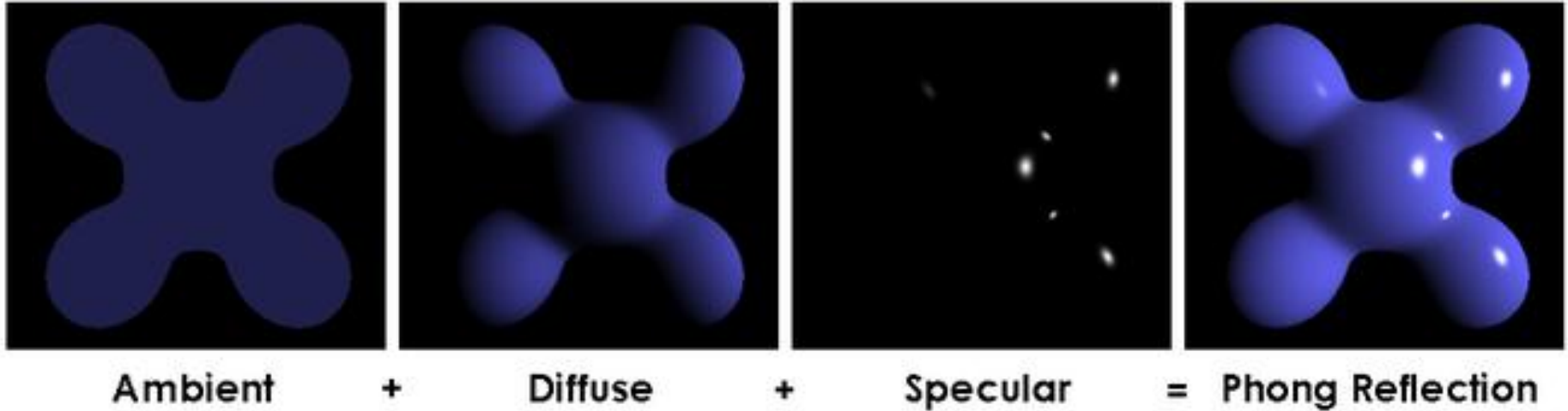


Shading / Light

Thanks to Srinivas Narasimhan, Langer-Zucker, Henrik Wann Jensen, Ravi Ramamoorthi, Hanrahan, Preetham

Phong Illumination Model



$$I_p = k_a i_a + \sum_{m \in \text{lights}} (k_d (L_m \cdot N) i_d + k_s (R_m \cdot V)^\alpha i_s).$$

See Shirley, Ch 10 and
http://en.wikipedia.org/wiki/Phong_shading

chalkboard

Phong vs. Gouraud Shading

Key: What is interpolated
when shading a triangle?



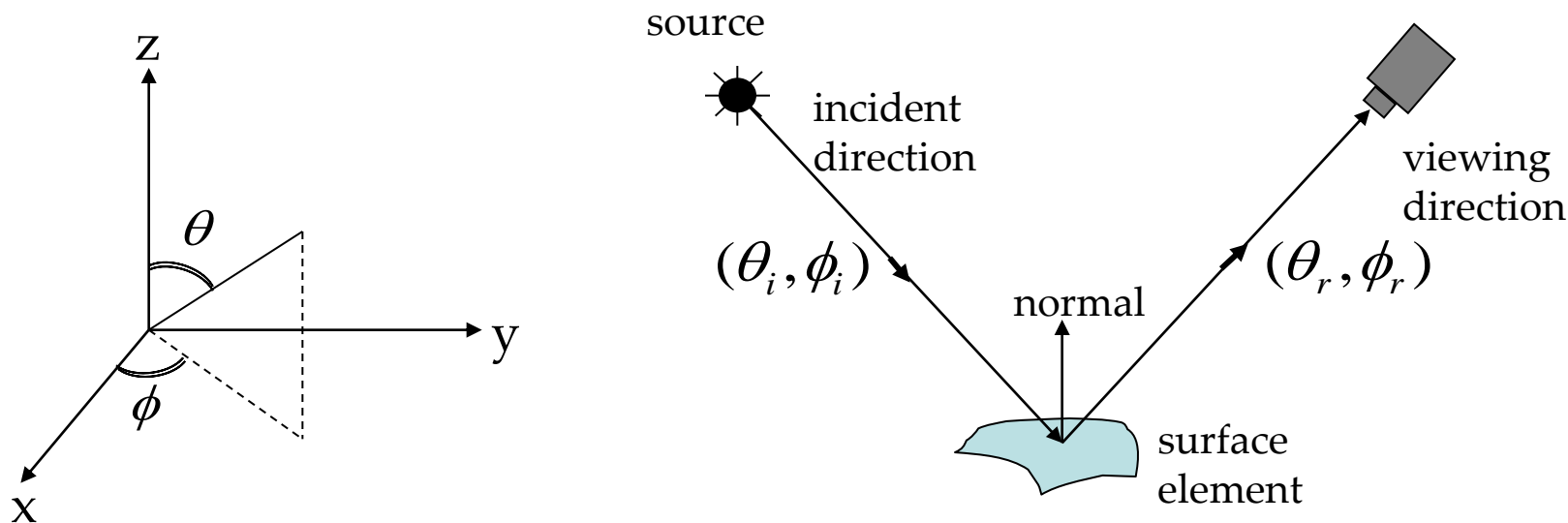
chalkboard

See Shirley, Ch 10 and
http://en.wikipedia.org/wiki/Gouraud_shading

A more general illumination function is needed to capture the appearance of real-world objects



BRDF: Bidirectional Reflectance Distribution Function

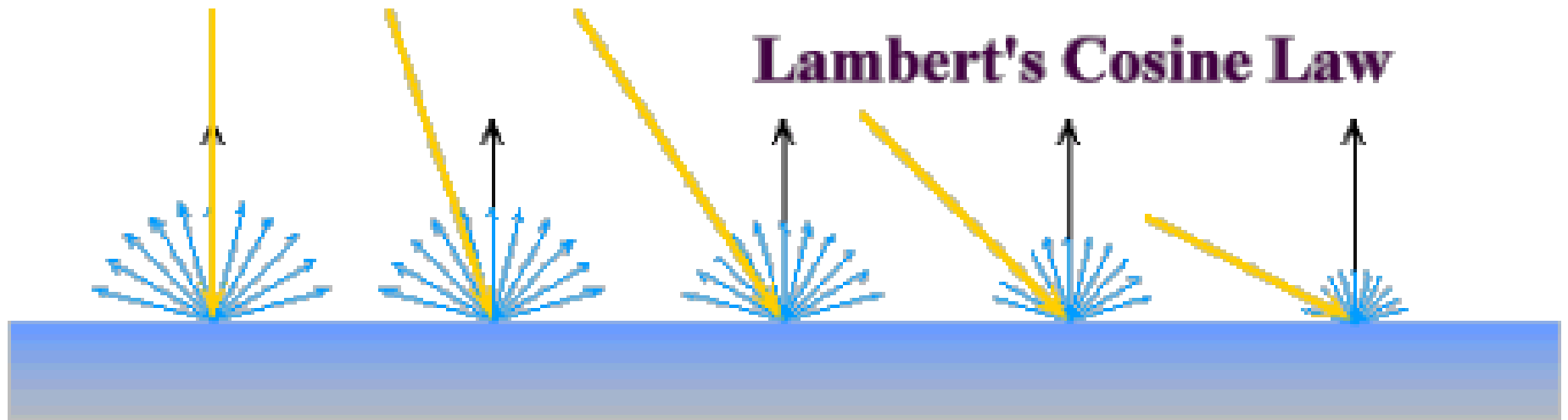


$E^{surface}(\theta_i, \phi_i)$ Irradiance at Surface in direction (θ_i, ϕ_i)

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

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

Diffuse Reflection and Lambertian BRDF

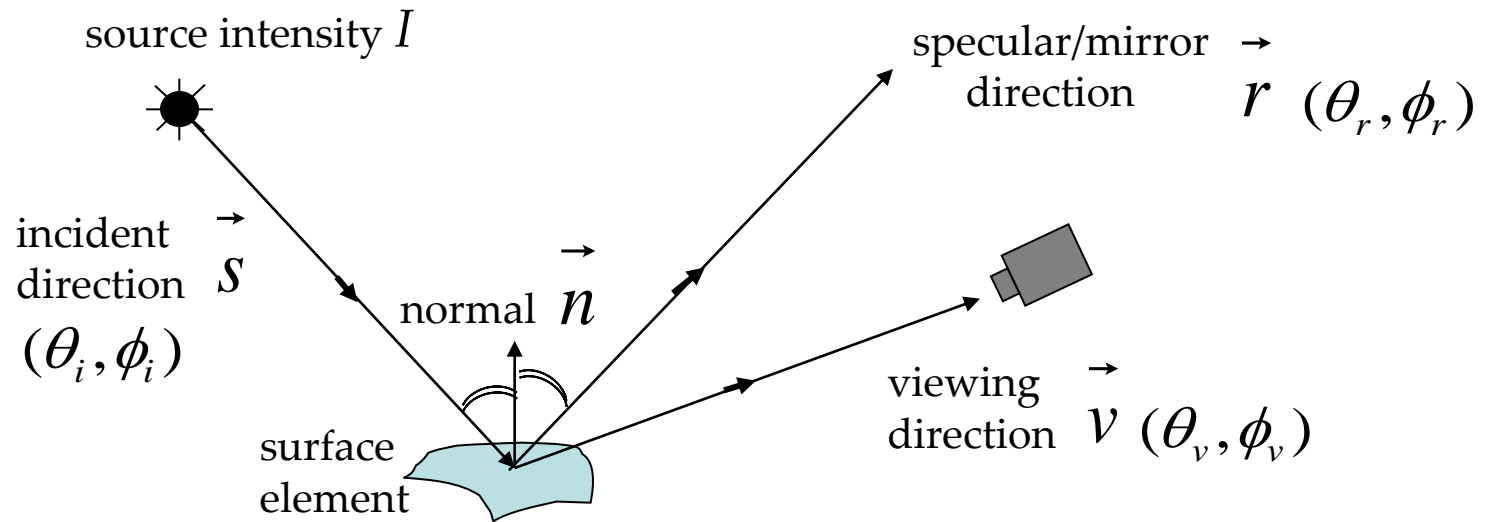


Rendered Sphere with Lambertian BRDF



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

Specular Reflection and Mirror BRDF



- Very smooth surface.
- All incident light energy reflected in a SINGLE direction. (only when $\vec{v} = \vec{r}$)

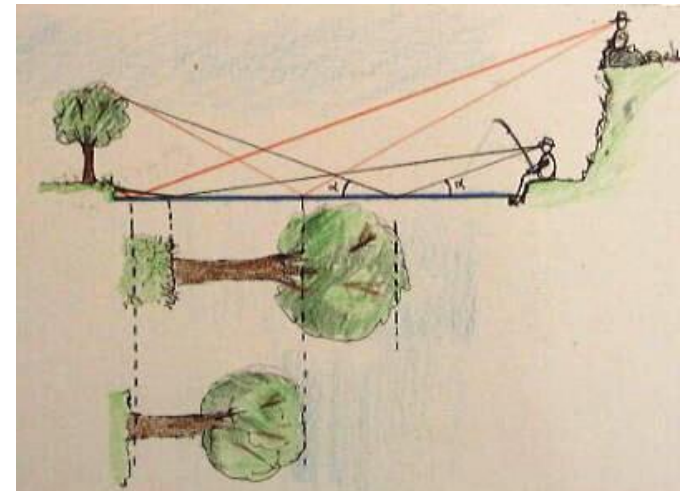
Specular Reflections in Nature



It's surprising how long the reflections are when viewed sitting on the river bank.

Compare sizes of objects and their reflections!

The reflections when seen from a lower view point are always longer than when viewed from a higher view point.



Specular Reflections in Nature



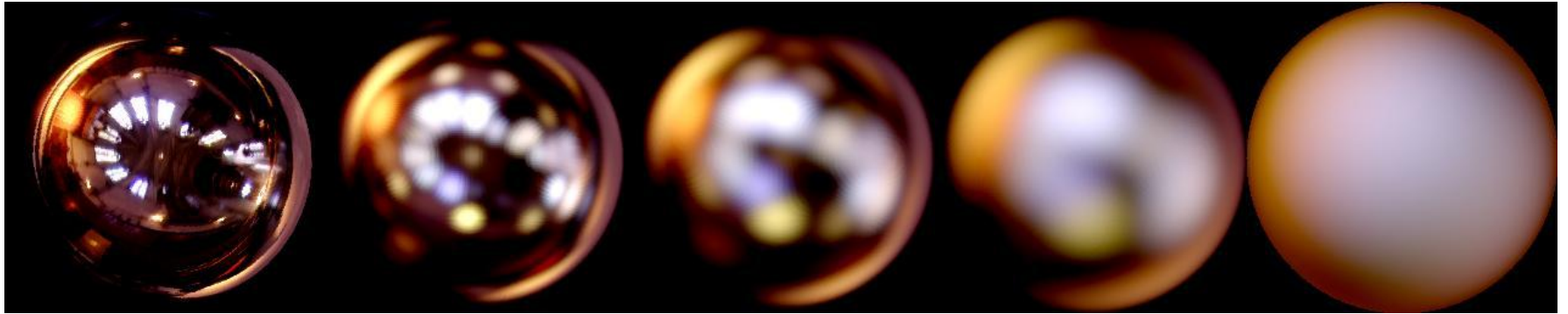
Glossy Surfaces

- 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).

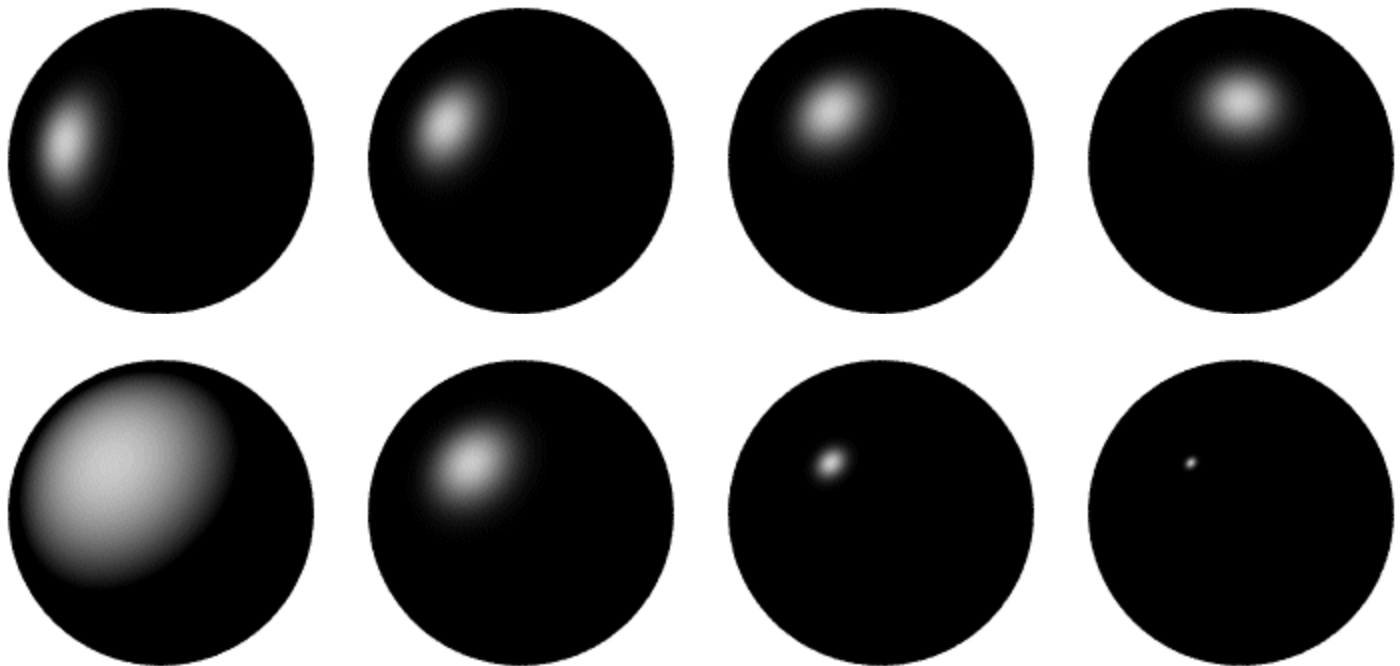
Blurred Highlights and Surface Roughness



Roughness

Phong Examples

- These spheres illustrate results from our simple Phong Illumination 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

Experiment

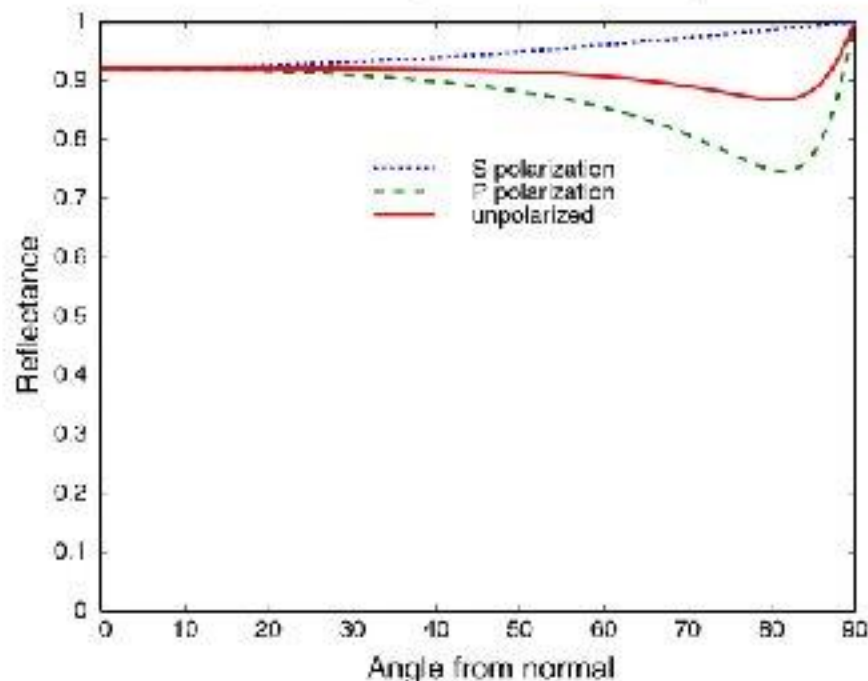
Reflections from a shiny floor



From Lafortune, Foo, Torrance, Greenberg, SIGGRAPH 97

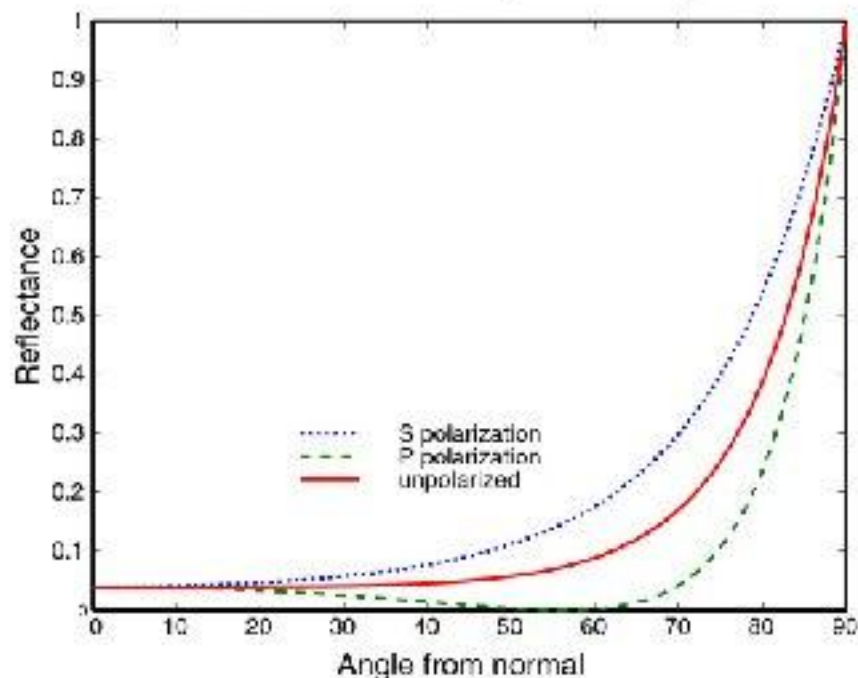
Fresnel Reflectance

Metal (Aluminum)



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

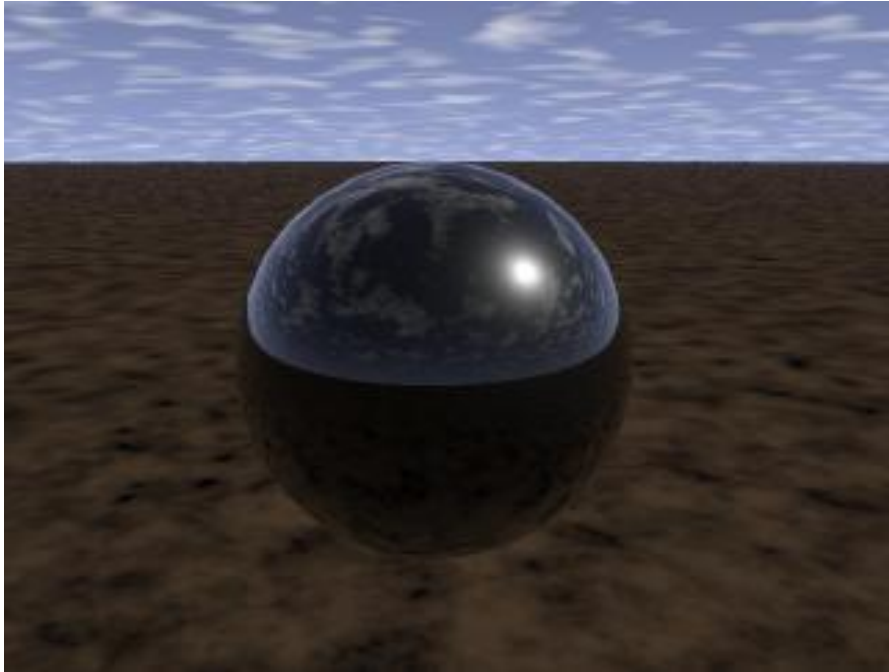
Dielectric (N=1.5)



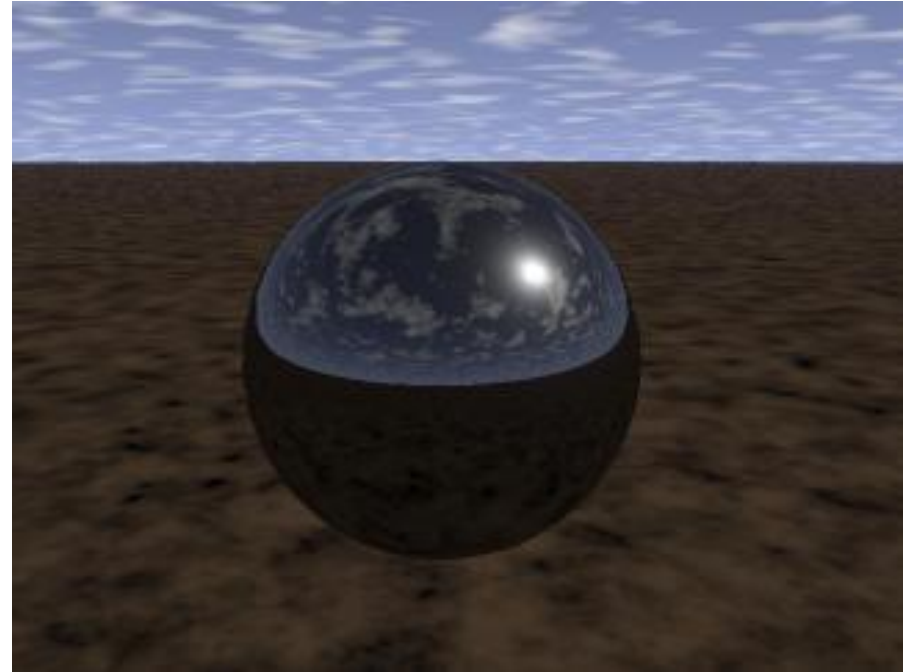
Glass $n=1.5$ $F(0)=0.04$
Diamond $n=2.4$ $F(0)=0.15$

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

With Fresnel Reflectance

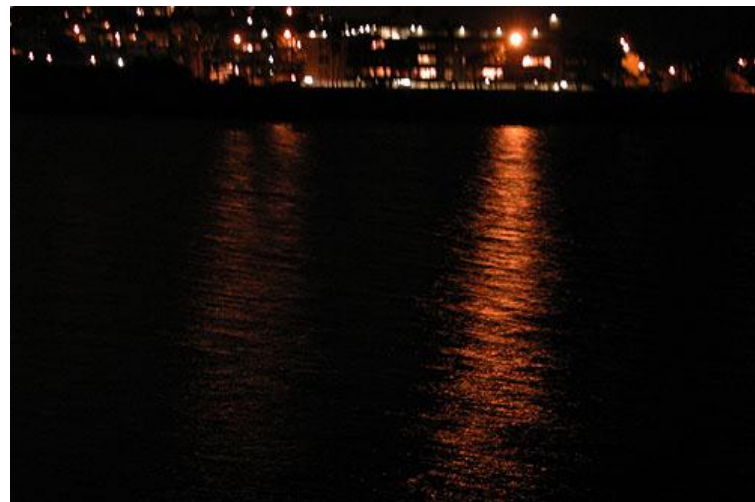
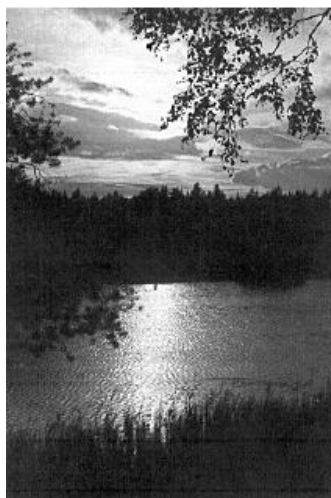


Without Fresnel Reflectance

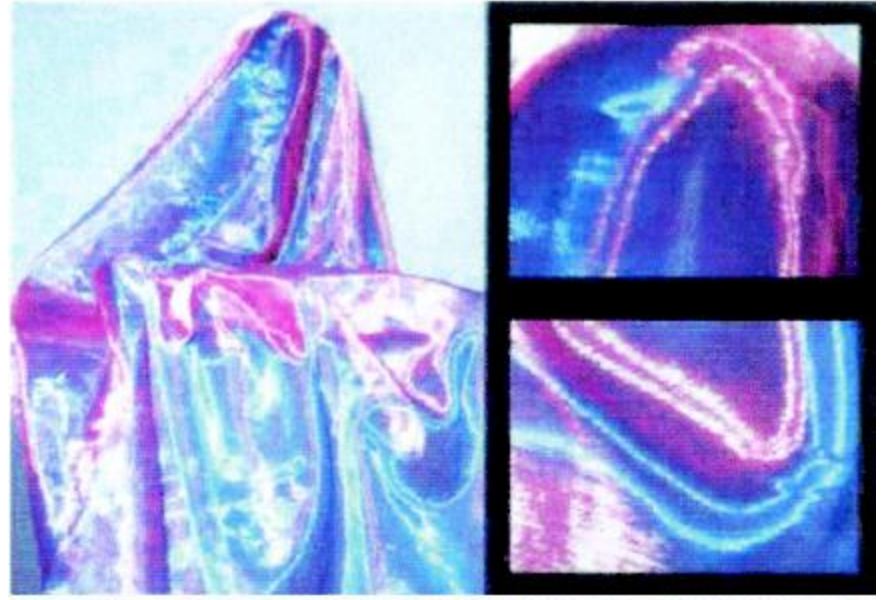
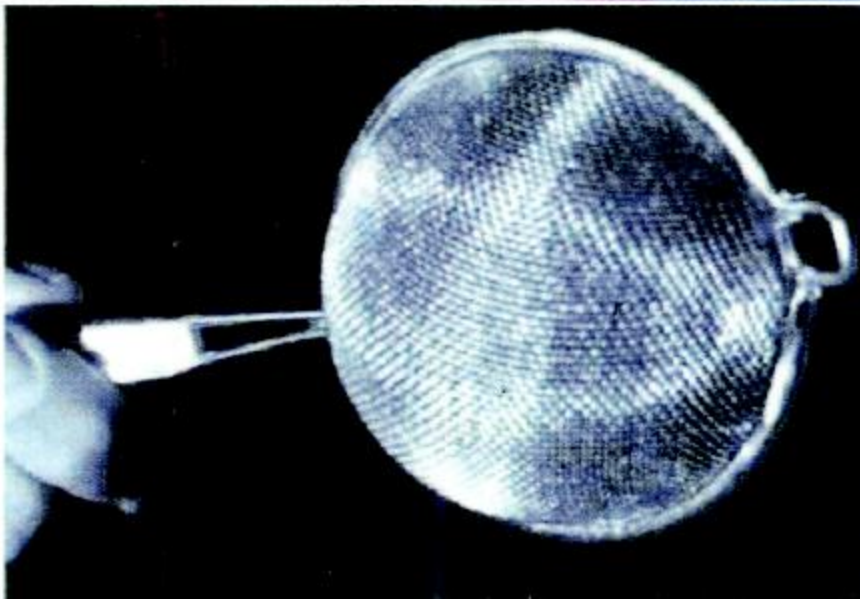


<http://www.graphics.cornell.edu/~westin/misc/fresnel.html>

Reflections on water surfaces - Glittering



Split off-specular Reflections in Woven Surfaces



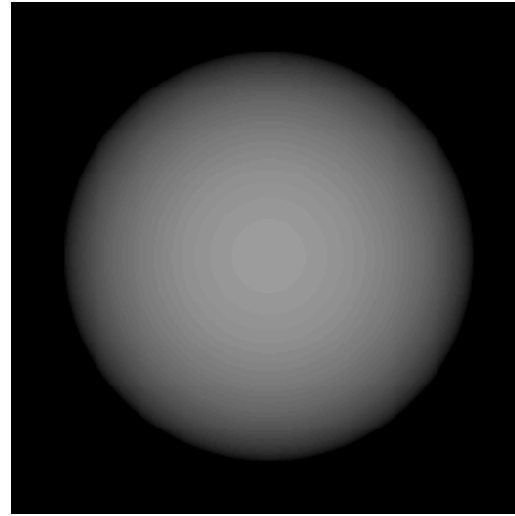
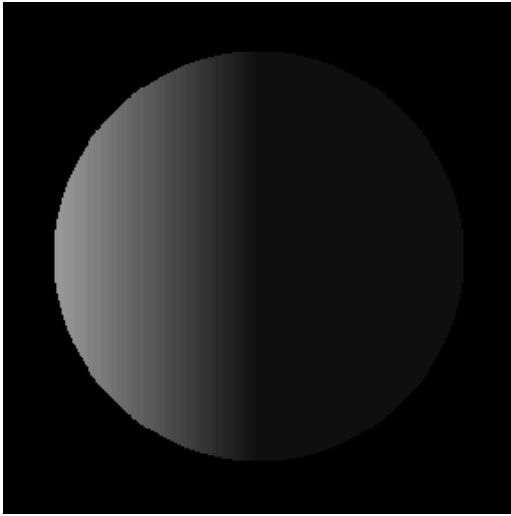
Why does the Full Moon have a flat appearance?



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

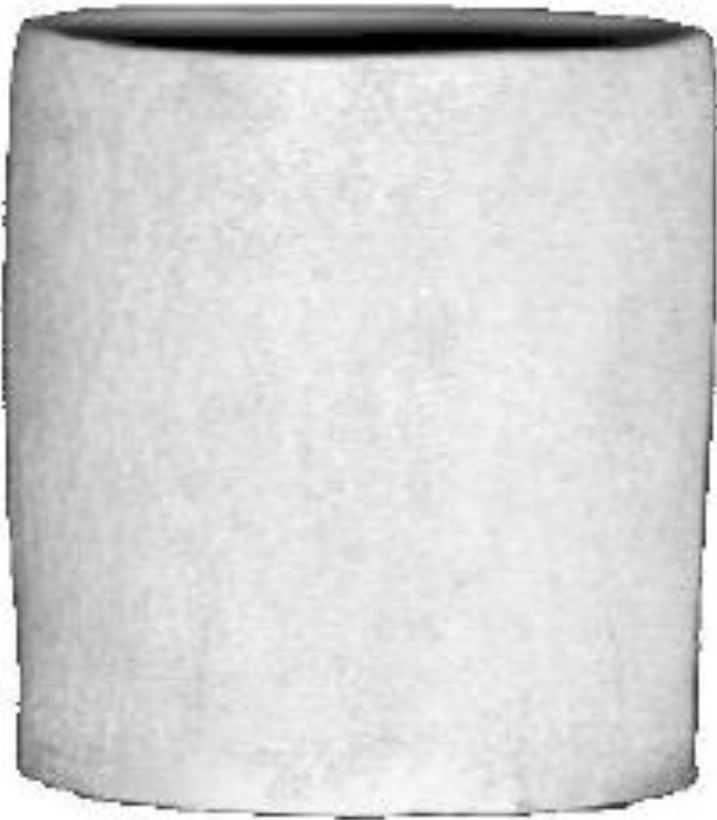


Why does the Full Moon have a flat appearance?

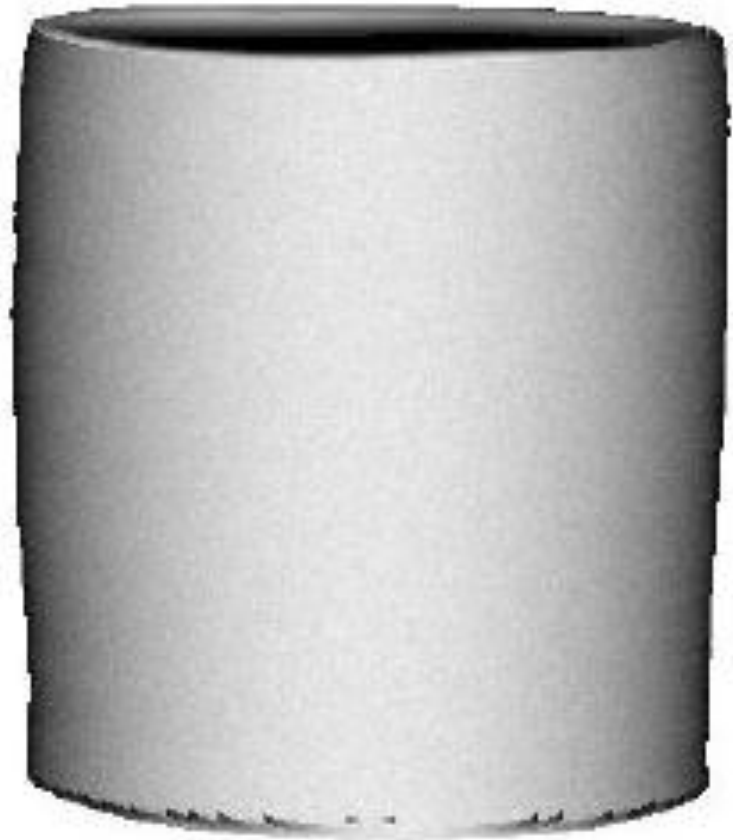


Lambertian Spheres and Moon Photos illuminated similarly

Surface Roughness Causes Flat Appearance



Actual Vase



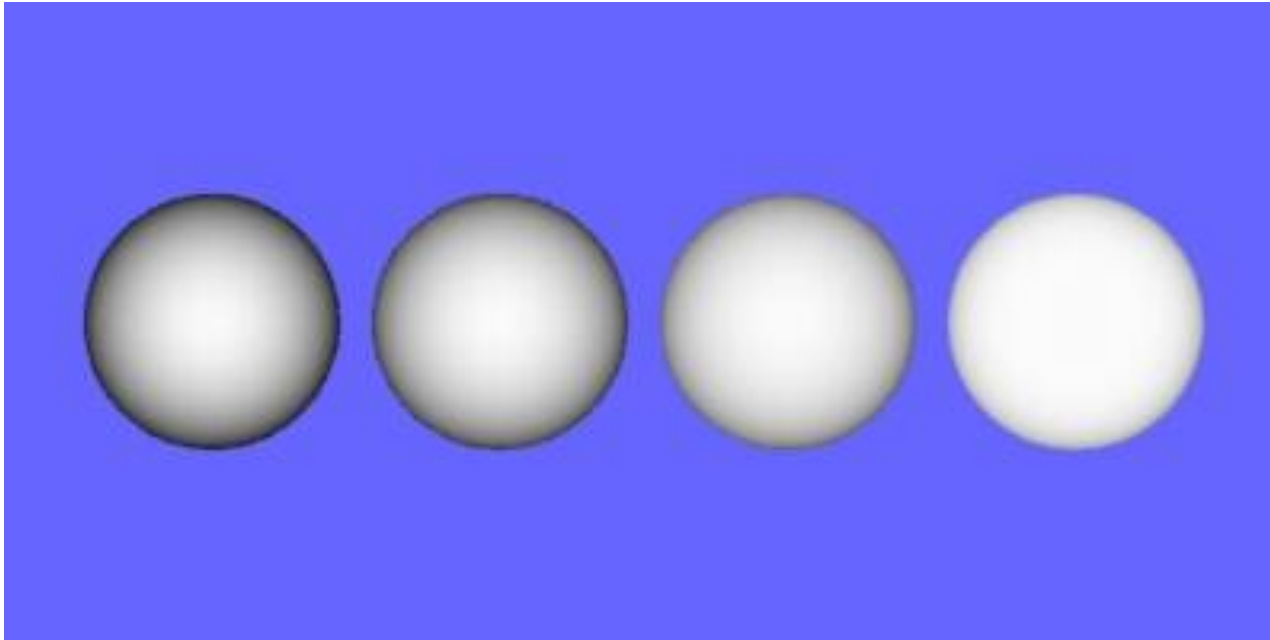
Lambertian Vase

Rendered Sphere with Lambertian BRDF



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

Surface Roughness Causes Flat Appearance



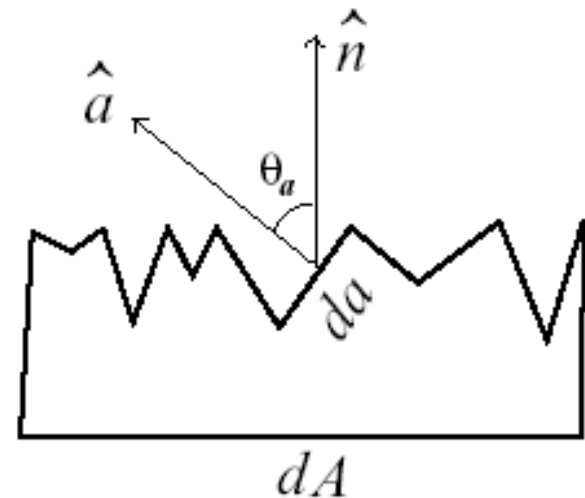
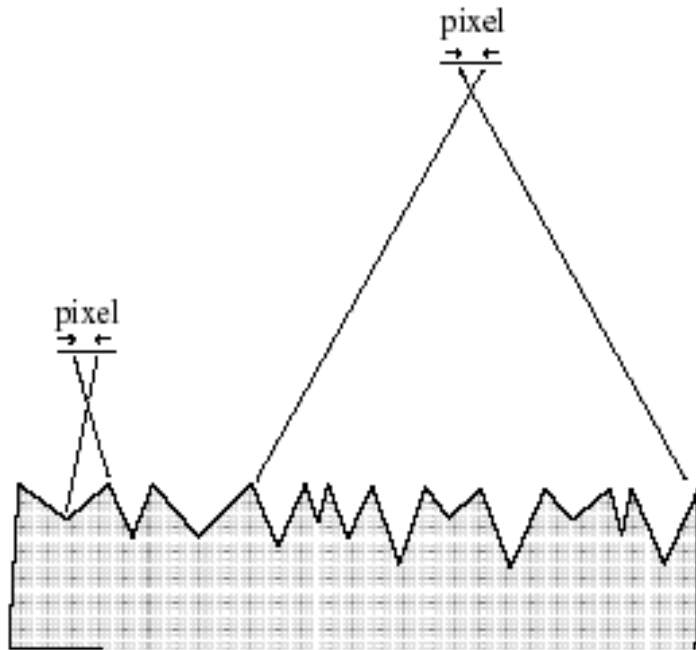
Increasing surface roughness 

Lambertian model

Valid for only SMOOTH MATTE surfaces.

Bad for ROUGH MATTE surfaces.

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**.
- For more information, look into the **Oren-Nayar Model**

Measuring BRDFs

Why bother modeling BRDFs?

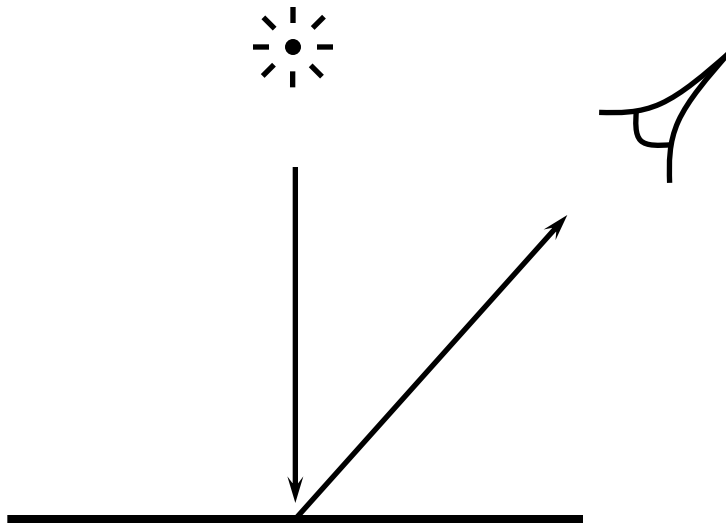
Why not directly measure BRDFs?

- True knowledge of surface properties
- Accurate models for graphics

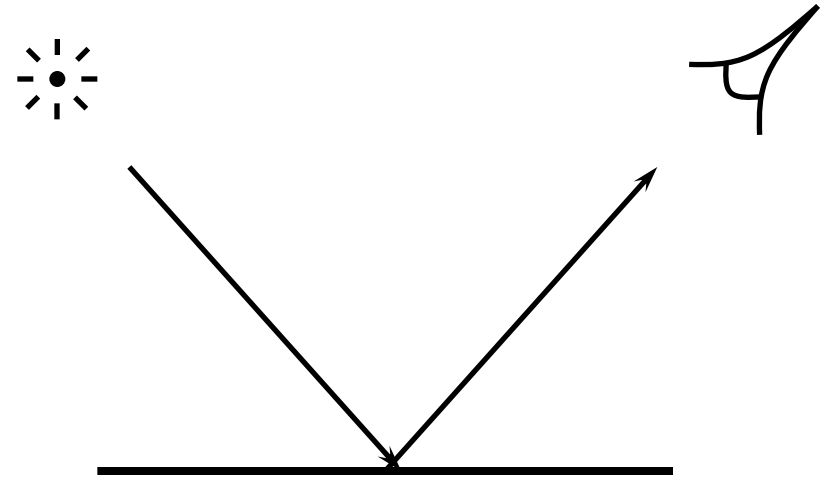
Measuring BRDFs

- A full BRDF is 4-dimensional
- Simpler measurements (0D/1D/2D/3D) often useful
- Lets start with simplest and get more complex

Measuring Reflectance



$0^\circ/45^\circ$
Diffuse Measurement



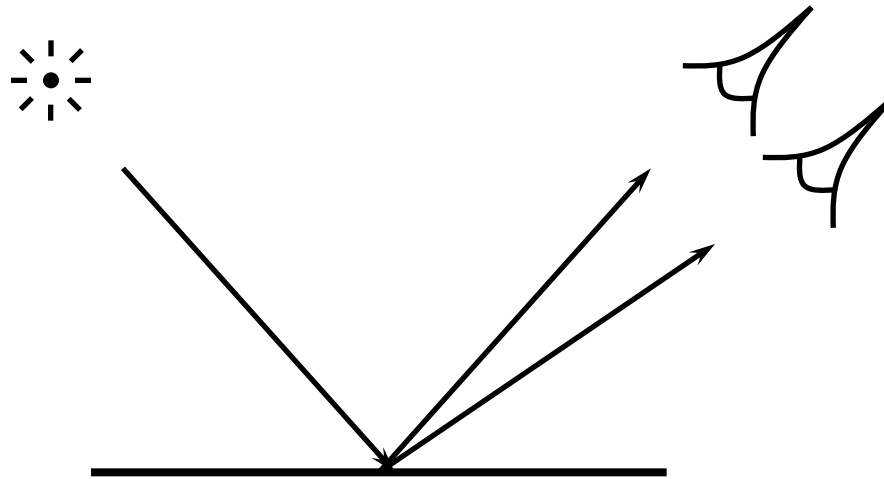
$45^\circ/45^\circ$
Specular Measurement

Gloss Measurements

- Standardized for applications such as paint manufacturing
- Example: “contrast gloss” is essentially ratio of specular to diffuse
- “Sheen” is specular measurement at 85°

Gloss Measurements

- “Haze” and “distinctness of image” are measurements of width of specular peak



Gonioreflectometers

- Three degrees of freedom spread among light source, detector, and/or sample
- Can add fourth degree of freedom to measure anisotropic BRDFs

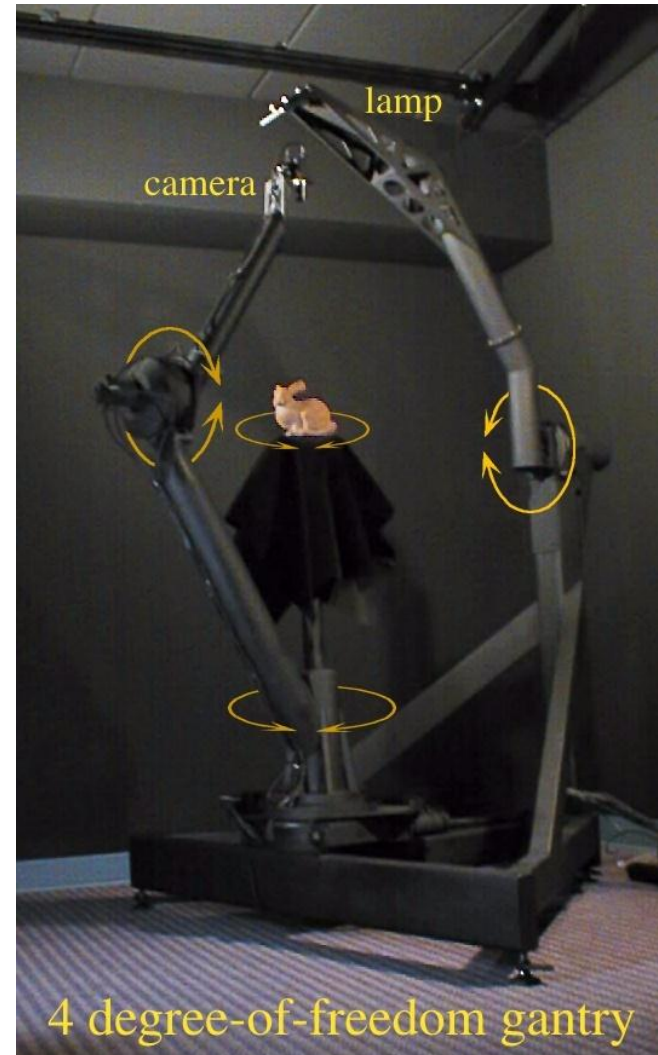


Image-Based BRDF Measurement

- Reduce acquisition time by obtaining larger (e.g. 2-D) slices of BRDF at once
- Idea: Camera can acquire 2D image
- Requires mapping of angles of light to camera pixels



SIGGRAPH2005

Measurement

- 20-80 million reflectance measurements per material
- Each tabulated BRDF entails $90 \times 90 \times 180 \times 3 = 4,374,000$ measurement bins





SIGGRAPH2005

Rendering from Tabulated BRDFs

- These BRDFs are immediately useful
- Direct renderings from measurements



Nickel

Hematite

Gold Paint


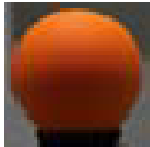


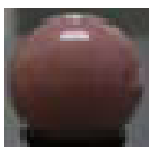
Pink Felt

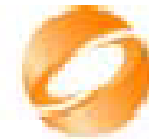


SIGGRAPH2005

Linear Combinations of BRDFs (LCB)

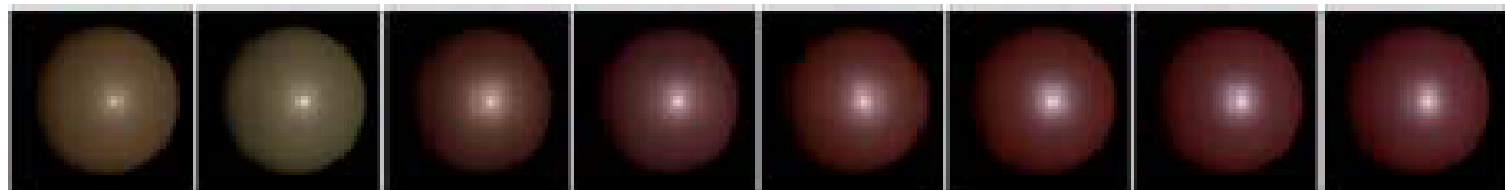
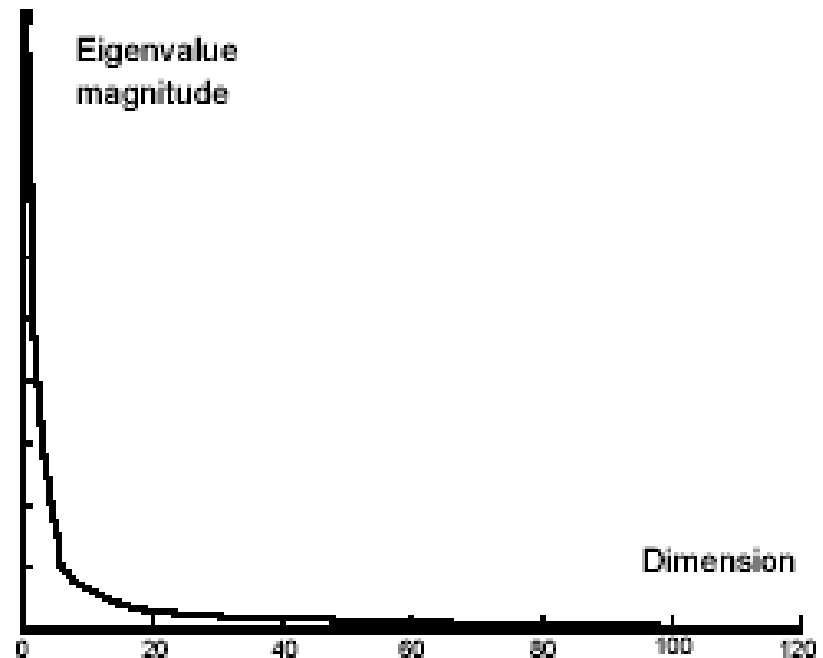
- Can we find a linear combination of our existing BRDFs that match any new one?
- Requires only estimating 100 coefficients for source BRDFs
- Compute a set of 800 constraints that allow estimating these 100 coefficients robustly

$$\alpha_1 \text{  + \alpha_2 \text{  + \alpha_3 \text{  + \alpha_4 \text{  + \dots = \text{ $$



Linear Analysis (PCA)

- Find optimal linear basis for our data set
- 45 components needed to reduce residue to under measurement error



mean

5

10

20

30

45

60

all



SIGGRAPH2005

Navigation Results



Adding Silver Trait



SIGGRAPH2005

Navigation Results



Adding Specular Trait

Navigation Results



SIGGRAPH2005



Adding Metallic Trait

Representing Physical Processes



SIGGRAPH2005

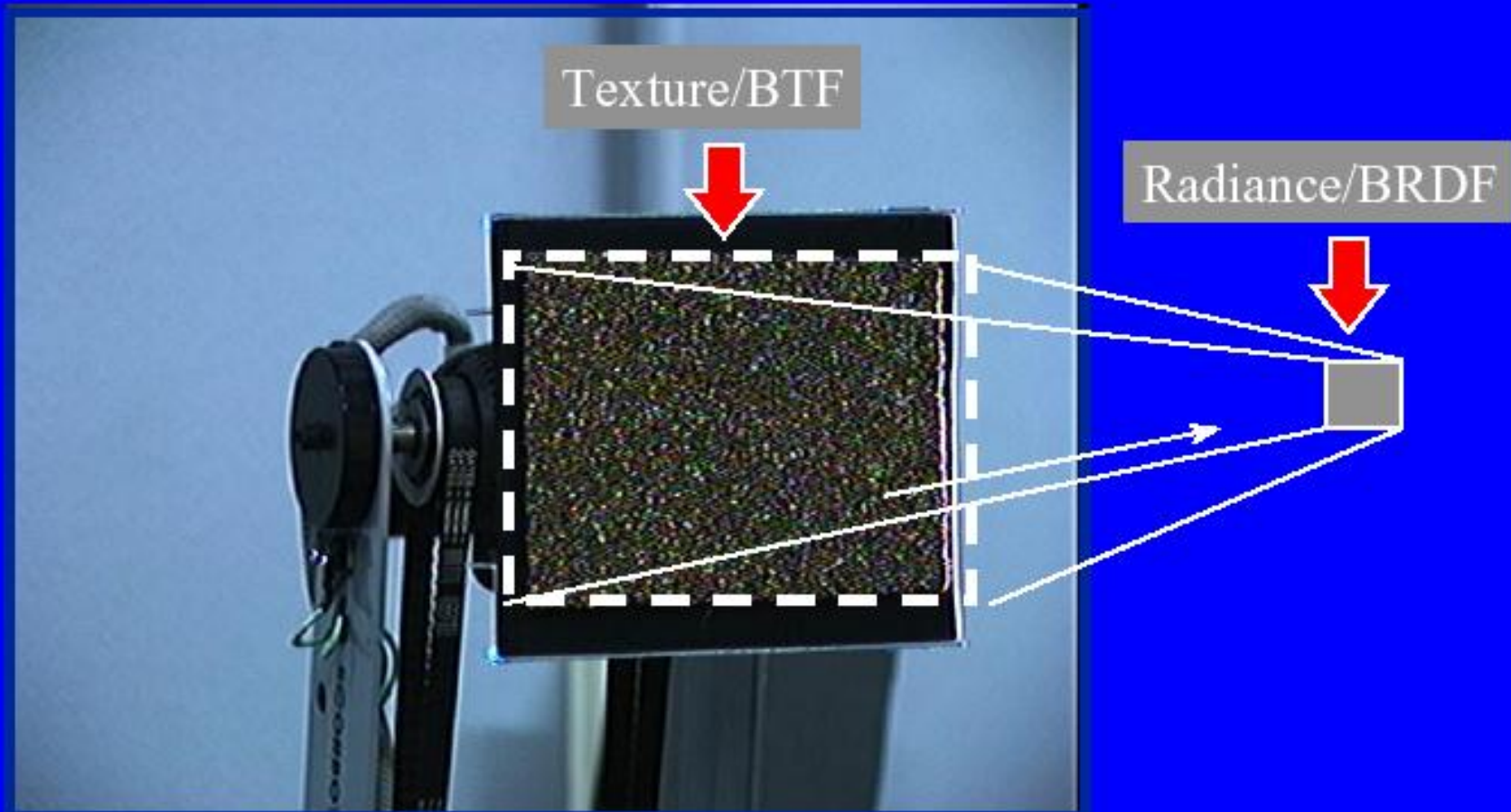


Steel Oxidation

Looking ahead – Real objects have texture!



Measurement Methods



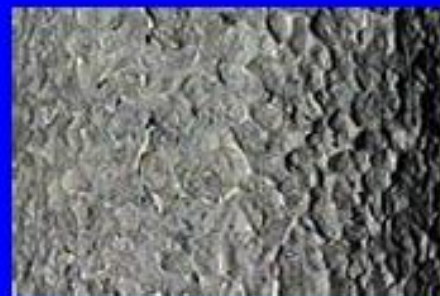
Texture-mapping using BTF



standard
texture-mapping



texture-mapping
with the BTF



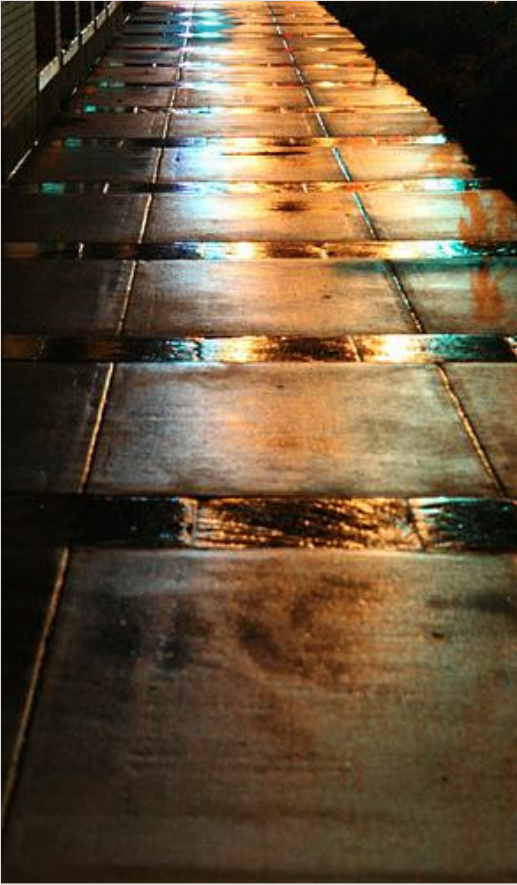
Texture-mapping using BTF

standard
texture-mapping



texture-mapping
with the BTF

Materials Change with Time



Practice Problems

Sketch a picture of what you think the BRDF might look like for a single incoming light direction and a particular surface. Please assume an incoming light direction 45 degrees from the surface normal. Assume a surface with both diffuse color and highlights, e.g. a green pepper. Write notes to explain your sketch.

Are there types of materials for which a constant is acceptable as a BRDF? What would such a surface look like?

Practice Problems

Describe an experiment to measure the BRDF that you sketched for the problem on the previous slide.

What data structure would you use to store such a BRDF?

Are there types of materials for which a one-dimensional function is acceptable as a BRDF? a two-dimensional function? a three-dimensional function? When do you need all four parameters to represent the BRDF adequately? When might you need five dimensions instead of four?