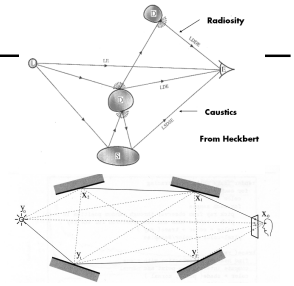
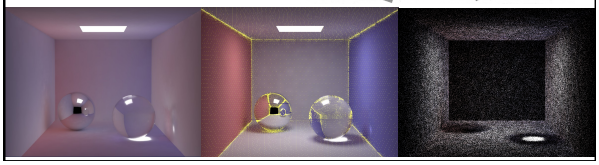
Subsurface Scattering

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

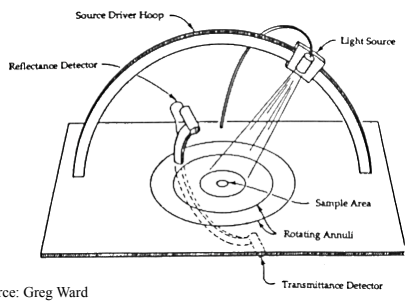
BRDFs in the Movie Industry

- Agent Smith's clothes are CG, with measured BRDF

http://www.virtualcinematography.org/publications/acrobat/BRDF-s2003.pdf

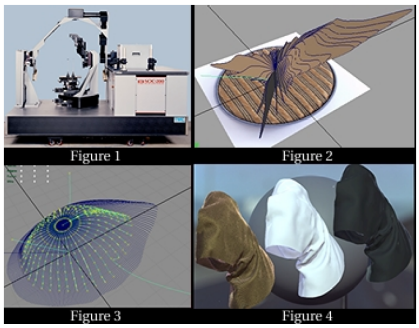
How Do We Obtain BRDFs?

- Gonioreflectometer
  - 4 degrees of freedom



Source: Greg Ward

BRDFs in the Movie Industry



- http://www.virtualcinematography.org/publications/acrobat/BRDF-s2003.pdf

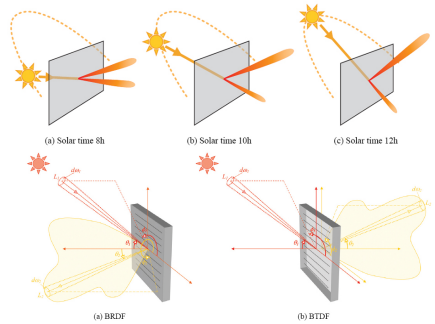
BRDFs in the Movie Industry

Photo CG Photo CG

Not just a BRDF…

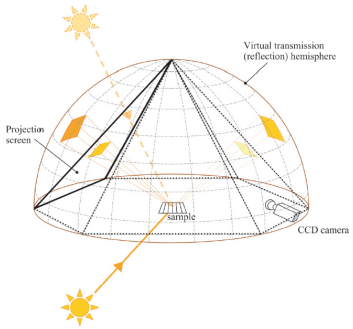
From presentation by
J.P. Lewis and George Borshukov

Materials – BRDF & BTDF



M. Andersen, "Innovative bi-directional video-goniophotometer for advanced fenestration systems", 2004.

Measuring Materials



M. Andersen, "Innovative bi-directional video-goniophotometer for advanced fenestration systems", 2004.

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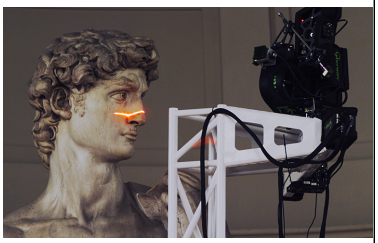
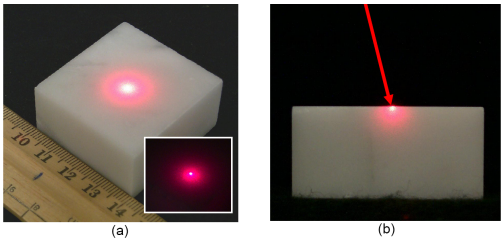
3D Digitizing

Cyberware



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

Scattering & Scanning



(a) (b)

Figure 1: Diffusion in a sample of Carrara Statuario marble.

An Assessment of Laser Range Measurement of Marble Surfaces, Godin et al, 2001.

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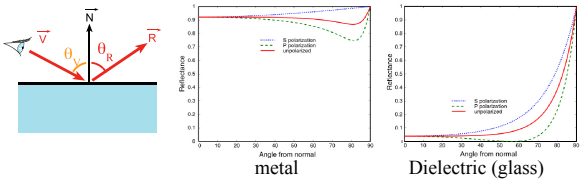
Amount of Reflection

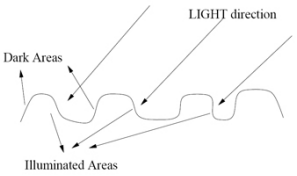
- Traditional ray tracing (hack)
  - Constant **`reflectionColor`**
- More realistic:
  - Fresnel reflection term (more reflection at grazing angle)
  - Schlick's approximation: $R(\theta)=R_0+(1-R_0)(1-\cos\theta)^5$



metal Dielectric (glass)

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.



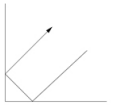
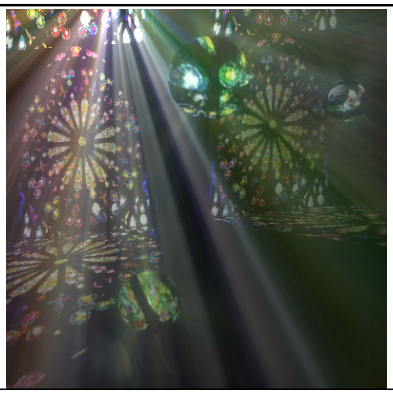


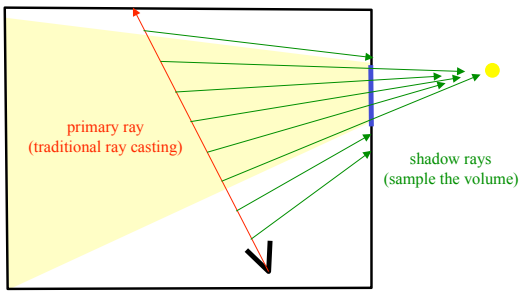
Figure 5: Showing retroreflection from a very rough surface (left). Only areas with normals close to the light direction are well lit, so there is a strong retroreflective peak. On the right, we see a corner reflector (the inside corner of 3 planes is the 3D analog) which produces the same effect.

Light Rays in a Dusty Room



Annie Ding, MIT
6.837 Final Project
December, 2004

Ray Tracing Participating Media



Participating Media

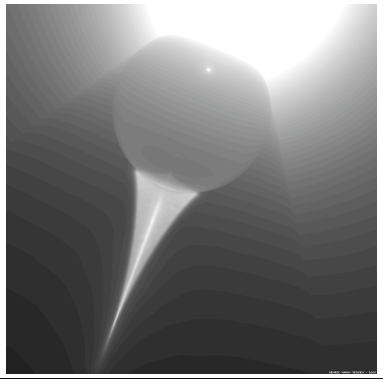


Image by Henrik Wann Jensen

Today

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- Fresnel Reflection
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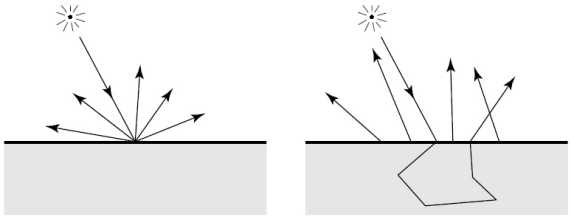
- BSSRDFs
- Other Complex Materials

Reading for Today:

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

BRDF vs. BSSRDF



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

Subsurface Scattering Variables

Name	Symbol	Units	Description
Scattering Coeff.	σ_s	$(\text{length})^{-1}$	Probability of scattering per unit length
Absorption Coeff.	σ_a	$(\text{length})^{-1}$	Probability of absorbtion per unit length
Phase Function	$p(x, \vec{\omega}', \vec{\omega})$		Angular distribution of scattering
Extinction Coeff.	σ_t	$(\text{length})^{-1}$	$\sigma_a + \sigma_s$
(Scattering) Albedo	A		σ_s / σ_t
Optical Depth	$\tau(0, d)$		$\int_0^d \sigma_t dx$
Transmittance	$t(0, d)$		$e^{-\tau(0,d)}$

- 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.

Sampling a BSSRDF

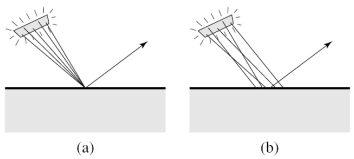
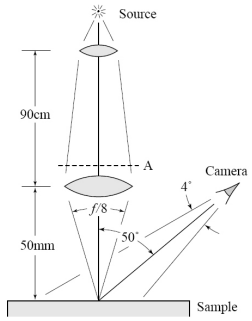


Figure 7: (a) Sampling a BRDF (traditional sampling), (b) sampling a BSSRDF (the sample points are distributed both over the surface as well as the light).

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

Single Scattering

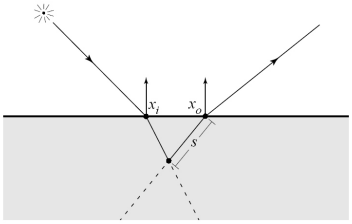


Figure 4: Single scattering occurs only when the refracted incoming and outgoing rays intersect, and is computed as an integral over path length s along the refracted outgoing ray.

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

Dipole Approx. for Diffuse Scattering

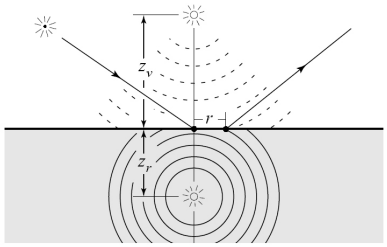


Figure 3: An incoming ray is transformed into a dipole source for the diffusion approximation.

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

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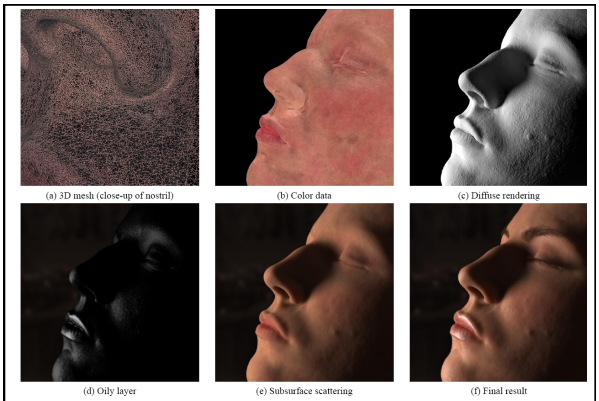


"Digital Face Cloning", Jensen, SIGGRAPH Sketch 2003

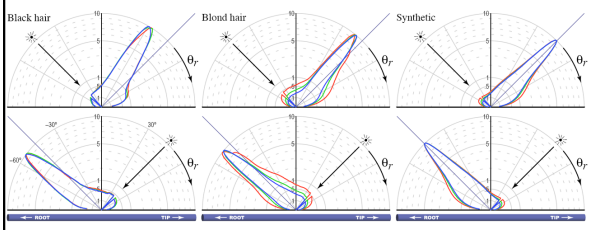
"Light Diffusion in Multi-Layered Translucent Materials" Donner & Jensen, *SIGGRAPH 2005*

Measuring BSSRDF by Dilution

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

(a) Acquired photographs (b) Rendering at low concentrations (c) Rendering at natural concentrations

Measuring Hair



Black hair **Blond hair** **Synthetic (wig)**

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

Rendering Hair

Old Method **New Method** **Photo**

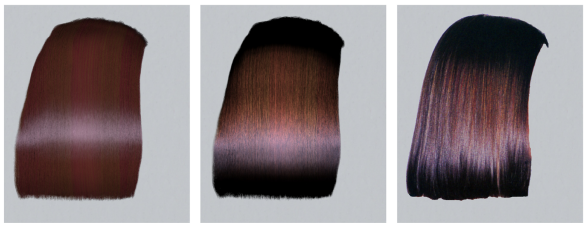


Figure 12: A comparison of Kajiya and Kay's model (left) under a single point source, our proposed model (center) with the same lighting, and the hair from the photograph in Figure 11 (removed from context to simplify the comparison). The Kajiya model's diffuse term results in a flat appearance, while the secondary highlight in our model correctly captures the colored shading of the real hair.

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

Readings for Friday:

Choose one:

- "An Image Synthesizer",
  Perlin, SIGGRAPH 1985
- "Procedural Modeling of Buildings"
  Mueller, Wonka, Haegler, Ulmer
  & Van Gool, SIGGRAPH 2006