Realistic Materials

Translucent Materials

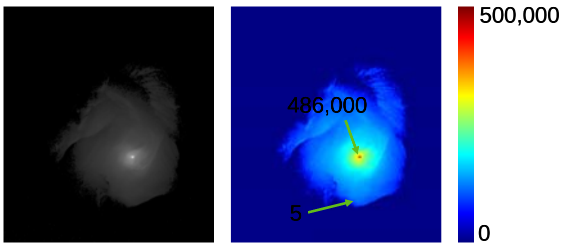
Translucent Objects


- light is scattered through the object
- incident illumination smoothed due to diffuse scattering inside media

Inhomogeneous Translucent Objects


- caused by material variation or internal structure
- required for realistic appearance

Inherent High Dynamic Range



Overview

- **models for translucent objects**
- the BSSRDF
- dipole approximation


Models for Translucent Objects

- basic physical properties
  - e.g., absorption and scattering cross sections σ_a and σ_s [Ishimaru78]
  - defined for the whole object volume
- rendering possible with variety of techniques such as
  - finite element methods [Rushmeier90, Sillion95, Blasi93]

Models for Translucent Objects

- rendering techniques (contd.)
  - finite element methods [Rushmeier90, Sillion95, Blasi93]
  - bidirectional path tracing [Hanrahan93, Lafortune96]
  - photon mapping [Jensen98, Dorsey99]
  - Monte Carlo simulations [Pharr00, Jensen99]
  - diffusion [Stam95, Stam01]
  - precomputed radiance transfer [Sloan03a]

Models for Translucent Objects

- specialized models
  - BSSRDF [Nicodemus 1977]
  - dipole approximation [Jensen et al. 2001]
    - includes measurements of physical parameters for homogeneous materials

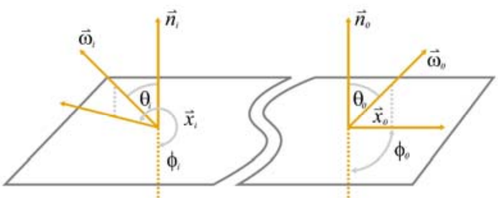
Overview

- models for translucent objects
- **the BSSRDF**
- dipole approximation

The BSSRDF

- bidirectional scattering-surface reflectance distribution function [Nicodemus 1977]
  - general model of light transport inside an object
  - (almost) equivalent to a reflectance field [Debevec et al. 2000]
  - ratio of reflected radiance to incident flux
  - 8 dimensional function

The BSSRDF



$$S(\vec{x}_i, \hat{\omega}_i; \vec{x}_o, \hat{\omega}_o) := \frac{dL^{\rightarrow}(\vec{x}_o, \hat{\omega}_o)}{d\Phi^{\leftarrow}(\vec{x}_i, \hat{\omega}_i)}$$

The BSSRDF

- outgoing radiance computed by integrating over the whole surface and all incoming directions

$$L^{\rightarrow}(\vec{x}_o, \hat{\omega}_o) = \int_A \int_\Omega L^{\leftarrow}(\vec{x}_i, \hat{\omega}_i) \cdot S(\vec{x}_i, \hat{\omega}_i; \vec{x}_o, \hat{\omega}_o) \langle \hat{n}_i \cdot \hat{\omega}_i \rangle d\hat{\omega}_i d\vec{x}_i$$

Single Scattering vs. Multiple Scattering

- single scattering contribution strongly dependent on incoming light direction
  - example: honey pot illuminated by a laser from the left

Single Scattering vs. Multiple Scattering

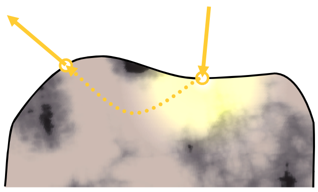
- multiple scattering (almost) independent of incident light direction
  - example: alabaster block illuminated by a laser from the left

Single Scattering vs. Multiple Scattering

- often modeled independently, e.g.,
  - single scattering using ray tracing
  - multiple scattering using a less complex model with diffuse approximation

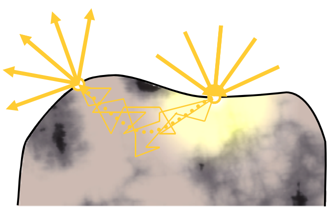
BSSRDF Approximation

- BSSRDF too complex for many application
  - acquisition, storage, …
  - all combinations of directions and positions



Diffuse Scattering Approximation

- neglect directional dependence
  - frequent scattering events in optically dense media lead to diffuse scattering inside the media



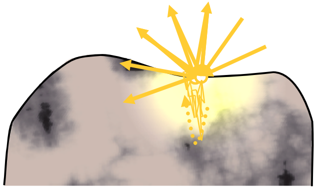
Diffuse Scattering Approximation

- approximate BSSRDF by diffuse reflectance
  - only 4 dimensions
  - requires Fresnel terms at incoming and outgoing locations
  - simplifies handling drastically – commonly used

$$S(\vec{x}_i,\hat{\omega}_i;\vec{x}_o,\hat{\omega}_o) = \frac{1}{\pi}F_t(\eta,\hat{\omega}_i)R_d(\vec{x}_i,\vec{x}_o)F_t(\eta,\hat{\omega}_o)$$

Diffuse BRDF Approximation

- neglect directional dependence (no Fresnel)
- assume incident and exitant location near



Diffuse BRDF Approximation

- approximate BSSRDF by diffuse BRDF
  - assume incident and outgoing locations are very close to each other
  - neglect Fresnel effect

$$S(\vec{x}_i, \hat{\omega}_i; \vec{x}_o, \hat{\omega}_o) = \frac{1}{\pi} k_d$$

Overview

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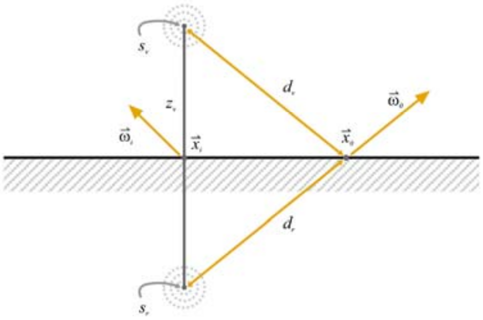
- **dipole approximation**

Dipole Approximation

- [Jensen et al. 2001]
- infinite half-space of homogeneous material
- optically dense, modeling of multiple scattering

$$R_d(\vec{x}_i, \vec{x}_o) = \frac{\alpha'}{4\pi} \left[z_r(1 + \sigma_{tr} d_r) \frac{e^{-\sigma_{tr} d_r}}{d_r^3} + z_v(1 + \sigma_{tr} d_v) \frac{e^{-\sigma_{tr} d_v}}{d_v^3} \right]$$

Dipole Approximation

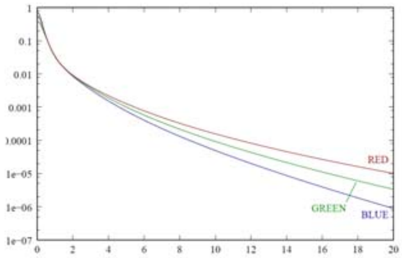


Dipole Approximation

$$\begin{aligned}
z_r &= 1/\sigma_t' \\
z_v &= z_r + 4AD \\
d_r &= \|\vec{x}_r - \vec{x}_o\|, \text{with } \vec{x}_r = \vec{x}_i - z_r \hat{n}_i \\
d_v &= \|\vec{x}_v - \vec{x}_o\|, \text{with } \vec{x}_v = \vec{x}_i + z_v \hat{n}_i \\
A &= \frac{1 + F_{dr}}{1 - F_{dr}} \\
F_{dr} &= -\frac{1.440}{\eta^2} + \frac{0.710}{\eta} + 0.668 + 0.0636\eta \\
D &= 1/3\sigma_t' \\
\sigma_{tr} &= \sqrt{3\sigma_a \sigma_t'} \\
\sigma_t' &= \sigma_a + \sigma_s' \\
\alpha' &= \sigma_s'/\sigma_t'
\end{aligned}$$

Dipole Approximation

- example: marble from [Jensen et al. 2001]

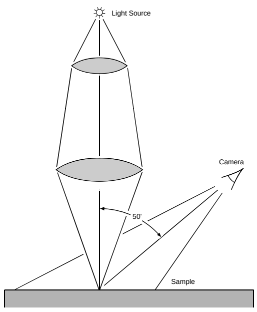


Determining Physical Parameters

- required for dipole approximation
  - scattering and absorption coefficient
  - relative index of refraction
- also required for evaluation of single scattering term

Determining Physical Parameters

- image-based measure-ment setup [Jensen et al. 2001]
  - surface point illuminated by focused beam of white light
  - object observed by digital camera
  - parameters determined via diffusion solution



Results

photograph

rendering

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