CS 5625
Lec 2: Shading Models

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Spring 2013

Next few weeks

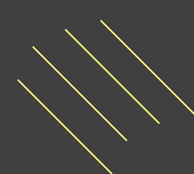
- Shading Models
  - Chapter 7
- Textures
- Graphics Pipeline

To compute images…

- Light Emission
  - What are the light sources?
- Light Propagation
  - Fog/Clear?
- Light Reflection
  - Interaction with media

Types of Lights

- Directional lights
  - E.g., sunlight
  - Light vector fixed direction



- Point lights
  - E.g., bulbs 
  - Light position fixed

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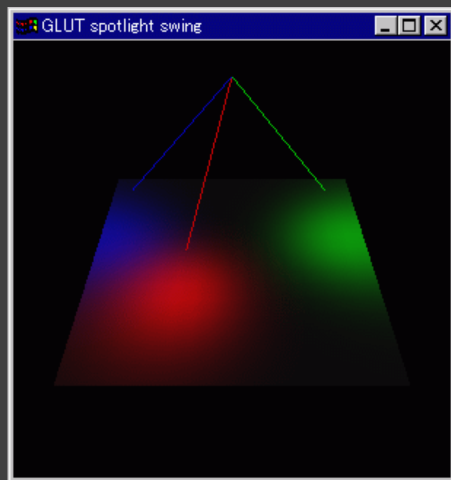
Types of Lights

- Spot lights: Like point light, but also
  - Cut-off angle
  - Attenuation



Types of Lights

- Area Lights: generate soft shadows

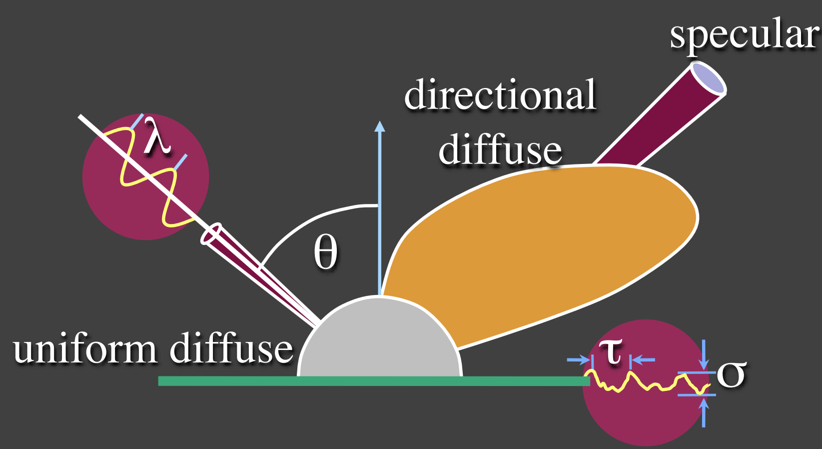
Types of Light

- Environment Maps

To compute images…

- Light Emission
  – What are the light sources?
- Light Propagation
  – Fog/Clear?
- Light Reflection
  – Interaction with media

Bidirectional Reflectance Distribution Function (BRDF)



Surface reflective characteristics

- Spectral distribution
  - Responsible for surface color
  - Tabulate in independent wavelength bands, or RGB
- Spatial distribution
  - Material properties vary with surface position
  - Texture maps
- Directional distribution
  - BRDF
  - Tabulation is impractical because of dimensionality

Radiometry

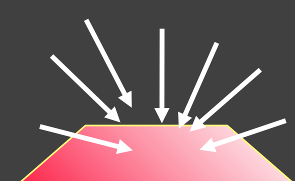
- Radiometry: measurement of light energy

- Defines relation between
  – Power
  – Energy
  – Radiance
  – Radiosity

Radiometric Terms

- Power: energy per unit time

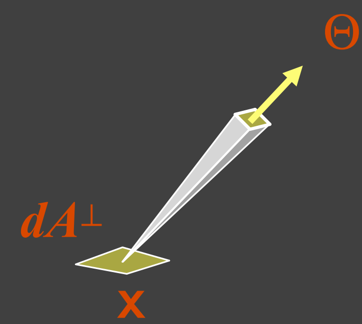
- Irradiance: Incident power per unit surface area
  – From all directions
  – $Watt/m^2$



- Radiosity: Exitant power per unit surface area
  – Same units

Radiance

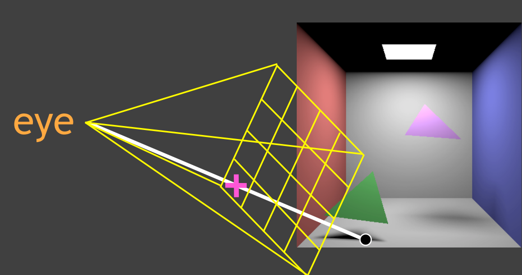
- Radiance is radiant energy at x in direction θ: 5D function
  – Power
    - per unit projected surface area
    - per unit solid angle



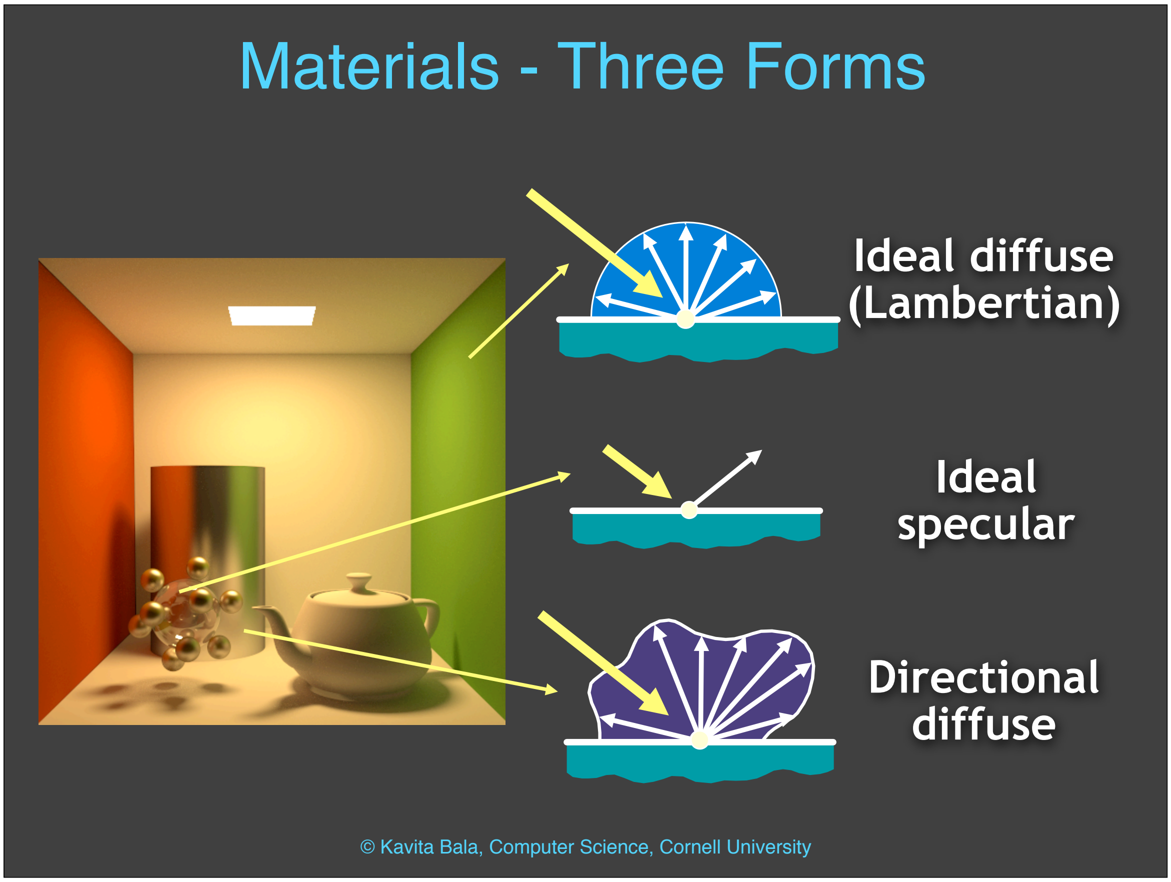
  – units: Watt / m^2.sr

Why is radiance important?

- Response of a sensor (camera, human eye) is proportional to radiance



- Pixel values in image proportional to radiance received from that direction


Materials - Three Forms
Ideal diffuse
(Lambertian)
Ideal
specular
Directional
diffuse
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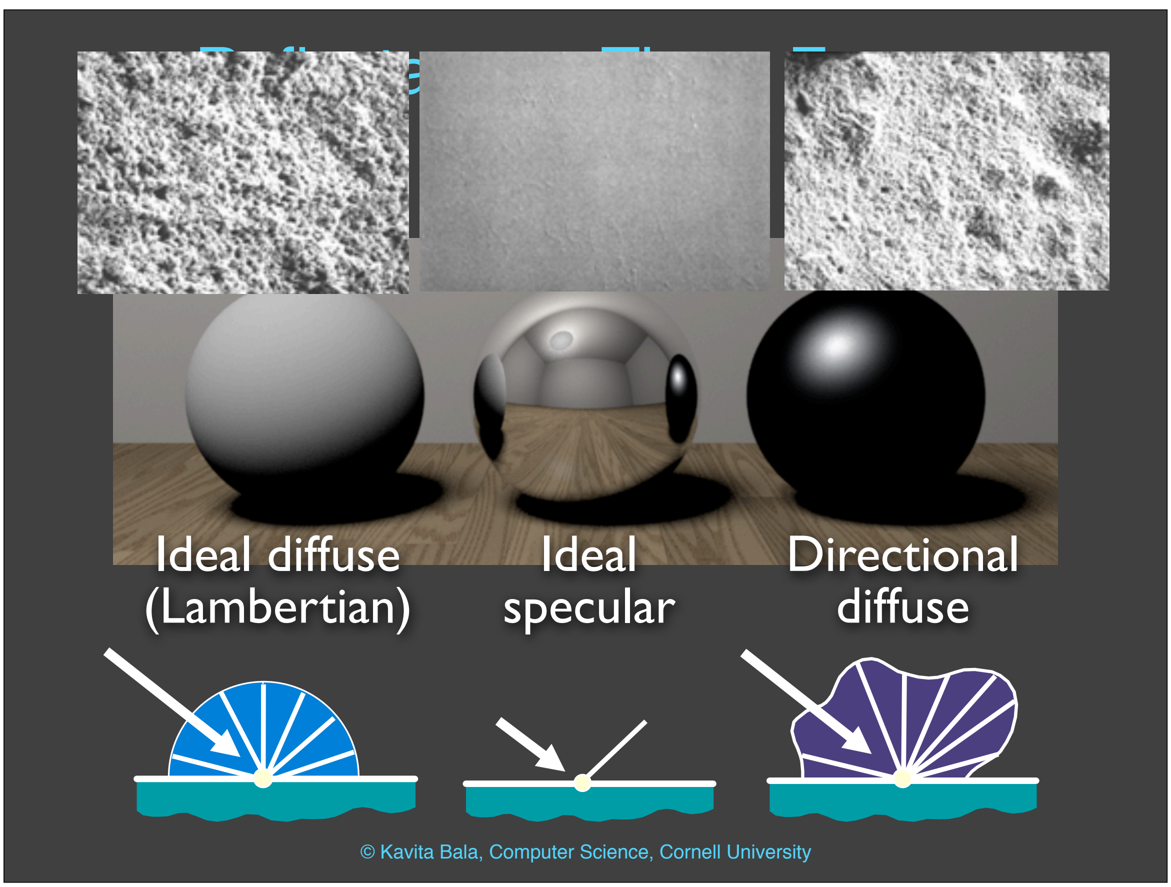
Ideal diffuse
(Lambertian)
Ideal
specular
Directional
diffuse
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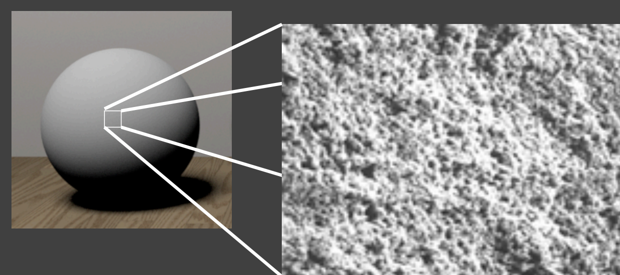
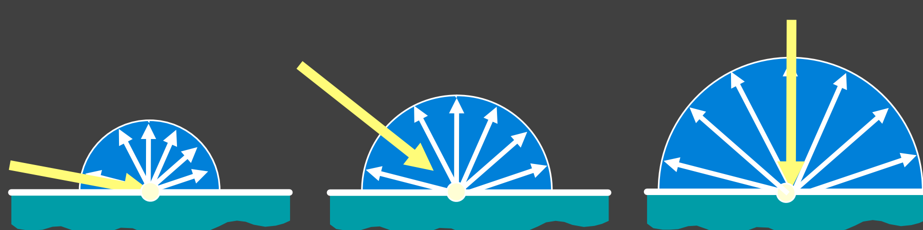
Ideal Diffuse Reflection

- Characteristic of multiple scattering materials
- An idealization but reasonable for matte surfaces
- Basis of most radiosity methods



Ideal Diffuse

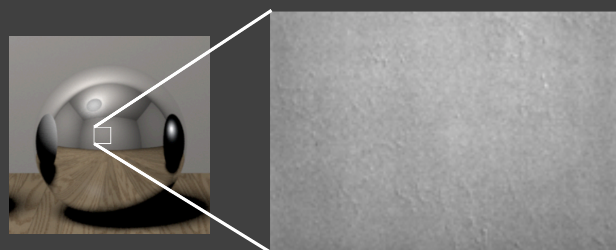
- Lambert's Law



$$I_{diffuse} = I_{light} k_d cos(\theta)$$
$$I_{diffuse} = I_{light} k_d N.L$$

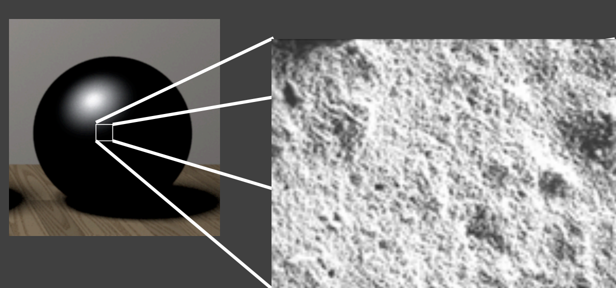
Ideal Specular Reflection

- Calculated from Fresnel's equations
- Exact for polished surfaces
- Basis of early ray-tracing methods



Directional Diffuse Reflection

- Characteristic of most rough surfaces
- Described by the BRDF



Classes of Models for the BRDF

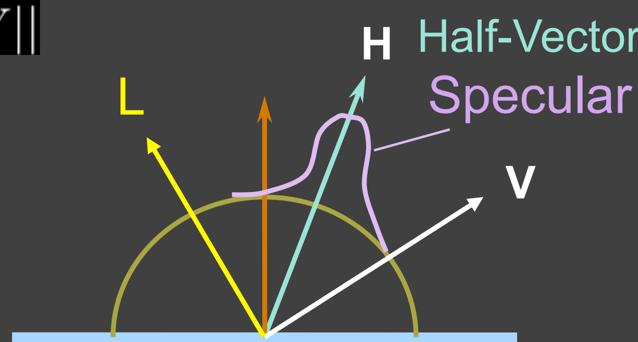
- Plausible simple functions
  - Phong 1975;
- Physics-based models
  - Cook/Torrance, 1981; He et al. 1992;
- Empirically-based models
  - Ward 1992

Phong Shading Model

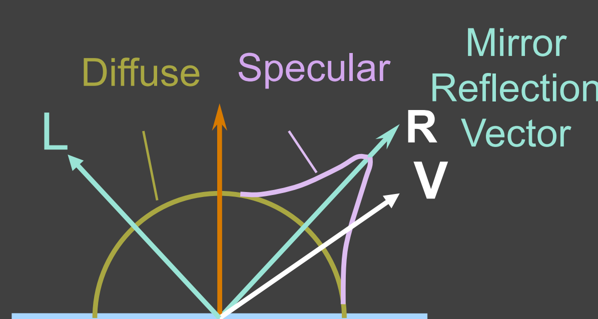
- Classic Phong
  - Ambient
  - Diffuse
  - Specular (Phong highlight)
  - Also fog and transparency possible
- For each light evaluate above

Specular

- Specular
  - Simulates surface smoothness
  - (max {**N** • **H**, 0})^{shininess}
  - $H = \frac{L+V}{||L+V||}$

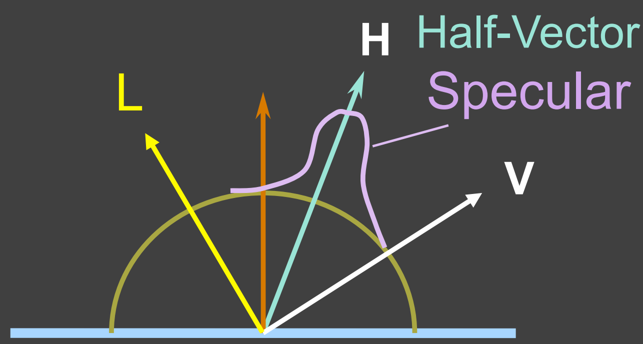


Phong Reflection Model



$$Diffuse = k_d(N.L)$$
$$Specular = k_s(R.V)^n$$

The Blinn-Phong Model



$$Diffuse = k_d(N.L)$$
$$Specular = k_s(N.H)^n$$

Phong Shading Model

- I = ambient + diffuse + specular

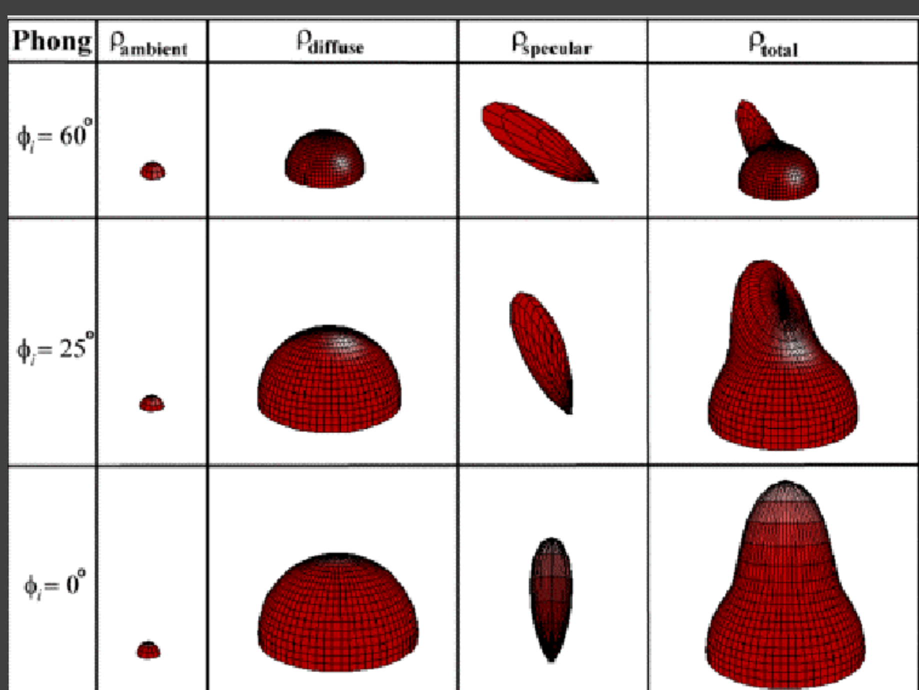
$$I = k_a I_a + k_d I_d (N.L) + k_s I_s (N.H)^n$$

- We want all the I's and k's to be functions of (R,G,B)
  - I's are function of light
  - k's are function of material

- Sum over all lights

Terms in Phong

- Ambient
  - "Fake" global illumination
  - Fixed from all directions
    - Makes it not black



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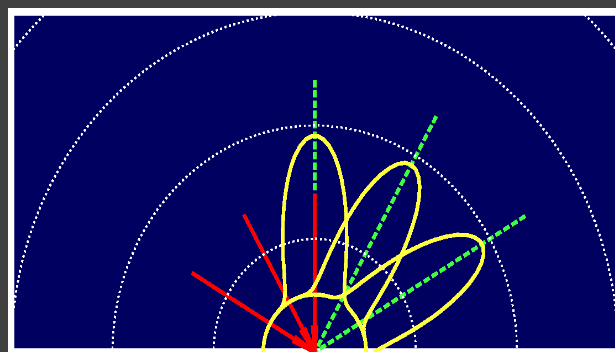
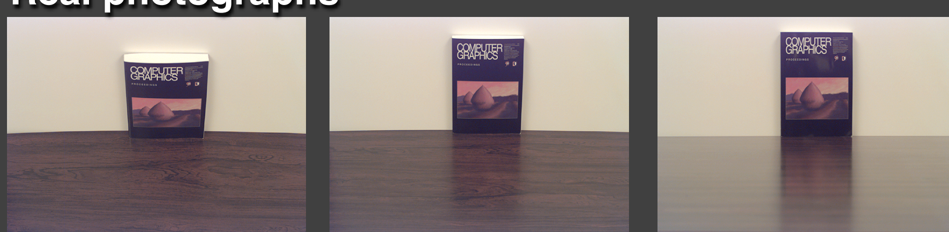
The Phong Model

- Computationally simple
- Visually pleasing

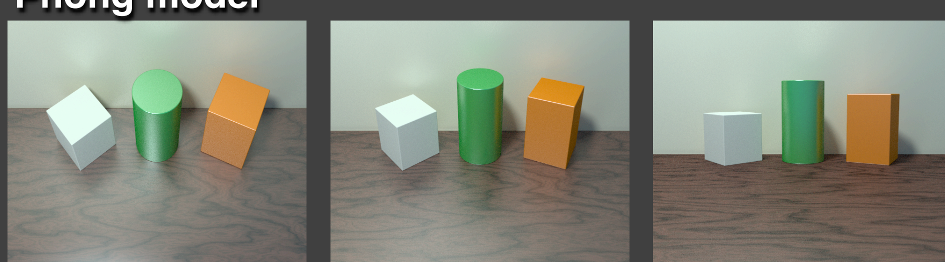


Phong: Reality Check

Real photographs

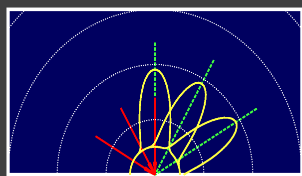


Phong model

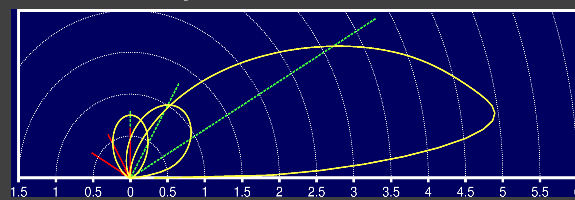


Phong: Reality Check

Phong model



Physics-based model



- Doesn't represent physical reality
  - Energy not conserved
  - Not reciprocal
  - Maximum always in specular direction

Reciprocity

- Interchange L and V
  - Photon doesn't know its direction
  - Same behavior

- Blinn-Phong vs. Phong

Classes of Models for the BRDF

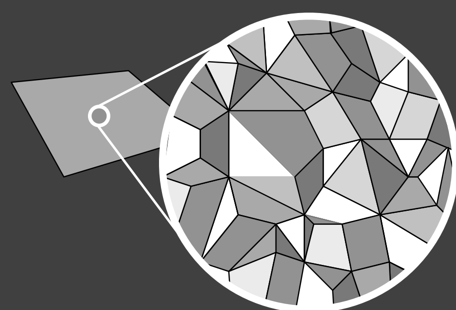
- Plausible simple functions
  - Phong 1975;
- Physics-based models
  - Cook/Torrance, 1981; He et al. 1992;
- Empirically-based models
  - Ward 1992, Lafortune model

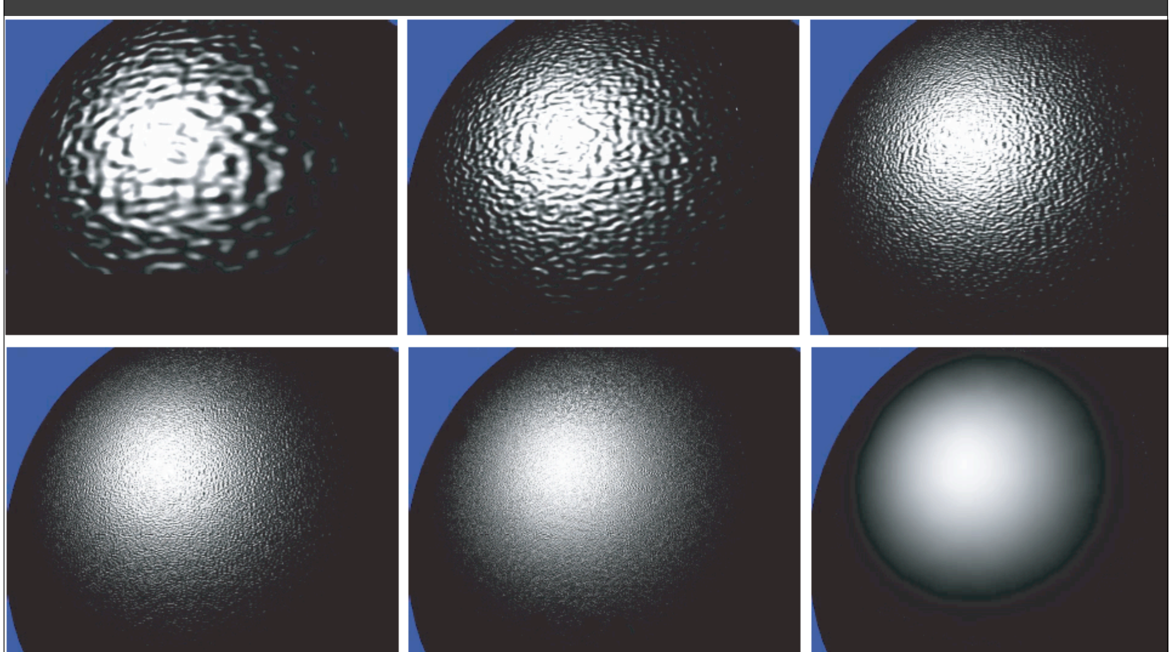
Motivation for Cook-Torrance

- Plastic has substrate that is white with embedded pigment particles
  - Colored diffuse component
  - White specular component
- Metal
  - Specular component depends on metal
  - Negligible diffuse component

Cook-Torrance BRDF Model

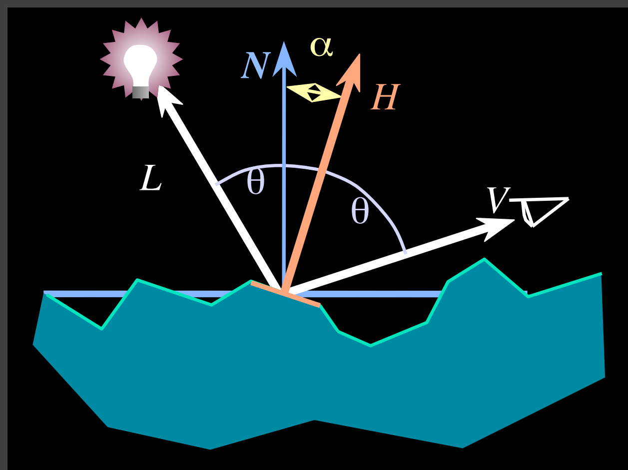
- Phong: too smooth
- A *microfacet* model
  - Surface modeled as random collection of planar facets
  - Incoming ray hits exactly one facet, at random





Facet Reflection

- Input: probability distribution of facet angle
- *H* vector used to define facets that contribute



Cook-Torrance BRDF Model

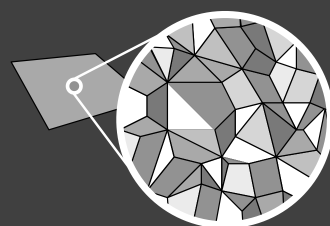
- "Specular" term (really directional diffuse)

$$f_s = \frac{\rho_s}{\pi} \frac{FDG}{N.LN.V}$$

Cook-Torrance BRDF Model

Facet distribution

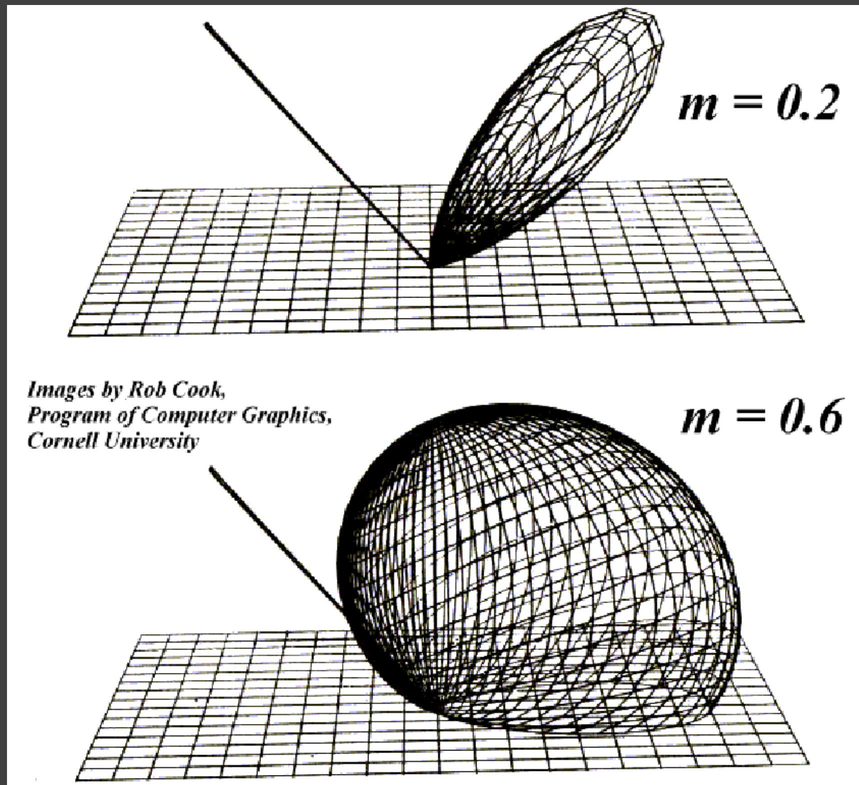
$F\ DG$



Facet Distribution

- ***D*** function describes distribution of ***H***
- Formula due to Beckmann
  - Statistical model
  - Alpha is angle between N and H
    - Intuitively, deviation of microgeometry from macro normal
  - m is RMS slope of microfacets: large m means more spread out reflections

$$D = \frac{1}{4m^2 cos^4 \alpha} e^{-[\frac{\tan \alpha}{m}]^2}$$



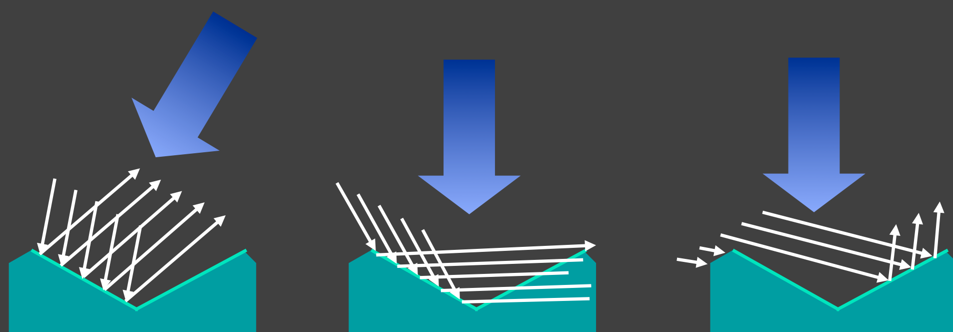
Cook-Torrance BRDF Model

$F \; D G$

Masking/shadowing

Masking and Shadowing

$$G = min[1, \frac{2N.HN.V}{V.H}, \frac{2N.HN.L}{V.H}]$$

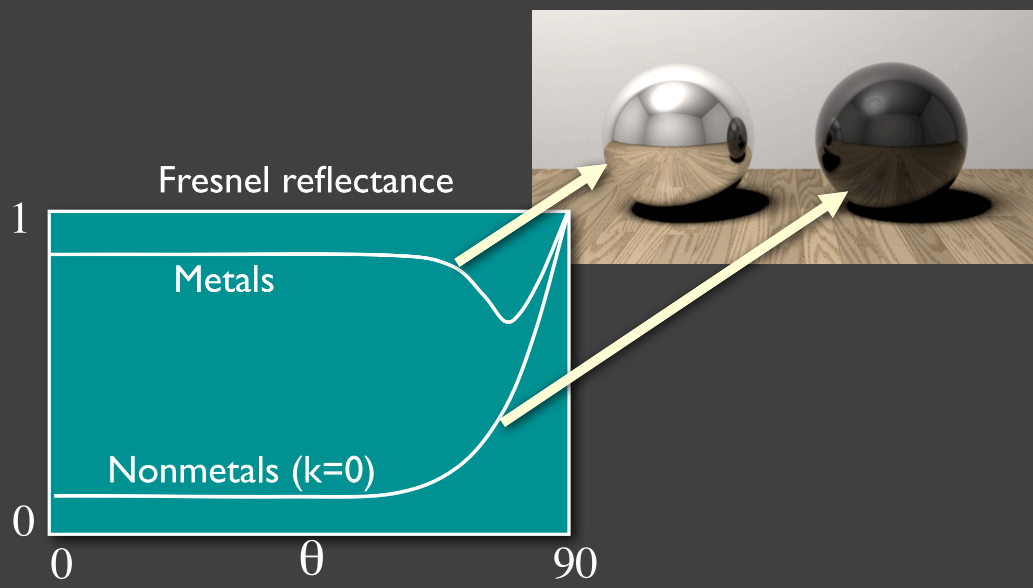


Fresnel Reflection Properties

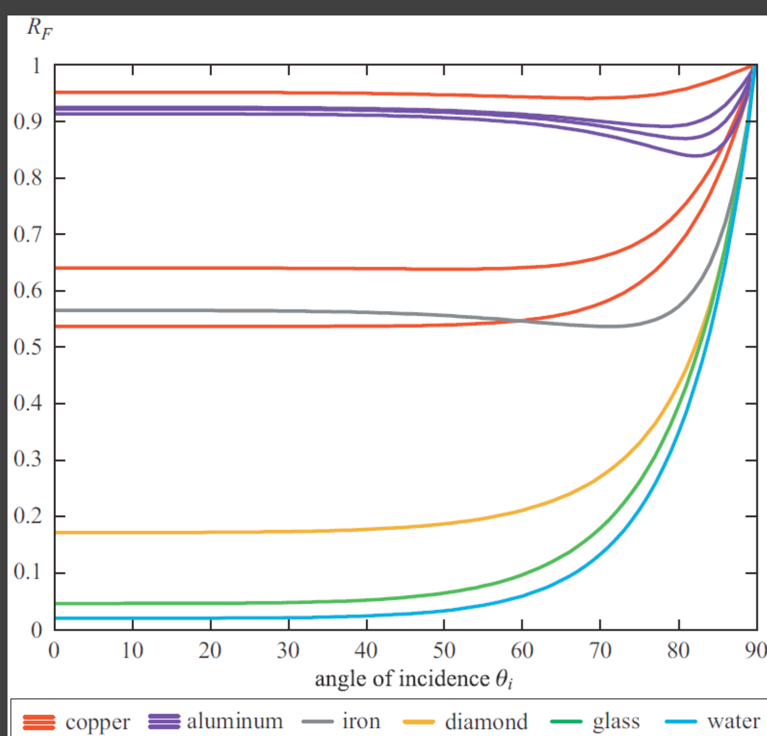
- Gives coefficients when light moves between different media
- Polarization
- Captures behavior of metals and dielectrics

- Explains why reflection increases (and surfaces appear more “mirror”-like) at grazing angles

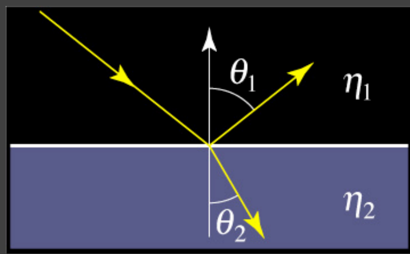
Metal vs. Nonmetal



Highly Non-Linear



Fresnel Equations



$$\eta_1 \sin(\theta_1) = \eta_2 \sin(\theta_2)$$

$$F_p = \frac{\eta_2 \cos(\theta_1) - \eta_1 \cos(\theta_2)}{\eta_2 \cos(\theta_1) + \eta_1 \cos(\theta_2)}$$

$$F_s = \frac{\eta_1 \cos(\theta_1) - \eta_2 \cos(\theta_2)}{\eta_1 \cos(\theta_1) + \eta_2 \cos(\theta_2)}$$

Fresnel Reflectance

$$F = \frac{F_s + F_p}{2}$$ for unpolarized light

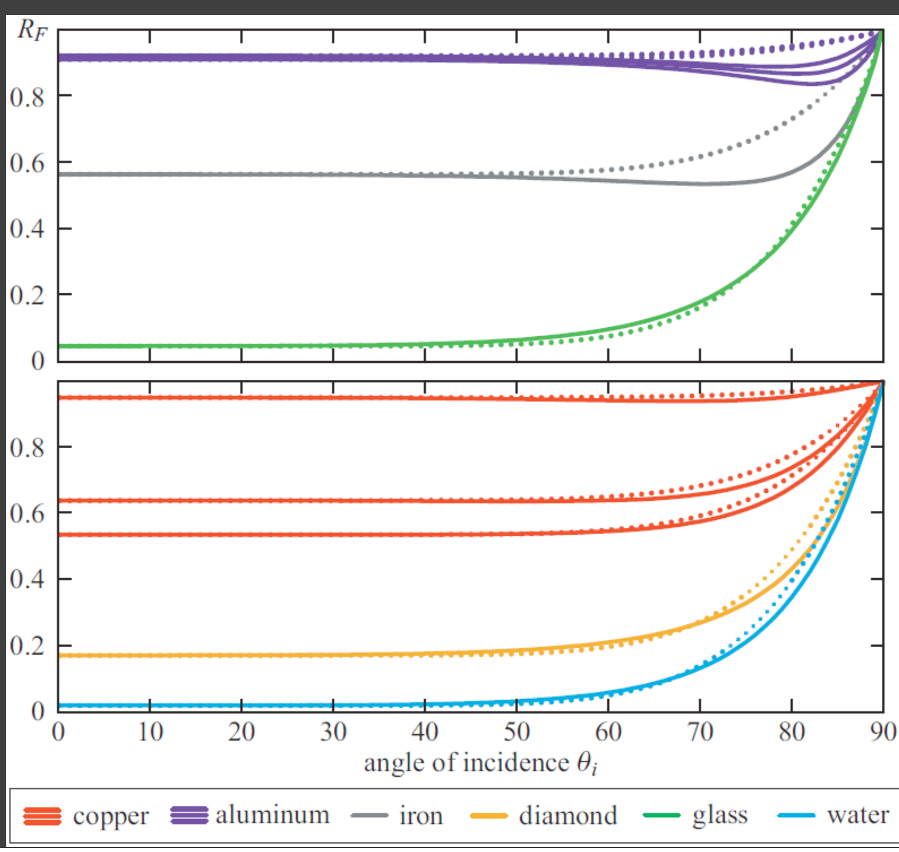
- Equations apply for metals and nonmetals
  - for metals, use complex index : n + ik
  - for nonmetals/dieletrics, k = 0

Schlick's approximation of Fresnel

$$R_F(\theta) = R_F(0) + (1 - R_F(0))(1 - cos(\theta))^5$$

- For dielectric

$$R_F(0) = (\frac{\eta - 1}{\eta + 1})^2$$



$R_F(0)$

Insulator: Water	0.02, 0.02, 0.02
Insulator: Plastic	0.03, 0.03, 0.03
Insulator: Glass	0.08, 0.08, 0.08
Insulator: Diamond	0.17, 0.17, 0.17
Metal: Gold	1.00, 0.71, 0.29
Metal: Silver	0.95, 0.93, 0.88
Metal: Copper	0.95, 0.64, 0.54
Metal: Iron	0.56, 0.57, 0.58
Metal: Aluminum	0.91, 0.92, 0.92

Rob Cook's vases

Source: Cook, Torrance 1981

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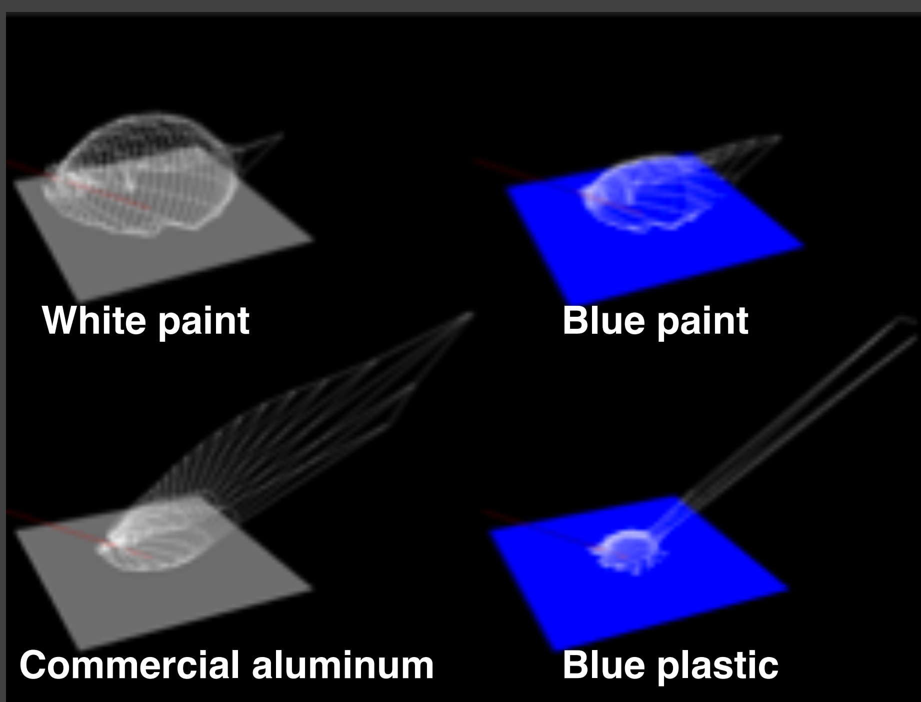
Measured BRDFs



Ward Model

- Physically valid
  - Energy conserving
  - Satisfies reciprocity
  - Easy to integrate
- Based on empirical data

Ward Model

- Isotropic and anisotropic materials

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Ward Model: Isotropic

$$f_s = \rho_s \frac{1}{4\pi m^2} \frac{1}{\sqrt{N.L N.V}} e^{-\frac{tan^2\theta_h}{m^2}}$$

- where,
  - m (usually α) is surface roughness

Ward Model: Anisotropic

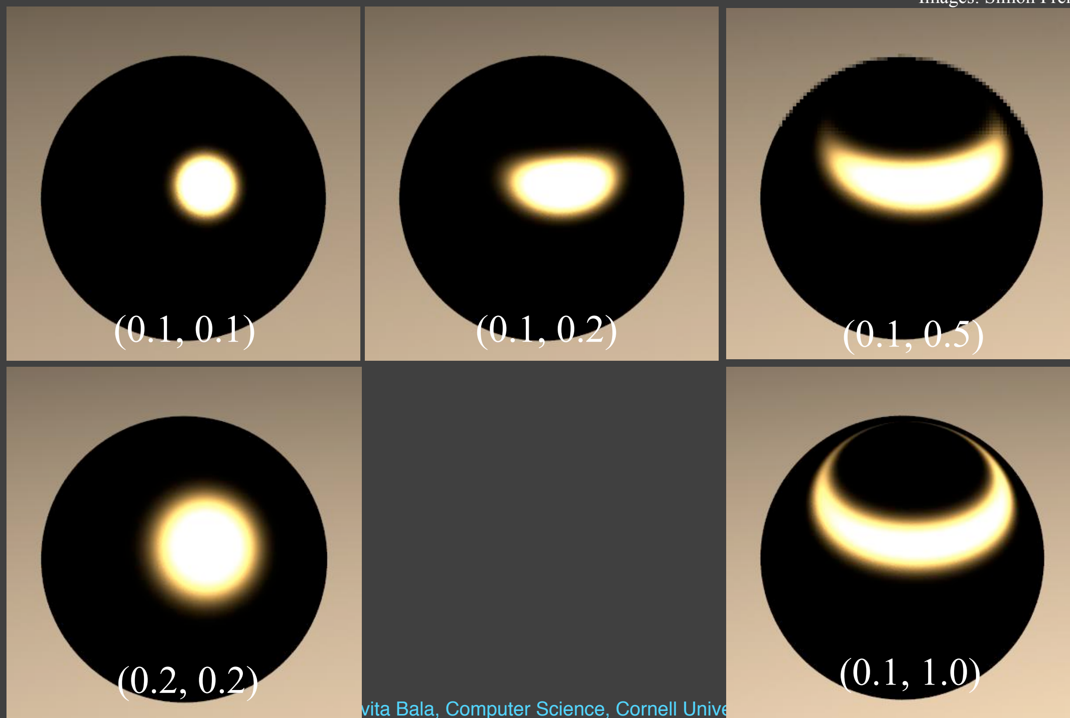
$$f_s = \rho_s \frac{1}{4\pi m_x m_y} \frac{1}{\sqrt{N.L N.V}} e^{-tan^2\theta_h(\frac{cos^2\phi_h}{m_x^2} + \frac{sin^2\phi_h}{m_y^2})}$$

$$f_s = \rho_s \frac{1}{4\pi m_x m_y} \frac{1}{\sqrt{N.L N.V}} e^{-2\frac{(\frac{H.\hat{x}}{m_x})^2 + (\frac{H.\hat{y}}{m_y})^2}{1+N.H}}$$

- where,
  - m_x, m_y are surface roughness in $\hat{x}, \hat{y}$
  - $\hat{x}, \hat{y}$ are mutually perpendicular to the normal

Examples

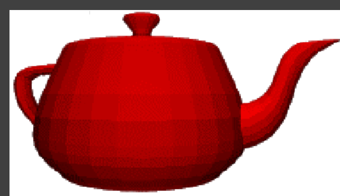
Images: Simon Premoze



Teapot

Normals for Illumination

- In polygonal models, each facet has normal
- But, faceted look (N constant)
  - Directional light (constant diffuse illumination)



Shading Normals

- Normal matches the object (not the polygons)
  - Assume polygons are piecewise smooth approximation
  - Ideally provided by underlying object
  - Otherwise, average normals of nearby facets

Shading Models

- Fast, easy: Phong
- Physically-based model: Cook-Torrance
- Empirically-based model: Ward
- Next time: textures

Books

- Email about RTR (3rd ed.)