Subsurface Scattering & Complex Material Properties

Sprout, PDI Dreamworks 2003

Lifted, Pixar, 2006

Today

- Final Project Proposals
- Measuring BRDFs
- 3D Digitizing
- Rendering Complex Phenomena
- Participating Media
- Papers for Today
  - Subsurface Scattering, BSSRDF
  - Hair Rendering
- Papers for Next Time

https://www.cs.rpi.edu/~cutler/classes/advancedgraphics/S23/final_project.php

Proposal

As you choose your topic and begin to flesh out the details, keep in mind that implementing new data structures or algorithms can take much longer than anticipated. Also be warned that designing and implementing even relatively simple user interfaces require alot of effort (and is not particularly relevant to this course).

Your proposal should be formatted using pdf. The document should be a minimum of 500 words (equivalent of 2 pages double spaced text) and include:

- A brief summary of the technical problem you are going to investigate.
- A list of the specific research papers and other sources you've collected for background reading. Talk with the instructor if you are unable to find at least 3 relevant research papers. Read and summarize the contributions of each paper and describe how your project relates to this work.
- As appropriate for your project, describe a sequence of examples (from the most trivial to moderately complex) that you plan to test to demonstrate the features of your project.
- A timeline for your assignment with a list of the tasks you will execute and *who will do what*. It's ok to list optional tasks that you will work on once the core features are functional. You will be graded relative to the completion of the core tasks, so make sure your plan is feasible.

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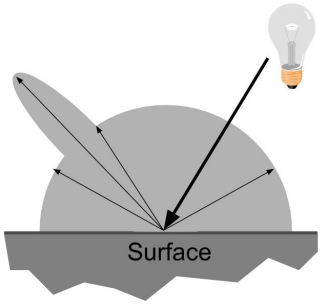
The Phong Material Model

- Sum of three components:
  diffuse reflection +
  specular reflection + “ambient”
- Assumes all materials are either (near) perfect mirrors, or perfectly diffuse/Lambertian, or a simple combination of the two.

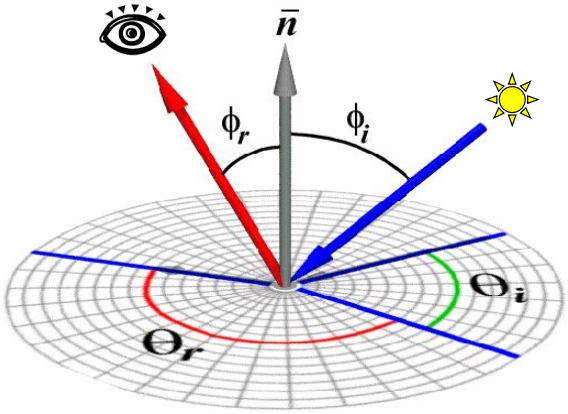
```
material
diffuse 0.4 0.4 0.1
reflective 0.5 0.5 0.5
refractive 0.0 0.0 0.0
roughness 0.1
emitted 0 0 0
```



- *Phong is “ok” for shiny new plastic… but not good enough for many other real-world materials.*

BRDF

- Ratio of light coming from one direction that gets reflected in another direction
- Bidirectional Reflectance Distribution Function
  - 4D
  - $R(\theta_i, \varphi_i; \theta_r, \varphi_r)$
  - Note: BRDF for *isotropic* materials is 3D



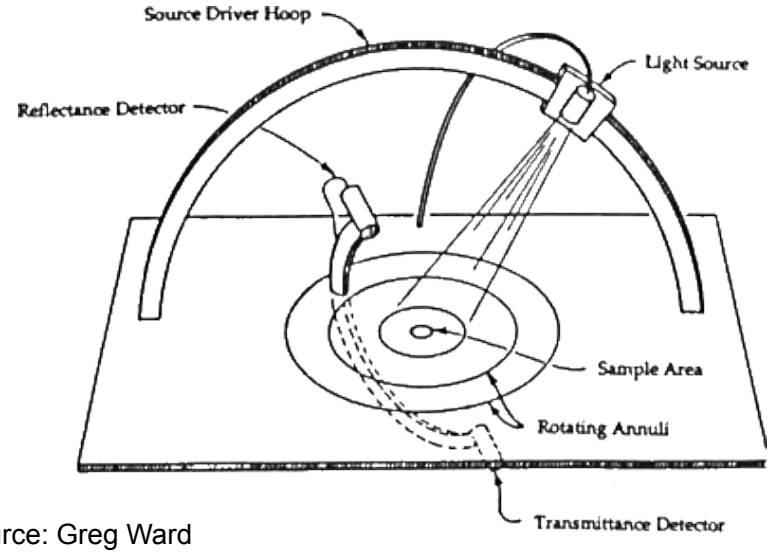
BRDFs in the Movie Industry

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

Measured BRDF in film production: realistic cloth appearance for "The Matrix Reloaded"
Borshukov, SIGGRAPH 2003 Sketches & Applications

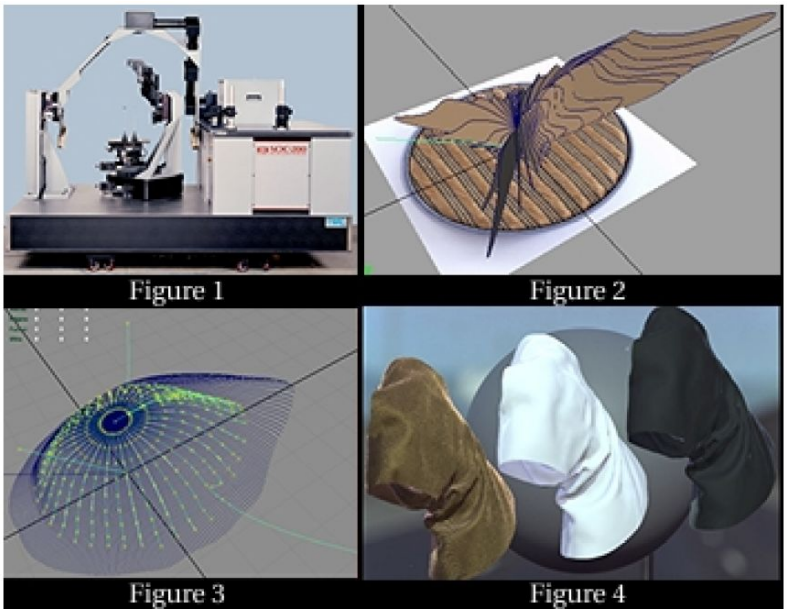
How Do We Obtain BRDFs?

- Gonioreflectometer
  - 4 degrees of freedom



Source: Greg Ward

BRDFs in the Movie Industry



Measured BRDF in film production: realistic cloth appearance for "The Matrix Reloaded"
Borshukov, SIGGRAPH 2003 Sketches & Applications

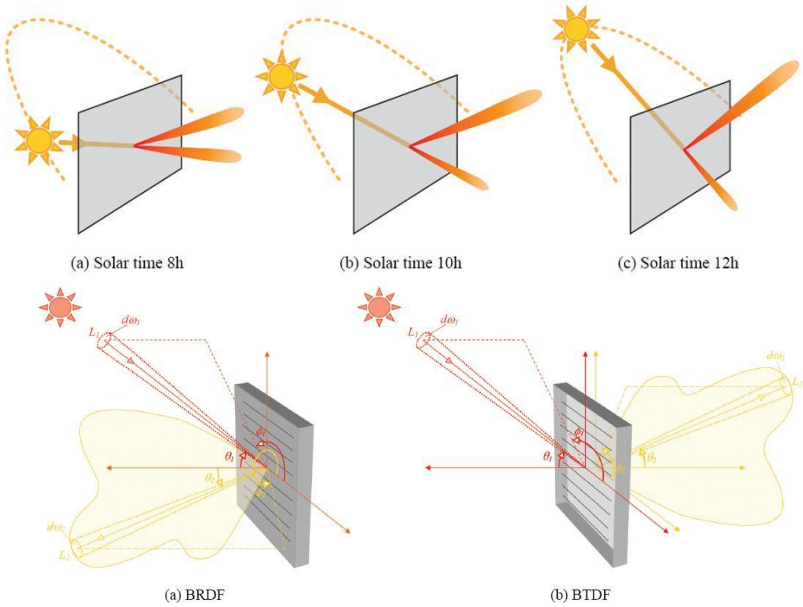
BRDFs in the Movie Industry

Photo CG Photo CG

Not just a BRDF…

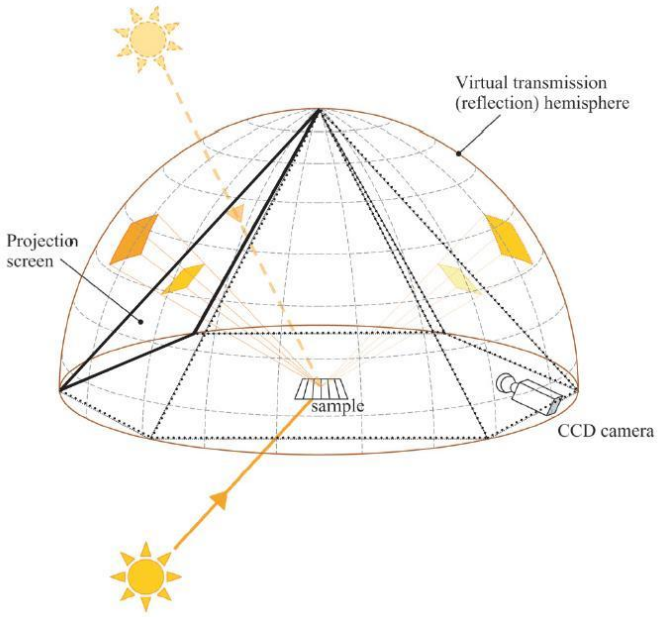
Realistic human face rendering for "The Matrix Reloaded"
Borshukov & Lewis, SIGGRAPH 2003 Sketches & Applications

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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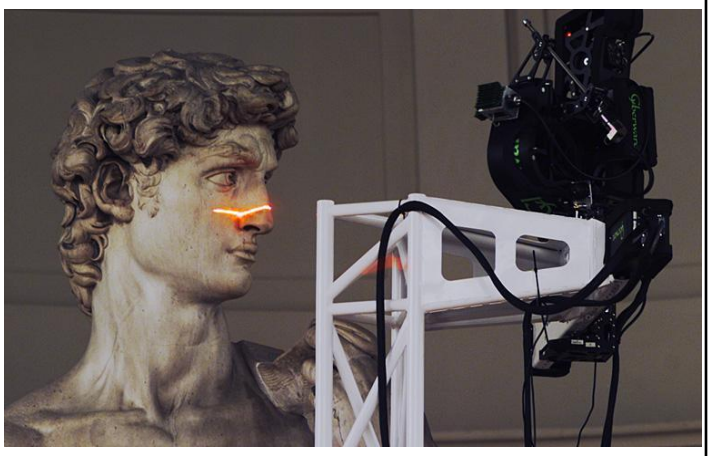
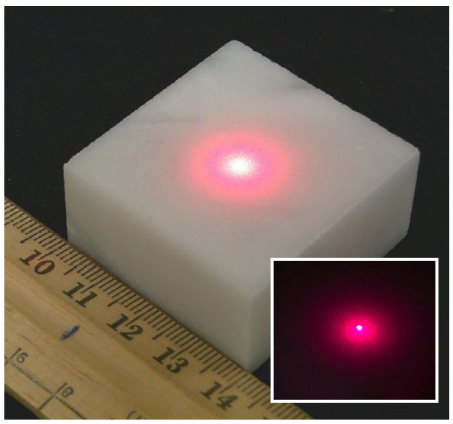
3D Digitizing

Cyberware

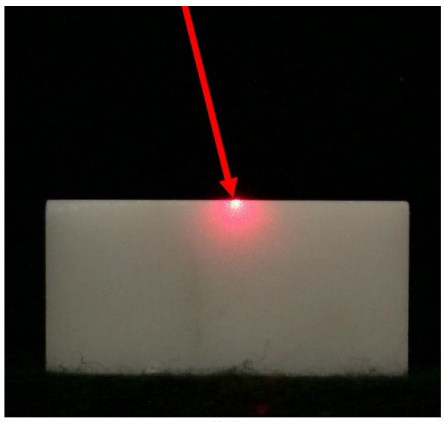


The Digital Michelangelo Project: 3D Scanning of Large Statues,
Levoy et al., *SIGGRAPH 2000*

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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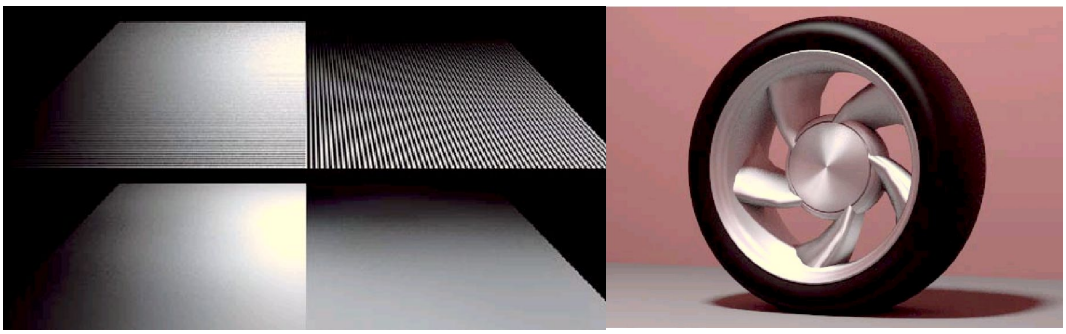
Anisotropic BRDFs

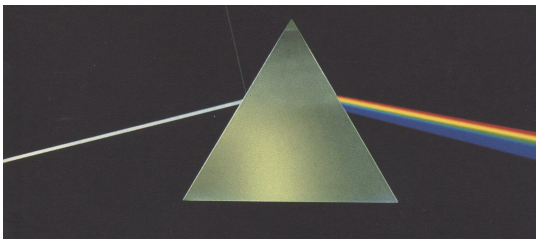
- Surfaces with strongly oriented microgeometry
- Examples:
  - brushed metals, hair, fur, cloth, velvet



Source: Westin et.al 92

What makes a Rainbow?

- Refraction is wavelength-dependent
  - Refraction increases as the wavelength of light decreases
  - violet and blue experience more bending than orange and red
- Usually ignored in graphics
- Rainbow is caused by refraction + internal reflection + refraction
- Why is the sky blue?



Pink Floyd, *The Dark Side of the Moon*

From "Color and Light in Nature" by Lynch and Livingstone

"Rendering Lunar Eclipses" Yapo & Cutler, Graphics Interface 2009

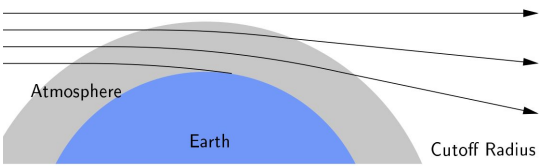
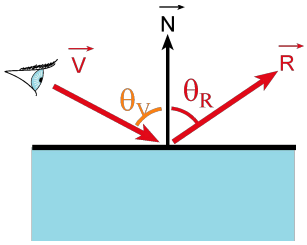
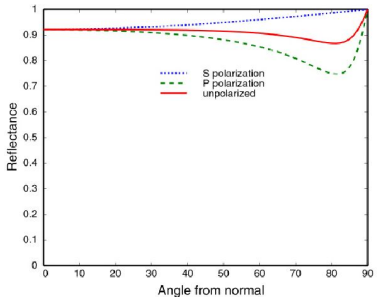


Figure 3: Exploiting symmetry of the Sun-Earth system. Illumination during a lunar eclipse is symmetric relative to the center line connecting the Sun and Earth, and is independent of the Moon's position. Any ray exiting the Earth's atmosphere could have exited from any point along a circle lying in the spherical shell of the atmosphere; these rays form a hyperboloid of revolution when rotated about the symmetric axis. This illustration is drawn to scale (the Sun is 48m to the left of this page).

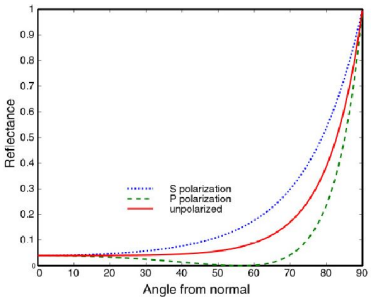
Amount of Reflection

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





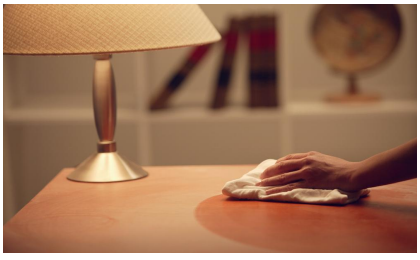
metal

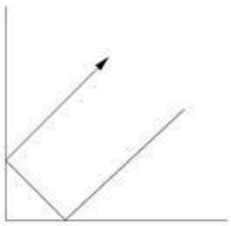


Dielectric (glass)

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
- Earth viewed from space appears brighter near the edges, due to increased atmospheric scattering
- Road paint is intentionally retro-reflective (so drivers see road markings illuminated by their own headlights)





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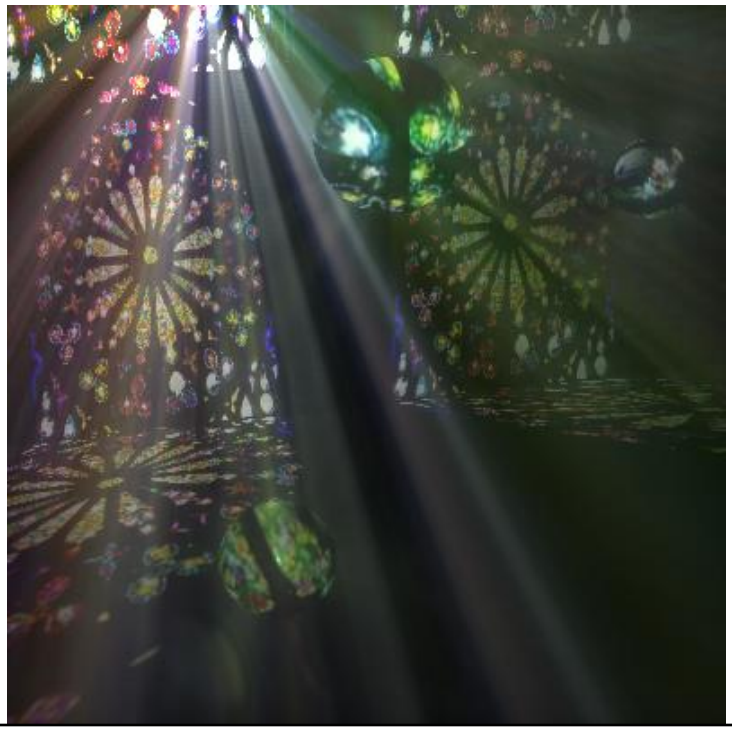
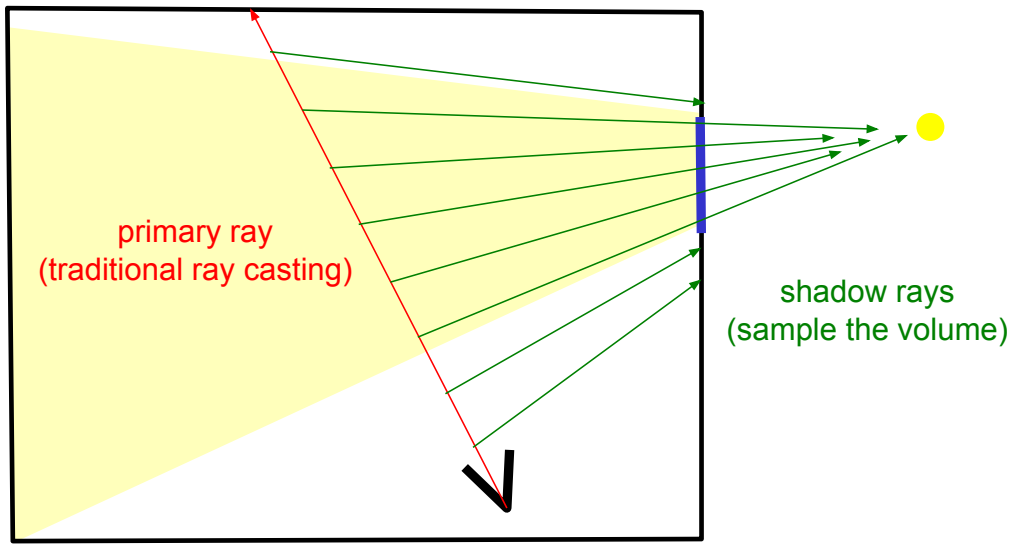
Light Rays in a Dusty Room



Annie Ding, MIT
6.837 Final Project
December, 2004

Ray Tracing Participating Media



Participating Media

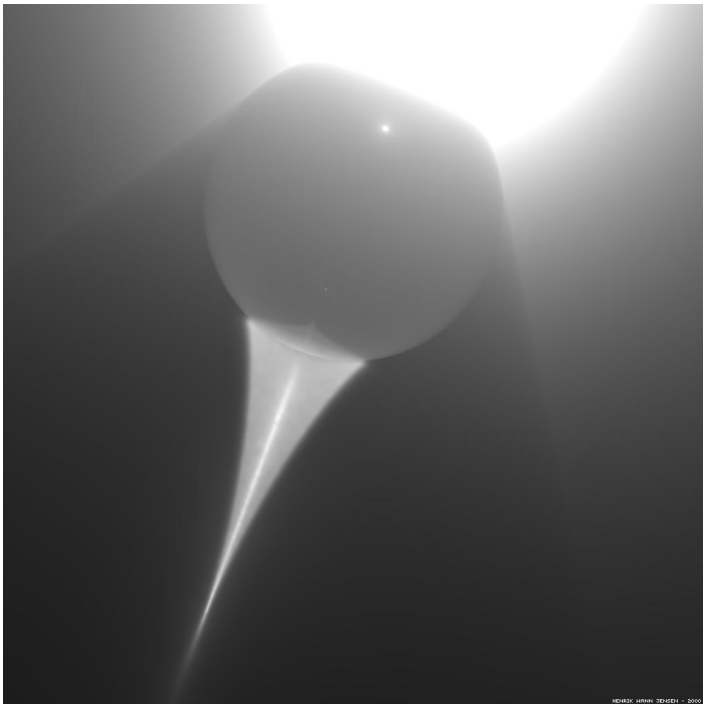
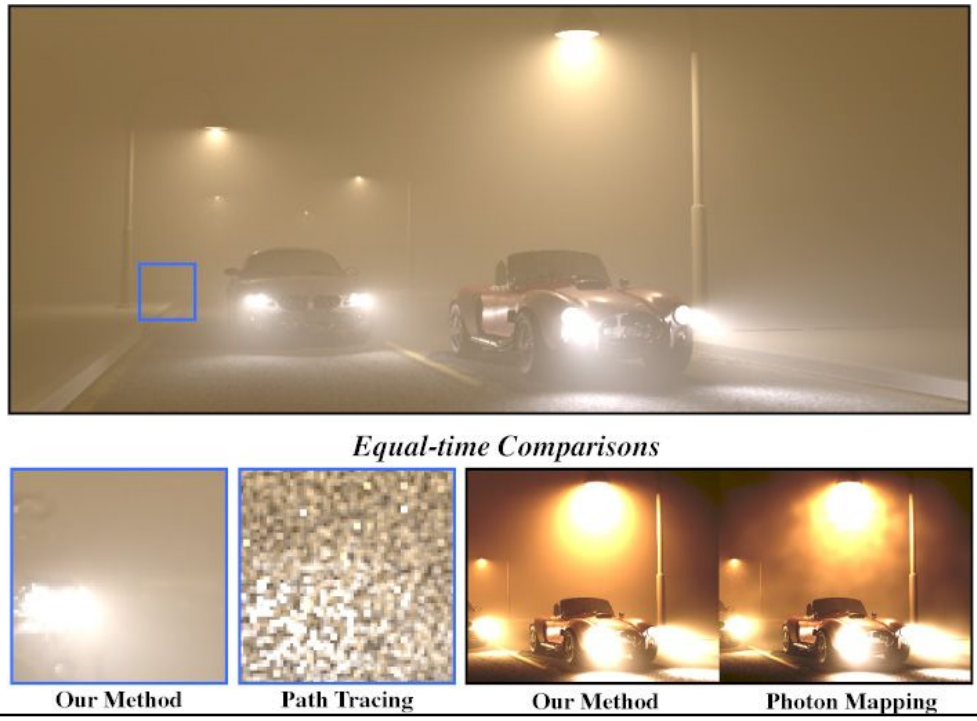


Image by
Henrik
Wann Jensen

“Radiance Caching for Participating Media”, Jarosz, Donner, Zwicker, & Jensen, 2008.



Equal-time Comparisons

Our Method | Path Tracing | Our Method | Photon Mapping

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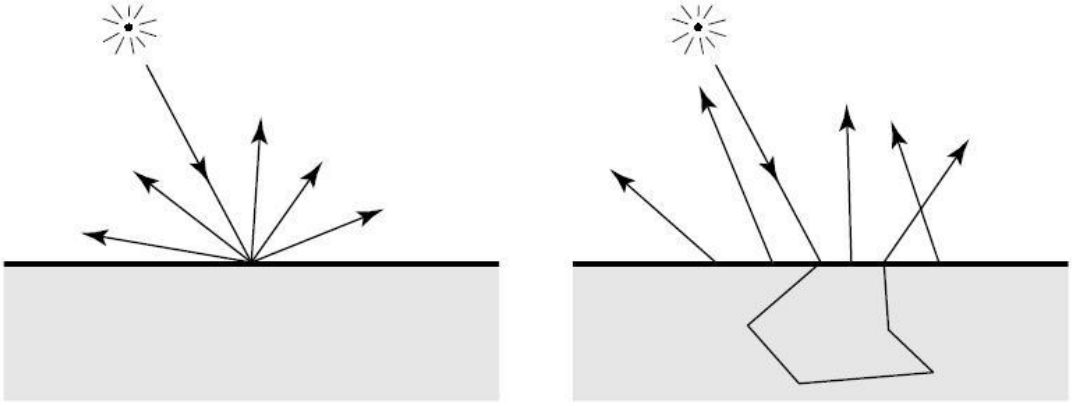
Reading for Today: *(pick one)*

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

Rendering Translucent Materials

Jensen, Marschner, Levoy, & Hanrahan, SIGGRAPH 2001

BRDF vs. BSSRDF



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

Single Scattering

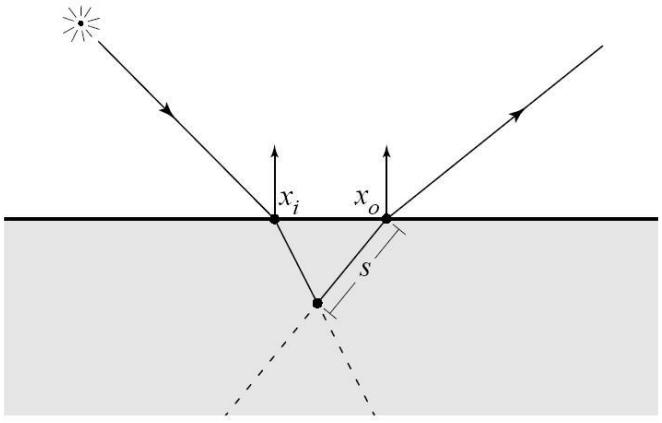


Figure 4: Single scattering occurs only when the refracted incoming and outgoing rays intersect, and is computed as an integral over path length s along the refracted outgoing ray.

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

Dipole Approx. for Diffuse Scattering

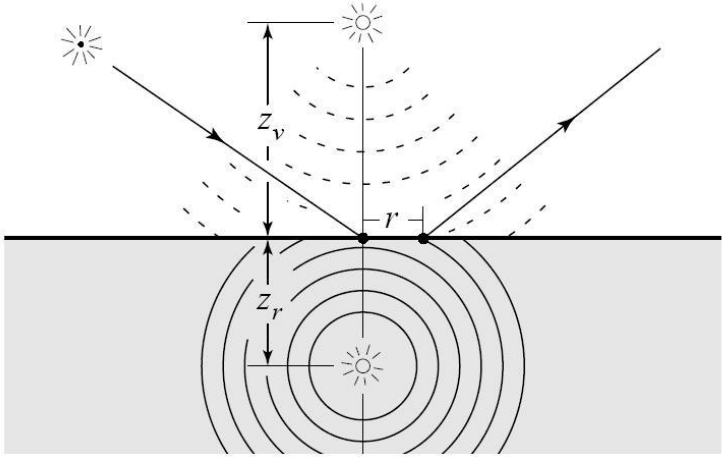
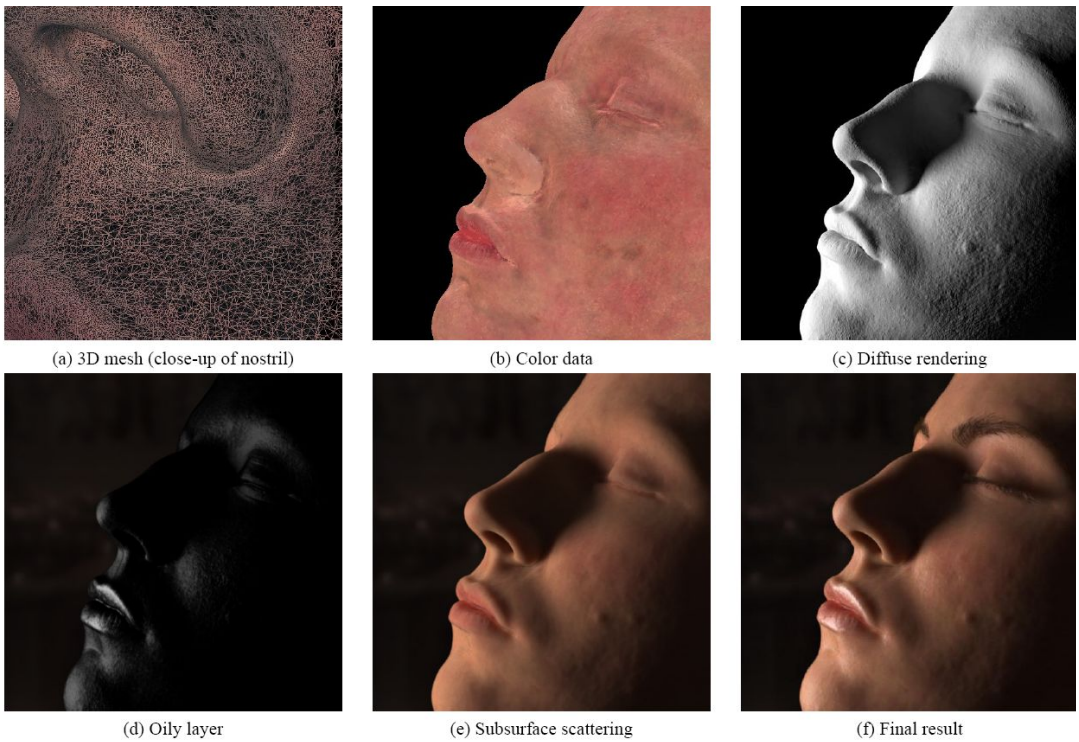


Figure 3: An incoming ray is transformed into a dipole source for the diffusion approximation.

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



(a) 3D mesh (close-up of nostril) (b) Color data (c) Diffuse rendering

(d) Oily layer (e) Subsurface scattering (f) Final result

"Digital Face Cloning", Jensen, SIGGRAPH Sketch 2003

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

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

Jade Jade + paint

Figure 5: *A buddha statuette sprayed with a thin layer of white paint. The first and third images are front-lit, the second and fourth back-lit.*

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

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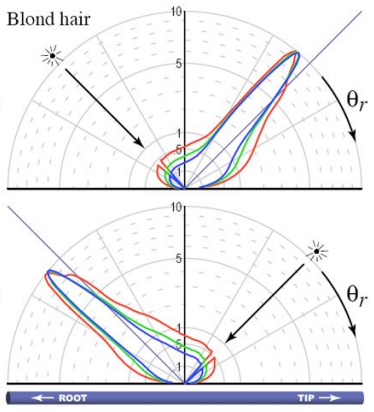
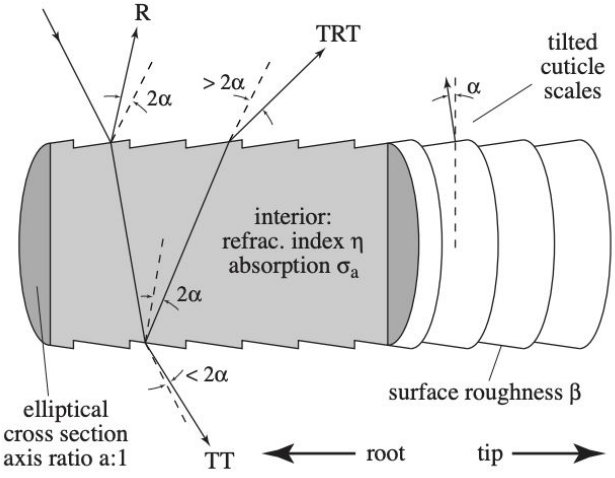
Figure 12: A comparison of Kajiya and Kay's model (left) under a single point source, our proposed model (center) with the same lighting, and the hair from the photograph in Figure 11 (removed from context to simplify the comparison). The Kajiya model's diffuse term results in a flat appearance, while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

Reading for Today

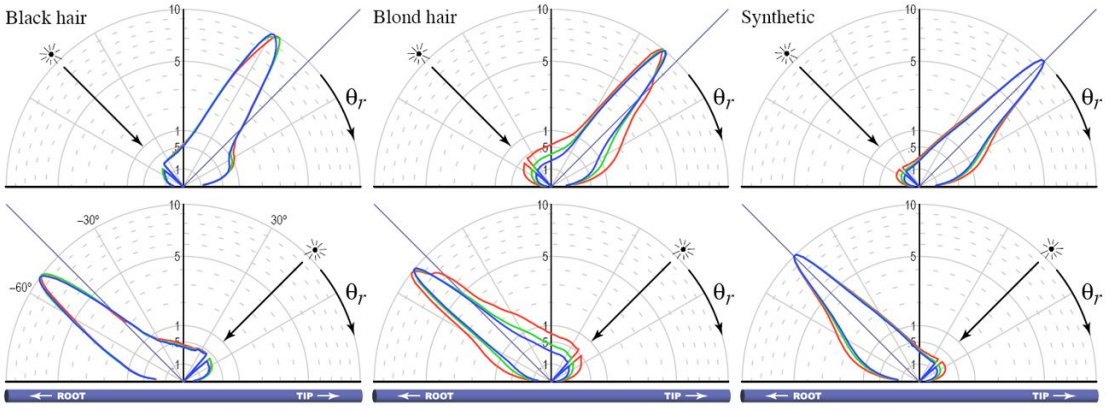




Blond hair

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

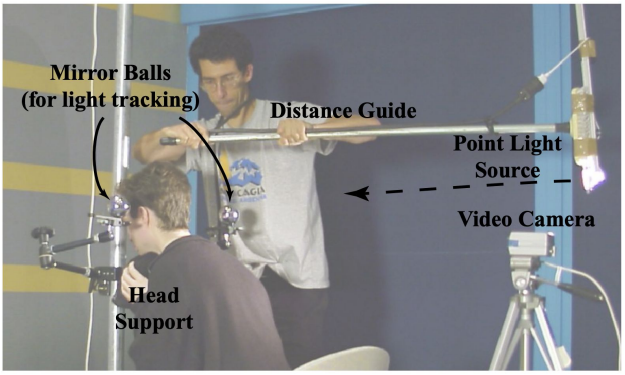
Reading for Today

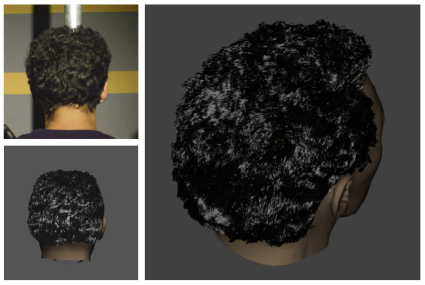


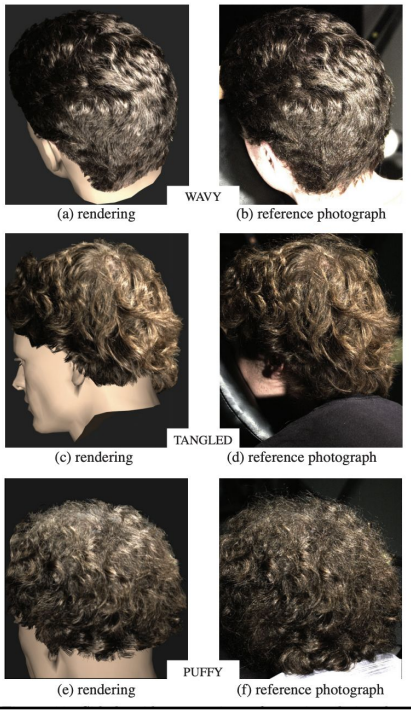
Black hair **Blond hair** **Synthetic (wig)**

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

"Capture of Hair Geometry from Multiple Images", Paris, Briceno, Sillion, SIGGRAPH 2004
"Hair Photobooth: Geometric and Photometric Acquisition of Real Hairstyles",
Paris, Chang, Kozhushnyan, Jarosz, SIGGRAPH 2008







ɔ: Capture of a black tangled hair. Left: comparis

"Multi-View Hair Capture Using Orientation Fields",
Luo, Li, Paris, Weise, Pauly, Rusinkiewicz, CVPR 2012

“Space Rangers with Cornrows: Methods for Modeling Braids and Curls in Pixar’s Groom Pipeline”
Sofya Ogunseitan
SIGGRAPH Talks 2022

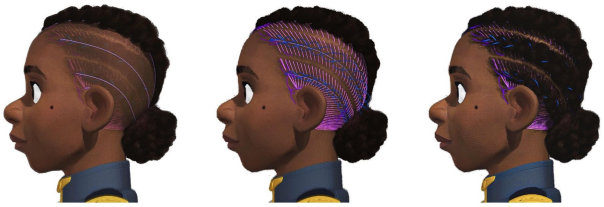


Figure 2: Process of creating braided and partitioning curves from hand-sculpted guide curves. ©Pixar.

AND… everyone should read

"Countering Racial Bias in Computer Graphics Research"
Kim et al., SIGGRAPH 2022

Possible ***(Weak & Unacceptable)*** Excuses/Rationalizations for Racial (or other) Bias in Graphics Research

-

Possible ***(Weak & Unacceptable)*** Excuses/Rationalizations for Racial (or other) Bias in Graphics Research

Why Diversity & Inclusion Matters

-

Why Diversity & Inclusion Matters

“Coded Bias”, 2020

“When MIT Media Lab researcher Joy Buolamwini discovers that facial recognition does not see dark-skinned faces accurately, she embarks on a journey to push for the first-ever U.S. legislation against bias in algorithms that impact us all.”

- Facial recognition is one of many modern “data driven” / AI / ML techniques that rely on huge training datasets.
- If the dataset is not appropriately representative of the actual population (e.g., skin color, language, accents, etc.) the model might overfit and be wildly incorrect on under-represented members of the population.

https://www.imdb.com/title/tt11394170/?ref_=ttmi_tt

Brenda Chapman is writer, animation story artist and director. In 1998, she became the first woman to direct an animated feature from a major studio, DreamWorks Animation's *The Prince of Egypt*.

Chapman moved to Pixar in 2003, and developed the ideas for Brave (based on her daughter) and was announced as the director of the film, making her Pixar's first female director. In October 2010, however, she was replaced by Mark Andrews. She remained on staff until shortly after the release of Brave (2012). It won the Oscar for Best Animated Feature.

https://oscars.fandom.com/wiki/Brenda_Chapman

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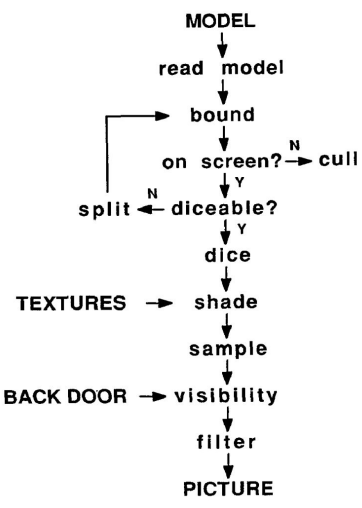
Reading for Next Time: *(pick one)*

"The Reyes Image Rendering Architecture",
Cook, Carpenter, and Catmull, SIGGRAPH 1987



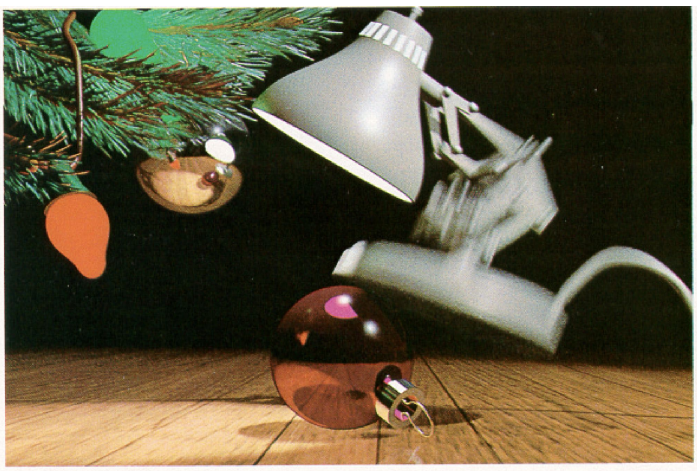


Figure 6. 1986 Pixar Christmas Card by John Lasseter and Eben Ostby.

Reading for Next Time: *(pick one)*

- "RenderMan: An Advanced Path Tracing Architecture for Movie Rendering", Christensen et al., TOG 2018

Fig. 8. Complex illumination in *Coco*: 8 million lights (© 2017 Disney•Pixar).