Lecture 14:

Introduction to Material Modeling

Computer Graphics and Imaging
UC Berkeley CS184/284A
What is Material in Computer Graphics?

3D coffee mug model
Rendered
Rendered

[From TurboSquid, created by artist 3dror]
Material == BRDF
What is this material?
Diffuse / Lambertian Material (BRDF)

Uniform colored diffuse BRDF

Textured diffuse BRDF

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[Mitsuba renderer, Wenzel Jakob, 2010]

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What is this material?
Glossy material (BRDF)

Copper

Aluminum

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[Mitsuba renderer, Wenzel Jakob, 2010] Ren Ng
What is this material?
Ideal reflective / refractive material (BSDF*)

Air <-> plastic interface
Air <-> glass interface (with absorption)

[Mitsuba renderer, Wenzel Jakob, 2010]
Microfacet Material Model
Microfacet Reflection

https://twitter.com/Cmdr_Hadfield/status/318986491063828480/photo/1
Microfacet Theory

Rough surface

• Macroscale: flat & rough
• Microscale: bumpy & specular

Individual elements of surface act like mirrors

• Known as “microfacets”
• Each microfacet has its own normal vector
Microfacet BRDF

• Key: the *distribution* of microfacets’ normals

• Concentrated $\iff$ glossy

• Spread out $\iff$ diffuse
Microfacet BRDF

• What kind of microfacets reflect wi to wo? (hint: microfacets are mirrors)

\[ f(i, o) = F(i, h)G(i, o, h)D(h) \]

\[ 4(n, i)(n, o) \]
Fresnel Reflection Term

Reflectance depends on incident angle (and polarization of light)

This example: reflectance increases with grazing angle

[Lafortune et al. 1997]
Fresnel Term (Dielectric, $\eta = 1.5$)
Fresnel Term (Conductor)
Microfacet BRDF: Examples

[Autodesk Fusion 360]
Anisotropic BRDFs
Isotropic vs Anisotropic Reflection

• So far, Point light + Metal = Round / Elliptical highlight
• But some reflection highlights look very different
Isotropic vs Anisotropic Reflection

Isotropic

Anisotropic
Anisotropic BRDF: Brushed Metal

• How is the pan brushed?
Isotropic / Anisotropic Materials (BRDFs)

- Key: **directionality** of underlying surface

Isotropic

Anisotropic

Surface (normals)

BRDF (fix wi, vary wo)
Isotropic BRDFs

Reflection independent of azimuthal angle $\phi$

$$f_r(\theta_i, \phi_i; \theta_r, \phi_r) = f_r(\theta_i, \theta_r, \phi_r - \phi_i)$$

Results from surface microstructure that lacks directional structure.
Anisotropic BRDFs

Reflection depends on azimuthal angle $\phi$

$$f_r(\theta_i, \phi_i; \theta_r, \phi_r) \neq f_r(\theta_i, \theta_r, \phi_r - \phi_i)$$

Results from oriented microstructure of surface, e.g., brushed metal
Anisotropic BRDF: Nylon

[Westin et al. 1992]
Anisotropic BRDF: Velvet

[Westin et al. 1992]
Anisotropic BRDF: Velvet

[https://www.youtube.com/watch?v=2hjoW8TYTd4]
Sampling of Advanced Material Modeling Topics
(Slides courtesy Prof Lingqi Yan)
Detailed / Glinty Material
Why details?

Microfacet model
Why details?

[Yan et al. 2014, 2016]
Why details?

[Yan et al. 2014, 2016]
Recap: Microfacet BRDF

Surface = Specular microfacets + statistical normals

\[ f(i, o) = \frac{F(i, h)G(i, o, h)D(h)}{4(n, i)(n, o)} \]

NDF: Normal Distribution Function
Statistical NDF vs. Actual NDF

Distribution of Normals (NDF)

What we have
(microfacet — statistical)

What we want
Define Details

Normal map
resolution:
\[ \approx 200K \times 200K \]

isotropic noise
normal map
Different Details

Metallic flakes
Ocean waves
Hair / Fur Appearance Models
Hair Appearance
Kajiya-Kay Model

[Image courtesy of Chiwei Tseng]
Kajiya-Kay Model

[Yuksel et al. 2008]
Marschner Model

- Glass-like cylinder

- 3 types of light interactions: R, TT, TRT
  (R: reflection, T: transmission)
Marschner model

[Marschner et al. 2003]  [d’Eon et al. 2011]

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Participating Media
Participating Media: Fog

[Novák et al. 2012]
Participating Media: Cloud

[by thephotographer0]
Participating Media

- At any point as light travels through a participating medium, it can be (partially) absorbed and scattered.

- Use Phase Function to describe the angular distribution of light scattering at any point $x$ within participating media.

[Images of absorption, emission, out-scattering, and in-scattering]

- $g < 0$ back-scattering
- $g = 0$ isotropic-scattering
- $g > 0$ forward-scattering
Participating Media: Rendering

- Randomly choose a direction to bounce
- Randomly choose a distance to go straight
- At each ‘shading point’, connect to the light

[Derek Nowrouzezahrai]
Participating Media: Application
Participating Media: Application

[Assassin’s Creed Syndicate. 2015 Ubisoft]
Translucent Material
(specific participating media)
Translucent Material: Jade
Translucent Material: Jellyfish
Subsurface Scattering

Visual characteristics of many surfaces caused by light exiting at different points than it enters

- Violates a fundamental assumption of the BRDF
- Different from transparent

[Jensen et al 2001]

[Donner et al 2008]
Scattering Functions

- **BSSRDF**: generalization of BRDF; exitant radiance at one point due to incident differential irradiance at another point:
  \[ S(x_i, \omega_i, x_o, \omega_o) \]

- Generalization of rendering equation: integrating over all points on the surface and all directions (!)
  \[
  L(x_o, \omega_o) = \int_A \int_{H^2} S(x_i, \omega_i, x_o, \omega_o) \, L_i(x_i, \omega_i) \cos \theta_i \, d\omega_i \, dA
  \]

[Jensen et al. 2001]
BSSRDF

[Jensen et al. 2001]
BRDF vs BSSRDF

[Jensen et al. 2001]

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Extra
Procedural Appearance
Procedural Appearance

- Can we define details without textures?
  - Yes! Compute a noise function on the fly.
Procedural Appearance

- Can we define details without textures?
  - Yes! Compute a noise function on the fly.
  - 3D noise -> internal structure if cut or broken
Procedural Appearance

- Can we define details without textures?
  - Yes! Compute a noise function on the fly.
  - Thresholding
    (noise -> binary noise)

Example:

```python
if noise(x, y, z) > threshold:
    reflectance = 1
else:
    reflectance = 0
```
Procedural Appearance

- Complex noise functions can be very powerful.
Procedural Appearance

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Procedural Appearance

- Complex noise functions can be very powerful.

[Liu et al. 2016]
Procedural Appearance

- Complex noise functions can be very powerful.