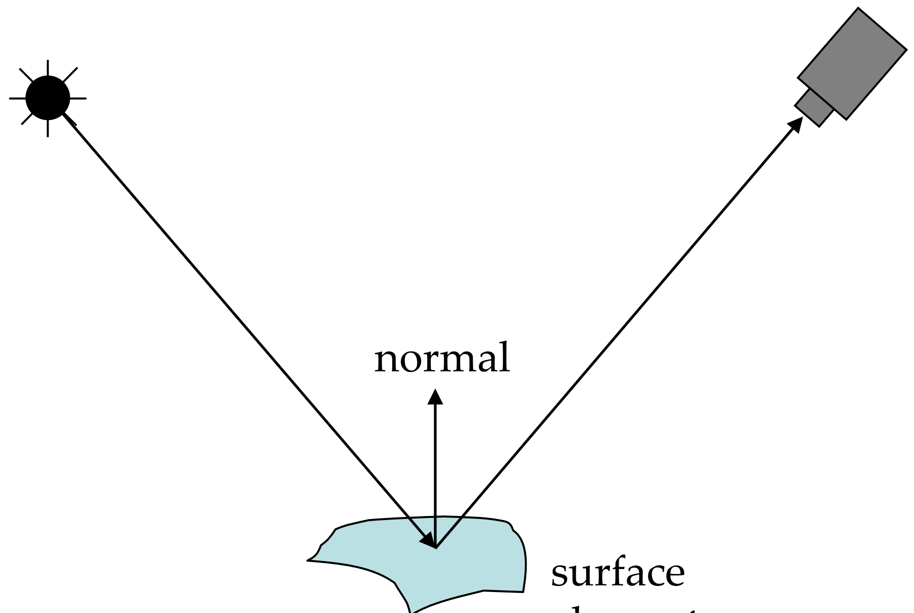
Materials and Surface Appearance

Thanks to Shree Nayar, Ravi Ramamoorthi, Pat Hanrahan

A Simple Illumination Model

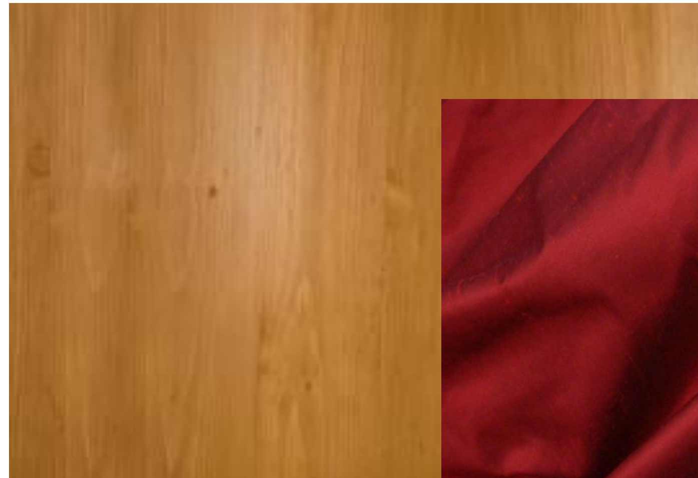


Phong Illumination Model:

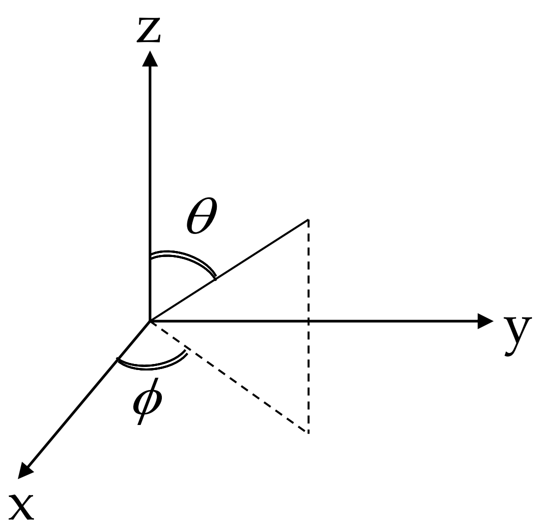
Image intensity is composed of diffuse, specular, and ambient terms

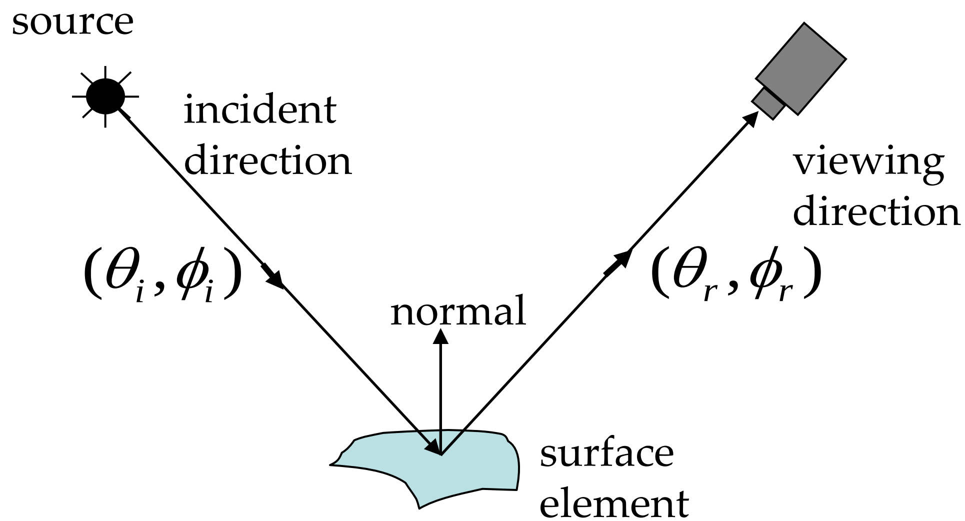
CHALKBOARD

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



BRDF: Bidirectional Reflectance Distribution Function



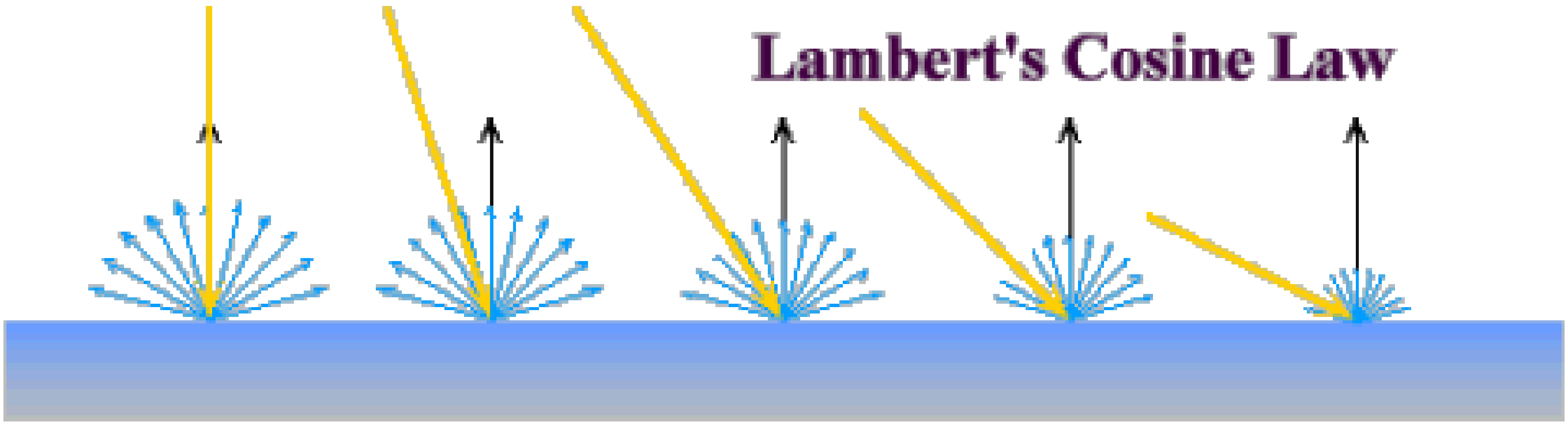


$E^{surface}(\theta_i, \phi_i)$ Irradiance at Surface in direction (θ_i, ϕ_i)

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

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

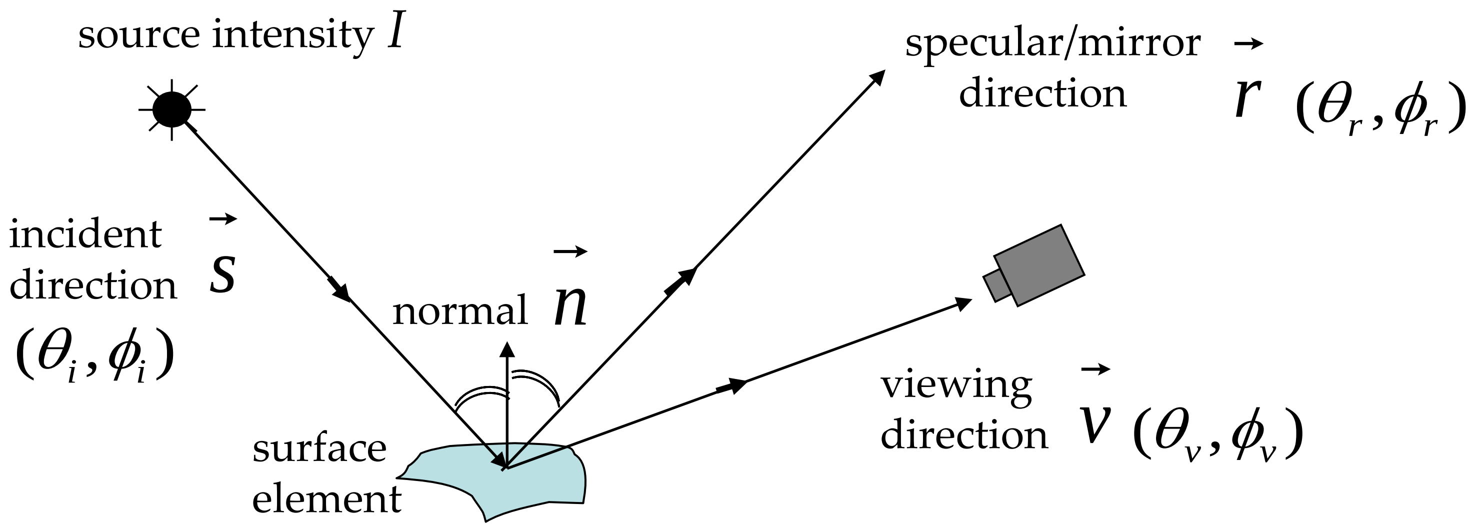
Diffuse Reflection and **Lambertian BRDF**



Rendered Sphere with Lambertian BRDF

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

Specular Reflection and **Mirror BRDF**



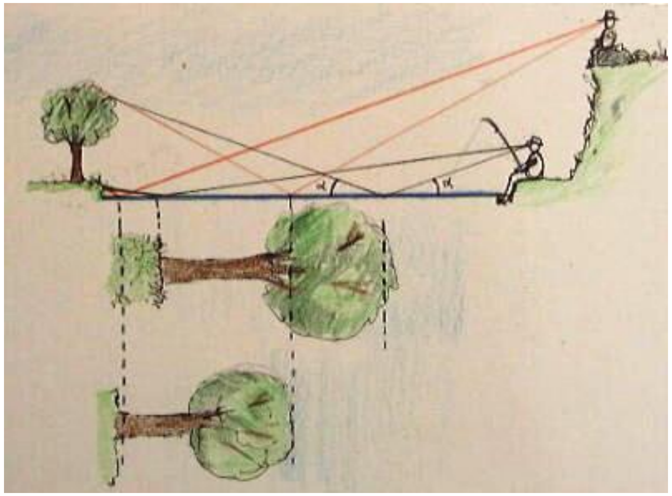
- Very smooth surface.
- All incident light energy reflected in a SINGLE direction. (only when $\vec{v} = \vec{r}$)

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

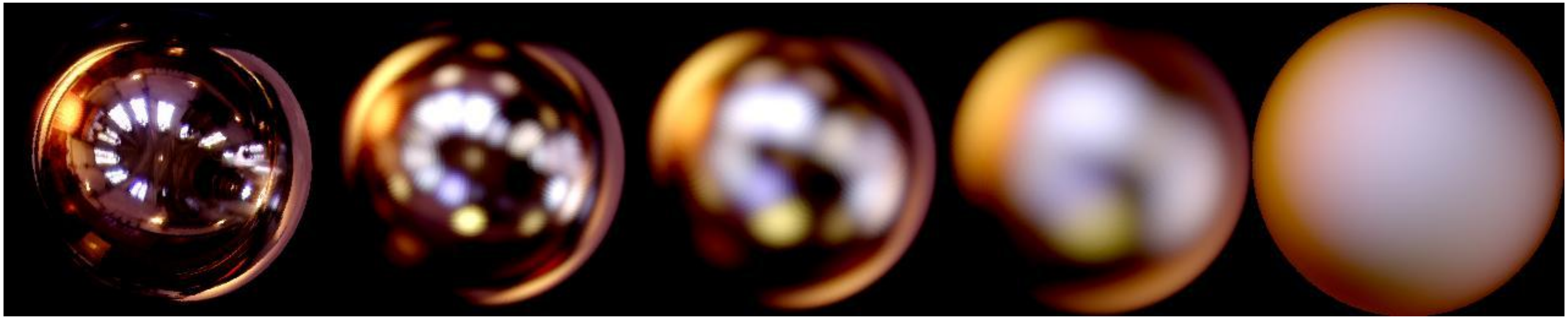
Glossy Surfaces

- 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).

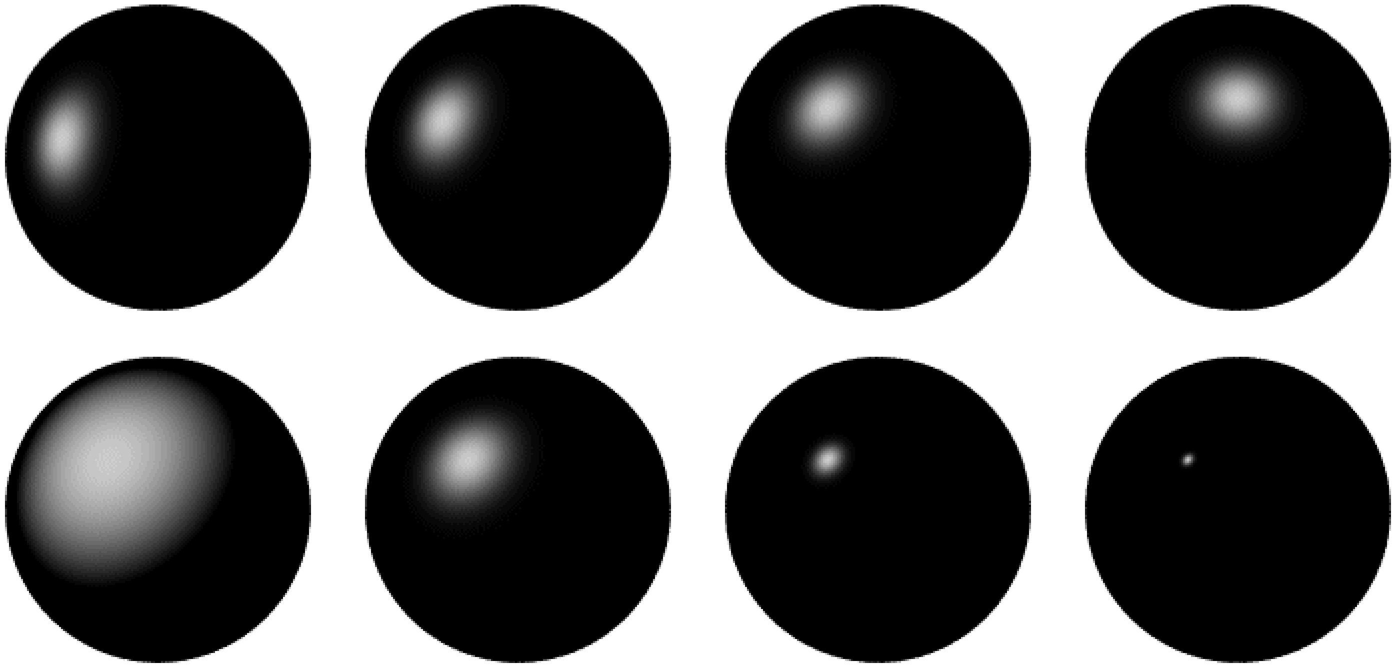
Blurred Highlights and Surface Roughness



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

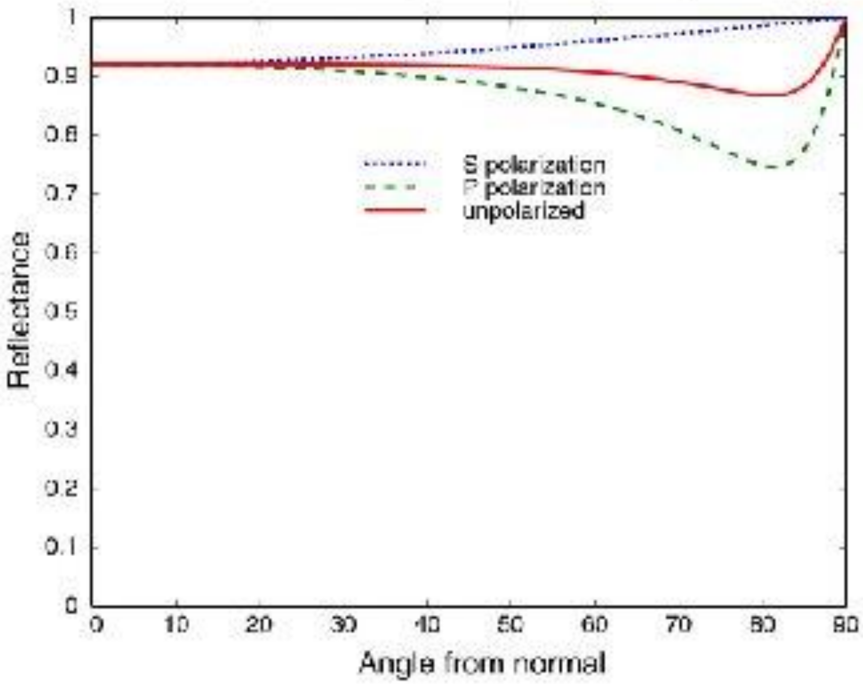
Experiment

Reflections from a shiny floor

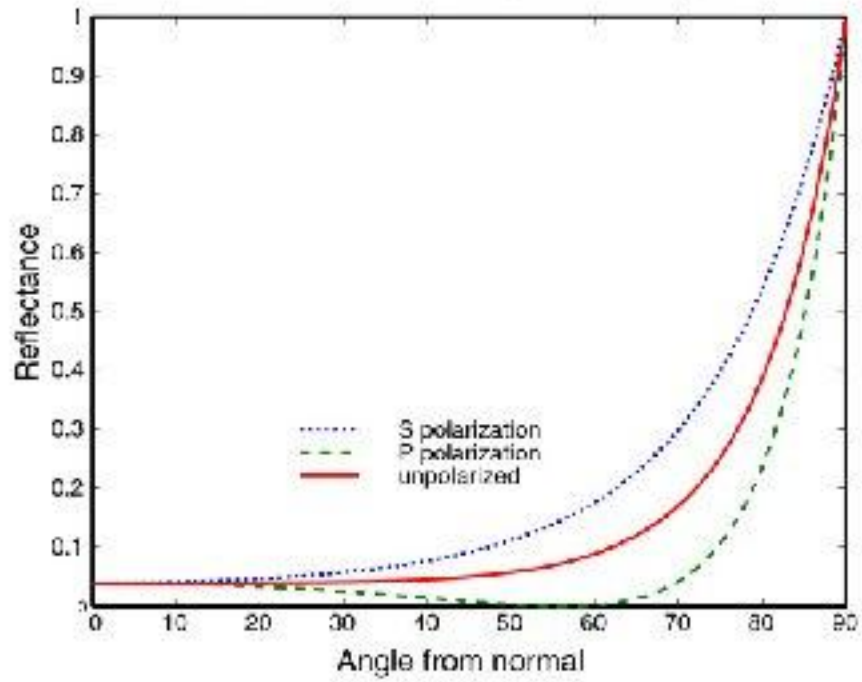
From Lafortune, Foo, Torrance, Greenberg, SIGGRAPH 97

Fresnel Reflectance

Metal (Aluminum)



Dielectric (N=1.5)

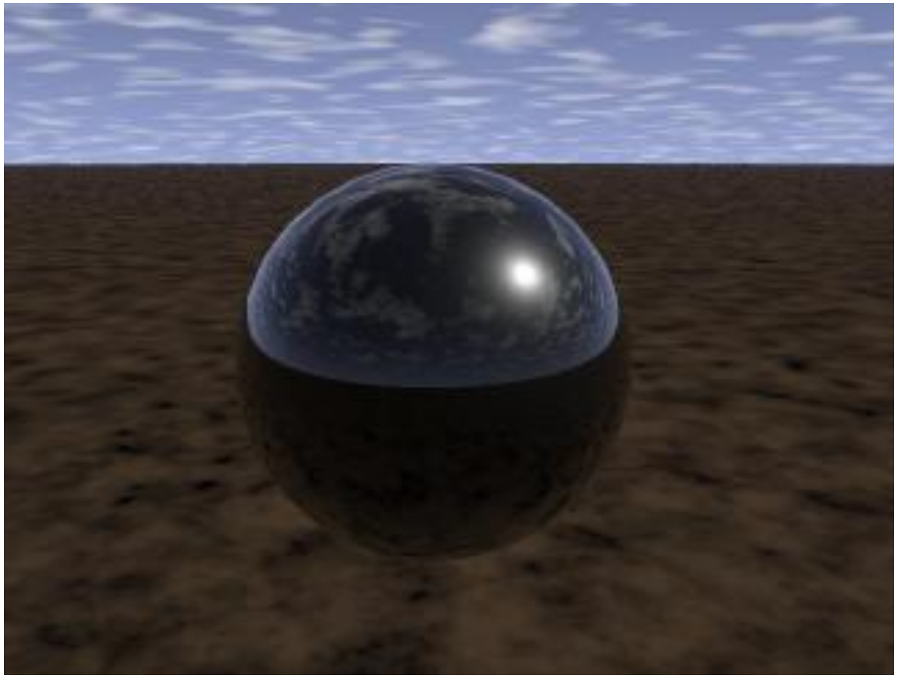


Gold F(0)=0.82
Silver F(0)=0.95

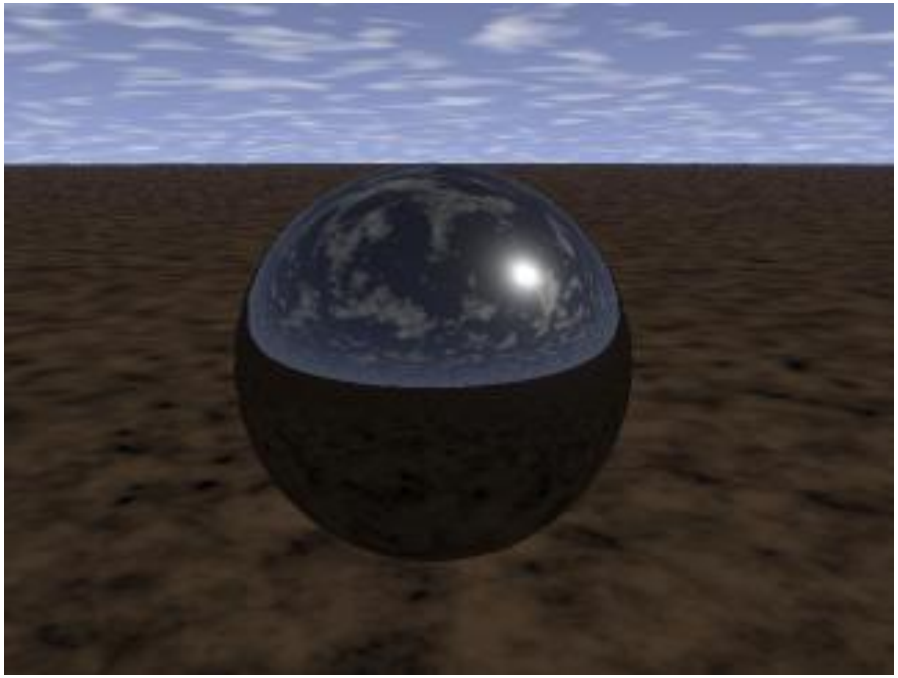
Glass n=1.5 F(0)=0.04
Diamond n=2.4 F(0)=0.15

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

With Fresnel Reflectance

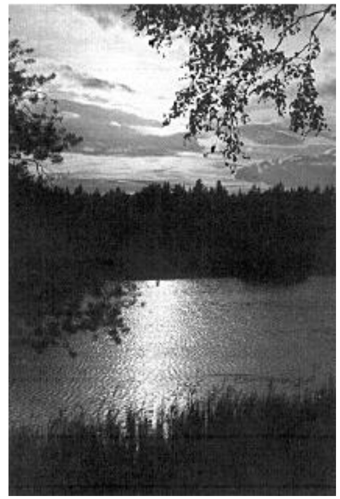


Without Fresnel Reflectance

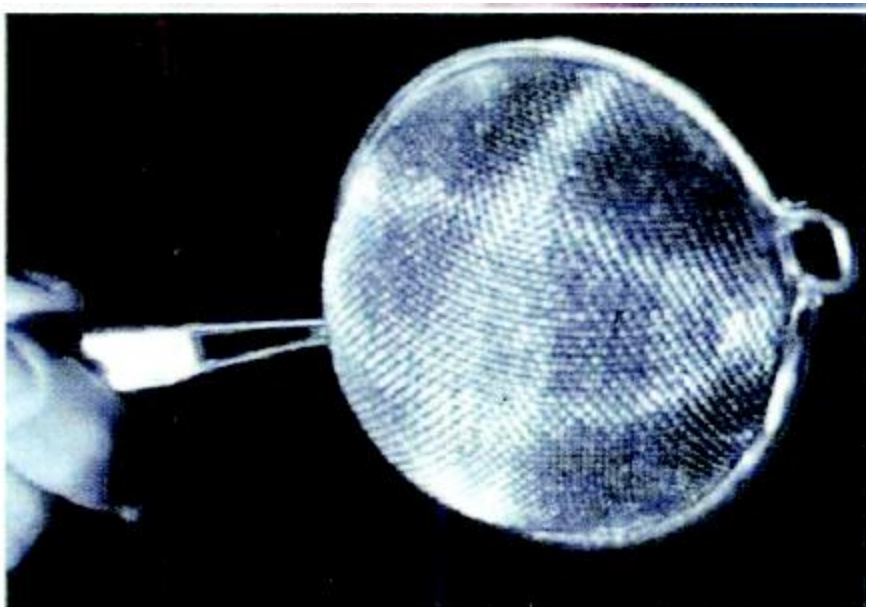


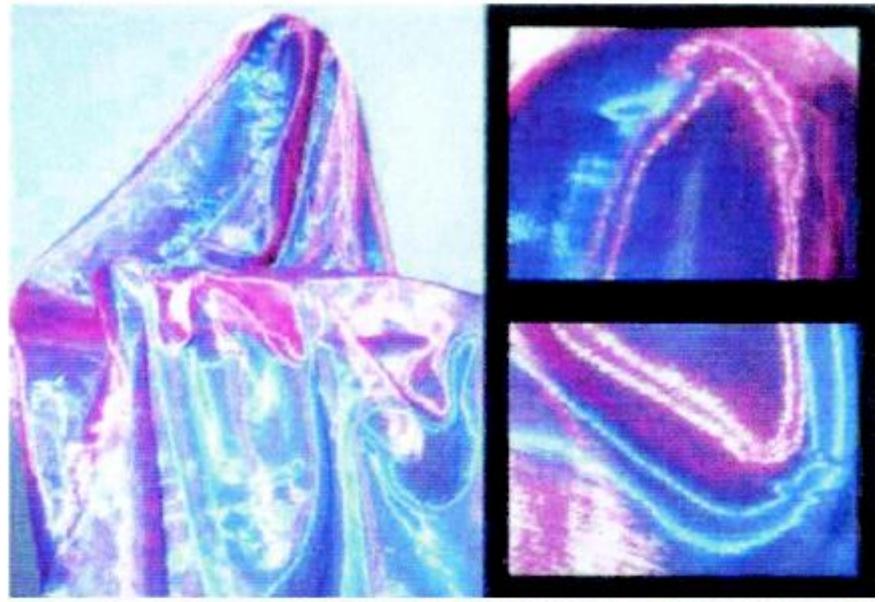
http://www.graphics.cornell.edu/~westin/misc/fresnel.html

Reflections on water surfaces - Glittering



Split off-specular Reflections in Woven Surfaces



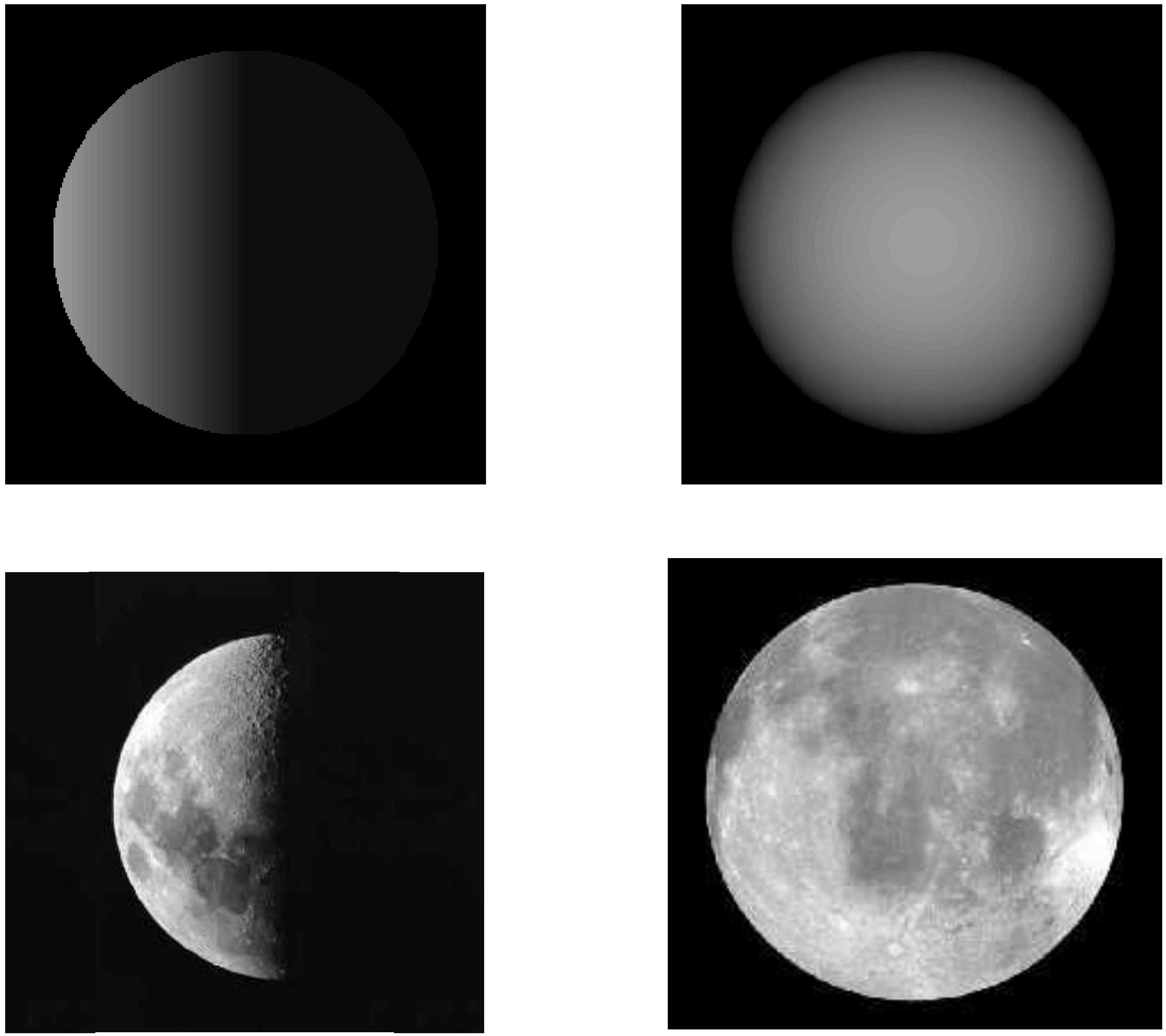


Why does the Full Moon have a flat appearance?

- The moon appears matte (or diffuse)

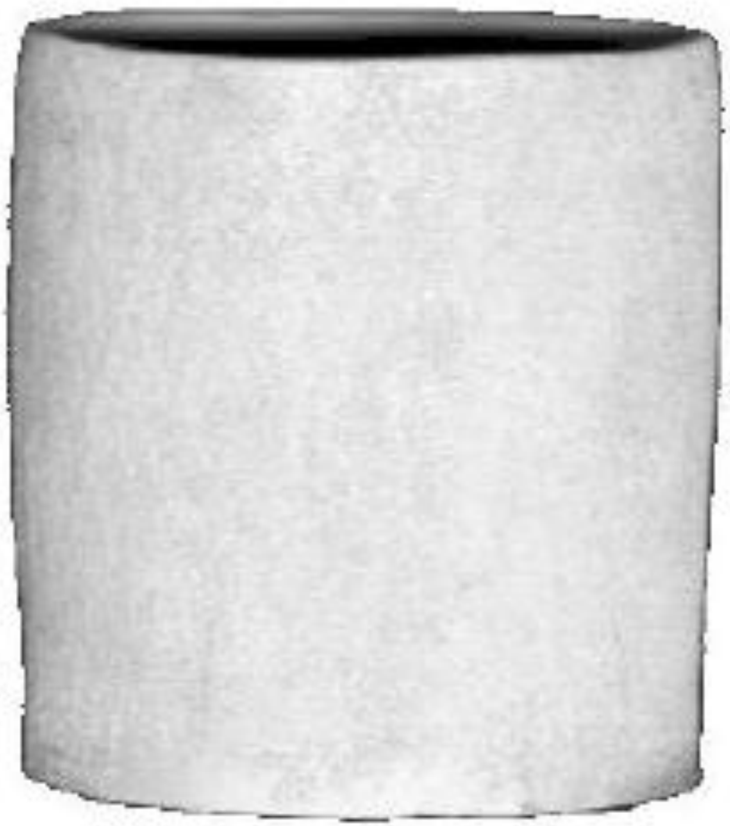
- But still, edges of the moon look bright (not close to zero) when illuminated by earth's radiance.

Why does the Full Moon have a flat appearance?



Lambertian Spheres and Moon Photos illuminated similarly

Surface Roughness Causes Flat Appearance



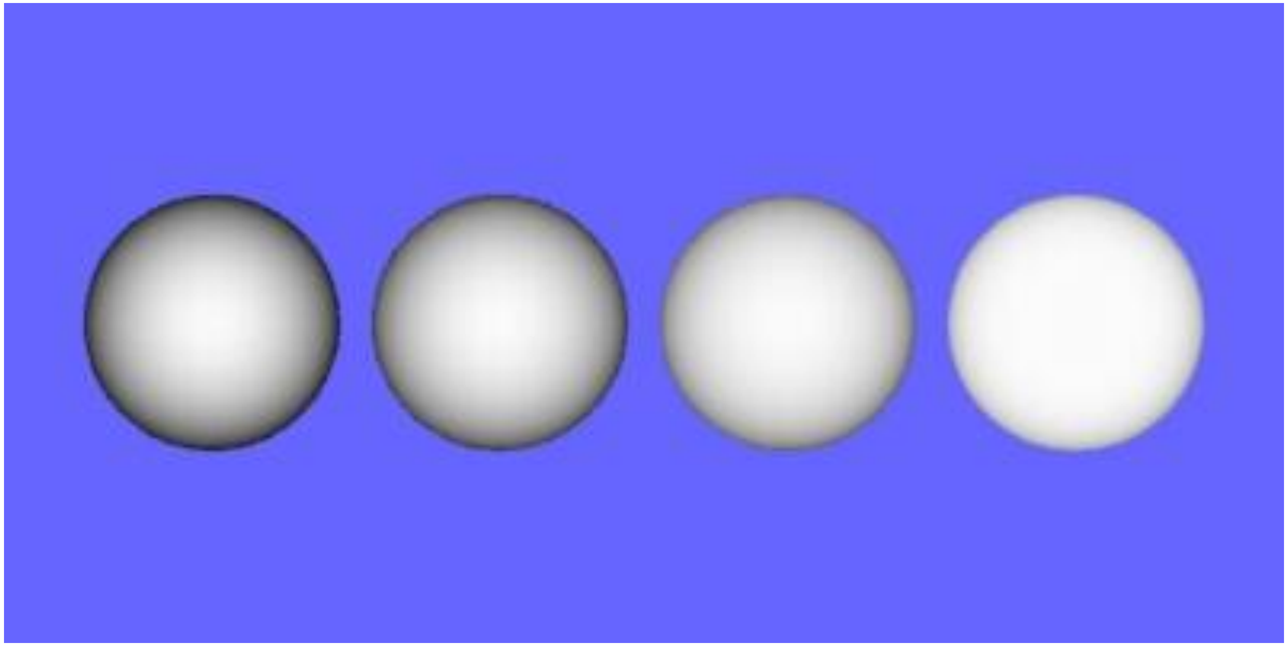
Actual Vase

Lambertian Vase

Rendered Sphere with Lambertian BRDF

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

Surface Roughness Causes Flat Appearance



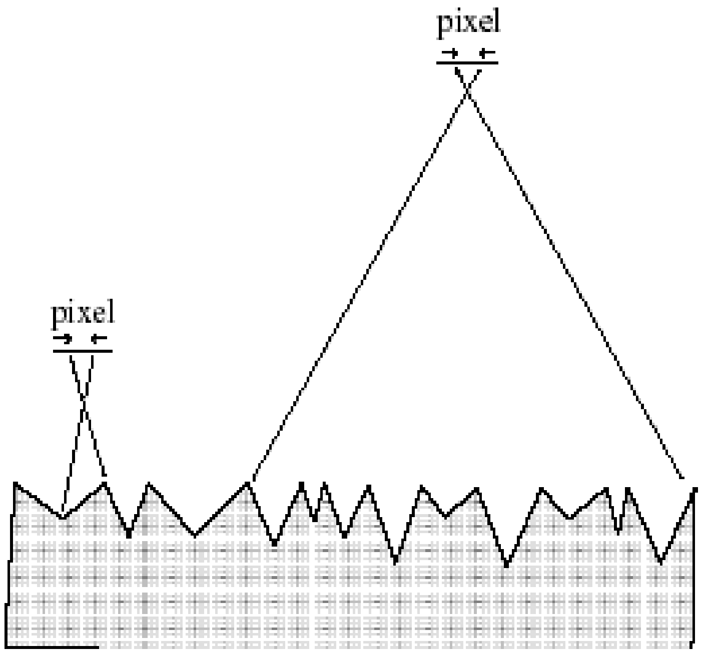
Increasing surface roughness →

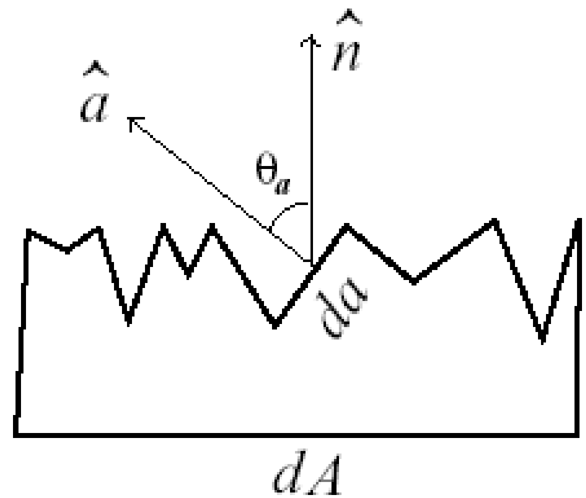
Lambertian model

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?

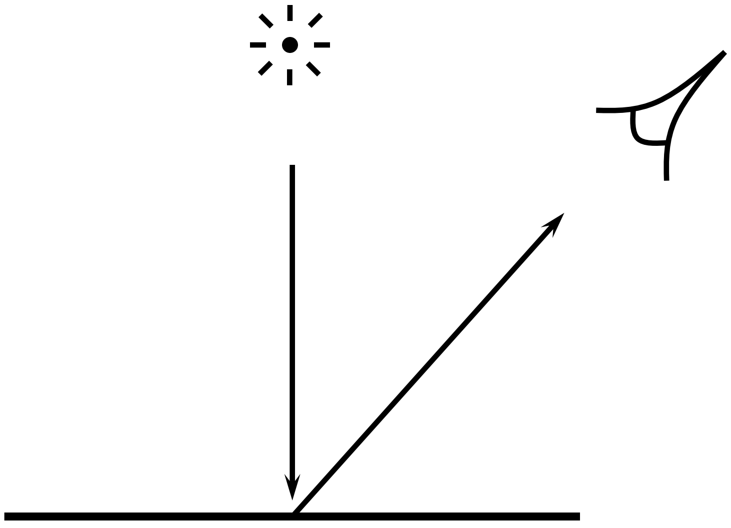
Why not directly measure BRDFs?

- True knowledge of surface properties
- Accurate models for graphics

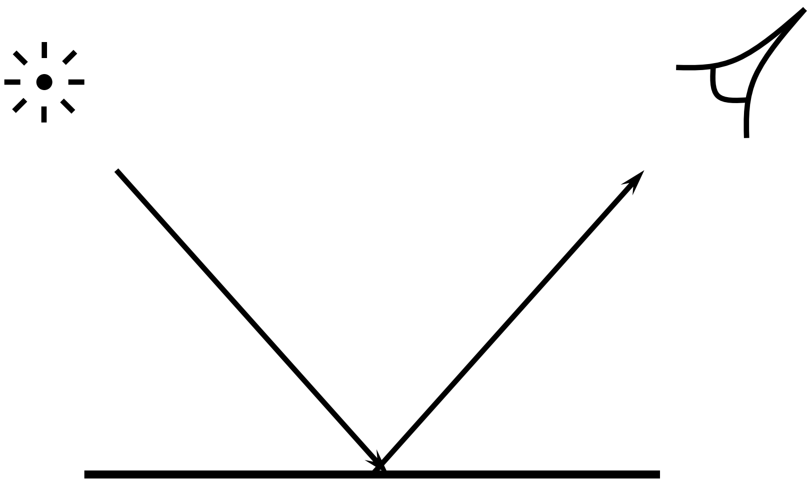
Measuring BRDFs

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

Measuring Reflectance



0º/45º
Diffuse Measurement



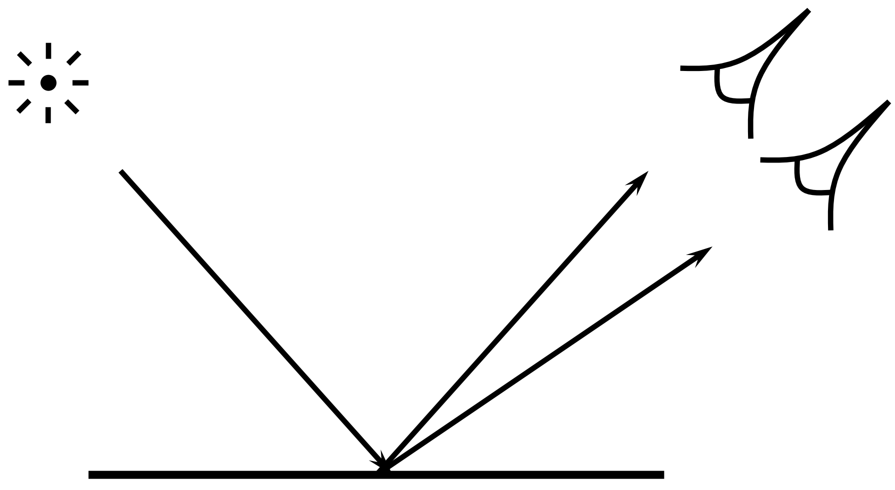
45º/45º
Specular Measurement

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

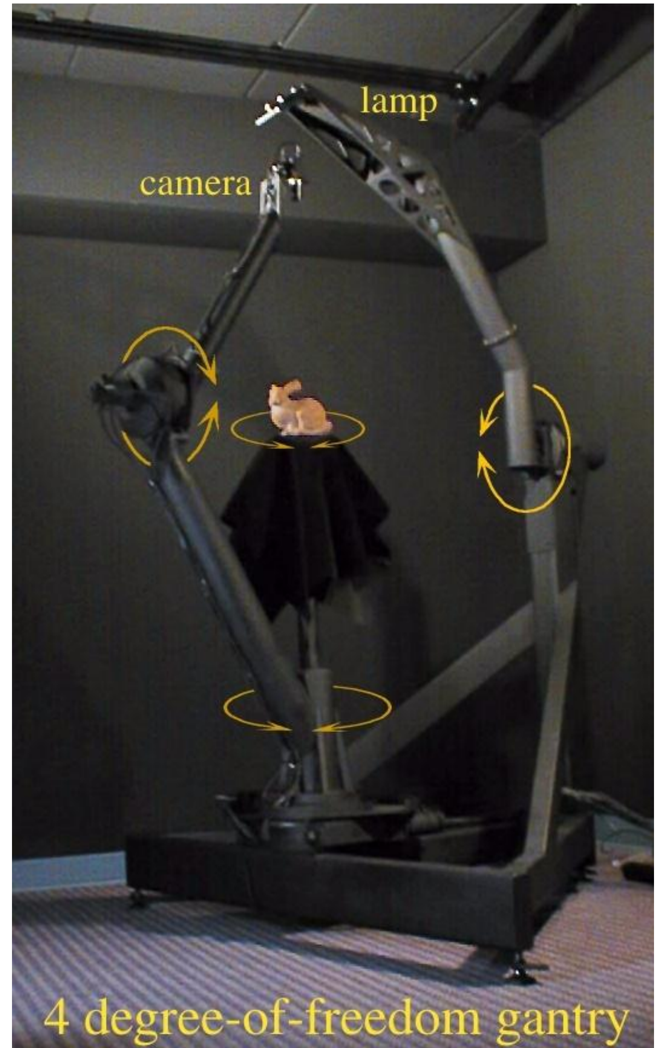


Image-Based BRDF Measurement

- 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

Measurement

SIGGRAPH2005

- 20-80 million reflectance measurements per material
- Each tabulated BRDF entails 90x90x180x3=4,374,000 measurement bins

Rendering from Tabulated BRDFs

SIGGRAPH2005

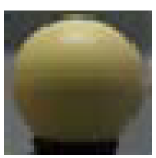
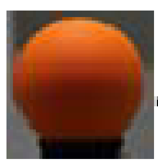
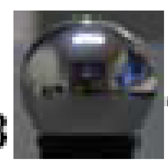
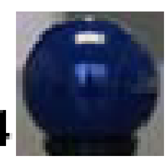
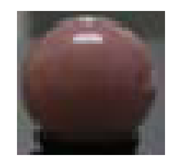
- These BRDFs are immediately useful
- Direct renderings from measurements

Nickel Hematite Gold Paint Pink Felt

Linear Combinations of BRDFs (LCB)

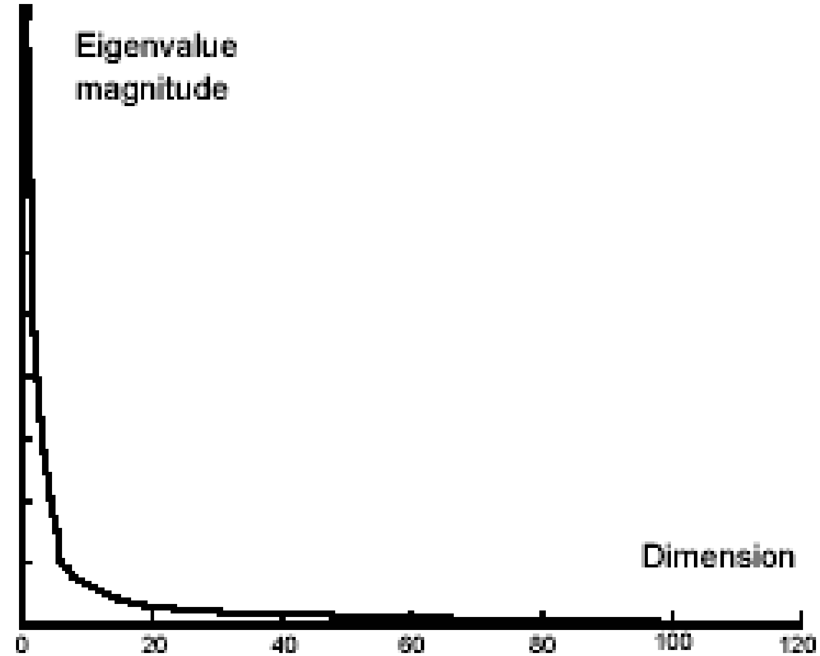
SIGGRAPH2005

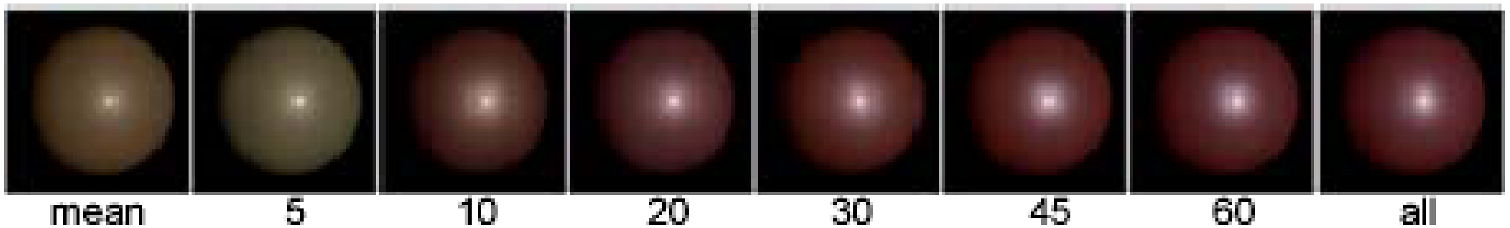
- Can we find a linear combination of our existing BRDFs that match any new one?
- Requires only estimating 100 coefficients for source BRDFs
- Compute a set of 800 constraints that allow estimating these 100 coefficients robustly

α_1  + α_2  + α_3  + α_4  + ... = 

Linear Analysis (PCA)

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





Navigation Results

SIGGRAPH2005

Adding Silver Trait

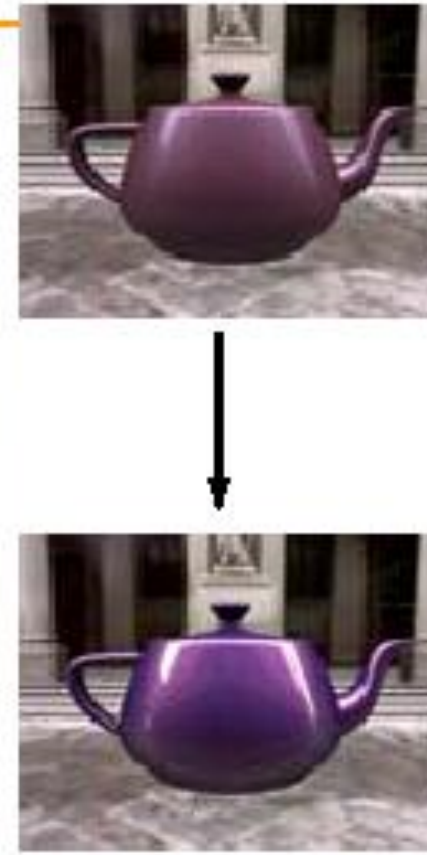
Navigation Results

SIGGRAPH2005

Adding Specular Trait

Navigation Results

SIGGRAPH2005



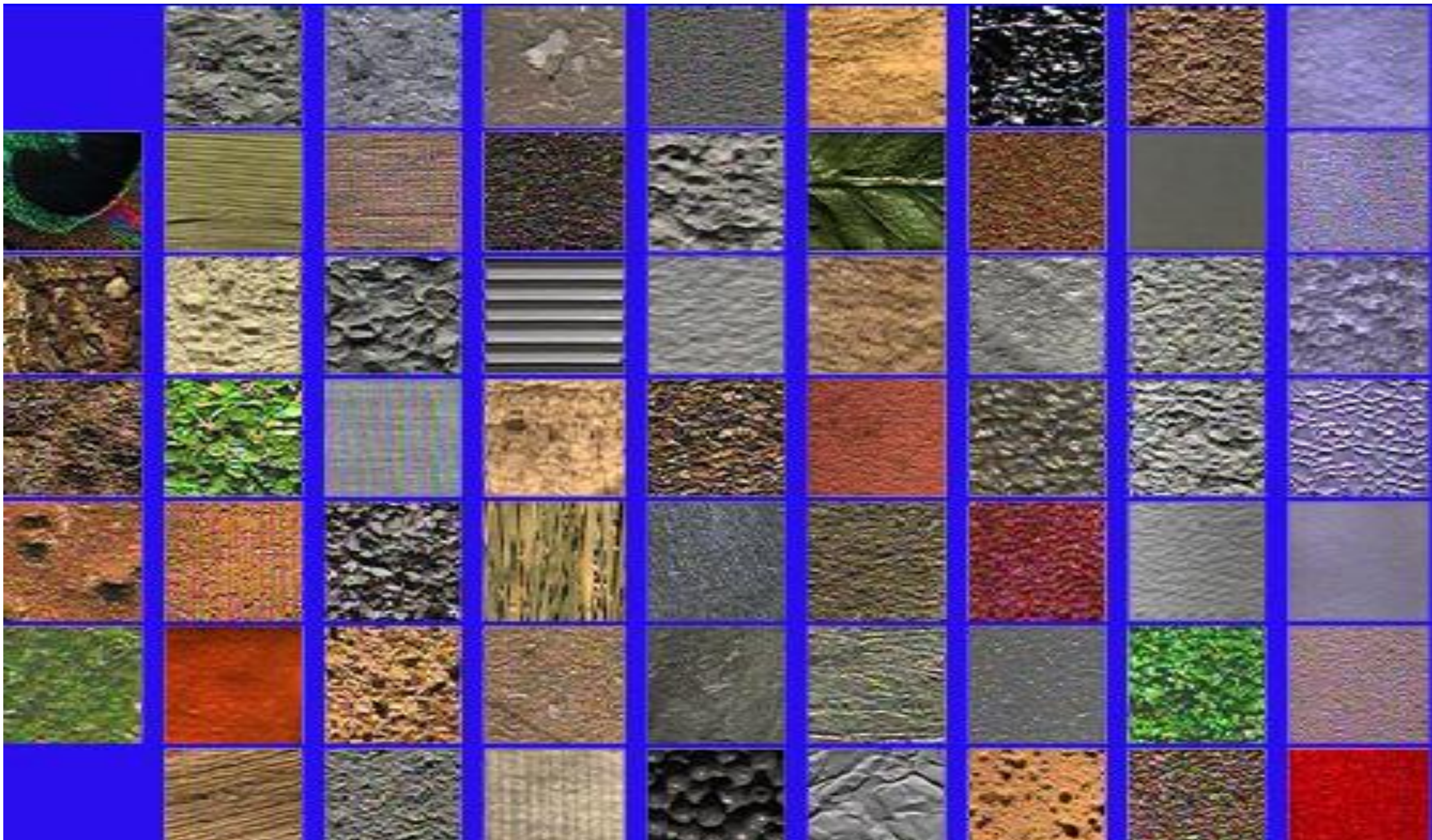
Adding Metallic Trait

Representing Physical Processes

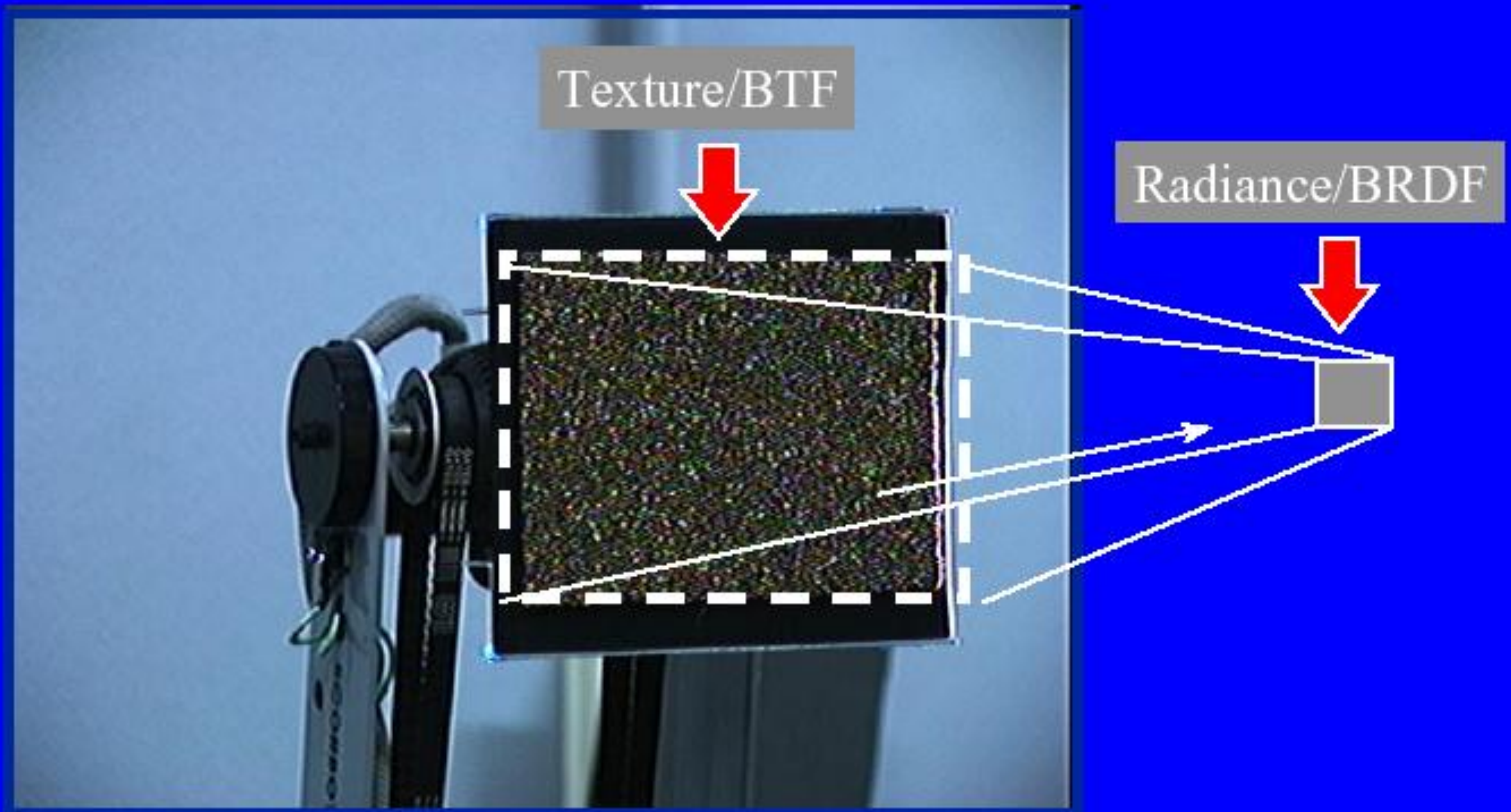
SIGGRAPH2005

Steel Oxidation

Looking ahead –
Real objects have texture!

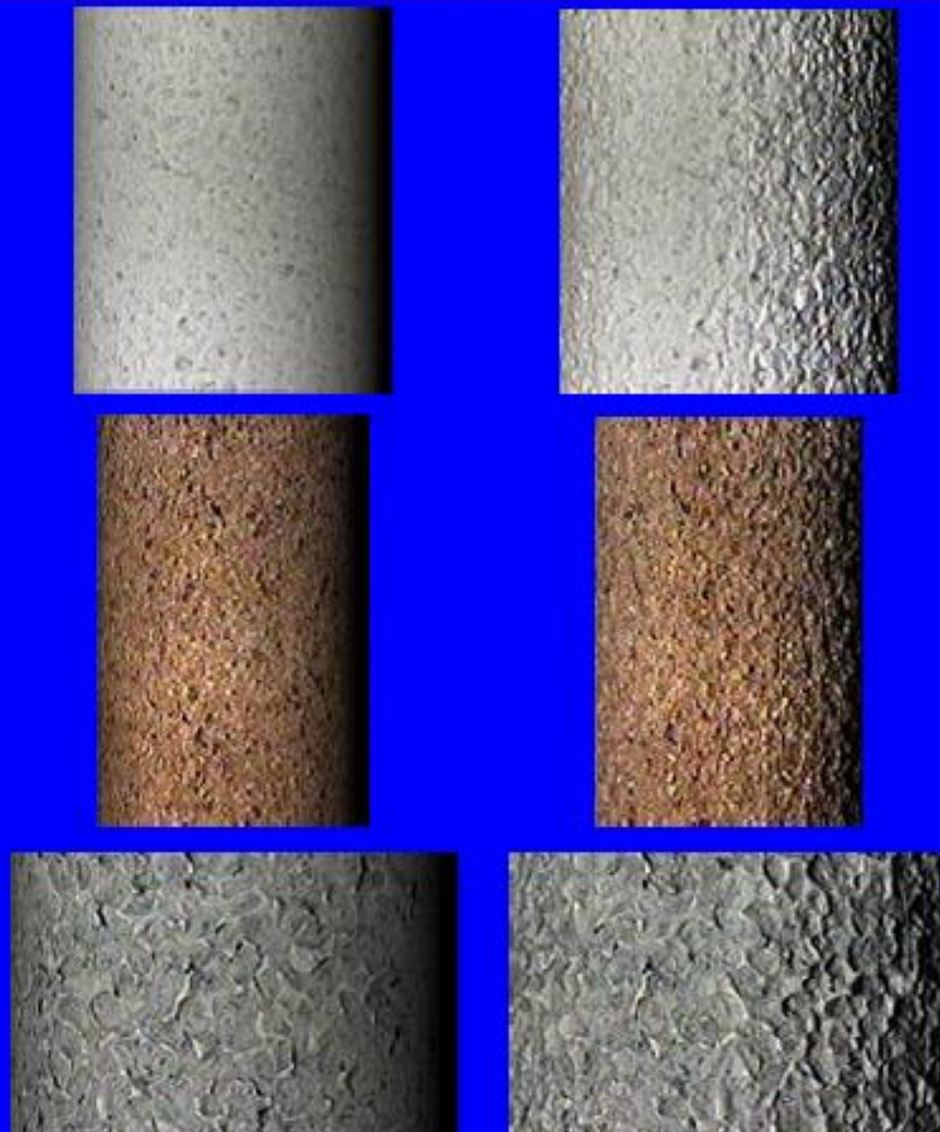


Measurement Methods



Texture-mapping using BTF

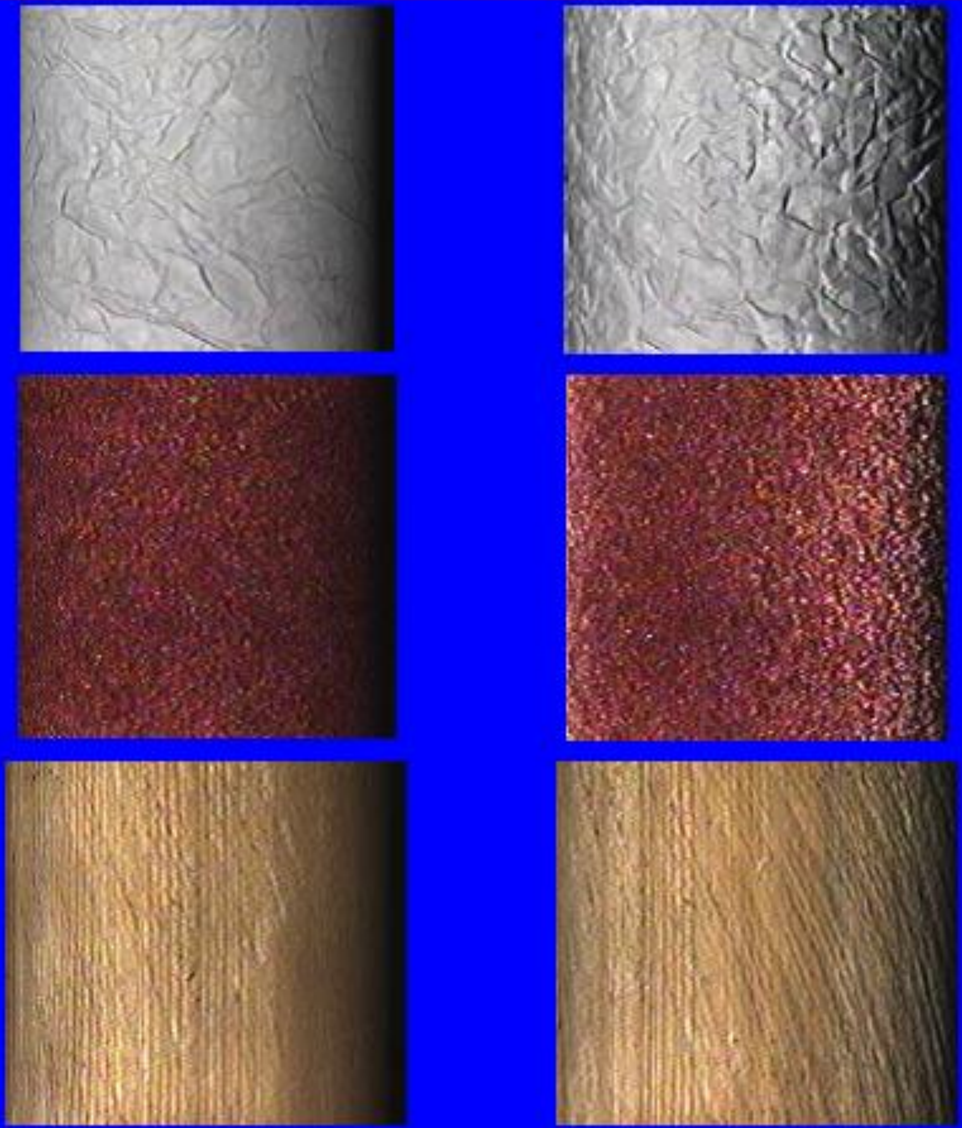
standard
texture-mapping



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?