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max planck institut informatik

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Course 10
Realistic Materials in Computer Graphics

Translucent Materials

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(moving to the University of Washington)

Translucent Objects


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

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Inhomogeneous Translucent Objects


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

Varying Local Illumination

- caused by shadows or directional light sources

Overview

- models for translucent objects
- the BSSRDF
- dipole approximation
- acquisition with DISCO
  - hierarchical model for multiple scattering


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]

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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]

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Models for Translucent Objects

- light fields / reflectance fields
  - light fields [Levoy96,Gortler96,Miller98,Wood00,…]
  - reflectance fields [Debevec00,Malzbender01]
  - opacity hulls [Matusik03]
  - incident light fields [Masselus03]

⇒ no correct response to locally varying illumination

⇒ see remainder of the course

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Models for Translucent Objects

- specialized models
  - BSSRDF [Nicodemus 1977]
  - dipole approximation [Jensen et al. 2001]
    - includes measurements of physical parameters for homogeneous materials
  - DISCO system to acquire diffuse multiple scattering model R_d [Goesele et al. 2004]
    - modeling of inhomogeneous materials

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Overview

- models for translucent objects
- **the BSSRDF**
- dipole approximation
- acquisition with DISCO
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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

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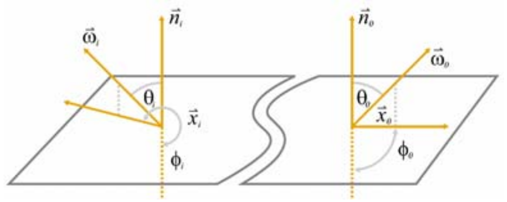
The BSSRDF



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

The BSSRDF

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

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

The BSSRDF

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

- 8 dimensional function, tedious to handle
- basic behavior of translucent objects:
  - light is scattered inside
  - light distribution gets diffuse after several scattering events

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

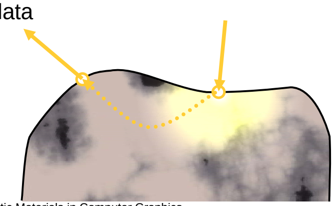
- multiple scattering (almost) independent of incident light direction
  - example: alabaster block illuminated by a laser from the left

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

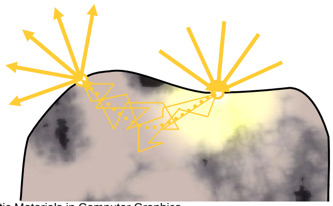
Diffuse Approximation

- BSSRDF too complex for many application
  - acquisition, storage, …
  - all combinations of directions and positions
  - 8D data



Diffuse Approximation

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



Diffuse Approximation

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

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

Overview

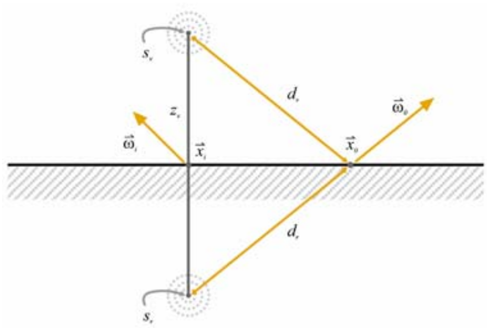
- models for translucent objects
- the BSSRDF
- **dipole approximation**
- acquisition with DISCO
  - hierarchical model for multiple scattering

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

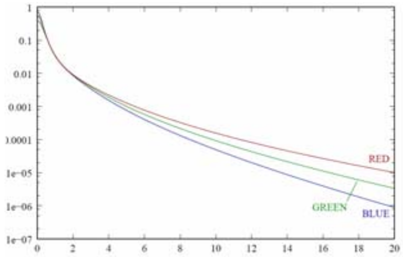


Dipole Approximation

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

Dipole Approximation

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

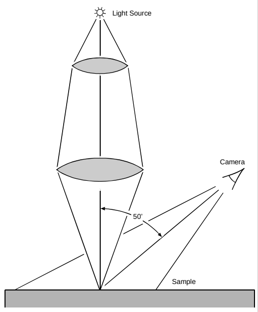


Determining Physical Parameters

- required for dipole approximation
  - scattering and absorption coefficient σ'_s σ_a
  - relative index of refraction η
- 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

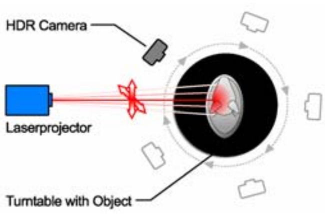


Overview

- models for translucent objects
- the BSSRDF
- dipole approximation
- **acquisition with DISCO**
  - **hierarchical model for multiple scattering**

DISCO Acquisition Approach

- illuminate individual surface points with laser projector
- record impulse response of the object with HDR video camera



Acquisition Equipment

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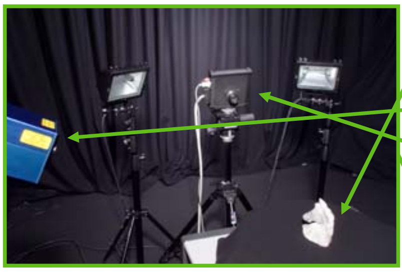

- turntable
- laser projector
- HDR camera
- black room

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Laser Projector

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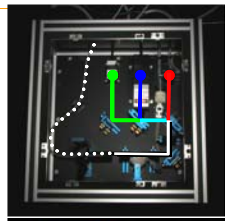
- three lasers
  - (635nm, 532nm, 476nm)
  - ~10mW optical power
- constancy
- resolution 4096x4096 steps
  - step size < 0.1 mm
    on object possible
- repeatable



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HDR Video Camera

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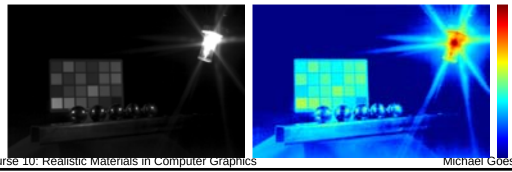
- Silicon Vision Lars III
  - other HDR video cameras also available
- monochrome HDR
- dynamic range > 1:1,000,000
- acquisition with 15 fps



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Inherent High Dynamic Range

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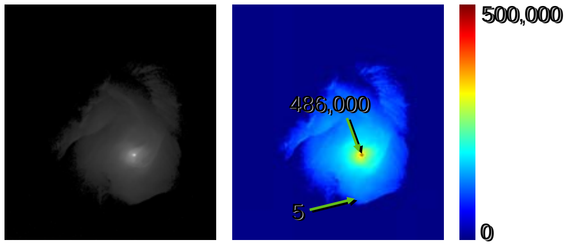

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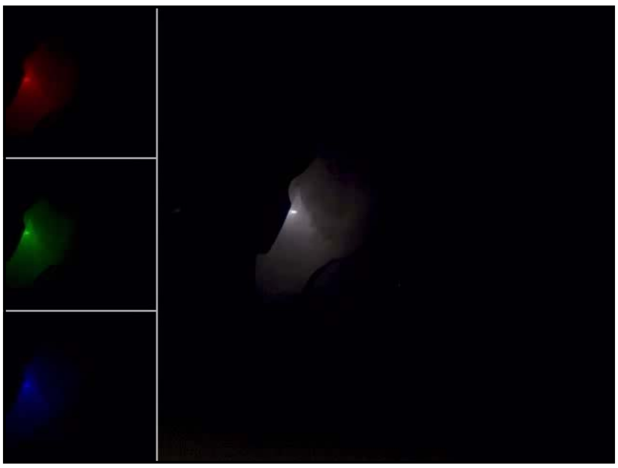

Throughput Factor Matrix

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- 500,000-1,000,000 images acquired
- all views where the same point is illuminated yield one column of the point-to-point matrix

- problems:
  - approx $100{,}000^2$ entries
  - still a lot of holes
  - impractical to render

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Hierarchical Model

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- properties of radiosity inside object
  - exponential fall-off
  - strong variation near incident illumination
  - smooth variation far away from incident illumination
    - modified by fine-scale structure close to surface

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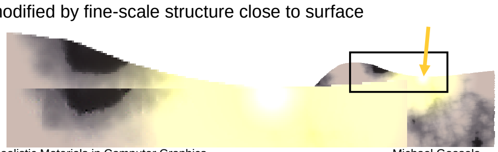

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Hierarchical Model

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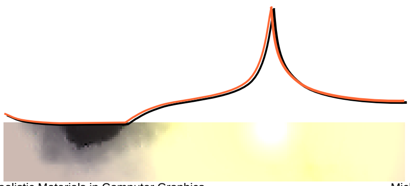

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Hierarchical Model

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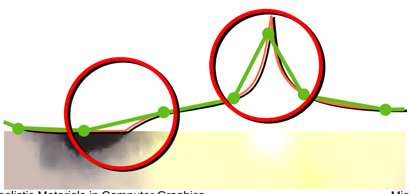
- global response as sparse transfer matrix
  - e.g., vertex-to-vertex throughput factors on mesh
  - fine scale detail preserved by a modulation texture



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Hierarchical Model

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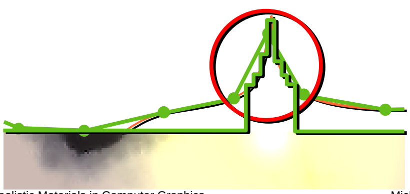
- local response
  - pixel-to-pixel throughput factors in texel space
  - small neighborhood only



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Resampling

- resample images into hierarchical model
  - assemble global term at vertex positions
  - determine filter kernels in texture space
- problems
  - incomplete sampling
    - → *missing data needs to be interpolated*
  - measurement noise
  - see [Goesele et al. 2004] for details

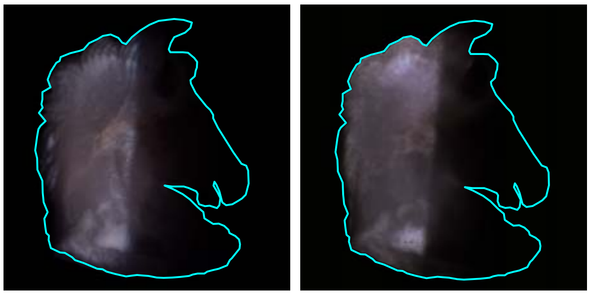
Results

photograph

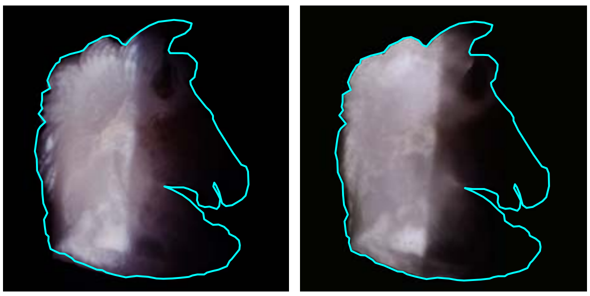
rendering

Results: Local Illumination Variation

Results: Local Illumination Variation



Results: Local Illumination Variation



Results

Overview

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- the BSSRDF
- dipole approximation
- acquisition with DISCO
  - hierarchical model for multiple scattering

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Schedule

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- 1:45 Transparent/Specular Materials (Y.-Y. Chuang)
- 2:30 Fibers (S. Marschner)
- 3:30 Break
- 3:45 BTFs (G. Müller)
- 4:30 Reflectance Fields (T. Hawkins)
- 5:15 Conclusion, Questions & Answers (all)

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Course Web Pages

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- find updated content at

  http://www.mpi-inf.mpg.de/resources/siggraph05-course-realistic-materials

- please enter your comments at

  http://www.siggraph.org/courses_evaluation

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