Closest Hit Shaders & BRDFs

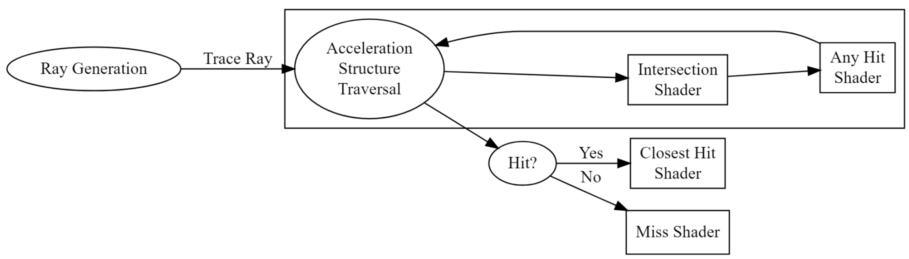
CS 481/681 Computer Graphics Rendering

University of Alaska Fairbanks

Overview

- Review the Ray Tracing Pipeline

Ray Tracing Pipeline



Closest Hit Shaders

- Reflection
- Refraction
- Shadow Rays

Bidirectional Reflectance Distribution Functions

- Specular
  - Phong
  - Blinn-Phong
  - Cook-Torrance
  - GGX
- Diffuse
  - Lambert's cosine law ($N \cdot L$)
  - Oren-Nayer
  - Disney Diffuse BRDF

Frame of Reference

- Geometric normal: $N - \omega_g$
- View direction: $V - \omega_o$
- Light direction: $L - \omega_i$
- Hemisphere: Ω
- Half-angle vector: $H - \omega_h$
- Reflection vector: $R - \omega_r$
- Refraction vector: $T - \omega_t$

The Rendering Equation

- [Nicodemus 1965] $f_r(\omega_i, \omega_o) = \frac{\mathrm{d}\, L_o(\omega_o)}{\mathrm{d}\, E_i(\omega_i)} \;=\; \frac{\mathrm{d}\, L_o(\omega_o)}{L_i(\omega_i) \cos\theta_i \;\mathrm{d}\,\omega_i}$
- [Kajiya 1986]

$$L_o(\mathbf{x} \to \omega_o) = L_e(\mathbf{x} \to \omega_o) + \int_\Omega f_r(\omega_i, \omega_o)\; L_i(\omega_i \to \mathbf{x})\; \langle \omega_i, \omega_o \rangle\; d\omega_i$$

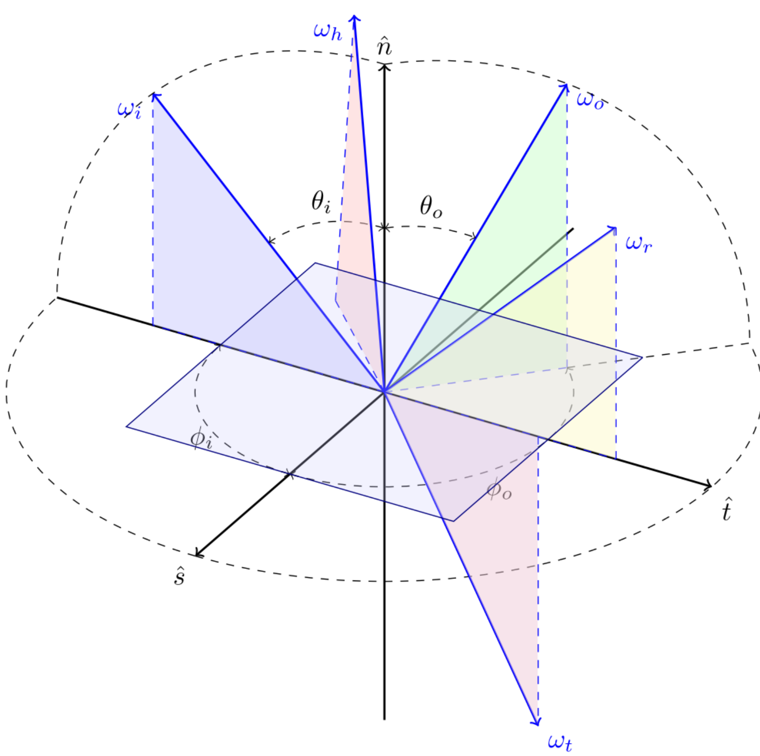


Figure 1: Frame of Reference

Paul Heckberts' Notation

- E is eye
- L is vector
- S is specular interface
- D is diffuse interface
- LSE path is light-specular-eye path
- $L\{SD\}E$ path is light to a *single* specular/diffuse interface to eye
- $L\{SD\}^+E$ path is light to *several* specular/diffuse interfaces to eye

Physically Based BRDFs

- Conservation of Energy

$$\int_\Omega f_r(\omega_i, \omega)\ d\omega_i \leq 1$$

- Helmholtz Reciprocity

$$f_r(\omega_i, \omega_o) = f_r(\omega_o, \omega_i)$$

- Positivity

$$f_r(\omega_i, \omega_o) \geq 0$$

- Conservation of visible projected area

$$\cos\theta_o = \int_\Omega G_1(\omega_o, \omega)\langle\omega_o, \omega\rangle D(\omega) d\omega$$

Diffuse BRDFs

- Lambertian $f_r = \frac{\rho}{\pi}$
- Oren-Nayer

$$\begin{aligned}
f_r =& \frac{\rho}{\pi}(A + (B \cdot \max\left[0, \cos(\phi_i - \phi_o)\right] \cdot \sin\alpha \cdot \tan\beta)) \\
A =& 1 - 0.5\frac{\sigma^2}{\sigma^2 + 0.33} \\
B =& 0.45\frac{\sigma^2}{\sigma^2 + 0.09} \\
\alpha =& \max(\theta_i, \theta_o) \\
\beta =& \min(\theta_i, \theta_o)
\end{aligned}$$

Specular BRDFs

- [Cook-Torrance 1981] $f_r(\omega_i, \omega_o) = \frac{D(\omega_h)\ F(\theta_d)\ G_2(\omega_i,\omega_o)}{4\cos\theta_i\cos\theta_o}$
- Microfacet Distribution
  - Normalized Blinn-Phong: $D_{\mathsf{BP}}(\omega_g, \omega_h) = \frac{1}{\pi\alpha^2}(\omega_g \cdot \omega_h)^{\frac{2}{\alpha^2+\epsilon}-(2+\epsilon)}$
  - GGX: $D_{\mathsf{GTR}}(\omega_g, \omega_h) = \frac{1}{\pi}\left(\frac{1}{(\alpha^2-1)(\omega_g\cdot\omega_h)^2+1}\right)^{\gamma}$

Masking-Shadowing Function

- $G_2(\omega_i, \omega_o, \omega_g) = \frac{1}{1+\Lambda(\omega_i)+\Lambda(\omega_o)}$
- GGX: $\Lambda(\omega) = \frac{-1+\sqrt{1+\frac{(\omega_g\cdot\omega)^2}{\alpha^2(1-(\omega_g\cdot\omega)^2)}}}{2}$
- Blinn-Phong: $G_2(\omega_i, \omega_o, \omega_g) = \min\left\{1, \frac{(\omega_g\cdot\omega_h)(\omega_g\cdot\omega_o)}{\omega_o\cdot\omega_h}, \frac{(\omega_g\cdot\omega_h)(\omega_g\cdot\omega_i)}{\omega_o\cdot\omega_h}\right\}$

Fresnel

- [Schlick 1995] $F(\theta_d) = F_0 + (1-F_0)(1-\cos^5\theta_d)$
- $F = \frac{\rho_\parallel^2+\rho_\perp^2}{2}$
- $\rho_\parallel^2 = \frac{(\eta_2^2+\kappa_2^2)\cos^2\theta_d-2\eta_2\cos\theta_d+1}{(\eta_2^2+\kappa_2^2)\cos^2\theta_d+2\eta_2\cos\theta_d+1}$
- $\rho_\perp^2 = \frac{(\eta_2^2+\kappa_2^2)-2\eta_2\cos\theta_d+\cos^2\theta_d}{(\eta_2^2+\kappa_2^2)+2\eta_2\cos\theta_d+\cos^2\theta_d}$

Hybrid Topics and Activity Worksheet

- Global Illumination
- Spherical Harmonics