Capturing Reflectance
From Theory to Practice

Near-field Reflectance Fields

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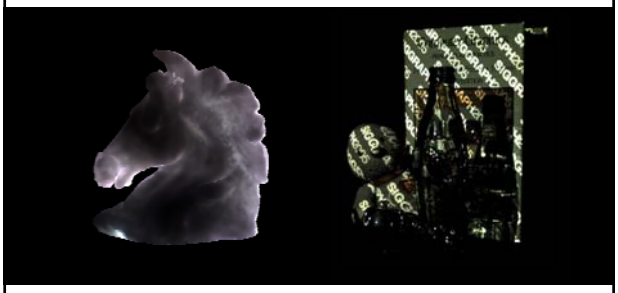
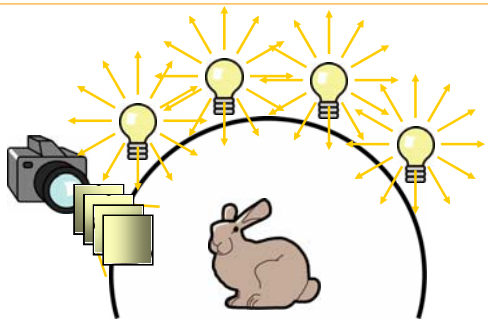
Digitizing Real World Objects



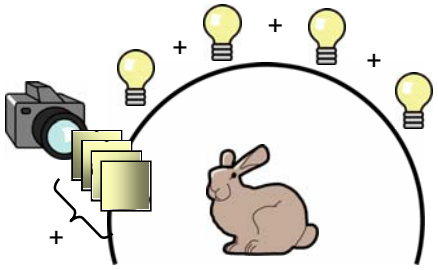
relighting with arbitrary illumination patterns

Relighting



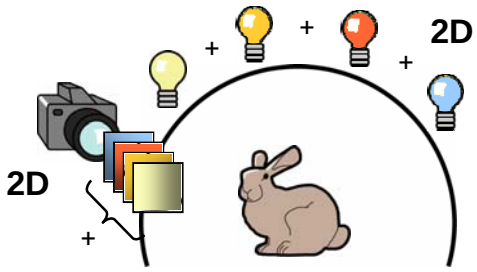
Relighting

[Debevec2000]



Far-Field Reflectance Fields

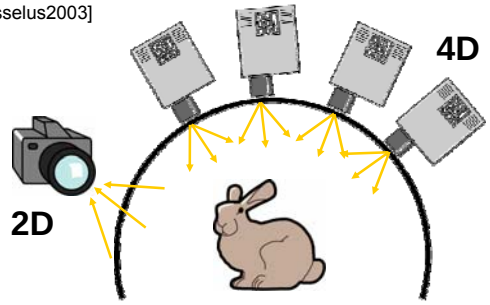
[Debevec2000]



Far- vs. Near-Field Illumination

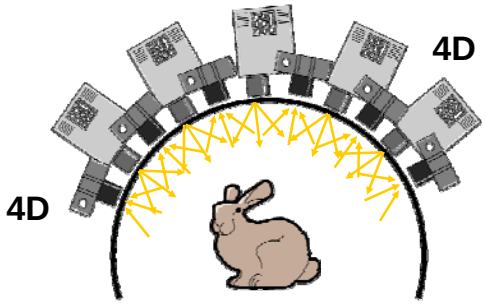
6D Reflectance Fields

[Masselus2003]



relighting with 4D incident light fields

8D Reflectance Fields

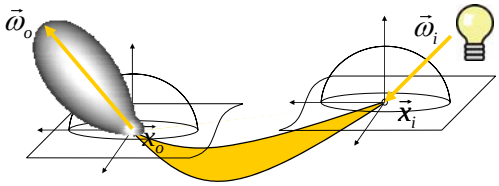


arbitrary view point + arbitrary illumination

Definition – Reflectance Field

8D fucntion

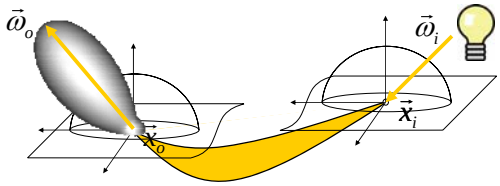
$$f_r\left((\vec{x}_i,\vec{\omega}_i)\rightarrow(\vec{x}_o,\vec{\omega}_o)\right)$$



Definition – Reflectance Field

ratio of reflected radiance to incident flux

$$f_r\left((\vec{x}_i,\vec{\omega}_i)\rightarrow(\vec{x}_o,\vec{\omega}_o)\right)=\frac{dL_o(\vec{x}_o,\vec{\omega}_o)}{d\phi_i(\vec{x}_i,\vec{\omega}_i)}$$



Main Problem

- sampling an ***8D function***
  - spending 100 samples/dimension
    → 10^{16} samples
  - hi-res 3D geometry: 10^8 vertices

- coherence in reflectance fields
  → reduced data complexity
- no complete solution yet

Approaches

- limited reflectance model
- limited reproduction
  - viewer position
  - incident illuminaton
- adaptive parallel acquisition
- advanced interpolation

Relighting with 4D Incident Light Fields

- goal: relighting with spatially varying illumination, e.g. spot lights [Masselus2003]

Acquisition with Large Blocks

- fixed camera perspective
- rotating illumination

Relighting Results

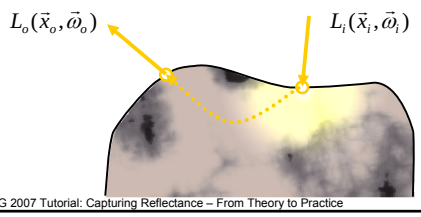
Translucent Objects

- light transport through the object
- scattering dampens high frequencies

BSSRDF – 8D

bidirectional scattering-surface reflectance distribution function [Nicodemus77]

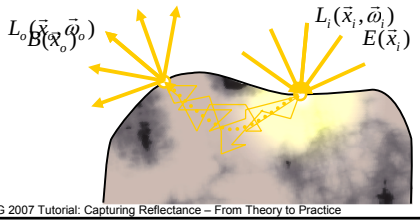
$$f_r\left((\vec{x}_i,\vec{\omega}_i)\rightarrow(\vec{x}_o,\vec{\omega}_o)\right)$$



Diffuse Approximation

neglect directional dependency [Jensen 2001]

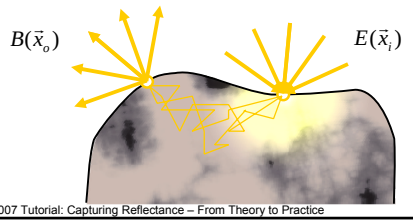
- multiple scattering leads to diffuse light transport



4D - Diffuse Approximation

⇒ diffuse reflectance function $R_d(\vec{x}_i, \vec{x}_0)$

- four dimensions only
- dense sampling is possible



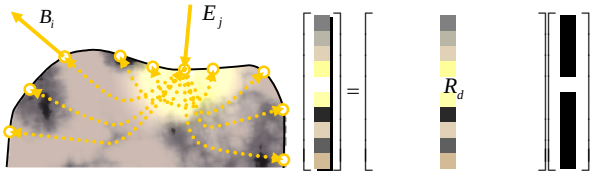
Diffuse Reflectance Fucntion R_d

- discretize the surface
  - enumerate all surface points
  - vectors for irradiance E and radiosity B
- matrix R_d
  - linear point-to-point transport

$$\begin{bmatrix} B_i \end{bmatrix} = \begin{bmatrix} R_d \end{bmatrix} \begin{bmatrix} E_j \end{bmatrix}$$

Basic Idea

- direct measurement of R_d
  - illuminate individual surface points
  - capture impulse response function



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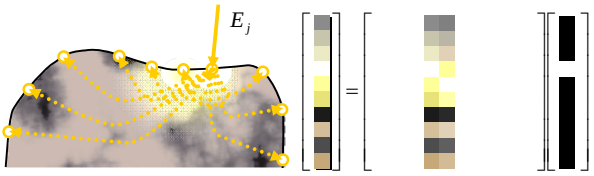

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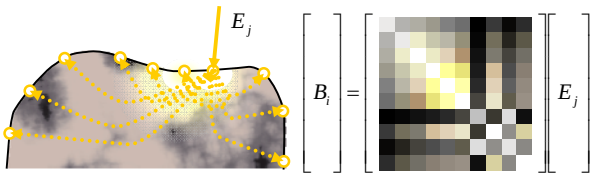
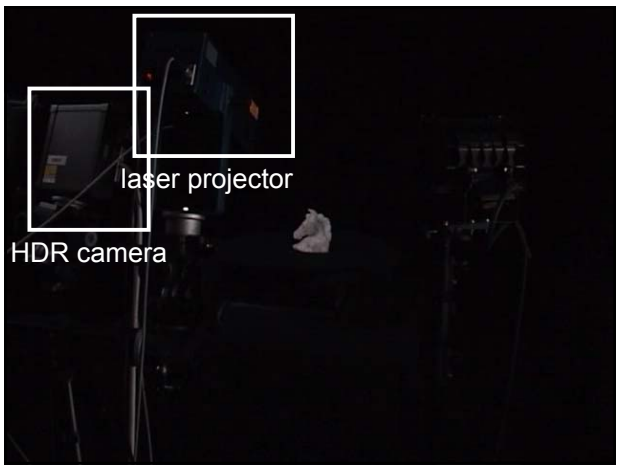




Matrix Representation

- 500.000 – 1.000.000 input images
  ⇒ ~100.000² entries
- fill up holes (inpainting)
- hierarchical representation
- hardware assisted rendering
  - analysis
  - real-time rendering

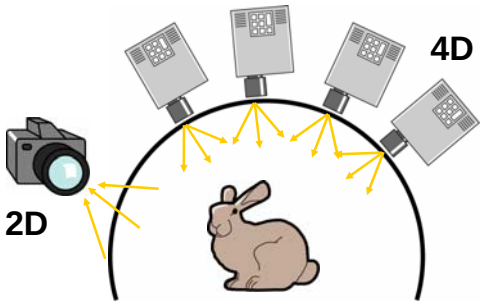
[Lensch, Goesele, Bekaert, Magnor, Lang, Seidel – PG2003]

Video

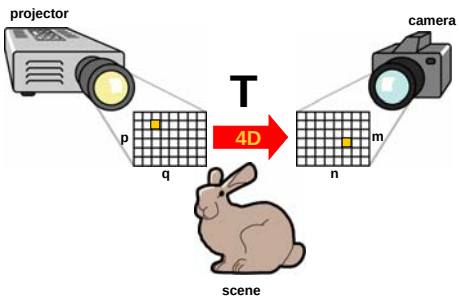
1.000.000 images, 22 hours → model - 800MB

[Goesele, Lensch, Lang, Fuchs, Seidel - SIGGRAPH 2004]

Fixed Perspective + Arbitrary Illumination

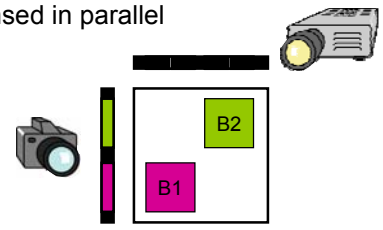


Pixel-to-Pixel Transport



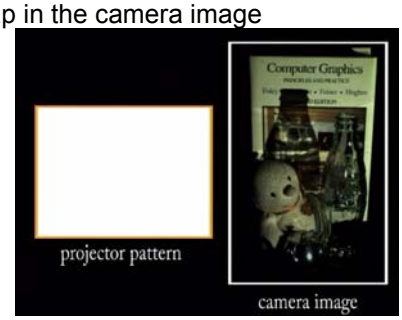
Adaptive Parallel Acquisition

- assumption: sparse matrix
- radiometrically independent blocks can be sensed in parallel



Adaptive Parallel Acquisition

parallelized acquisition of regions which do not overlap in the camera image



Adaptive Parallel Acquisition

parallelized acquisition of regions which do not overlap in the camera image

Relighting with Arbitrary Patterns

1.200 images, 2 hours → model - 220MB

Captured Global Light Transport

Helmholtz Reziprocity

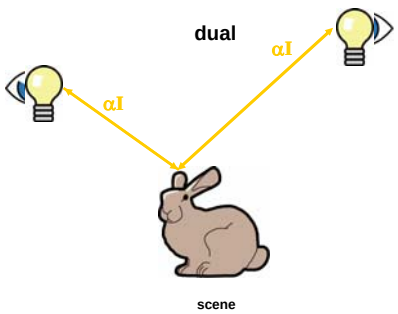


Image Acquisition without a Camera

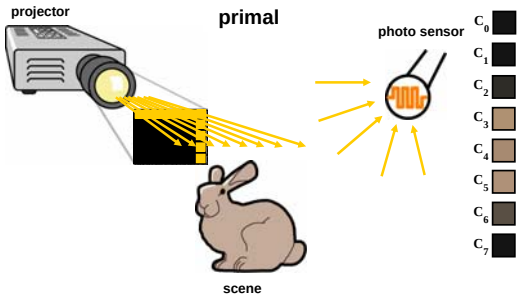
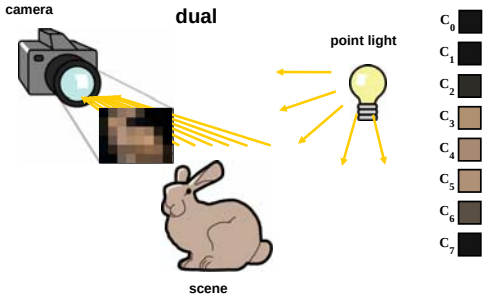
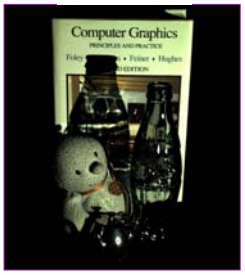


Image Acquisition without a Camera

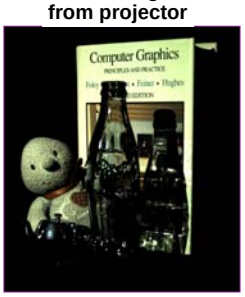


Dual Photography

photograph from camera



dual image from projector



[Sen, Chen, Garg, Marschner, Horowitz, Levoy, Lensch - SIGGRAPH 2005]

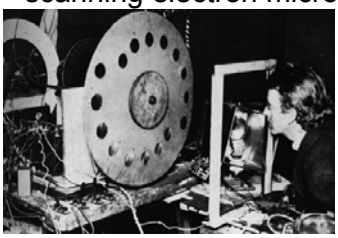
Examples

primal

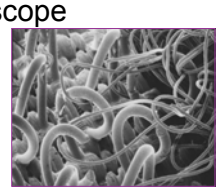
dual

Related Techniques

- "Flying-spot" TV camera [Baird 1926]
- scanning electron microscope

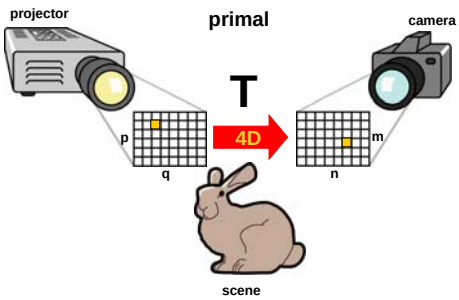


[Baird 1926]

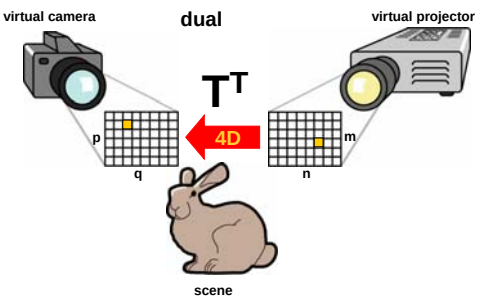


35x magnification
[museum of Science, Boston]

Relighting with Dual Photography

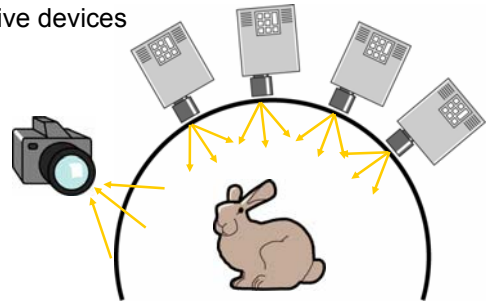


Relighting with Dual Photography



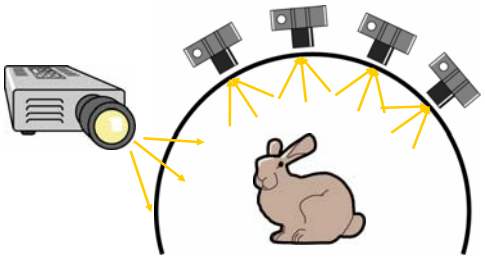
Acquisition of 6D Reflectance Fields

active devices



Dual Acquisition Process

parallel acquisition by passive devices

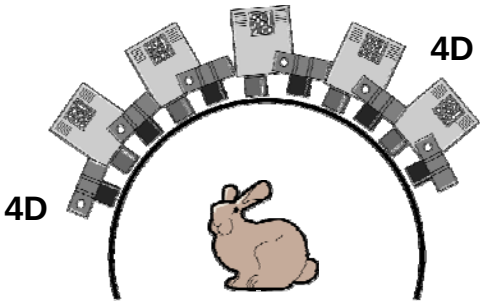


Smooth Interpolation

100.000 images, 26 hours → model - 4.5GB

[Chen, Lensch - VMV2005]

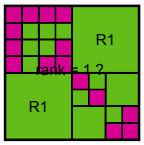
8D Reflectance Fields



arbitrary view point + arbitrary illumination

H -Matrices

[Hackbusch2000]

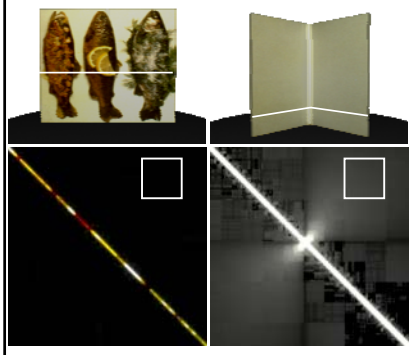


efficient representation of dense but ***data-sparse*** matrices

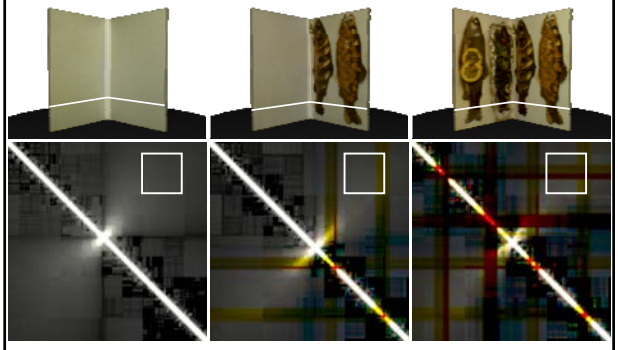
- subdivision hierarchy
- local low-rank approximation
- efficient evaluation

Direct vs. Indirect Reflections

Direct vs. Indirect Reflections

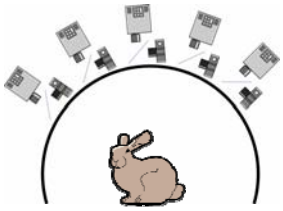


Direct vs. Indirect Reflections



2D Slices through a Reflectance Field

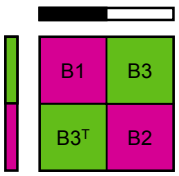
Symmetric Acquisition



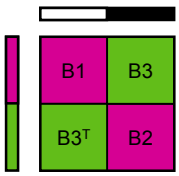
- symmetric 8th order tensor
- rank-1 approximation from two images only
- parallel acquisition of dense matrices

[Garg, Talvala, Levoy, Lensch – EGSR06]

Symmetric Exploration

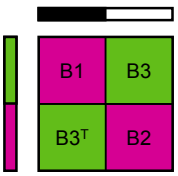


B3 – row sums
B2 – rows+columns

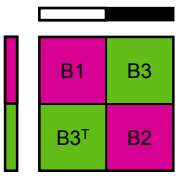


B3 – column sums
B1 – rows+columns

Symmetric Exploration



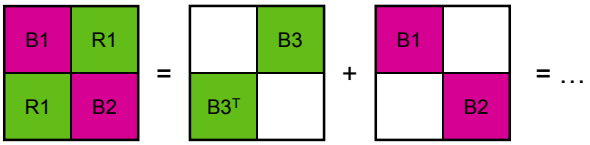
B3 – row sums
B2 – rows+columns



B3 – column sums
B1 – rows+columns

rank-1 approximation?

Hierarchical Rank-1Decomposition



already determined

radiometrically independent

B1 and B2 are investigated in parallel.

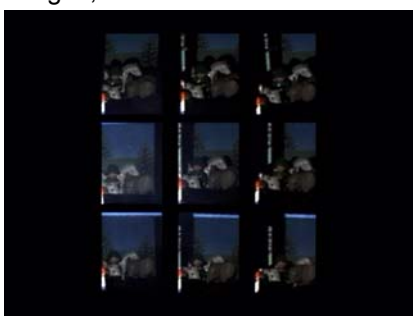
parallel acquisition even for dense matrices

Dual vs. Symmetric Photography

- increased SNR because regions are determined at large block sizes

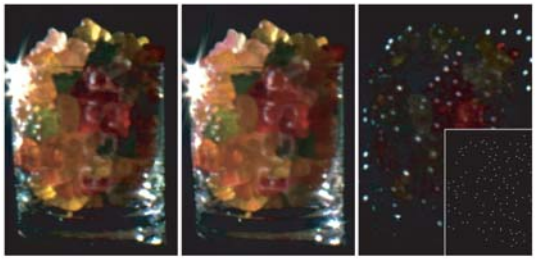
An 8D Reflectance Field

3.300 images, 6 hours → model – 1.4 GB



Virtual Photography

- reflectance fields of arbitrarily complex scenes

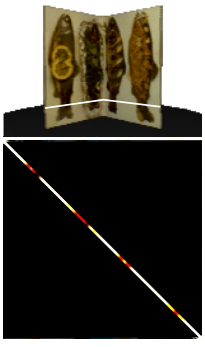


novel illumination original acquisiton pattern

[Garg, Talvala, Levoy, Lensch – EGSR 2006]

Application of Near-field Reflectance Fields

- getting rid of global effects



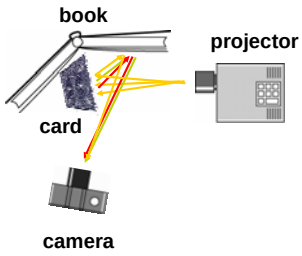
compare [Nayar2006]

Application to 3D Scanning

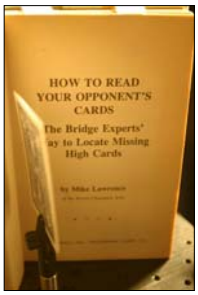
[Chen, Fuchs, Lensch, Seidel – CVPR 2007]

Card Experiment

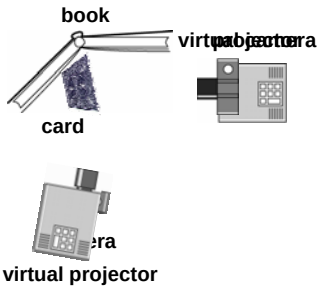
primal



Card Experiment



primal



Card Experiment

primal

dual

Near-Field Reflectance Fields

- Sequential Sampling
- Dual Photography
- Symmetric Photography based on **H** –matrices

- first methods for acquiring the global light transport in arbitrary scenes

Challenges

- densely sampled 8D reflectance fields
- upsampling / interpolation
- dynamic near-field reflectance fields
- interactive relighting
- global illumination with reflectance fields
- theory on the complexity of reflectance fields

Thanks

- BMBF (FKC01IMC01)
- DFG – Emmy Noether Program

Max Planck Center

http://mpi-inf.mpg.de/~lensch