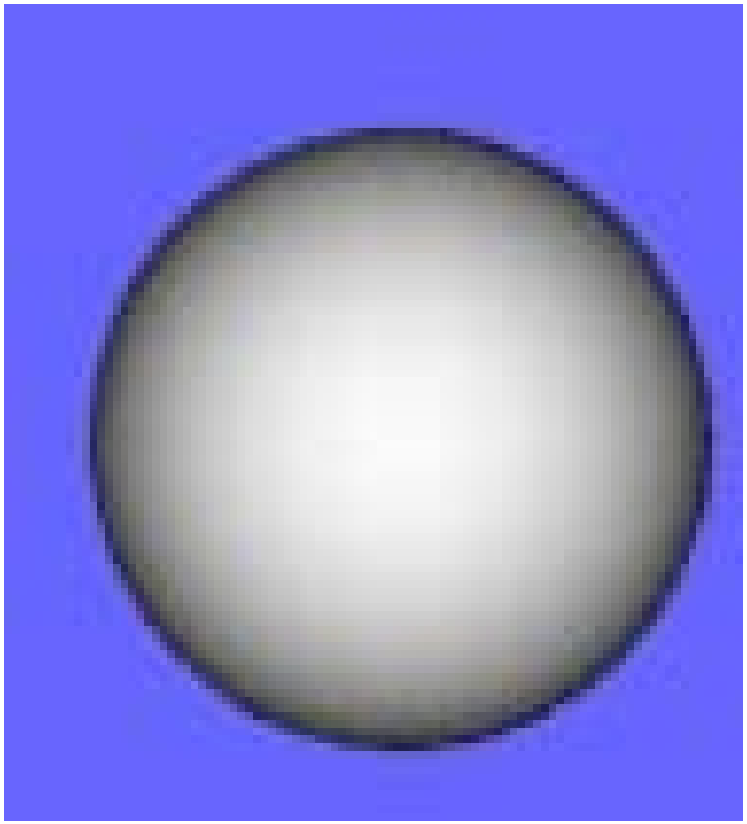

- Surface appears equally bright from ALL directions! (independent of $\vec{v}$ )
- Lambertian BRDF is simply a constant : $f(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{\rho_d}{\pi}$ albedo
- Surface Radiance : $L = \frac{\rho_d}{\pi} I \cos\theta_i = \frac{\rho_d}{\pi} I \ \vec{n} . \vec{s}$ source intensity
- Commonly used in Vision and Graphics!

# Diffuse Reflection and Lambertian BRDF - Recap




Radiance decreases with increase in angle between surface normal and source

# Rendered Sphere with Lambertian BRDF



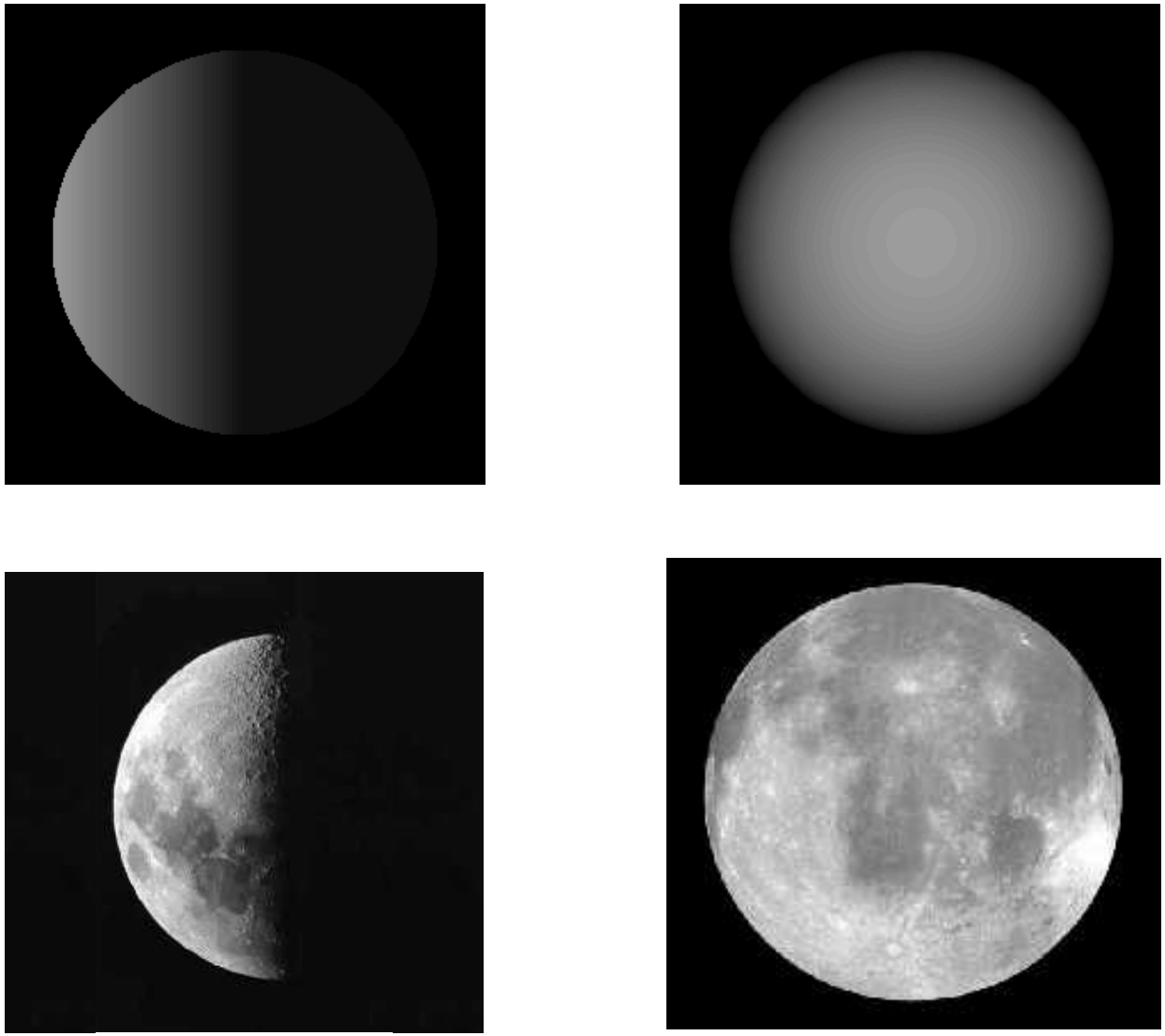
- Edges are dark (N.S = 0) when lit head-on
- See shading effects clearly.

# Why does the Full Moon have a flat appearance?

- The moon appears matte (or diffuse)

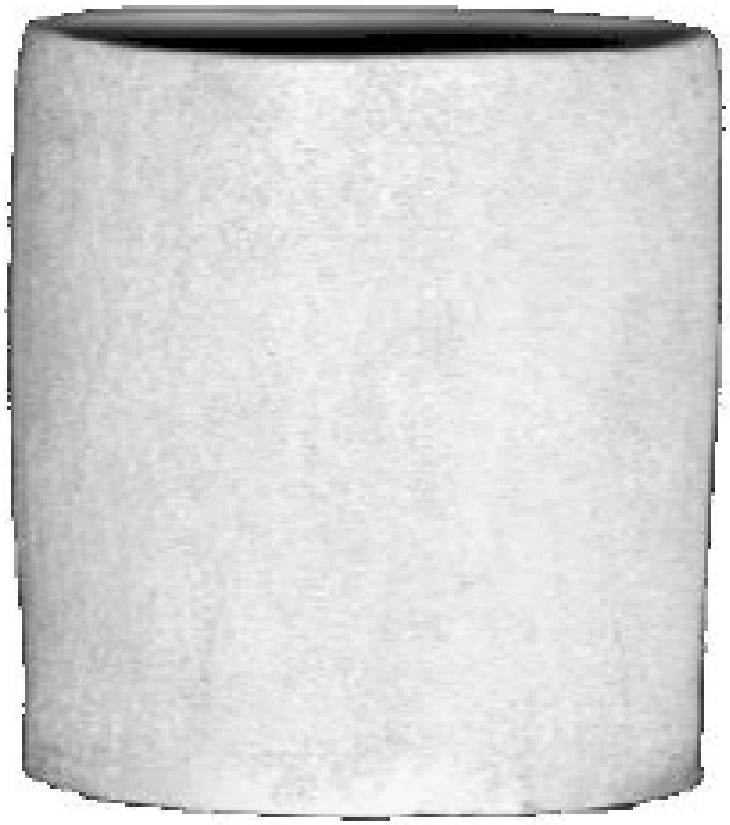
- But still, edges of the moon look bright (not close to zero) when illuminated by earth's radiance.

# Why does the Full Moon have a flat appearance?

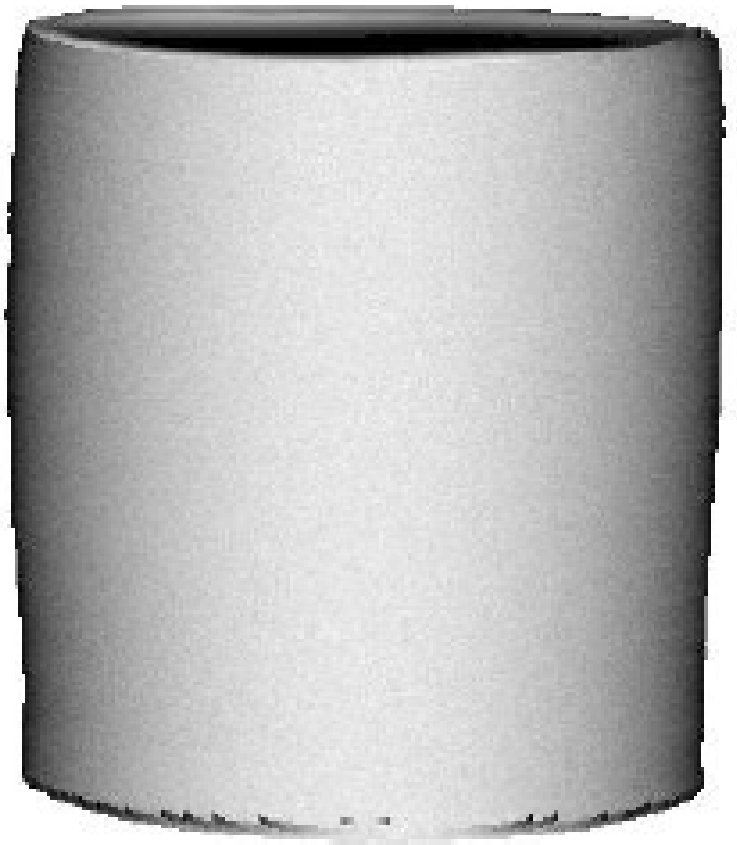


Lambertian Spheres and Moon Photos illuminated similarly

# Surface Roughness Causes Flat Appearance

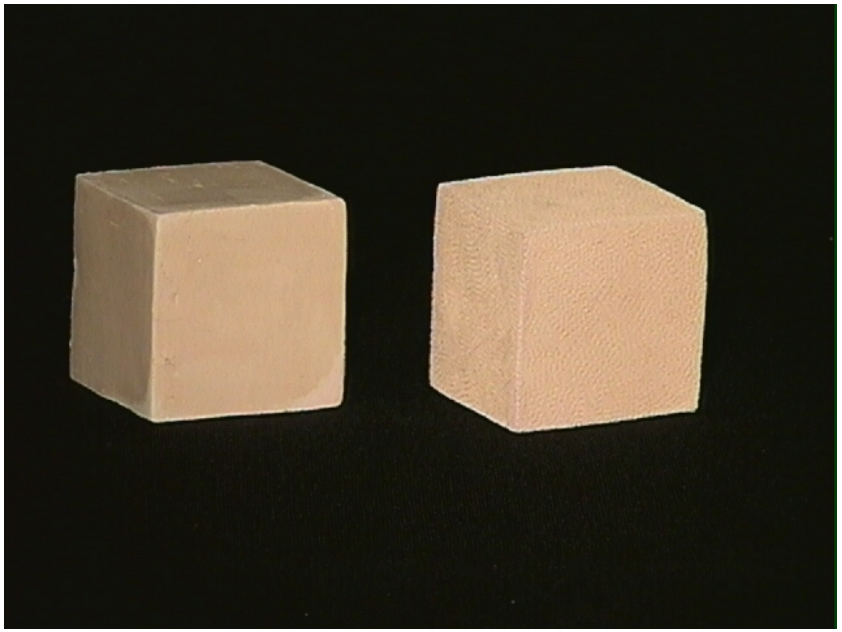


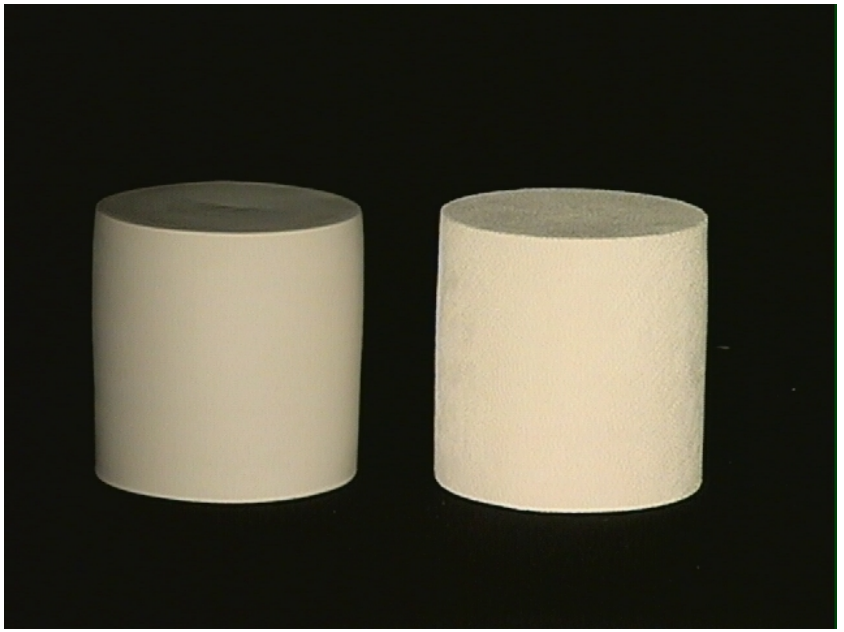
Actual Vase



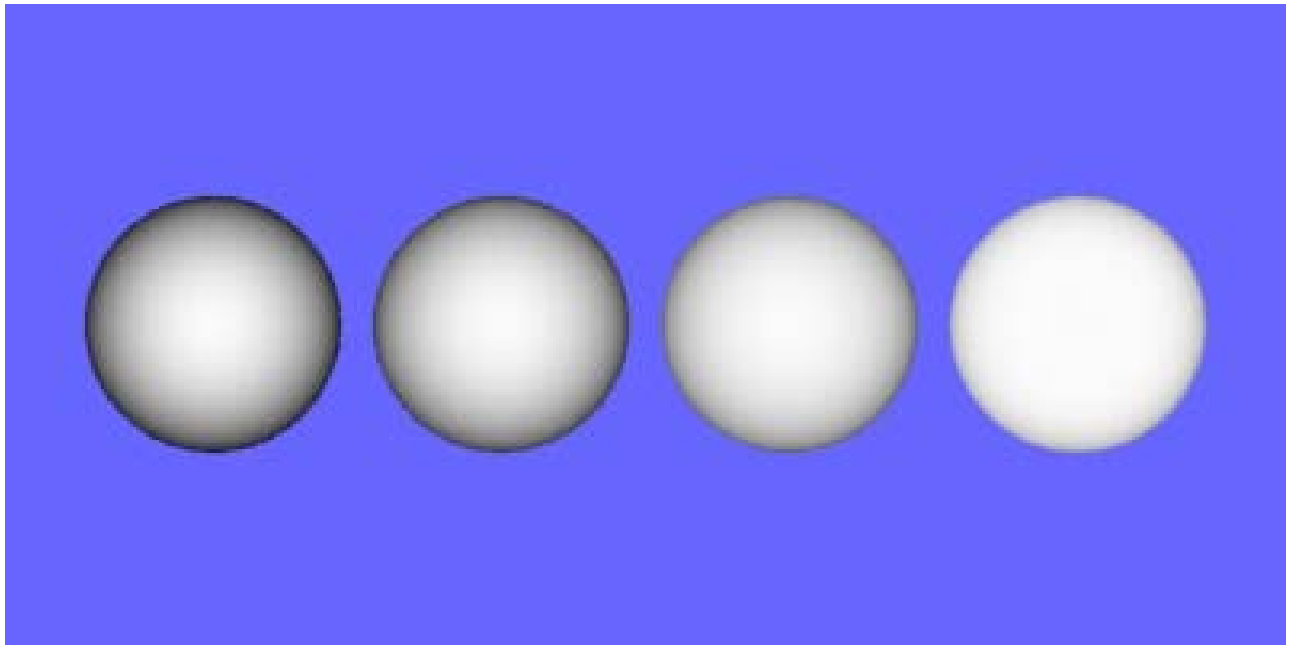
Lambertian Vase

# Surface Roughness Causes Flat Appearance – More Examples





# Surface Roughness Causes Flat Appearance



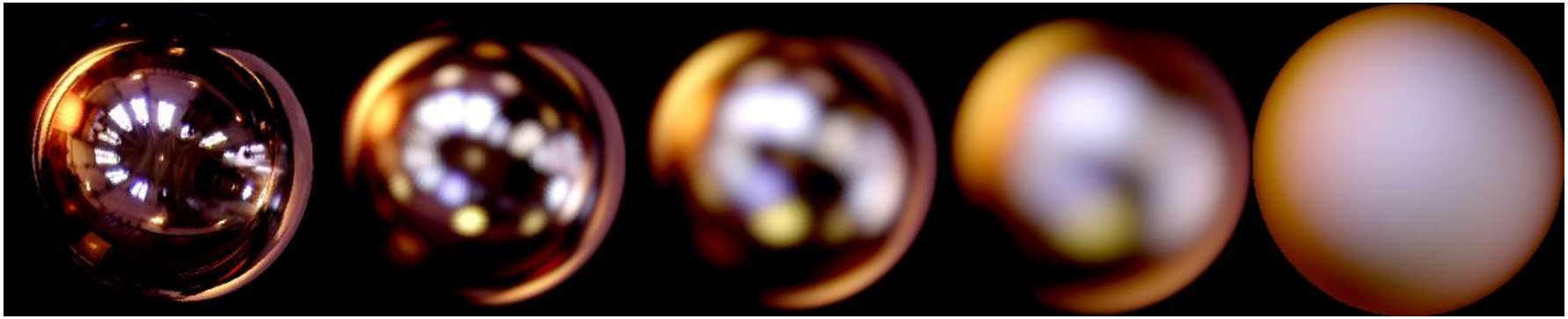
Increasing surface roughness →

Lambertian model

Valid for only SMOOTH MATTE surfaces.

Bad for ROUGH MATTE surfaces.

# Blurred Highlights and Surface Roughness - RECAP

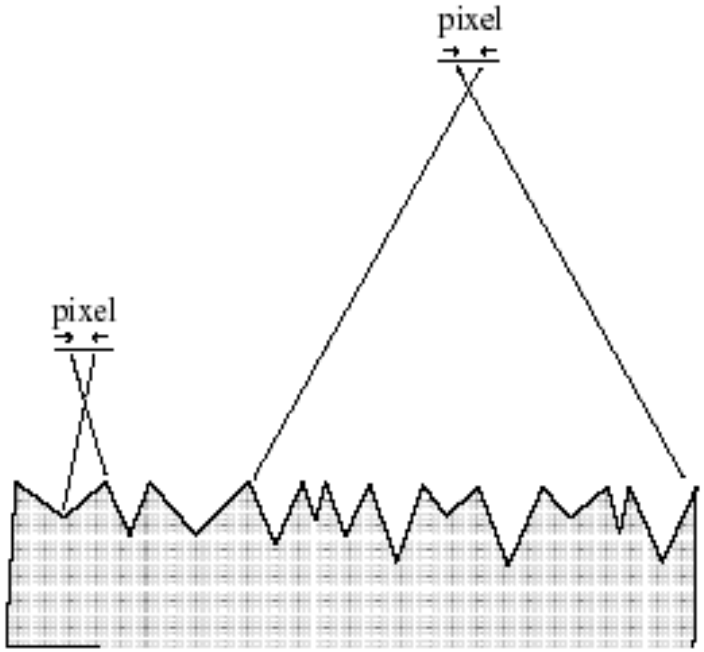


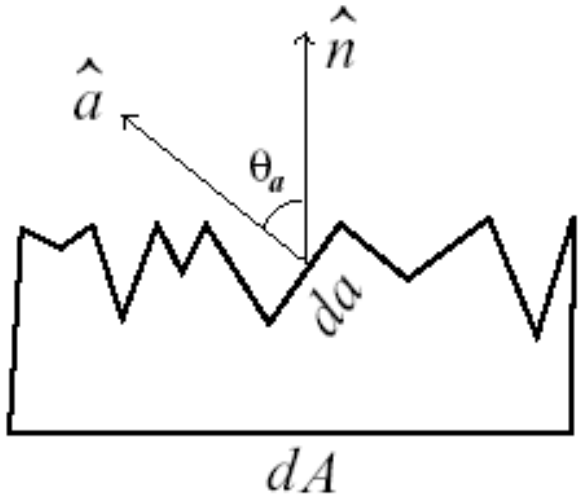
Roughness

# 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.

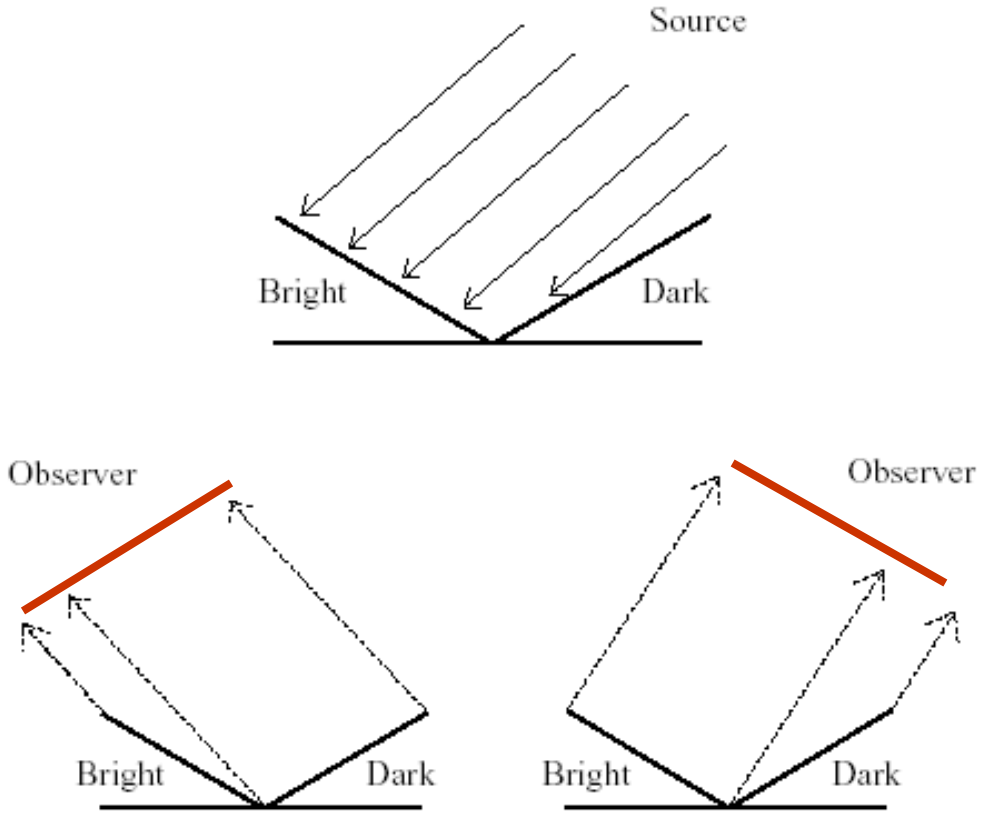
# Modeling Rough Surfaces - Microfacets




- Roughness simulated by Symmetric V-groves at Microscopic level.
- Distribution on the slopes of the V-grove faces are modeled.
- Each microfacet assumed to behave like a **perfect lambertian surface.**

# View Dependence of Matte Surfaces - Key Observation




• Overall brightness increases as the angle between the source and viewing direction decreases. WHY?

• Pixels have finite areas. As the viewing direction changes, different mixes between dark and bright are added up to give pixel brightness.

# Torrance-Sparrow BRDF – Different Factors (RECAP)

Fresnel term: allows for wavelength dependency

Geometric Attenuation: reduces the output based on the amount of shadowing or masking that occurs.

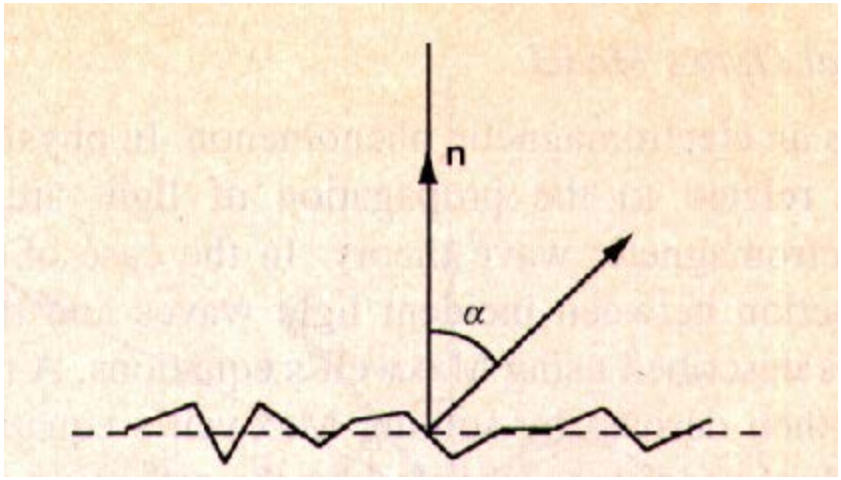
$$f = \frac{F(\theta_i)G(\omega_i, \omega_r)D(\theta_h)}{4\cos(\theta_i)\cos(\theta_r)}$$

Distribution: distribution function determines what percentage of microfacets are oriented to reflect in the viewer direction.

How much of the macroscopic surface is visible to the light source

How much of the macroscopic surface is visible to the viewer

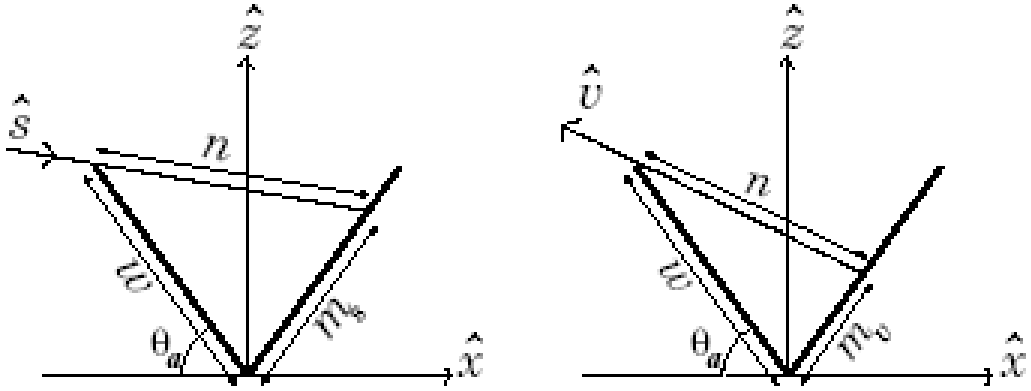
# Slope Distribution Model




- Model the distribution of slopes as Gaussian.
- Mean is Zero, Variance represents ROUGHNESS.

$$\rho_\alpha(\alpha) = \frac{1}{\sqrt{2\pi}\sigma_\alpha} e^{-\frac{\alpha^2}{2{\sigma_\alpha}^2}}.$$

# Geometric Attenuation Factor




(a) Shadowing (b) Masking

$$G(\theta_i, \theta_r, \phi_r) = \min\left(1, \frac{2\cos\alpha\cos\theta_r}{\cos\theta_i'}, \frac{2\cos\alpha\cos\theta_i}{\cos\theta_i'}\right).$$

- No interreflections taken into account in above function.
- Derivation found in 1967 JOSA paper (read if interested).

# Torrance-Sparrow BRDF – Different Factors (RECAP)

Fresnel term: allows for wavelength dependency

Geometric Attenuation: reduces the output based on the amount of shadowing or masking that occurs.

$$f = \frac{F(\theta_i)G(\omega_i, \omega_r)D(\theta_h)}{4\cos(\theta_i)\cos(\theta_r)}$$

Distribution: distribution function determines what percentage of microfacets are oriented to reflect in the viewer direction.

How much of the macroscopic surface is visible to the light source

How much of the macroscopic surface is visible to the viewer

# Oren-Nayar Model – Different Factors

Fresnel term: allows for wavelength dependency

Geometric Attenuation: reduces the output based on the amount of shadowing or masking that occurs.

$$f = \frac{F(\theta_i)G(\omega_i, \omega_r)D(\theta_h)}{4\cos(\theta_i)\cos(\theta_r)}$$

How much of the macroscopic surface is visible to the light source

How much of the macroscopic surface is visible to the viewer

Distribution: distribution function determines what percentage of microfacets are oriented to reflect in the viewer direction

# Oren-Nayar Model – Different Factors

Fresnel term: allows for wavelength dependency

Geometric Attenuation: reduces the output based on the amount of shadowing or masking that occurs.

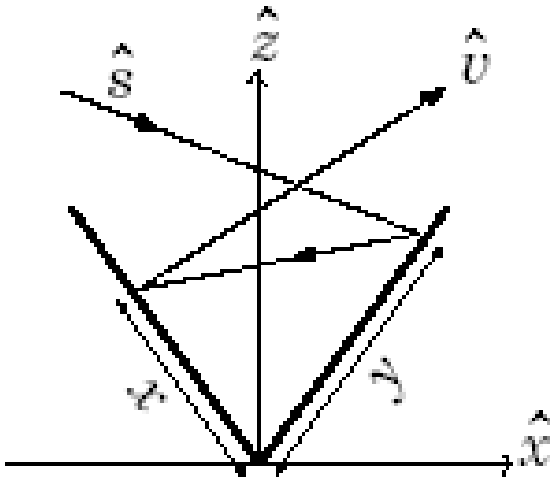
$$f = \frac{F(\theta_i)G(\omega_i, \omega_r)D(\theta_h)}{4\cos(\theta_i)\cos(\theta_r)}$$

Distribution: distribution function determines what fraction of the surface area do the facets of the same orientation cover?

How much of the macroscopic surface is visible to the light source

How much of the macroscopic surface is visible to the viewer

# Oren-Nayar Model – Different Factors (contd.)




(c) Interreflection

- Take into account two light bounces (reflections).
- Hard to solve analytically, so they find a functional approximation.

# Oren-Nayar Model – Final Expression

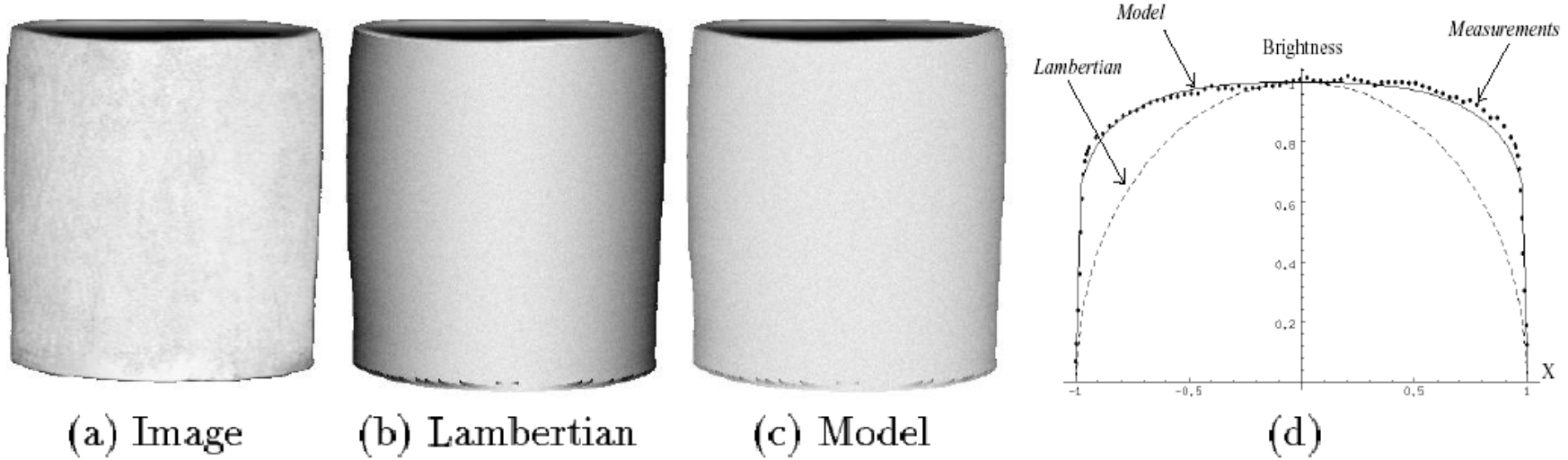
$$L(\theta_r, \theta_i, \phi_r - \phi_i; \rho, \sigma) = \frac{\rho}{\pi} E_0 \cos\theta_i (A + BMax\left[0, \cos(\phi_r - \phi_i)\right] \sin\alpha \tan\beta),$$

$$A = 1.0 - 0.5\frac{\sigma^2}{\sigma^2 + 0.33}, \qquad \alpha = Max(\theta_r, \theta_i)$$

$$B = 0.45\frac{\sigma^2}{\sigma^2 + 0.09}, \qquad \beta = Min(\theta_r, \theta_i).$$

Lambertian model is simply an extreme case with roughness equal to zero.

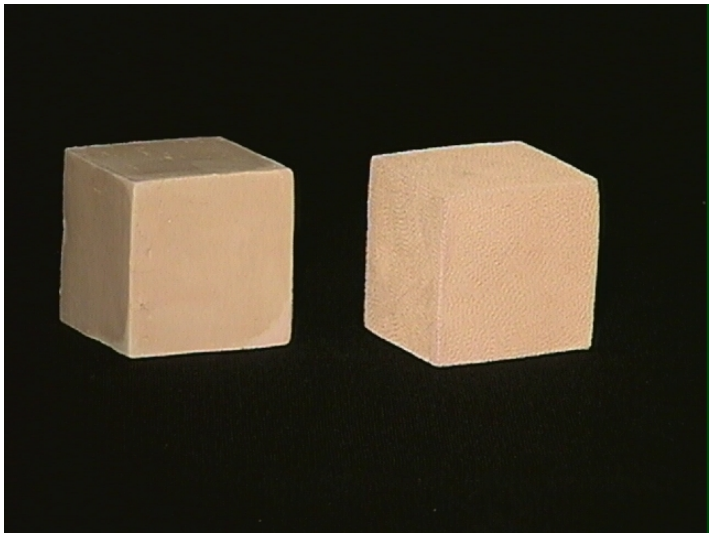
# Comparison to Ground Truth

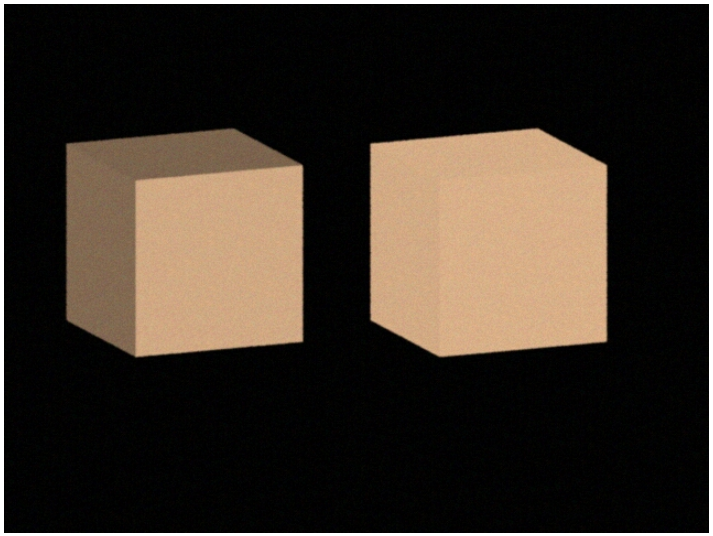


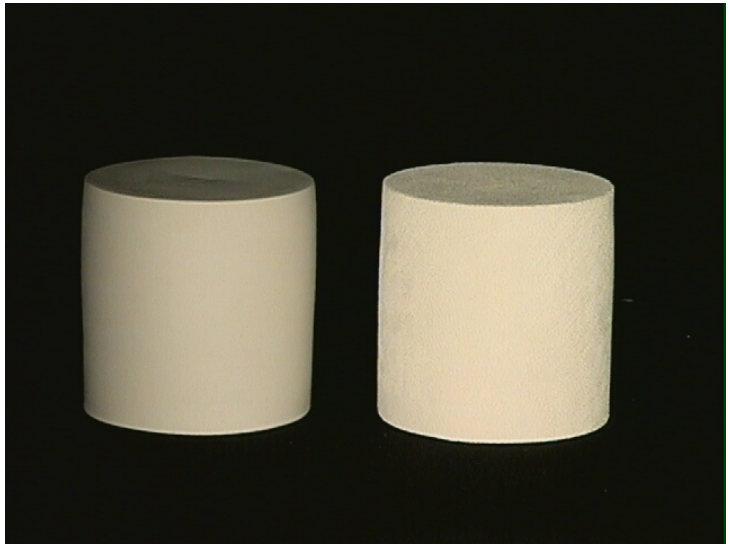

(a) Image (b) Lambertian (c) Model (d)

**Fig. 7.** (a-c) Real image of a cylindrical clay vase compared with images rendered using the Lambertian and proposed models. Illumination is from the direction $\theta_i = 0°$. (d) Comparison between image brightness along the cross-sections of the three vases.

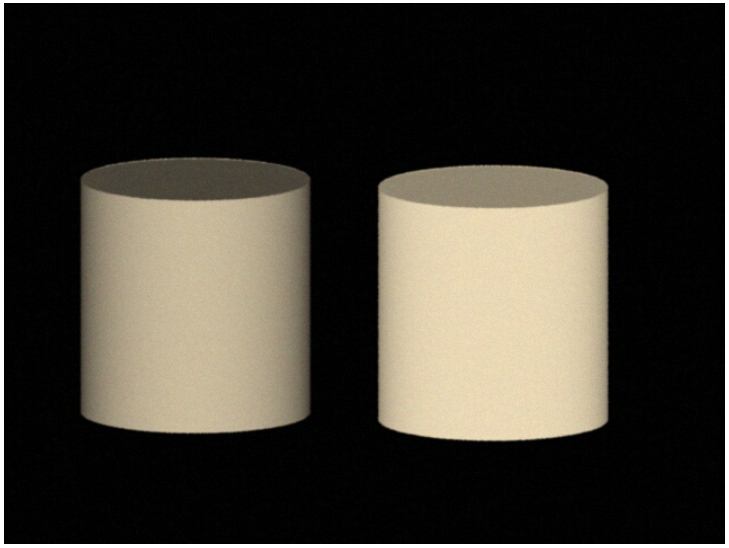
# Comparison to Ground Truth





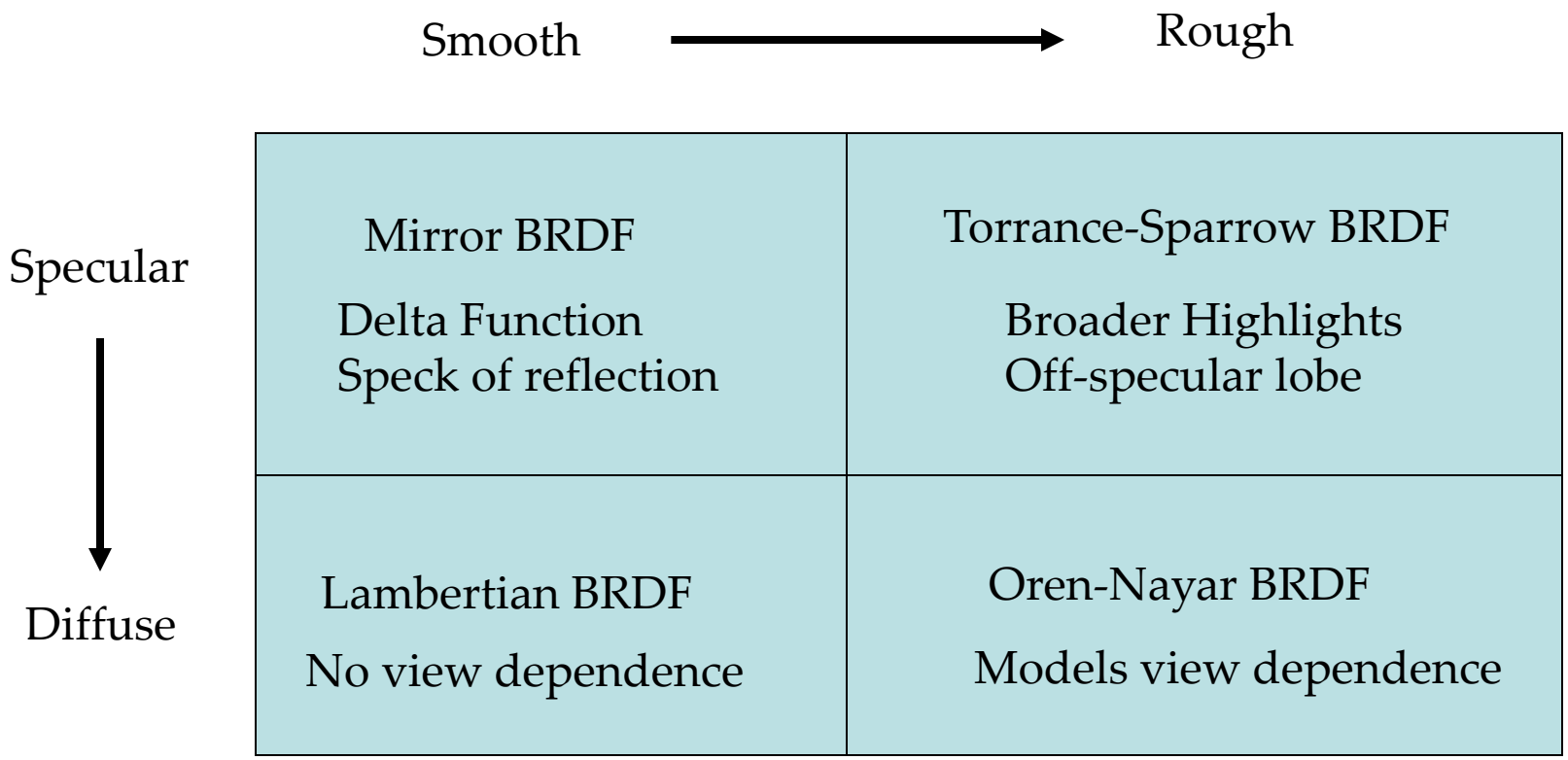


Real Objects



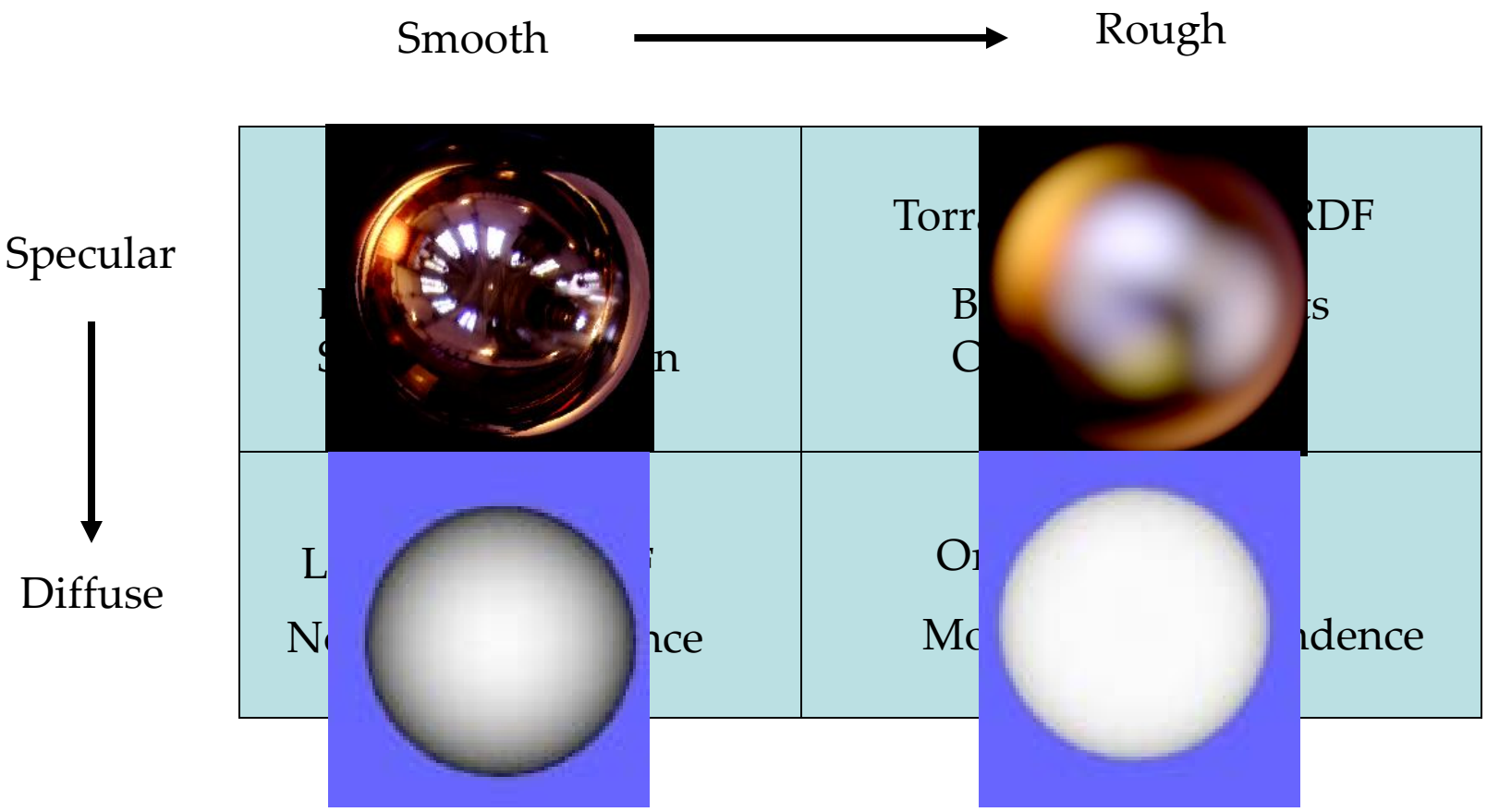
Renderings

# Summary of Surfaces and BRDFs




Many surfaces may be rough and show both diffuse and surface reflection.

# Summary of Surfaces and BRDFs




Many surfaces may be rough and show both diffuse and surface reflection.

# NEXT CLASS

Why bother modeling BRDFs?

Why not directly measure BRDFs?

- True knowledge of surface properties
- Accurate models for graphics