Lecture 11:
Real-Time Physically-Based Materials
(surface models cont.)
Announcements

• No lecture next week
  - SIGGRAPH Asia deadline

• GAMES101 resubmission
  - Have to work on it after next week
Last Lecture

- Real-Time Physically-Based Materials
  - Microfacet BRDF
  - NDF: Beckmann, GGX, GTR
  - Shadowing-masking term
  - Kulla-Conty Approximation for multiple bounces
    - Disney principled BRDF

- Shading with microfacet BRDFs under polygonal lighting
  - Linearly Transformed Cosines (LTC)
Today

- Shading with microfacet BRDFs under polygonal lighting
  - Linearly Transformed Cosines (LTC)
- Real-Time Physically-Based Materials cont.
  - Disney principled BRDF
- Non-photorealistic rendering (NPR)
Shading Microfacet Models using Linearly Transformed Cosines (LTC)
Linearly Transformed Cosines

- Solves the shading of microfacet models
  - Mainly on GGX, though others are also fine
  - No shadows
  - Under polygon shaped lighting
Linearily Transformed Cosines

- **Key idea**
  - Any outgoing 2D BRDF lobe can be transformed to a cosine
  - The shape of the light can also be transformed along
  - Integrating the transformed light on a cosine lobe is *analytic*
Linearity Transformed Cosines

- Observations
  - BRDF $\xrightarrow{M^{-1}}$ Cosine
  - Direction: $\omega_i \xrightarrow{M^{-1}} \omega'_i$
  - Domain to integrate: $P \xrightarrow{M^{-1}} P'$
Linearily Transformed Cosines

• Approach
  - A simple change of variable

\[
\omega_i = \frac{M \omega'_i}{\|M \omega'_i\|}
\]

\[
L(\omega_o) = L_i \cdot \int_P \mathcal{F}(\omega_i) \, d\omega_i
\]

\[
= L_i \cdot \int_P \cos(\omega'_i) \, d\omega'_i \frac{M \omega'_i}{\|M \omega'_i\|}
\]

\[
= L_i \cdot \int_{P'} \cos(\omega'_i) J \, d\omega'_i
\]  

--- Analytic!
Linearly Transformed Cosines

• Results
Questions?
Disney’s Principled BRDF
Why is it needed?

• **Motivation**
  - No physically-based materials are good at rep. all real materials
    - e.g. lacking diffuse term in most microfacet models
  - Physically-based materials are not artist friendly
    - e.g. “the complex index of refraction n-ik”

• **High level design goal**
  - Art directable, not necessarily physically correct
  - But again, referred to as PBR in real-time rendering…”
What is “principled”? 

- The BRDF is designed with a few important principles
  - Intuitive rather than physical parameters should be used.
  - There should be as few parameters as possible.
  - Parameters should be zero to one over their plausible range.
  - Parameters should be allowed to be pushed beyond their plausible range where it makes sense.
  - All combinations of parameters should be as robust and plausible as possible.
How does it work?

- A table showing the effects of **individual** parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0.0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>subsurface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>metallic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>specular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>specularTint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>roughness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>anisotropic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sheen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sheenTint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>clearcoat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>clearcoatGloss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pros and Cons

- Easy-to-understand / control
- A wide range of materials in a single model
- Open source implementation is available
- Not physically based
  - But is it a big problem?
  - Academia vs. industry
- Huge parameter space
Questions?
Non-Photorealistic Rendering (NPR)  

==

stylization
In real-time rendering,

Non-Photorealistic Rendering (NPR)

==

(fast and reliable) stylization
Photorealistic Rendering

- Goal
  - Indistinguishable from photos
  - Focus: lighting, shadows, materials, etc.
Non-Photorealistic Rendering (NPR)

- Goal
  - Producing artistic appearances
Characteristics of NPR

- Starts from photorealistic rendering
- Exploits abstraction
- Strengthens important parts
Applications of NPR

- Art
- Visualization
- Instruction
- Education
- Entertainment
- …
Applications of NPR

[Atelier Ryza 2: Lost Legends & the Secret Fairy]

[Attack on Titan, Season 4]
What are Styles?

- Can we summarize styles from this image?

[Xenoblade Chronicles 2]
What are Styles?

• Can we summarize styles from this image?
  - Bold contours (actually, outlines)
  - Blocks of colors
  - Strokes on surfaces
Outline Rendering

- Outlines are not just contours
  - [B]oundary / border edge
  - [C]rease
  - [M]aterial edge
  - [S]ilhouette edge
Outline Rendering -- Shading

- Shading normal contour edges
  - Darken the surface area where the shading normal is perpendicular to viewing direction
Outline Rendering -- Geometry

• Backface fattening
  - Render frontface normally
  - “Fatten” backfaces, then render again
  - Extension: fatten along vertex normals
Outline Rendering -- Image

• Edge detection in images
  - Usually use a Sobel detector
Outline Rendering -- Image

• Edge detection in images
  - May work on different information
Color blocks

- Two different ways
  - Hard shading: thresholding on shading
  - Posterization: thresholding on final image color
Color blocks

• May not be binary
  - Quantization
Color blocks

- Different styles on different components
Strokes Surface Stylization

• Sometimes you do not want color blocks

• Instead you want to mimic sketching

• Idea
  - Replace point-wise shading with pre-generated stroke textures
  - Density?
  - Continuity?
Strokes Surface Stylization

- Tonal art maps (TAMs)
  - Strokes of different densities
  - Each density has a MIPMAP
Strokes Surface Stylization

Example stroke → Tonal Art Map → Lapped texture → Real-Time → Result

Mesh → Preprocess → Lapped texture → Real-Time
Some Notes

- NPR is art driven

- But you need the ability to “translate” artists’ needs into rendering insights
  - e.g. edge

- Communication is important

- Sometimes, per character, even per part
Key Observations

• Something people still haven’t paid much attention to
  - Photorealistic models are super important in NPR

• Example: cloth
Next Lecture

• Real-Time Physically-Based Materials (scattering models)

Thank you!

(And thank Prof. Kun Xu for some of the NPR slides)