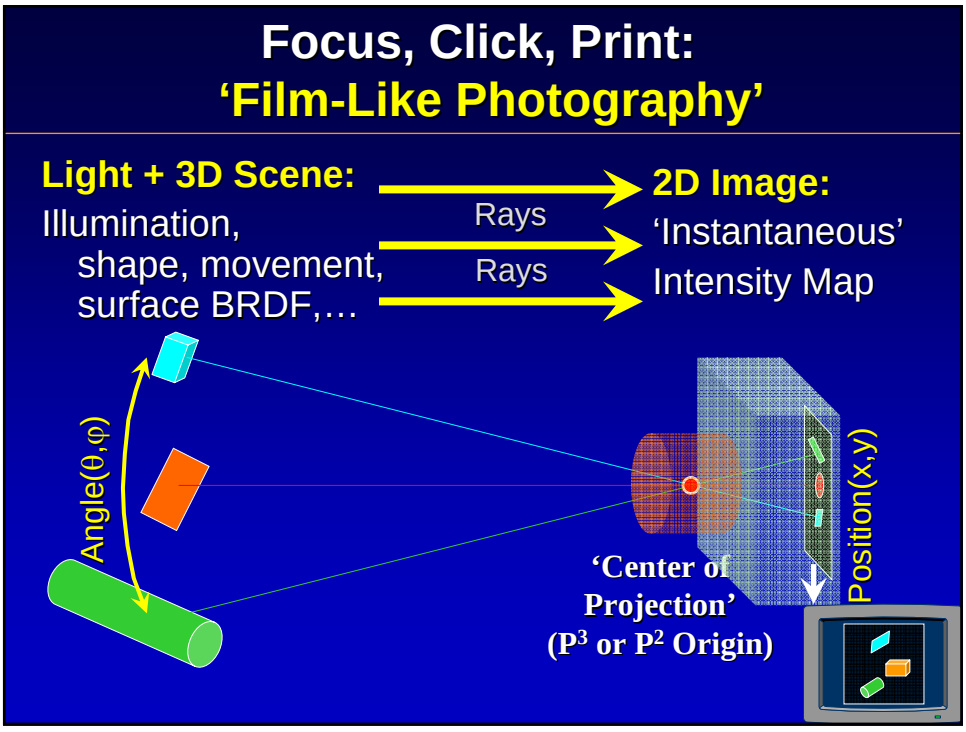
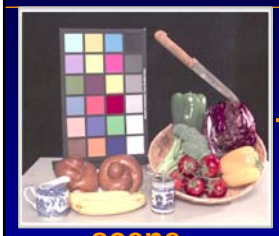
Computational Photography: Advanced Topics

Courtsey: Jack Tumblin, Northwestern University

Focus, Click, Print: 'Film-Like Photography'



Perfect Copy : Perfect Photograph?

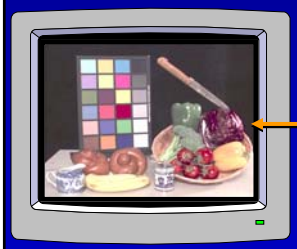


scene

Scene
Light
Intensities

'Pixel values'

(scene intensity? display intensity?
perceived intensity? 'blackness/whiteness' ?)



display

Display
Light
Intensities

'Film-Like' Photography

Ideals, Design Goals:

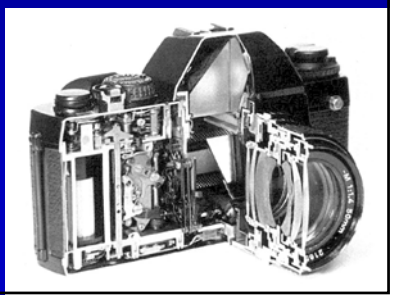
- 'Instantaneous' light measurement…
- Of focal plane image behind a lens.
- Reproduce those amounts of light.

Implied:

"What we see is ≅
focal-plane intensities."

well, no…we see *much* more!

(seeing is *deeply* cognitive)



Our Definitions

- **'Film-like' Photography:**

  Displayed image ≅ sensor image

- **'Computational' Photography:**

  Displayed image ≠ sensor image

  ≅ visually meaningful scene contents

  A more expressive & controllable displayed result, transformed, merged, decoded data from compute-assisted sensors, lights, optics, displays

What *is* Photography?

Safe answer:

A wholly new, expressive medium (ca. 1830s)

- Manipulated display of what we think, feel, want, …
  - Capture a memory, a visual experience in tangible form
  - 'painting with light'; express the subject's visual essence
  - *"Exactitude is not the truth."* –Henri Matisse

What *is* Photography?

- A 'bucket' word: a neat container for messy notions (e.g. aviation, music, comprehension)
- A record of what we see, or would like to see, in tangible form.
- **Does 'film' photography always capture it?** Um, no...
- **What do we see?**

Harold 'Doc' Edgerton 1936

What *is* Photography?

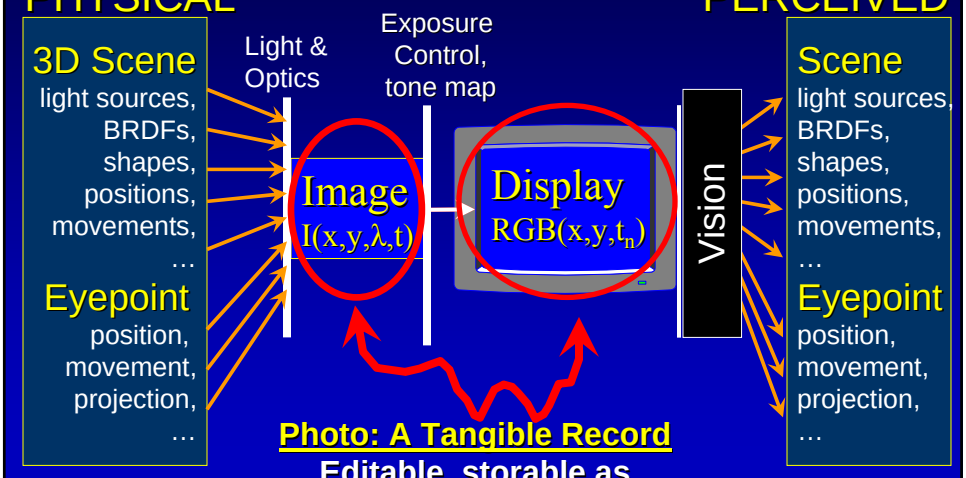
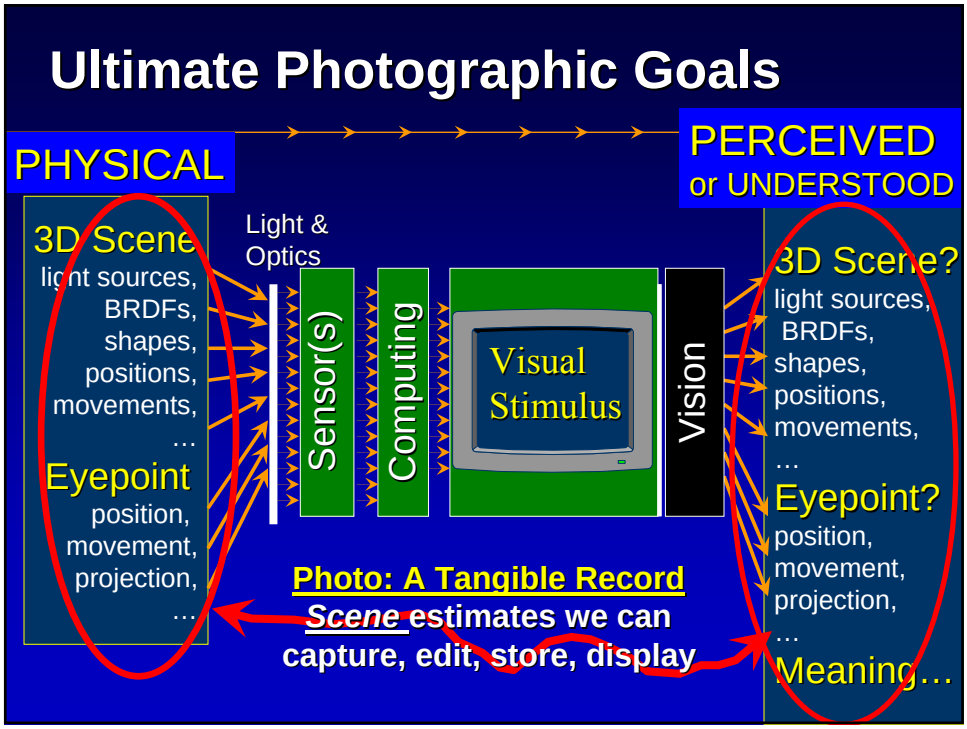


Photo: A Tangible Record
Editable, storable as Film or Pixels

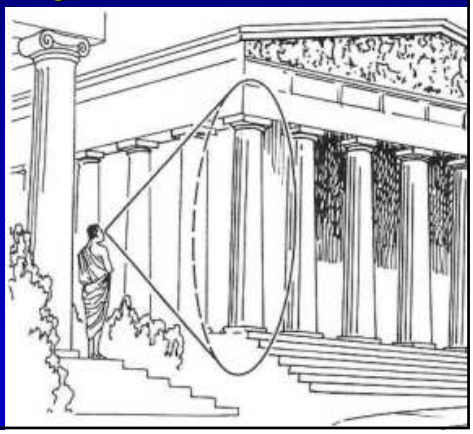
Ultimate Photographic Goals



Photographic Signal: ~~Pixels~~ Rays

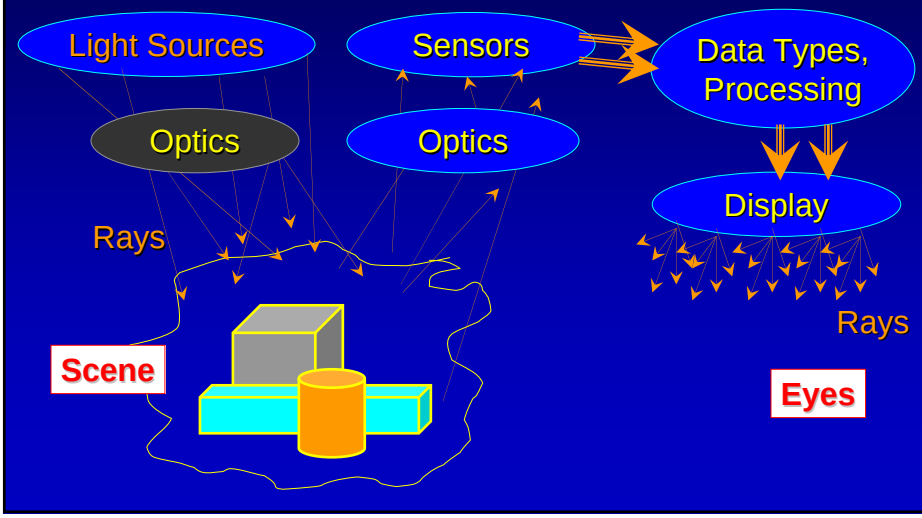
- Core ideas are ancient, simple, seem obvious:
  - **Lighting:** ray sources
  - **Optics:** ray bending/folding devices
  - **Sensor:** measure light
  - **Processing:** assess it
  - **Display:** reproduce it
- Ancient Greeks:
  'eye rays' wipe the world to feel its contents…

http://www.mlahanas.de/Greeks/Optics.htm



The Photographic Signal Path

Claim: Computing can improve *every* step



Review: How many Rays in a 3-D Scene?

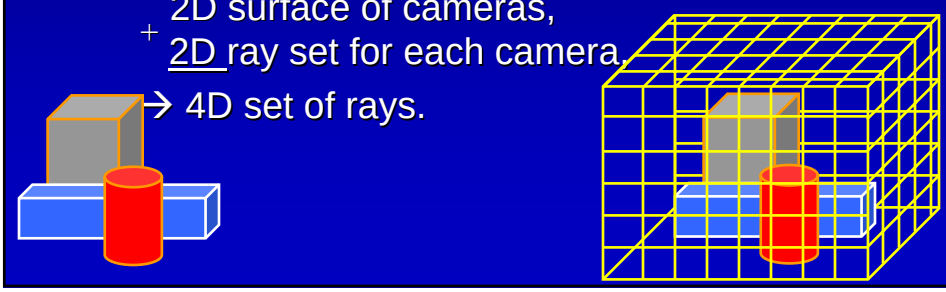
A 4-D set of infinitesimal members.

Imagine:

(Levoy et al. SIGG'96) (Gortler et al. '96)

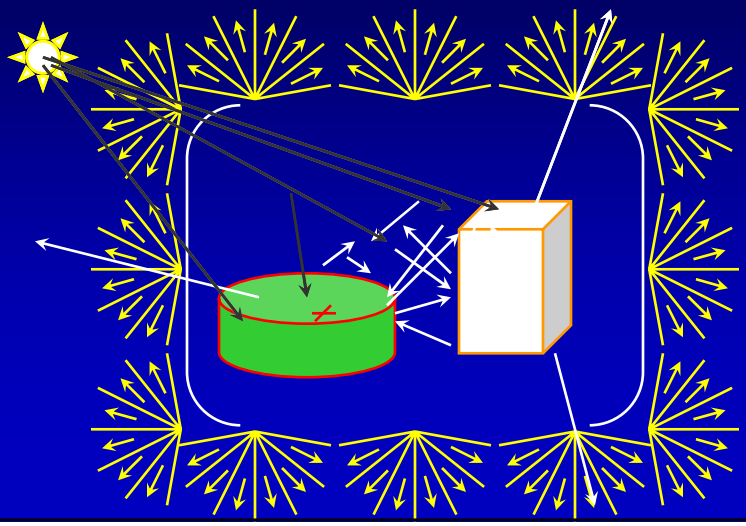
- Convex Enclosure of a 3D scene
- Inward-facing ray camera at every surface point
- Pick the rays you need for ANY camera outside.

\+ 2D surface of cameras,
2D ray set for each camera.
→ 4D set of rays.



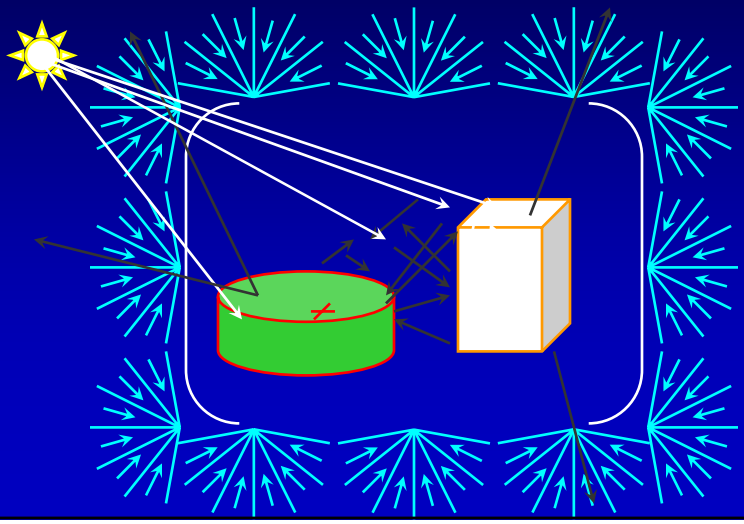
4-D Light Field / Lumigraph

Measure all the ***outgoing*** light rays.



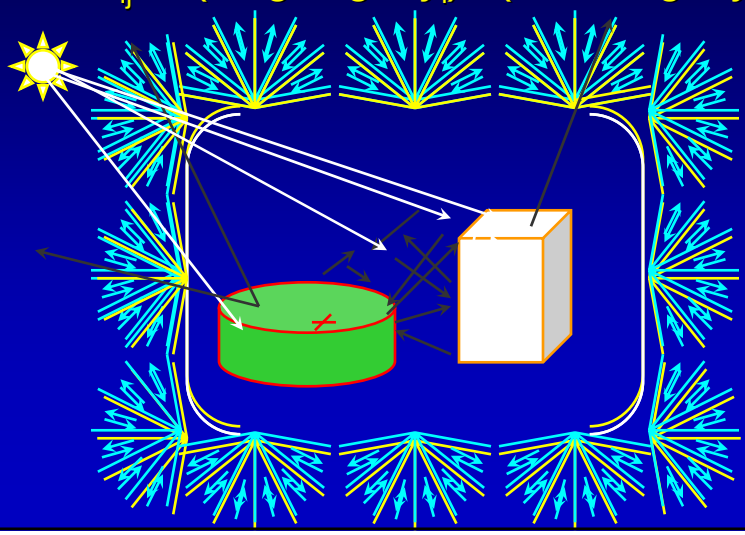
4-D Illumination Field

Same Idea: Measure all the ***incoming*** light rays



4D x 4D = 8-D Reflectance Field

Ratio: R_{ij} = (outgoing ray_i) / (incoming ray_j)



Because Ray *Changes* Convey Appearance

- These rays + all these rays give me…

- MANY more useful details I can examine…

Missing:
Expressive Time Manipulations

What other ways better reveal appearance to human viewers?

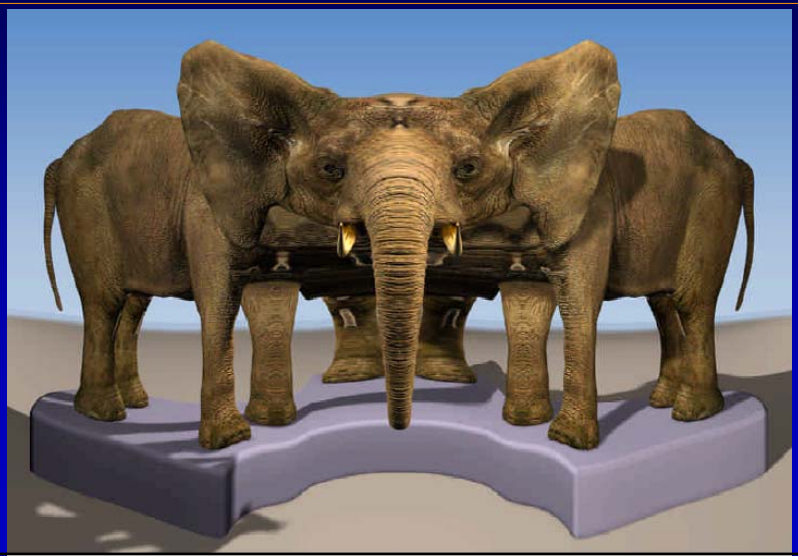
(Without direct shape measurement?)

Can you understand this shape better?

Time for space wiggle. Gasparini, 1998.

Missing:
Viewpoint Freedom

"Multiple-Center-of-Projection Images" Rademacher, P, Bishop, G., SIGGRAPH '98



Missing: Interaction…

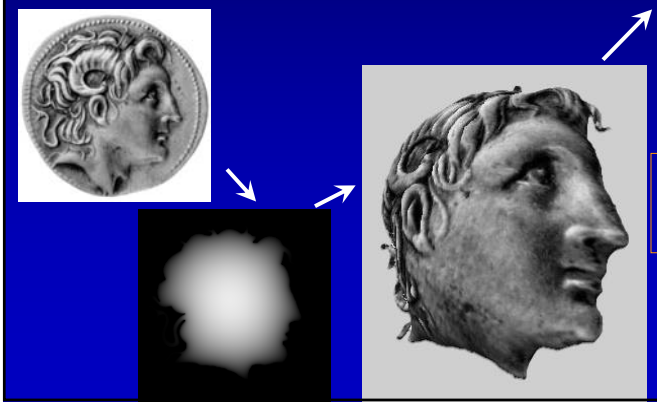
Adjust everything: lighting, pose, viewpoint, focus, FOV,…

Winnemoller EG 2005: after Malzbender, SIGG2001

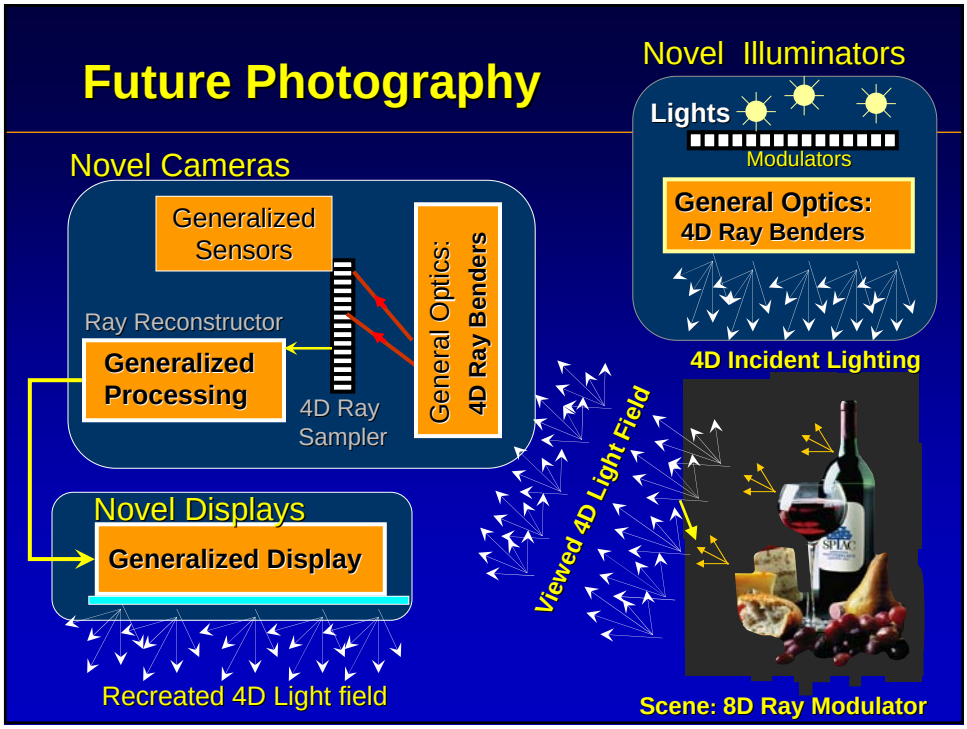
Mild Viewing & Lighting Changes; (is true 3D shape necessary?)

Convicing visual appearance:
Is Accurate Depth really necessary?

a few good 2-D images may be enough…



"Image jets, Level Sets, and Silhouettes"
Lance Williams,
talk at Stanford, 1998.



'The Ideal Photographic Signal'

I CLAIM IT IS:

~~All Rays? Some Rays?~~ ***Changes*** **in Some Rays**

Photographic ray space is vast and redundant
>8 dimensions: 4D view, 4D light, time, λ,

? Gather only 'visually significant' ray changes ?

? What rays should we measure ?
? How should we combine them ?
? How should we display them ?

Beyond ‘Film-Like’ Photography

Call it **‘Computational Photography’:**
To make ‘meaningful ray changes’ tangible,

- **Optics** can do more…
- **Sensors** can do more…
- **Light Sources** can do more…
- **Processing** can do more…

by applying low-cost storage, computation, and control.

Background

- Plenoptic Modeling
- Light Field
- Reflectance Field

Plenoptic Modeling

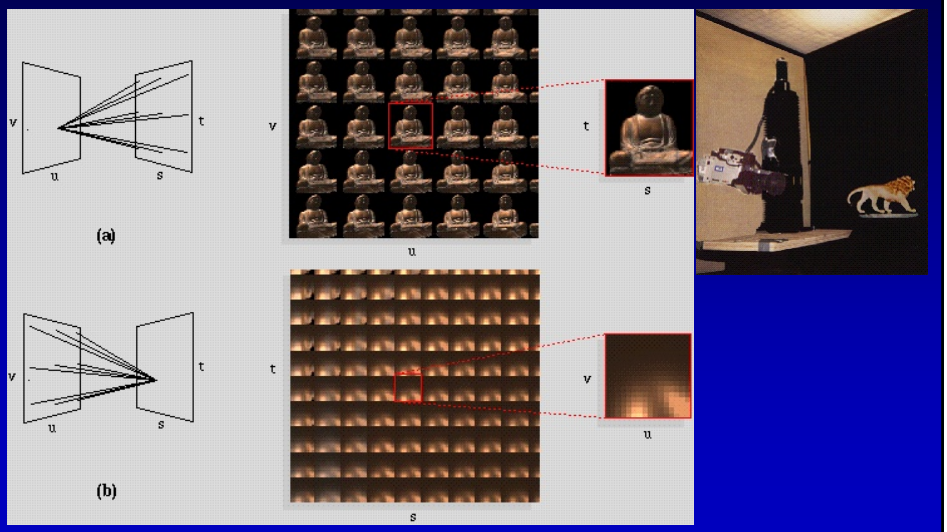
Panoramic view (cylinder opened up on a plane)

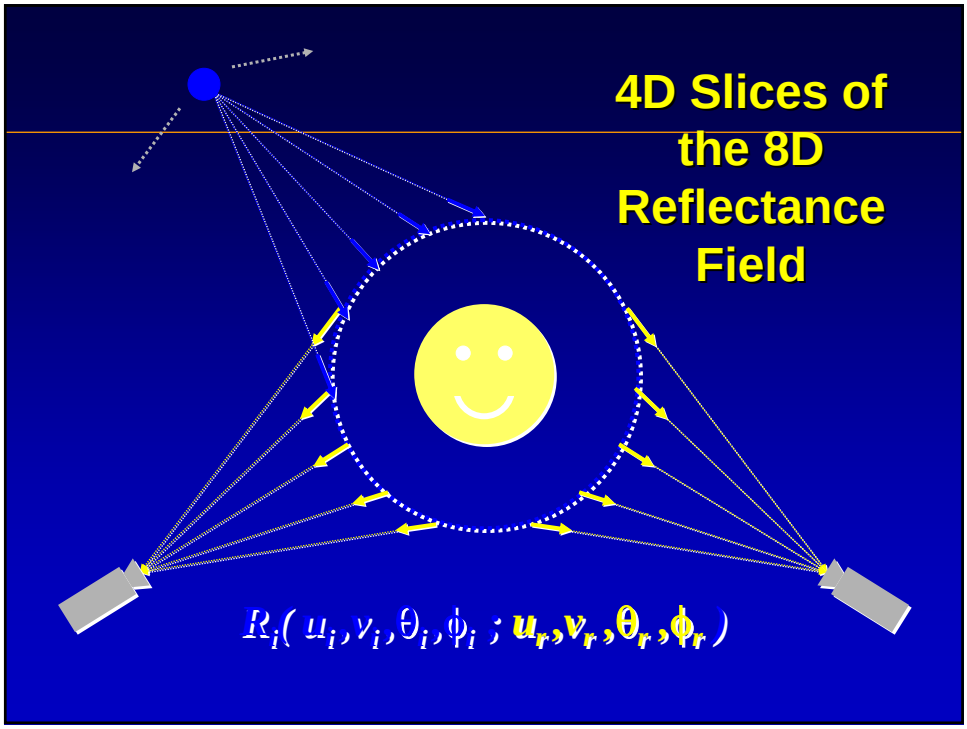
Panoramic view from 60 inches away

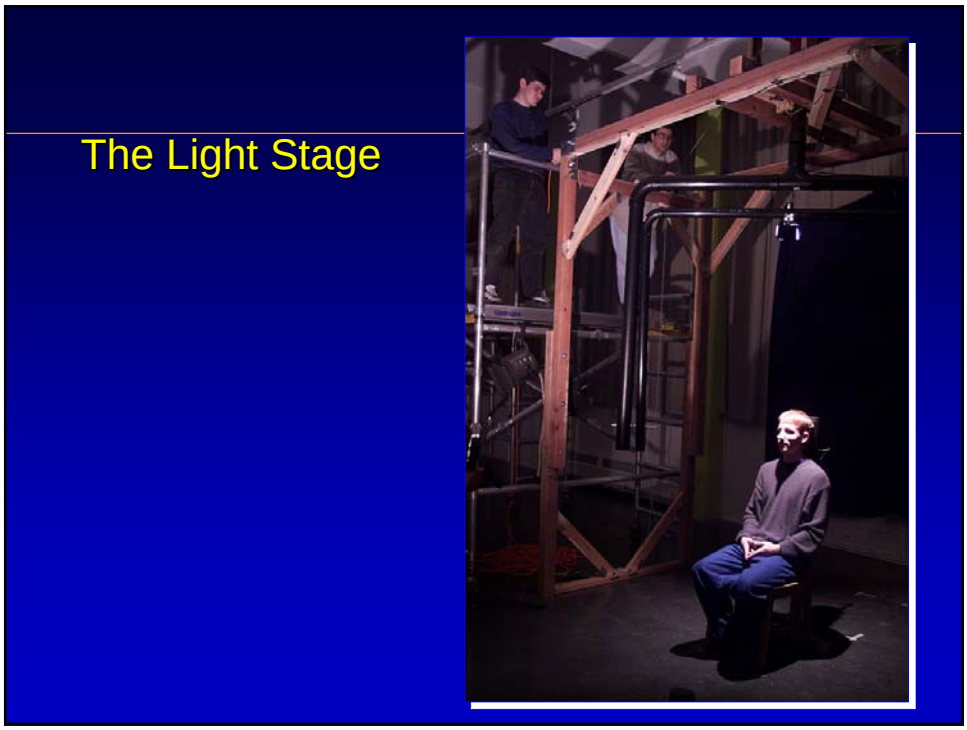
New Views

–http://www.cs.unc.edu/~ibr/pubs/mcmillan-plenoptic/plenoptic-abs.html

Light field/Lumigraph




4D Slices of the 8D Reflectance Field
$R_i(u_i, v_i, \theta_i, \phi_i ; u_r, v_r, \theta_r, \phi_r)$


The Light Stage

Light Stage Data

Original Resolution: 64×32

Light Stage Results

Environments from the **Light Probe Image Gallery**
www.debevec.org