Capturing Reflectance
From Theory to Practice

Reflectance Sharing

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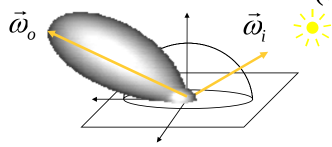
BRDF

(bi-directional reflectance distribution function)

$$f_r(\vec{\omega}_i \rightarrow \vec{\omega}_o) = \frac{dL(\vec{\omega}_o)}{dE(\vec{\omega}_i)}$$



ratio of reflected radiance to incident irradiance

BRDF Measurement

- Gonioreflectometer

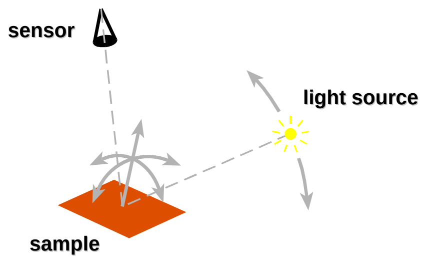


Image-Based BRDF Measurement

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

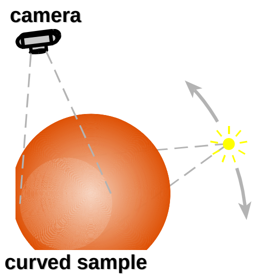
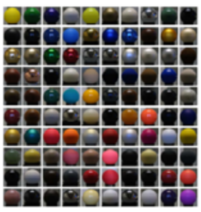


Image-Based BRDF Measurement

- [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



from http://www.merl.com/brdf/

Image-Based BRDF Measurement

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

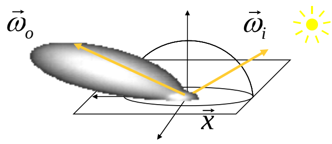
Homogeneous BRDF

Spatially Varying BRDF

Spatially Varying BRDF

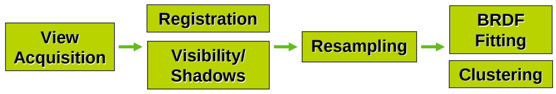
- heterogeneous materials

$$f_r(\vec{x};\vec{\omega}_i \rightarrow \vec{\omega}_o)$$



Spatially Varying BRDF

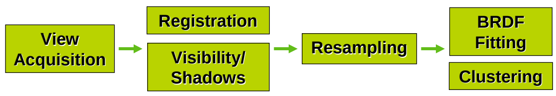
- measurement approach by [Lensch et al. 2003]



Acquisition Setup

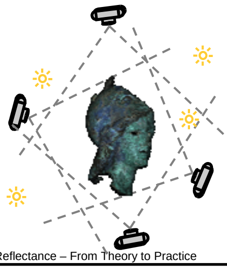
- Camera and light source are moved manually around the object.
- Positions are calibrated with respect to the object.
- The dark room reduces reflections from the environment.

BRDF Fitting and Clustering



BRDF Acquisition

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



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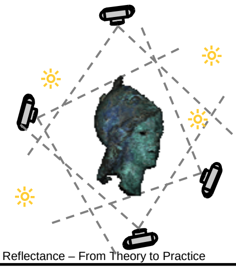
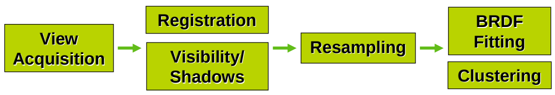
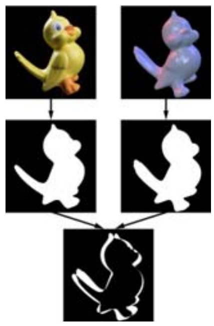


BRDF Fitting and Clustering



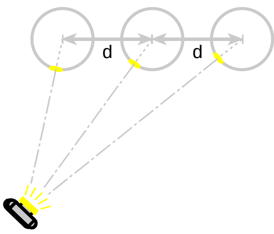
3D-2D Registration

– calibrated gantry
– corresponding points
– silhouette-based method



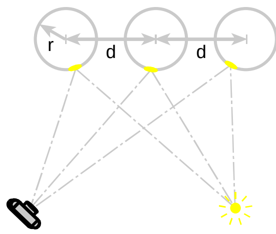
Light Source Position

– detect highlights of ring flash reflections
– determine the position of the spheres



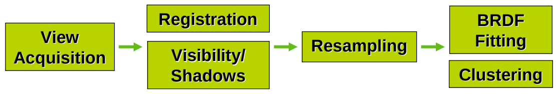
Light Source Position

– detect highlights of light source reflections
– reconstruct light source position

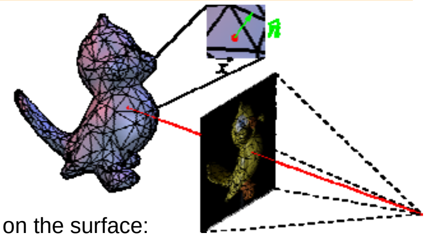


Light Source Position

BRDF Fitting and Clustering



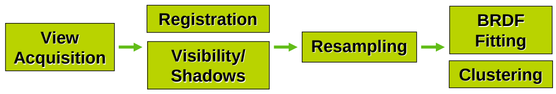
Resampling



– for each point on the surface:
find all images where the point is visible and lit
take sample at corresponding pixel position

$$(r,\vec{x},\vec{\omega}_i,\vec{\omega}_o)$$

BRDF Fitting and Clustering



Key Idea

- 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 avg. BRDF of the entire surface

The Lafortune Model

$$f_r(\hat{\omega}_i,\hat{\omega}_o)=\rho_d+\sum_j\left(C_{x,j}(\omega_{ix}\omega_{ox}+\omega_{iy}\omega_{oy})+C_{z,j}\omega_{iz}\omega_{oz}\right)^{N_j}$$

– physically plausible
– diffuse component plus a number of lobes
– 3*(1+ i*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:

$$E_{f_r}(L) = \frac{1}{|L|} \sum_{R_j \in L} \left(f_r(\vec{\omega}_{i_j}, \vec{\omega}_{o_j}) \vec{\omega}_{i_j z} - r_j \right)^2$$

= average error over all radiance samples

– perform non-linear least square optimization for a ***set*** of lumitexels using Levenberg-Marquardt

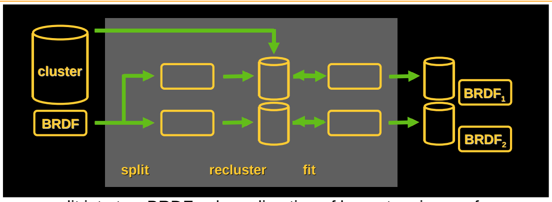
– yields a single BRDF (i.e. its parameters) per ***set*** of lumitexels

Fitting Result

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_π of every lumitexel by a linear combination of already determined BRDFs of the clusters $f_1, f_2, \dots, f_m$

$$f_\pi = t_1 f_1 + t_2 f_2 + \dots + t_m f_m$$

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

Projection

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

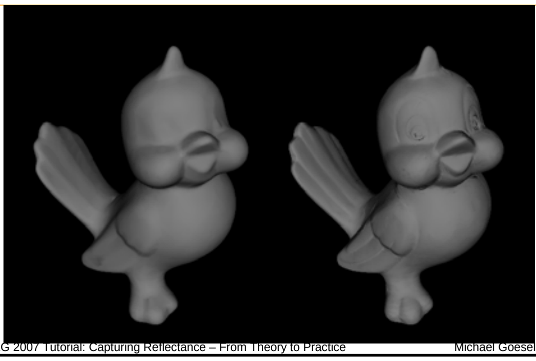
$$\begin{pmatrix} r_1 \\ r_2 \\ \vdots \\ r_{|L|} \end{pmatrix} = \begin{pmatrix} f_1(\hat{\omega}_{i1}, \hat{\omega}_{o1})\hat{\omega}_{i1,z} & f_2(\hat{\omega}_{i1}, \hat{\omega}_{o1})\hat{\omega}_{i1,z} & \cdots & f_m(\hat{\omega}_{i1}, \hat{\omega}_{o1})\hat{\omega}_{i1,z} \\ f_1(\hat{\omega}_{i2}, \hat{\omega}_{o2})\hat{\omega}_{i2,z} & f_2(\hat{\omega}_{i2}, \hat{\omega}_{o2})\hat{\omega}_{i2,z} & \cdots & f_m(\hat{\omega}_{i2}, \hat{\omega}_{o2})\hat{\omega}_{i2,z} \\ \vdots & \vdots & \ddots & \vdots \\ f_1(\hat{\omega}_{i|L|}, \hat{\omega}_{o|L|})\hat{\omega}_{i|L|,z} & f_2(\hat{\omega}_{i|L|}, \hat{\omega}_{o|L|})\hat{\omega}_{i|L|,z} & \cdots & f_m(\hat{\omega}_{i|L|}, \hat{\omega}_{o|L|})\hat{\omega}_{i|L|,z} \end{pmatrix} \cdot \begin{pmatrix} t_1 \\ t_2 \\ \vdots \\ t_m \end{pmatrix}$$

- it is a linear problem!

Results

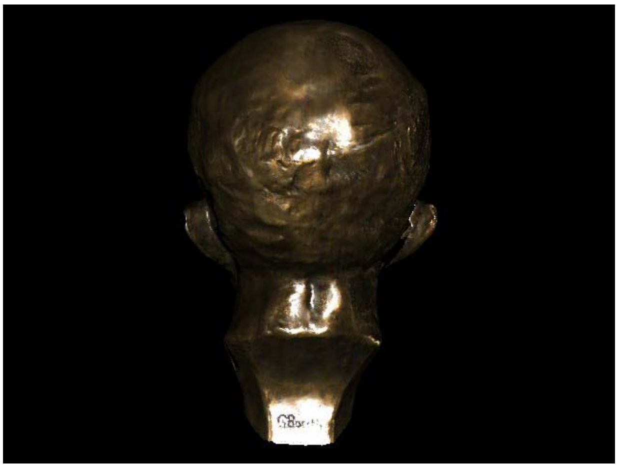
Why to do the complicated clustering?

Normal Fitting



Without Normal Fitting

With 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