Lecture 4: Reflection Models

CS 6620, Spring 2009

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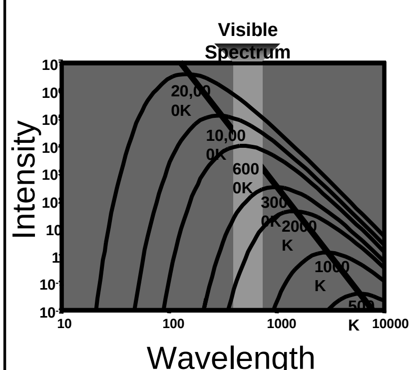
Outline

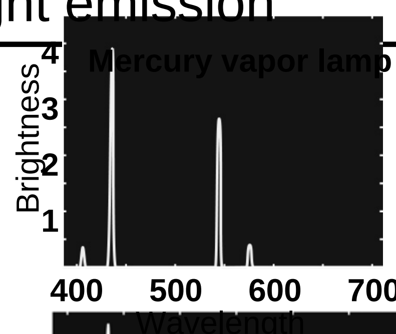
- Light sources
  - – Light source characteristics
  - – Types of sources
- Light reflection
  - – Physics-based models
  - – Empirical models

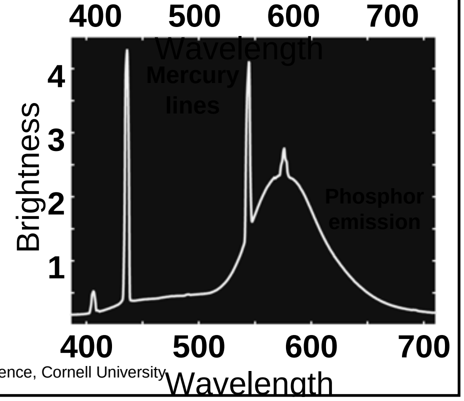
Sources of light radiation

- Thermal radiation ("blackbody")
  - Sun, tungsten & tungsten-halogen lamps; arc lamps
- Electric discharge
  - gas discharge lamps (neon, sodium, mercury vapor)
  - arc lamps, fluorescent lamps
- Other phenomena
  - fluorescence (fluorescent lamps, fluorescent dyes)
  - phosphorescence (CRTs); LEDs; lasers

Examples of light emission



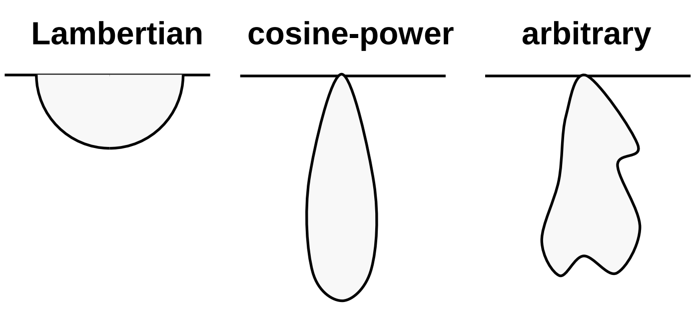




Modeling luminaires

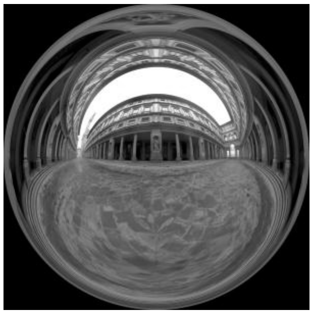
- Spectral distribution
  - Determined by physics of source
  - Generally tabulated, often RGB used
- Spatial distribution
  - Modeled as point or simple area light
  - Also light probes create high dynamic range inputs
- Directional distribution
  - Often shaped by reflectors
  - Tabulated when necessary, cosine lobe is common approximation

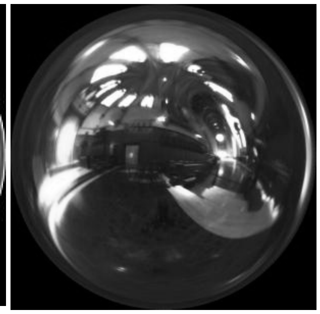
Directional distributions



Lighting w/ Environment Maps

- High lighting complexity





- Rich: captures real world

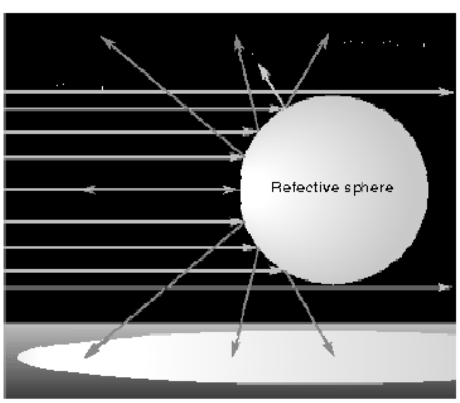
Image-based lighting

- Acquiring lighting information of real scenes
  - Image-based techniques
- Use light probe
- Varying exposure

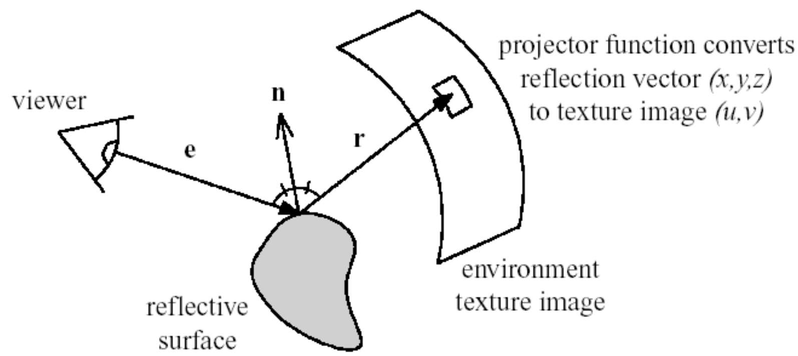
Mirror Ball

Sphere Maps

- Assume viewing is from infinity
- Creation uses photographs or ray tracing or warping



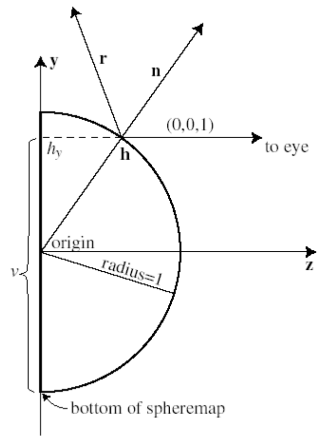
Environment Mapping



Sphere Environment Mapping

Types of Mappings

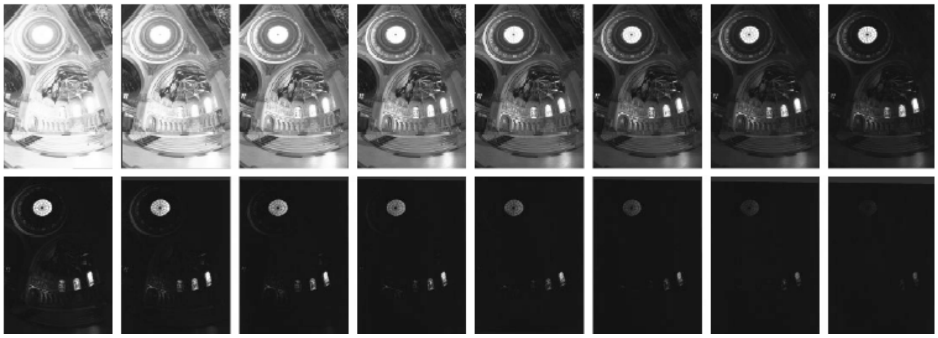
Cube mapping



Sphere mapping

Dynamic Range of Sun

Multiple Exposures



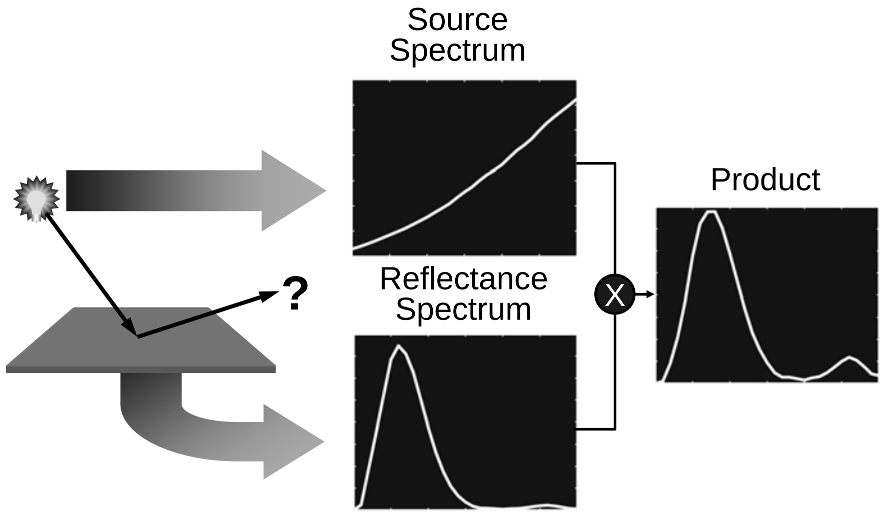
Light interaction with matter

- Volumetric scattering: interaction in 3D
  - Atmosphere, water, semi-transparent objects
- Surface scattering: interaction in 2D
  - Surfaces of mainly opaque materials
  - The common case in many scenes
  - Heavily relied upon for graphics

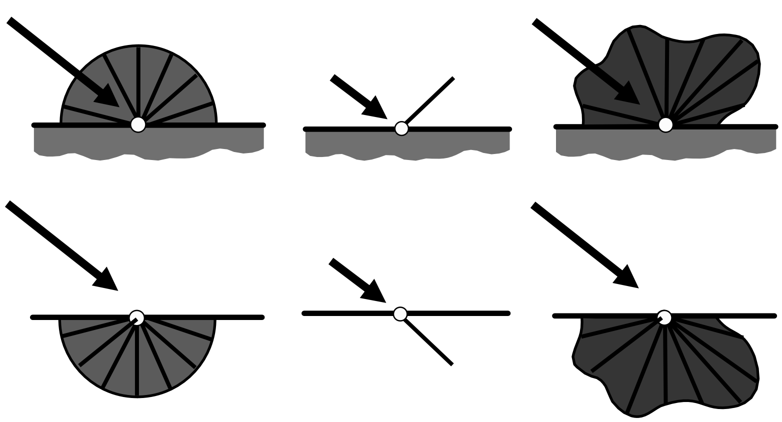
Surface reflective characteristics

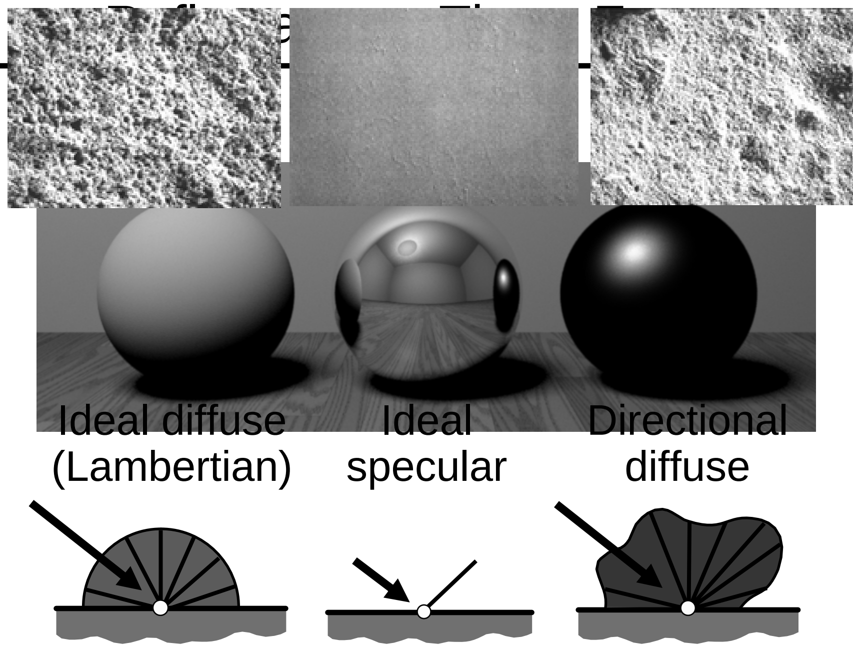
- Spectral distribution
  - Responsible for surface color
  - Tabulate in independent wavelength bands, or RGB
- Spatial distribution
  - Material properties vary with surface position
  - Texture maps
- Directional distribution
  - BRDF — more complex than source
  - Tabulation is impractical because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

Reflection spectrum



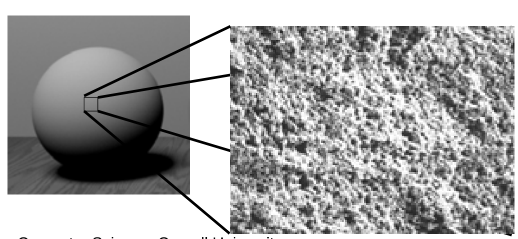
Directional Distribution





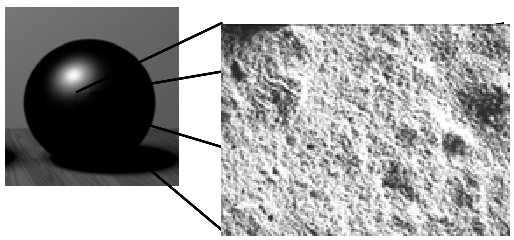
Ideal Diffuse Reflection

- Characteristic of multiple scattering materials
- An idealization but reasonable for matte surfaces
- Basis of most radiosity methods
- BRDF is a constant function



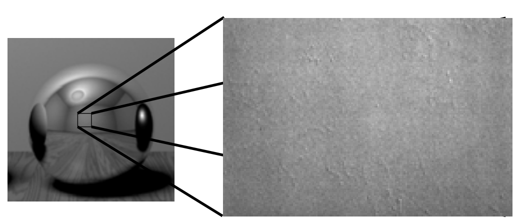
Directional Diffuse Reflection

- Characteristic of most rough surfaces
- Described by the BRDF



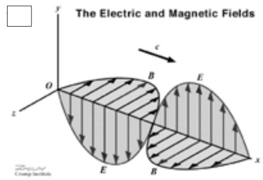
Ideal Specular Reflection

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



Fresnel Reflection

- Considers light as electromagnetic wave

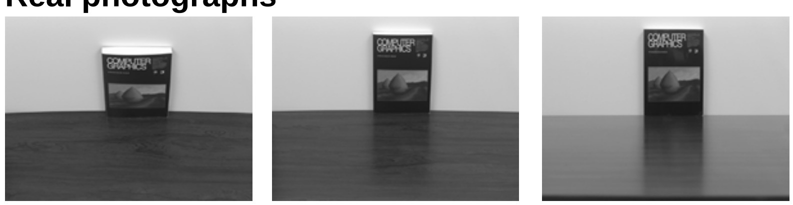


- Polarization: rotation of electric field

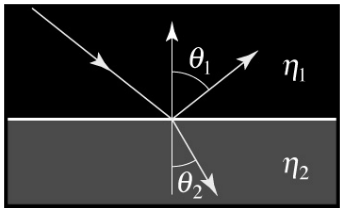
- Effect of Fresnel reflection:
  - Most objects act as mirror reflectors when light strikes them at grazing angles

Grazing Angle

Real photographs



Fresnel Equations



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

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

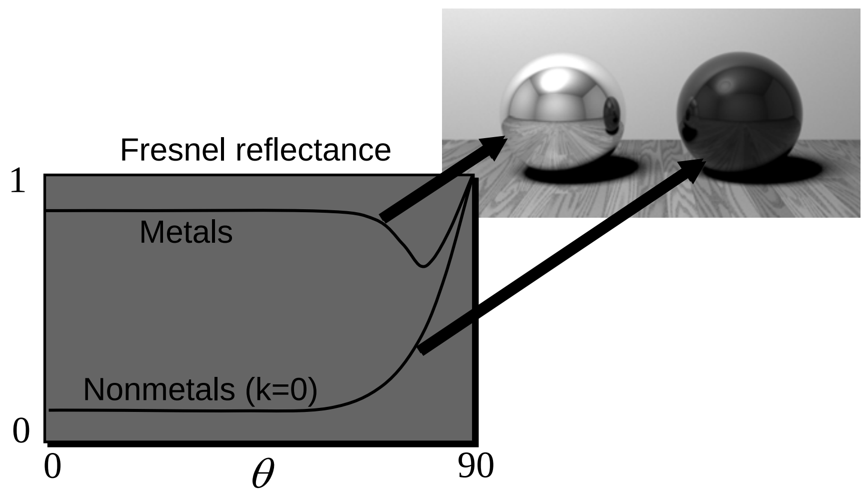
$$F_s = \frac{\eta_1 \cos\theta_1 - \eta_2 \cos\theta_2}{\eta_1 \cos\theta_1 + \eta_2 \cos\theta_2}$$

Fresnel Reflectance

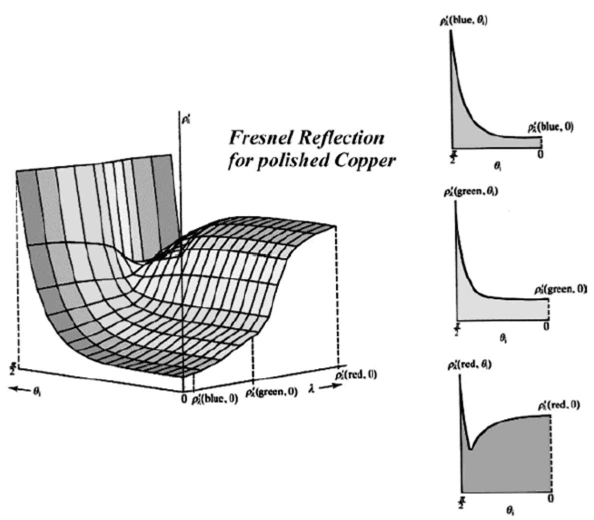
$$F = \frac{(|F_s|^2 + |F_p|^2)}{2}$$ for unpolarized light

- Equations apply for metals and nonmetals
  - for metals, use complex index $\eta = n+ik$
  - for nonmetals, $k=0$

Metal vs. Nonmetal



Fresnel Equations



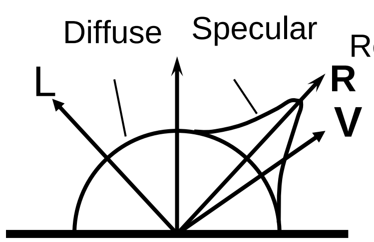
Mies van der Rohe's unbuilt Courtyard House

Directional Reflectance

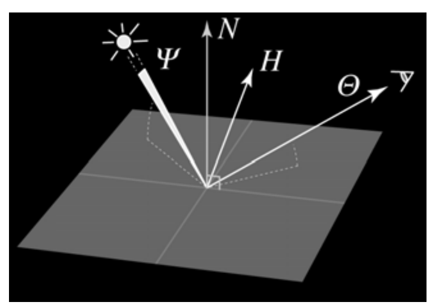
Classes of Models for the BRDF

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

Phong Reflection Model



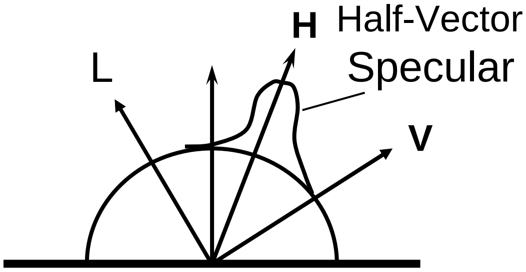
Mirror Reflection Vector

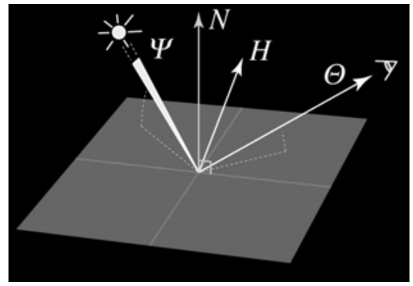


Diffuse = $k_d (\overline{N} \cdot \overline{L})$ Specular = $k_s (\overline{R} \cdot \overline{V})^n$

$$f_r(\Theta \leftrightarrow \Psi) = k_s \frac{(R.\Theta)^n}{(N.\Psi)} + k_d$$

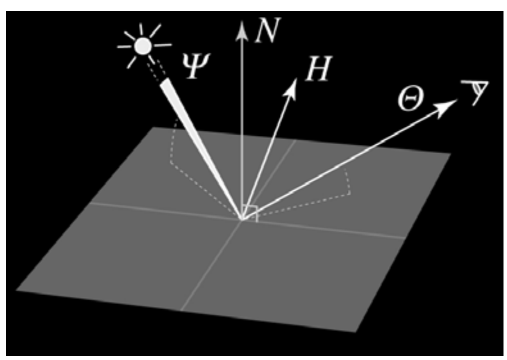
The Blinn-Phong Model



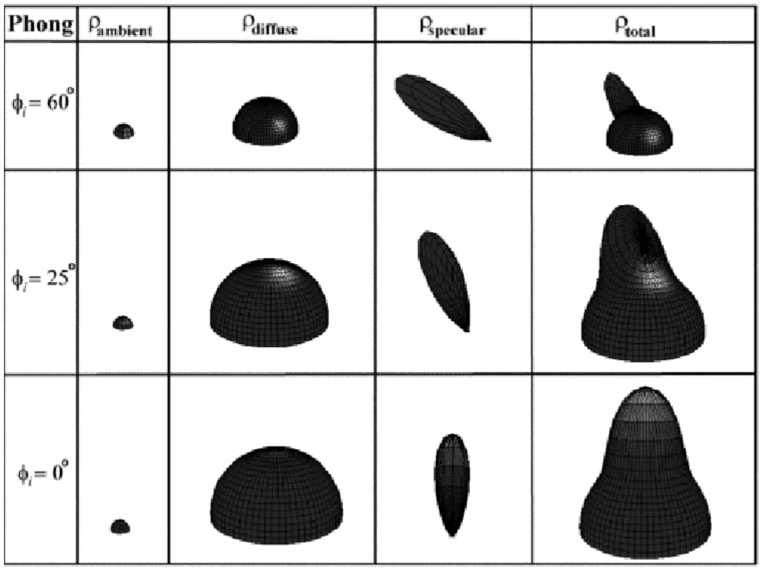


$$f_r(\Theta \leftrightarrow \Psi) = k_s \frac{(N.H)^n}{(N.\Psi)} + k_d$$

The Modified Blinn-Phong Model

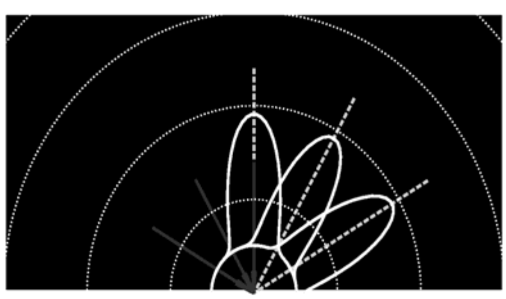


$$f_r(\Theta \leftrightarrow \Psi) = k_s (N.H)^n + k_d$$



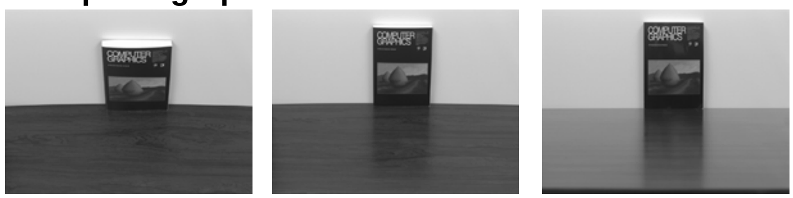
The Phong Model

- Computationally simple
- Visually pleasing



Phong: Reality Check

Real photographs



Phong: Reality Check

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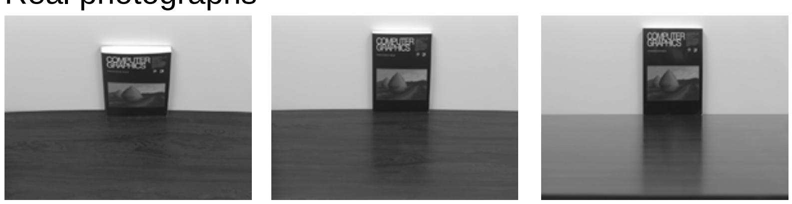
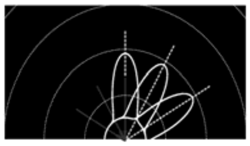


Phong model

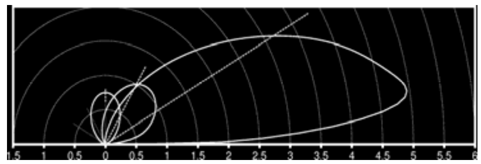
Therefore, physically-based models

Phong: Reality Check

Phong model



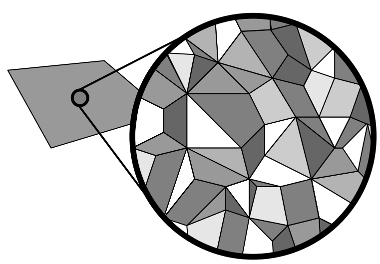
Physics-based model



- Computationally simple, visually pleasing
- Doesn't represent physical reality
  - – Energy not conserved
  - – Not reciprocal (can be fixed with modification)
  - – Maximum always in specular direction

Cook-Torrance BRDF Model

- A *microfacet* model
  - – Surface modeled as random collection of planar facets
  - – Incoming ray hits exactly one facet, at random
- Input: probability distribution of facet angle

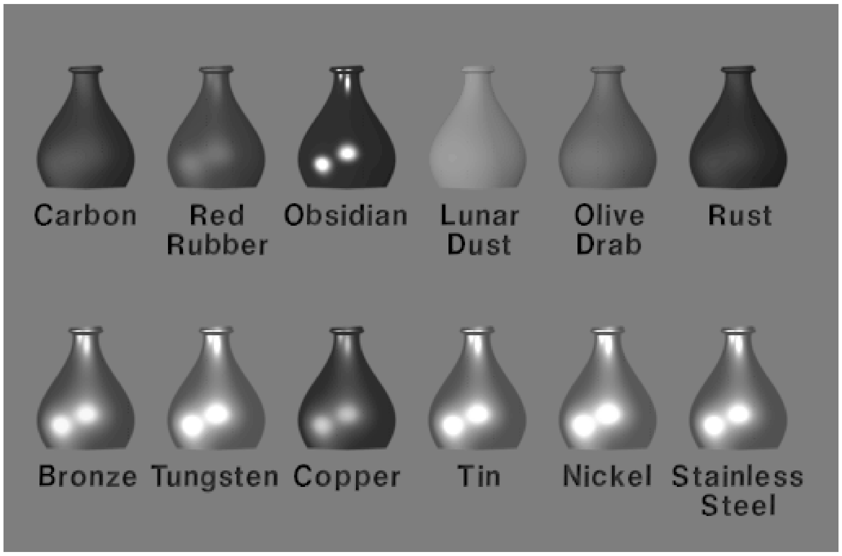


Result of Cook-Torrance

- 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

Rob Cook's vases



Source: Cook, Torrance 1981

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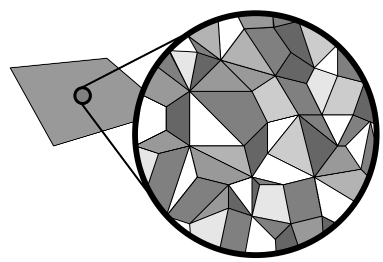
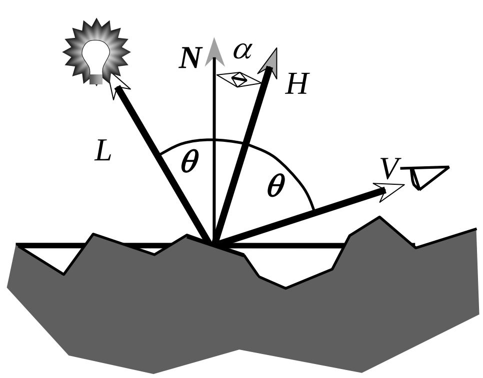


Facet Reflection

- *H* vector used to define facets that contribute



Cook-Torrance BRDF Model

Fresnel Reflectance

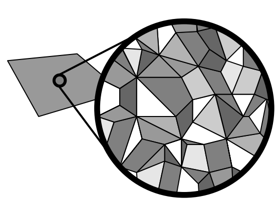
$$R_s = \frac{F}{\pi} \frac{DG}{(N \cdot L)(N \cdot V)}$$

- “Specular” term (really directional diffuse)
- Fresnel reflectance for smooth facet

Cook-Torrance BRDF Model

Facet distribution

$$R_s = \frac{F}{\pi} \frac{DG}{(N \cdot L)(N \cdot V)}$$



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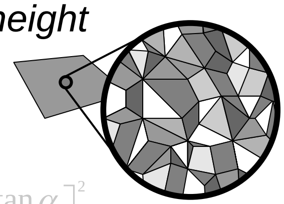
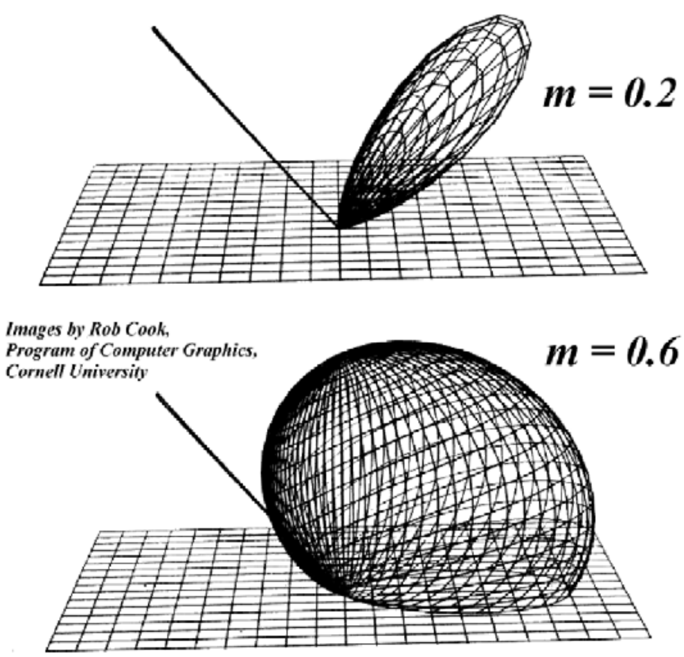
Facet Distribution

- ***D*** function describes distribution of ***H***
- Formula due to Beckmann
  - *derivation based on Gaussian height distribution*



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

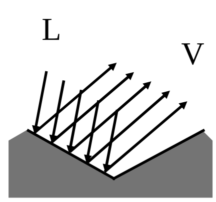


Cook-Torrance BRDF Model

Masking/shadowing

$$R_s = \frac{F}{\pi} \frac{DG}{(N \cdot L)(N \cdot V)}$$

Unoccluded



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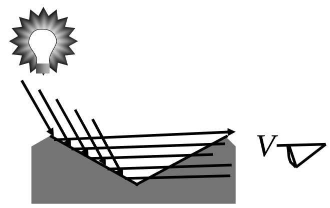
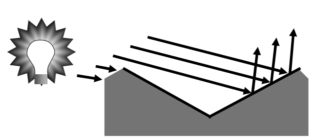
Masking



$N.V$

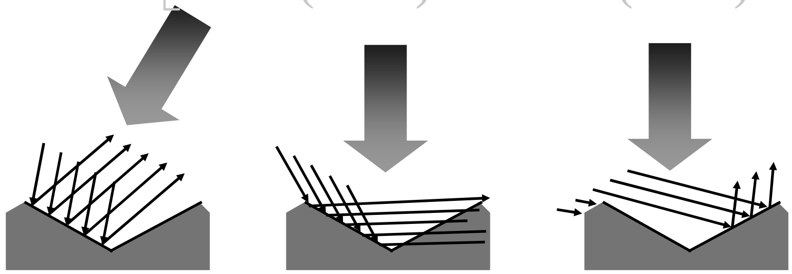
Self-Shadowing



$N.L$

Masking and Shadowing

$$G = \min\left[1, \frac{2(N \cdot H)(N \cdot V)}{(V \cdot H)}, \frac{2(N \cdot H)(N \cdot L)}{(V \cdot H)}\right]$$



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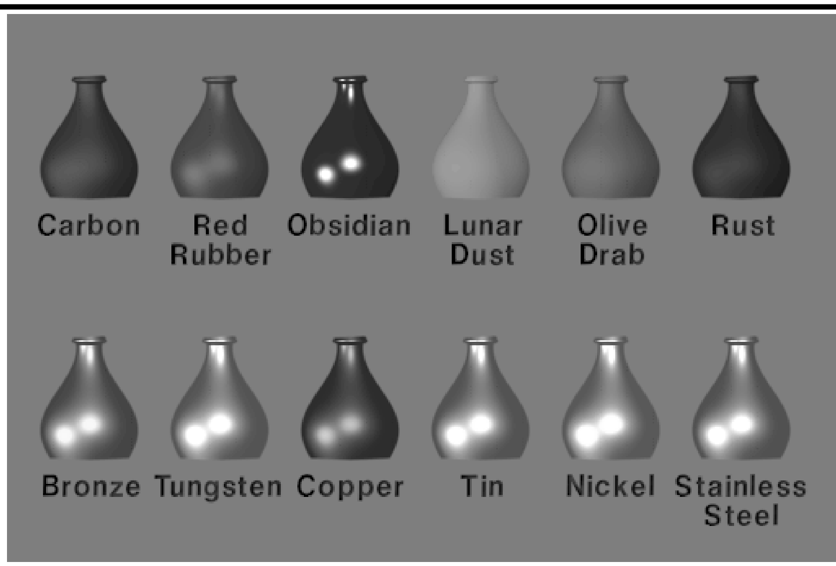

Source: Cook, Torrance 1981

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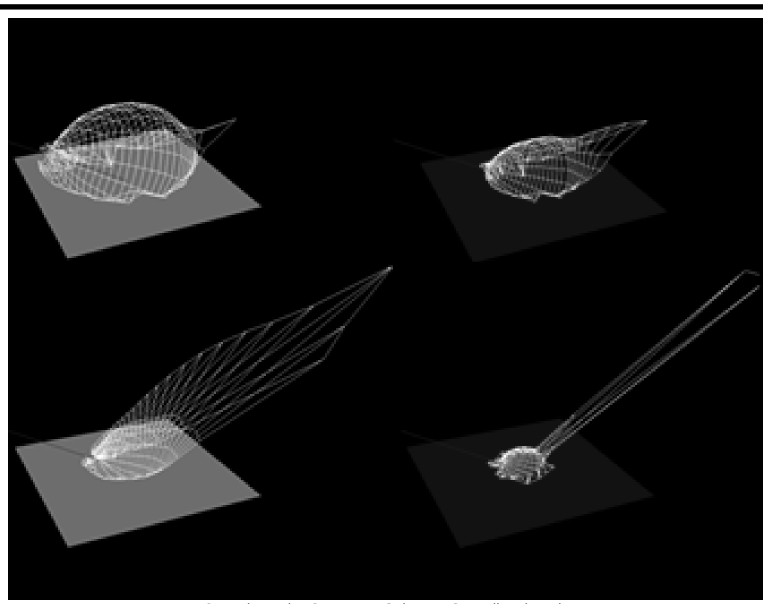
Measured BRDFs



Empirical BRDF Representation

- Generalized Phong model (Lafortune 1997)
- Used to represent:
  - Measured data
  - Wave optics reflectance model
- Features:
  - Efficient and compact
  - Easily added to rendering algorithms

Ward Model

- Physically valid
  - Energy conserving
  - Satisfies reciprocity: $f_r(\Theta_i \rightarrow \Theta_r) = f_r(\Theta_r \rightarrow \Theta_i)$
- Based on empirical data
- Isotropic and anisotropic materials

Ward Model: Isotropic

$$f_s = \rho_s \frac{1}{4\pi\alpha^2} \frac{\exp(-\frac{\tan^2\theta_h}{\alpha^2})}{\sqrt{(\vec{N}\cdot\vec{V})(\vec{N}\cdot\vec{L})}}$$

- where,
  - α is surface roughness

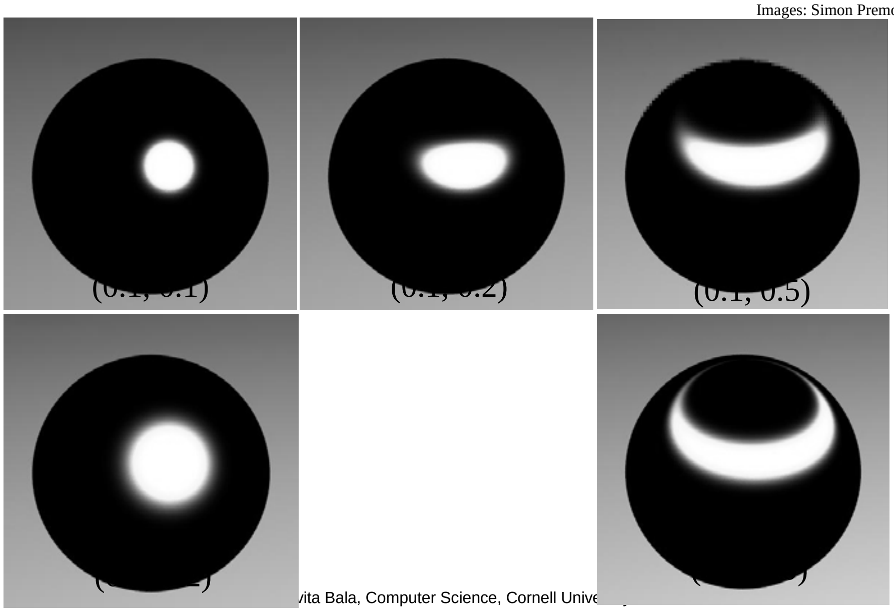
Ward Model: Anisotropic

$$f_s = \rho_s \frac{1}{4\pi\alpha_x\alpha_y} \sqrt{\frac{\vec{N}\cdot\vec{L}}{\vec{N}\cdot\vec{V}}} \exp(-2\frac{\left(\frac{\vec{H}\cdot\hat{x}}{\alpha_x}\right)^2 + \left(\frac{\vec{H}\cdot\hat{y}}{\alpha_y}\right)^2}{1+\vec{H}\cdot\vec{N}})$$

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

Examples

Images: Simon Premoze



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Teapot

Conclusions

- Light modeling and BRDF modeling
- Shading models:
  - Physically-based model: Cook-Torrance
  - Empirically-based model: Ward
  - Recent work
    - anisotropic Cook-Torrance[SIG'08]