CSCI 4530/6530 Advanced Computer Graphics

https://www.cs.rpi.edu/~cutler/classes/advancedgraphics/S25/

Lecture 16: 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
- Papers for Next Time

https://www.cs.rpi.edu/~cutler/classes/advancedgraphics/S25/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. Read these papers and summarize the contributions of each paper in your proposal. Describe how your project relates to each paper. Talk with the instructor if you are unable to find at least 3 relevant research papers. At least 2 of the papers should be something we have not already read & discussed in lecture.

  Index of Graphics Conferences & Journal Publications:
  Ke-Sen Huang's Home Page, indexing the graphics conference papers 2005-current
  Tim Rowley's Home Page, indexing graphics conference papers 2000-2007

  NOTE: As an RPI student, you can request materials through RPI Libraries Interlibrary loan (at no cost to you). Don't let a paywall stop you from accessing research materials.
- As appropriate for your project, describe a sequence of examples (from the most trivial to moderately complex) that you plan to test to demonstrate (and debug) 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.

Form Teams on Submitty
by Monday March 17th

Individuals & teams of 3
must talk to Barb in advance!
(Monday office hours 1-3pm)

Proposal due
Thursday March 20th
Late days may be
used for proposal

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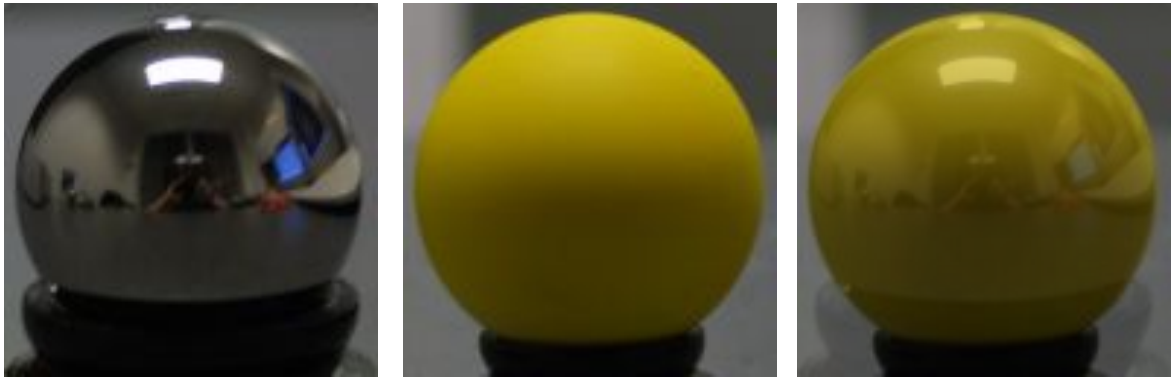
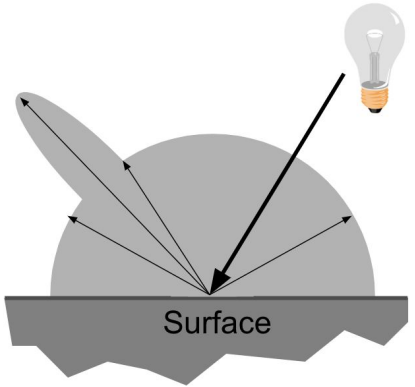
The Phong Material Model

```
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
```

- 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.

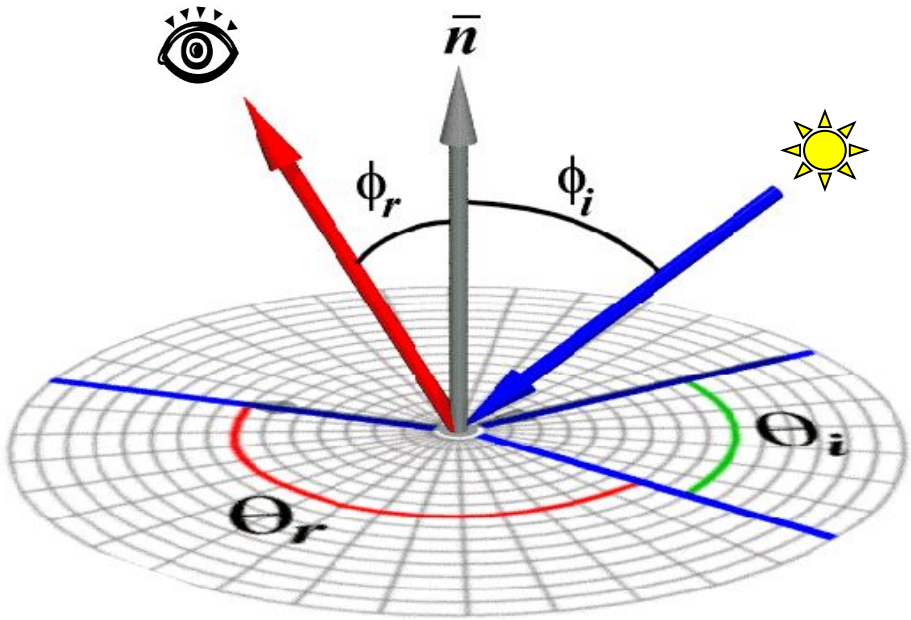




- *Phong is “ok” for shiny new plastic…*
  but not good enough for many other real-world materials.

Bidirectional Reflectance Distribution Function

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



Reading option from a few weeks ago…

"Measuring and Modeling Anisotropic Reflection",
Greg Ward,
SIGGRAPH 1992

Gonioreflectometer

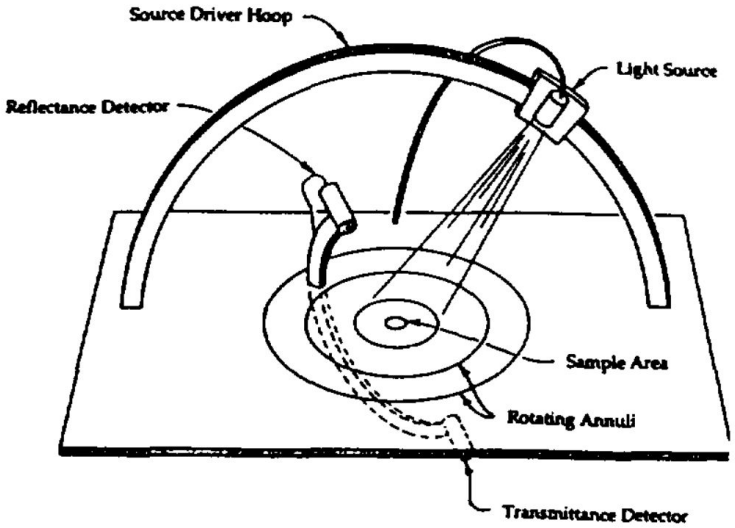
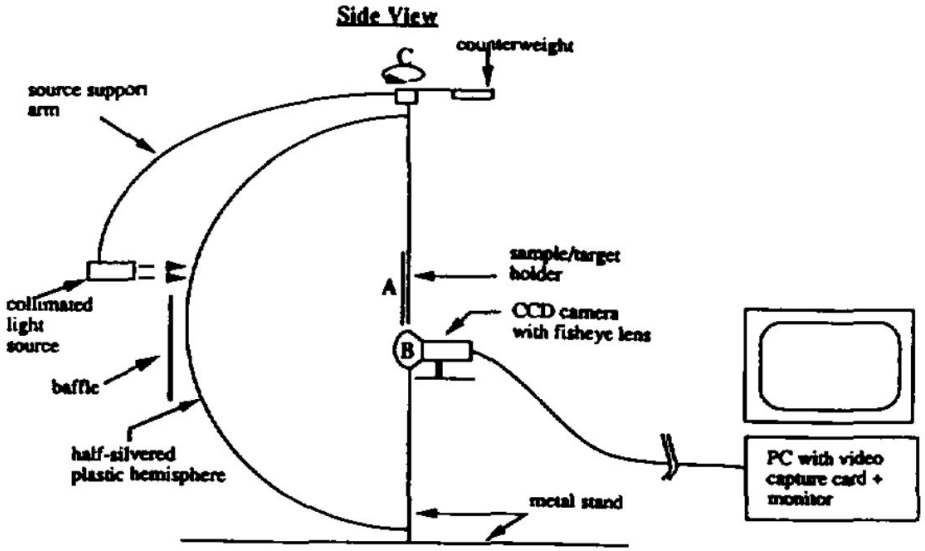


Figure 1. A conventional gonioreflectometer with movable light source and photometer.



Traditional: motorized sampling of many combinations of angles (expensive & slow)

Introduced by Ward 1992: hemi-ellipsoidal dome to capture lots (all?) angles at once (more cost effective)

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

Measured BRDF in film production: realistic cloth appearance for "The Matrix Reloaded"
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Figure 1

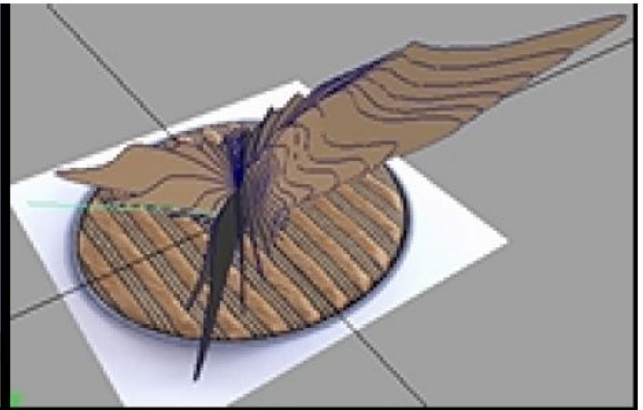


Figure 2

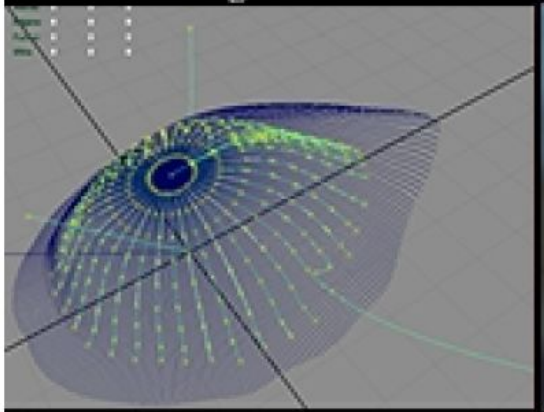


Figure 3

Figure 4

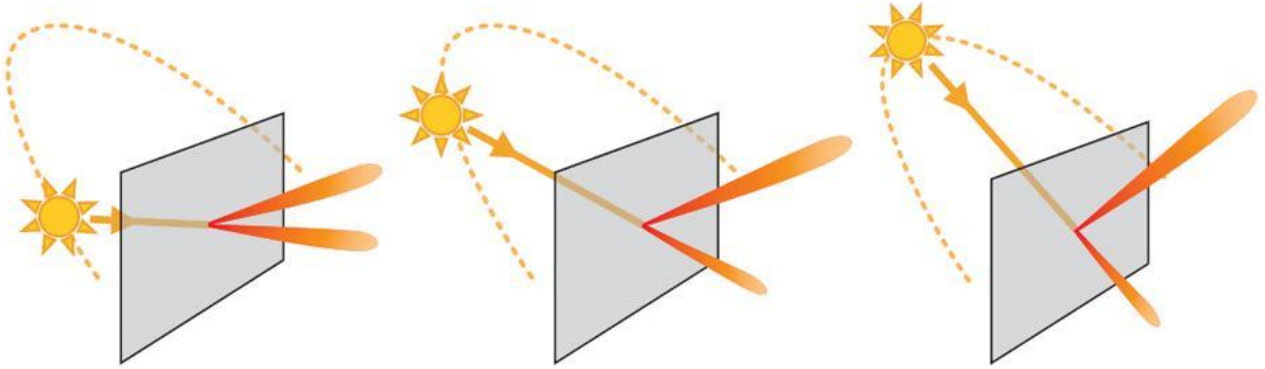
BRDFs in the Movie Industry

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

Not just a BRDF…

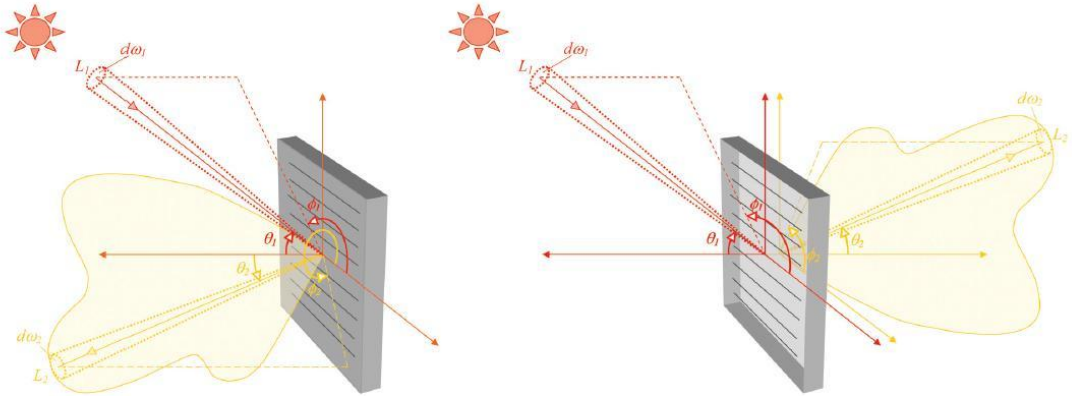
Realistic human face rendering for "The Matrix Reloaded”
Borshukov, SIGGRAPH 2003 Sketches & Applications

Materials – BRDF & BTDF



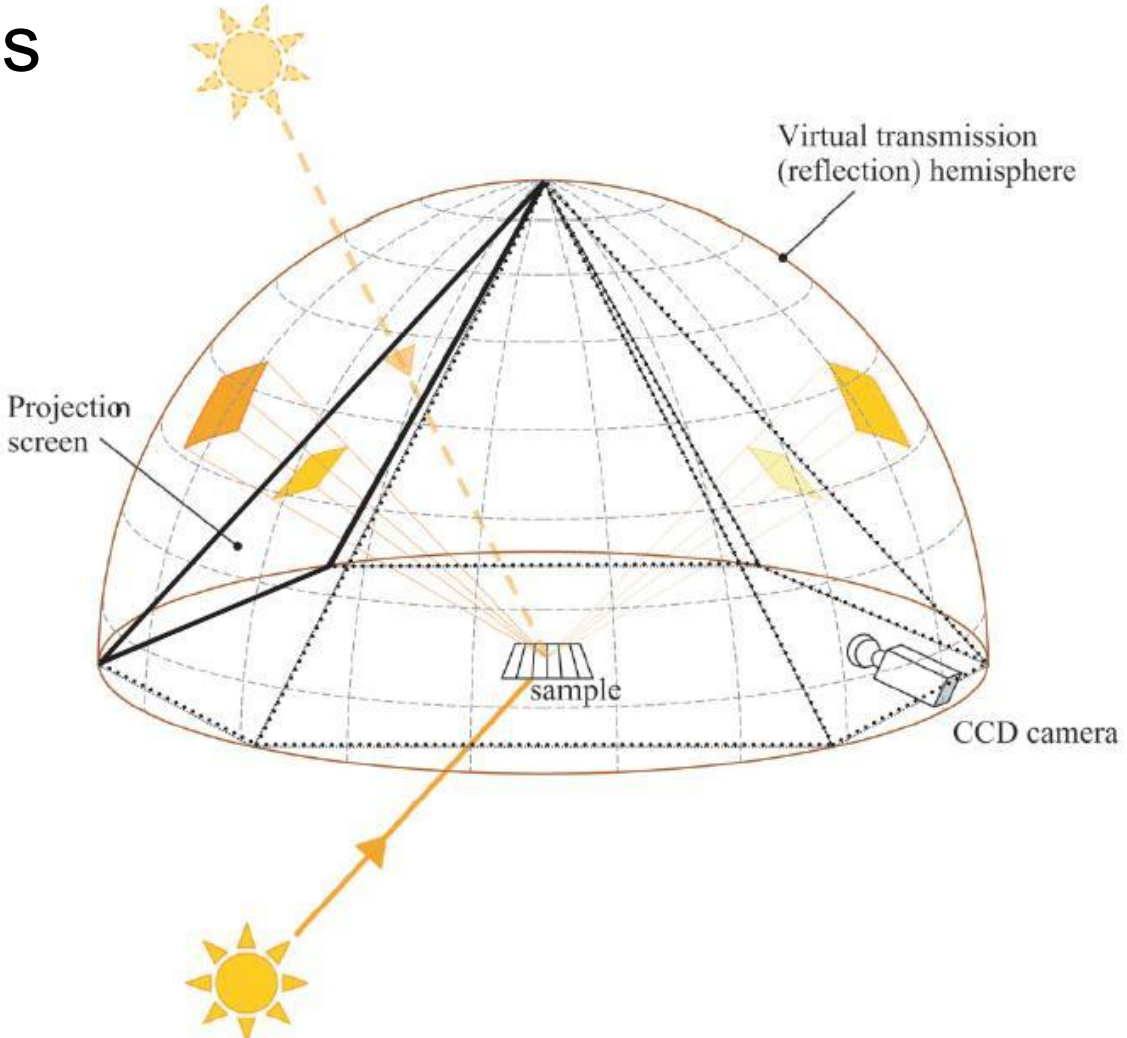
(a) Solar time 8h (b) Solar time 10h (c) Solar time 12h

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



(a) BRDF (b) BTDF

Measuring Materials



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

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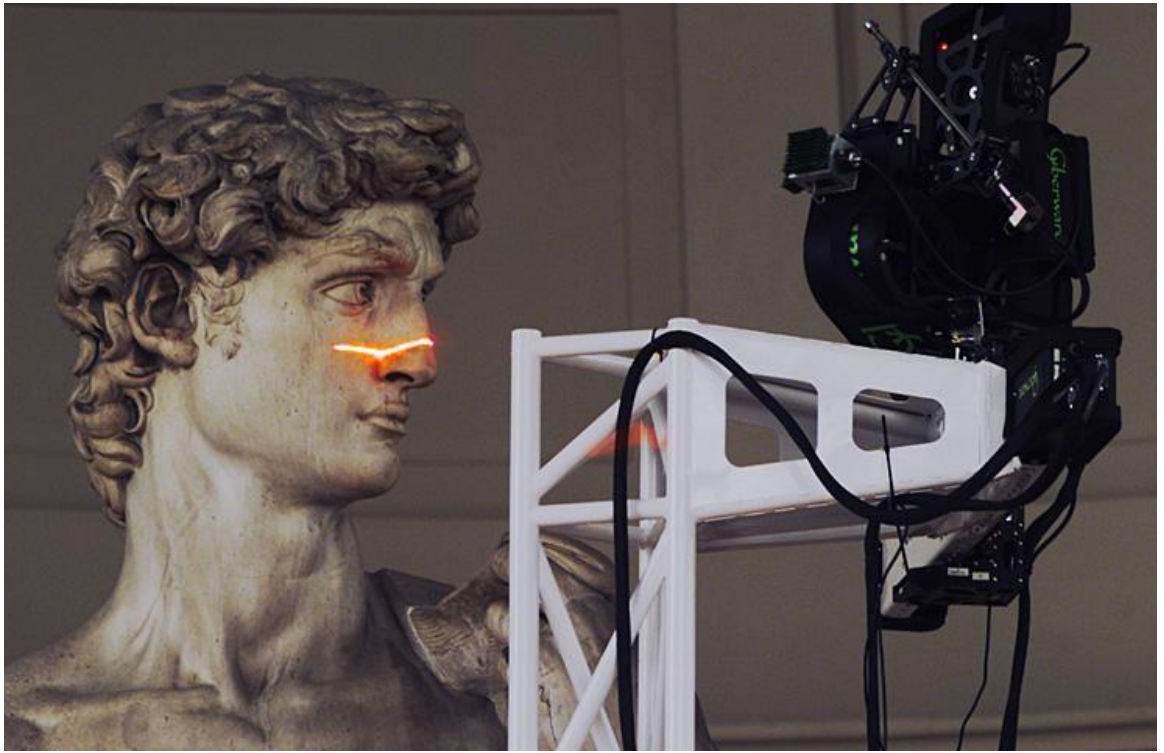
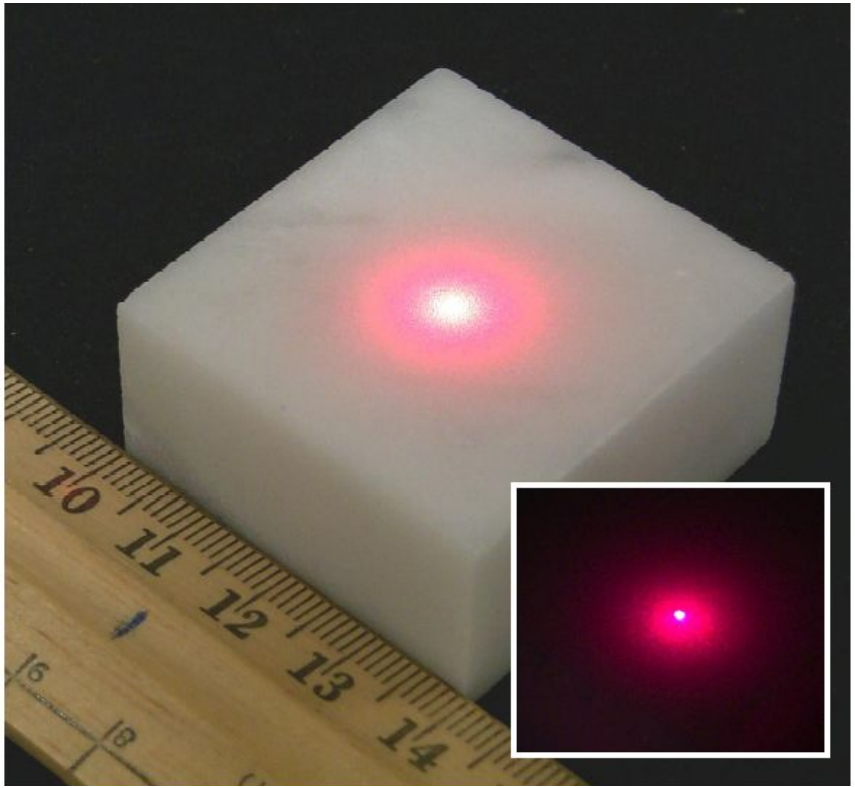
3D Digitizing

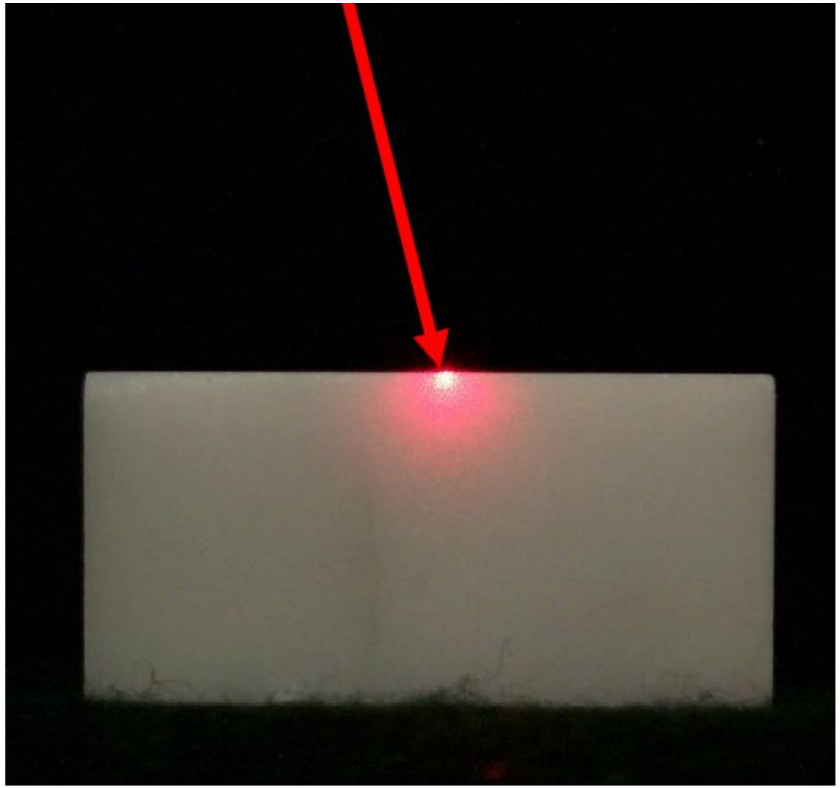
Cyberware



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

Scattering & Scanning





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

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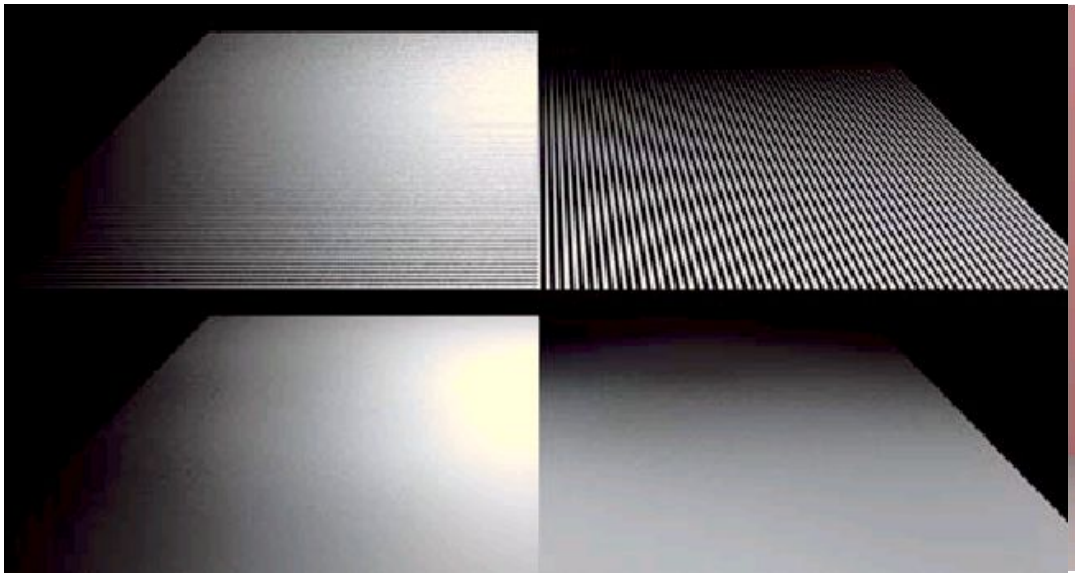
Anisotropic BRDFs

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



“Predicting reflectance functions from complex surfaces”, Westin, Arvo, & Torrance, SIGGRAPH 1992

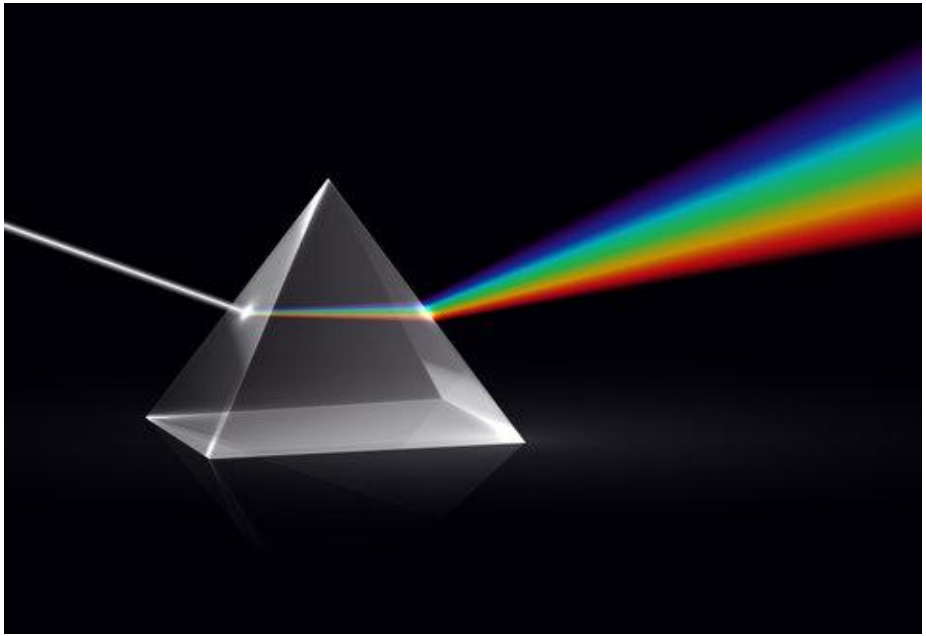
What makes a Rainbow?

- 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
- Also: Why is the sky blue?

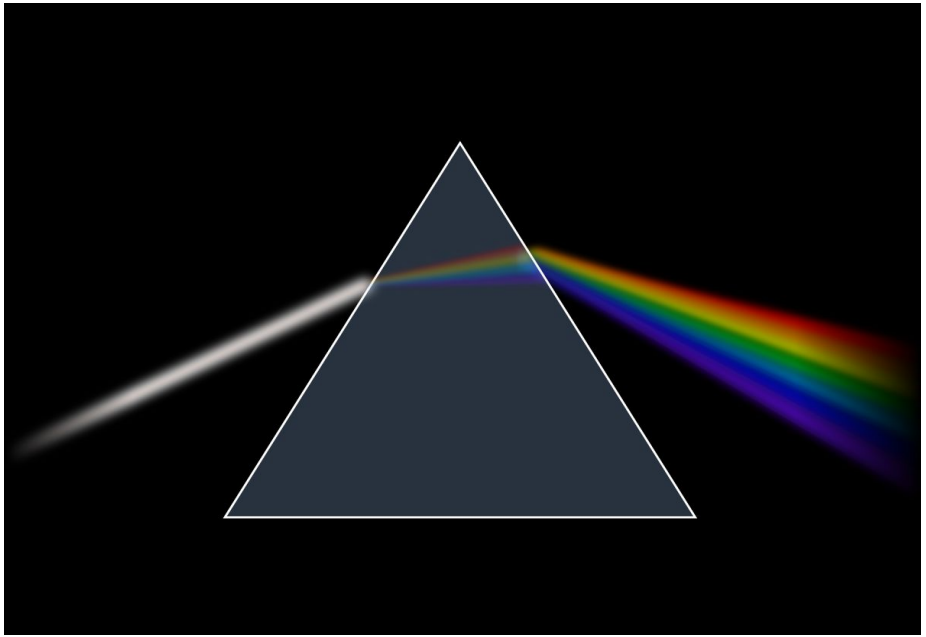
From “Color and Light in Nature” by Lynch and Livingstone

Don’t believe everything on the internet…

- *Which illustration is correct???*



https://stock.adobe.com/search?k=prism+rainbow



https://commons.wikimedia.org/wiki/File:Prism-rainbow-black-2.svg

“Rendering Lunar Eclipses”
Yapo & Cutler,
Graphics Interface 2009

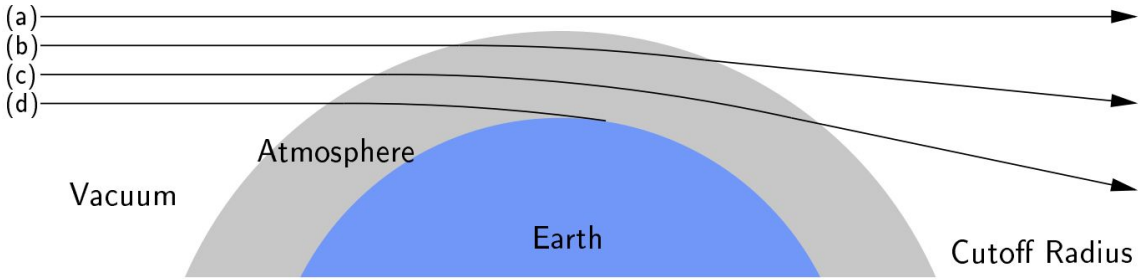
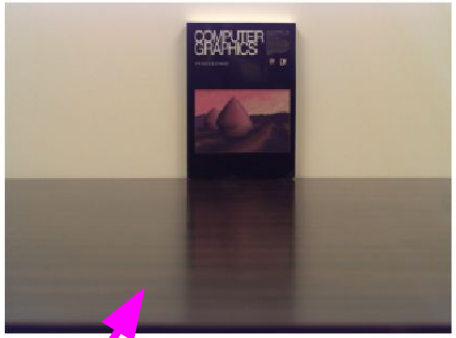
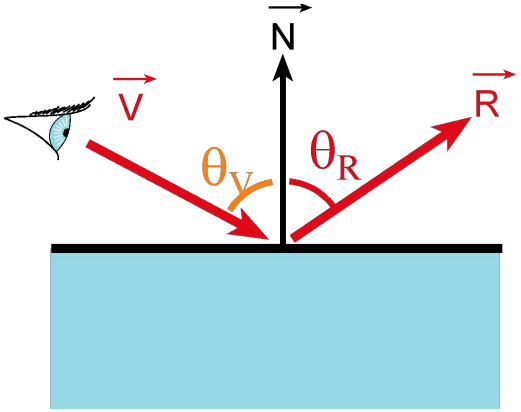


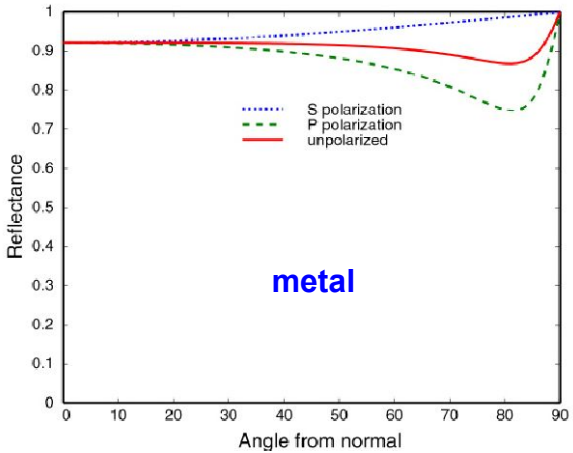
Figure 3: Exploiting symmetry of the Sun-Earth system. Illumination during a lunar eclipse is symmetric relative to the center line connecting the Sun and Earth, and is independent of the Moon’s position. Any ray exiting the Earth’s atmosphere could have exited from any point along a circle lying in 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).

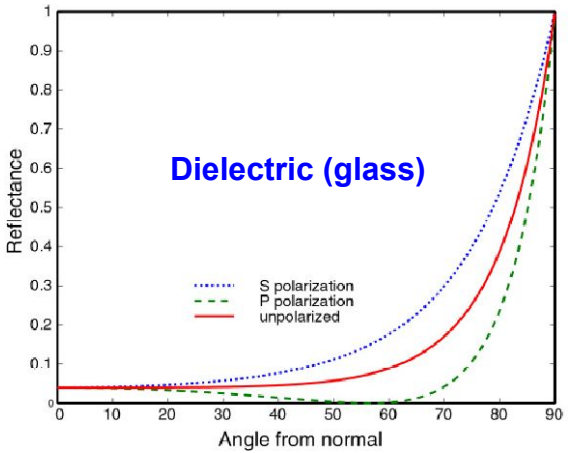
Amount of Reflection



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

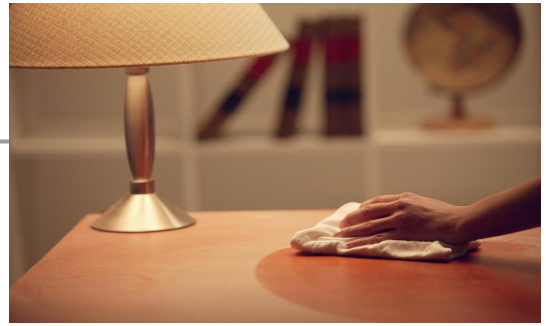


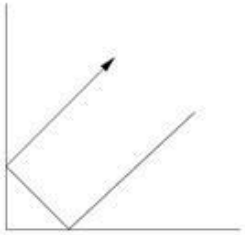




Dusty Surfaces & Retro-Reflection

- 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
- 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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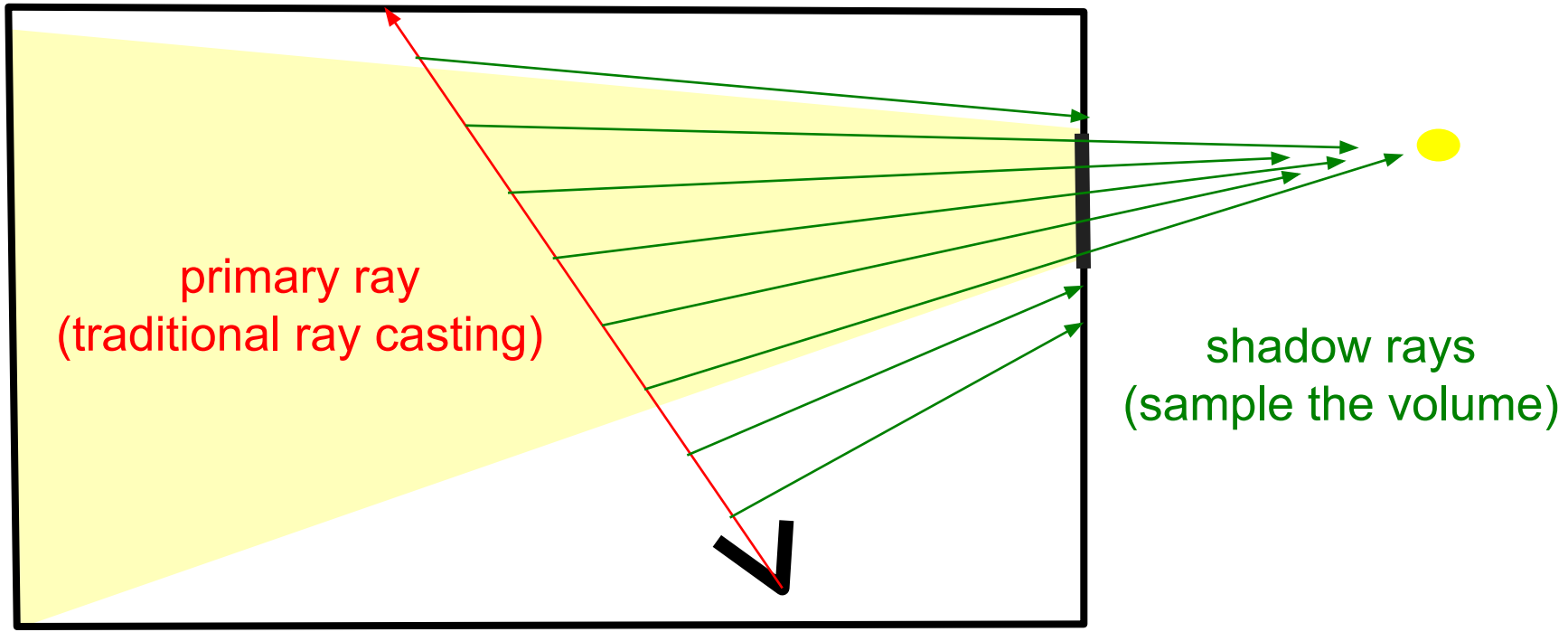
Light a Dusty Room

Annie Ding, MIT
6.837 Final Project
December, 2004

Ray Tracing Participating Media



Participating Media

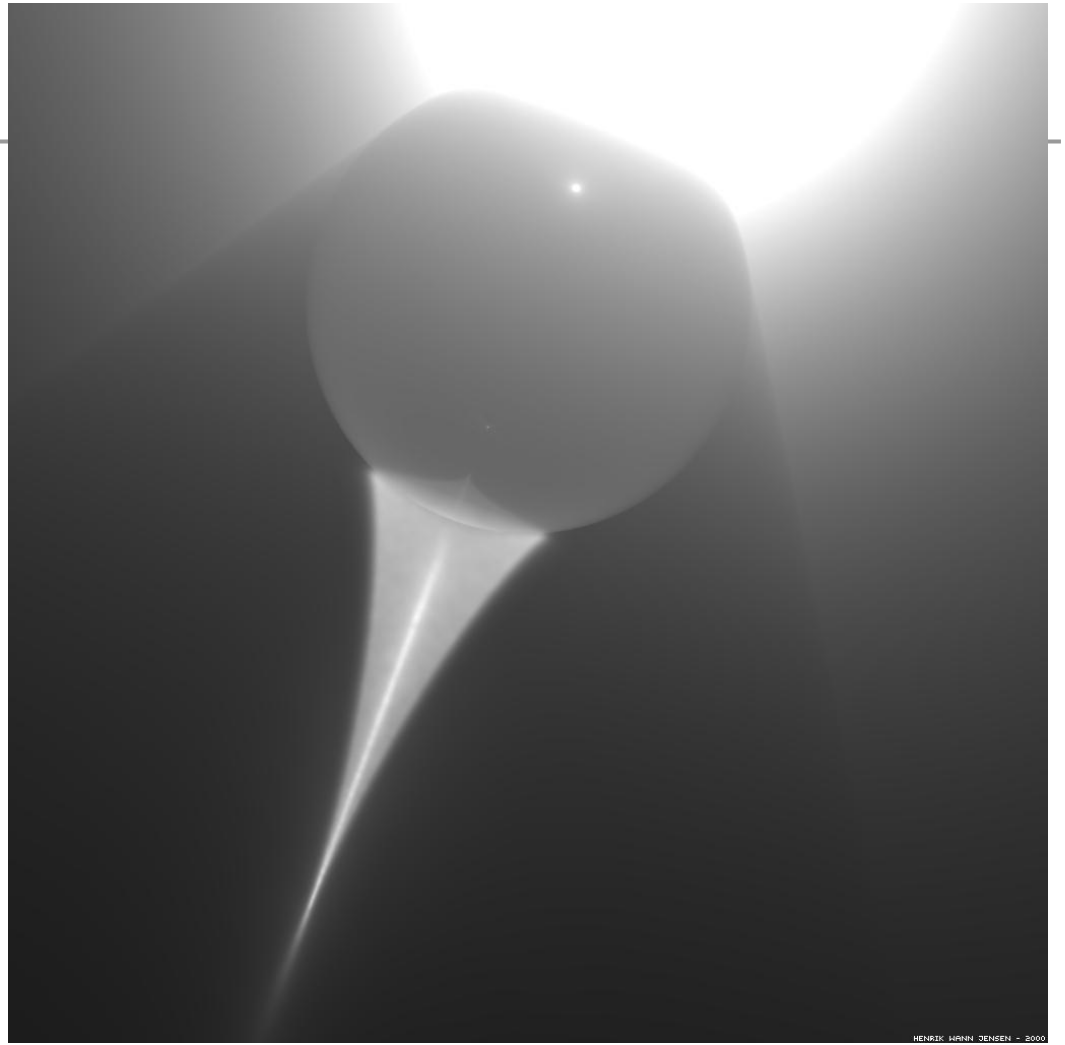


Image by
Henrik Wann Jensen

“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

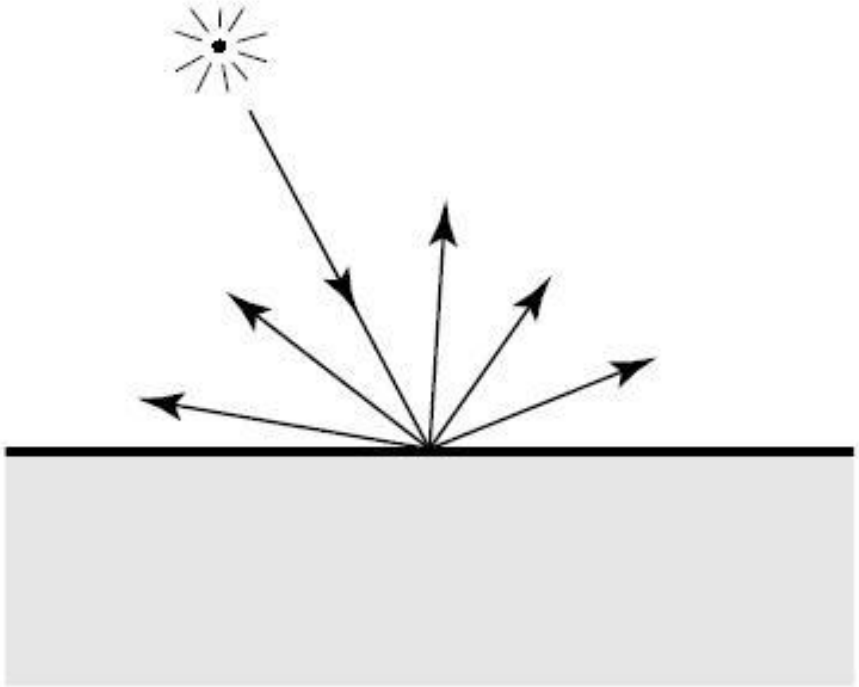
"A Practical Model for Subsurface Light Transport",
Jensen, Marschner, Levoy, & Hanrahan, SIGGRAPH 2001

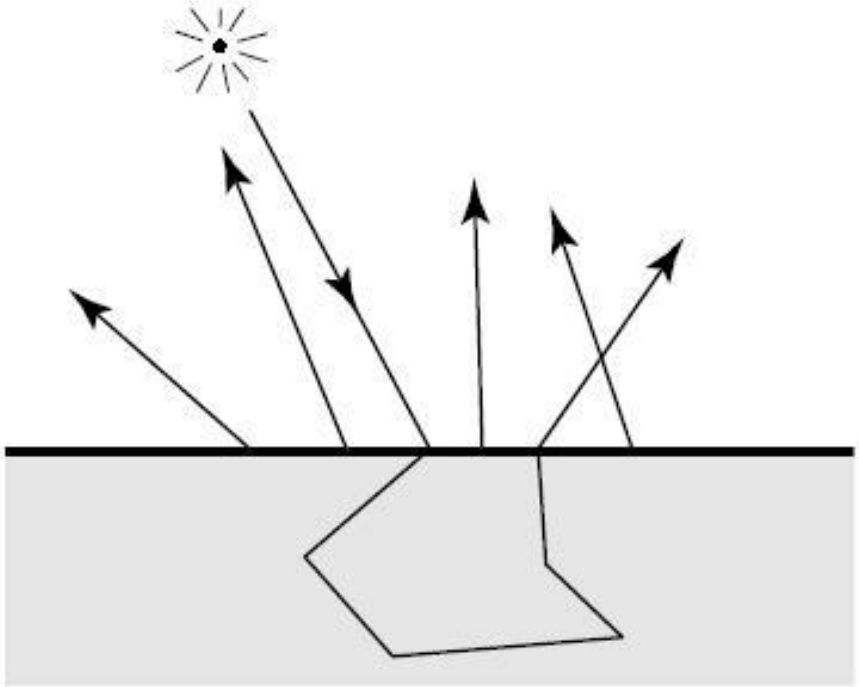
- Image based technique to measure real-world materials
- Important to prevent uncanny valley problems rendering humans
- Huge performance improvement w/ very similar visual results
- Dipole to approximate huge number of interreflections within the material from full path tracing simulation
- Paper was dense / difficult to read
  - ‘Felt like I was missing something while reading’
- Method works for semi-infinite translucent objects
  - What about very thin surfaces or layered surfaces or variations within the material? *They have follow on papers to handle those cases with other techniques*

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

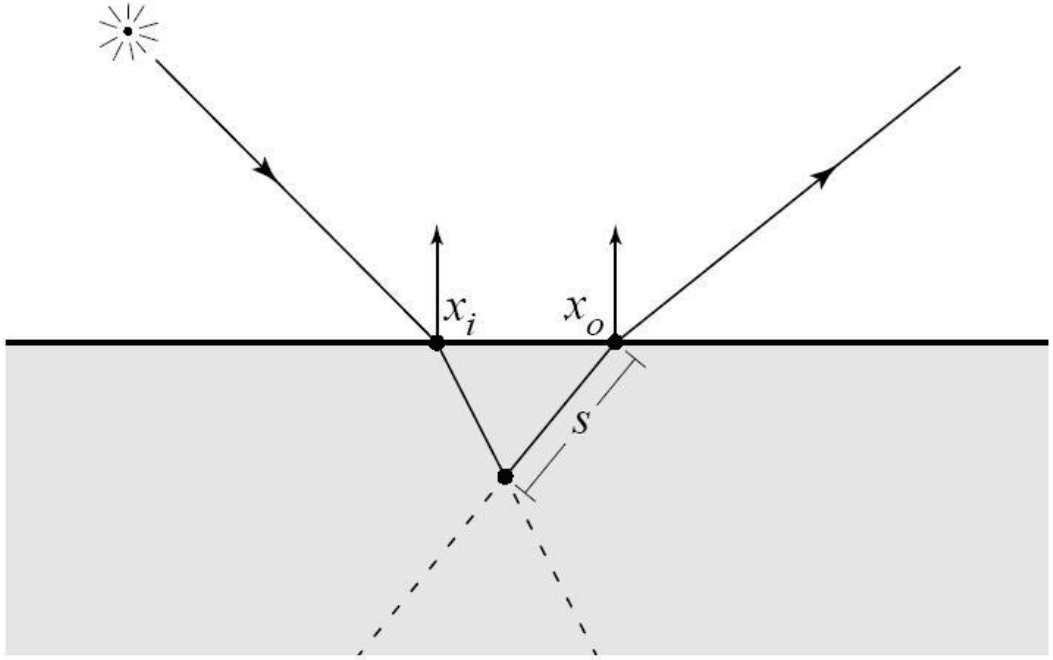


Figure 4: Single scattering occurs only when the refracted incoming and outgoing rays intersect, and is computed as an integral over path length s along the refracted outgoing ray.

Dipole Approx. for Diffuse Scattering

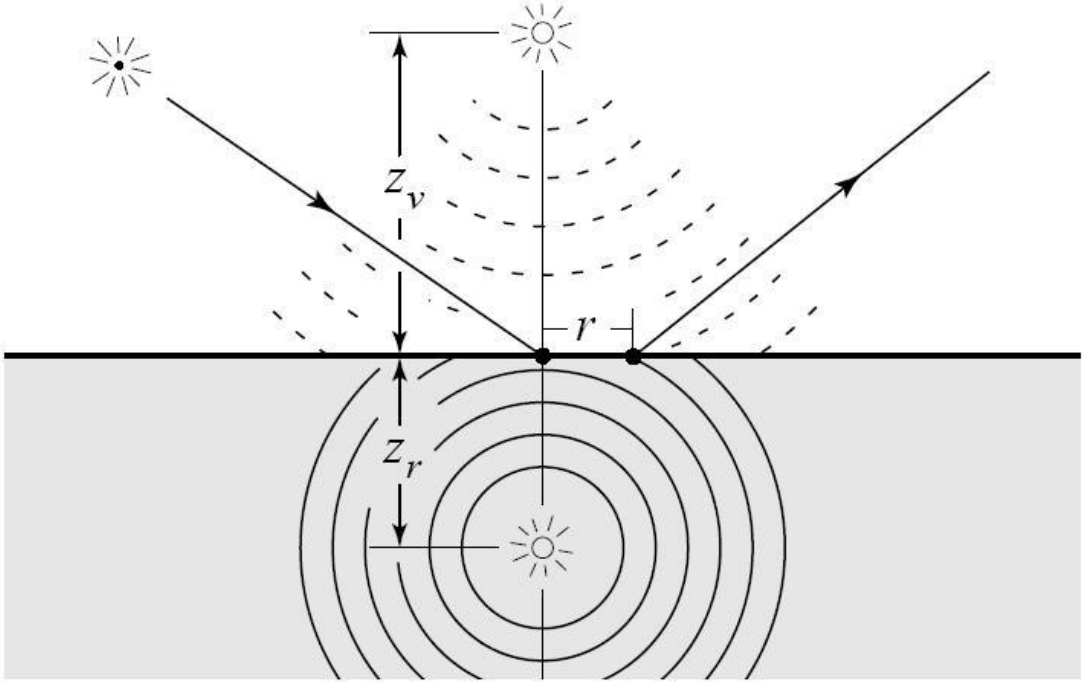
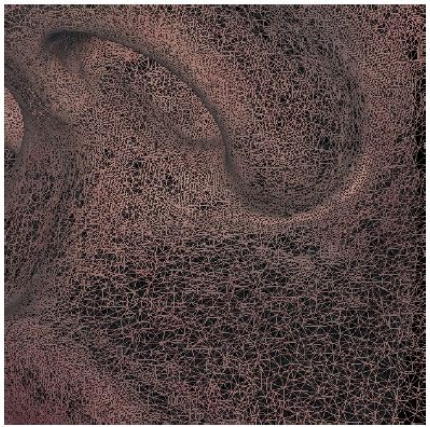


Figure 3: An incoming ray is transformed into a dipole source for the diffusion approximation.

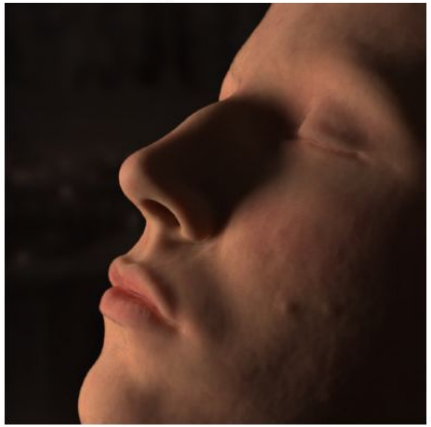


(a) 3D mesh (close-up of nostril)

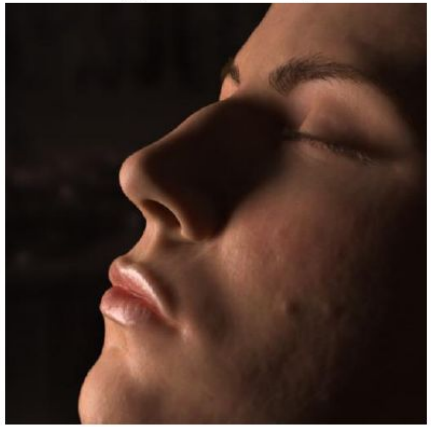
(b) Color data

(c) Diffuse rendering

(d) Oily layer



(e) Subsurface scattering



(f) Final result

“Digital Face Cloning”, Jensen, SIGGRAPH Sketch 2003

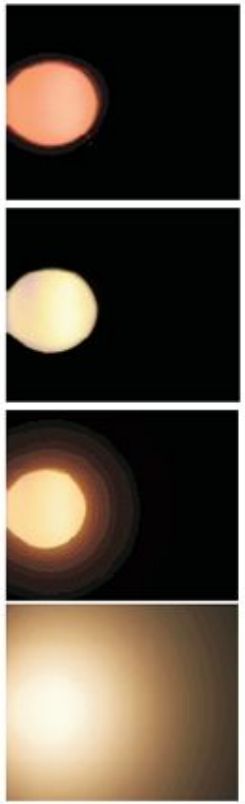
"Light Diffusion in Multi-Layered Translucent Materials“ Donner & Jensen, *SIGGRAPH 2005*

"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.*

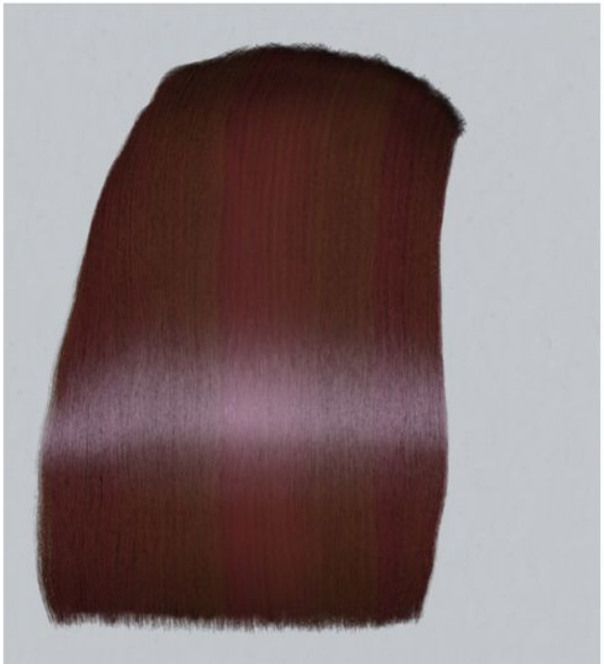
“Acquiring Scattering Properties of Participating Media by Dilution”
Narasimhan et al. SIGGRAPH 2006



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

Reading for Today

Old Method

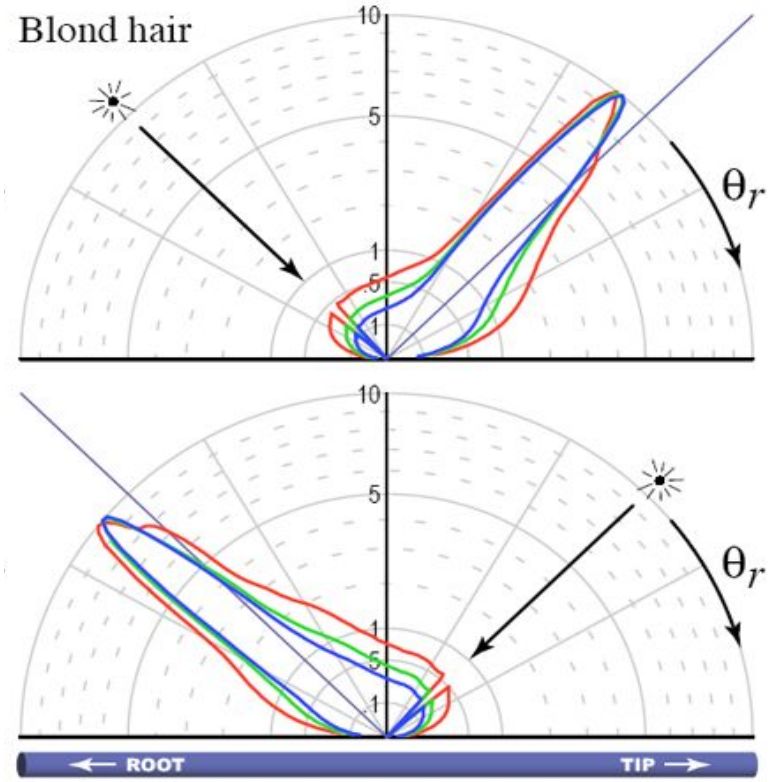


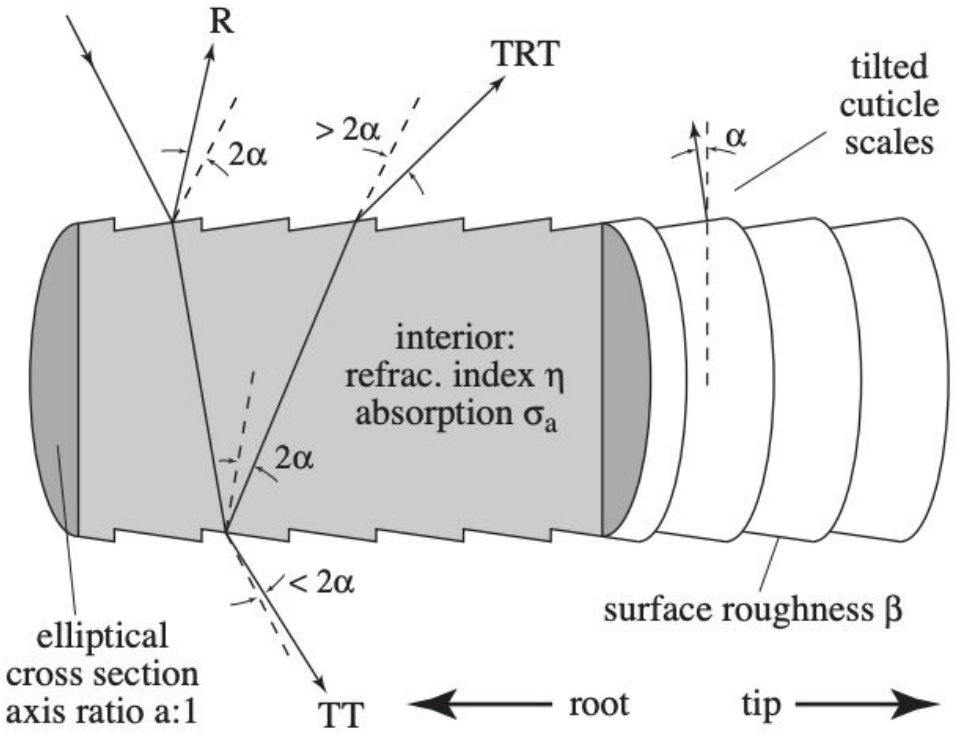
New Method

Photo

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

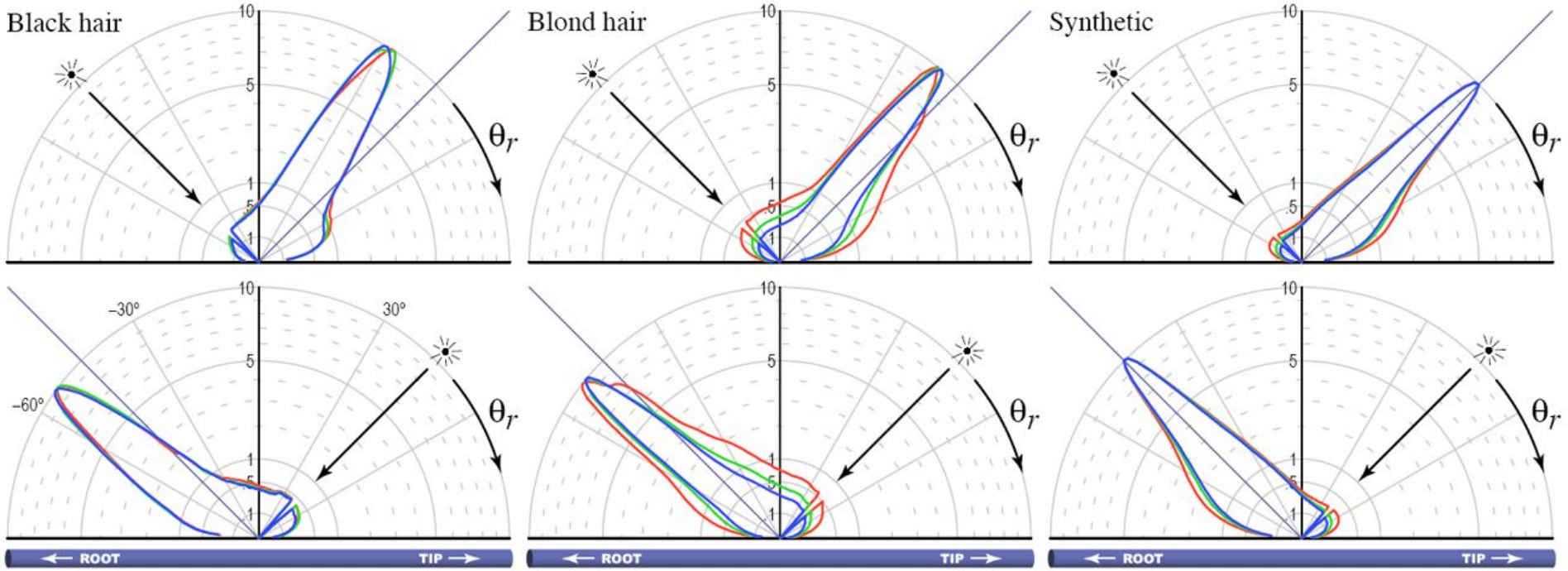
- Paper didn’t discuss - but a single individual can have a variety of hair (thin/thick, colors, etc.)
- Importance of a real-world context/full model to evaluate/judge results
- Hair is complicated! Lots of info about hair in this paper
- Light scattering in hair is complicated!
- Does this technique advance other materials w/ microfacets or scales?
  - Bird feathers and iridescence
    https://blaire9989.github.io/assets/2_FeatherLab/project.html
  - Reptiles or fish?





Blond hair

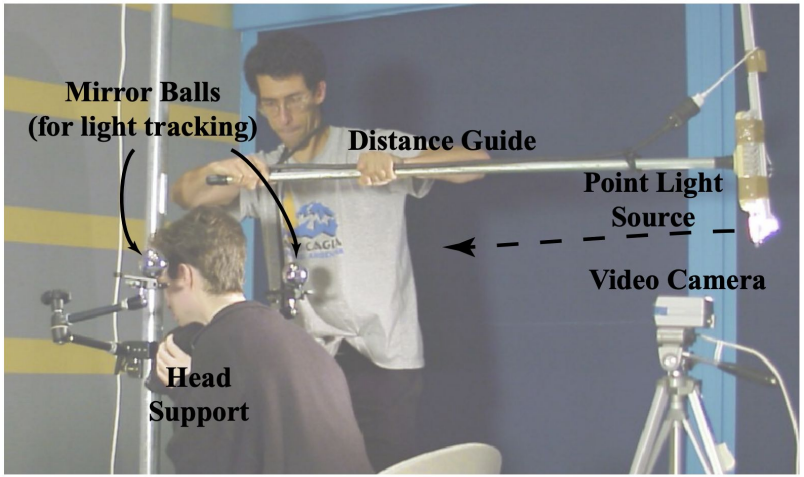
"Light Scattering from Human Hair Fibers"
Marschner et al., SIGGRAPH 2003

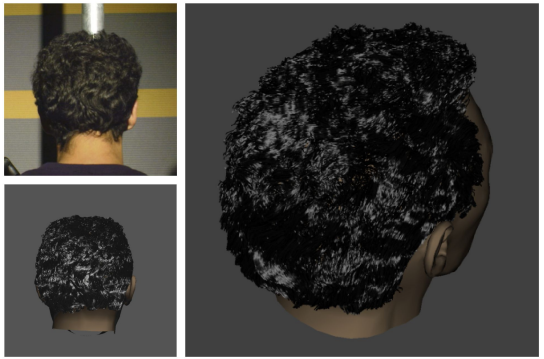


Black hair **Blond hair** **Synthetic (wig)**

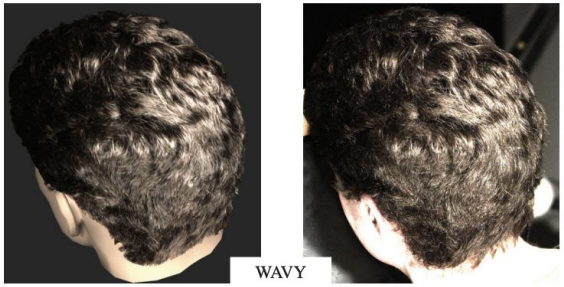
"Light Scattering from Human Hair Fibers"
Marschner et al., SIGGRAPH 2003

"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



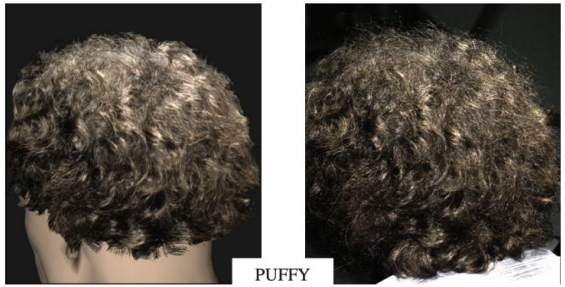


5: Capture of a black tangled hair. Left: comparis



(a) rendering (b) reference photograph

(c) rendering (d) reference photograph



(e) rendering (f) reference photograph

“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

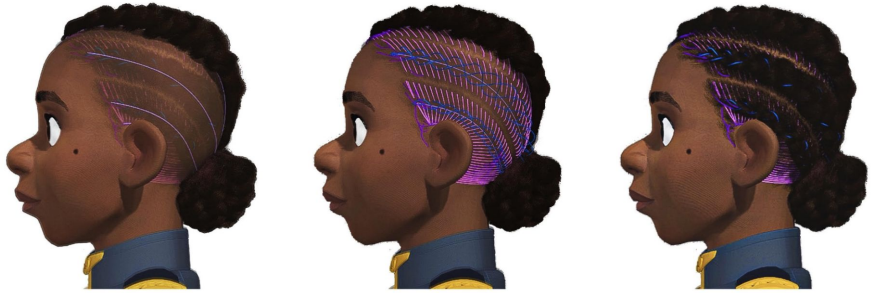


Figure 2: Process of creating braided and partitioning curves from hand-sculpted guide curves. ©Pixar.

AND… everyone should read

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

- "More than Killmonger Locs - a style guide to Black Hair
  (in computer graphics)",
  Slides from A.M.Darke, 2024

Optional reading:

- "Curly-Cue: Geometric Methods for Highly Coiled Hair",
  Wu, Shi, Darke, & Kim, Siggraph Asia 2024

- Disappointing that it has taken so long to acknowledge this is a problem
- We need more diversity in tech & art & interdisciplinary collaborations
- Not enough to “not be part of the problem”, we all need to help make change happen
- Character customization is a long standing problem, insufficient skin color choices, insufficient variety in hair styles, insufficient variety in facial hair, etc., etc.
- Industry has constrained resources, and is profit motivated - *it’s not surprising that options are limited and advances/improvements are slow*

- Optimistic takeaway: It is nice to see that some things are finally getting better in some parts of research & industry / commercial products…

Rationalizations for Bias in Graphics Research

But it's not acceptable! We shouldn't accept it!

- "The problem is really hard – we started with white skin / short, straight hair. We'll do other skin colors / hair types for our next paper."
- "We assume that with basic parameter tweaks, our model & results will extrapolate to all other types."
- "I always ask my colleagues and friends for feedback on the prototype (e.g., game-testing) or for personal data (e.g., hair samples). Hmm… we don't know anyone who doesn't look like us."
- "We have a [token] female / person of color on our team. They didn't say anything was wrong. They will be tasked with preventing / fixing any future problems."
- "Author X is smart and famous and good. And they aren't racist."

Why Do Diversity & Inclusion Matter?

-

Why Do Diversity & Inclusion Matter?

- If research teams / corporate development teams are diverse and representative:
  - Research proposals will have diverse input from initial conception of the ideas
  - Prototypes will be used and beta-tested by a diverse population
  - Research results will be broadly applicable
  - Software will be better
- A person isn't racist or anti-racist.
  Actions and ideas are racist or anti-racist.
  [Paraphrased from *"How to be an Antiracist", Ibram X. Kendi, 2019*]

“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

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

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*.

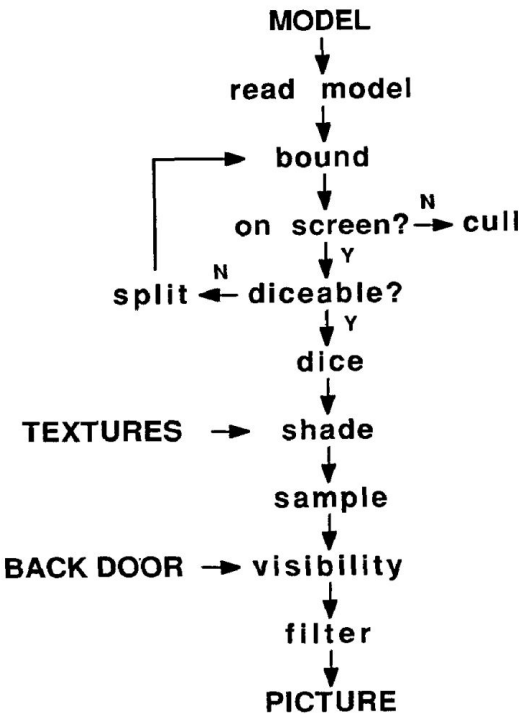
Chapman moved to Pixar in 2003, and developed the ideas for Brave (based on her daughter) and was announced as the director of the film, making her Pixar's first female director. In October 2010, however, she was replaced by Mark Andrews. She remained on staff until shortly after the release of Brave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

Today

- Final Project Proposals
- Measuring BRDFs
- 3D Digitizing
- Rendering Complex Phenomena
- Participating Media
- Papers for Today
- Papers for Next Time

Reading for Next Time: *(pick one)*

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



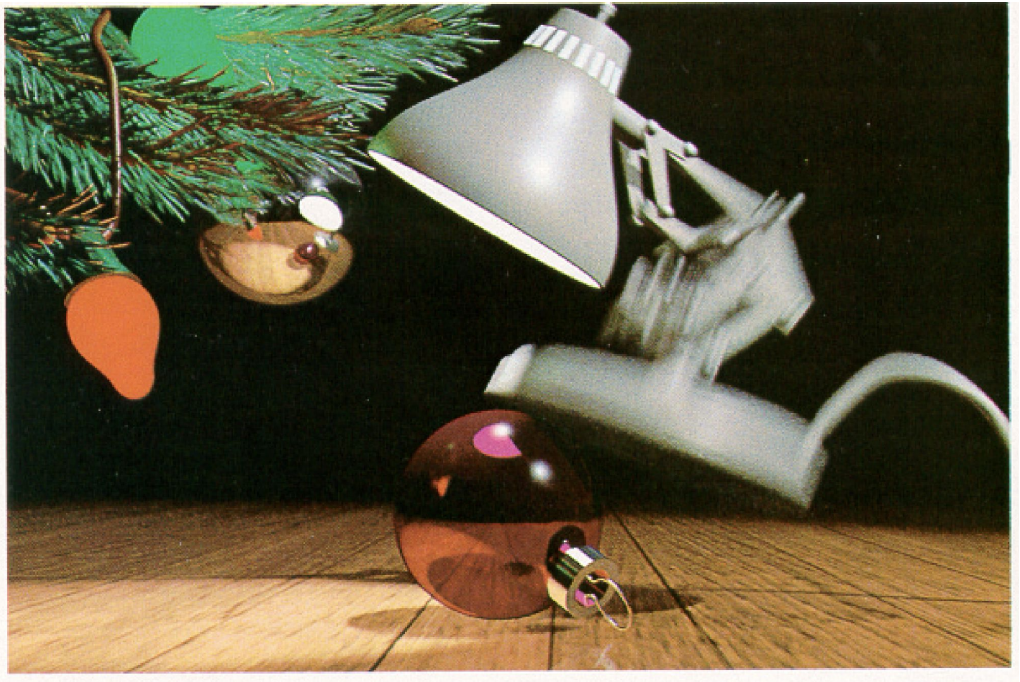


Figure 6. 1986 Pixar Christmas Card by John Lasseter and Eben Ostby.

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).