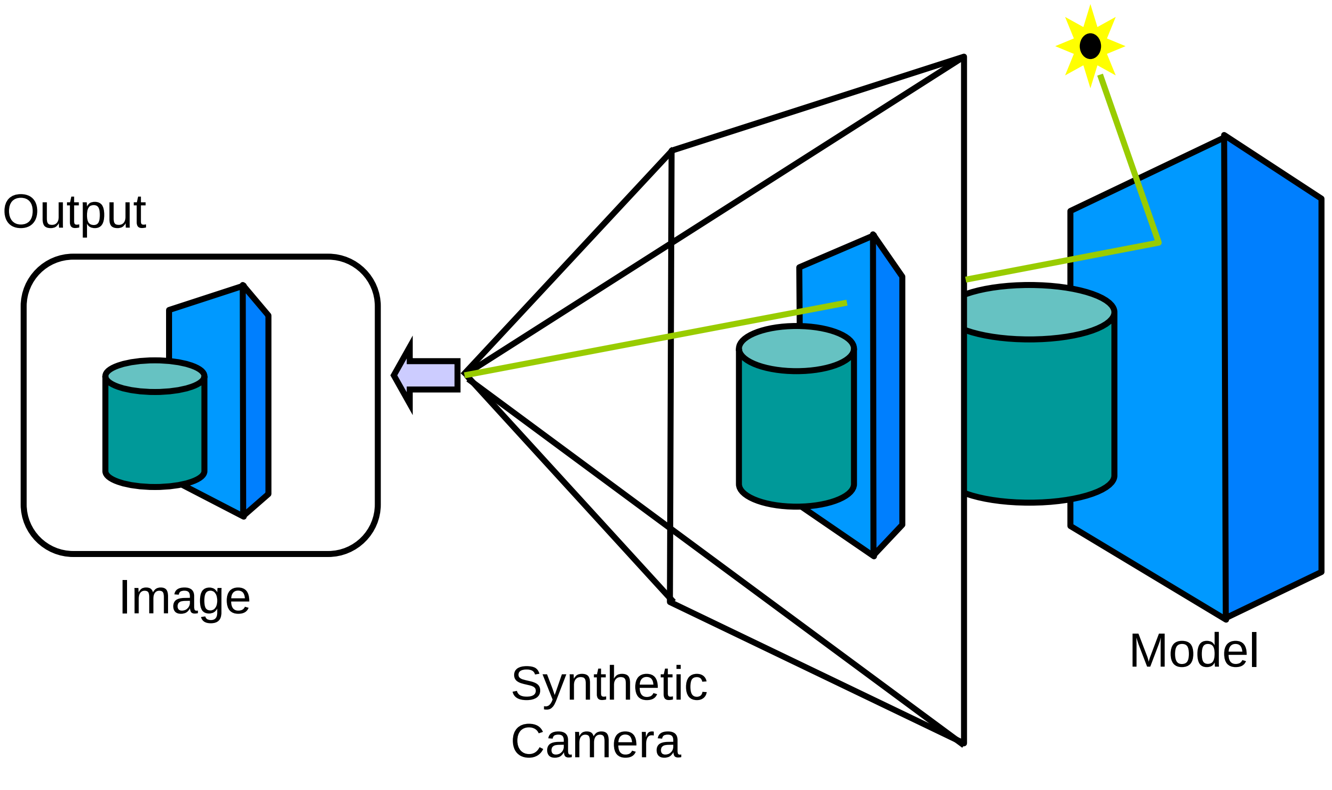
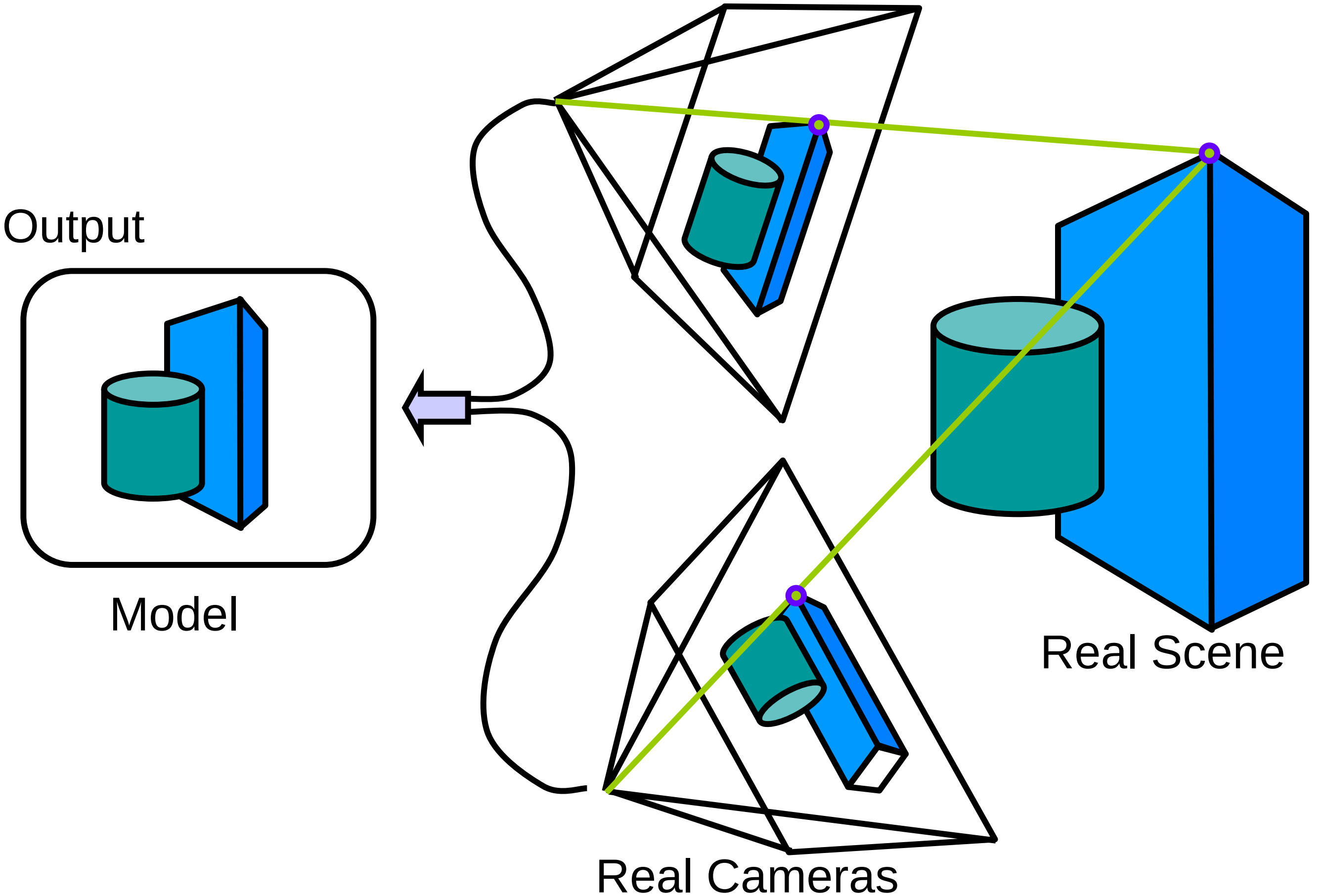
Image-Based Rendering and Lighting

MIT EECS 6.837 Computer Graphics
Wojciech Matusik
with many slides from Rick Szeliski, Steve Seitz, Paul Debevec

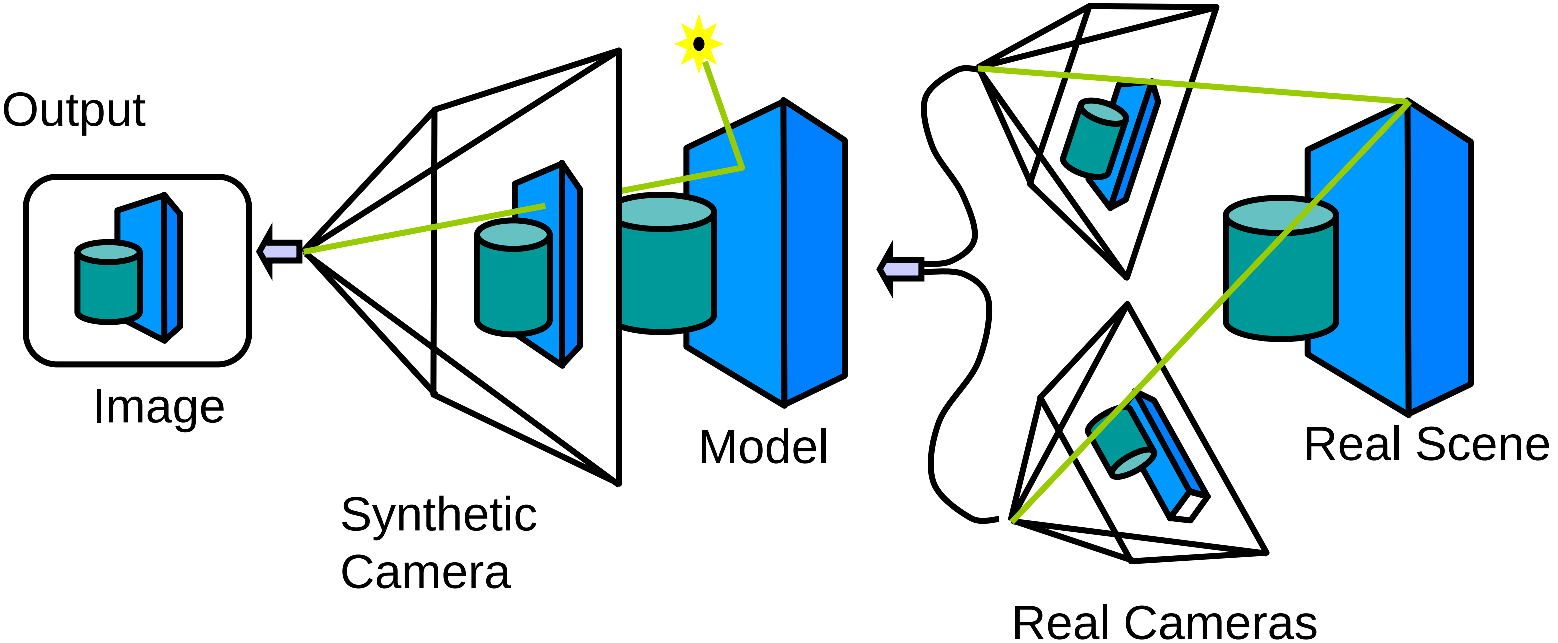
Traditional Computer Graphics



Computer Vision

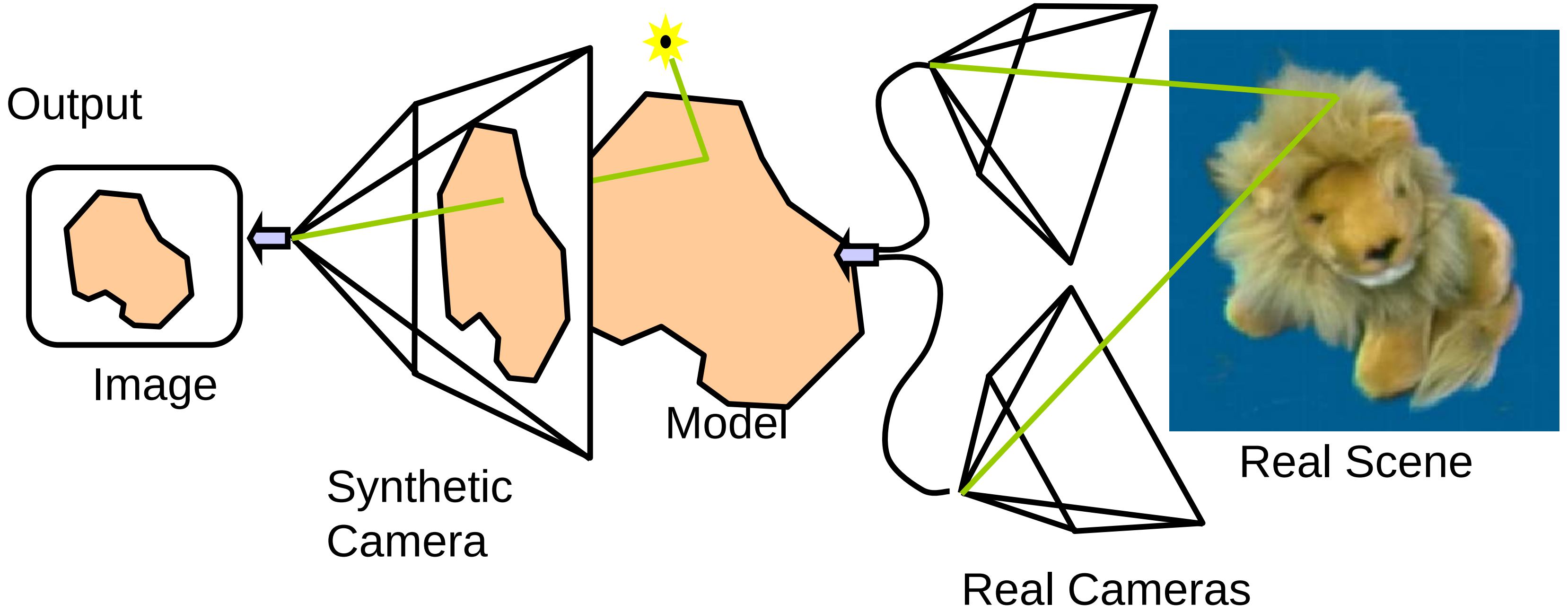


Combined



Output
Image
Synthetic
Camera
Model
Real Cameras
Real Scene

But, computer vision falls short



… and so does graphics.

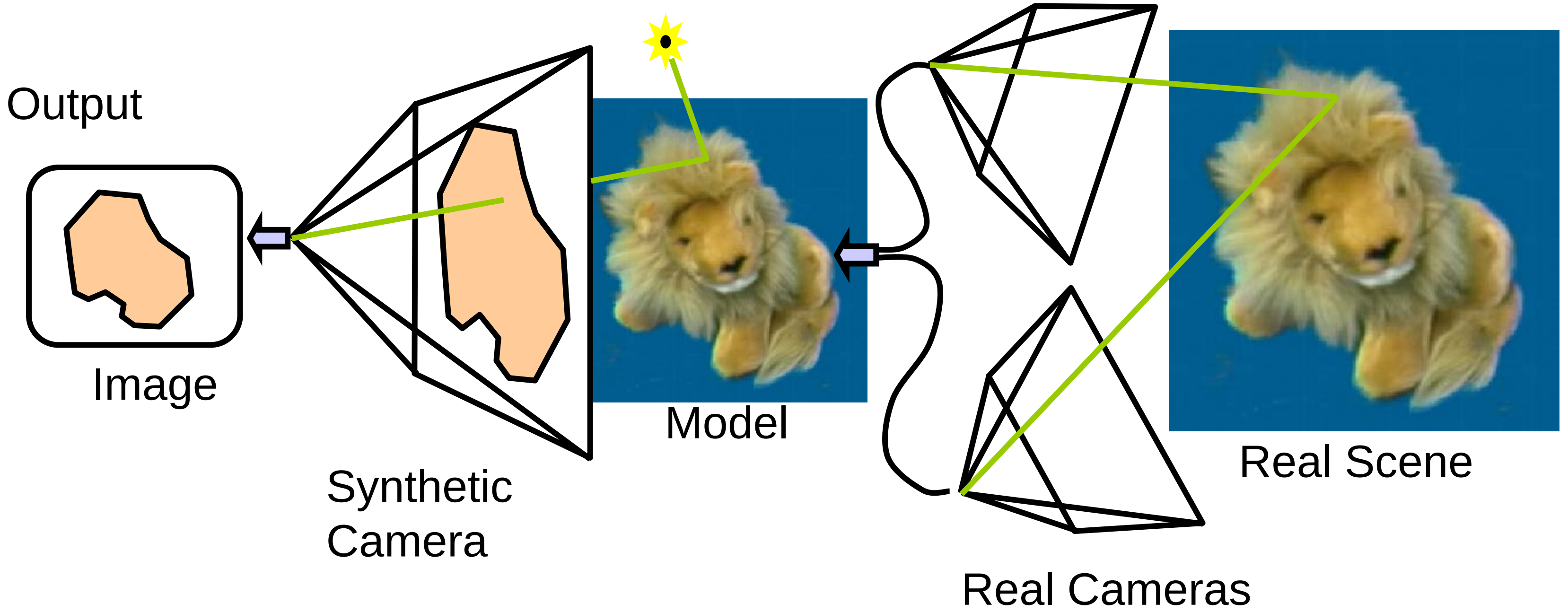
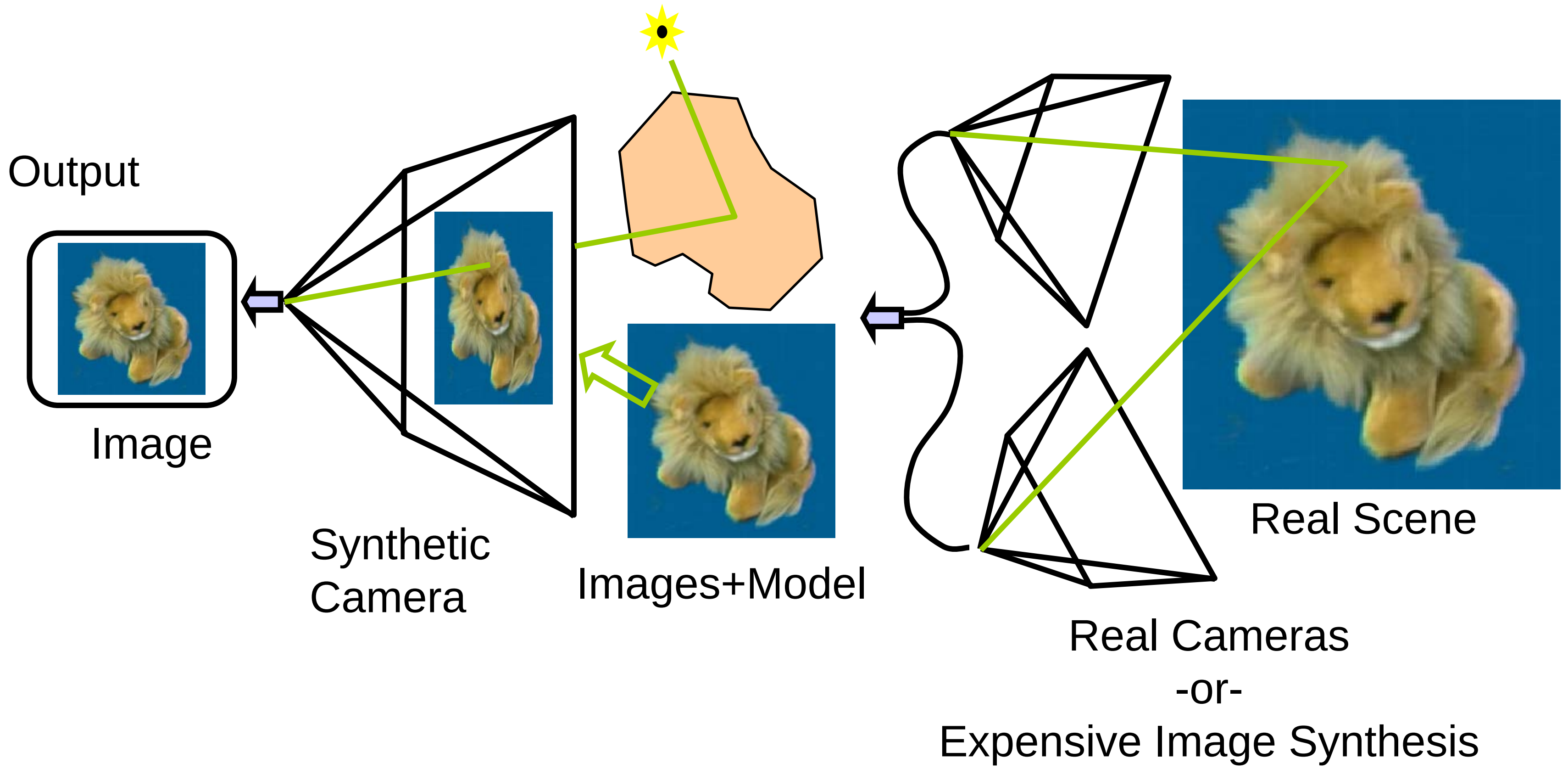
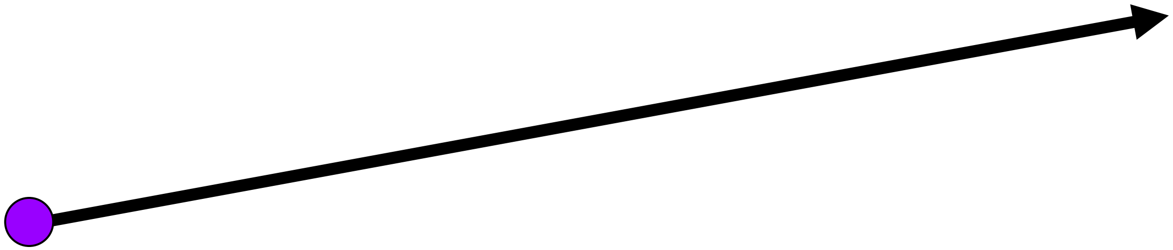


Image-Based Rendering



All Rays: The Plenoptic Function

- Ray carries a constant radiance
  - time is fixed



- 5D
  - 3D position
  - 2D direction

All Rays: Plenoptic Function

- Rendering reduces to a ray-database query
  - Fast
  - But a lot of data!

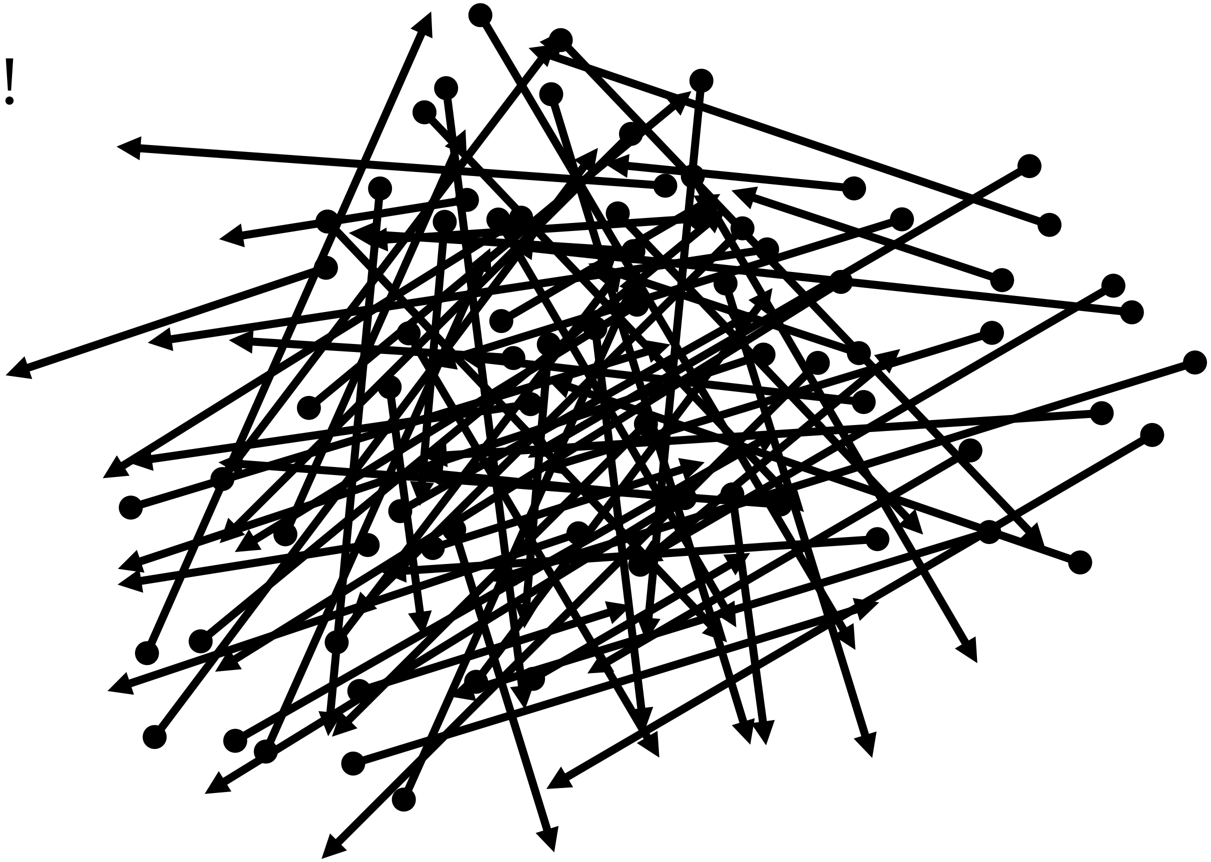
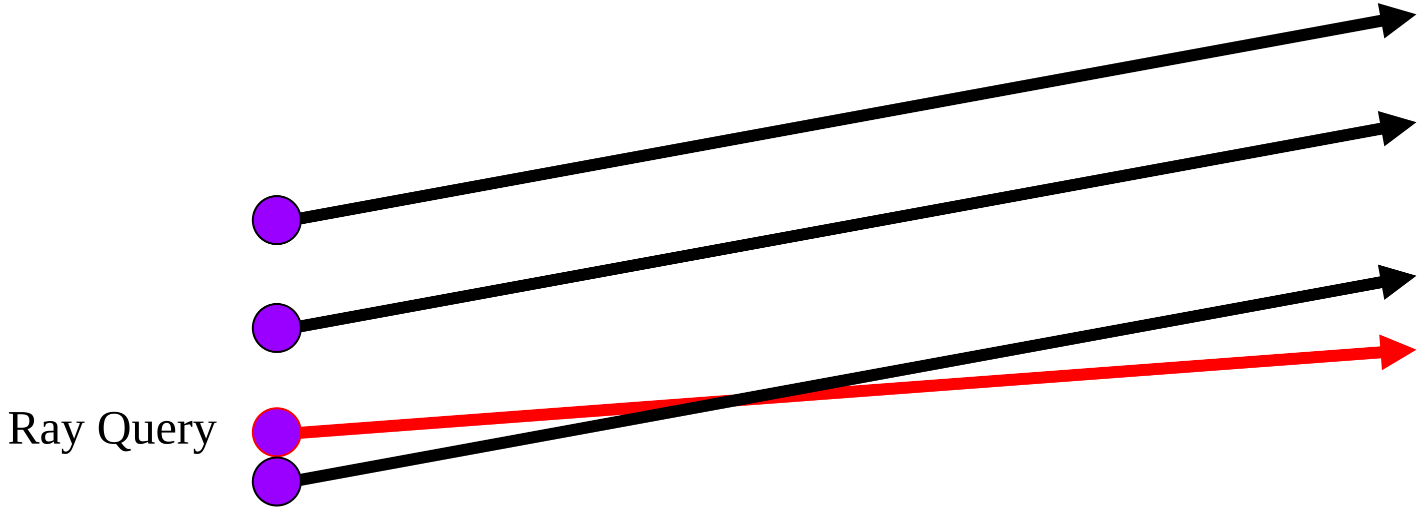


Image-Based Rendering

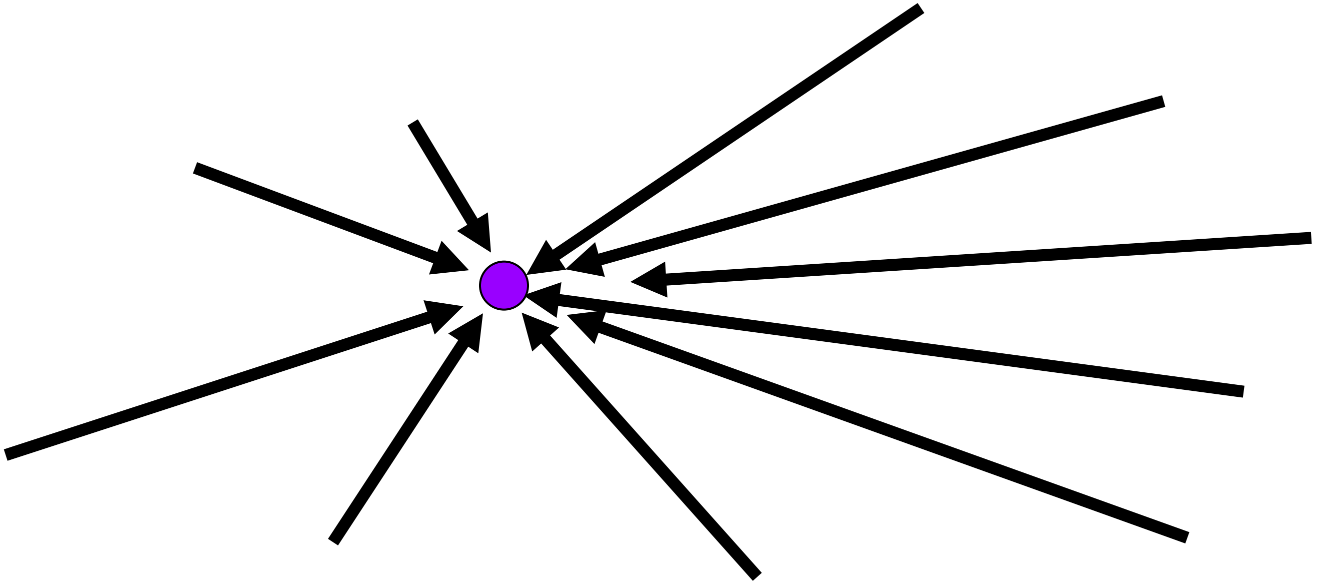
- Query the ray database to look-up closest rays
- Interpolate the values

- Distance between 2 rays
  - Which is closer together?



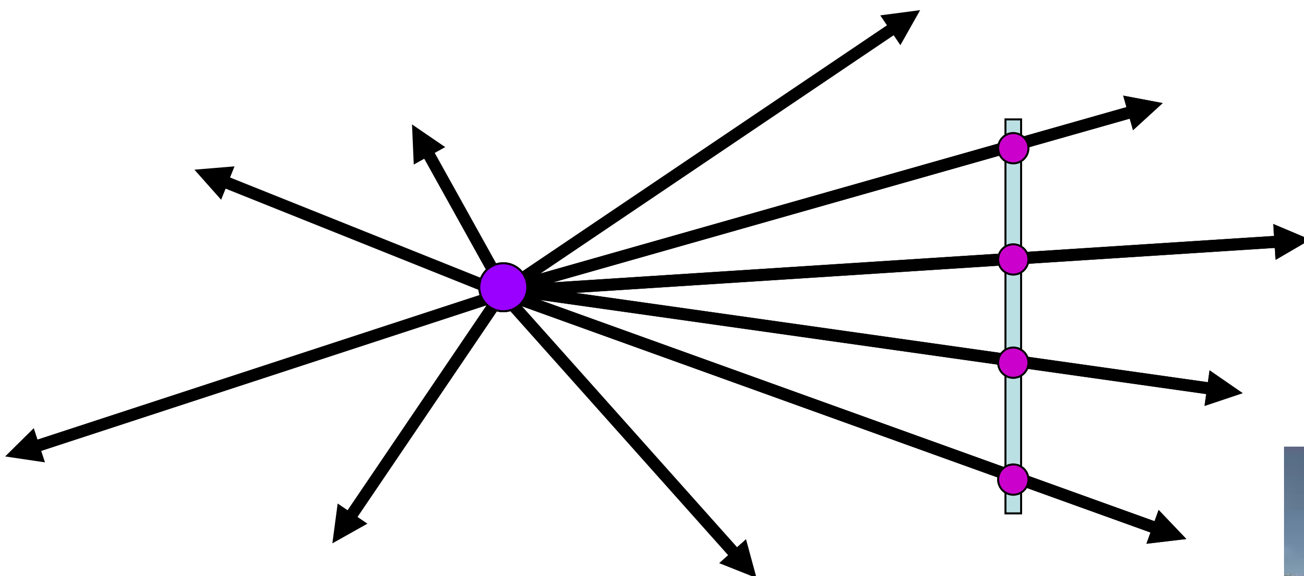
Recording all rays through a point

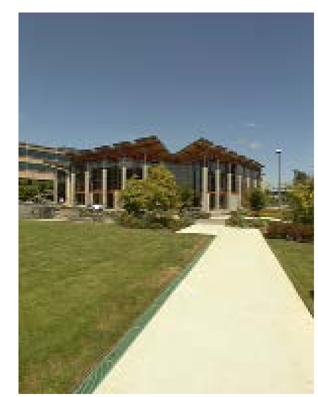
- 2D subset of the plenoptic function



How to synthesize an image?

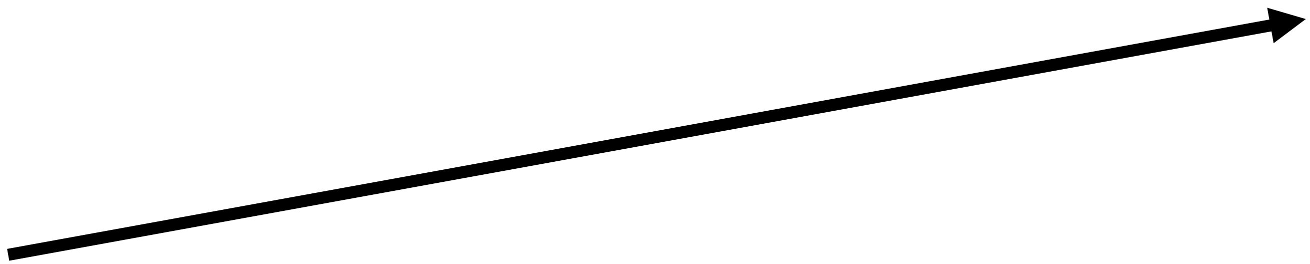
- Also a 2D subset of the plenoptic function





Reduction to 4D in free space

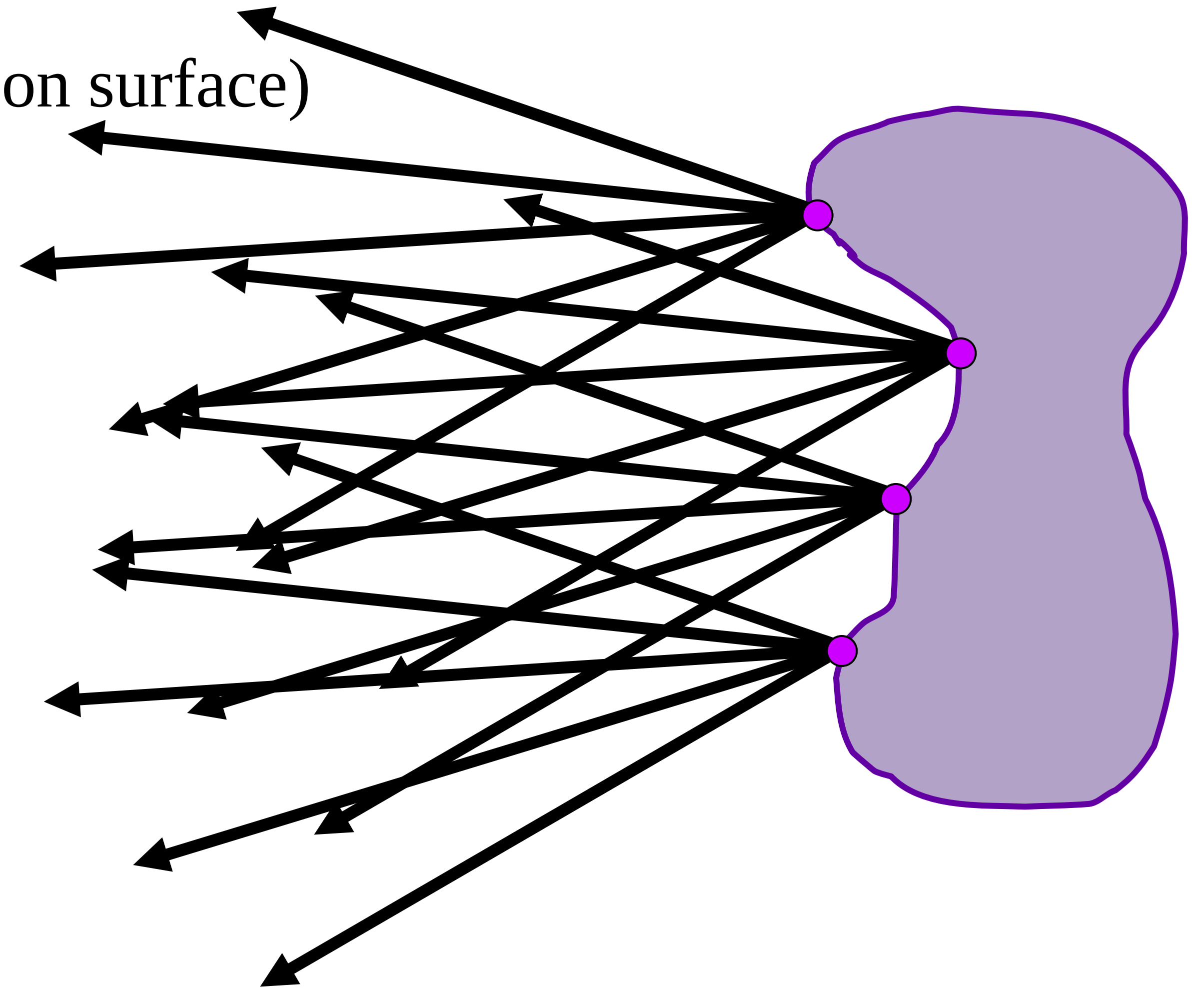
- Infinite line
  - Radiance is constant along a line in free space



- 4D
  - 2D direction
  - 2D position
  - non-dispersive medium

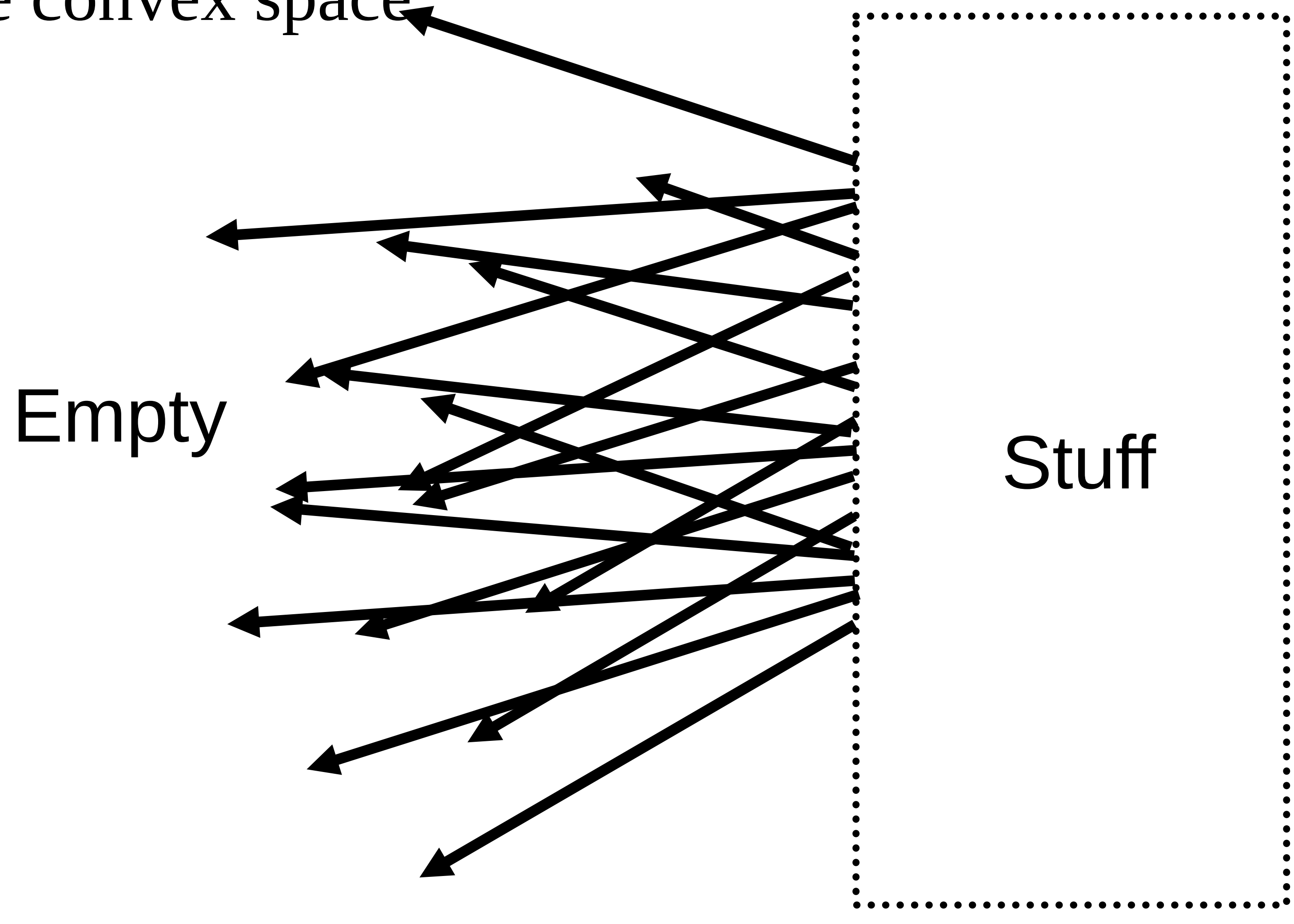
All light leaving object

- 4D Function
  - 2D position (on surface)
  - 2D direction



Lumigraph/Light field

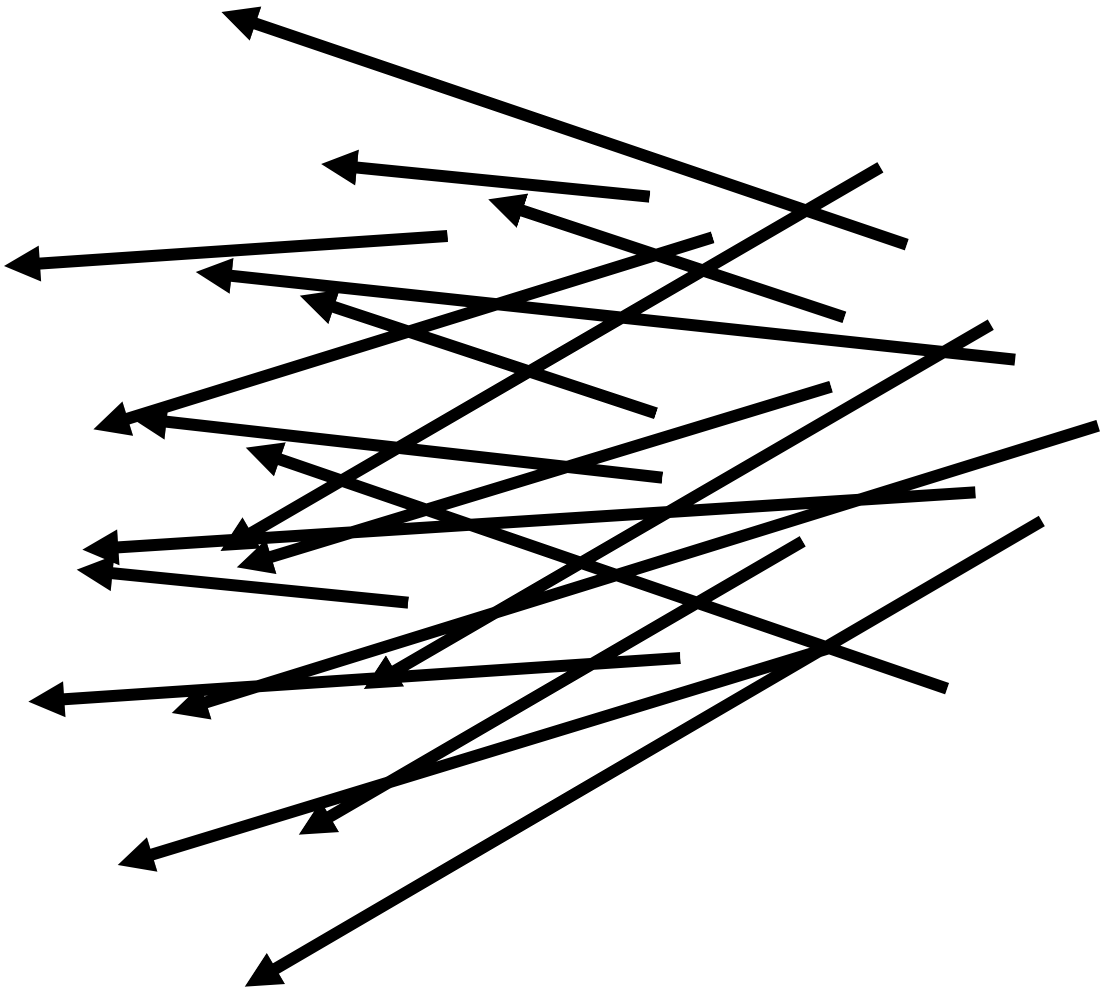
- Outside convex space



- 4D

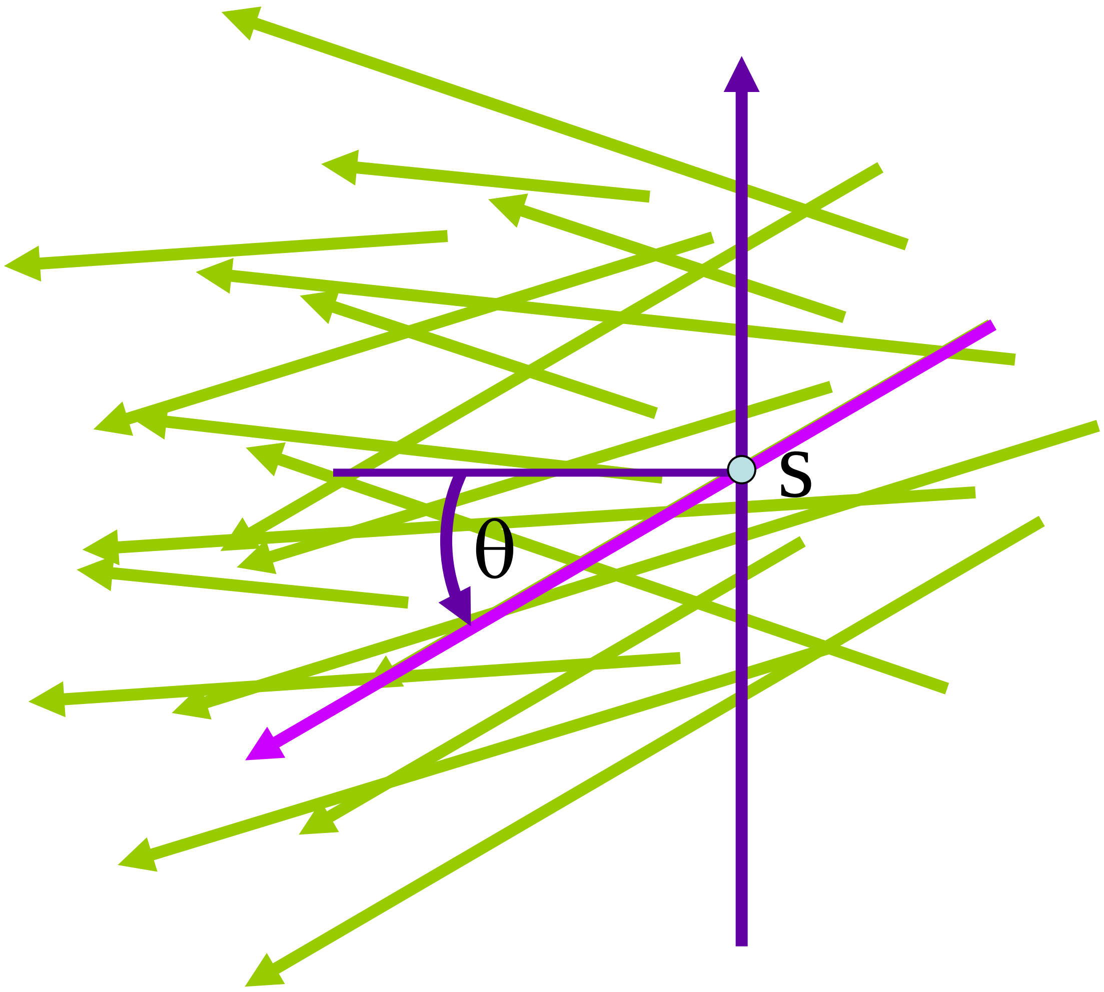
Lumigraph/Light field

- How to ?
  - organize
  - capture
  - render



Lumigraph/Light field – Organization

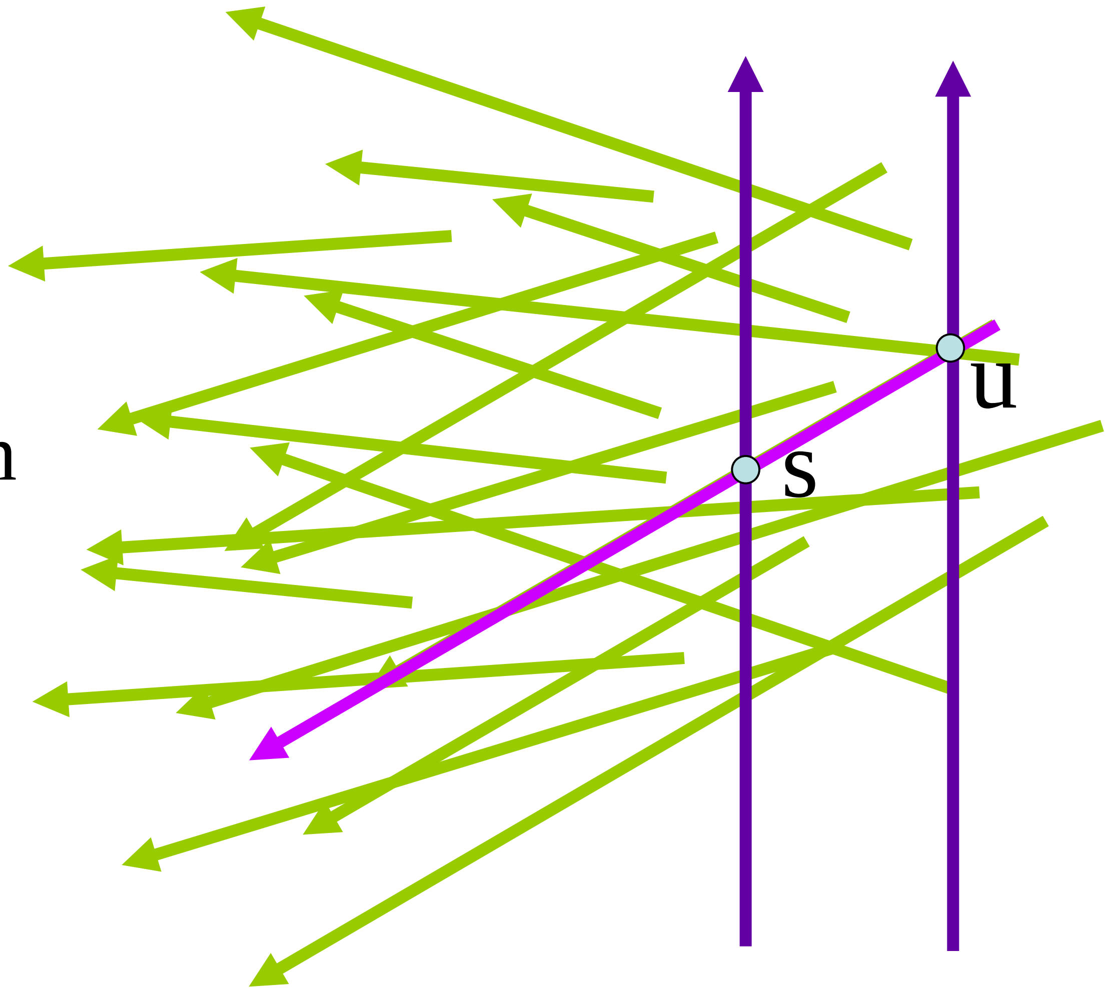
- 2D position
- 2D direction



Lumigraph/Light field – Organization

- 2D position
- 2D position

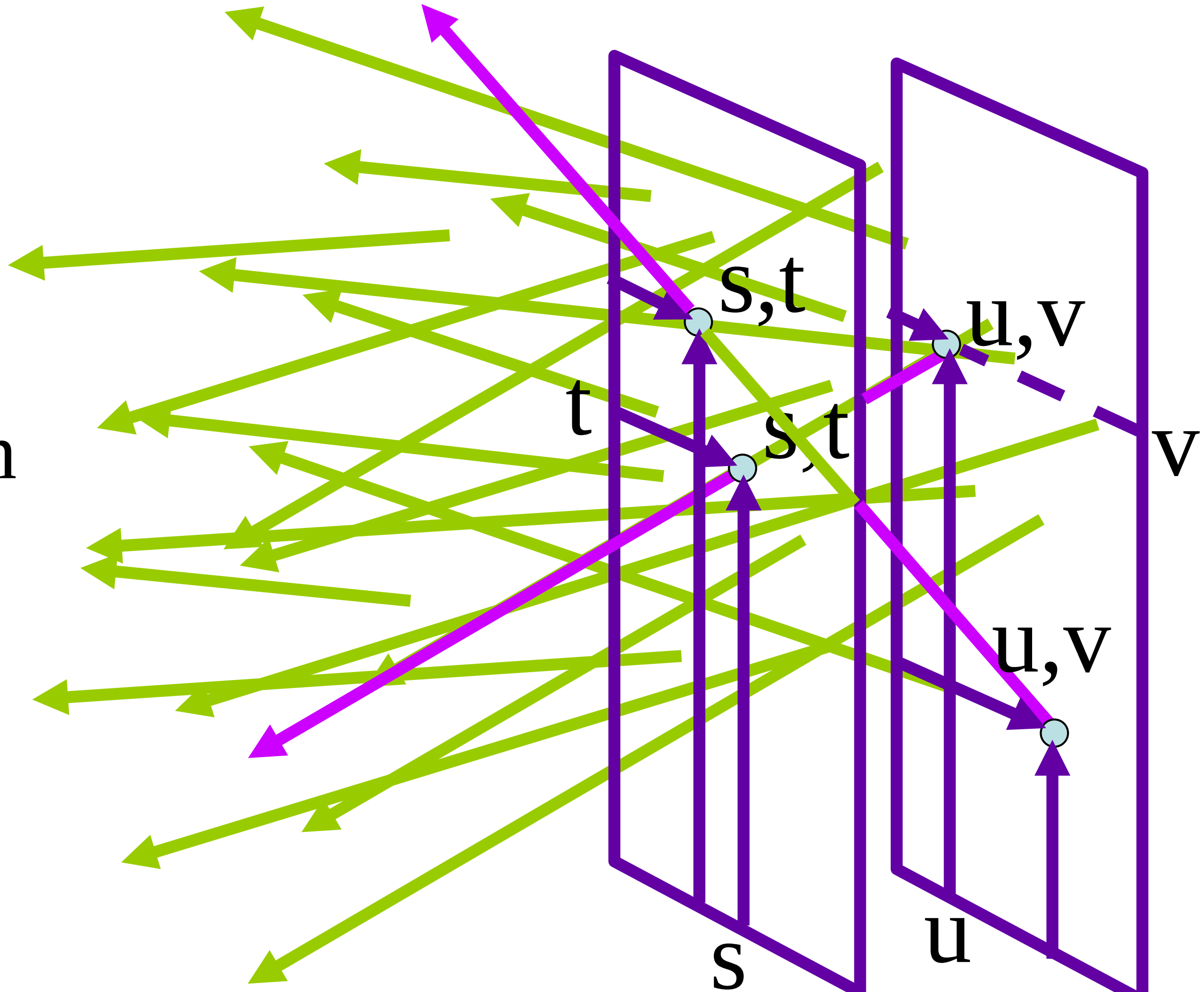
2 plane parameterization



Lumigraph/Light field – Organization

- 2D position
- 2D position

2 plane parameterization

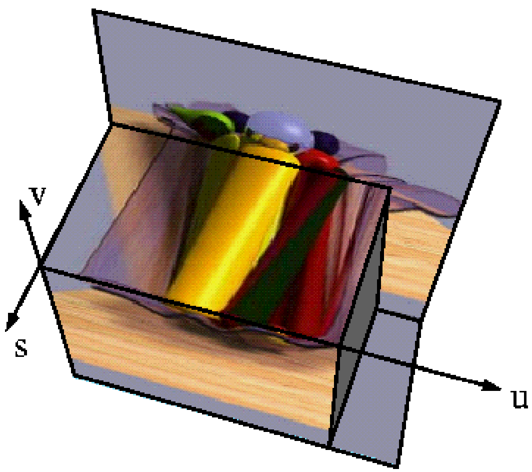


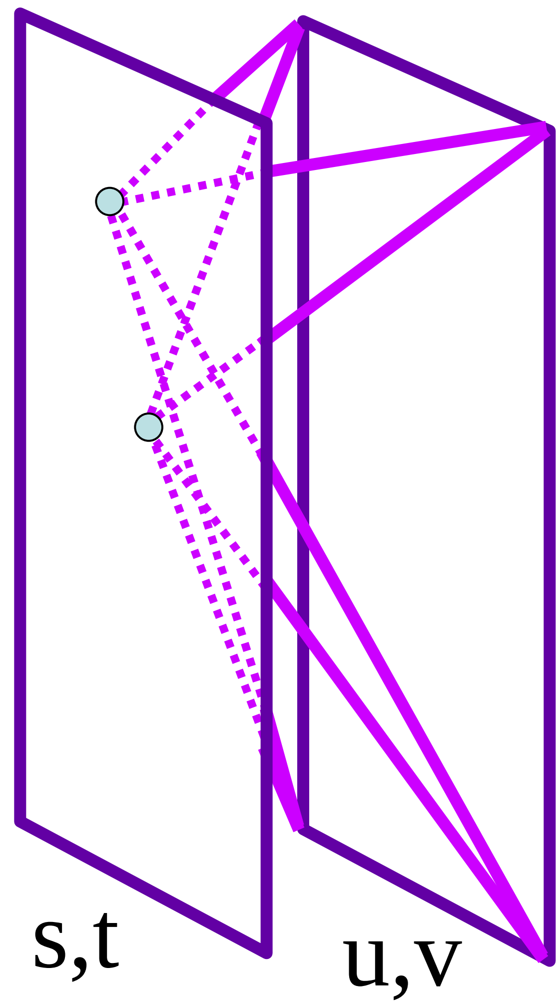
Lumigraph/Light field – Organization

Hold s,t constant

Let u,v vary

An image

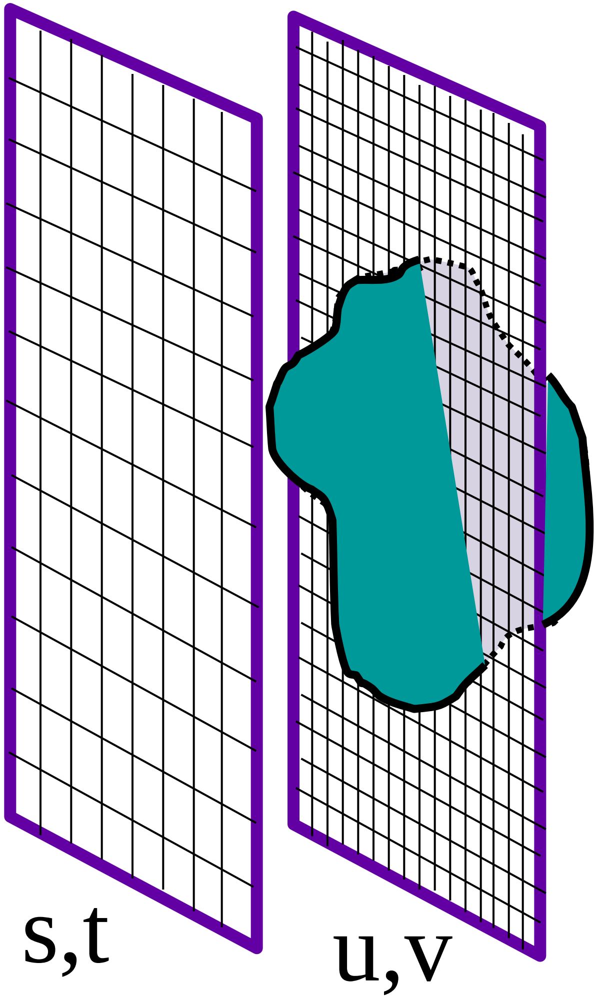




Lumigraph/Light field – Organization

Discretization

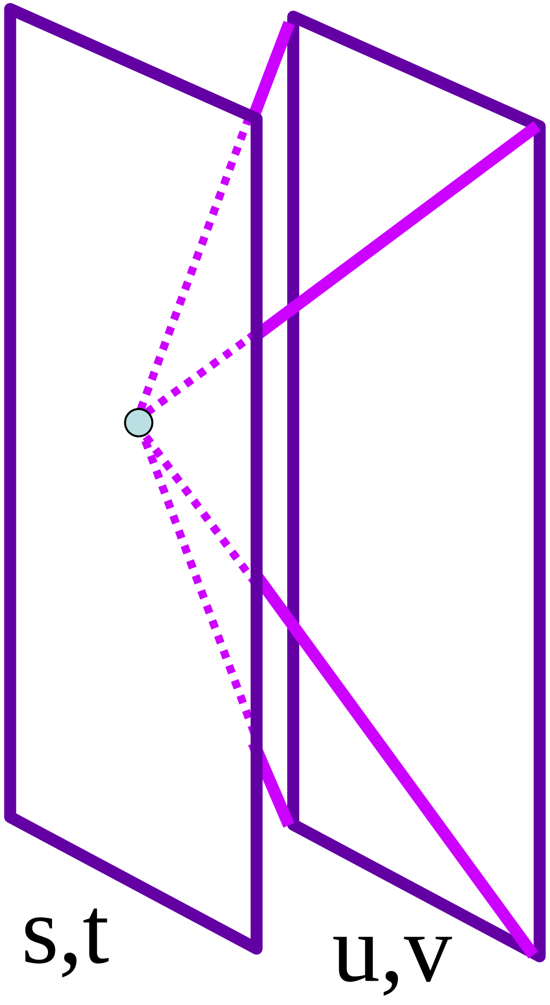
- higher res near object
  - if diffuse
  - captures texture
- lower res away
  - captures directions



Lumigraph/Light field – Capture

Idea 1

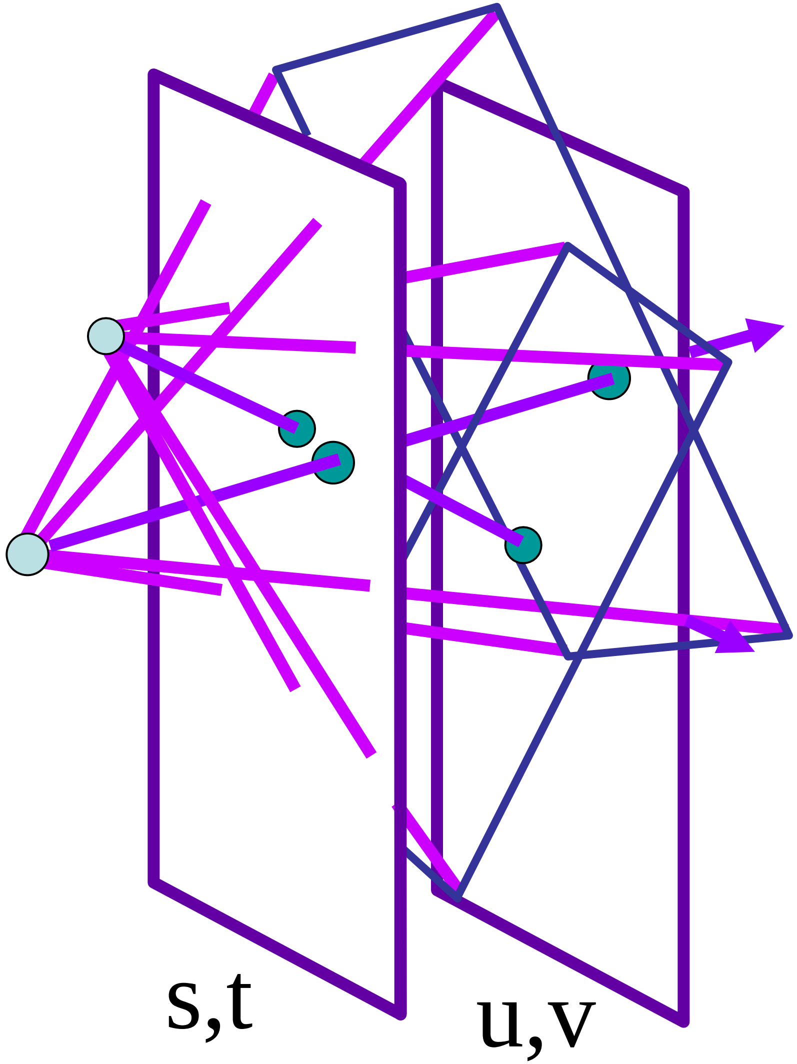
- Move camera carefully over s,t plane
- Gantry



Lumigraph/Light field – Capture

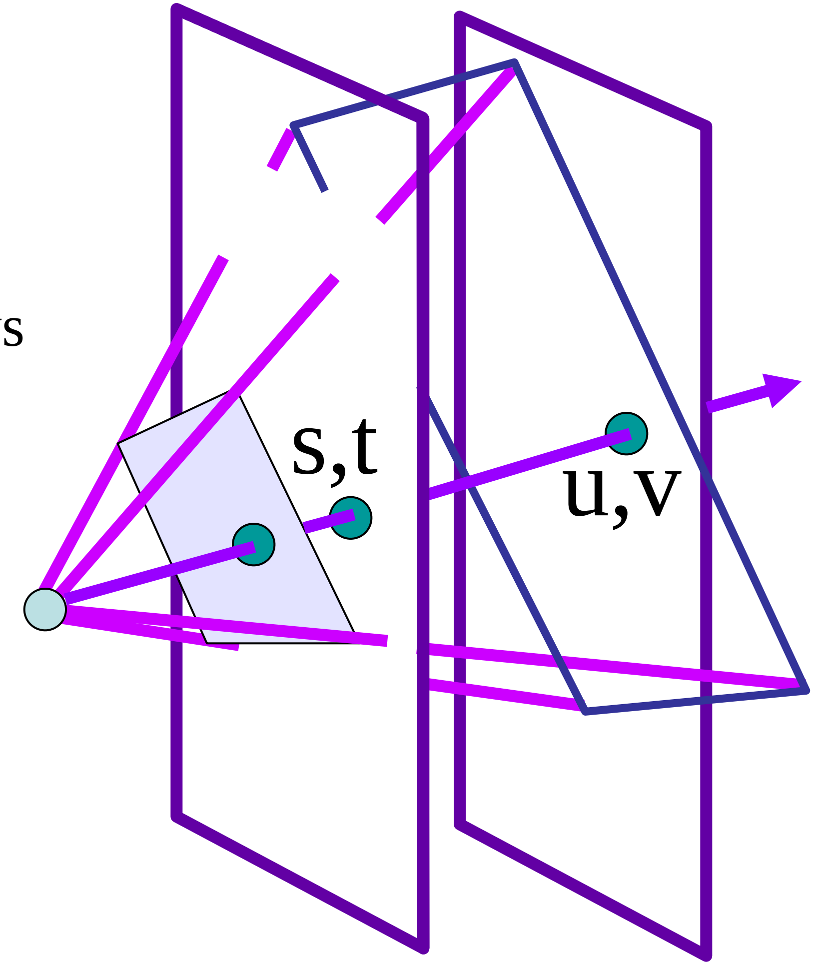
Idea 2

- Move camera anywhere
- Rebinning



Lumigraph/Light field – Rendering

- For each output pixel
  - determine s,t,u,v
  - either
    - copy value of closest ray
    - interpolate values of closest rays



Lumigraph/Light field – Rendering

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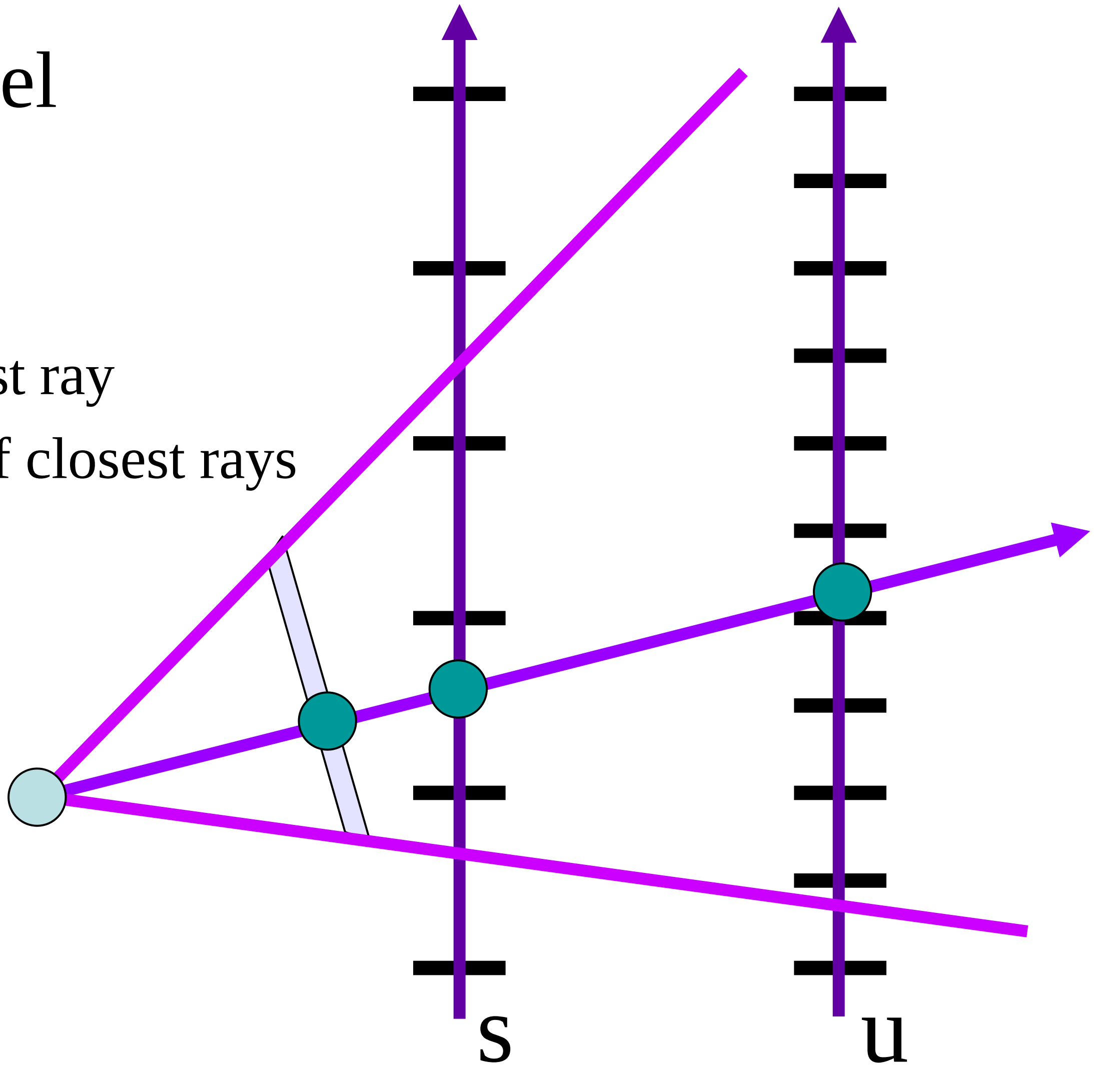
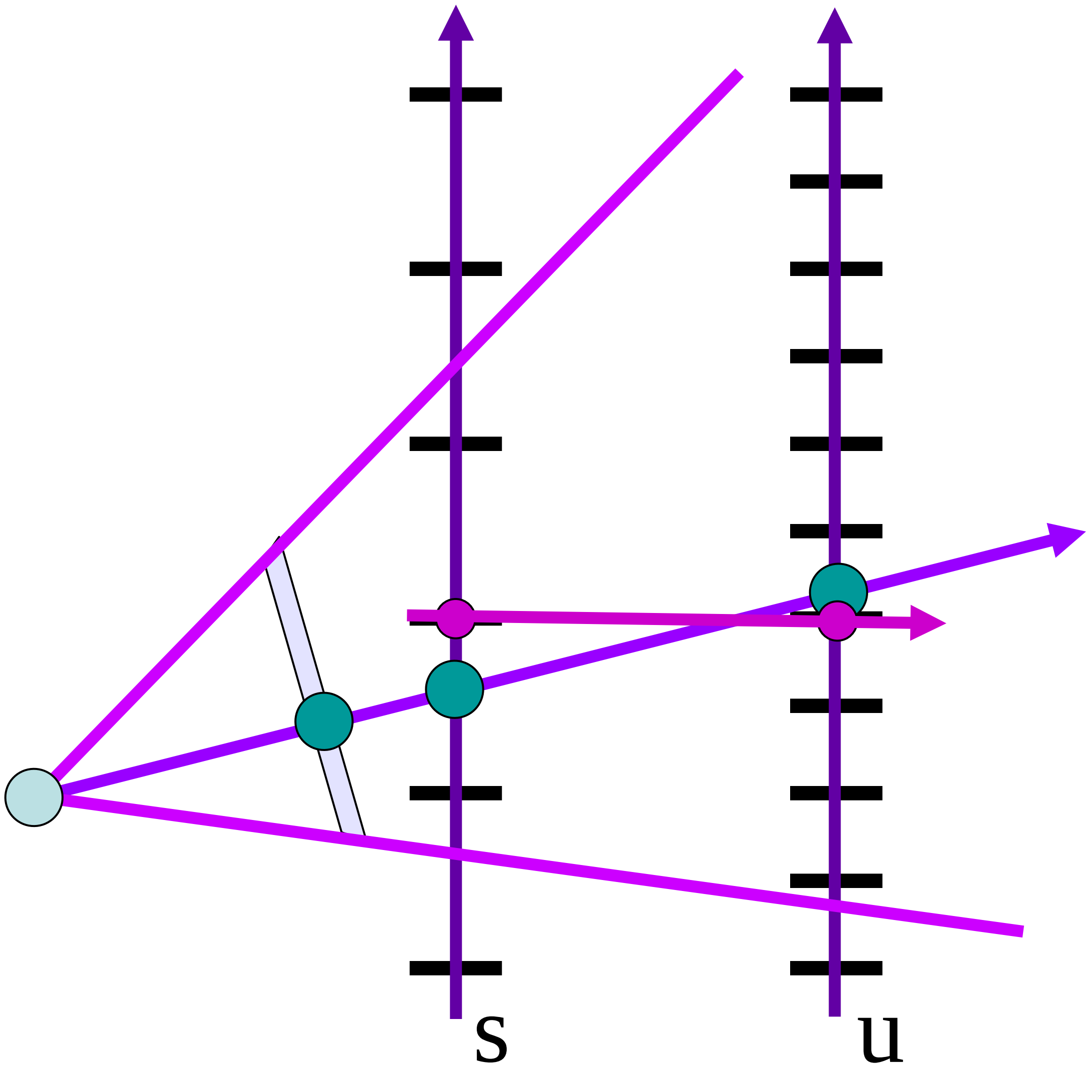


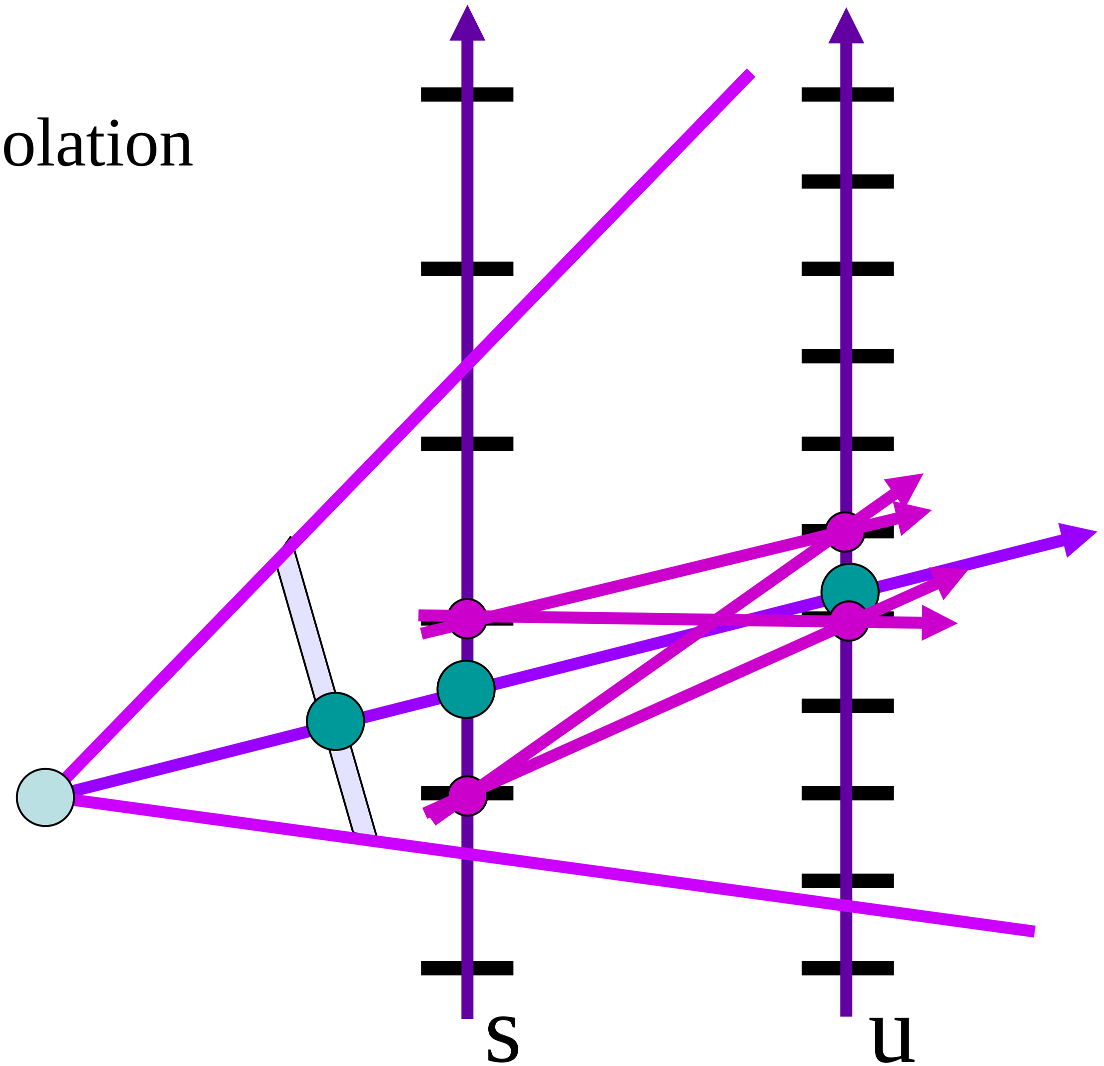
Lumigraph/Light field – Rendering

- Closest Ray
  - closest s
  - closest u
  - draw it



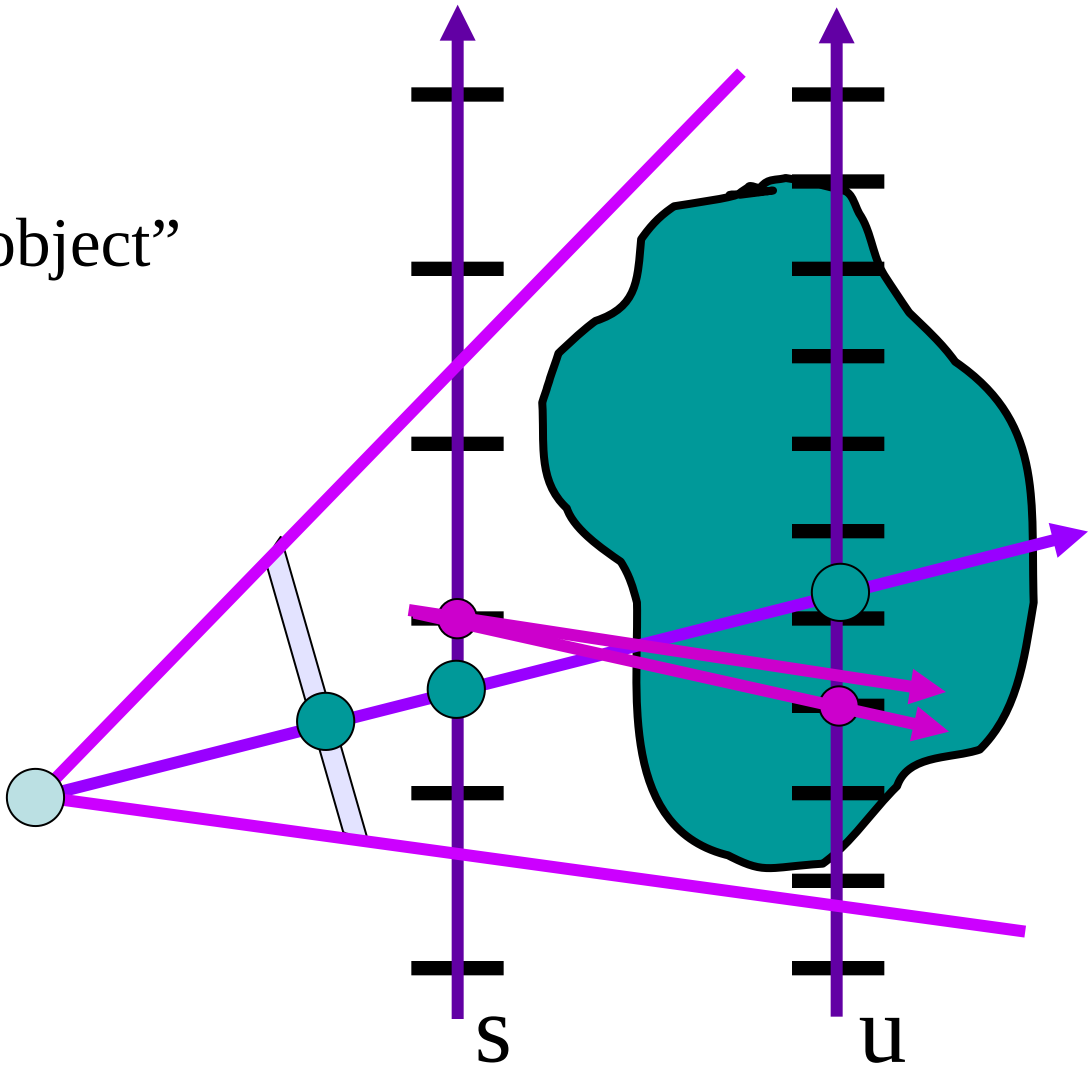
Lumigraph/Light field – Rendering

- Blend 16 nearest
  - quadrilinear interpolation



Lumigraph/Light field – Rendering

- Depth Correction
  - closest s
  - intersection with “object”
  - best u
  - closest u
- Reduces sampling problems



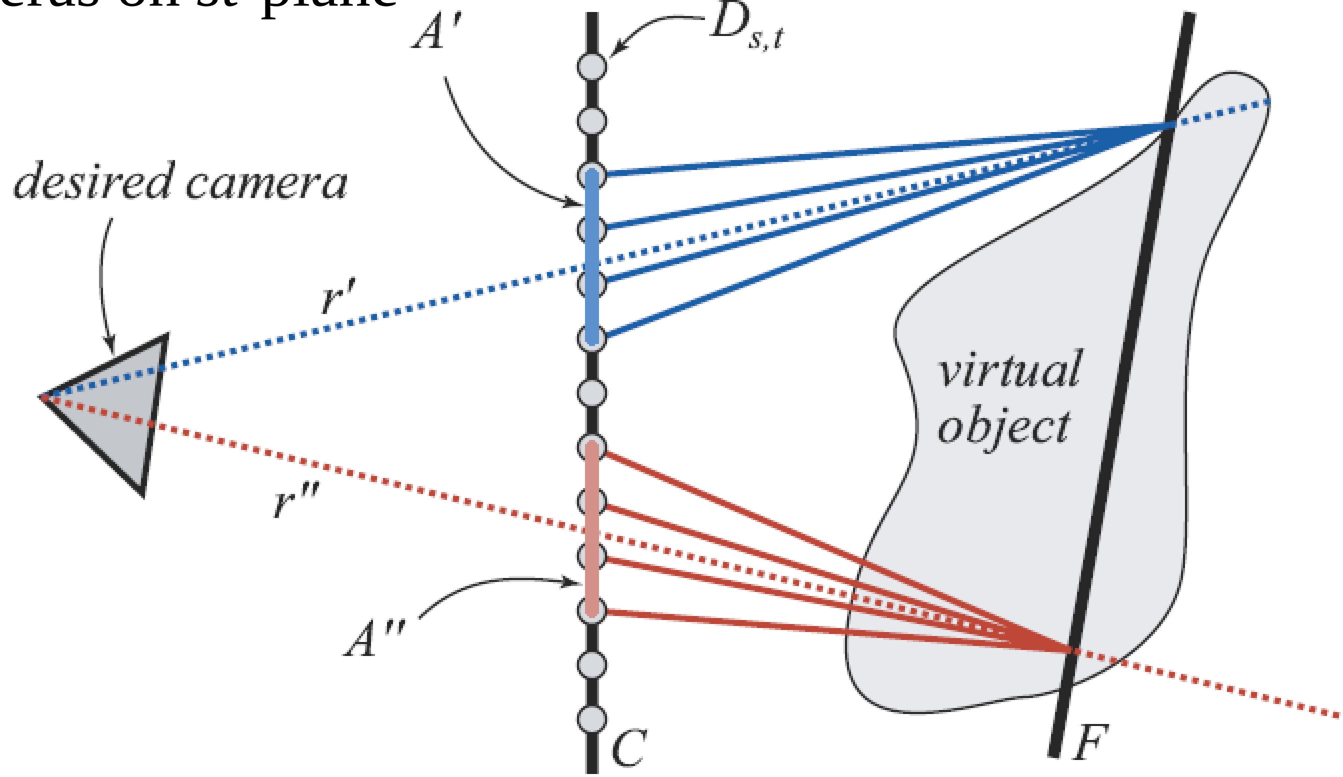
Lumigraph/Light field – Rendering

Without using geometry (ghosting)

Using approximate geometry

Synthetic Aperture

- So far we have only reconstructed pinhole images
- We can control the aperture size by selecting the number of cameras on *st*-plane



- [Dynamically Reparameterized Light Fields, Isaksen, 2000]

Synthetic Aperture

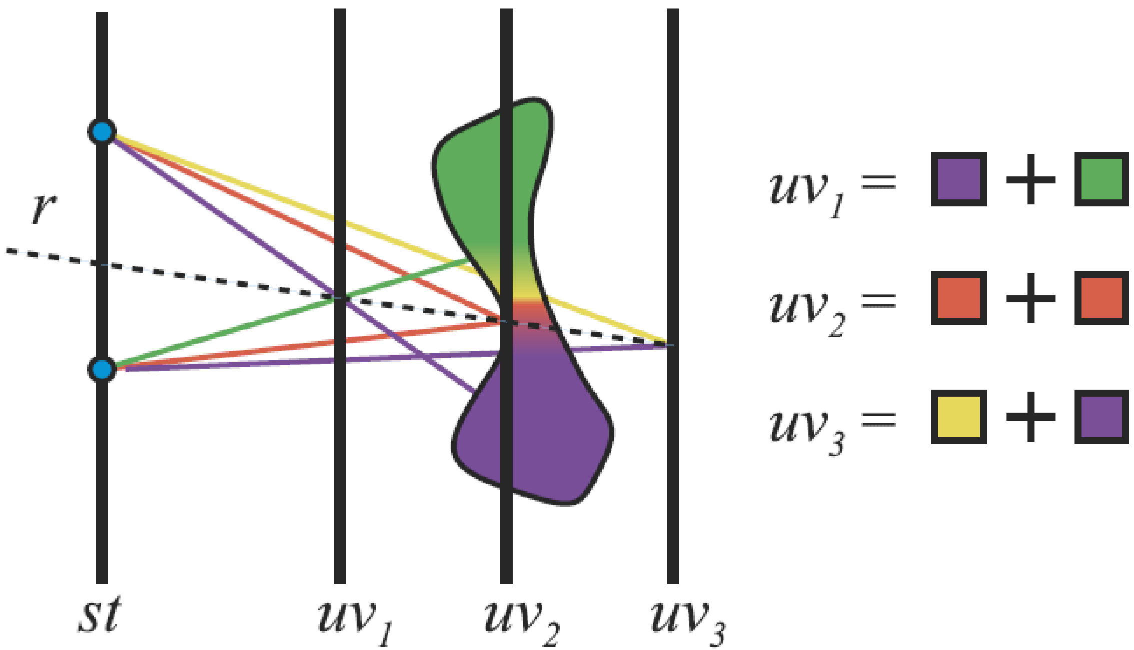
Small synthetic aperture
large depth of field

Large synthetic aperture
shallow depth of field

- [Dynamically Reparameterized Light Fields, Isaksen, 2000]

UV-plane choice

- The parameterization of the *uv* plane affects the reconstruction of a desired ray *r*.
- *uv* plane acts as a focal surface



- [Dynamically Reparameterized Light Fields, Isaksen, 2000]

Synthetic Focus/Aperture Example

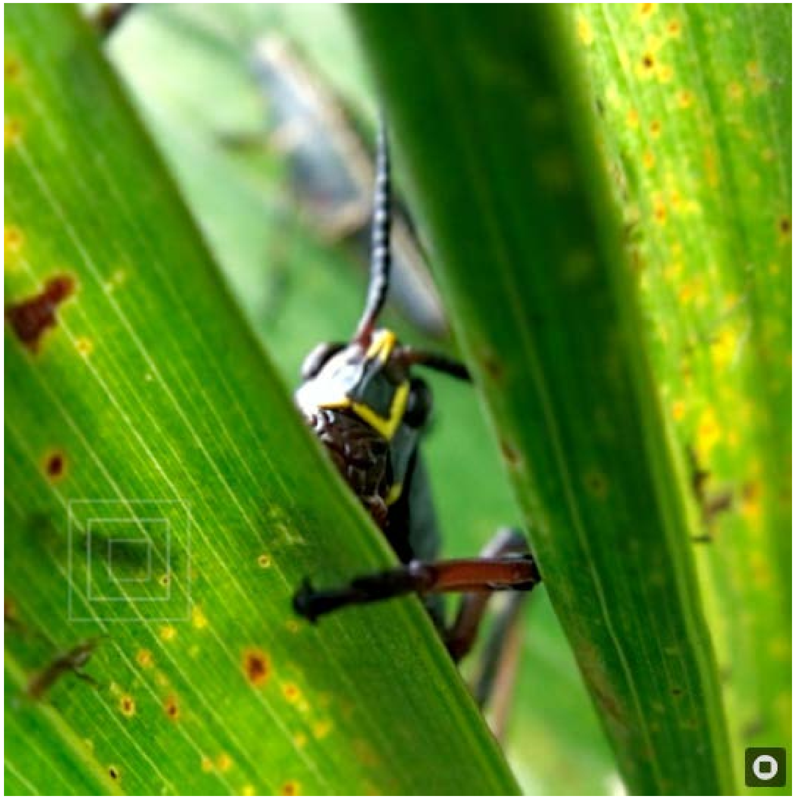
Focus plane – near

Focus plane – further

- [Dynamically Reparameterized Light Fields, Isaksen, 2000]

Synthetic Focus/Aperture

- Refocusing after the shot
- Available in light field cameras by Lytro



Focus plane – near

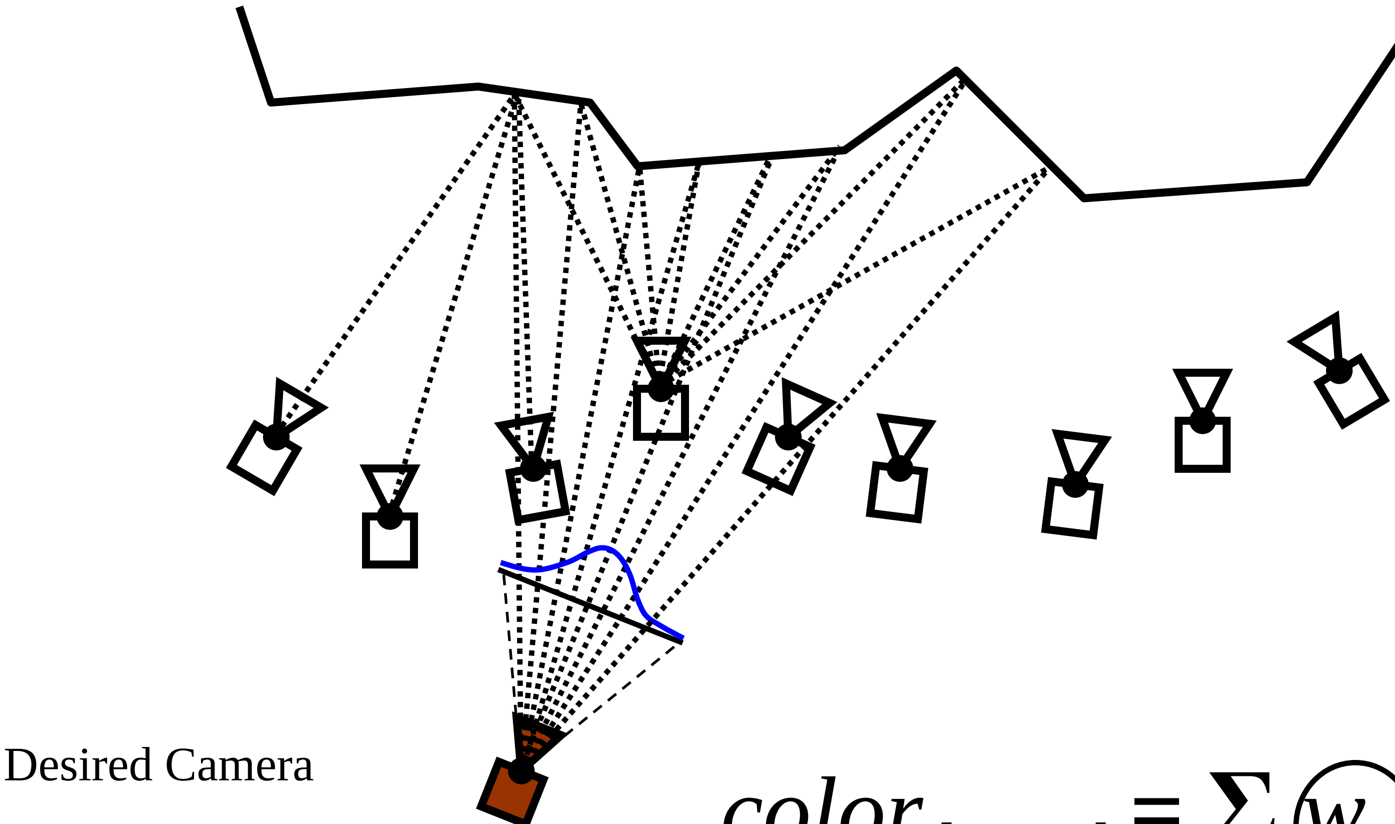
Focus plane – further

Unstructured Lumigraph Rendering

- What if images are not sampled on a regular 2D grid?
- ULR stores original images, no rebinning
- Explicitly construct blending field
  - Computed using penalties
  - Sample and interpolate over desired image
- Render with hardware
  - Projective texture mapping and alpha blending

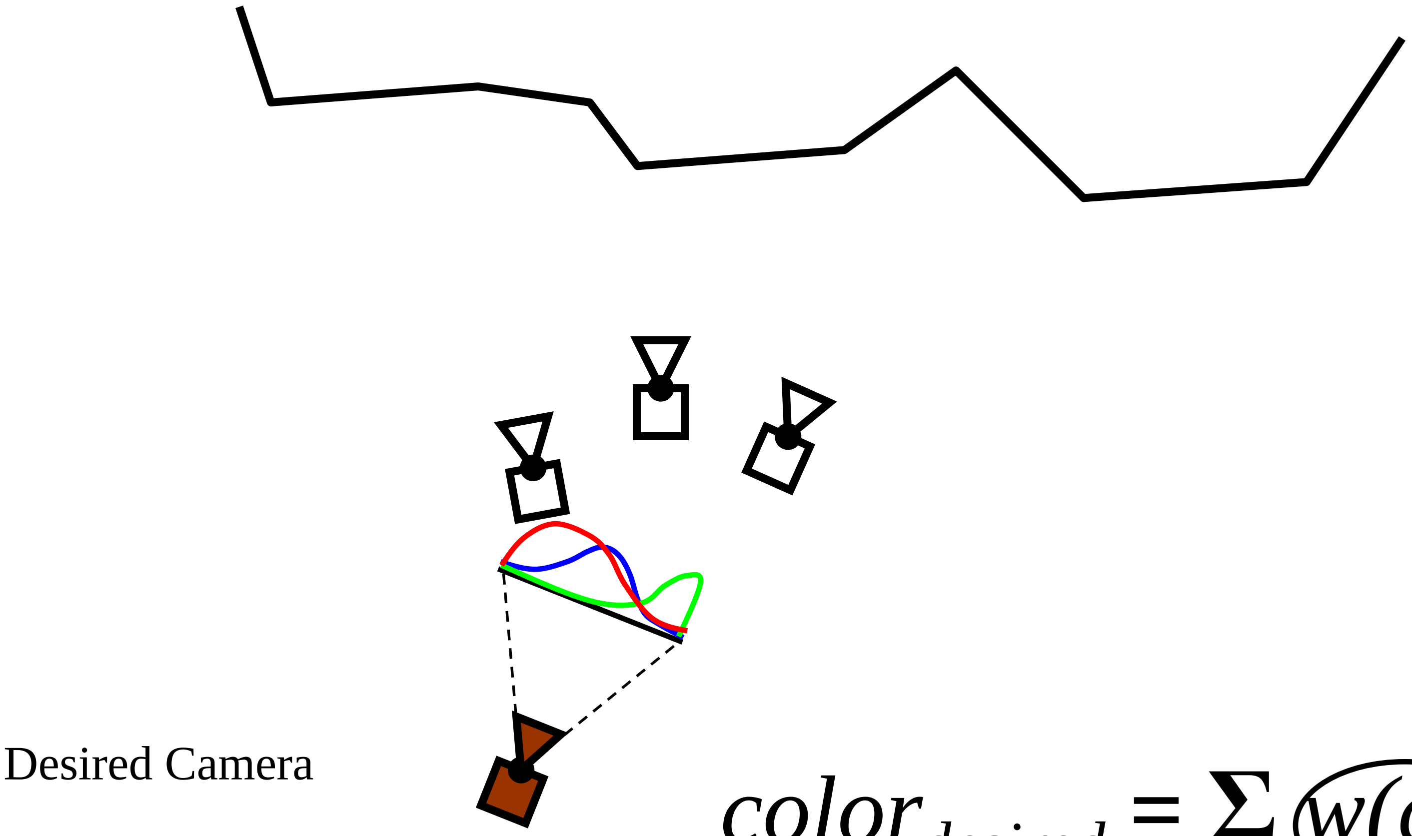
- [Buehler *et al.*, SIGGRAPH’2000]

ULR Blending Fields



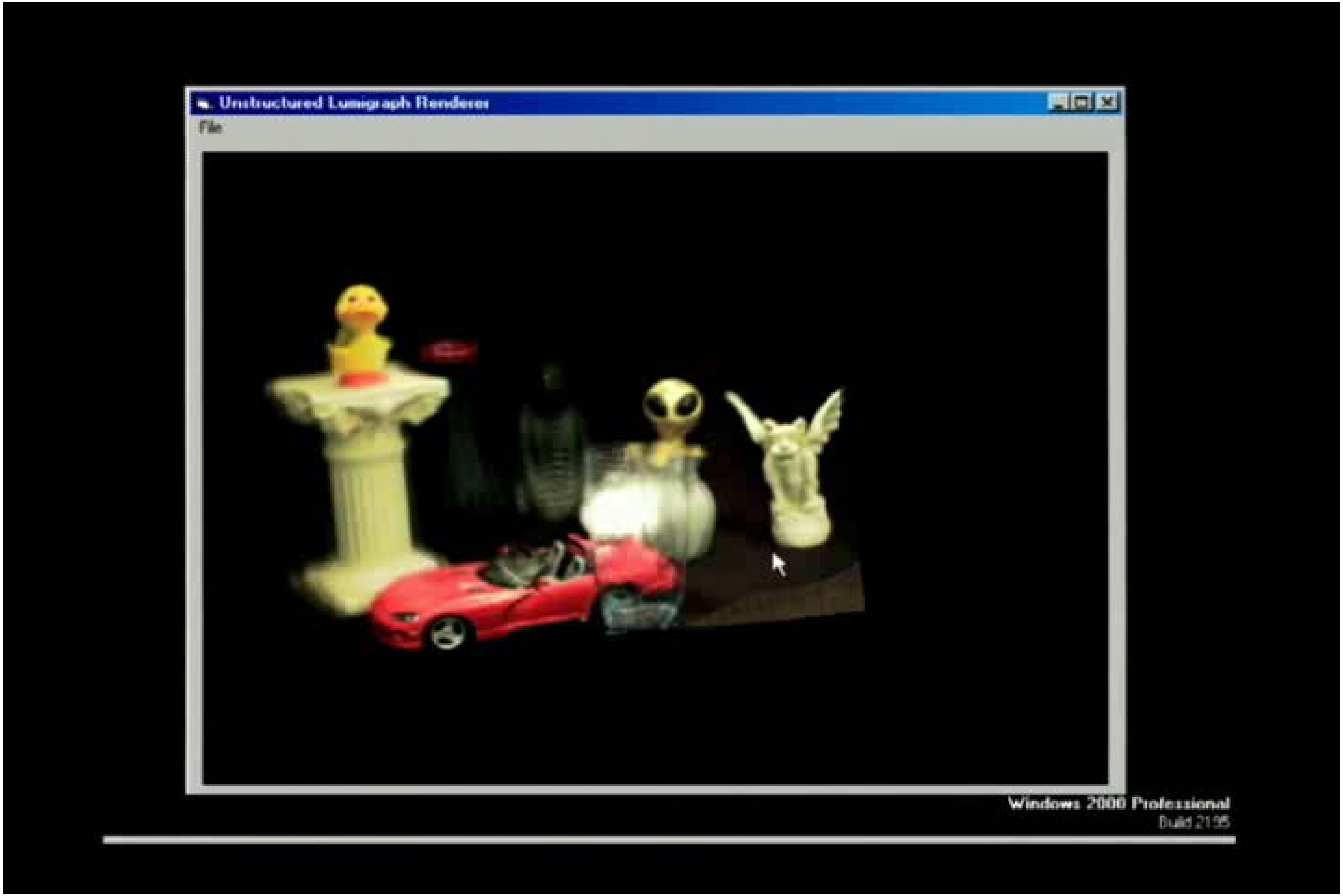
$$color_{desired} = \sum_i w_i \, color_i$$

ULR Blending Fields



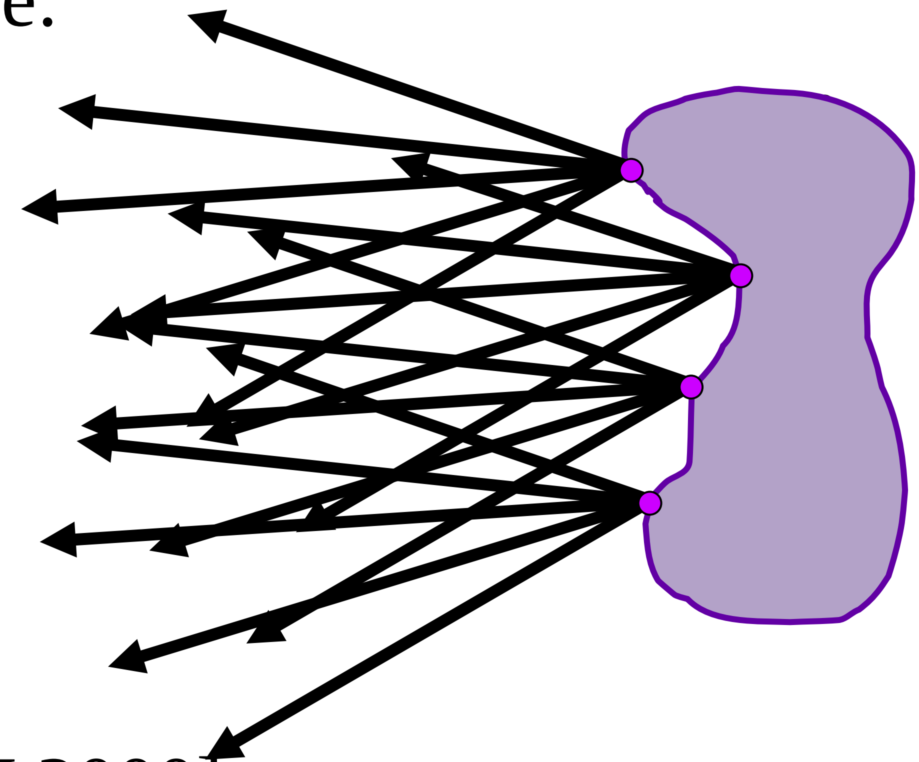
$$color_{desired} = \sum_i w(c_i)\, color_i$$

ULR Results


Unstructured Lumigraph Renderer
File
Windows 2000 Professional
Build 2195

Surface Light Fields

- 4D dataset: store 2D angular radiance values for each surface point
- Very good data coherence:
  - Dense angular samples can be compressed well
  - Sparse angular sampling still works fine
- Surface does not have to be exactly aligned with the object
- [Wood et al, SIGGRAPH 2000]

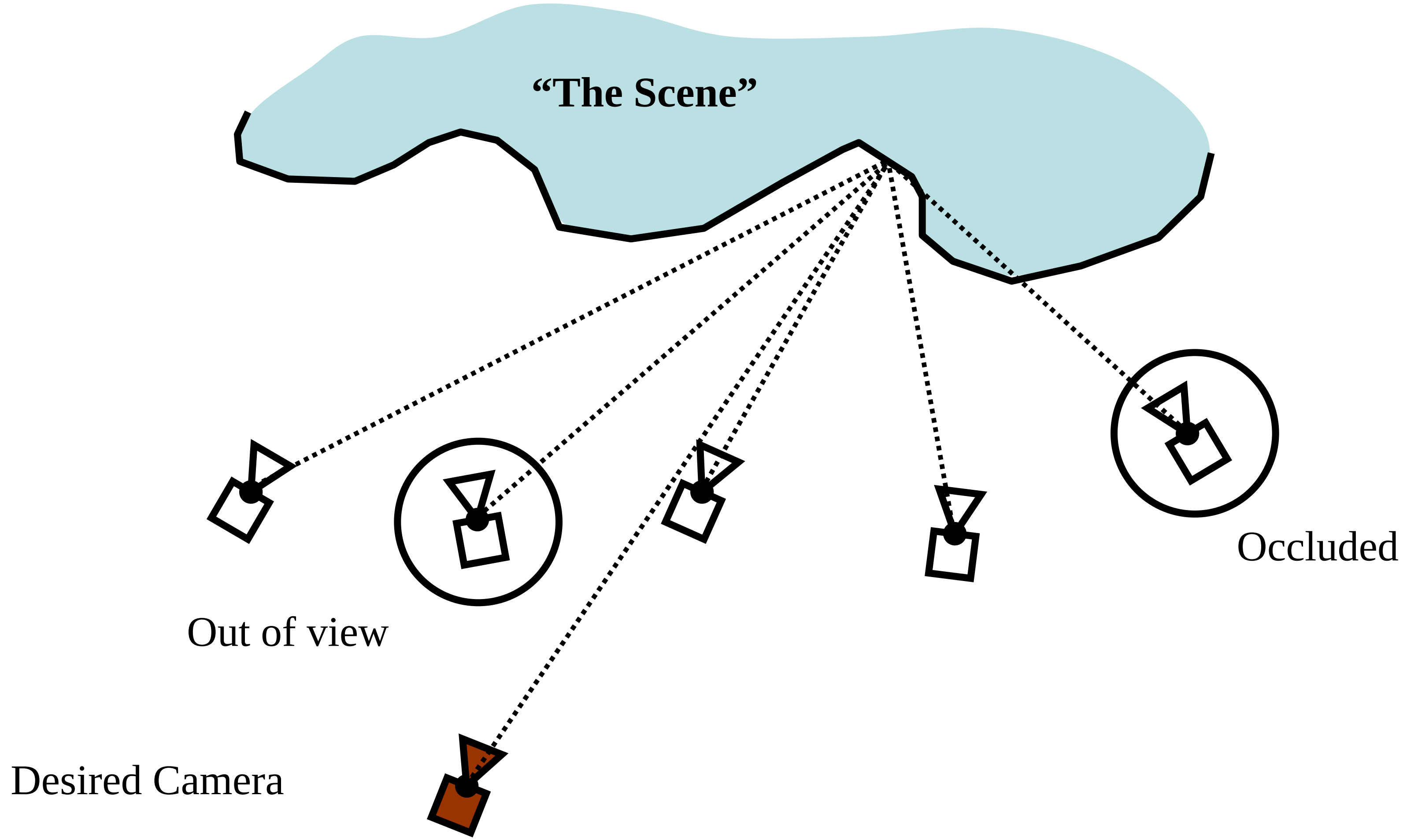


Surface Light Fields

View-dependent Texture Mapping

Debevec, SIGGRAPH ’96, EGRW ‘98

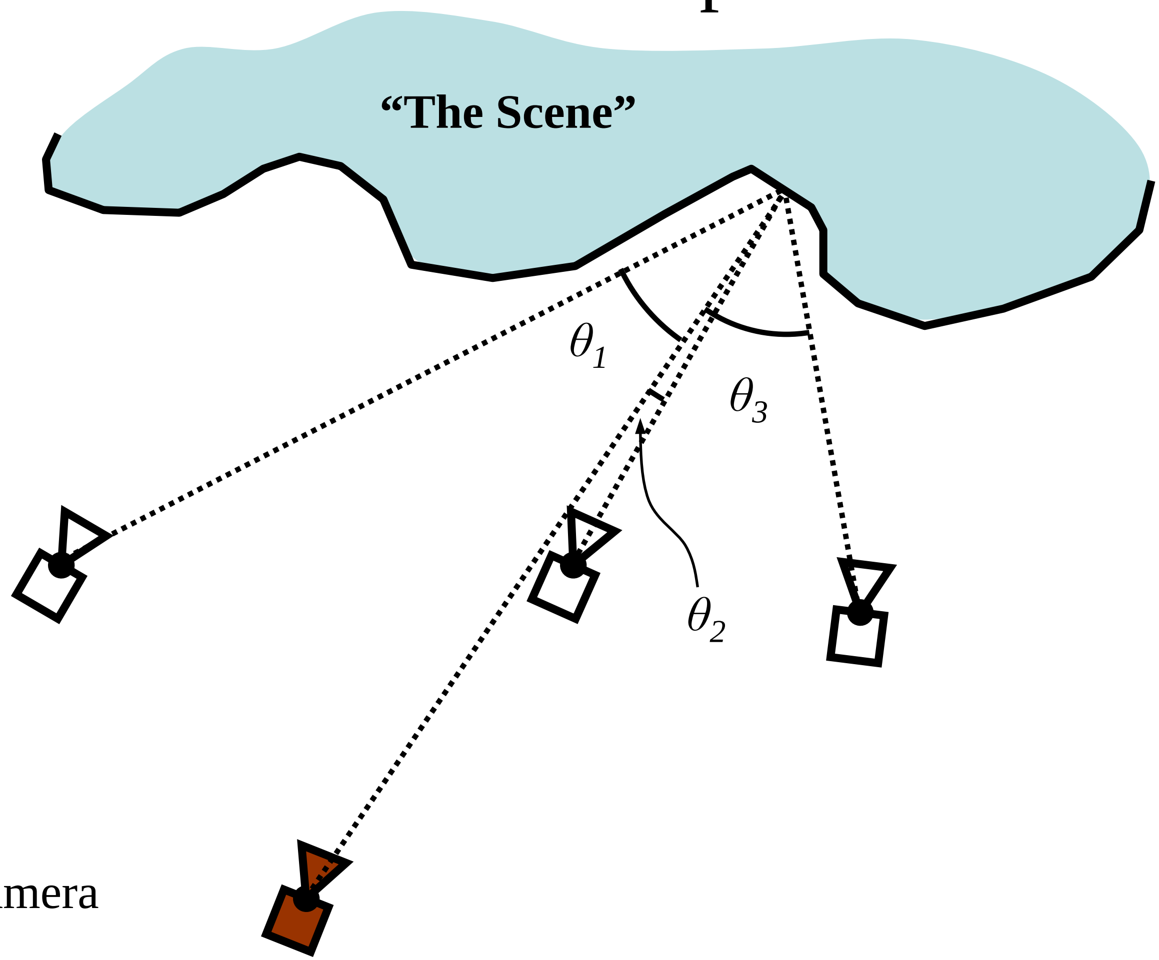
Determine visible cameras for each surface element



View-dependent Texture Mapping

Debevec, SIGGRAPH ’96, EGRW ‘98

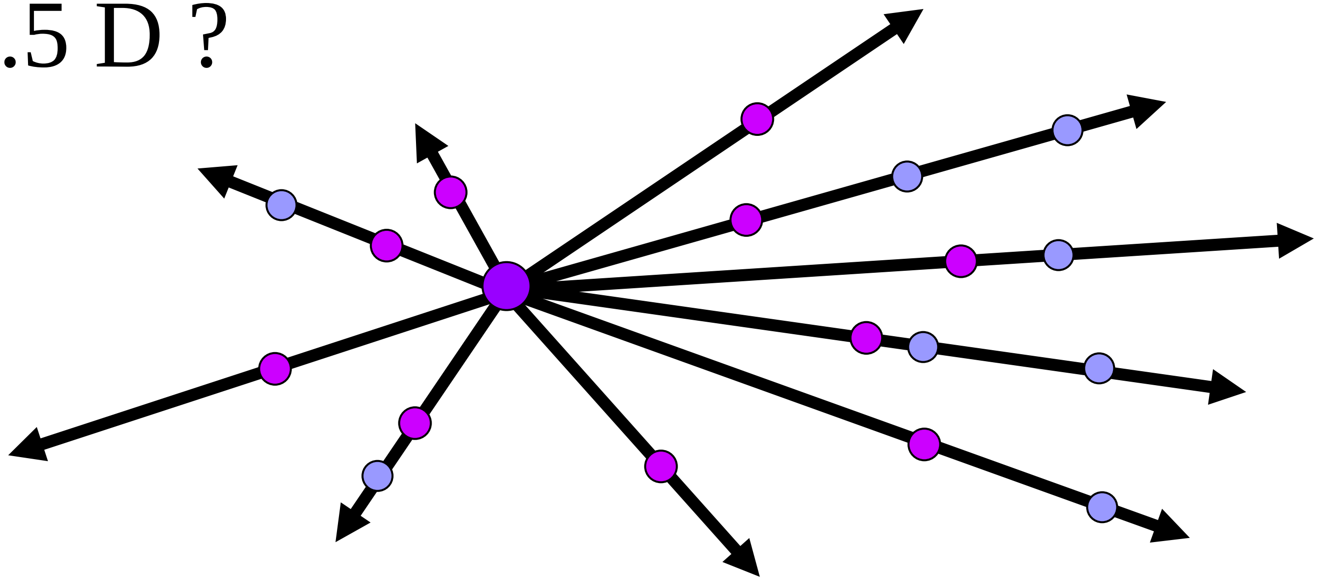
Blend textures (images) depending on distance between original camera and novel viewpoint



Desired Camera

Layered Depth Images

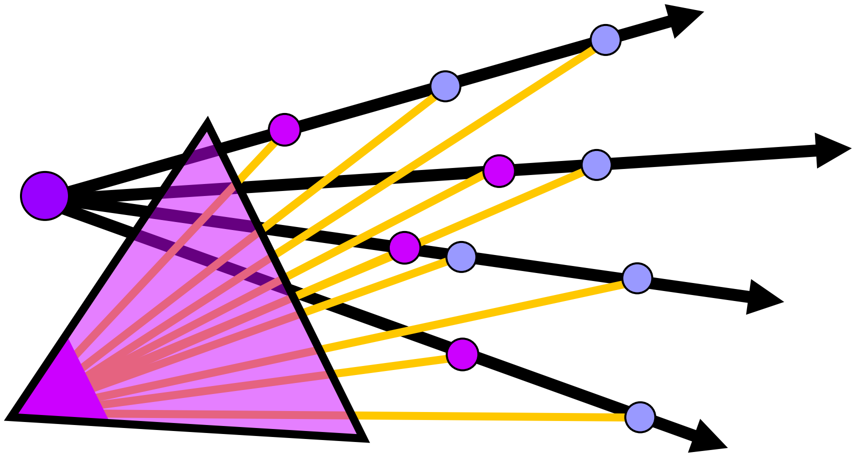
2.5 D ?



Layered Depth Image

Layered Depth Images

- Rendering from LDI [Shade *et al.*, SIGGRAPH’98]
  - Incremental in LDI X and Y
  - Guaranteed to be in back-to-front order



Layered Depth Images

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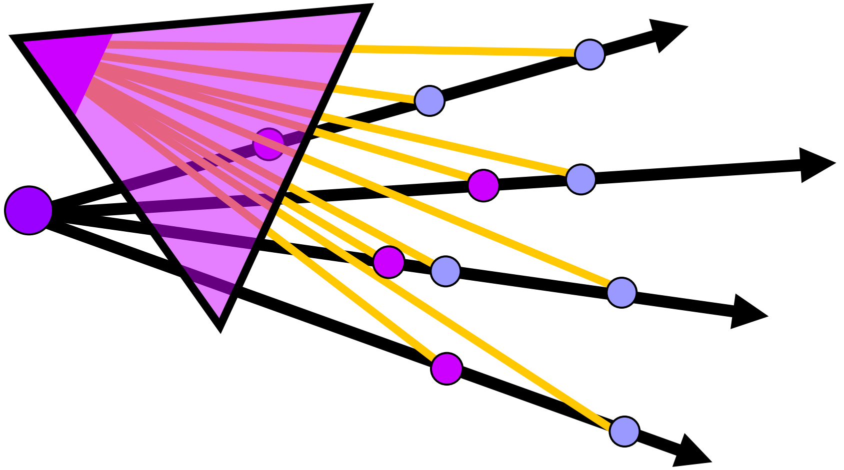


Graphics/Imaging Continuum

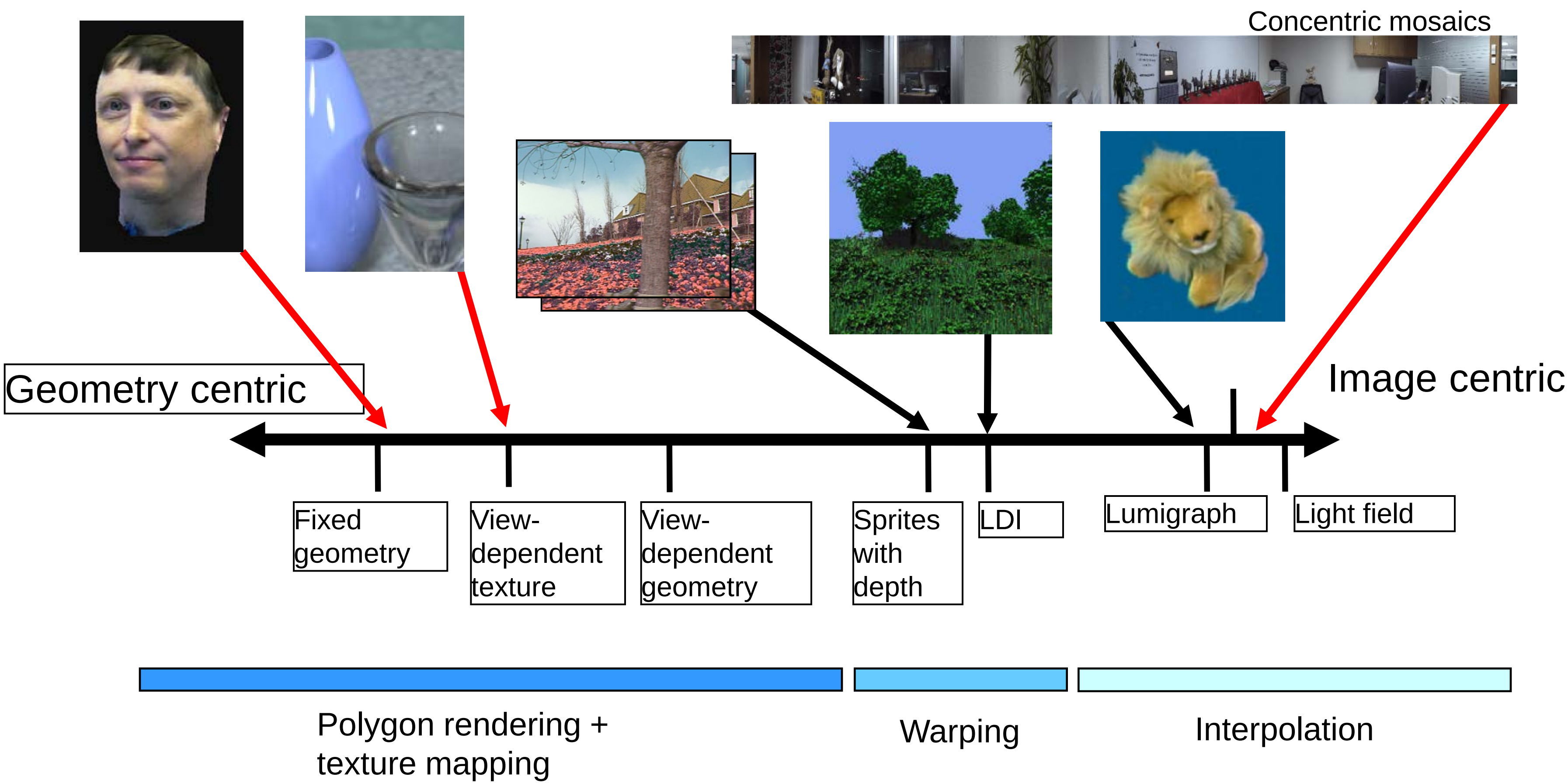
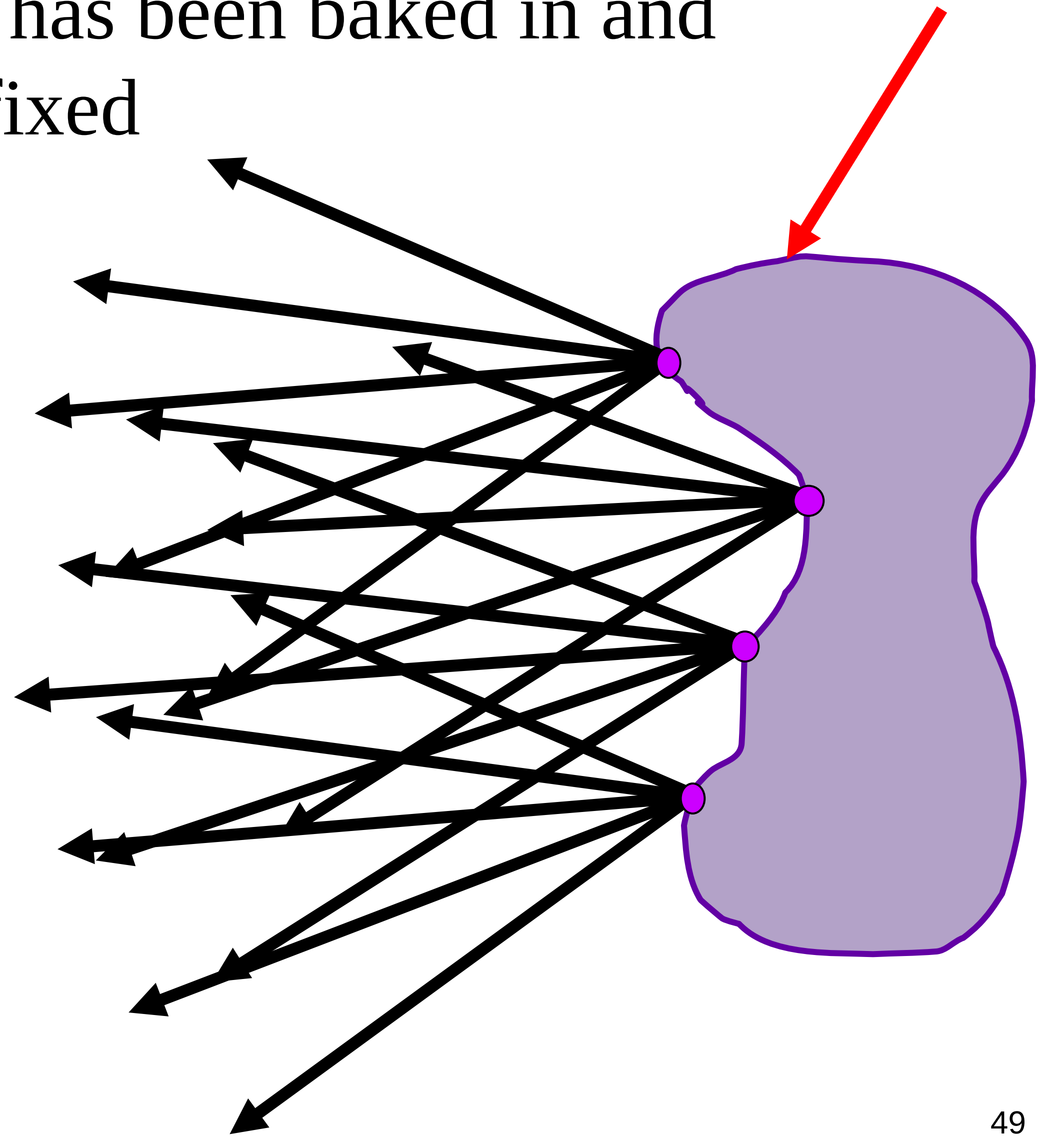


Image-based Lighting

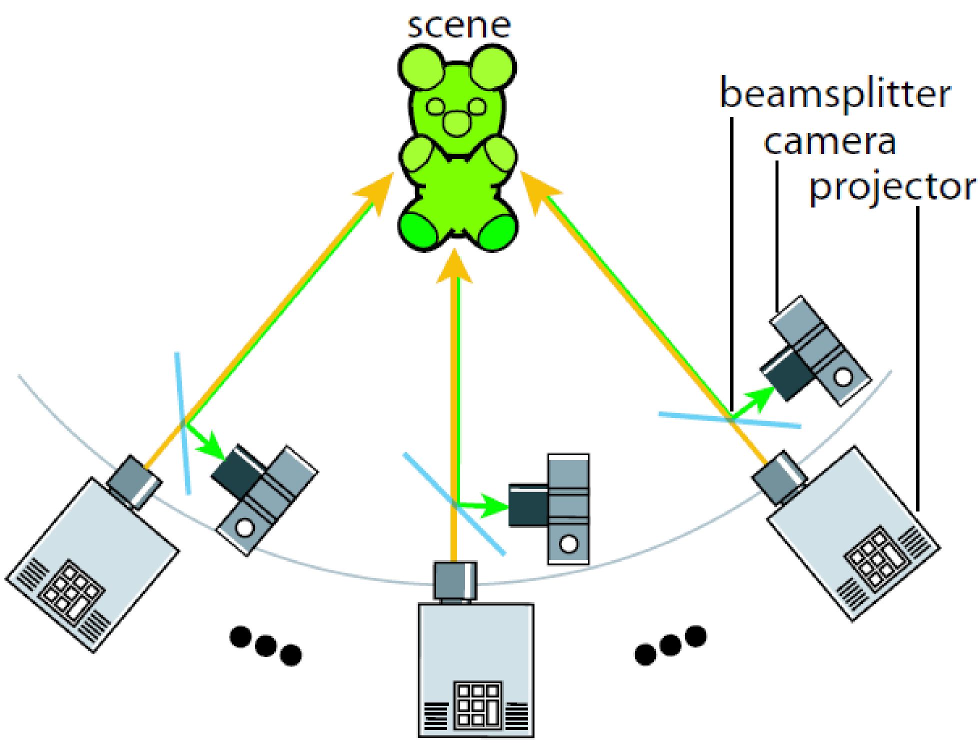
- So far the illumination has been baked in and illumination has been fixed



- For changing lighting we need to capture 8D function
  - Incoming light
    - 2D position
    - 2D direction
  - Outgoing light
    - 2D position
    - 2D direction

Bi-Directional Surface Scattering Distribution Function

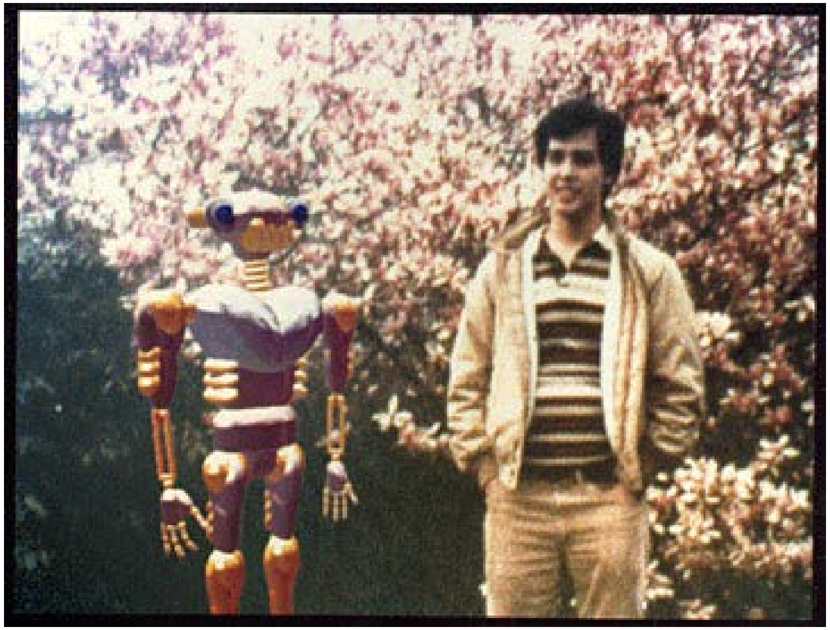
- Capturing 8D BSSRDF is difficult, impractical but not impossible [Garg et al. 06]



- Typically, various slices are acquired 2D, 4D, 6D

Reflection Mapping – 1982

- Environment Maps – 2D Slice



Mike Chou and Lance Williams

Gene Miller and Ken Perlin

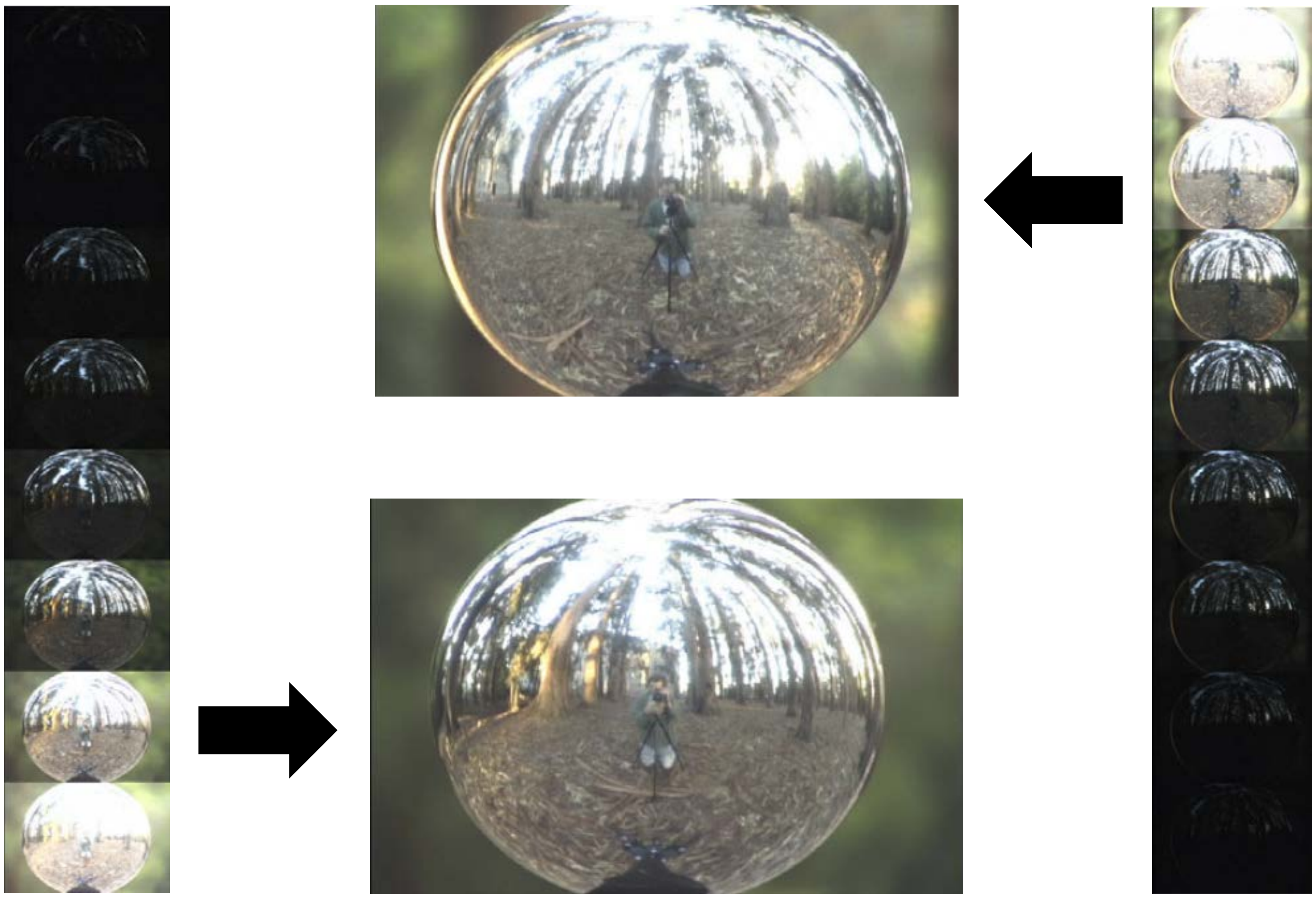
Today: can perform in real time with graphics hardware
http://www.debevec.org/ReflectionMapping/


Canon
Canon
REMOTE SWITCH

Fisheye Images

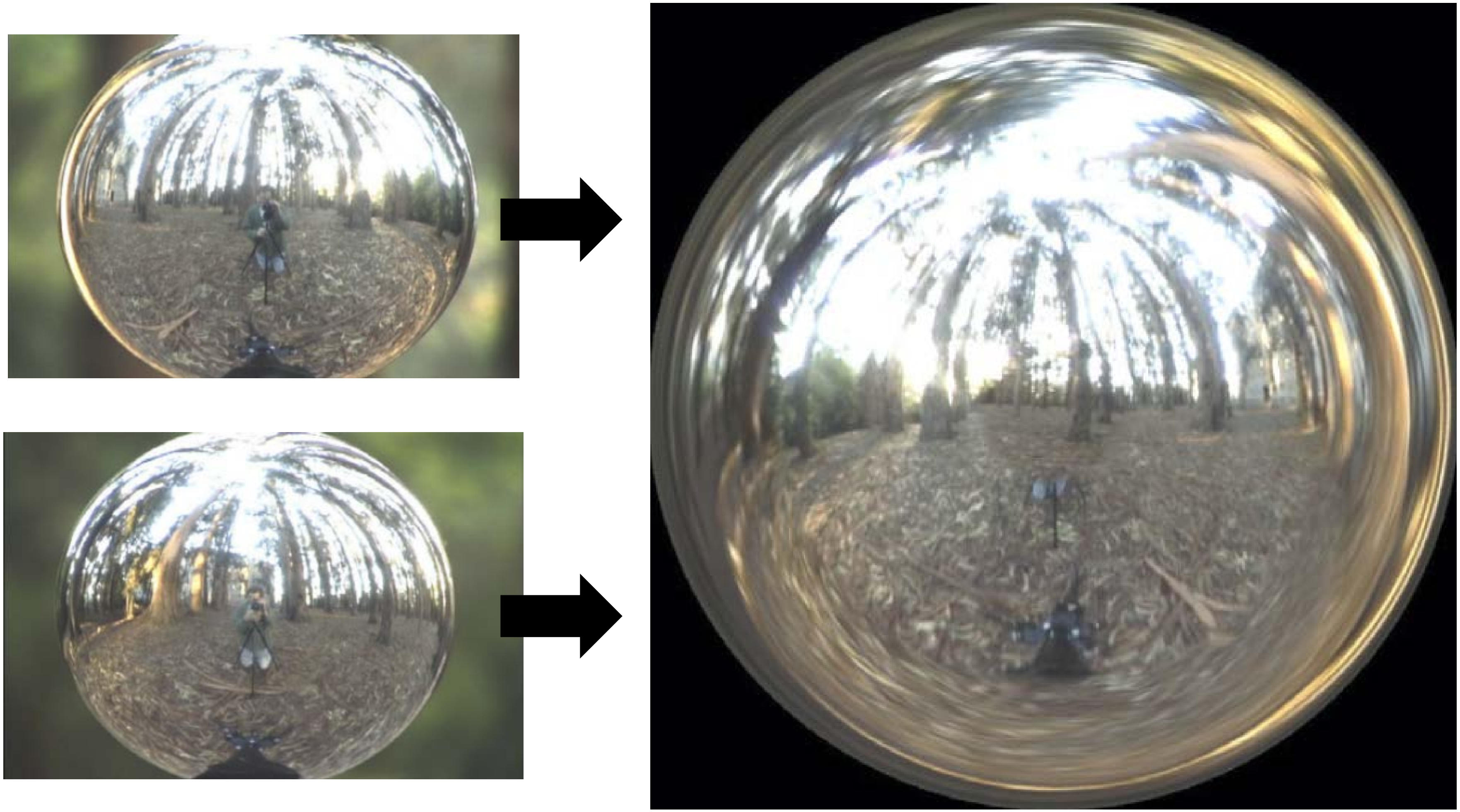
Acquiring the light probe

- High-dynamic range (HDR) imaging



Acquiring the light probe

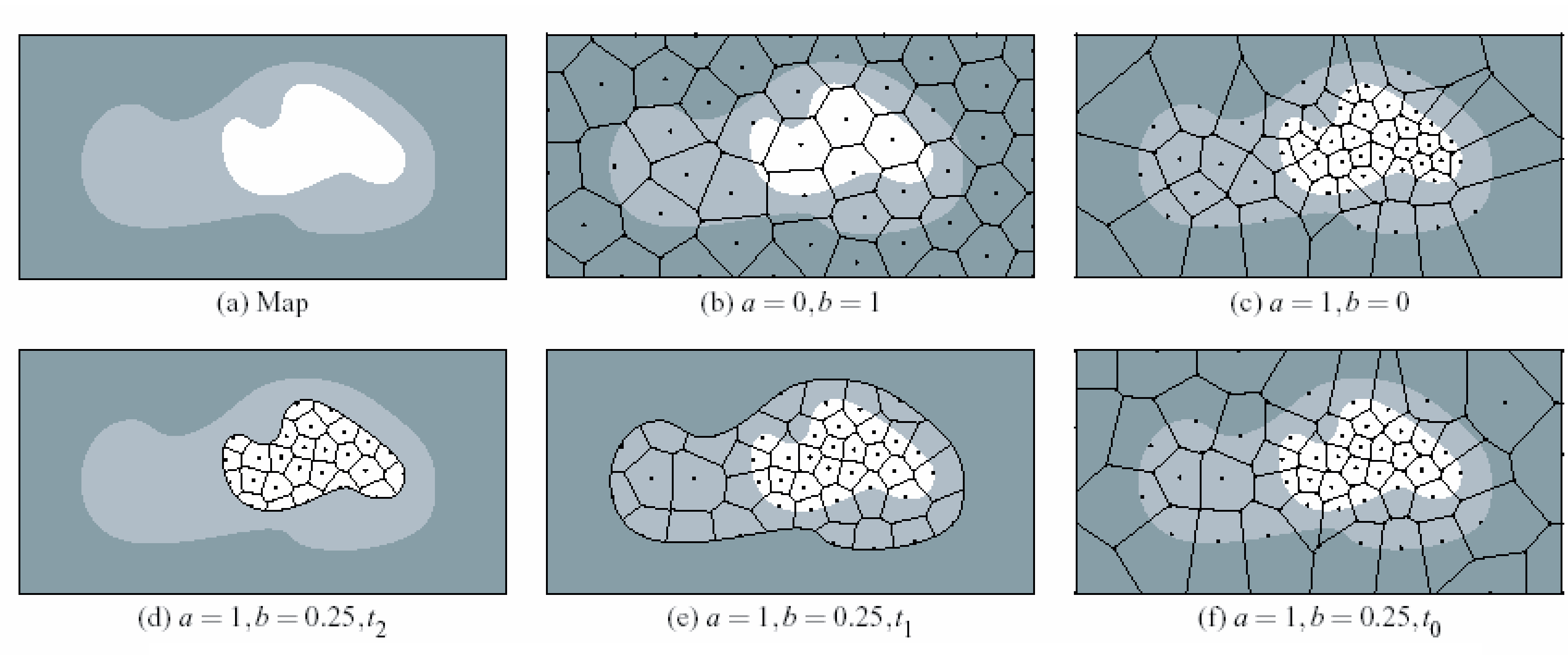
- High-dynamic range (HDR) imaging

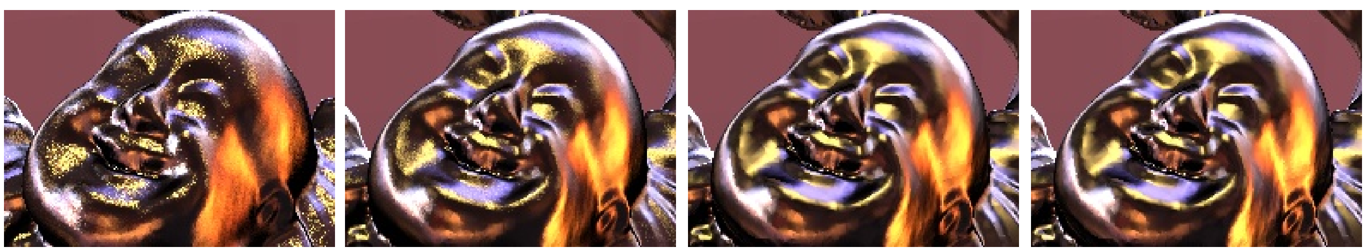


Rendering with natural light

Debevec 1998. Currently rendered using graphics hardware

Rendering using light probes





Importance sampling with 300 samples | Importance sampling with 3000 samples | Structured importance sampling with 300 samples | Structured importance sampling + sorting - 4.7 rays/pixel

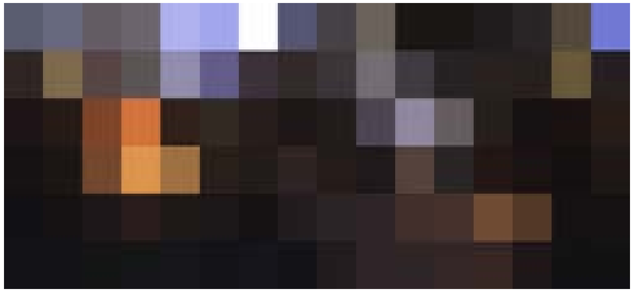
"Structured Importance Sampling of Environment Maps“ Agarwal, 2003

Image-based lighting real objects

- Light stage, Debevec et al. 2000

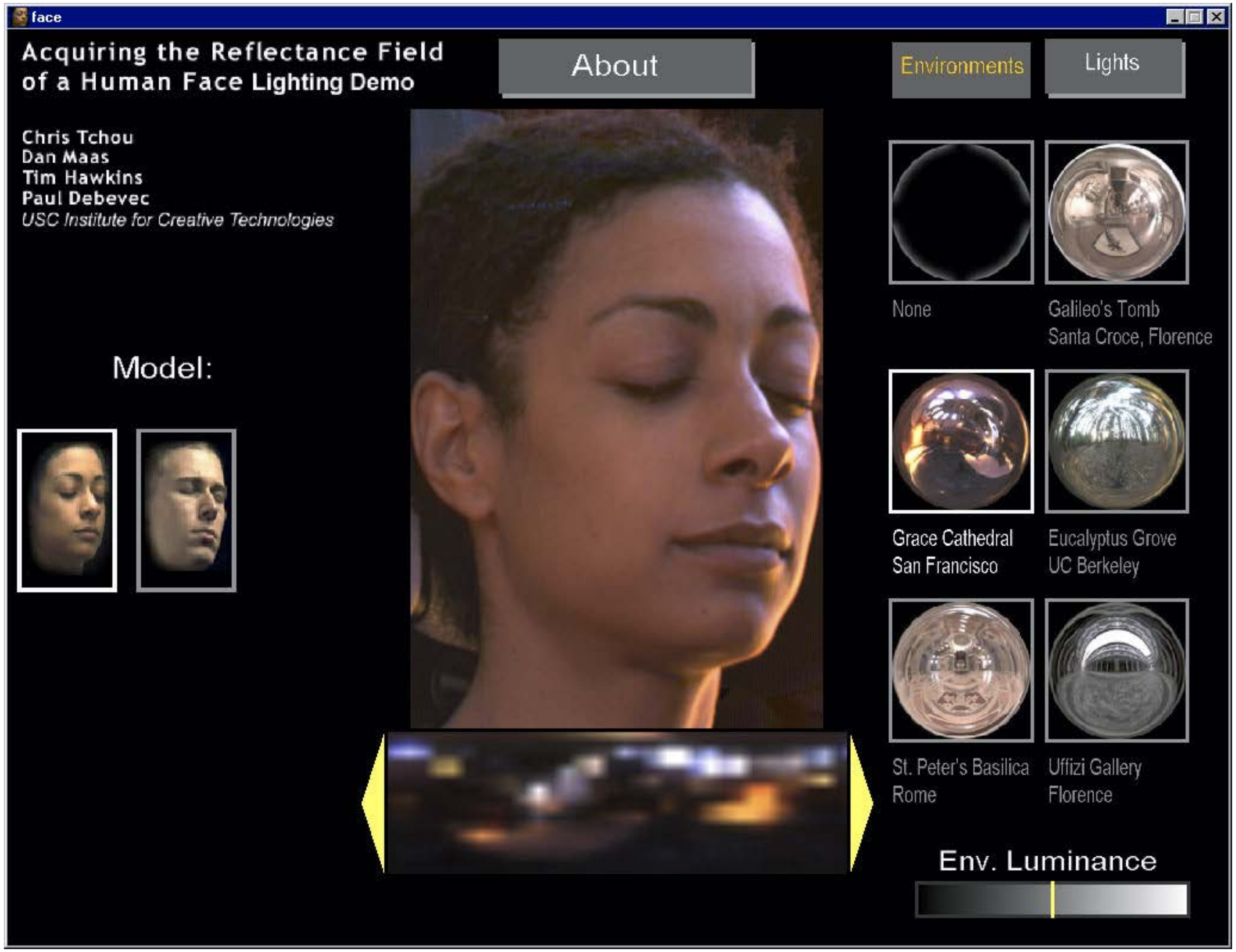
Light Stage – 4D Reflectance Field

- Fixed view, lights at infinity



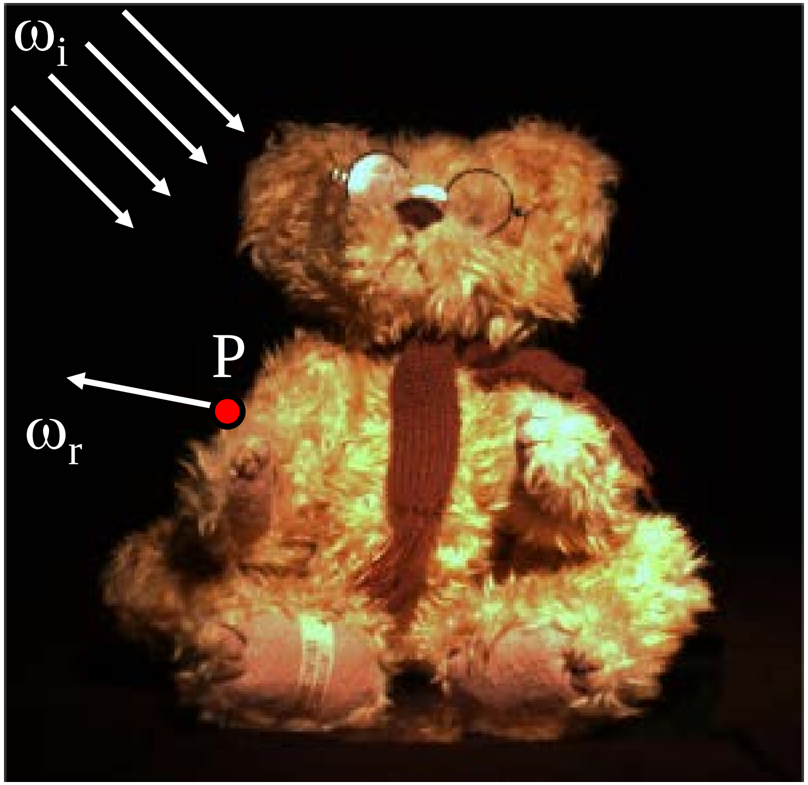
Face lighting demo

- Chris Tchou, Dan Maas, Tim Hawkins, and Paul Debevec
- http://www.debevec.org/Face



Surface Reflectance Field

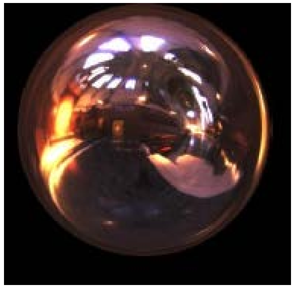
- 6D function: $R(P, \omega_i, \omega_r) = R(u_r, v_r; \theta_i, \Phi_i; \theta_r, \Phi_r)$



- Assumes directional illumination at infinity

Capturing 6D Function

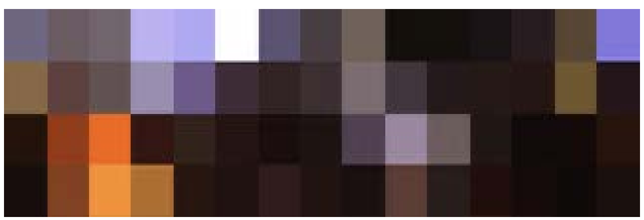
1st step: relighting original viewpoints



New Illumination

Down-sample

Surface reflectance field



x

=

V0

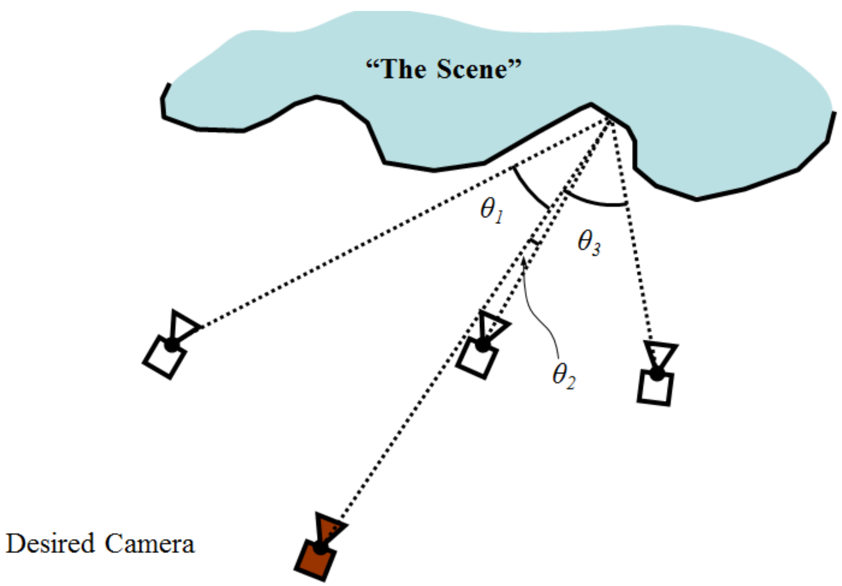
V1

V2

… Vn

2nd step: view interpolation

- Interpolate opacity and radiance.
  - Unstructured lumigraph interpolation [Buehler et al., 01]
  - View-dependent texture mapping [Debevec 98].
- From new viewpoint, for each surface point, find nearest acquired viewpoints and blend their values



Relighting Results

Relighting Results

Relighting Results

IBR&L Summary

- Advantages
  - Photorealistic - by definition
  - Do not have to create 3D detailed model
  - Do not have to do lighting simulation
  - Performance independent of scene
- Disadvantages
  - Dynamic scenes are difficult
  - Difficult for scenes with specularities, etc.
  - Limited range of viewpoints
  - Limited resolution