Capturing Reflectance
From Theory to Practice

Reflectance Sharing

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BRDF
(bi-directional reflectance distribution function)

\[
f(\omega_i \rightarrow \omega_o) = \frac{dL(\omega_o)}{dE(\omega_i)}
\]

ratio of reflected radiance to incident irradiance

BRDF Measurement

- Gonioreflectometer

![Diagram of BRDF Measurement](image)

Image-Based BRDF Measurement

- [Marschner 1999, Lu et al. 1998, …]
  - capture lots of BRDF samples at one shot by a sensor array / camera
  - homogeneous, isotropic materials only

- [Matusik et al. 2003, Ngan et al. 2005]
  - systematic capture effort for large number of materials
  - includes anisotropic materials
  - BRDF database available online
  - analysis of captured data using dimensionality reduction techniques

- [Zickler et al. 2005]
  - reflectance sharing
  - treat reflectance estimate as a scattered-data interpolation problem
  - mixed angular-spatial domain
  - works on sparse input data

Image-Based BRDF Measurement
Homogeneous BRDF

Spatially Varying BRDF

Spatially Varying BRDF

• heterogeneous materials

\[ f_i(\vec{x}; \vec{\omega}_i \rightarrow \vec{\omega}_o) \]

• measurement approach by [Lensch et al. 2003]

Acquisition Setup

• Camera and light source are moved manually around the object.
• Positions are calibrated with respect to the object.
• The dark room reduces reflections from the environment.

BRDF Fitting and Clustering

• View Acquisition → Registration → Visibility/Shadows → Resampling → BRDF Fitting → Clustering
**BRDF Acquisition**

- Capture HDR-images from various viewpoints with different light source positions.

**BRDF Fitting and Clustering**

- View Acquisition
- Registration of Visibility/Shadows
- Resampling
- BRDF Fitting
- Clustering

**Light Source Position**

- Detect highlights of ring flash reflections
- Determine the position of the spheres

**3D-2D Registration**

- Calibrated gantry
- Corresponding points
- Silhouette-based method
Light Source Position

BRDF Fitting and Clustering

Resampling

BRDF Fitting and Clustering

Key Idea

The Lafortune Model

- Very few radiance samples per texel
  - no dense sampling of the BRDF

- Most real-world objects consist of a small set of distinct materials.
  - fit a BRDF model for each basis material
  - start with the average BRDF of the entire surface

\[ f_r(\omega_i, \omega_o) = a \sum_j \left( \omega_x \omega_y \omega_x \omega_y + \omega_y \omega_z \right) \]

- physically plausible
- diffuse component plus a number of lobes
- \(3(1+1^3)\) parameters (12 for a single lobe model)
- fit parameters to samples using Levenberg-Marquardt
Fitting BRDFs to Lumitexels

- define error measure between a BRDF and a lumitexel:

\[
E_f(L) = \frac{1}{|L|} \sum_{j \in L} \left( f_r(\hat{\omega}_i, \hat{\omega}_o, \hat{\omega}_{io}) - r_j \right)^2
\]

- average error over all radiance samples

- perform non-linear least square optimization for a set of lumitexels using Levenberg-Marquardt
- yields a single BRDF (i.e. its parameters) per set of lumitexels

Clustering

- Goal: separate the different materials
  - similar to Lloyd iteration

  - start with a single cluster containing all lumitexels
  - split cluster along direction of largest variance
  - stop after \(n\) clusters have been constructed

Split-Recluster-Fit Cycle

- split into two BRDFs along direction of largest variance of parameters (covariance matrix)
- distribute initial lumitexels forming two new clusters
- refit new BRDFs
- repeat reclustering and fitting until clusters are stable

Clustering Results

Spatially Varying Materials
**Projection**

- Goal: assign a separate BRDF to each lumitexel
  - too few radiance samples for a reliable fit
- represent the BRDF $f_x$ of every lumitexel by a linear combination of already determined BRDFs of the clusters $f_1, f_2, \ldots, f_m$

\[ f_x = t_1 f_1 + t_2 f_2 + \ldots + t_m f_m \]

- determine linear weights $t_1, t_2, \ldots, t_m$

**Projection**

- compute the pseudo-inverse using non-negative SVD to get a least squares solution for

\[
\begin{pmatrix}
\begin{array}{c}
\hat{t}_1 \\
\hat{t}_2 \\
\vdots \\
\hat{t}_m
\end{array}
\end{pmatrix} =
\begin{pmatrix}
\begin{array}{ccc}
\hat{f}_1 \hat{f}_1 & \hat{f}_1 \hat{f}_2 & \cdots & \hat{f}_1 \hat{f}_m \\
\hat{f}_2 \hat{f}_1 & \hat{f}_2 \hat{f}_2 & \cdots & \hat{f}_2 \hat{f}_m \\
\vdots & \vdots & \ddots & \vdots \\
\hat{f}_m \hat{f}_1 & \hat{f}_m \hat{f}_2 & \cdots & \hat{f}_m \hat{f}_m
\end{array}
\end{pmatrix}\begin{pmatrix}
\begin{array}{c}
\hat{t}_1 \\
\hat{t}_2 \\
\vdots \\
\hat{t}_m
\end{array}
\end{pmatrix}
\]

- It is a linear problem!

**Results**

**Normal Fitting**

**Why to do the complicated clustering?**

**Without Normal Fitting**
Conclusion

- determine BRDF of a few basis materials
- spatial variation as a blend of basis BRDFs
- highly efficient acquisition

- model based
- requires geometry model

Course Web Pages

- find updated content at http://www.mpi-inf.mpg.de/resources/eg07-capturing-reflectance

Schedule

14:00-14:25 – Introduction (Lensch)
14:25-15:00 – Acquisition Basics (Goesele)
15:00-15:30 – Reflectance Sharing (Goesele)
15:30-16:00 – Break
16:00-16:45 – Reflectance Fields for Distant Lights (Müller)
16:45-17:20 – Near-field Reflectance Fields (Lensch)
17:20-17:30 – Conclusion, Q/A