Visual Information and Image Acquisition

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IMPA

Outline

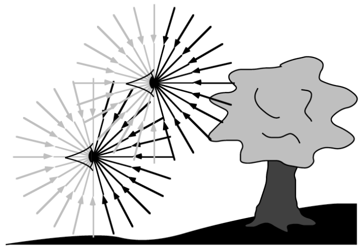
- Mathematical Concepts
  - Plenoptic Function
  - Light Fields
- Image Acquisition
  - Cameras
  - Lenses

Plenoptic Function

Complete description of Visual Information in a 3D environment

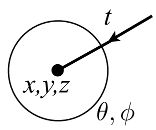
- $I_\lambda = P(x, y, z, \theta, \phi, t)$

  Holographic Image



- $P : \mathbb{R}^3 \times \mathbb{S}^2 \times \mathbb{R} \mapsto \mathcal{E}$

  6D Phase Space



OBS: No Explicit Geometry

Light Field

A Slice of the Plenoptic Function

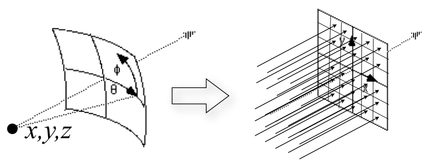
✳ Structured Sampling of P

- Dimension of a Light Field
  - 2D
  - 3D
  - 4D

Cameras

- Point Sampling (0D + 2D = 2D)

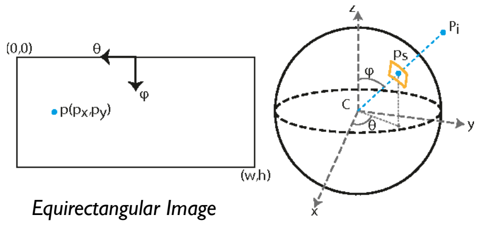
  - Pinhole *Camera*



Normal Image

Ray Space

  - Omnidirectional *Camera*



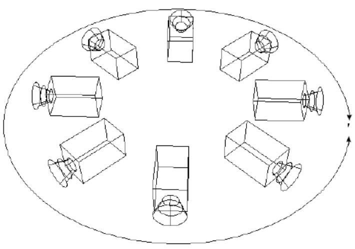
Equirectangular Image

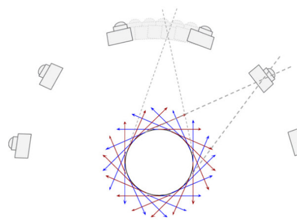
x,y,z fixed / limited FOV

x,y,z fixed / 360 FOV

Stereo Panoramas

- Line Sampling (1D + 2D = 3D)



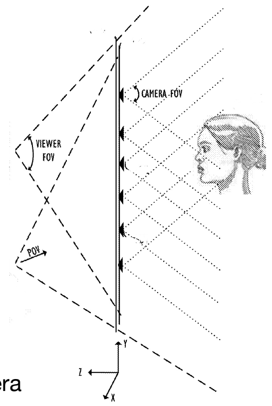


- Examples
  - Google Jump
  - Facebook 360 Surround

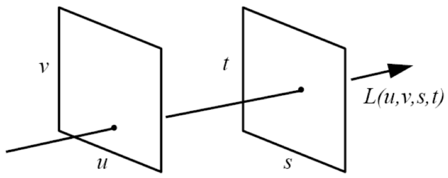
More on That Later …

Full Light-Field Cameras

- Surface Sampling (2D + 2D = 4D)



Ex: Lytro Camera



Two Plane Parametrization

More on That Later …

Cameras & Lenses

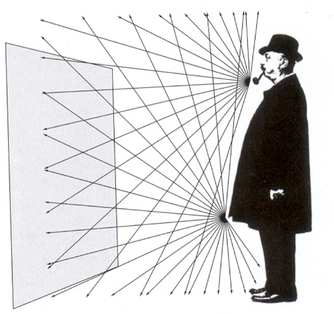
based on slides by Fredo Durand

Lens Design Principles

- **Motivation**
- **Pinhole Geometric Optics**
- **Simple Lenses**

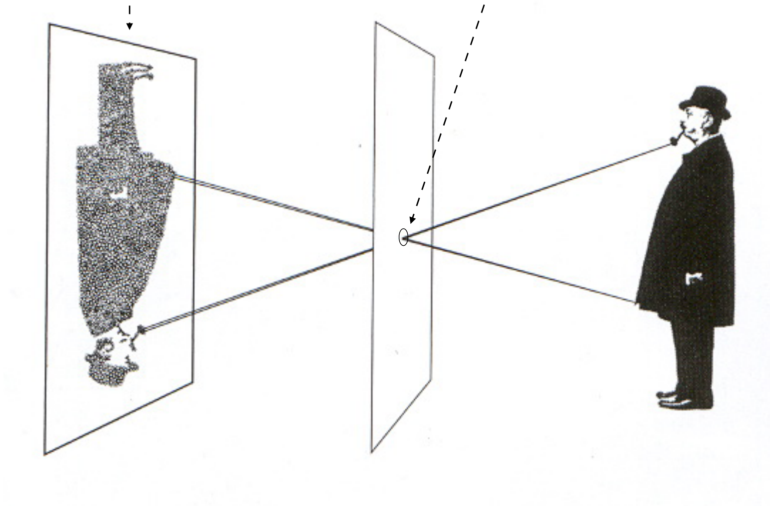
Why not use sensors without optics?

- It receives light from all directions
- It gets all possible images from all possible viewpoints
- We need to be more selective



From Photography, London et al.

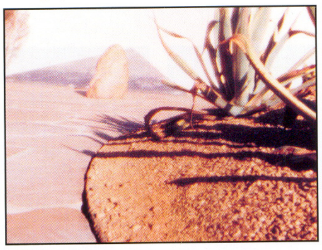
Pinhole Camera

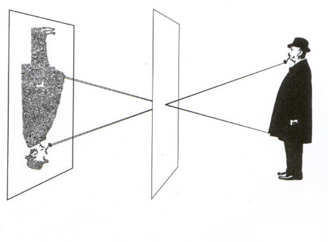


From Photography, London et al.

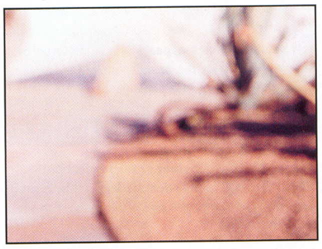
Pinhole size? Effect..

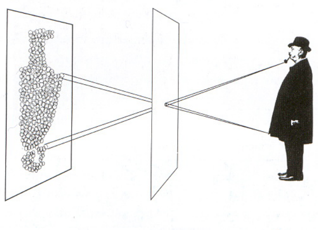
Photograph made with small pinhole





Photograph made with larger pinhole

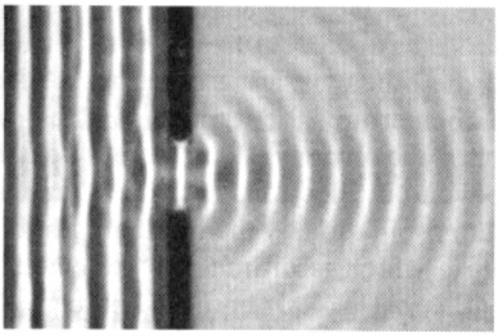




From Photography, London et al.

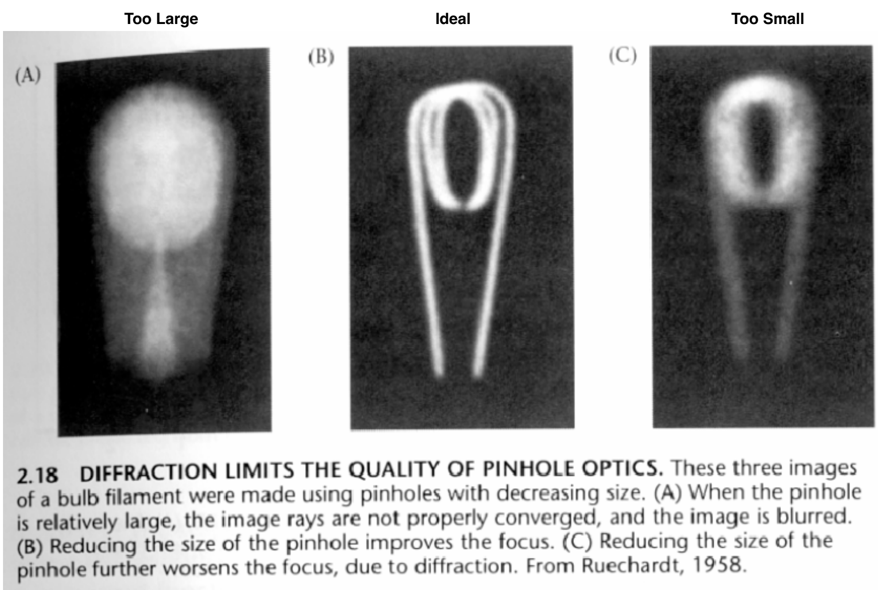
Diffraction

- Wave nature of light
- Smaller aperture means more diffraction
- For Fourier fans:
  - diffraction pattern = Fourier transform of the aperture. Smaller aperture means bigger Fourier spectrum.



diffraction of water waves

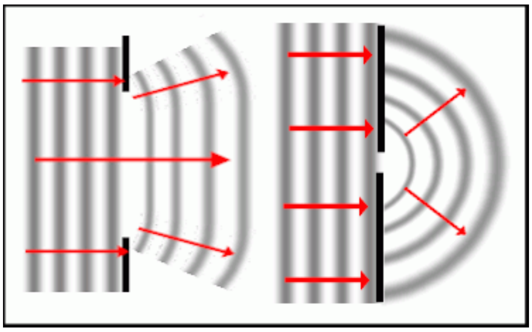
Diffraction limit!



From Wandell

Bottom line

- The smaller the hole, the more diffraction



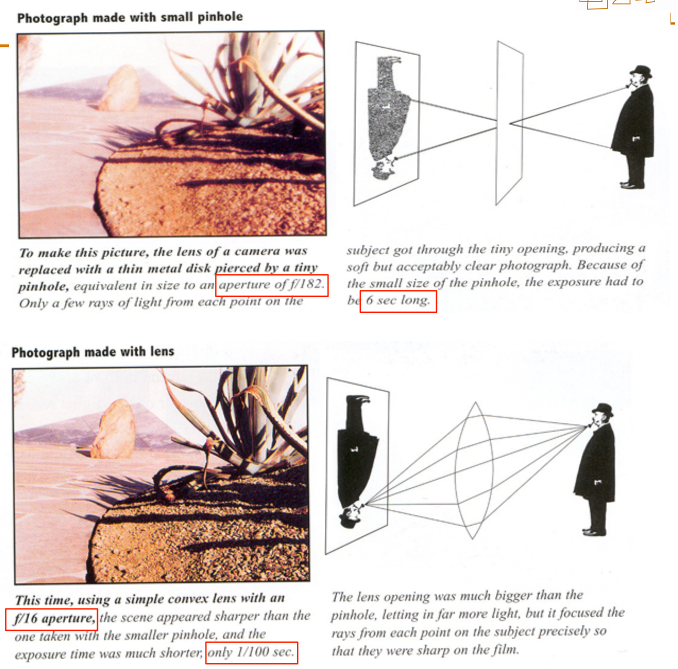
http://www.mashpedia.com/Ripple_tank

Pinhole? Alternative

- **Problem**
  - Small Pinhole:
    - Not enough light!
    - Diffraction limits sharpness
- **Solution**
  - Refraction
  - i.e., Lenses

Lenses

- Gather more light!
- But need to be focused



Small Aperture
Long Exposure

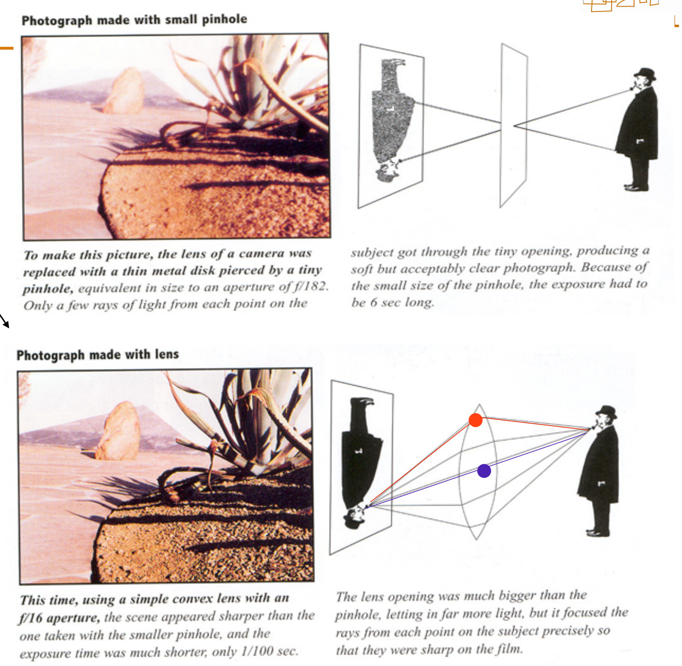
Large Aperture
Short Exposure

From Photography, London et al.

Lenses

- Essentially add multiple pinhole images
- ~ shift them to align (refraction)
- Alignment works only for one distance

Focus



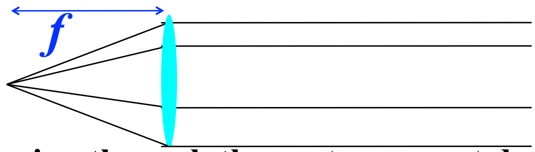
From Photography, London et al.

Thin lens optics

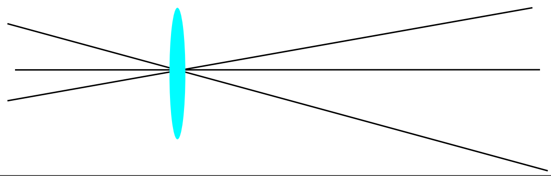
CSAIL

- **Simplification of geometrical optics for well-behaved lenses**

- **All parallel rays converge to one point on a plane located at the focal length *f***

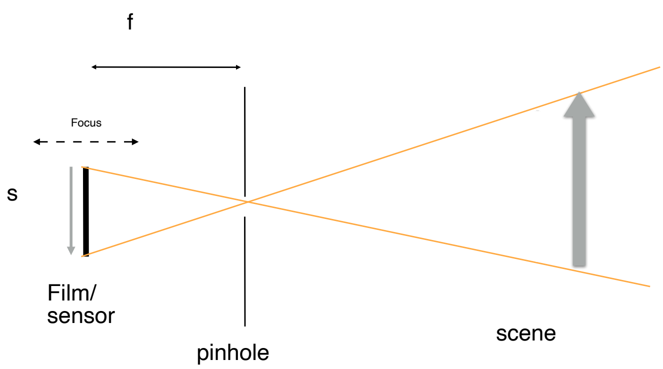


- **All rays going through the center are not deviated**
  – Hence same perspective as pinhole



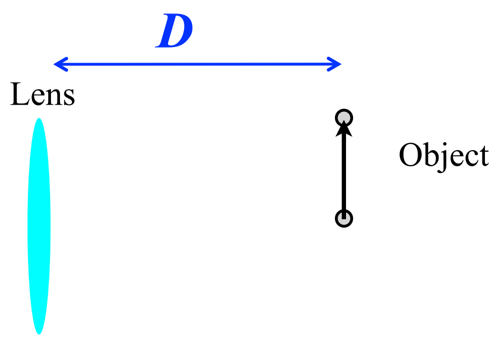
Focal length

CSAIL



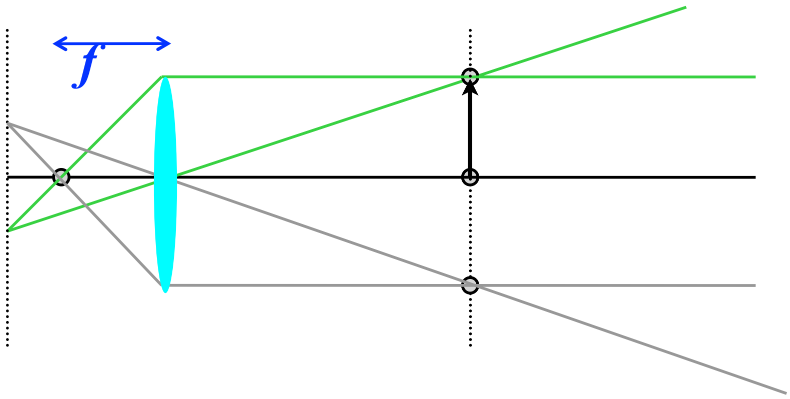
How lenses focus

- **Let's look at an object at distance D**



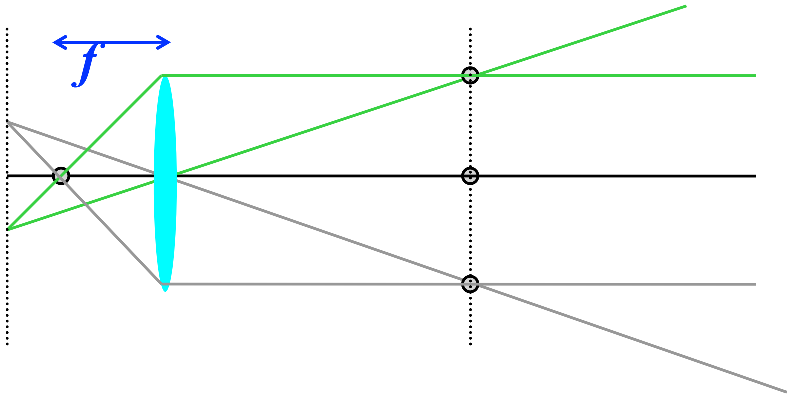
How to trace rays

- **Start by rays through the center**
- **Choose focal length, trace parallels**
- **You get the focus plane for a given scene plane**
  – All rays coming from points on a plane parallel to the lens are focused on another plane parallel to the lens



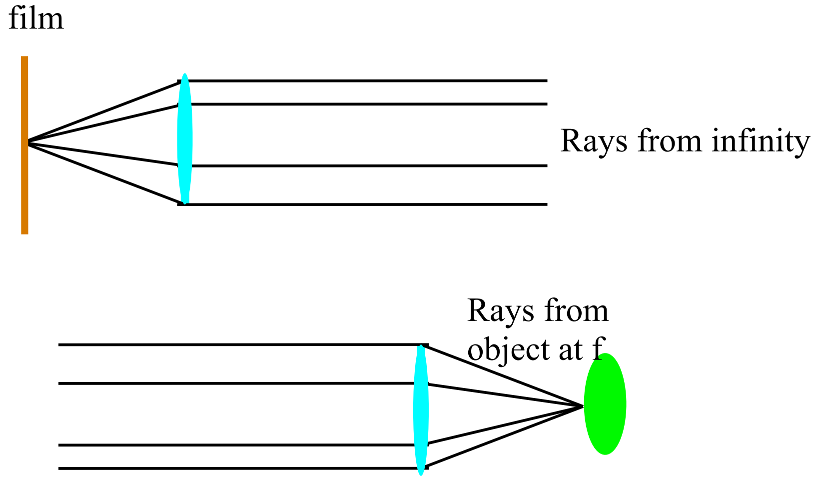
Focusing

- **To focus closer than infinity**
  - Move the sensor/film ***further*** than the focal length



Minimum focusing distance

- **By symmetry, an object at the focal length requires the film to be at infinity.**



Cameras & Light Fields

adapted from slides by Fredo Durand

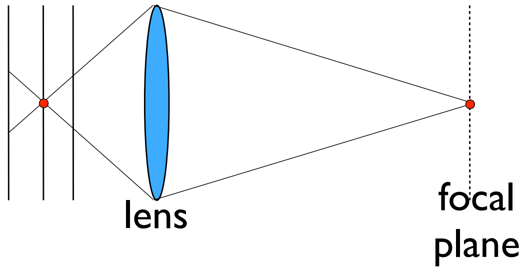
Overview

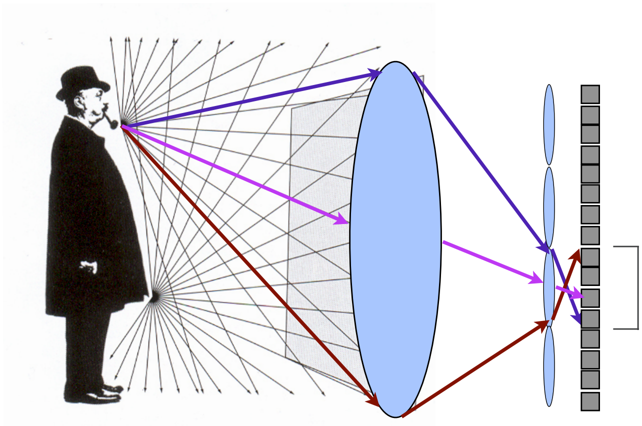
- 4D Light Fields
- Omnidirectional Light Fields
- RDB-D

4D Light Field Acquisition and Representation

Focusing / defocus in a regular camera

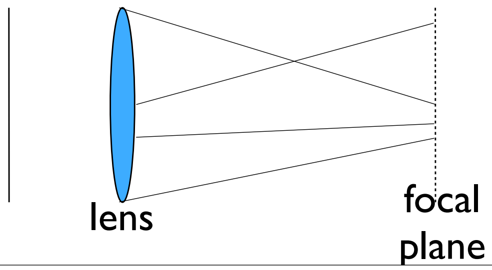
- Each pixel is the integral of many light rays across the aperture
- Which rays are integrated at which pixel changes the focus
- Idea: *capture rays, not pixels*





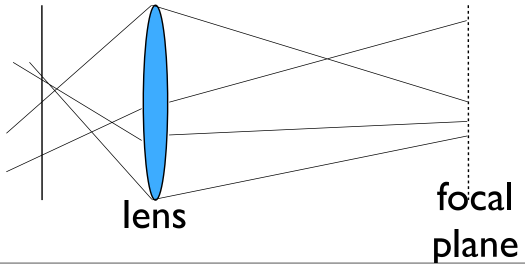
For a camera

- Capture all rays reaching the lens
- 4D:
  - 2D for lens aperture
  - 2D for focal plane (or any other plane)



For a camera: conjugate

- Same on the image side
- 4D:
  - 2D for lens aperture
  - 2D for sensor



Two-plane parameterization

- **Line parameterized by intersection with 2 planes**
  - Careful, there are different "isotopes" of such parameterization (slightly different meaning of *st uv*)

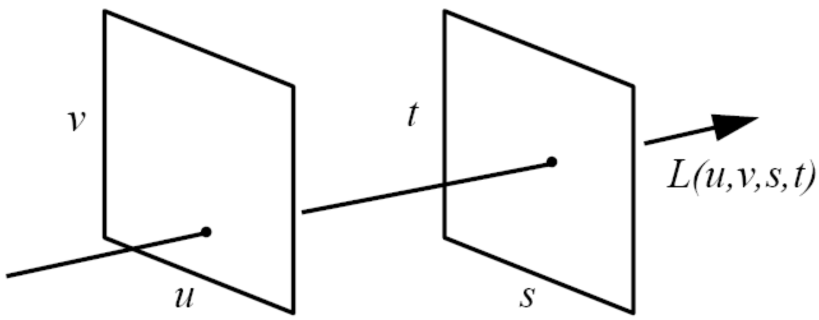
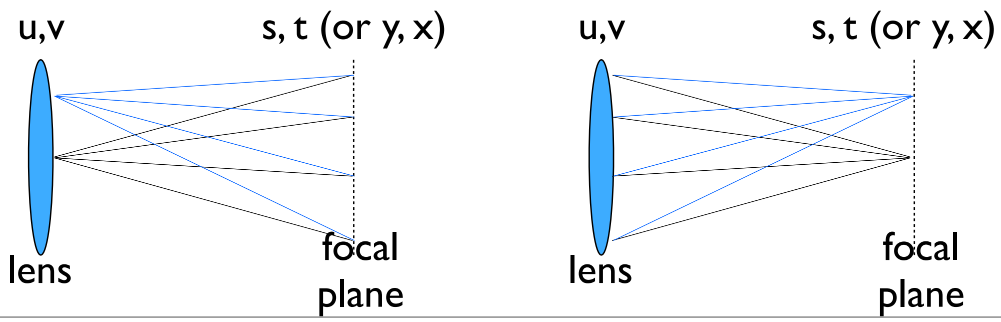


Figure 1: The light slab representation.

Understanding 4D

- 2D slices
  - constant u, v:
    - regular pinhole images from different aperture points
  - constant x, y: aperture view
    - how much the color of a point on the focal plane varies with angle (but depends on depth)



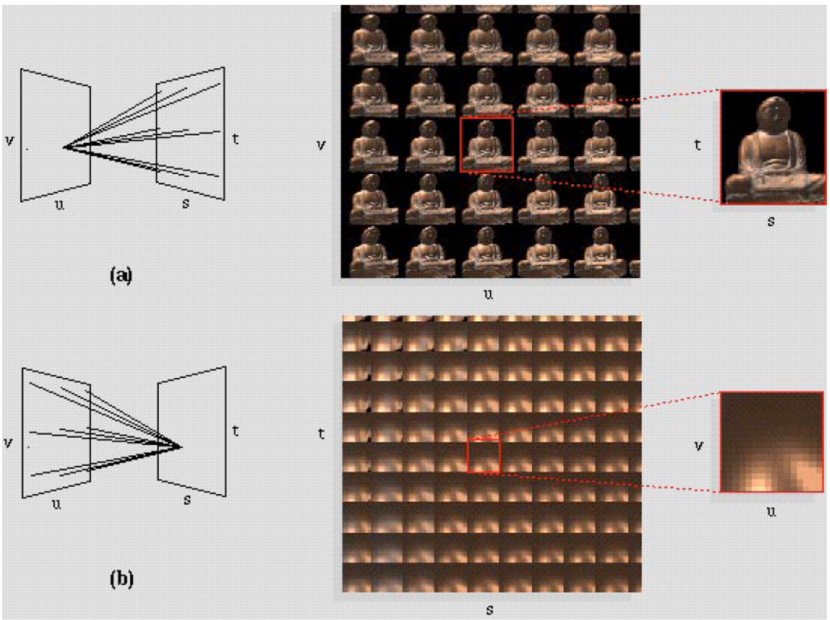


Figure 6: Two visualizations of a light field. (a) Each image in the array represents the rays arriving at one point on the uv plane from all points on the st plane, as shown at left. (b) Each image represents the rays leaving one point on the st plane bound for all points on the uv plane. The images in (a) are off-axis (i.e. sheared) perspective views of the scene, while the images in (b) look like reflectance maps. The latter occurs because the object has been placed astride the focal plane, making sets of rays leaving points on the focal plane similar in character to sets of rays leaving points on the object.

Cool visualization

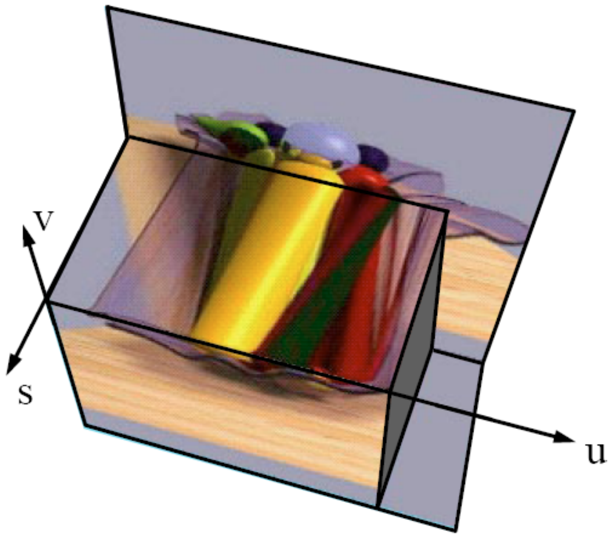


Figure 7: An (s, u, v) slice of a Lumigraph

From Gortler et al.

View = 2D plane in 4D

- **With various resampling issues**

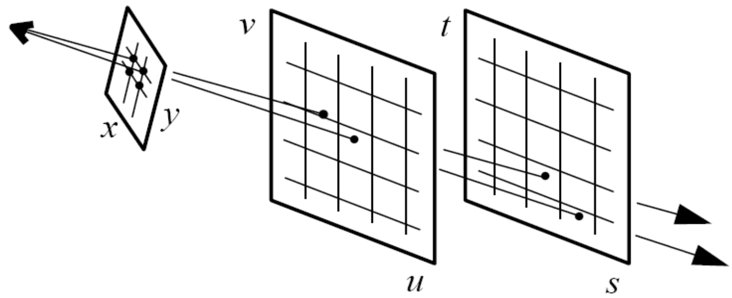


Figure 12: The process of resampling a light slab during display.

Light field pinhole rendering

- **For each pixel x,y in new view**
  - –consider ray from viewpoint to pixel
  - –compute intersection with two planes => s, t, u, v
  - –lookup RGB in light field at s, t, u, v

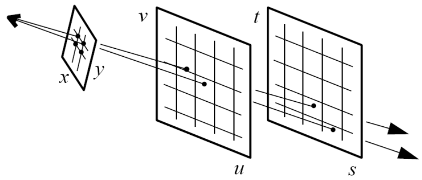
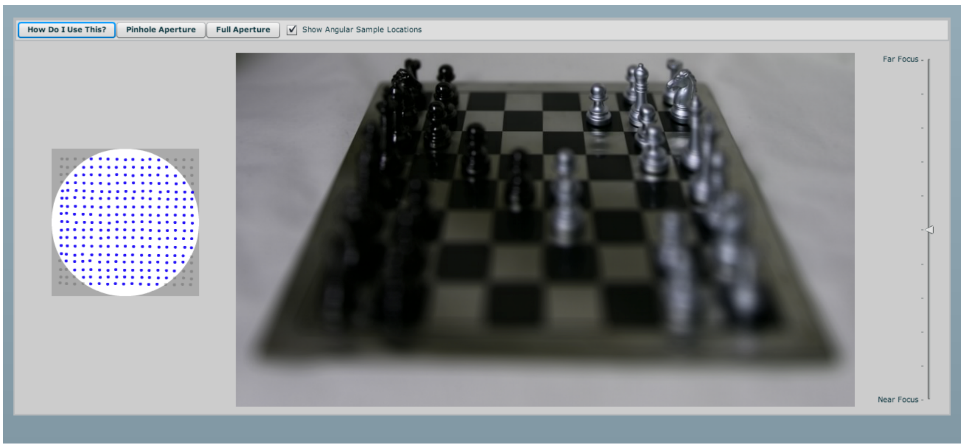


Figure 12: The process of resampling a light slab during display.

OBS: Good Resampling Benefits from Depth Information!

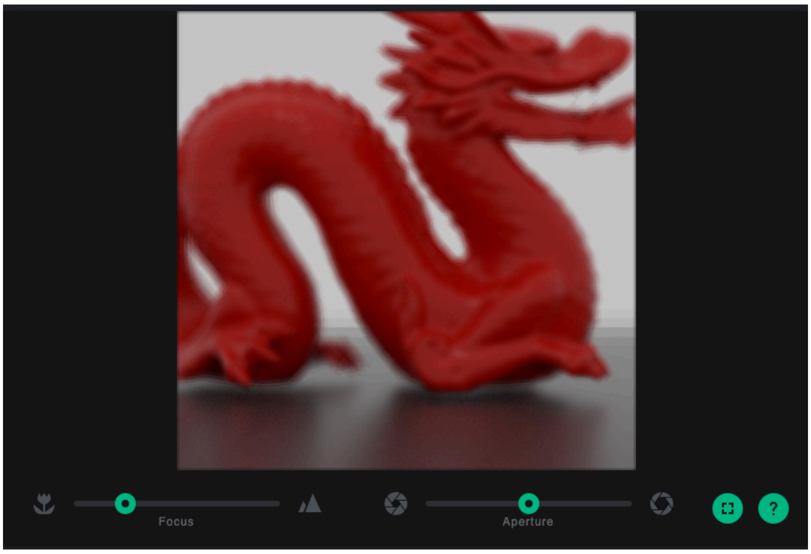
Demo light field viewer

- **http://lightfield.stanford.edu/lfs.html**



Light Field Viewer

- https://raytracey.neocities.org/

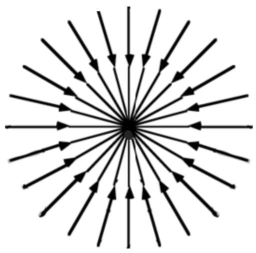


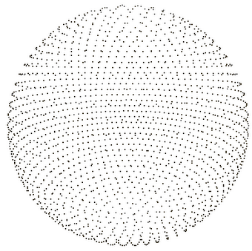
Omnidirectional Light Fields

Omnindirectional Image

The Set of <u>All Rays</u> incident at <u>a point</u> (x,y,z)

- Spherical Light Field
  - 360 degrees (2D)





Capturing Spherical Light Fields

- Omnidirectional Cameras
  - Catadioptric
  - Dioptric
  - Multi-Camera

More on That Later …

360˚ Image Formats

Omnidirectional Panoramas

- Parametrizations of the Sphere
  - Lat-Long
  - Cube Map
  - Azimuthal
  - Stereographic

More on That Later …

What About RGB-D ?

Images with Depth

- Enters Geometry
  - 2 1/2 D
- Layered Panoramas

More on That Later …