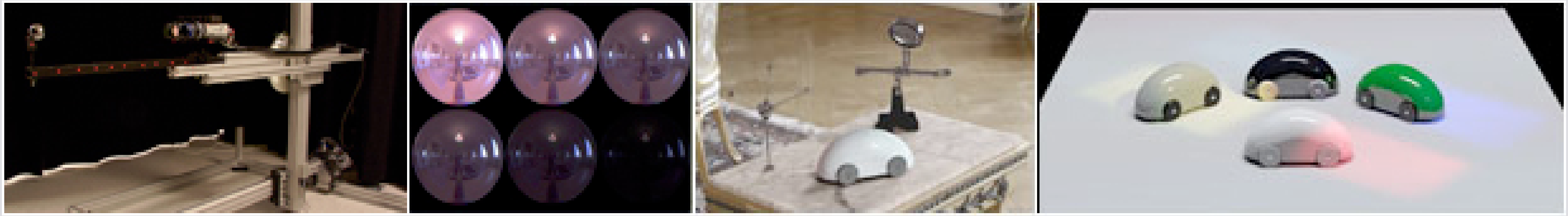
Free Form Incident Light Fields



Jonas Unger, Stefan Gustavson, Per Larsson and Anders Ynnerman

VITA, Linköping University, Sweden

Eurographics Symposium on Rendering 2008

Image Based Lighting

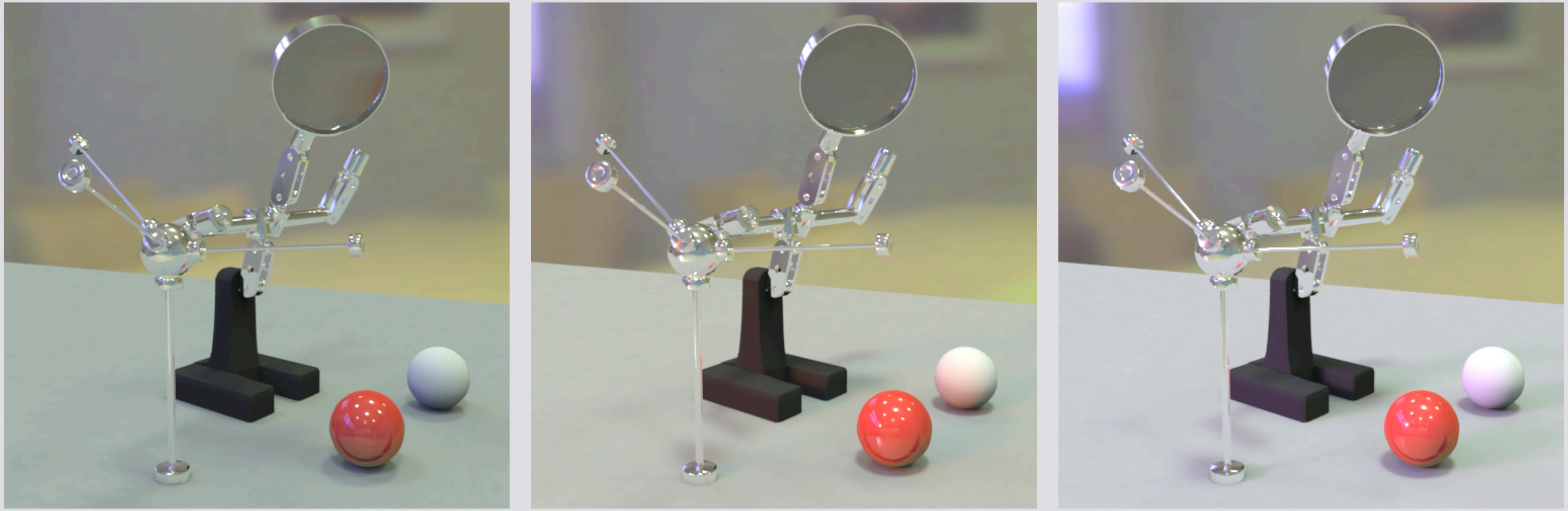
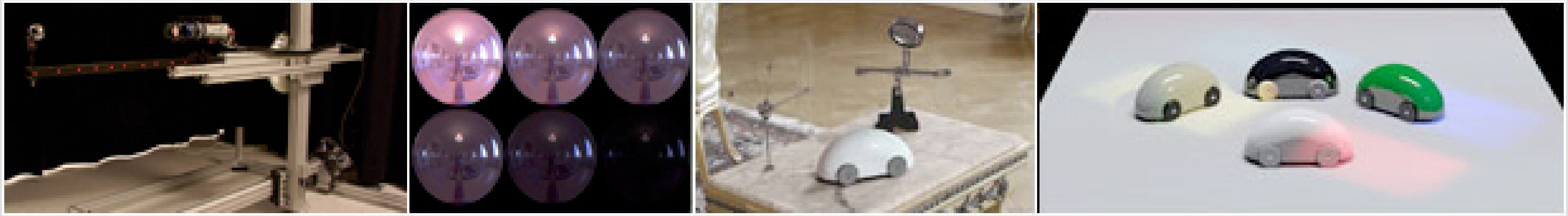


Image Based Lighting

Incident Light Fields

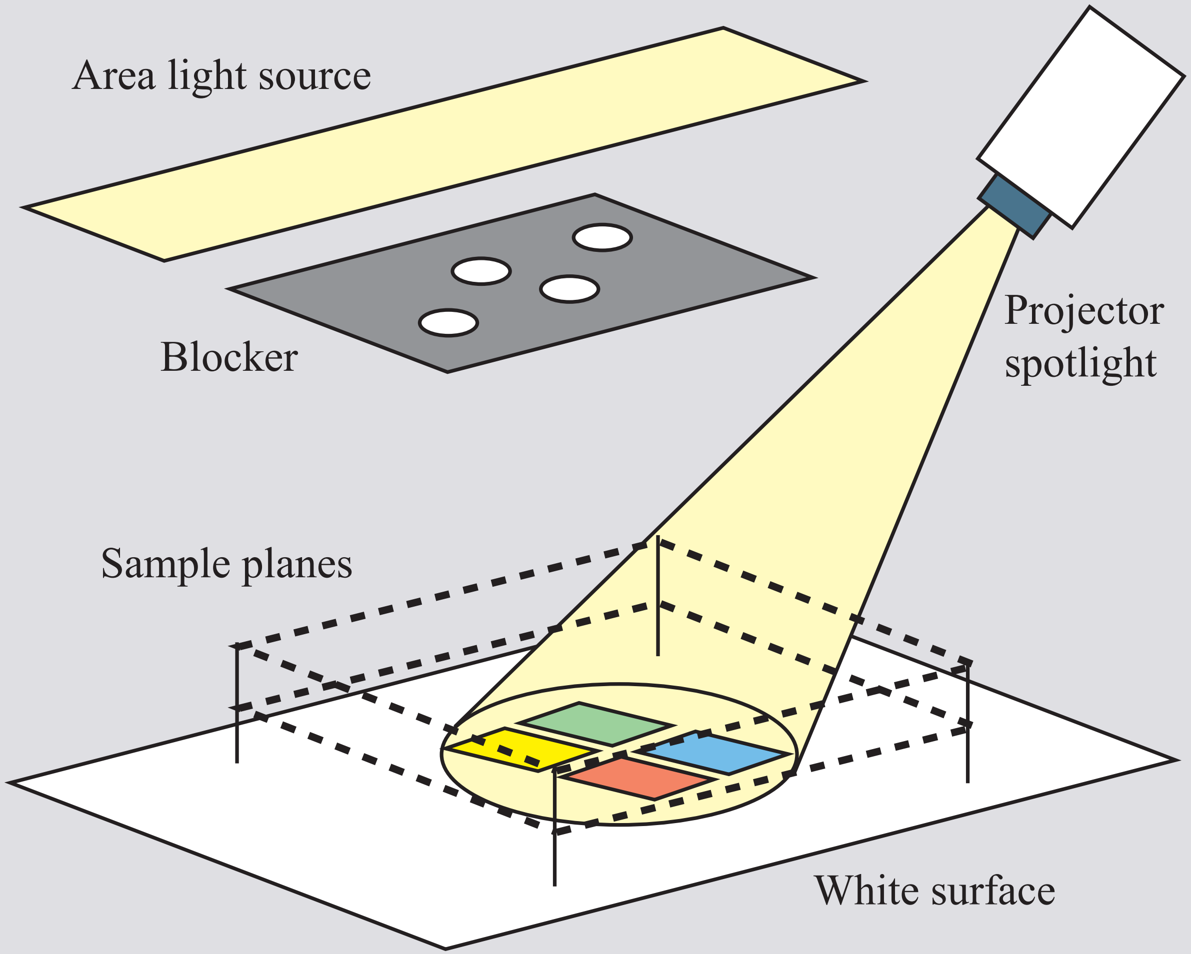
- Capture and Render with complex, spatially varying real world illumination
- High Dynamic Range (HDR) image sequences
- 4D Free Form Incident Light Field (ILF) representation
- Light source extraction
- Editing of the captured illumination



Related Work

- Image Based Lighting
  - [Deb98][SSI99][UGY07][ISG*08]
- Light Field Techniques
  - [LH96][GGSC96][UWH*03][WJV*05]
- HDR Imaging
  - [RWPD06][UG07]

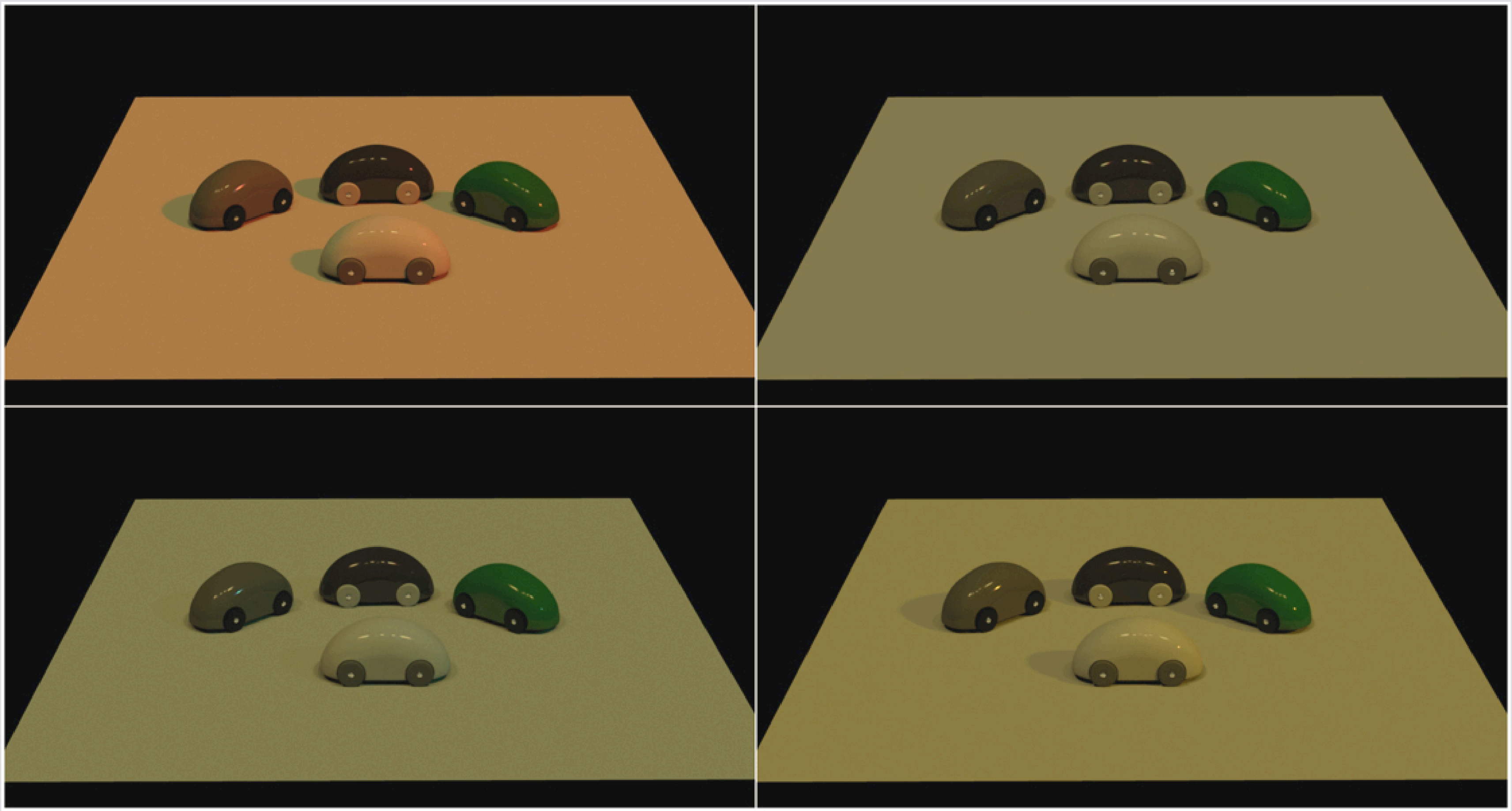
Spatially Varying Illumination



Spatially Varying Illumination

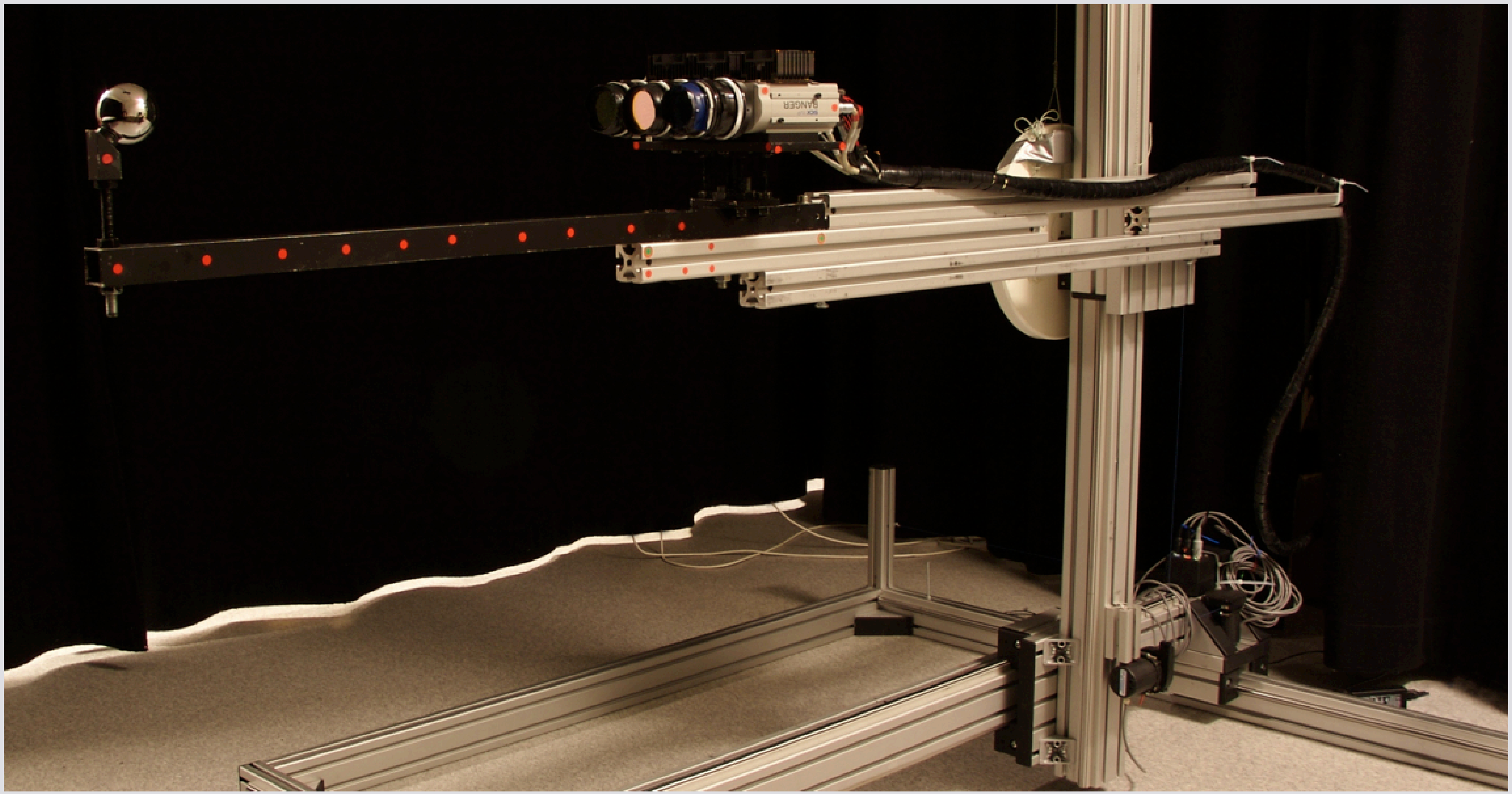
Reference Photograph

Spatially Varying Illumination



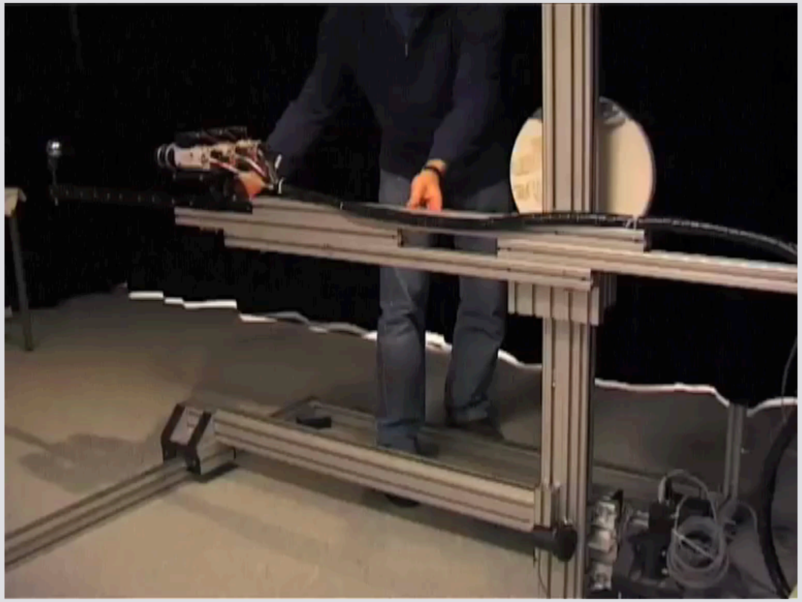
Rendering with a single light probe

Capture System



Capture System

- 25 HDR frames per second with a dynamic range of up to 1:10,000,000, resolution 892x512 [UG07][UGY07]
- Hardware platform, SICK IVP Ranger-C55
- Translation stage 1.5 m^3
- Position tracking sub-millimeter accuracy
- Hand-driven manual capture

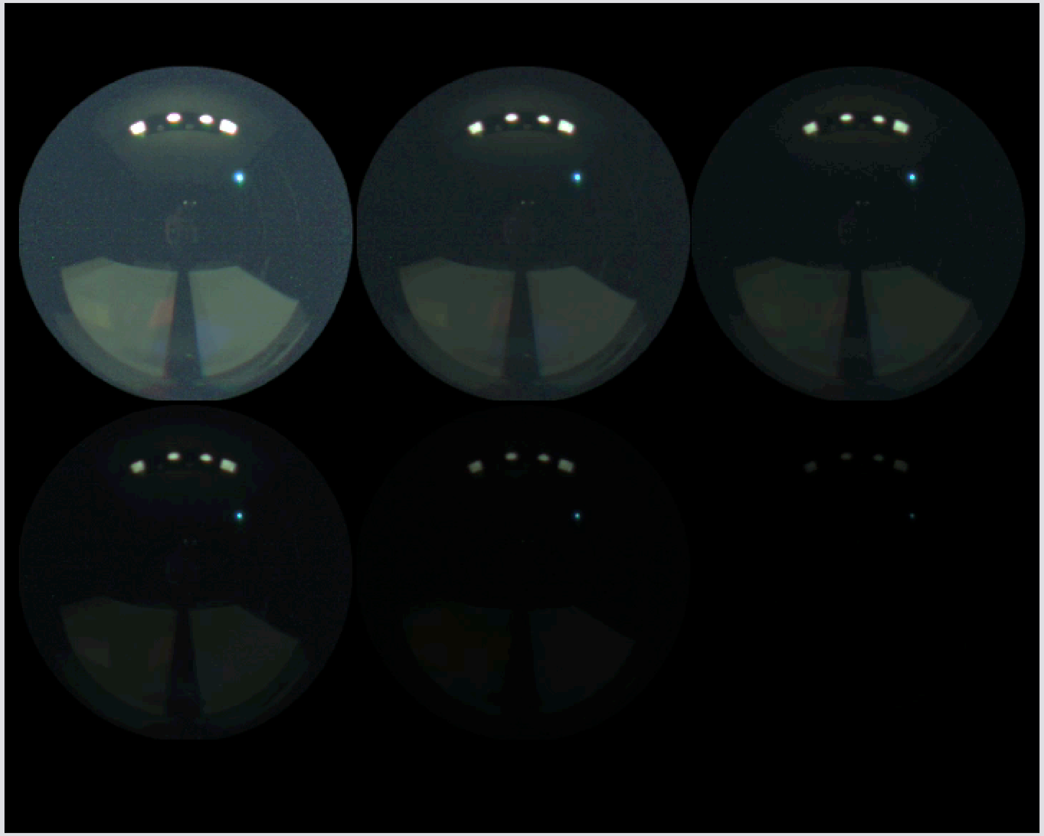


ILF Capture

- Assume that the scene is stationary during capture and that there are no occluding objects within the sampling volume
- Sampling of the plenoptic function as: $P(x, y, z, \phi, \theta)$

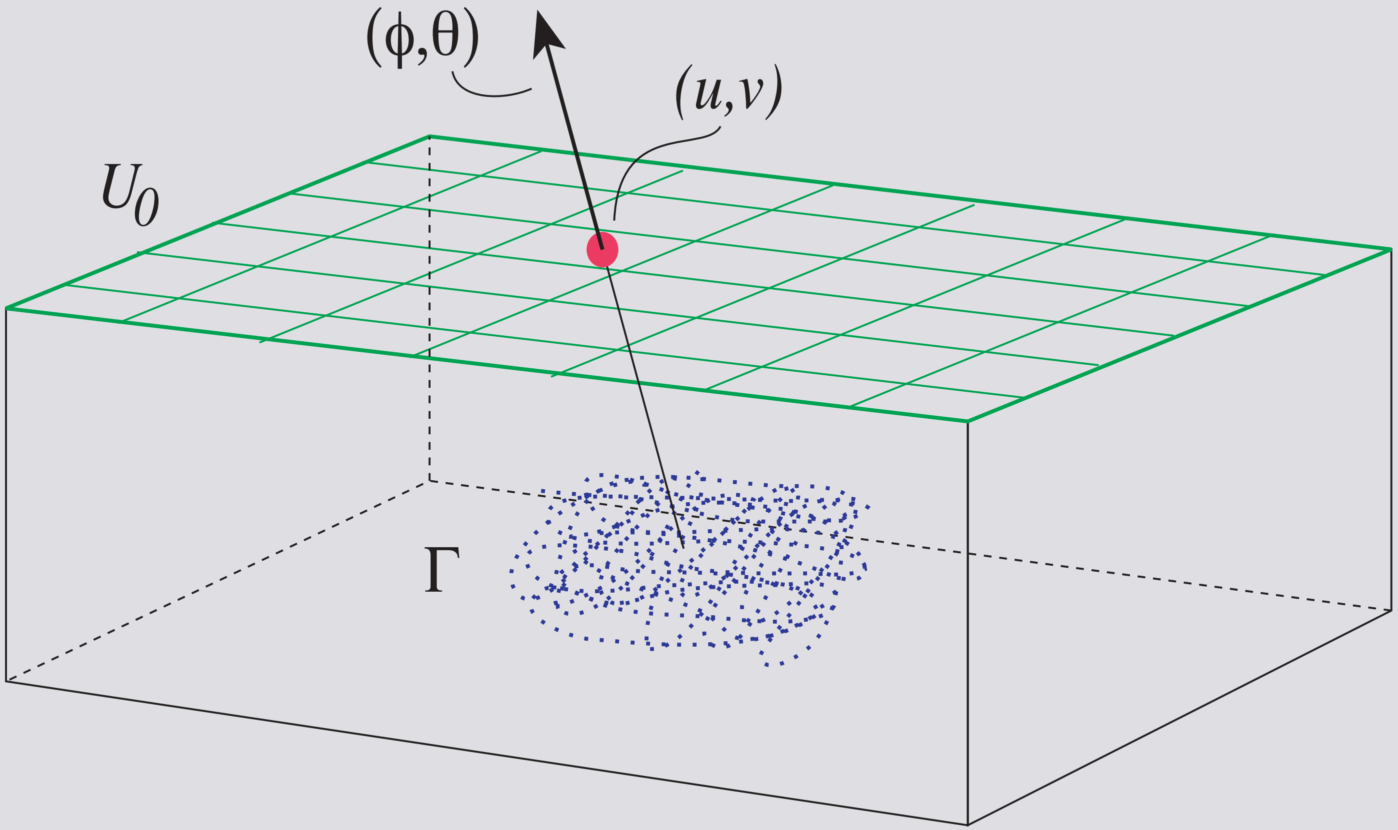
$$B(\mathbf{x}, \vec{\omega}_o) = \int_{\forall \vec{\omega}_i} L(\mathbf{x}, \vec{\omega}_i) T(\mathbf{x}, \vec{\omega}_i \rightarrow \vec{\omega}_o)(\mathbf{n} \cdot \vec{\omega}_i) d\vec{\omega}_i$$

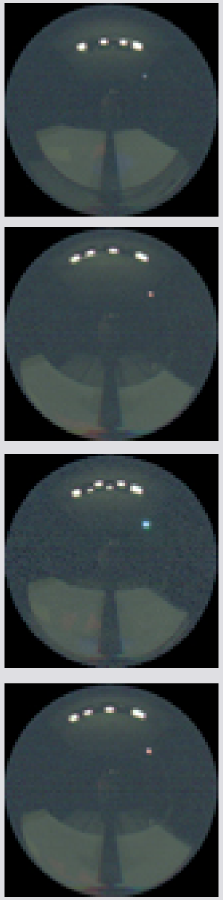
ILF Capture



- 26.000 irregularly spaced HDR light probes captured in the test scene ~80GB floating point image data

ILF Representation





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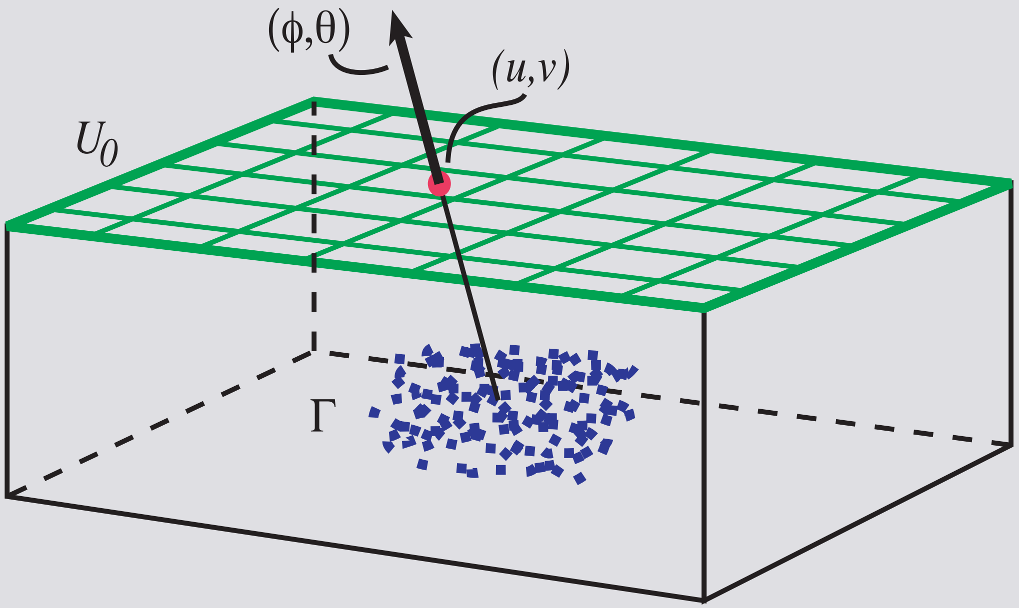
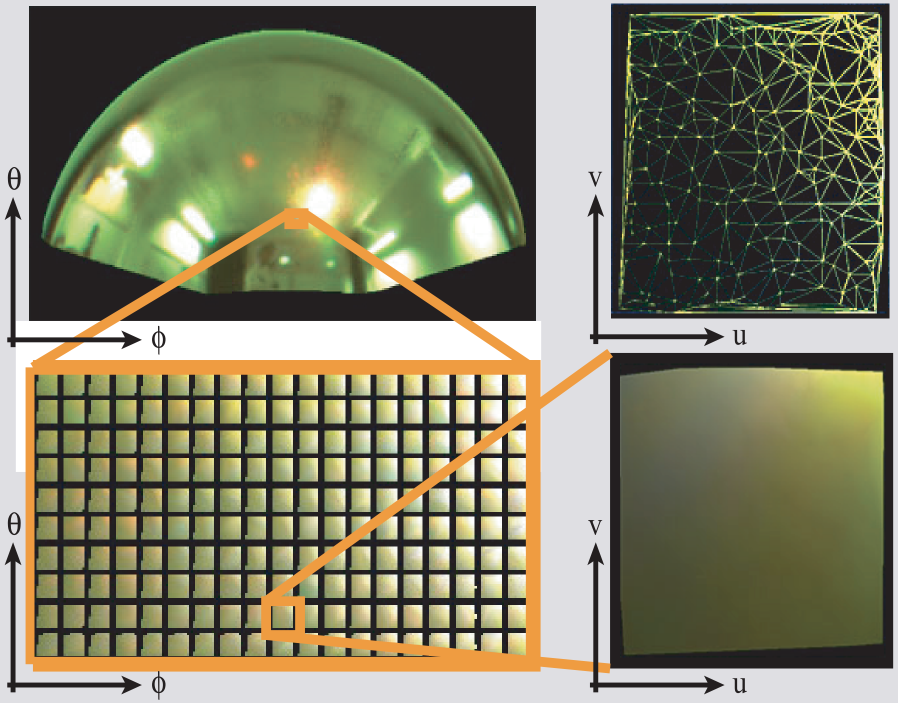
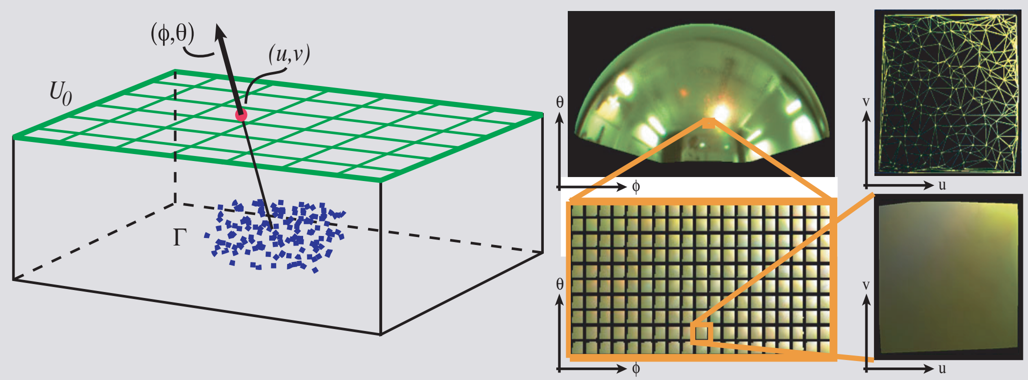
ILF Representation





ILF Representation

- The light rays are stored in angular buckets located at a set of 2D ILF surfaces enclosing the scene, in this case planes
- Each bucket contains a projection of the irregular sample points along the corresponding direction (ϕ, θ)
- The illumination incident at a certain point from a certain direction is found by linear interpolation in the 4D ray structure $L(u, v, \phi, \theta)$
- Stored in Delaunay triangle mesh
- No regularization



Adaptive Decimation

- Local regions with slowly varying illumination
- Remove redundant vertices in the triangle mesh
- Standard triangle decimation [Sch97]
- A vertex is considered redundant if the error in energy introduced is less than a threshold

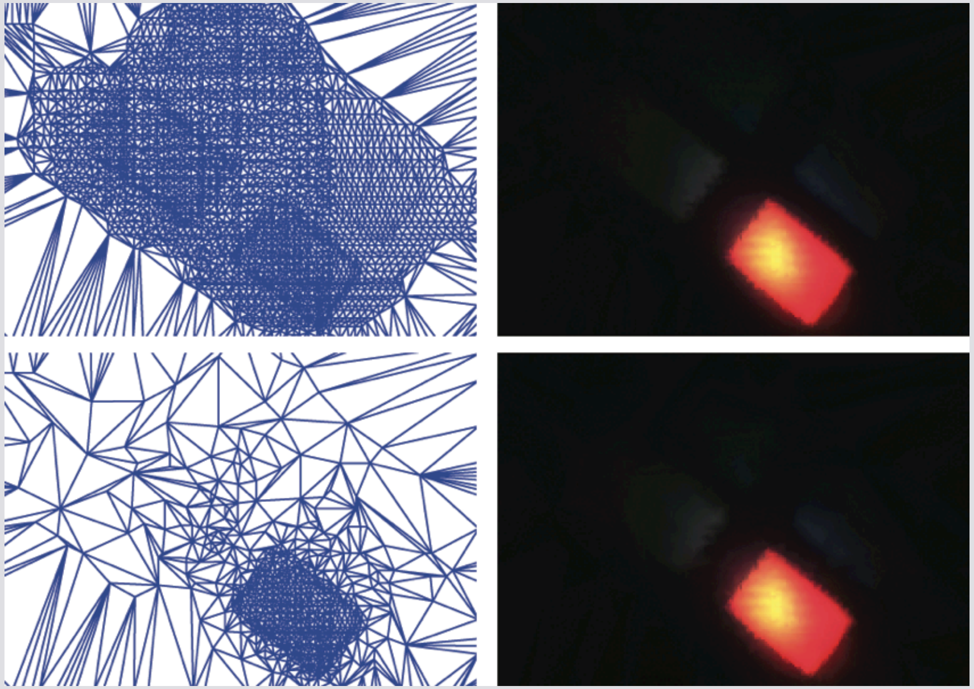
$$E_{Li} = \sum_n \int_{\triangle_n} L(u, v, \vec{\omega}_j) du dv - \sum_m \int_{\triangle_m} L(u, v, \vec{\omega}_j) du dv$$

$$|E_{Li}| < T$$

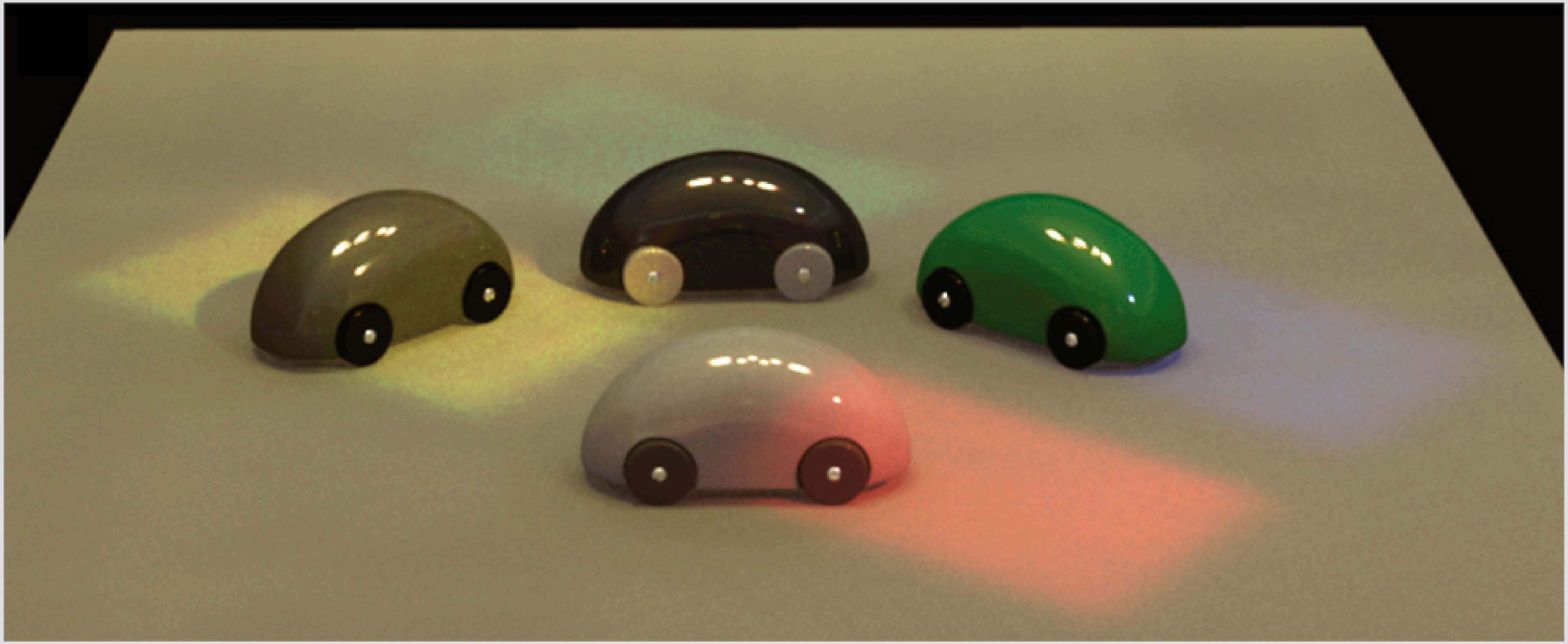
VITA

ILF Decimation

- ~250M rays in the top plane
- *T* was set to 0.1% of the average radiant energy per square mm
- ~8M rays after decimation
- Data reduction 97%
- RMS 0.3%
- Total relative error 0.1%

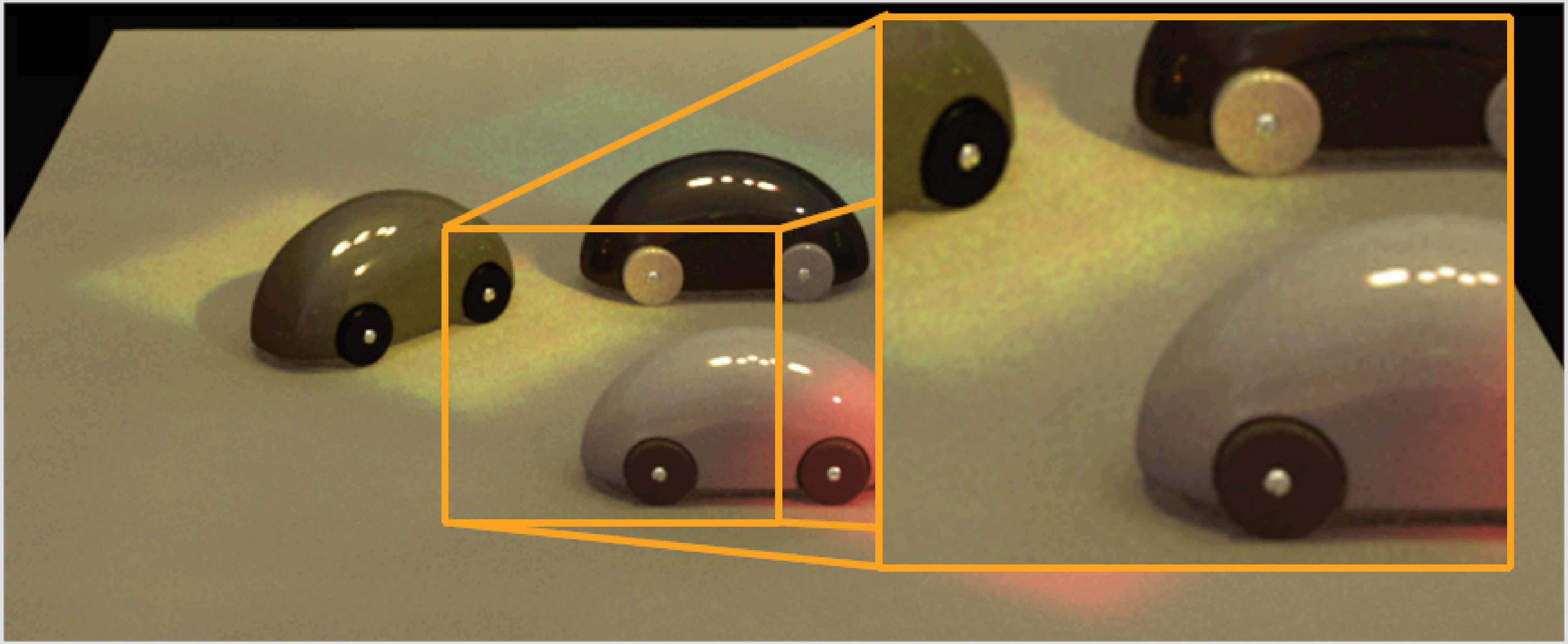


ILF Rendering



Brute force rendering: 5 hours

ILF Rendering



Brute force rendering: 5 hours

Illuminant Extraction

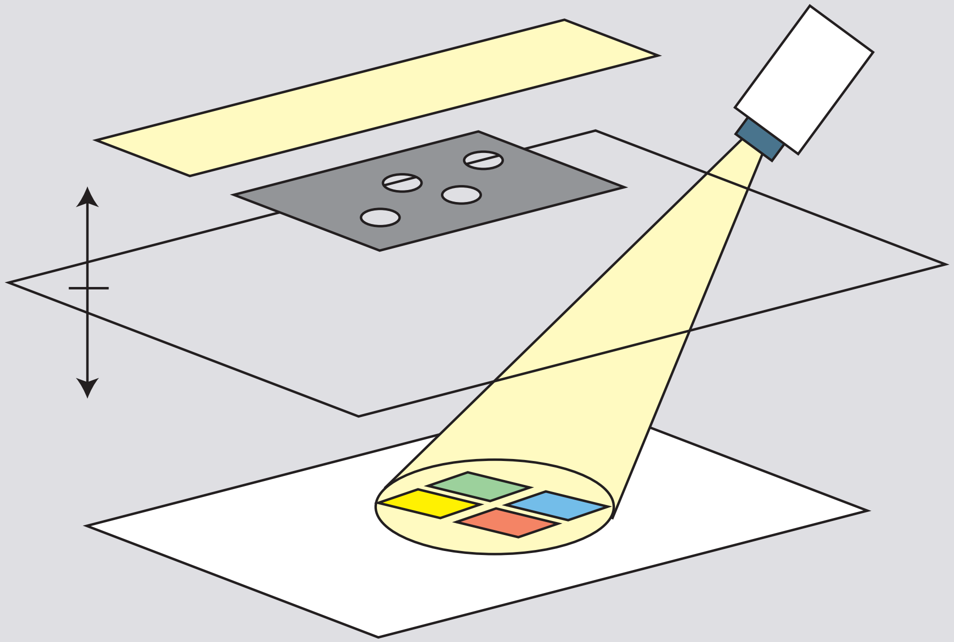
- Long rendering time and noisy renderings
- Noise is introduced by the stochastic sampling
- Pre-tabulated importance sampling difficult due to the large size and generality of the ILF data
- Illuminant extraction: a scene-based approach

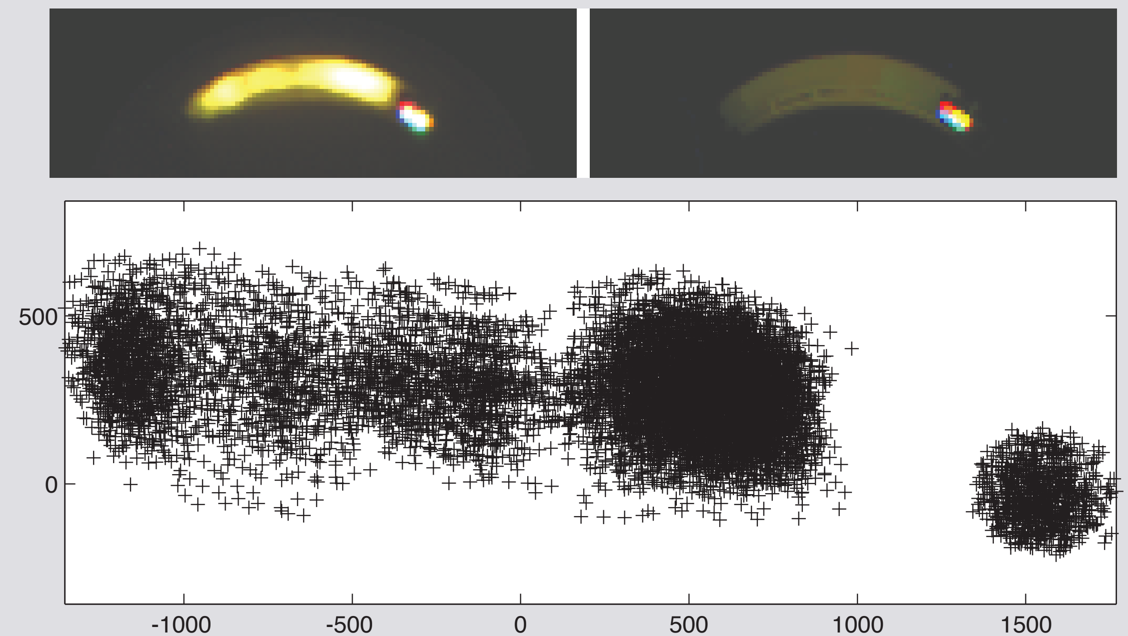
Illuminant Extraction

- Represent the illumination as a residual ILF with low frequency and low contrast content and a set of concentrated high intensity Source Light Fields (SLFs) re-projected to their approximate original position in the scene

$$L(\mathbf{u}, \vec{\omega}) = L_0(\mathbf{u}_{k_0}, \vec{\omega}_{k_0}) + \sum_{n=1}^{N} L_n(\mathbf{u}_{k_n}, \vec{\omega}_{k_n})$$

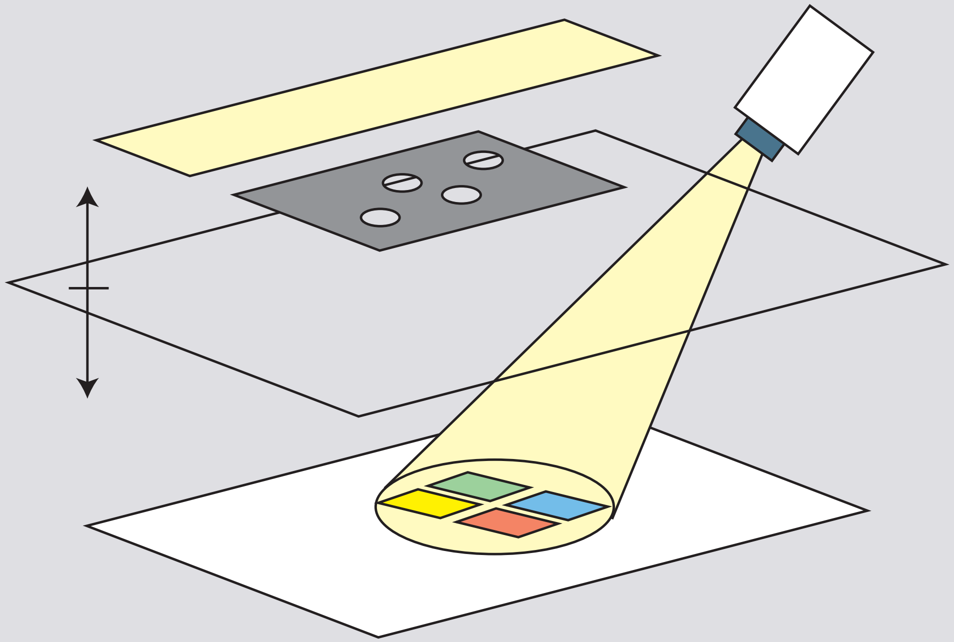
Illuminant Extraction

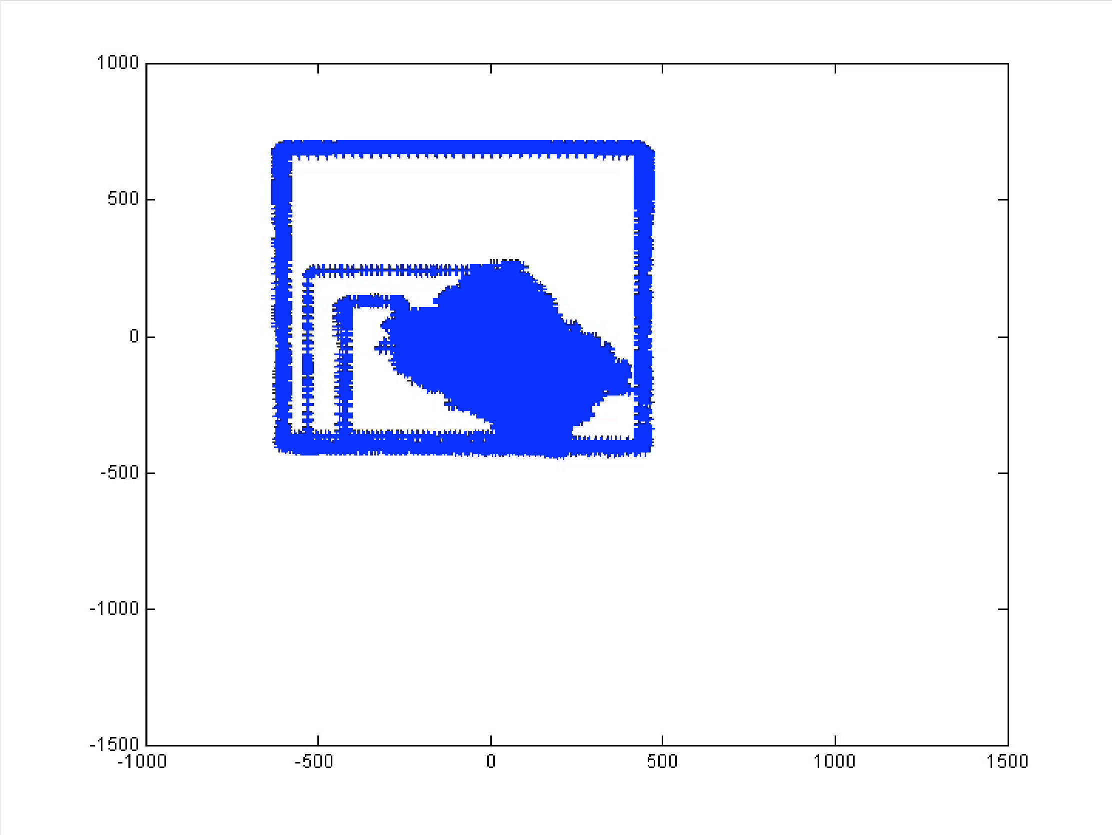




- High energy rays can be selected from the ILF data set based on angular selections, spatial selections and thresholding

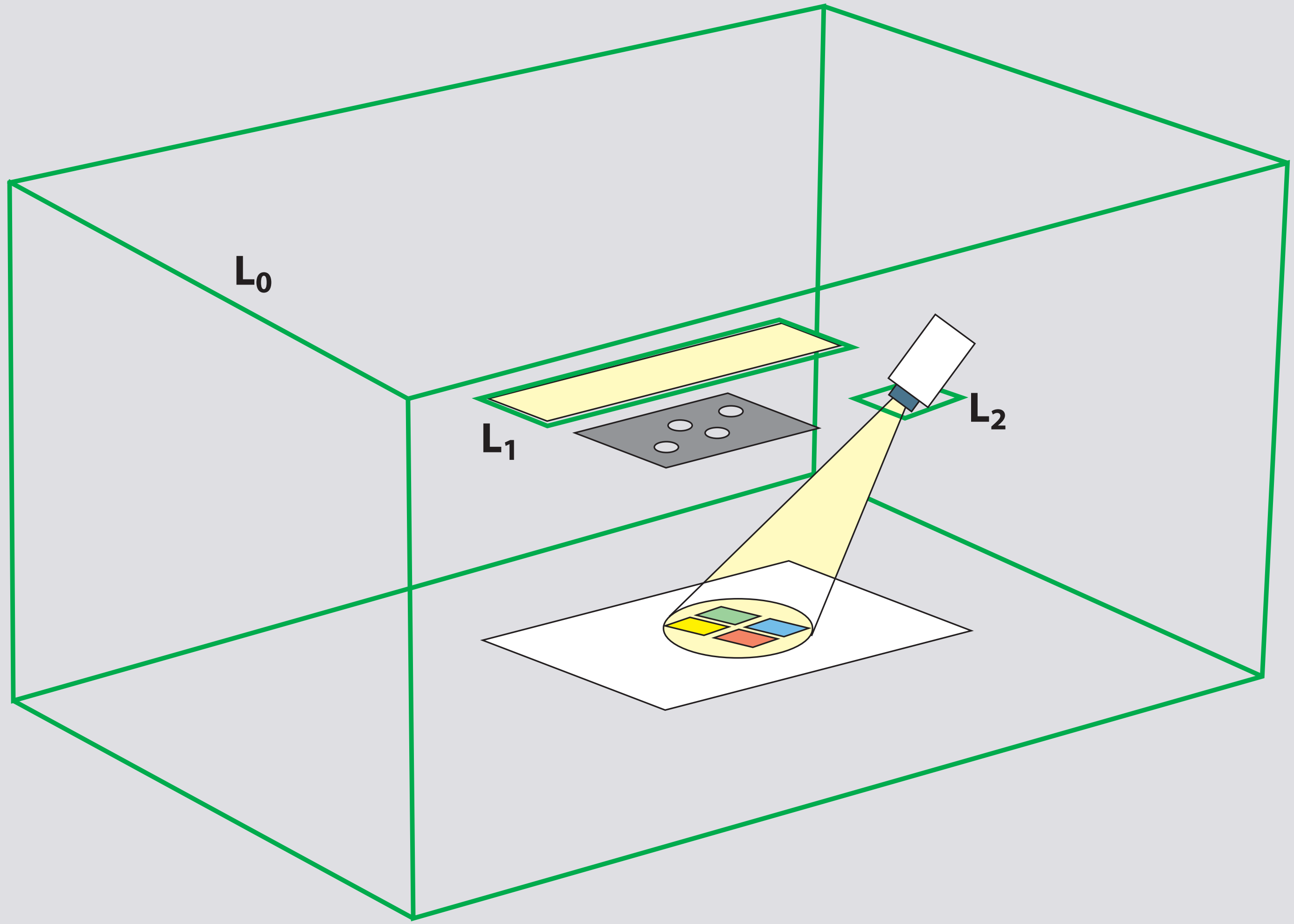
Illuminant Extraction



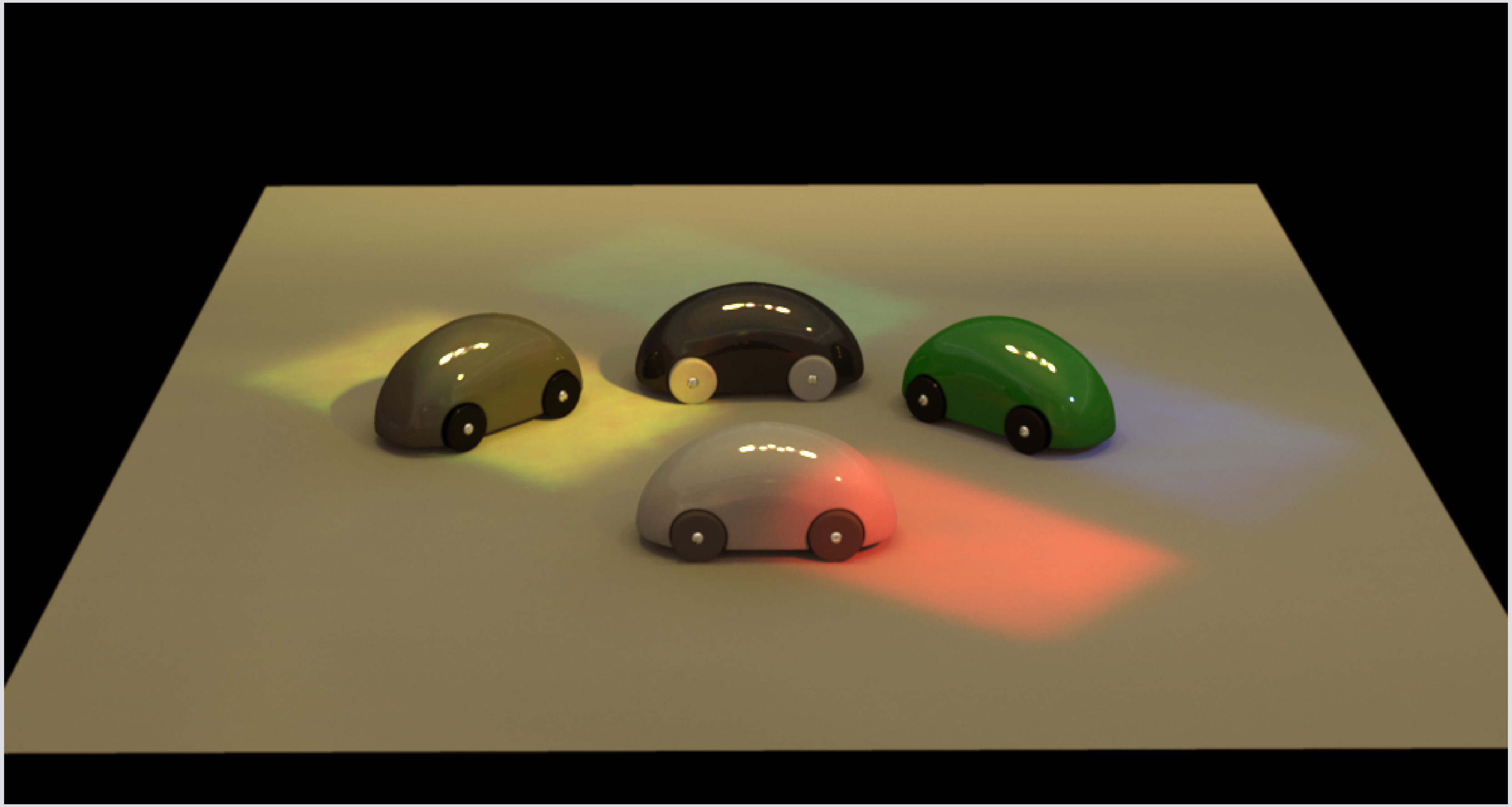


$$z_n = \arg\min_z \left(A(\tilde{\mathbf{u}}_{k_n}(z))\right)$$

Illuminant Extraction

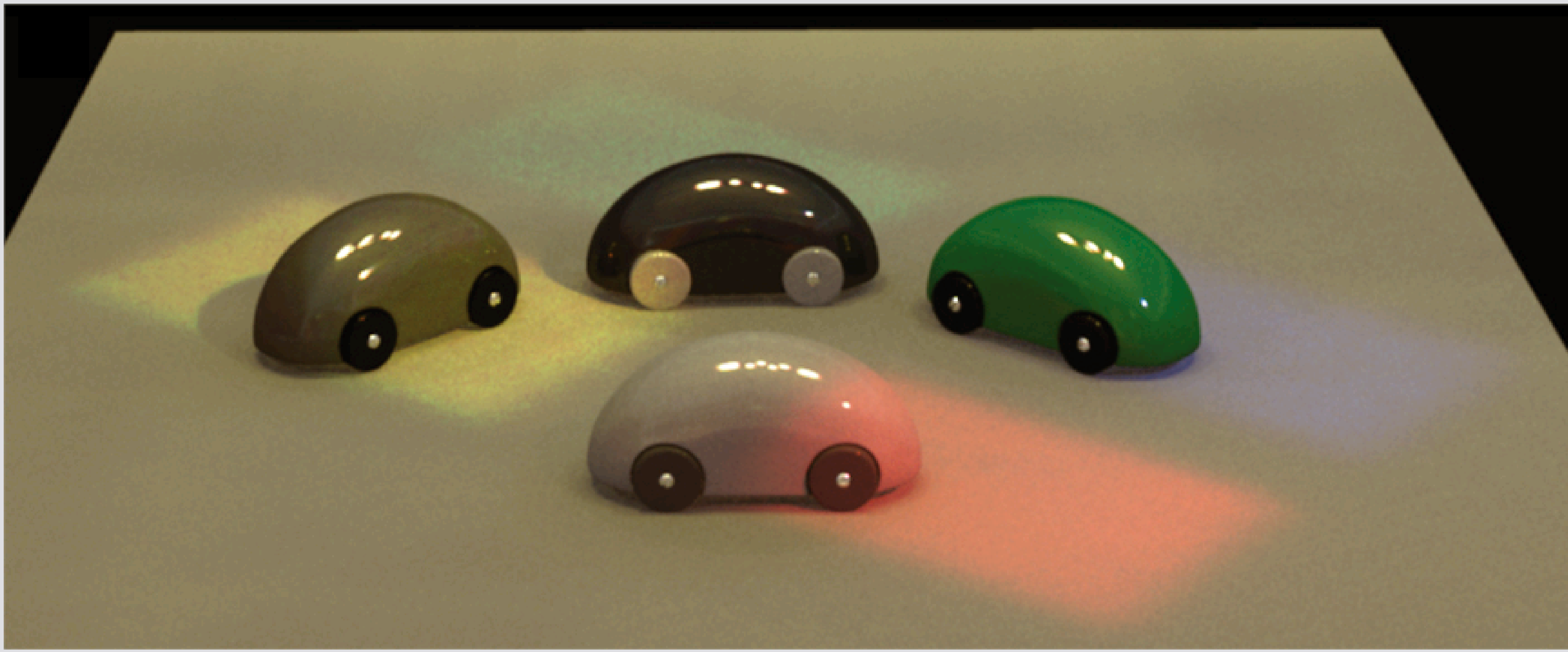


ILF Rendering



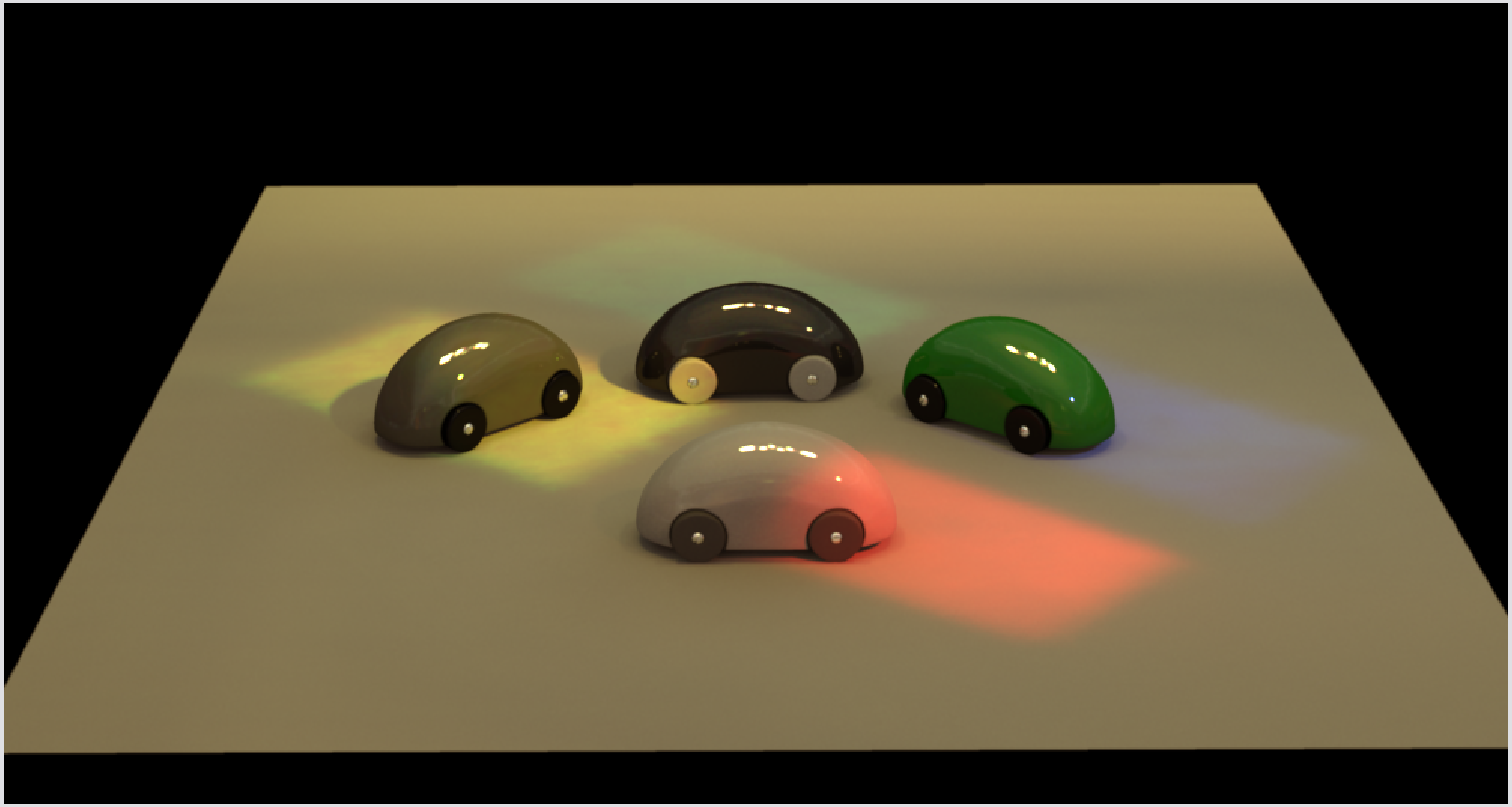
Rendering with extracted light sources: 2 minutes

ILF Rendering



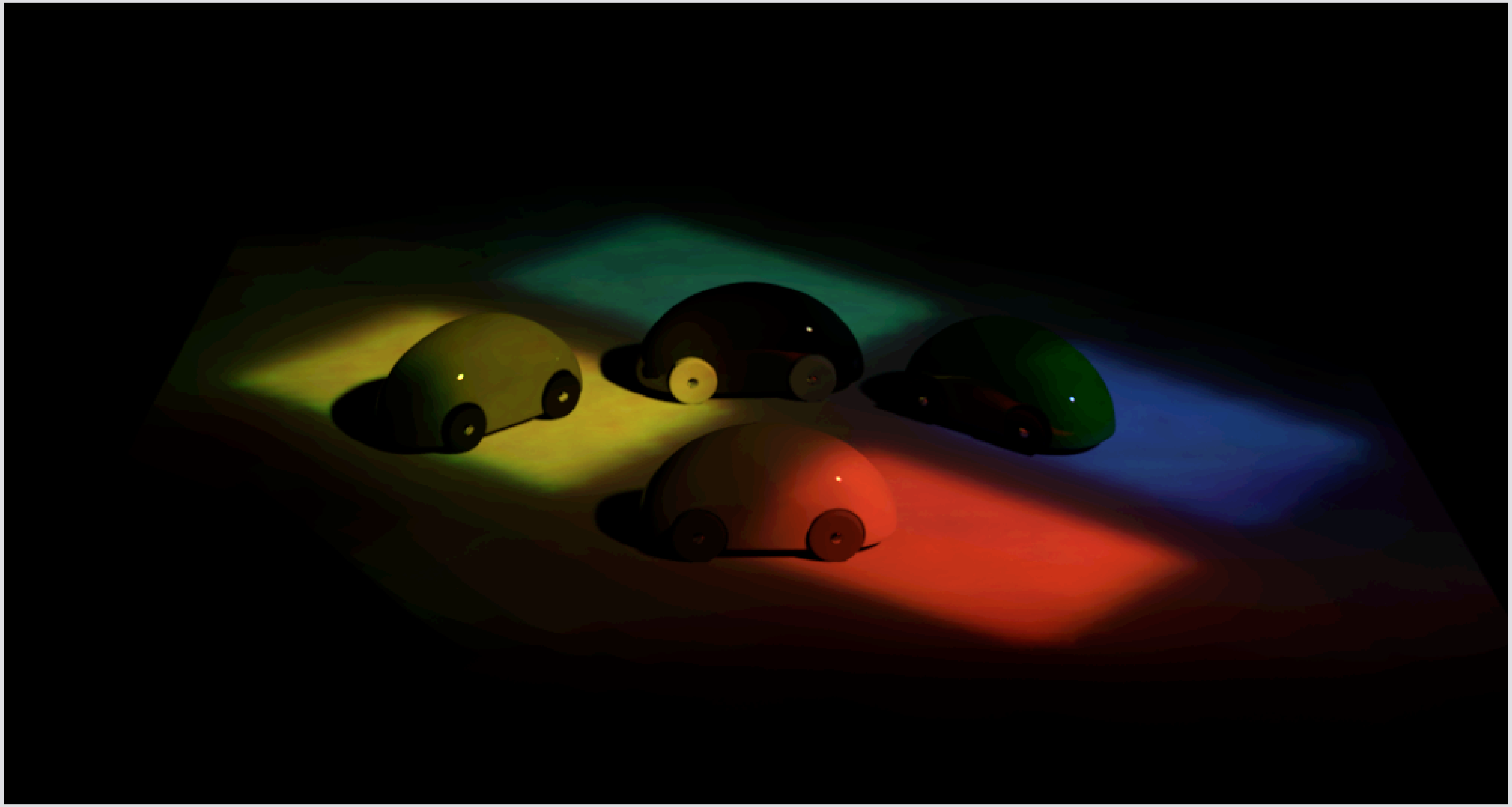
Brute force rendering: 5 hours

ILF Rendering



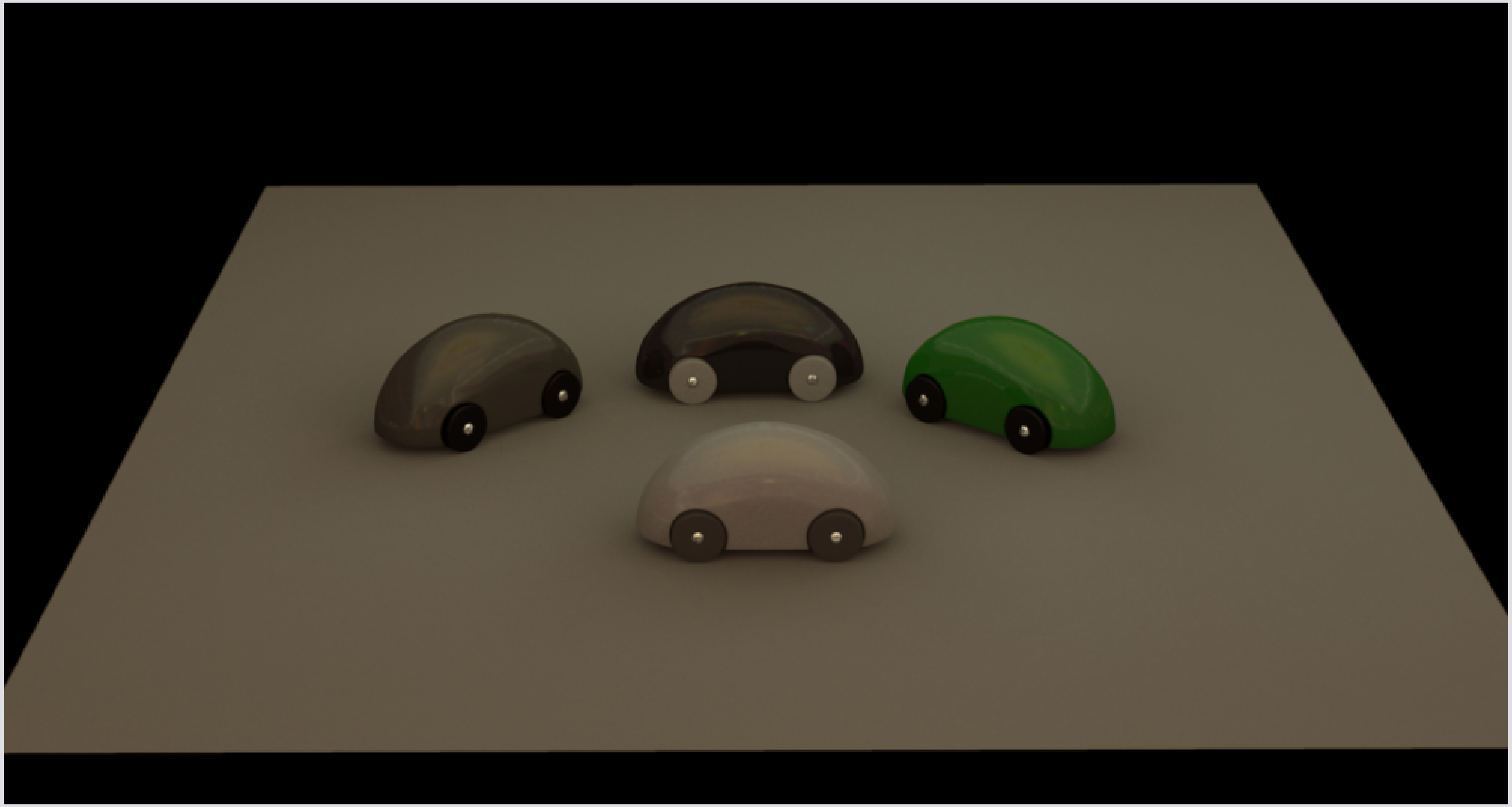
Rendering with extracted light sources: 2 minutes

ILF Rendering



Extracted projector

ILF Rendering



Effect of residual ILF after illuminant extraction

ILF Rendering

Residual ILF and two extracted SLFs

ILF Rendering

Area light with blocker removed

SLF Editing

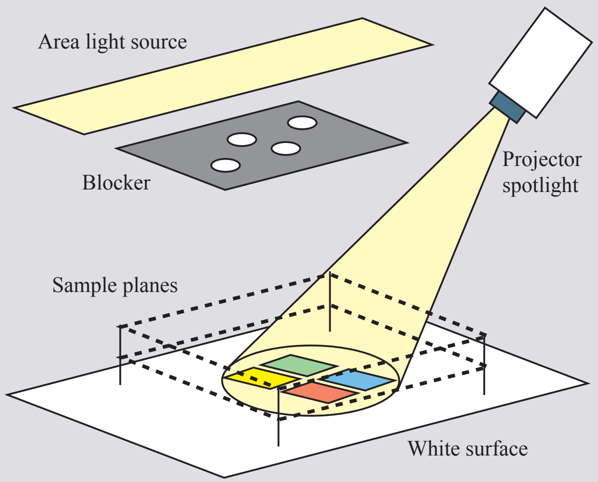
- SLFs can be edited like traditional light sources, translation, rotation, color etc.
- Individual rays can also be edited in the 4D SLF data sets

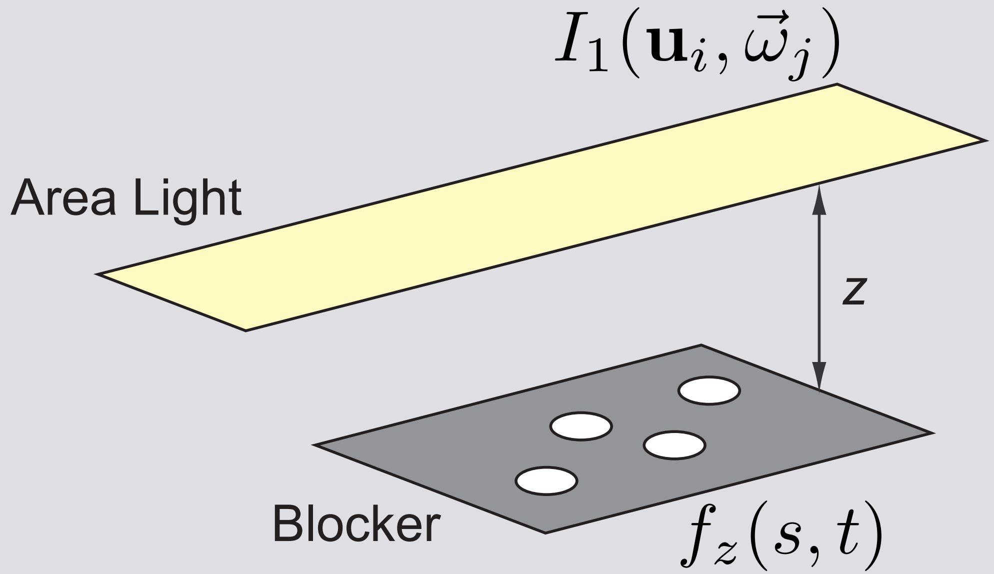
SLF Editing

- Edit collections of rays in the SLFs
- The selection of rays is similar to the extraction: angular and spatial selection and thresholding
- We model the extracted SLF as a collection of equal intensity rays and a 2D modulation function at a distance z from the SLF

$$L_n(\mathbf{u}_i, \vec{\omega}_j) = I_n(\mathbf{u}_i, \vec{\omega}_j) \times f_z(s, t)$$

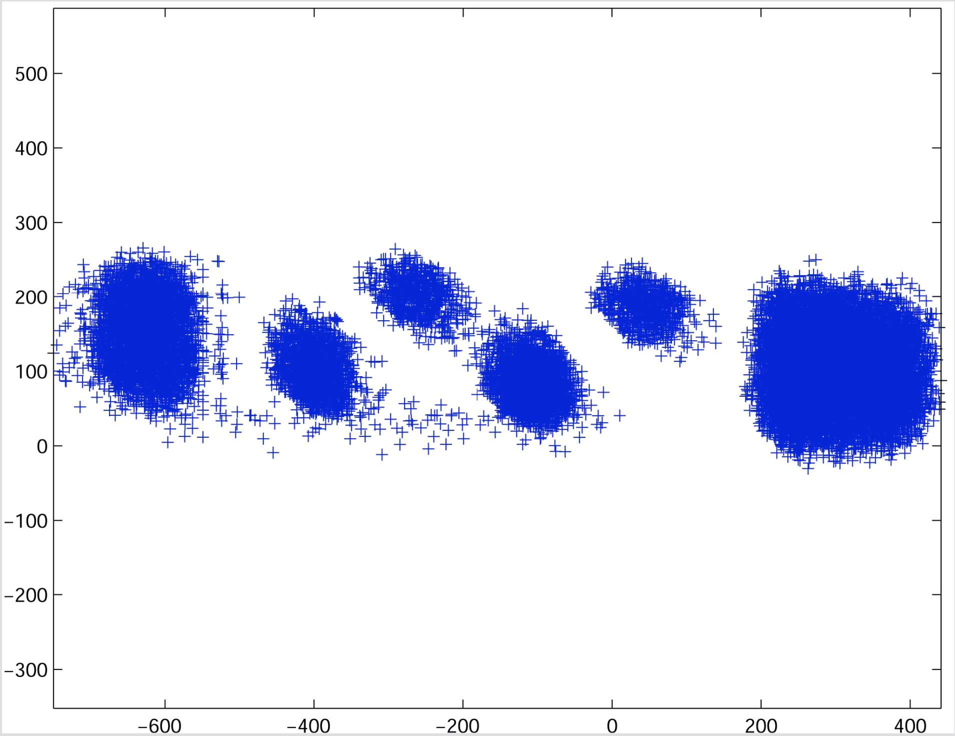
SLF Editing



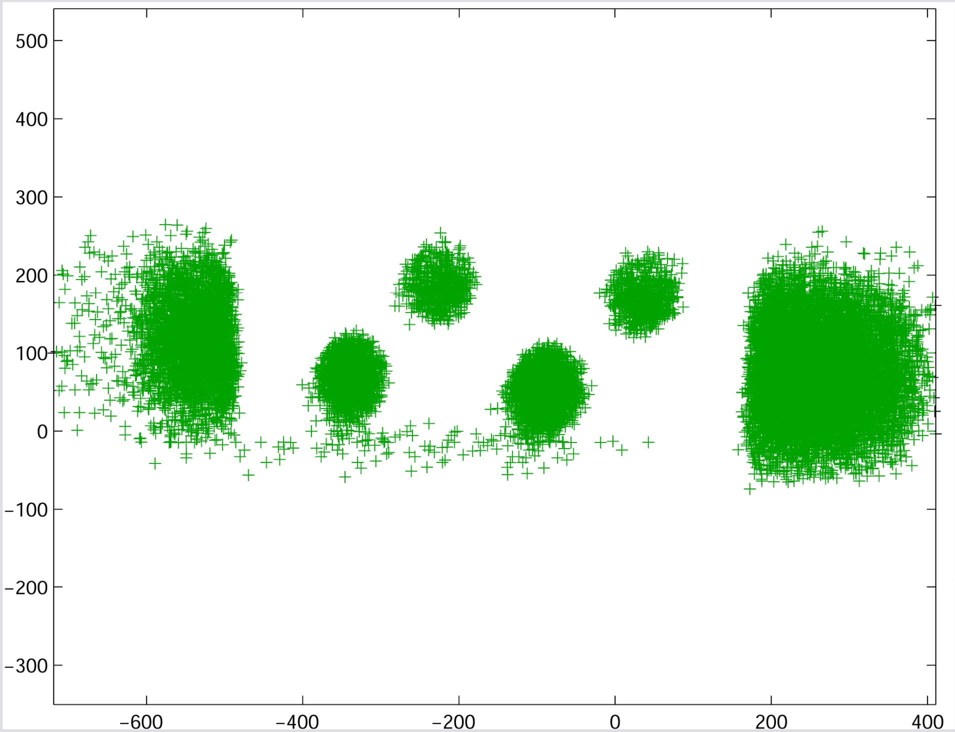


$$L_n(\mathbf{u}_i, \vec{\omega}_j) = I_n(\mathbf{u}_i, \vec{\omega}_j) \times f_z(s,t)$$

SLF Editing



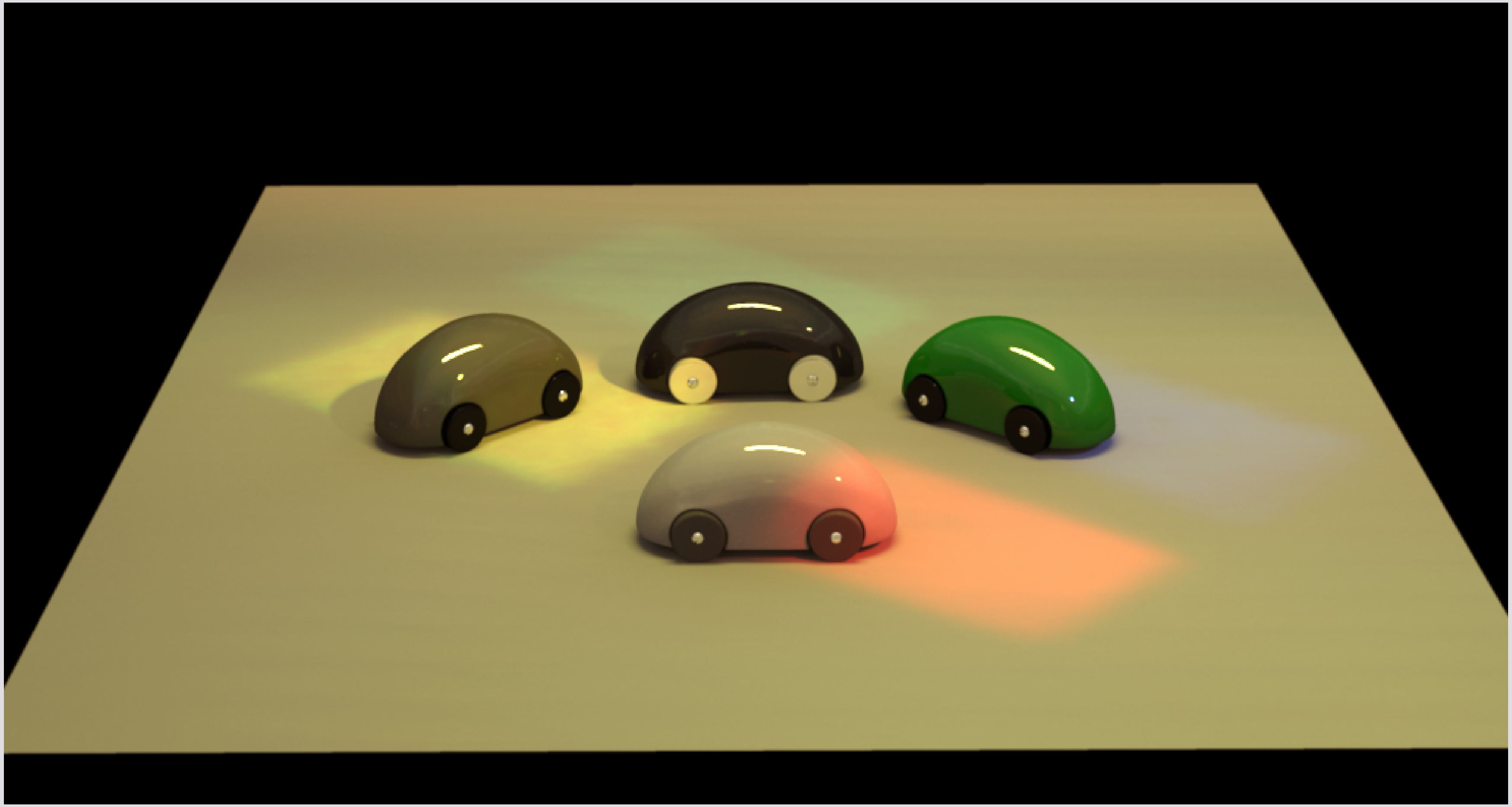
Area light source



Blocker

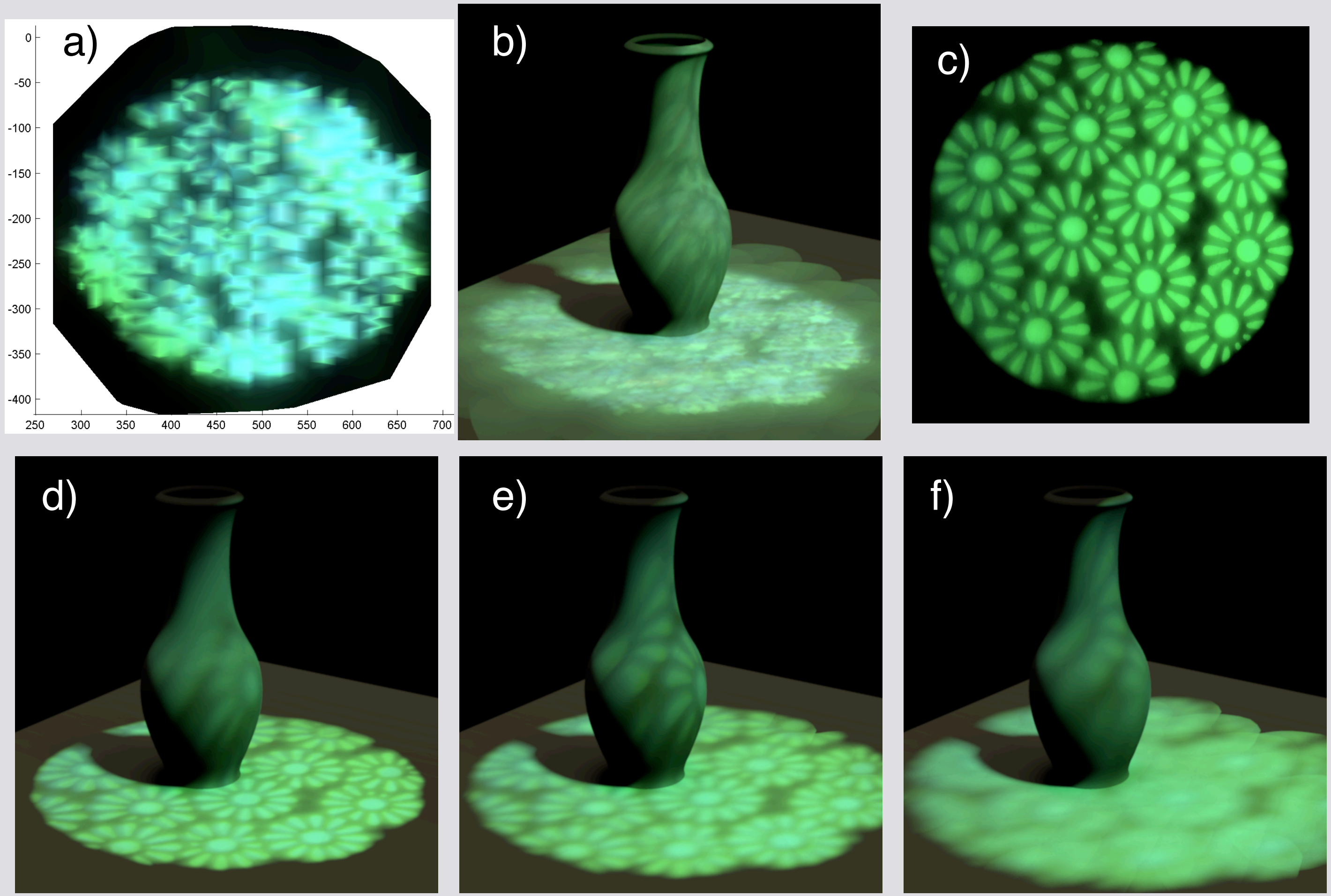
$$L_n(\mathbf{u}_i, \vec{\omega}_j) = I_n(\mathbf{u}_i, \vec{\omega}_j) \times f_z(s, t)$$

SLF Editing



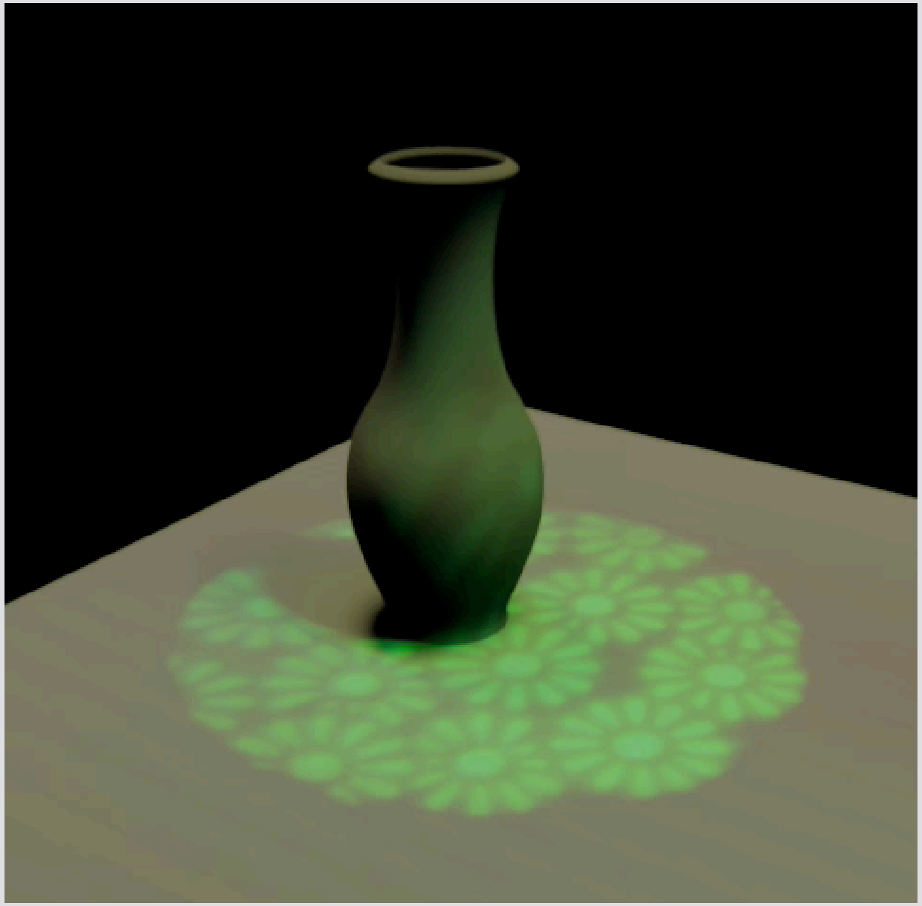
Synthetic removal of an occluding object

SLF Editing 2



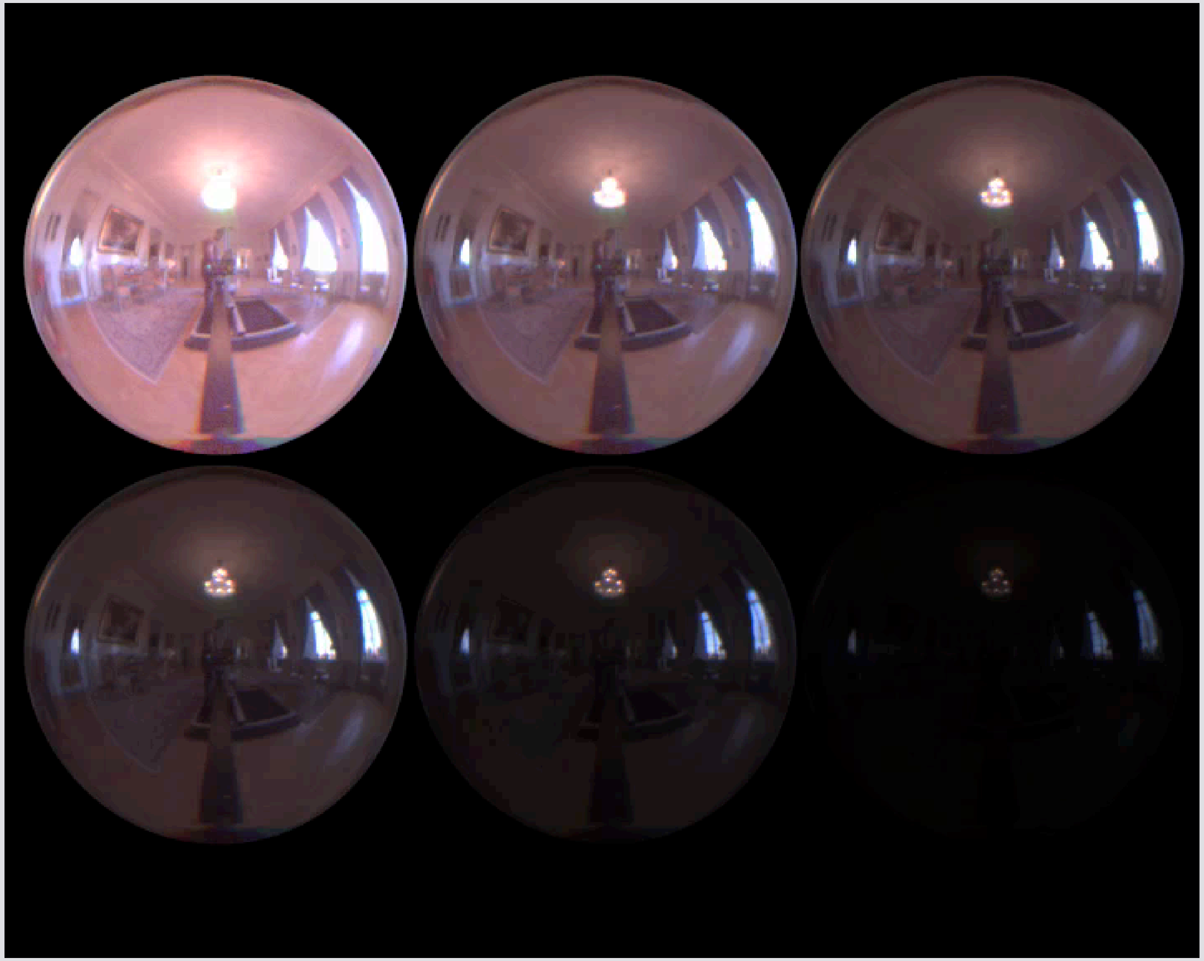
Editing of under-sampled flower pattern

SLF Editing 2

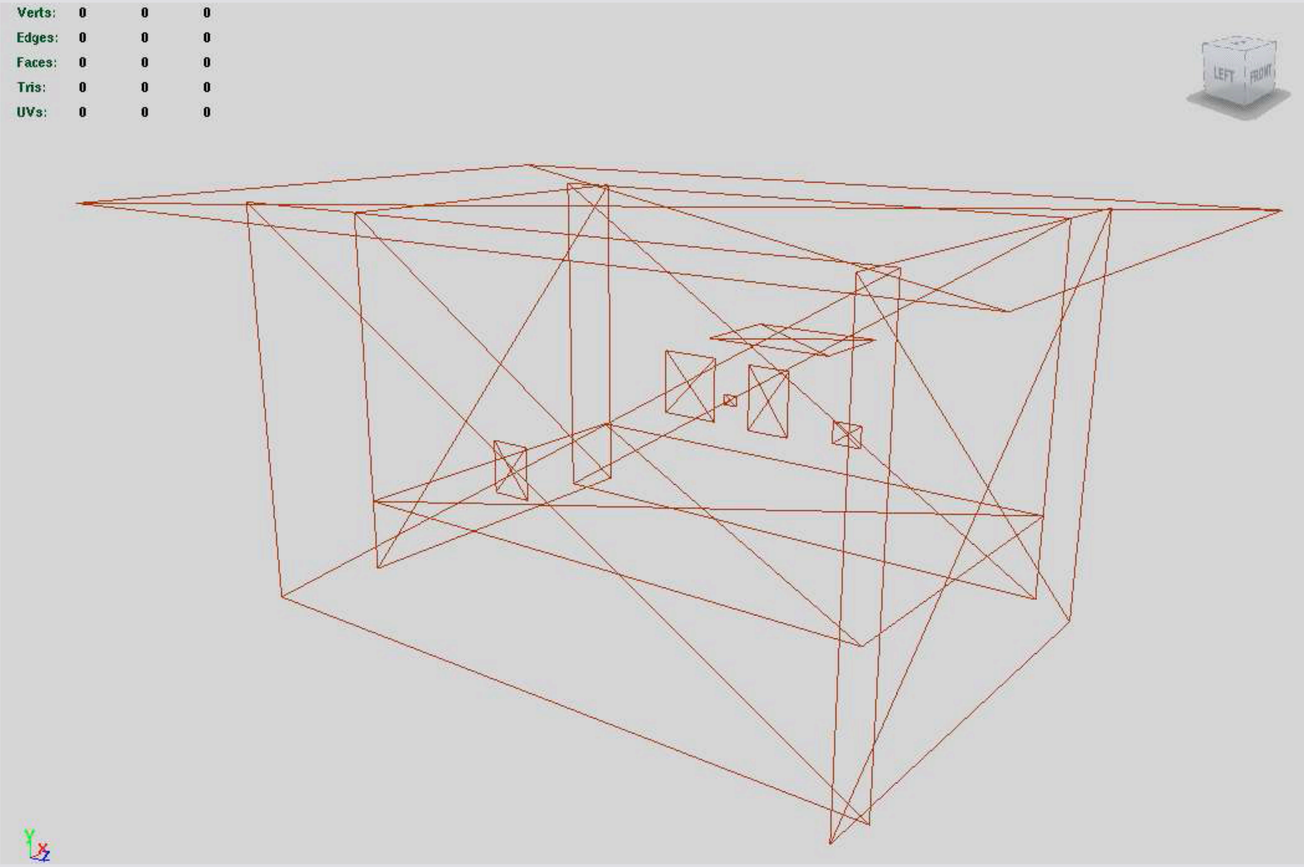


Editing of under-sampled flower pattern

Example Capture



SLF Extraction



ILF and SLF data loaded in Maya

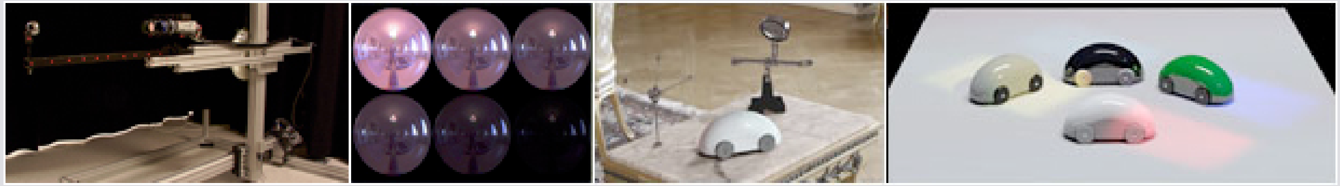
Rendering

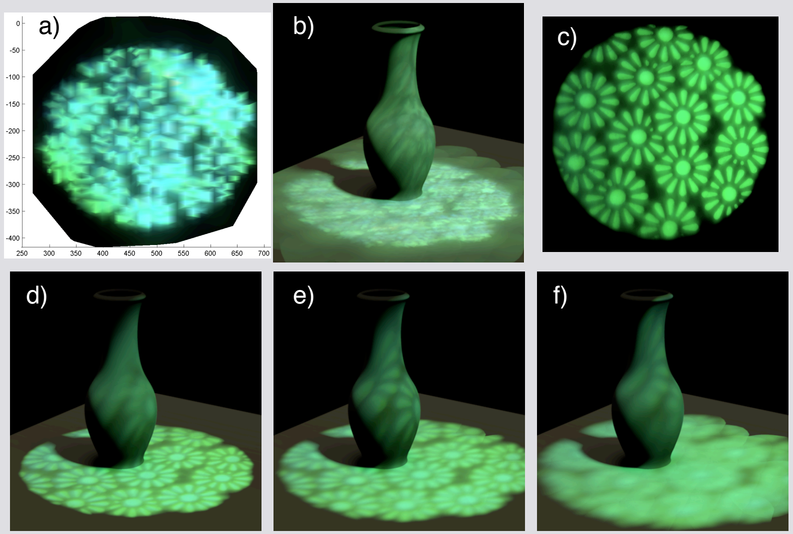
Some numbers

- ~44.000 HDR images
- 256x256 angular buckets
- ~2.25G rays in total
- ~90M rays after decimation (1.8GB)
- Data reduction 96%

- 82% of the total energy was extracted to six SLFs
- The SLFs contained 13M rays, (270MB)

VITA





a)
b)
c)
d)
e)
f)