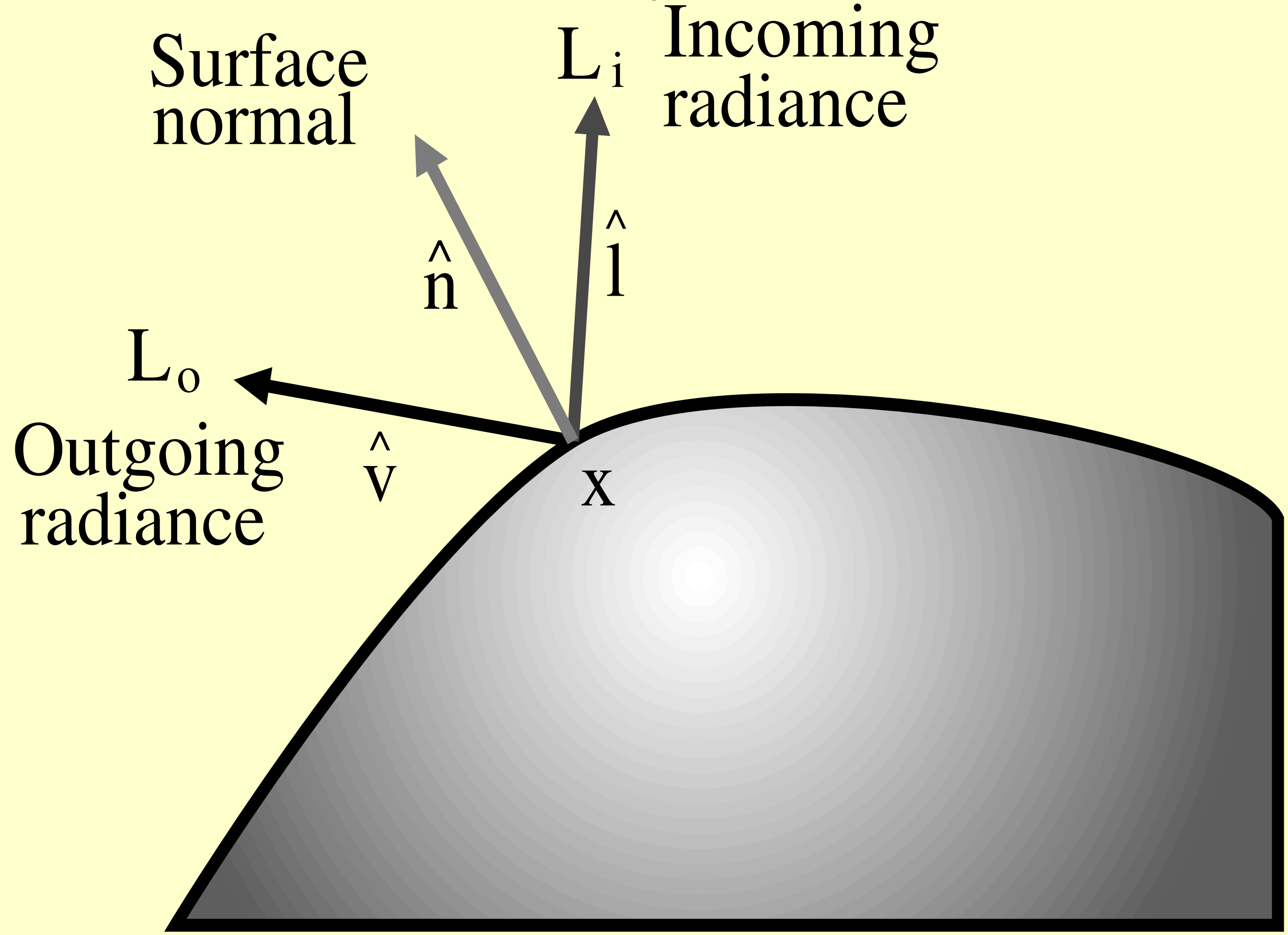
CMSC 435/634

Reflectance

BRDF

Bidirectional Reflectance Distribution Function

- How much light reflects from L_i to L_o



Physically Plausible BRDF

Positive

Reciprocity

- Same light from L_i to L_o as from L_o to L_i

Conservation of Energy

- Don’t reflect more energy than comes in

Computing Reflected Light

Integral of all incoming light

$$L_o(\hat{\mathbf{v}}) = \int_{\Omega(\hat{\mathbf{n}})} f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}})\, L_i(\hat{\mathbf{l}})\, \langle \hat{\mathbf{n}}, \hat{\mathbf{l}} \rangle \, d\omega(\hat{\mathbf{l}})$$

Parts of this equation:

$L_o(\hat{\mathbf{v}})$	outgoing light in direction $\hat{\mathbf{v}}$
$\Omega(\hat{\mathbf{n}})$	hemisphere above $\hat{\mathbf{n}}$
$f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}})$	BRDF from $\hat{\mathbf{l}}$ to $\hat{\mathbf{v}}$
$L_i(\hat{\mathbf{l}})$	incoming light from direction $\hat{\mathbf{l}}$
$\langle \hat{\mathbf{n}}, \hat{\mathbf{l}} \rangle \, d\omega(\hat{\mathbf{l}})$	solid angle for integration

Diffuse

Integral of all incoming light

$$L_o(\hat{\mathbf{v}}) = \int_{\Omega(\hat{\mathbf{n}})} f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}})\, L_i(\hat{\mathbf{l}})\, \langle \hat{\mathbf{n}}, \hat{\mathbf{l}} \rangle\, d\omega(\hat{\mathbf{l}})$$

Dot product is **part** of the integral

- Diffuse = constant BRDF

$$f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}}) = \frac{k_d}{\pi}$$

Phong as BRDF

Original Phong:

$$f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}}) = k_d + k_s \langle \hat{\mathbf{r}}_{\hat{\mathbf{n}}}(\hat{\mathbf{v}}), \hat{\mathbf{l}} \rangle^e / \langle \hat{\mathbf{n}}, \hat{\mathbf{l}} \rangle$$

- Not reciprocal
- Not energy conserving

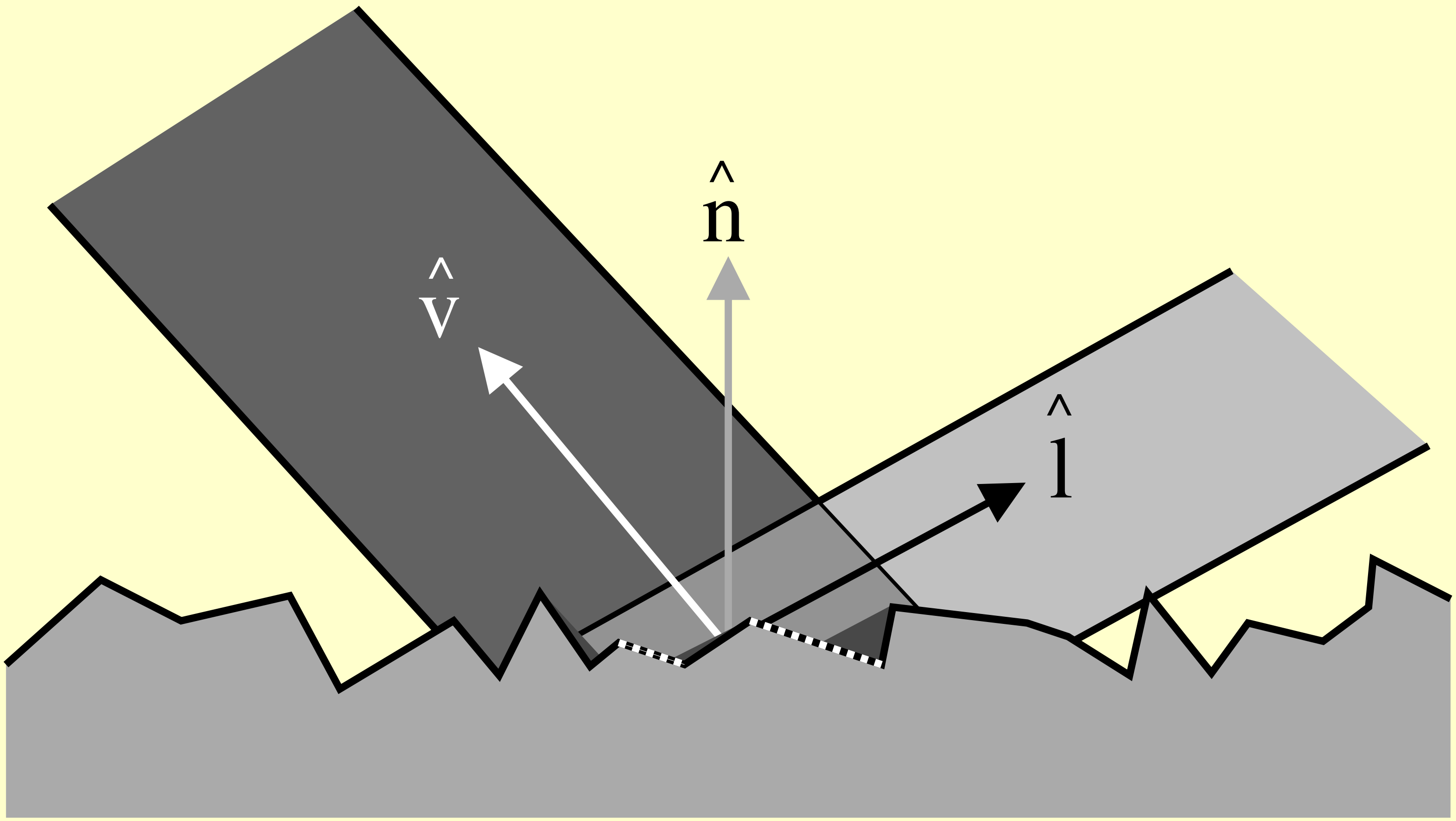
Blinn-Phong

$$f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}}) = k_d + k_s \langle \hat{\mathbf{h}}, \hat{\mathbf{n}} \rangle^e / \langle \hat{\mathbf{n}}, \hat{\mathbf{l}} \rangle$$

Microfacet Models

Surface consists of microscopic reflective facets

- Distribution of facets
- Shadowing/Masking



Cook-Torrance

$$f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}}) = k_d f_d + k_s f_s(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}})$$

Specular component:

$$f_s(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}}) = \frac{1}{\pi} \frac{F \cdot D \cdot G}{\langle \hat{\mathbf{n}}, \hat{\mathbf{v}} \rangle \langle \hat{\mathbf{n}}, \hat{\mathbf{l}} \rangle}$$

- F = Fresnel Reflectance term
- D = Distribution term
- G = Geometry (shadowing/masking) term

Fresnel

Stronger reflection at glancing angles

- Depends on index of refraction
- Stronger for light polarized parallel to surface

Fresnel

For unpolarized, can average power:

$$
\begin{aligned}
r_\perp &= \frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2} \\
r_{||} &= \frac{n_2 \cos\theta_1 - n_1 \cos\theta_2}{n_2 \cos\theta_1 + n_1 \cos\theta_2} \\
F &= \frac{r_\perp^2 + r_{||}^2}{2}
\end{aligned}
$$

$$
\begin{aligned}
c &= \cos\gamma = \langle \hat{\mathbf{v}}, \hat{\mathbf{h}} \rangle = \langle \hat{\mathbf{l}}, \hat{\mathbf{h}} \rangle \\
n &= \frac{n_1}{n_2} \\
g^2 &= n^2 + c^2 - 1 \\
F(c) &= \frac{(g-c)^2}{2(g+c)^2} \left(1 + \frac{(c(g+c)-1)^2}{(c(g-c)+1)^2}\right)
\end{aligned}
$$

Distribution

Probability facet has angle δ to overall normal

- Choose a probability distribution function

Beckmann distribution

- Gaussian distribution in $\tan\delta$

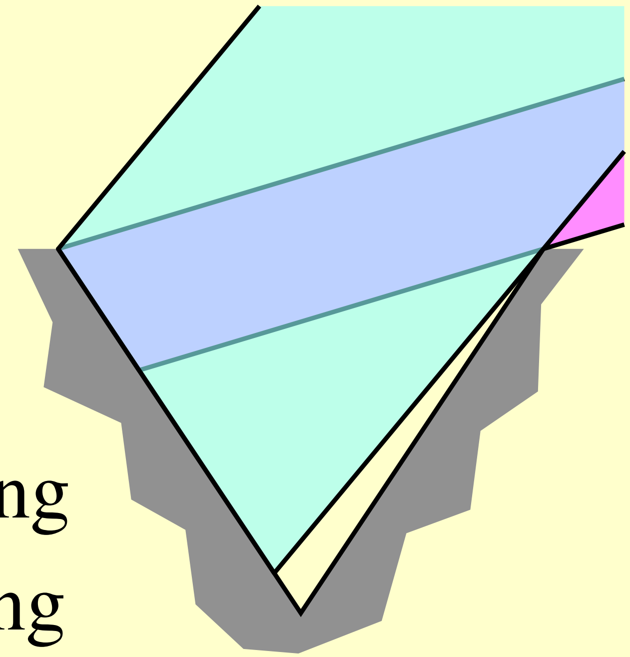
$$D(\cos\delta) = \frac{1}{m^2\cos^4\delta}\exp\left(-\frac{\tan^2\delta}{m^2}\right)$$
$$= \frac{1}{m^2\langle\hat{\mathbf{n}},\hat{\mathbf{h}}\rangle^4}\exp\left(-\frac{1-\langle\hat{\mathbf{n}},\hat{\mathbf{h}}\rangle^2}{\langle\hat{\mathbf{n}},\hat{\mathbf{h}}\rangle^2 m^2}\right)$$

- $\tan\delta$ = projection of facet normal onto plane parallel to surface

Geometry

Symmetric V-shaped grooves

- Can derive shadowing geometrically
- Three cases
  - No shadowing or masking
  - Shadowing blocks more than masking
  - Masking blocks more than shadowing



$$G = \min\left(1, \frac{2\langle \hat{\mathbf{n}}, \hat{\mathbf{h}}\rangle \cdot \langle \hat{\mathbf{n}}, \hat{\mathbf{v}}\rangle}{\cos\gamma}, \frac{2\langle \hat{\mathbf{n}}, \hat{\mathbf{h}}\rangle \cdot \langle \hat{\mathbf{n}}, \hat{\mathbf{l}}\rangle}{\cos\gamma}\right)$$

Anisotropic

Oriented micro-geometry

- Grooves (Poulin-Fournier, Banks)
- Woven fabric (Westin-Arvo-Torrance)