Subsurface Scattering & Complex Material Properties

Sprout, PDI Dreamworks 2003
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
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 a lot 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.

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
  - $R(\theta_i, \phi_i; \theta_r, \phi_r)$
  - 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
Realistic human face rendering for "The Matrix Reloaded"
Borshukov & Lewis, SIGGRAPH 2003 Sketches & Applications

Materials – BRDF & BTDF

Measuring Materials


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3D Digitizing

Cyberware

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

Scattering & Scanning

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

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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 \texttt{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
- 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

- Primary ray (traditional ray casting)
- Shadow rays (sample the volume)

Participating Media

Image by Henrik Wann Jensen

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Reading for Today: *(pick one)*


Rendering Translucent Materials

rendering using measured skin

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 "Digital Face Cloning", Jensen, SIGGRAPH Sketch 2003

(e) Subsurface scattering "Light Diffusion in Multi-Layered Translucent Materials" Donner & Jensen, SIGGRAPH 2005

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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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
"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

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

- "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 extrapolate to all other types."
- "It's convenient to 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 really smart and famous. They are a good person and aren't racist."
Why Diversity & Inclusion Matters

• 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]
“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
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).