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Course 10
Realistic Materials in Computer Graphics

Heterogeneous Isotropic BRDFs

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Homogeneous BRDF

Spatially Varying BRDF

Approaches - Sampling

- dense sampling for each texel
  - Reflectance Fields, BTF
- sparse sampling
  - image-based BRDF Measurement
  - combining samples from different surface points
- spatial variation
  - constant specular part vs. clustered BRDFs

Approaches - Illumination

- point light
  - controlled condition
  - interreflections most often neglected
- environment maps
  - still direct illumination only
- global inverse illumination

BRDF Measurement

- Gonioreflectometer

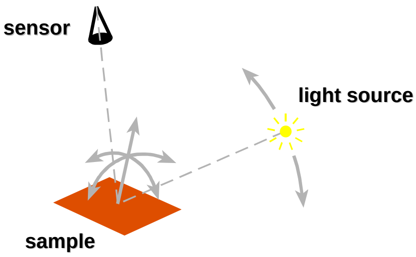
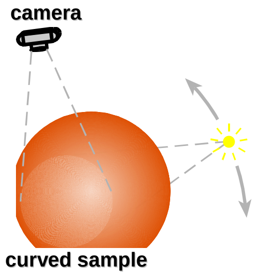


Image-Based BRDF Measurement

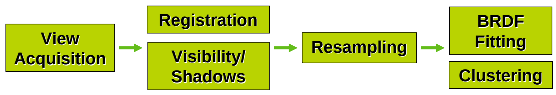
- [Marschner 1999, Lu & Koenderink 1998, …]
  - capture lots of BRDF samples at one shot by a sensor array / camera
  - homogeneous, isotropic materials only



Acquisition Setup

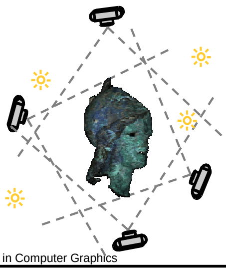
- Camera and light source are moved manually around the object.
- Positions are calibrated with respect to the object.
- The dark room reduces reflections from the environment.

BRDF Fitting and Clustering



BRDF Acquisition

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



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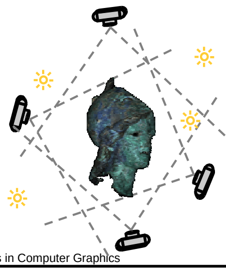

BRDF Fitting and Clustering

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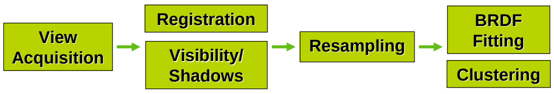

3D-2D Registration

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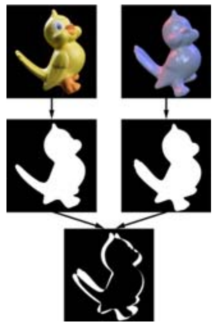
- calibrated gantry
- corresponding points
- silhouette-based method



Light Source Position

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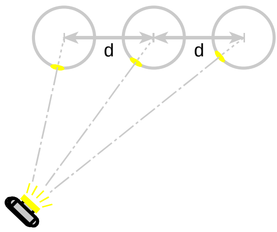
- detect highlights of ring flash reflections
- determine the position of the spheres



Light Source Position

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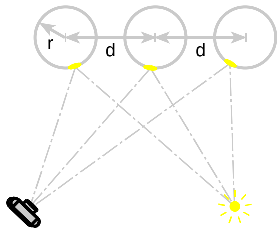
- detect highlights of light source reflections
- reconstruct light source position



Light Source Position

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BRDF Fitting and Clustering

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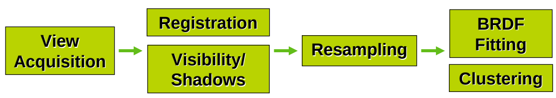

Resampling

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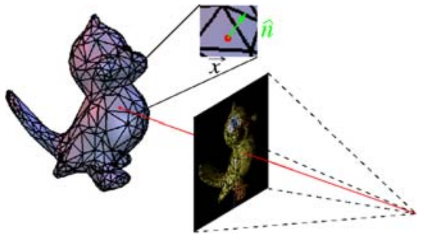

– for each point on the surface:

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

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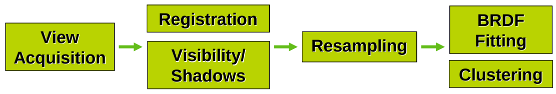

Key Idea

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- 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

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

– 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

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– 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

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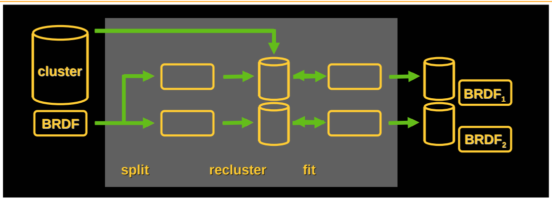
Clustering

- 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 $f_1, f_2, \ldots, f_m$:

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

  - 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

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

- it is a linear problem!

Results

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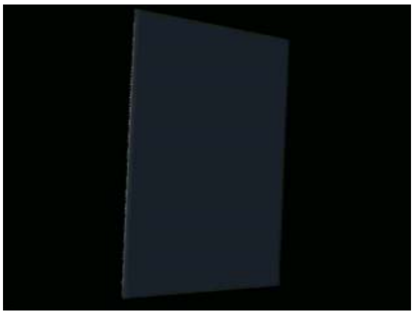
Why to do the complicated clustering?



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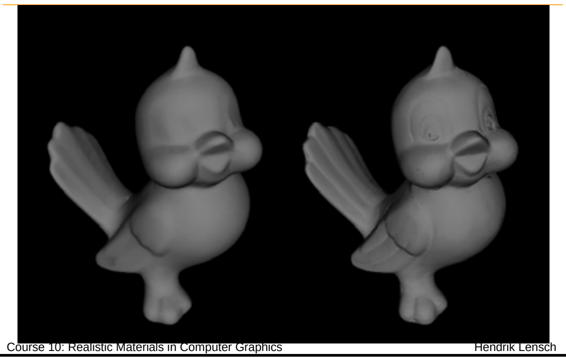
Normal Fitting



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Without Normal Fitting

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With Normal Fitting

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Model Exhibition for Cultural Heritage Applications

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- Preservation, documentation, restoration, communication, accessibility

Conclusion

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

- model based
- requires geometry model