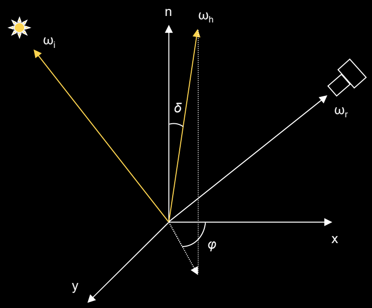
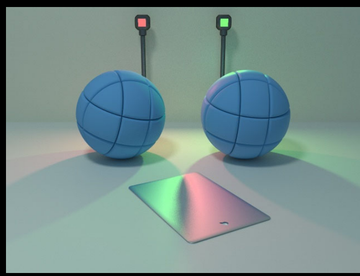
Reflection Models and Measurement





70001 – Advanced Computer Graphics: Photographic Image Synthesis

Abhijeet Ghosh

Lecture 08, Feb. 02nd 2024

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Reflection Models

- Mathematical representation a class of BRDFs
  - typically with a small number of parameters
- Types of BRDF models
  - Phenomenological
  - Physically based
- Parameter fitting
  - Empirically
  - Measured data

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Phenomenological Models

- Equations that describe the "qualitative behavior" of surfaces
  - matte, glossy or plastic, roughness
- Examples
  - Lambertian diffuse reflection
  - Phong specular reflection [Phong75]

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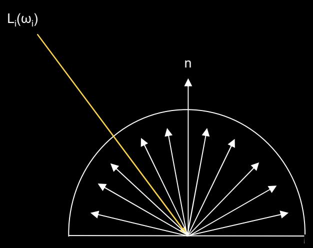
Lambertian Reflection



- $f_r(\omega_r, \omega_i) = \rho_d / \pi$
  - ρ_d is the diffuse reflection coefficient [0,1]
  - $\pi = \int_\Omega \cos\theta \, d\omega$, is the normalization constant!

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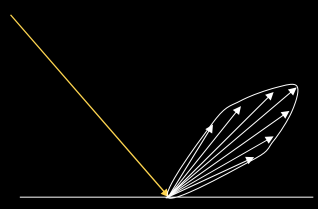
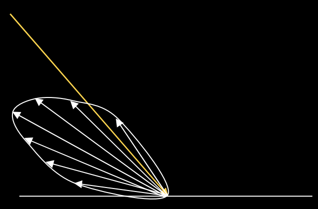
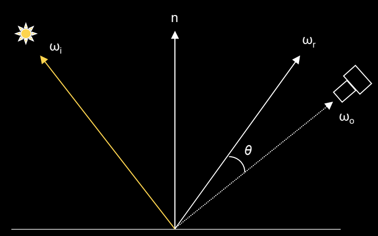
Glossy and Retro-reflective





- Glossy surfaces – plastic, high gloss paints, polished wood
- Retro-reflective – velvet, moon's surface, road signs, bike reflectors

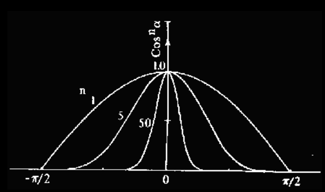
Phong Model



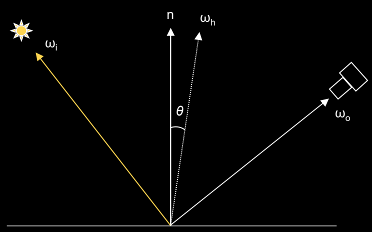
- $f_r(\omega_o, \omega_i) = \rho_d / \pi + \rho_s (\omega_r \cdot \omega_o)^s / (n \cdot \omega_i)$

  $= \rho_d / \pi + \rho_s (\cos\theta)^s / (n \cdot \omega_i)$

  - ρ_s is the specular reflection coefficient [0,1]
  - *S* controls the specular lobe width



Blinn-Phong Model



$\omega_h = (\omega_i + \omega_o) / ||\omega_i + \omega_o||$

- $f_r(\omega_o, \omega_i) = \rho_d / \pi + \rho_s (n \cdot \omega_h)^s / (n \cdot \omega_i)$

  $= \rho_d / \pi + \rho_s (\cos\theta)^s / (n \cdot \omega_i)$

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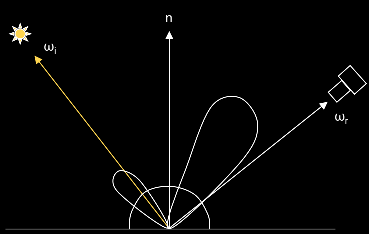
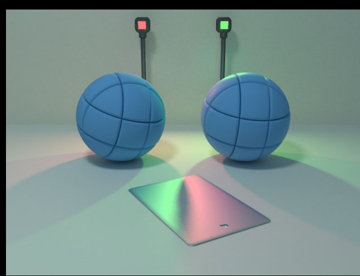
Lafortune Generalized Cosine Lobe





- $f_r(\omega_r, \omega_i) = \rho_d / \pi + \sum_j [C_{x,j} (\omega_{i.x} \cdot \omega_{r.x}) + C_{y,j} (\omega_{i.y} \cdot \omega_{r.y}) + C_{z,j} (\omega_{i.z} \cdot \omega_{r.z})]^{s,j}$
  - Off-specularity, retro-reflection, anisotropy
  - Well suited for measured data!

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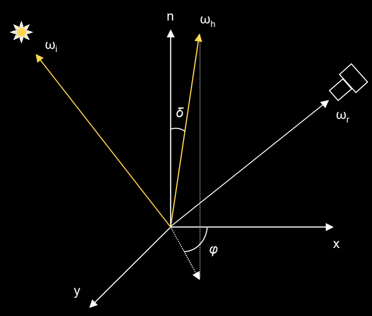
Ward Anisotropic Model

Generlization of microfacet model to account for anisotropy!



- $f_r(\omega_r, \omega_i) = \rho_d / \pi + \rho_s \dfrac{1}{\sqrt{\cos\theta_i \cos\theta_r}} \dfrac{\exp[-\tan^2\delta(\cos^2\varphi/\alpha_x^2 + \sin^2\varphi/\alpha_y^2)]}{4\pi\alpha_x\alpha_y}$
  - elliptical Gaussians, α_x & α_y control standard deviation in x & y
  - energy preserving & reciprocal

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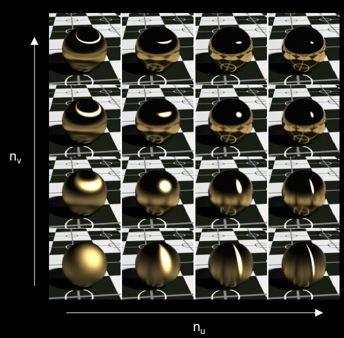
Ashikhmin-Shirley Phong Model



$s = n_u \cos^2\varphi + n_v \sin^2\varphi$

- $f_r(\omega_r, \omega_i) = \dfrac{\sqrt{(n_u + 1)(n_v + 1)}}{8\pi} \dfrac{(n \cdot \omega_h)^s}{(\omega_i \cdot \omega_h)\, max((n \cdot \omega_i), (n \cdot \omega_r))} F_r((\omega_i \cdot \omega_h))$
  - $F_r((\omega_i \cdot \omega_h))$, Schlick's Fresnel term

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Physically-Based Models

- Based on low level geometric structure of surfaces
- Closed form solutions
  - Microfacet distributions for rough surfaces
  - Cylindrical grooves for threaded structures

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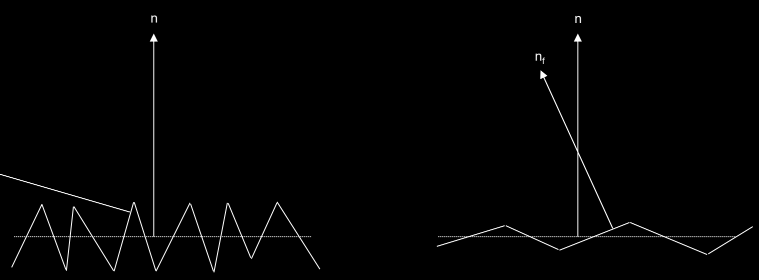
Microfacet Models



- Rough surfaces modeled as a collection of microfacets
  - each face a perfect specular reflector
  - distribution of faces described statistically

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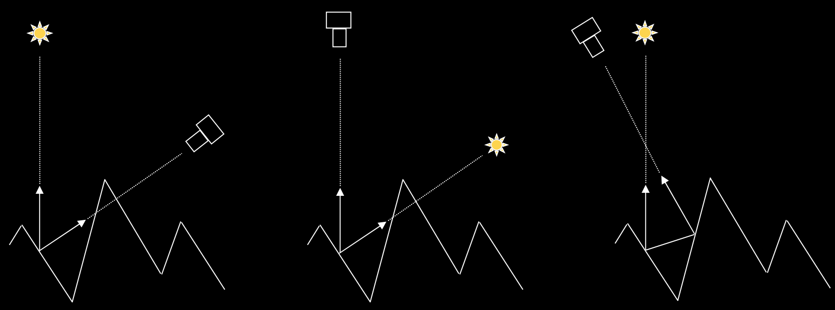
Microfacet Models



- Geometric effects of microfacets
  - masking
  - shadowing
  - interreflections

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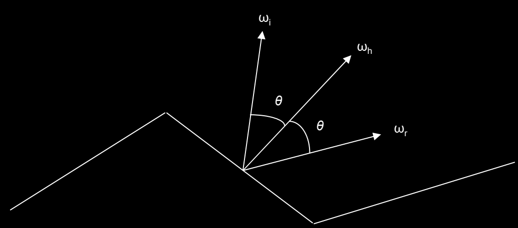
Torrance-Sparrow Model



- $f_r(\omega_r, \omega_i) = \dfrac{D(\omega_h)\, G(\omega_r, \omega_i)\, F_r(\omega_h)}{4\,(n \cdot \omega_i)\,(n \cdot \omega_r)}$
  - D, the distribution term
  - G, the geometric term
  - F, the Fresnel term

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Torrance-Sparrow Model

- $D(\omega_h) = \dfrac{\exp{-[\tan\delta/m]^2}}{\pi m^2 \cos^4\delta}$ Beckman distribution
  - δ, angle between n and ω_h
  - m, root-mean-square slope of microfacets

- $G(\omega_r, \omega_i) = \min\{1, \dfrac{2\,(n \cdot \omega_h)\,(n \cdot \omega_r)}{(\omega_r \cdot \omega_h)}, \dfrac{2\,(n \cdot \omega_h)\,(n \cdot \omega_i)}{(\omega_r \cdot \omega_h)}\}$
  - V-shaped grooves

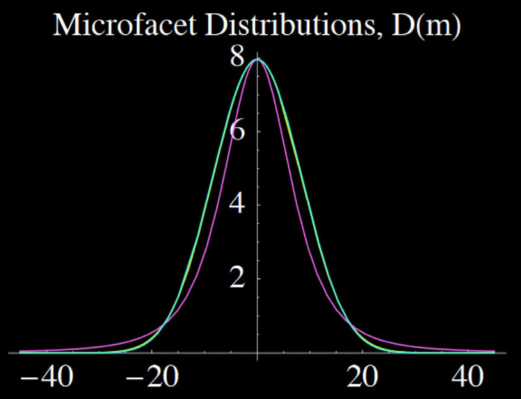
Blinn Microfacet Distribution

- $D(\omega_h) = \dfrac{(s + 2)\,(n \cdot \omega_h)^s}{2\pi}$
  - Replace Gaussian with a cosine lobe
  - Normalization term $(s + 2)/\,2\pi = \int_\Omega (n \cdot \omega_h)^s \cos\theta_h \, d\omega_h$

GGX microfacet distribution

- $D(\omega_h) = \dfrac{\alpha^2}{\pi \cos^4\delta\,(\alpha^2 + \tan^2\delta)^2}$
  - δ, angle between n and ω_h
  - α, width of distribution
  - Better fit to measured data
  - Longer tail, sharper peak
  - Beckmann, GGX

GGX distribution



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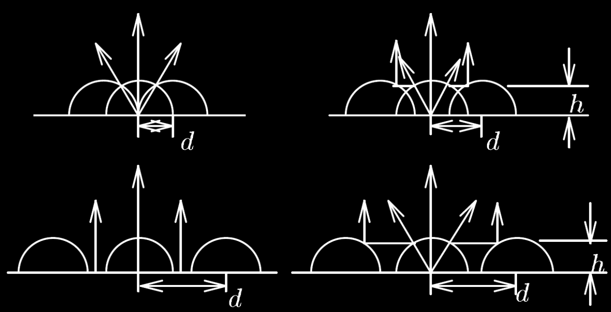
Poulin-Fournier Model



- Anisotropy modeled by cylindrical grooves
  - d & h control the level of anisotropy
  - for fabrics such as satin and velvet

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Satin and velvet [Ashikhmin et al. 2000]

Satin

Velvet

- Anisotropy gaussian for satin distribution
  - $p(\mathbf{h}) = c * \exp(-\tan^2\theta(\cos^2\phi/\sigma_x^2 + \sin^2\phi/\sigma_y^2))$
- Velvet has bright isotropic highlights only at grazing angle
  - $p(\mathbf{h}) = c * \exp(-\cot^2\theta/\sigma^2)$

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