Subsurface Scattering

Last Time?
- Bi-Directional Path Tracing
- Irradiance Caching
- Photon Mapping
- Ray Grammar

Today
- Measuring BRDFs
- 3D Digitizing & Scattering
- Fresnel Reflection
- Importance of Participating Media
- BSSRDFs
- Other Complex Materials

BRDFs in the Movie Industry
- Agent Smith’s clothes are CG, with measured BRDF

How Do We Obtain BRDFs?
- Gonioreflectometer
  - 4 degrees of freedom

Source: Greg Ward

BRDFs in the Movie Industry

BRDFs in the Movie Industry

Not just a BRDF…

Materials – BRDF & BTDF


Measuring Materials


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3D Digitizing

The Digital Michelangelo Project: 3D Scanning of Large Statues, Levoy et al., SIGGRAPH 2000
Scattering & Scanning

![Image: Diffusion in a sample of Carrara Statuario marble.](image)


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Amount of Reflection

- Traditional ray tracing (hack)
  - Constant reflectionColor
- More realistic:
  - Fresnel reflection term (more reflection at grazing angle)
  - Schlick’s approximation: \( R(\theta) = R_0 + (1-R_0)(1-\cos \theta)^5 \)

Dusty Surfaces & Retro-Reflection

- Viewed perpendicular to the surface, there is little scattering off dust
- At grazing angles, there is increased scattering with the dust making the surface appear brighter
- Similarly, the earth viewed from space appears brighter near the edges, because of increased scattering of the atmosphere.

Light Rays in a Dusty Room

![Image: Light rays in a dusty room.](image)

Annie Ding, MIT 6.837 Final Project December, 2004

Participating Media

![Image: Participating media.](image)

Image by Henrik Wann Jensen
Today

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Reading for Today:

• “A Practical Model for Subsurface Light Transport”, Jensen, Marschner, Levoy, & Hanrahan, SIGGRAPH 2001

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**BRDF vs. BSSRDF**

Images from "A Practical Model for Subsurface Light Transport" Jensen, Marschner, Levoy, & Hanrahan SIGGRAPH 2001

**Subsurface Scattering Variables**

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scattering Coeff.</td>
<td>$\sigma_s$</td>
<td>(length)$^{-1}$</td>
<td>Probability of scattering per unit length</td>
</tr>
<tr>
<td>Absorption Coeff.</td>
<td>$\sigma_a$</td>
<td>(length)$^{-1}$</td>
<td>Probability of absorption per unit length</td>
</tr>
<tr>
<td>Phase Function</td>
<td>$p(x,\theta_{\text{r}})$</td>
<td></td>
<td>Angular distribution of scattering</td>
</tr>
<tr>
<td>Extinction Coeff.</td>
<td>$\sigma_e$</td>
<td>(length)$^{-1}$</td>
<td>$\sigma_a + \sigma_s$</td>
</tr>
<tr>
<td>(Scattering) Albedo</td>
<td>$\rho$</td>
<td></td>
<td>$\rho = \frac{\sigma_s}{\sigma_e}$</td>
</tr>
<tr>
<td>Optical Depth</td>
<td>$\tau(0,\theta)$</td>
<td></td>
<td>$\int_{0}^{\tau} \rho \text{d}x$</td>
</tr>
<tr>
<td>Transmission</td>
<td>$\tau(0,\theta)$</td>
<td></td>
<td>$e^{-\tau(0,\theta)}$</td>
</tr>
</tbody>
</table>

- Albedo: first approximation of BRDF, % of light reflected off the surface
  - When the albedo = 1, no absorption occurs and light is only transmitted or scattered. This is an ok approximation for snow or clouds.

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**Sampling a BSSRDF**

*Figure 7: (a) Sampling a BRDF (traditional sampling), (b) sampling a BSSRDF (the sample points are distributed both over the surface as well as the light).*

Images from "A Practical Model for Subsurface Light Transport" Jensen, Marschner, Levoy, & Hanrahan SIGGRAPH 2001

**BSSRDF Measurement**

Images from "A Practical Model for Subsurface Light Transport" Jensen, Marschner, Levoy, & Hanrahan SIGGRAPH 2001
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Measuring BSSRDF by Dilution

"Acquiring Scattering Properties of Participating Media by Dilution" Narasimhan et al. SIGGRAPH 2006

Measuring Hair

"Light Scattering from Human Hair Fibers" Marschner et al., SIGGRAPH 2003
**Rendering Hair**

<table>
<thead>
<tr>
<th>Old Method</th>
<th>New Method</th>
<th>Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Old Method Image]</td>
<td>![New Method Image]</td>
<td>![Photo Image]</td>
</tr>
</tbody>
</table>

Figure 12: A comparison of Kirkup and Kim’s model (left) to our single generated model (center) with the same lighting and the hair from the photograph (right). The hair in our model differs somewhat in detail and appearance, but the remainder highlights our model’s capability to capture the colored shading of the real hair.

“Light Scattering from Human Hair Fibers”
Marschner et al., SIGGRAPH 2003

**Readings for Friday 4/11:**

*Choose one:*
- “Estimating the Location of a Camera with Respect to a 3D Model”, Yang, Becker, & Stewart, 3DIM 2007
- “Procedural Modeling of Buildings”
Mueller, Wonka, Haegler, Ulmer & Van Gool, SIGGRAPH 2006