EUROGRAPHICS 2007

Tutorial 6
Capturing Reflectance
From Theory to Practice

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Michael Goesele, TU Darmstadt
Gero Müller, Bonn University

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

Capturing Reflectance
From Theory to Practice

Introduction

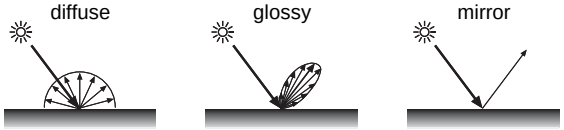
Hendrik P.A. Lensch
MPI Informatik

Material Samples

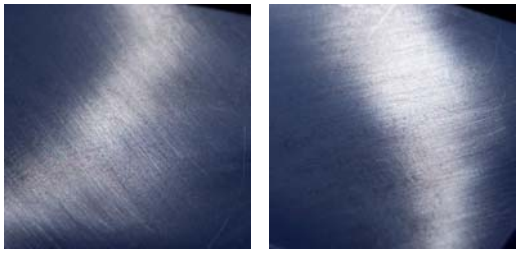
diffuse glossy mirror

Material Samples

diffuse glossy mirror



Material Samples

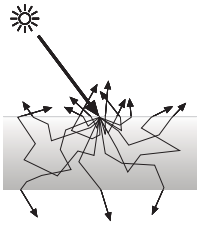


anisotropic

Material Samples

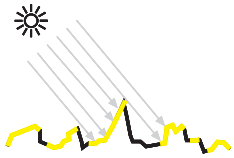
translucent

Material Samples



translucent

Material Samples



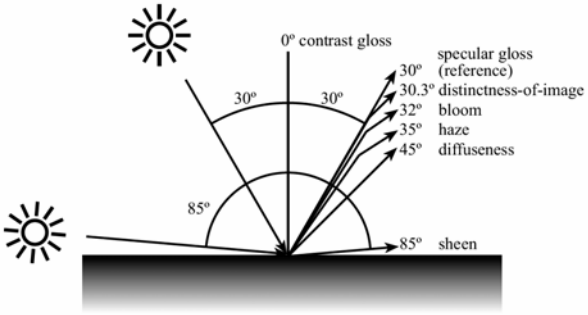
complex surface structure

How to describe materials?

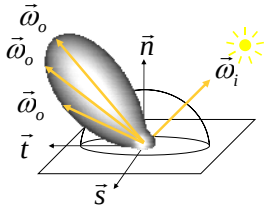
- mechanical, chemical, electrical properties
- reflection properties
- surface roughness
- geometry/meso-structure

- **relightable** representation of appearance

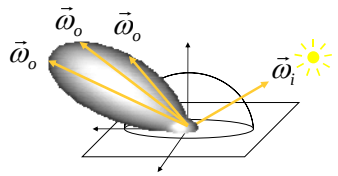
Gloss Model



Reflection of an Opaque Surface



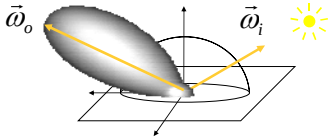
Reflection of an Opaque Surface



BRDF – 4D

(bidirectional reflectance distribution function)

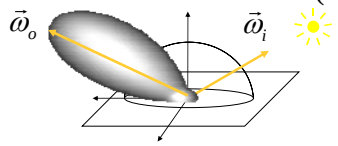
$$f_r(\vec{\omega}_i \rightarrow \vec{\omega}_o)$$



BRDF – 4D

(bidirectional reflectance distribution function)

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

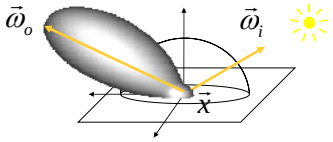


ratio of reflected radiance to incident irradiance

Spatially Varying BRDF – 6D

- heterogeneous materials

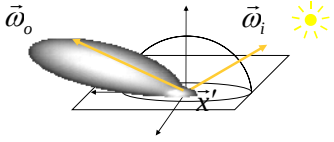
$$f_r(\vec{\omega}_i \rightarrow \vec{\omega}_o)$$



Spatially Varying BRDF – 6D

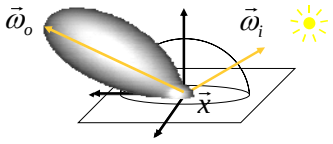
- heterogeneous materials

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



Isotropic BRDF – 3D

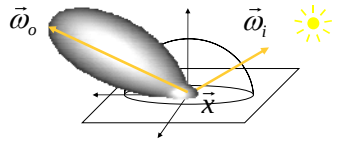
- invariant with respect to rotation about the normal



Isotropic BRDF – 3D

- invariant with respect to rotation about the normal

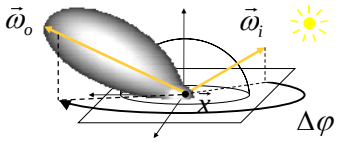
$$f_r(\vec{\omega}_i \rightarrow \vec{\omega}_o)$$



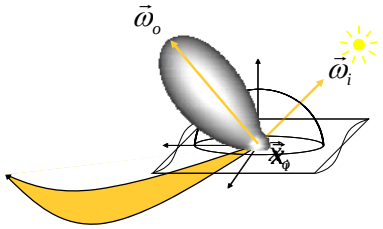
Isotropic BRDF – 3D

- invariant with respect to rotation about the normal

$$f_r((\theta_i, \varphi_i) \rightarrow (\theta_o, \varphi_o))$$



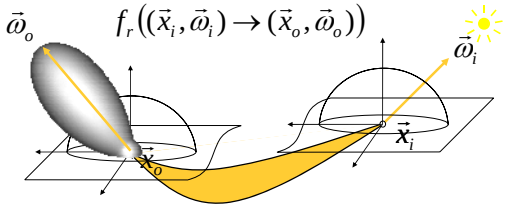
Subsurface Scattering



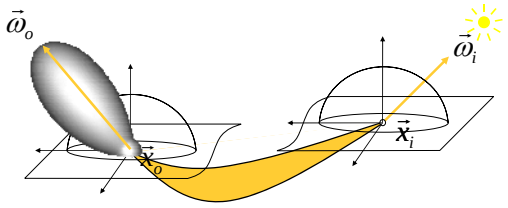
BSSRDF – 8D

(bidirectional scattering surface reflectance distribution function)

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

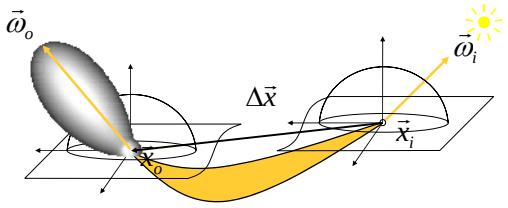


Subsurface Scattering Homogeneous Material



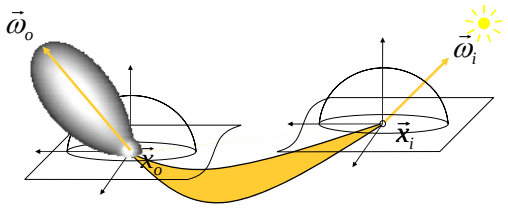
Homogeneous Material BSSRDF – 6D

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



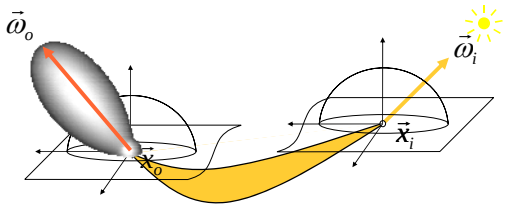
Generalization – 12D

$$f_r\left(\lambda;(\vec{x}_i,\vec{\omega}_i)\rightarrow(\vec{x}_o,\vec{\omega}_o)\right)$$



Generalization – 12D

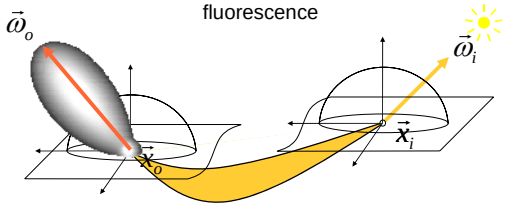
$$f_r\left(\lambda;(\vec{x}_i,\vec{\omega}_i)\rightarrow(\vec{x}_o,\vec{\omega}_o)\right)$$



Generalization – 12D

$$f_r\left((\vec{x}_i,\vec{\omega}_i,\lambda_i)\rightarrow(\vec{x}_o,\vec{\omega}_o,\lambda_o)\right)$$

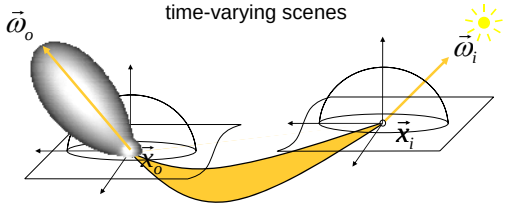
fluorescence



Generalization – 12D

$$f_r\left(t;(\vec{x}_i,\vec{\omega}_i,\lambda_i)\rightarrow(\vec{x}_o,\vec{\omega}_o,\lambda_o)\right)$$

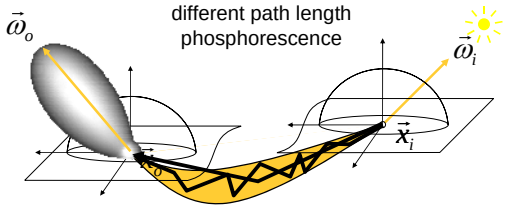
time-varying scenes



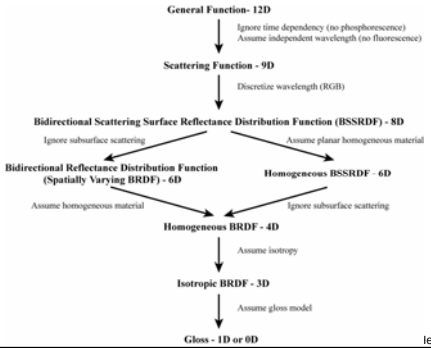
Generalization – 12D

$$f_r\left((\vec{x}_i,\vec{\omega}_i,t_i,\lambda_i)\rightarrow(\vec{x}_o,\vec{\omega}_o,t_o,\lambda_o)\right)$$

different path length
phosphorescence



Taxonomy of Appearance Representations

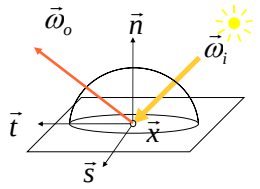


Properties of Reflectance Functions

- Helmholtz reciprocity
- energy conservation
- Fresnel effect

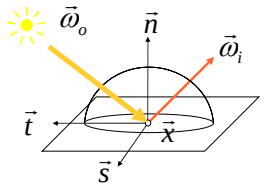
Helmholtz Reciprocity

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



Helmholtz Reciprocity

$$f_r(\vec{\omega}_i \rightarrow \vec{\omega}_o) = f_r(\vec{\omega}_o \leftarrow \vec{\omega}_i)$$



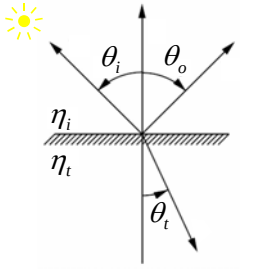
Energy Conservation

- The sum of energy reflected into all directions has to be smaller or equal than the incident energy.

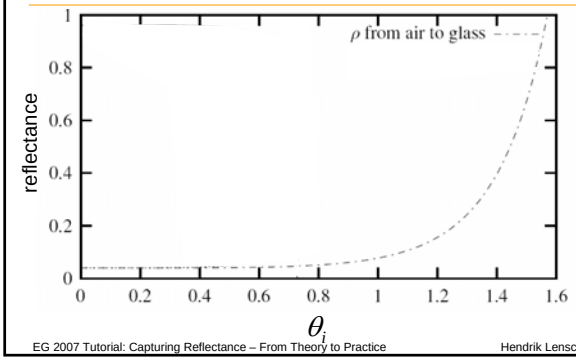
$$\int_{\Omega_o} f_r(\vec{\omega}_i \rightarrow \vec{\omega}_o)\cos(\theta_i)d\omega_o \leq 1$$

Snell's Law

$$\eta_i(\lambda)\sin\theta_i = \eta_t(\lambda)\sin\theta_t$$



Fresnel Formula



Material Acquisition

- single picture
  - no interaction

Material Acquisition

- diffuse color + geometry model
  - no relighting

Material Acquisition

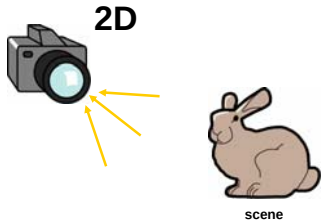
- BRDF + geometry model
  - moving highlights

Material Acquisition

- spatially-varying BRDF + geometry model
  - moving highlights

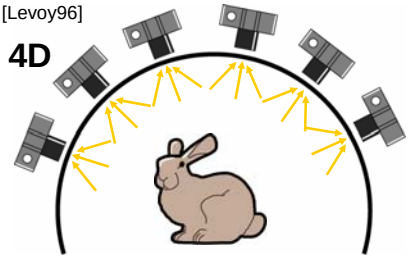
Digitizing real-world Objects

a single photograph



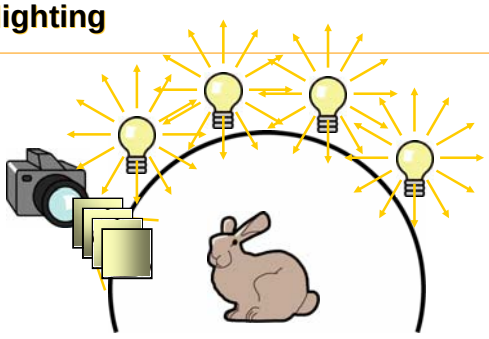
Light Fields

[Gortler96], [Levoy96]



distribution of all reflected light rays

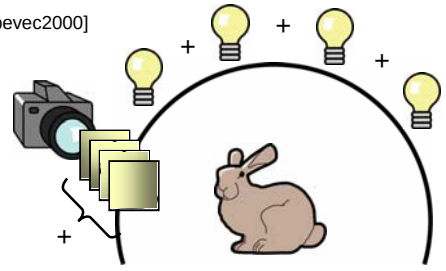
Relighting



one picture for each light direction

Relighting

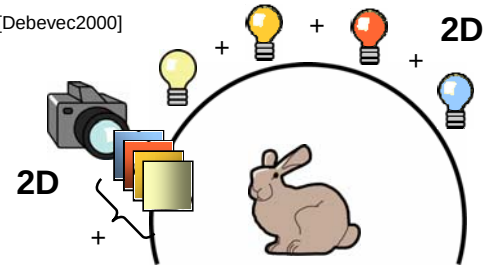
[Debevec2000]



superposition principle

4D Reflectance Fields

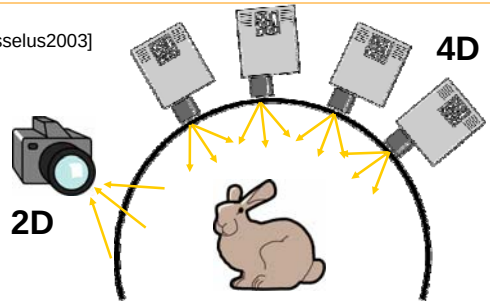
[Debevec2000]



Far- vs. Near-Field Illumination

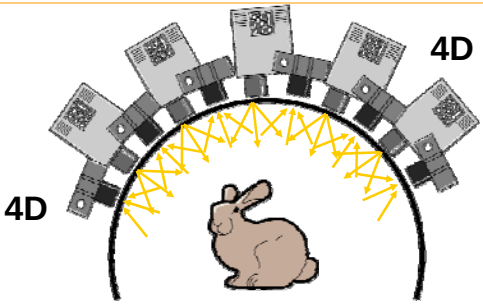
6D Reflectance Fields
Near Field illumination

[Masselus2003]



relighting with 4D incident light fields

8D Reflectance Fields



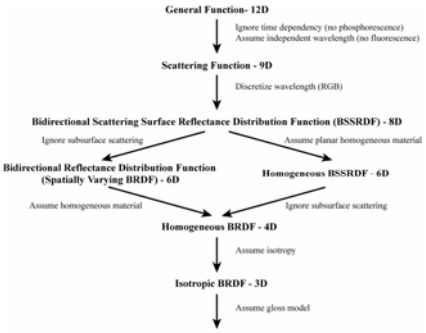
arbitrary perspective + arbitrary illumination

Acquisition Approaches

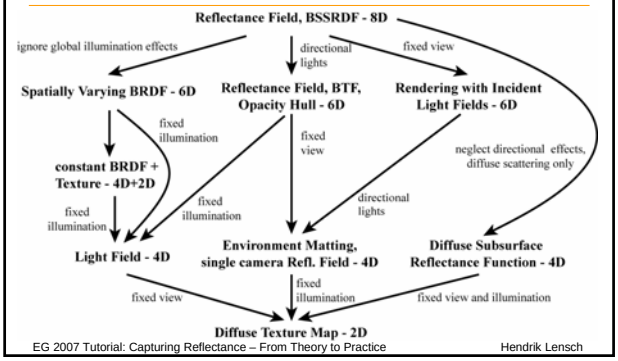
- hard to sample an 8D function
- dimensionality reduction
- sampling density

- restricted viewing and relighting capabilities
- restriction to a specific class of materials/objects

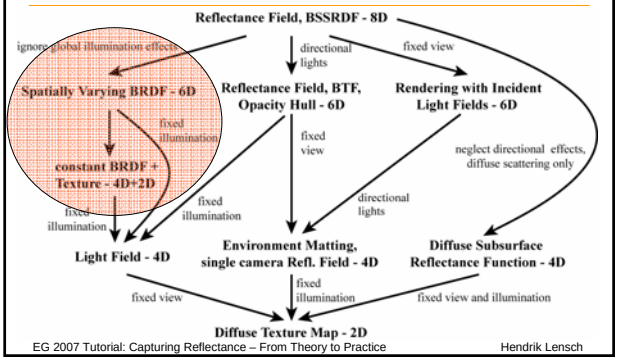
Taxonomy of Appearance Representations



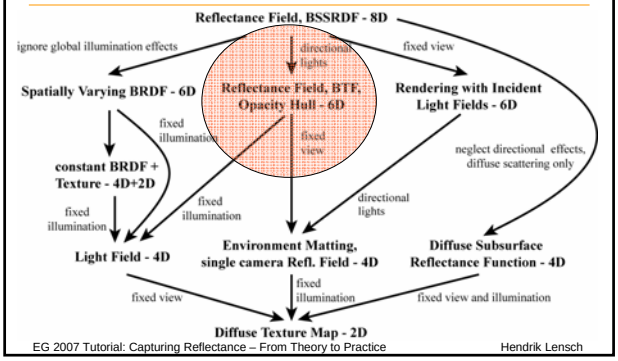
Acquisition Taxonomy



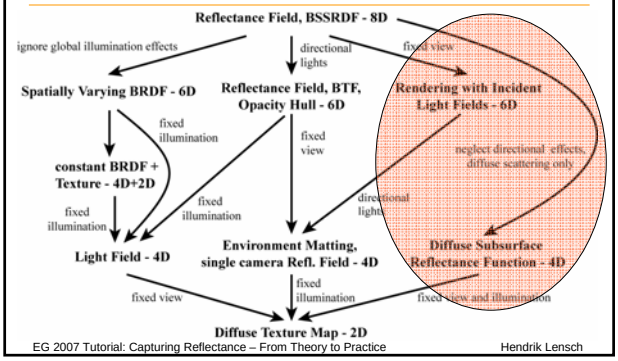
Reflectance Sharing



Reflectance Fields for Distant Lights



Near-Field Reflectance Fields



Summary

- densely sampling 8D functions almost impossible
- less dimensions might be sufficient for specific tasks / materials