

Modeling Light



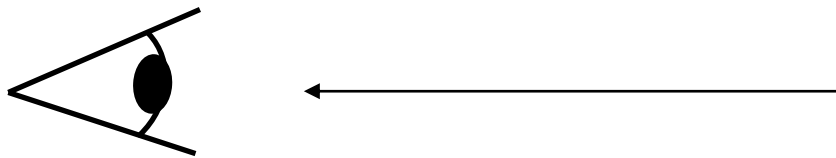
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15-463: Computational Photography
Alexei Efros, CMU, Spring 2010

What is light?

Electromagnetic radiation (EMR) moving along rays in space

- $R(\lambda)$ is EMR, measured in units of power (watts)
 - λ is wavelength

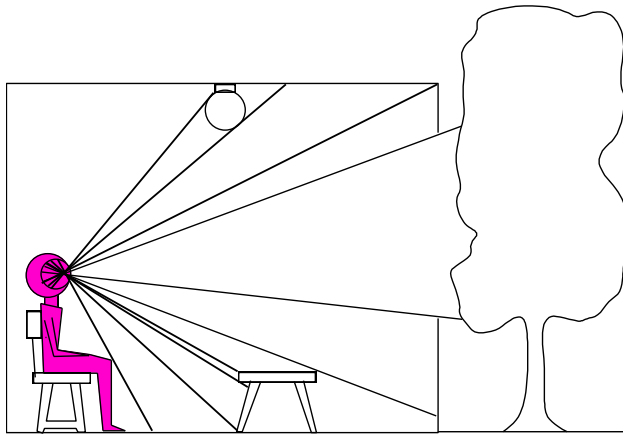


Useful things:

- Light travels in straight lines
- In vacuum, radiance emitted = radiance arriving
 - i.e. there is no transmission loss

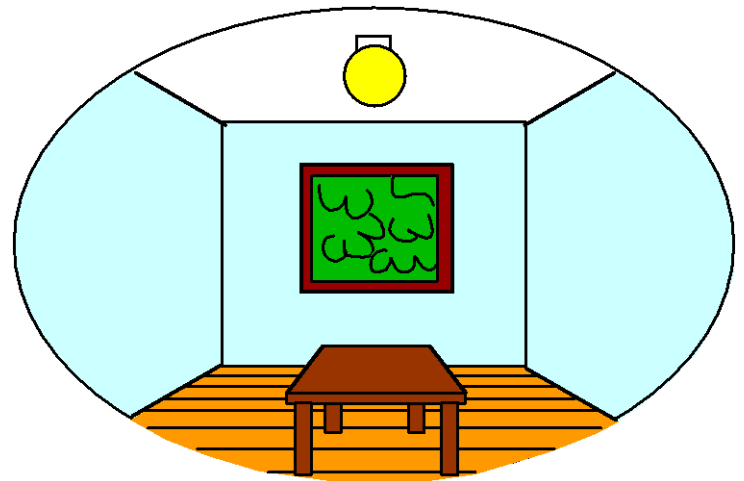
What do we see?

3D world



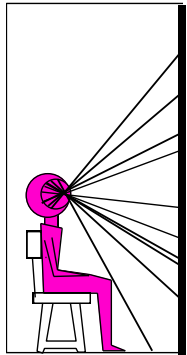
Point of observation

2D image



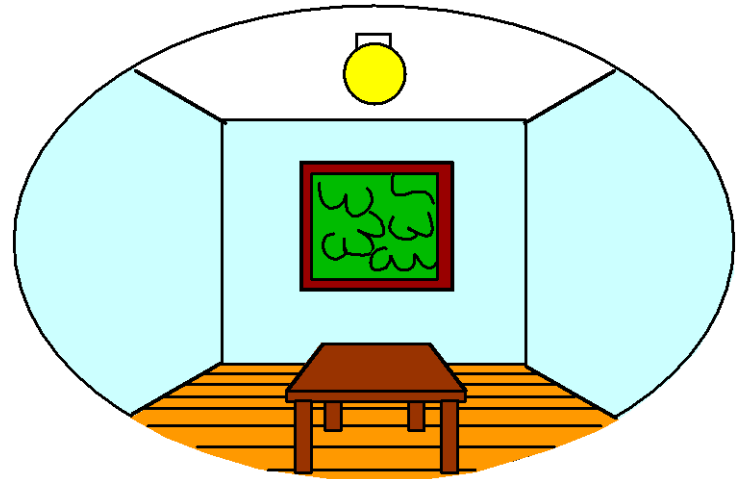
What do we see?

3D world



Painted
backdrop

2D image



On Simulating the Visual Experience

Just feed the eyes the right data

- No one will know the difference!

Philosophy:

- Ancient question: “Does the world really exist?”

Science fiction:

- Many, many, many books on the subject, e.g. *slowglass* from [“Light of Other Days”](#)
- Latest take: *The Matrix*

Physics:

- *Slowglass* might be possible?

Computer Science:

- Virtual Reality

To simulate we need to know:

What does a person see?

The Plenoptic Function

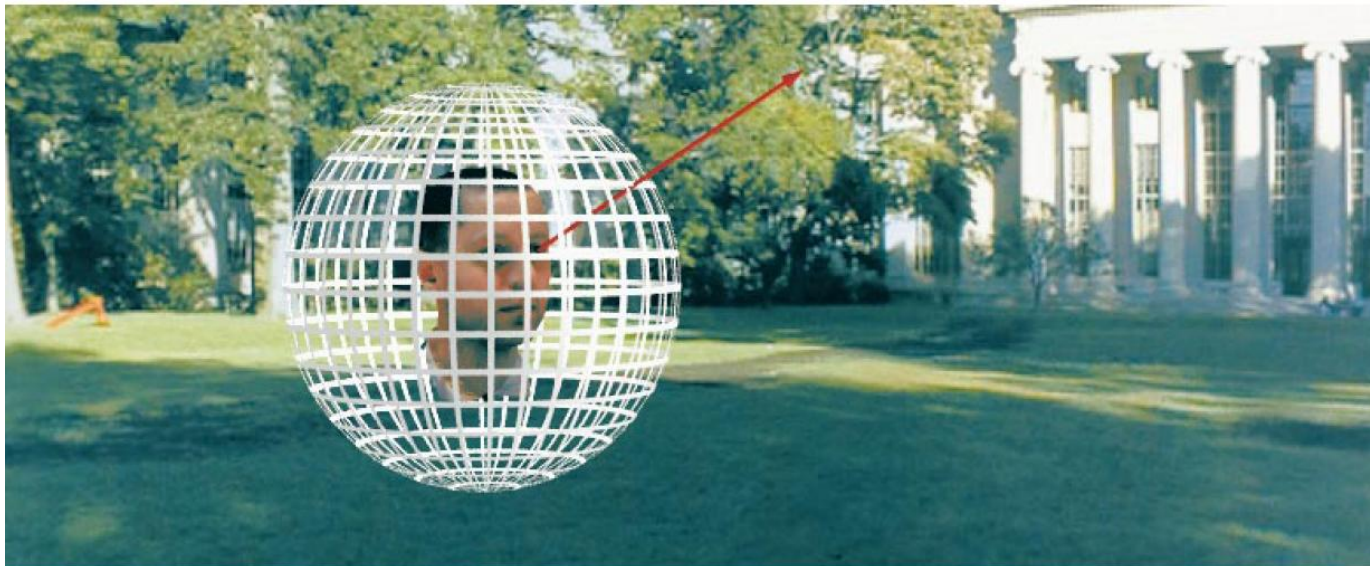


Figure by Leonard McMillan

Q: What is the set of all things that we can ever see?

A: The Plenoptic Function (Adelson & Bergen)

Let's start with a stationary person and try to parameterize everything that he can see...

Grayscale snapshot



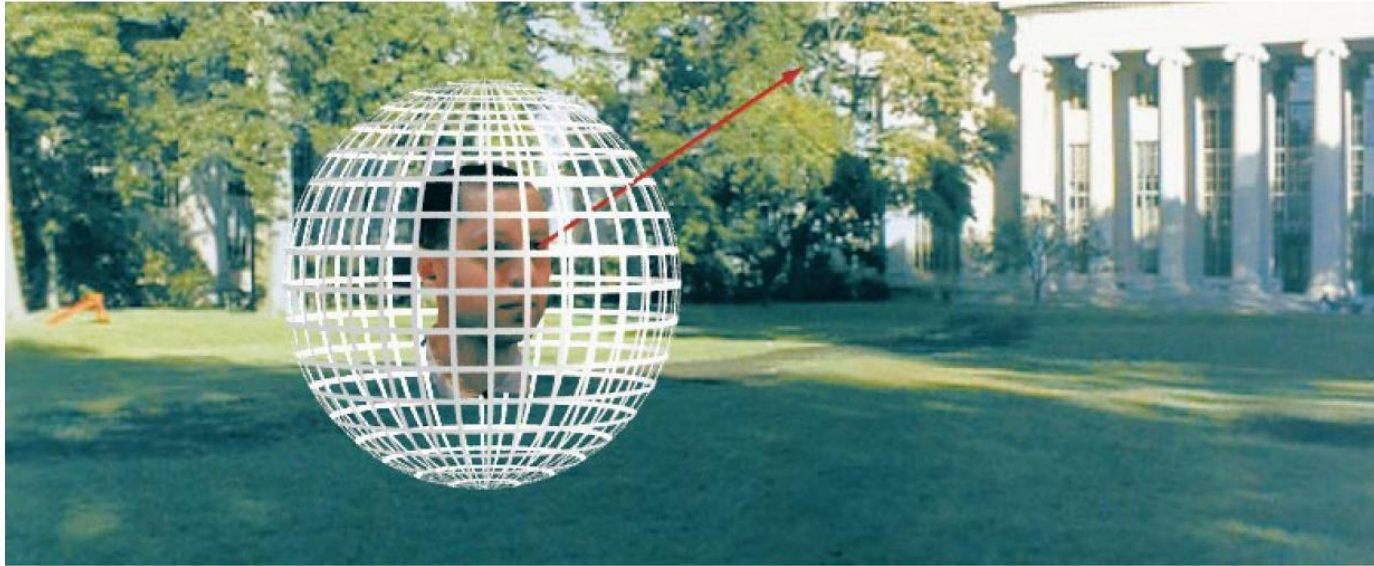
$$P(\theta, \phi)$$

is intensity of light

- Seen from a single view point
- At a single time
- Averaged over the wavelengths of the visible spectrum

(can also do $P(x,y)$, but spherical coordinate are nicer)

Color snapshot

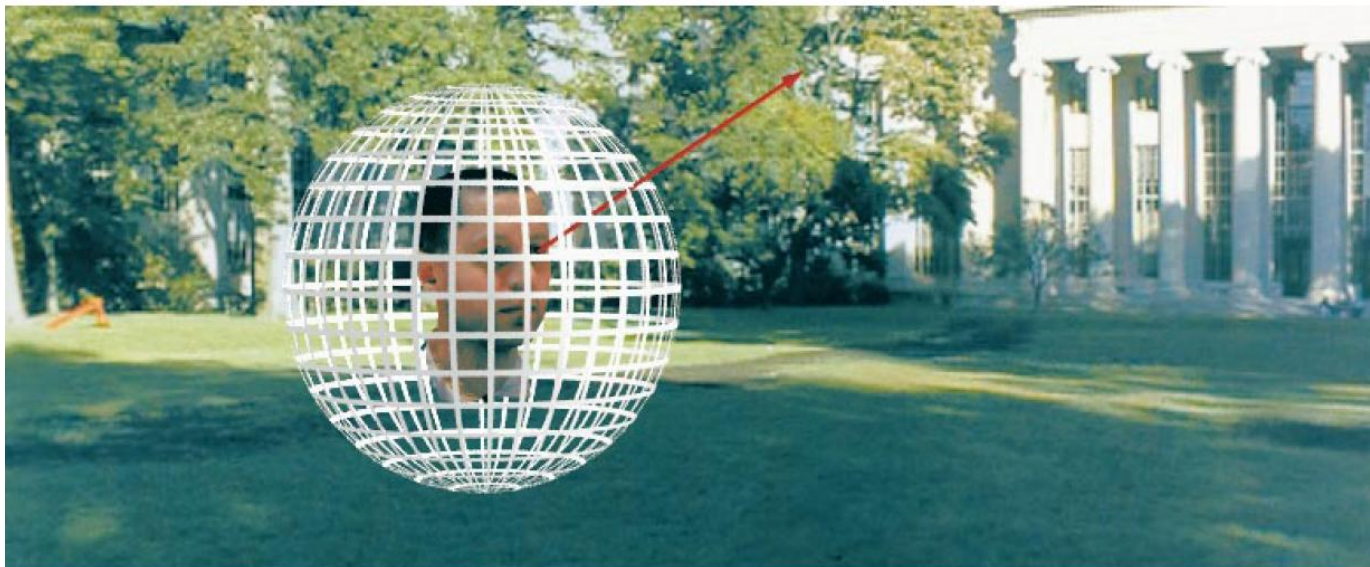


$$P(\theta, \phi, \lambda)$$

is intensity of light

- Seen from a single view point
- At a single time
- As a function of wavelength

A movie

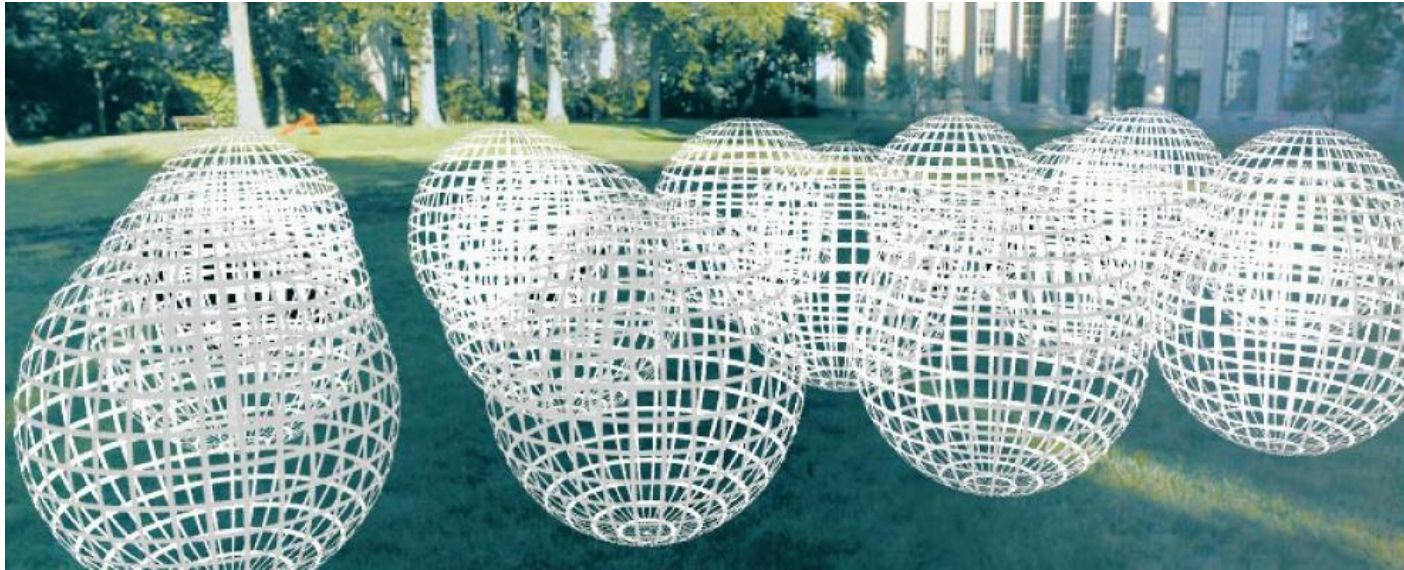


$$P(\theta, \phi, \lambda, t)$$

is intensity of light

- Seen from a single view point
- Over time
- As a function of wavelength

Holographic movie

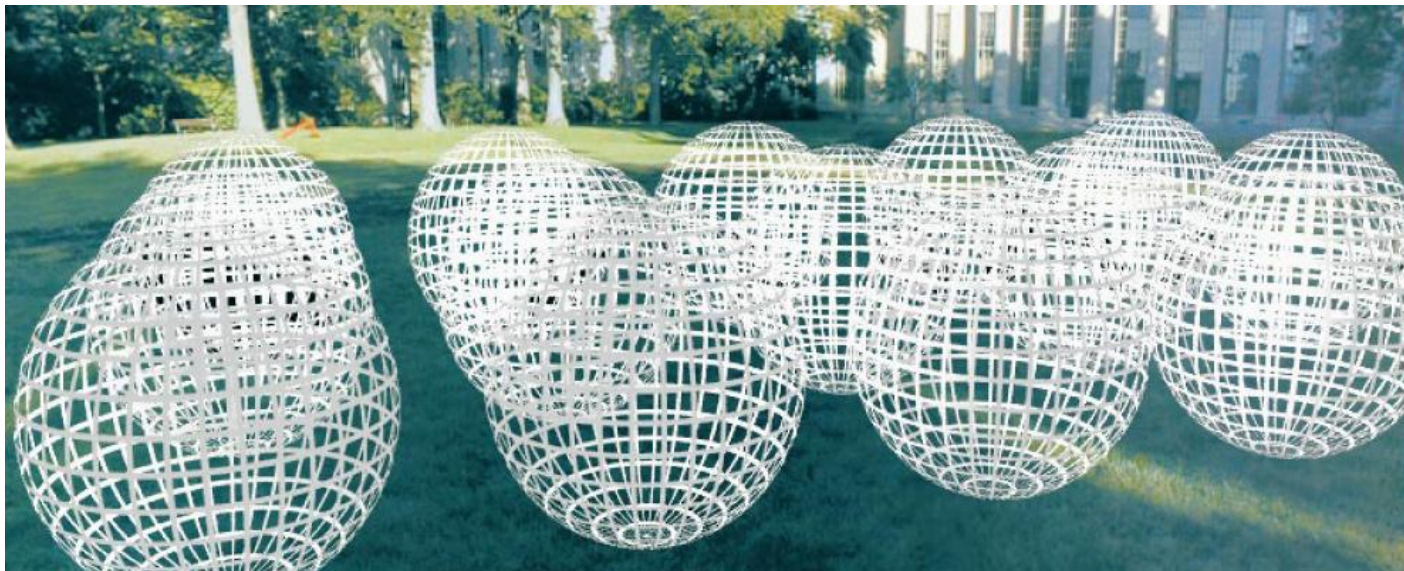


$$P(\theta, \phi, \lambda, t, V_x, V_y, V_z)$$

is intensity of light

- Seen from ANY viewpoint
- Over time
- As a function of wavelength

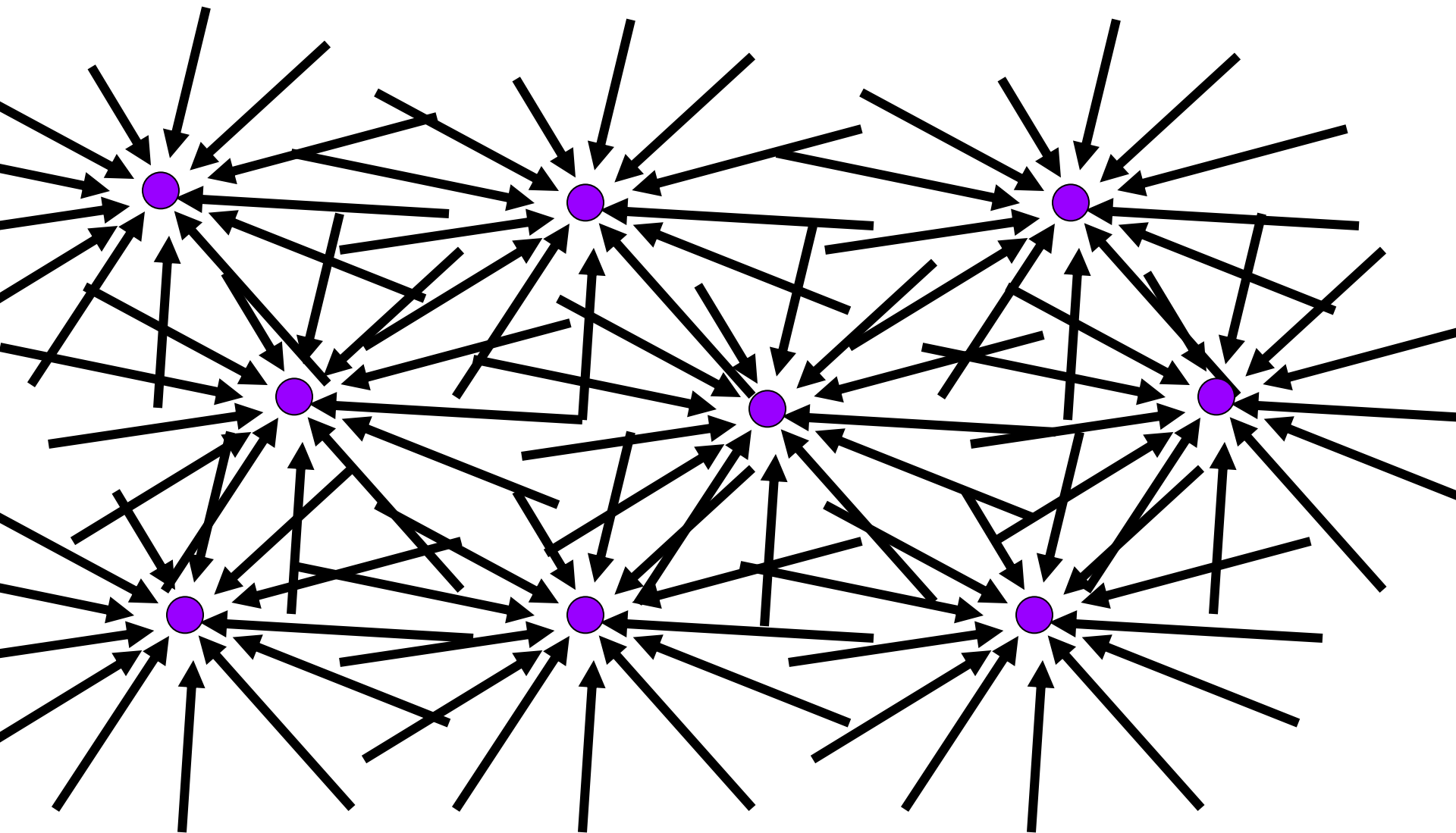
The Plenoptic Function



$$P(\theta, \phi, \lambda, t, V_x, V_y, V_z)$$

- Can reconstruct every possible view, at every moment, from every position, at every wavelength
- Contains every photograph, every movie, everything that anyone has ever seen! it completely captures our visual reality! Not bad for a function...

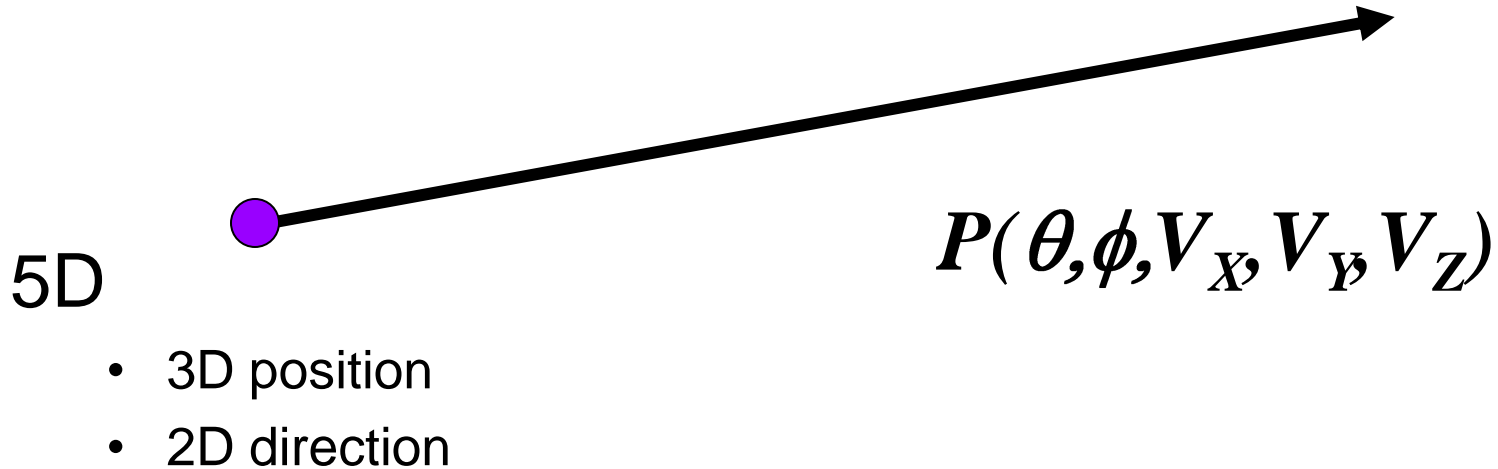
Sampling Plenoptic Function (top view)



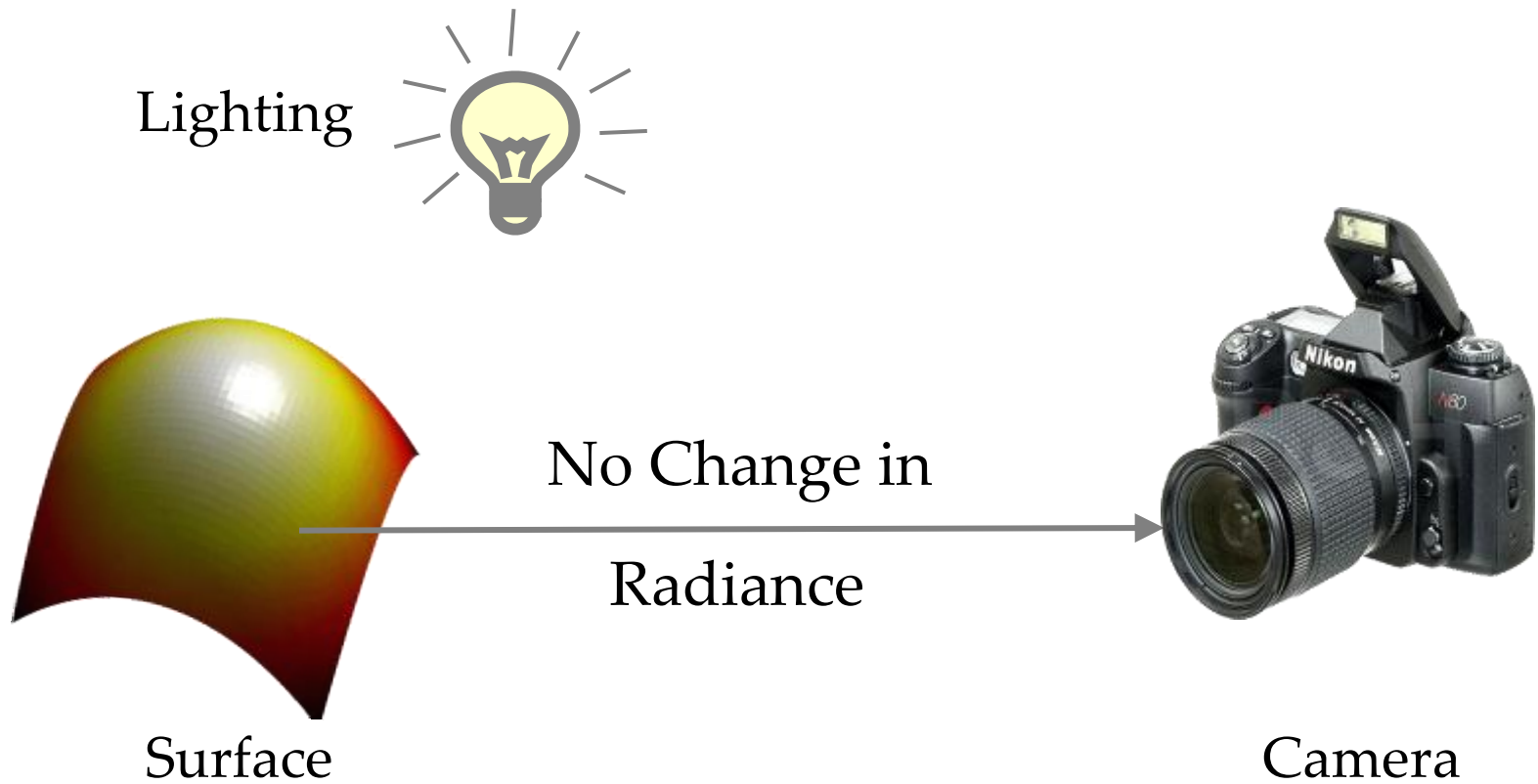
Just lookup -- Quicktime VR

Ray

Let's not worry about time and color:



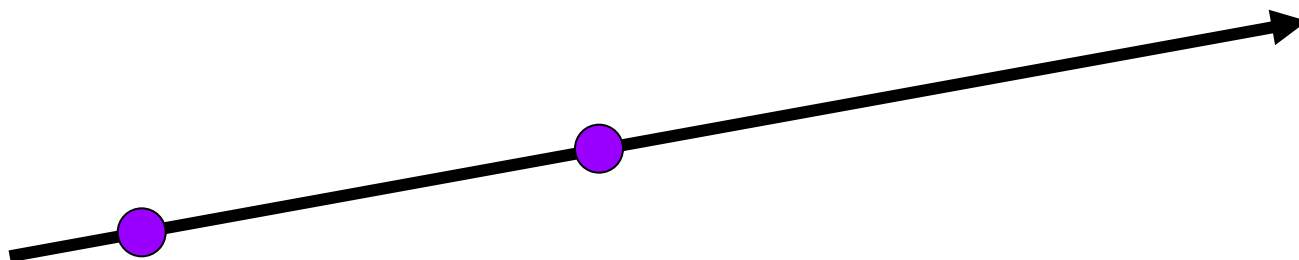
How can we use this?



Ray Reuse

Infinite line

- Assume light is constant (vacuum)



4D

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

Only need plenoptic surface

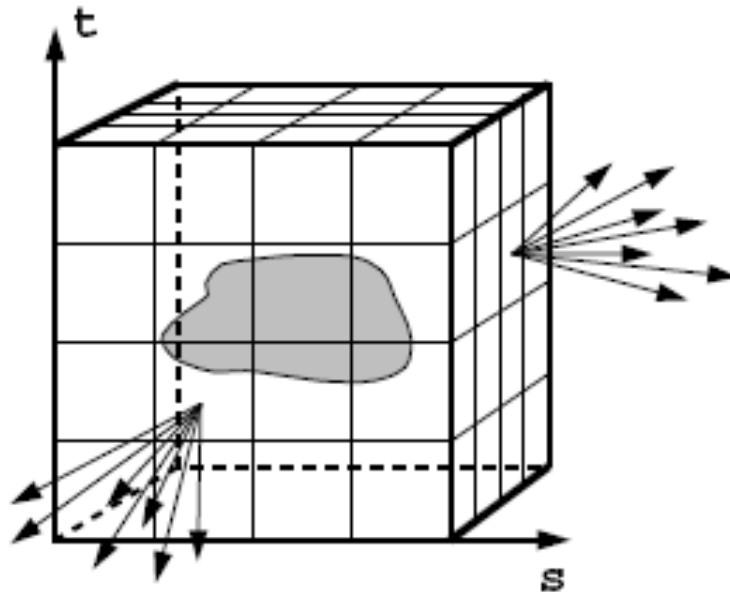
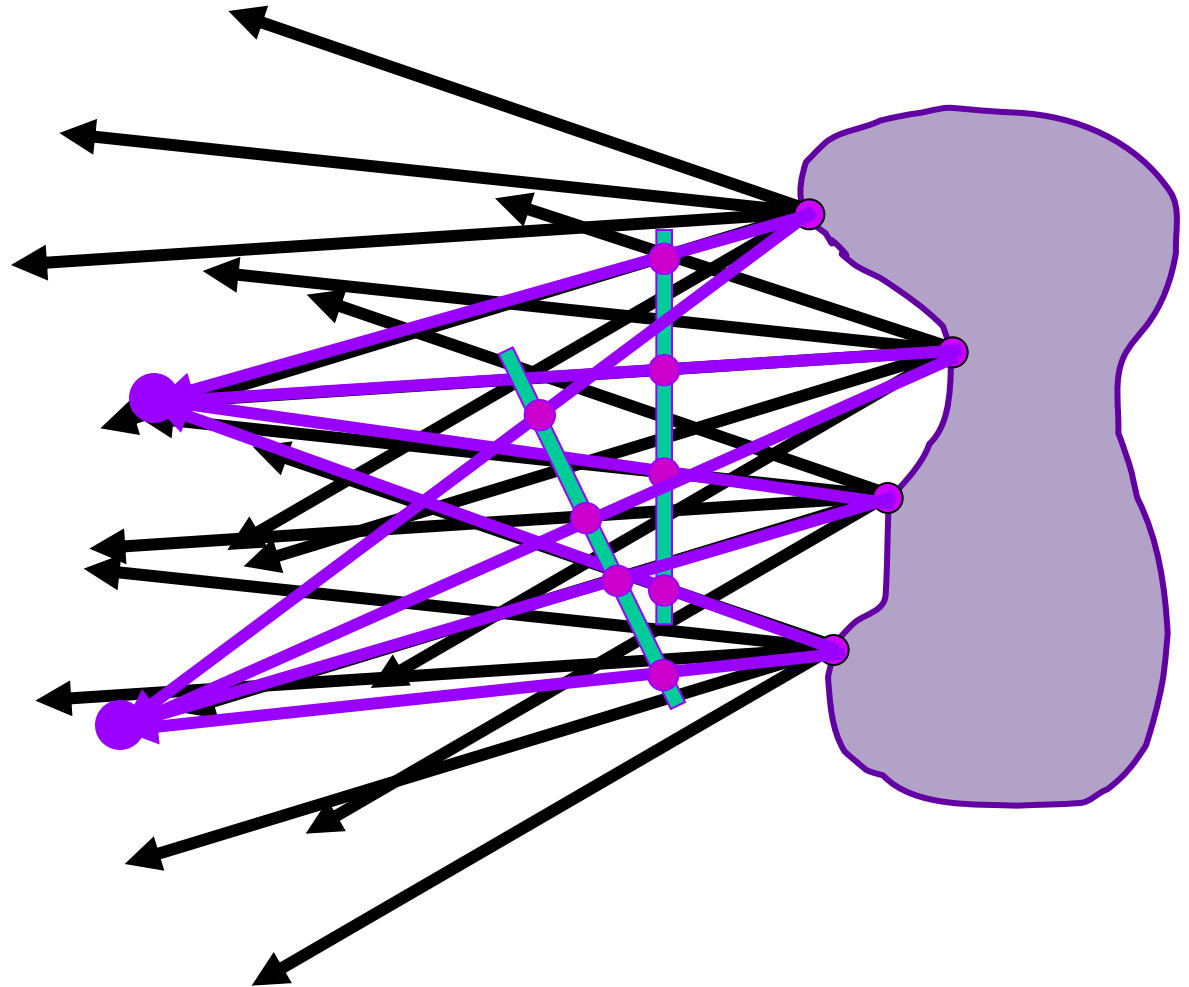


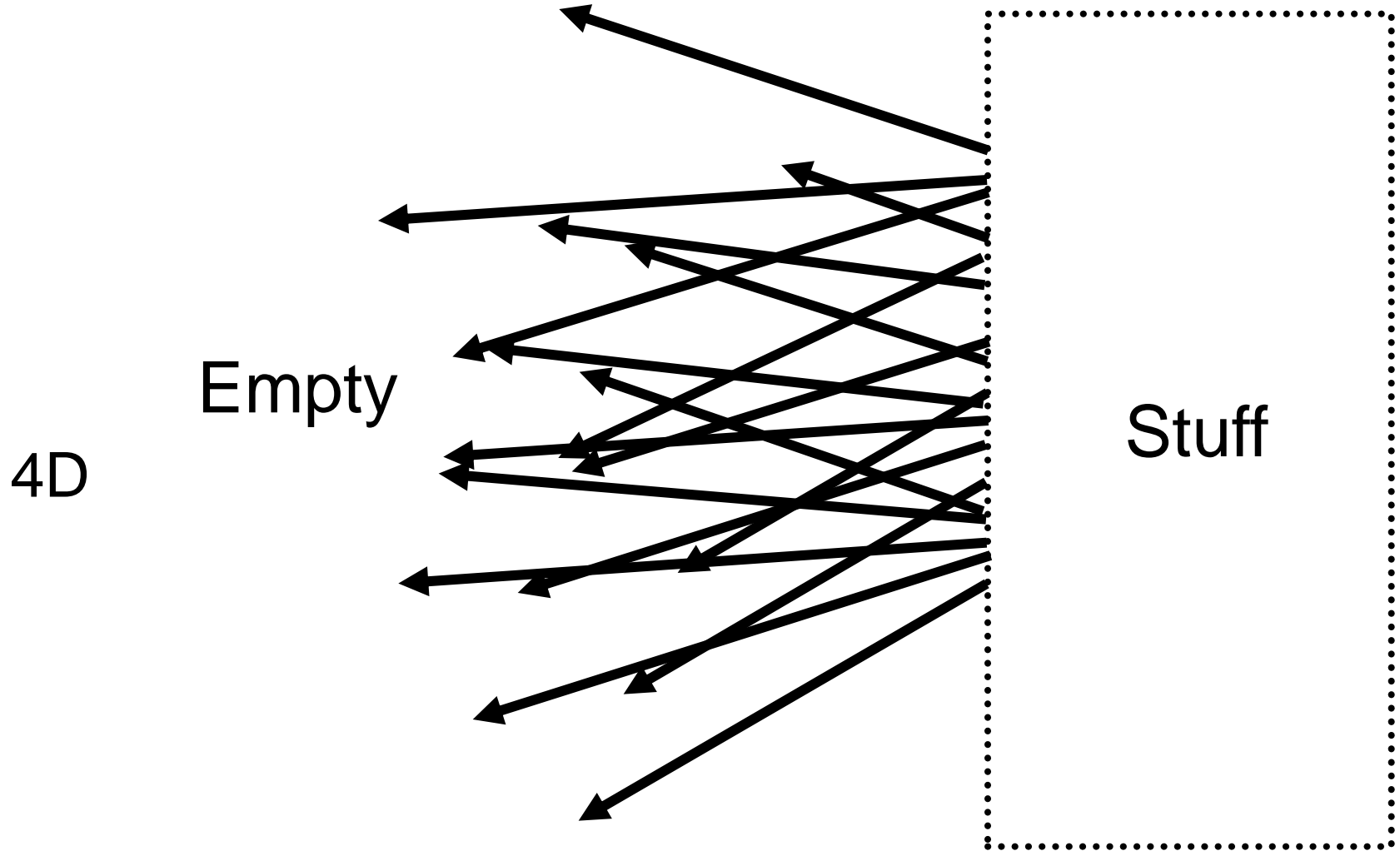
Figure 1: The surface of a cube holds all the radiance information due to the enclosed object.

Synthesizing novel views



Lumigraph / Lightfield

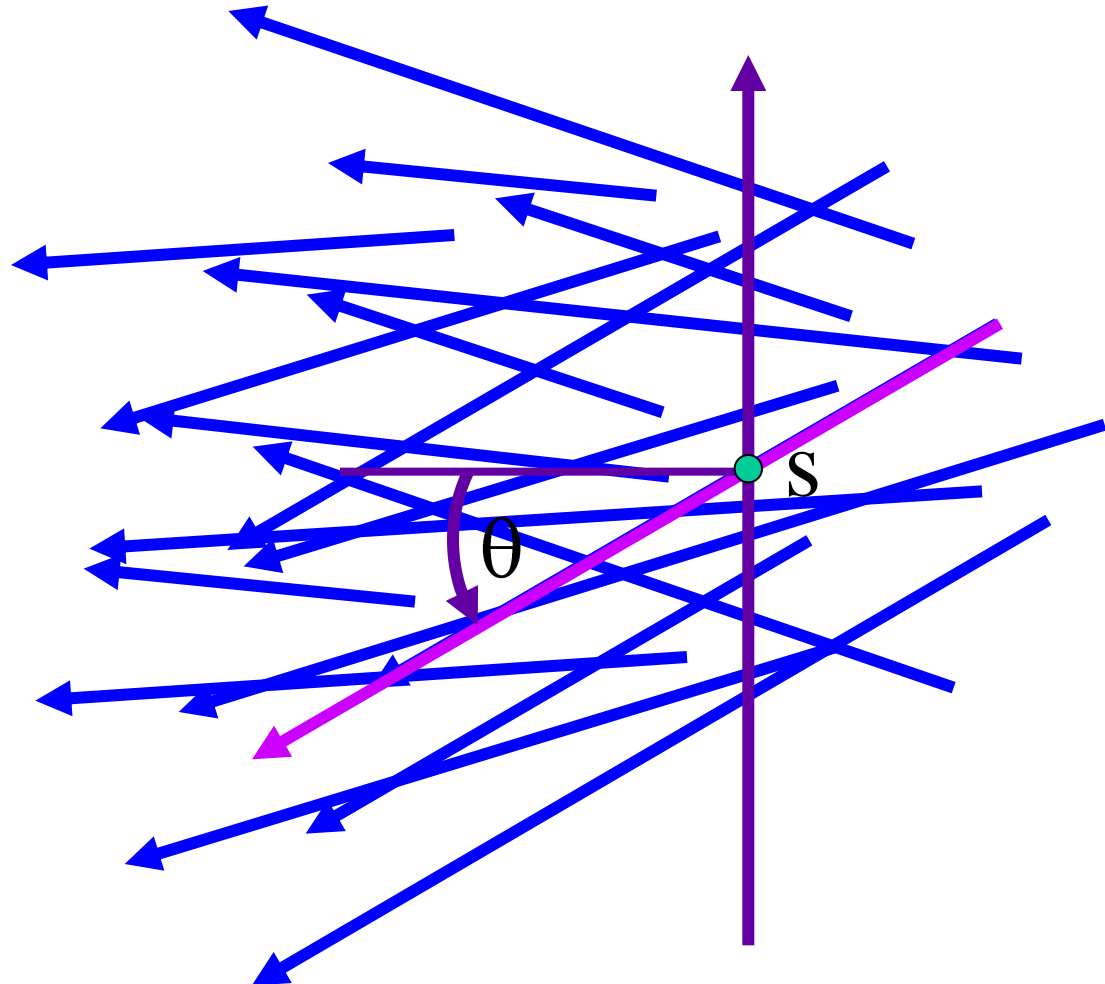
Outside convex space



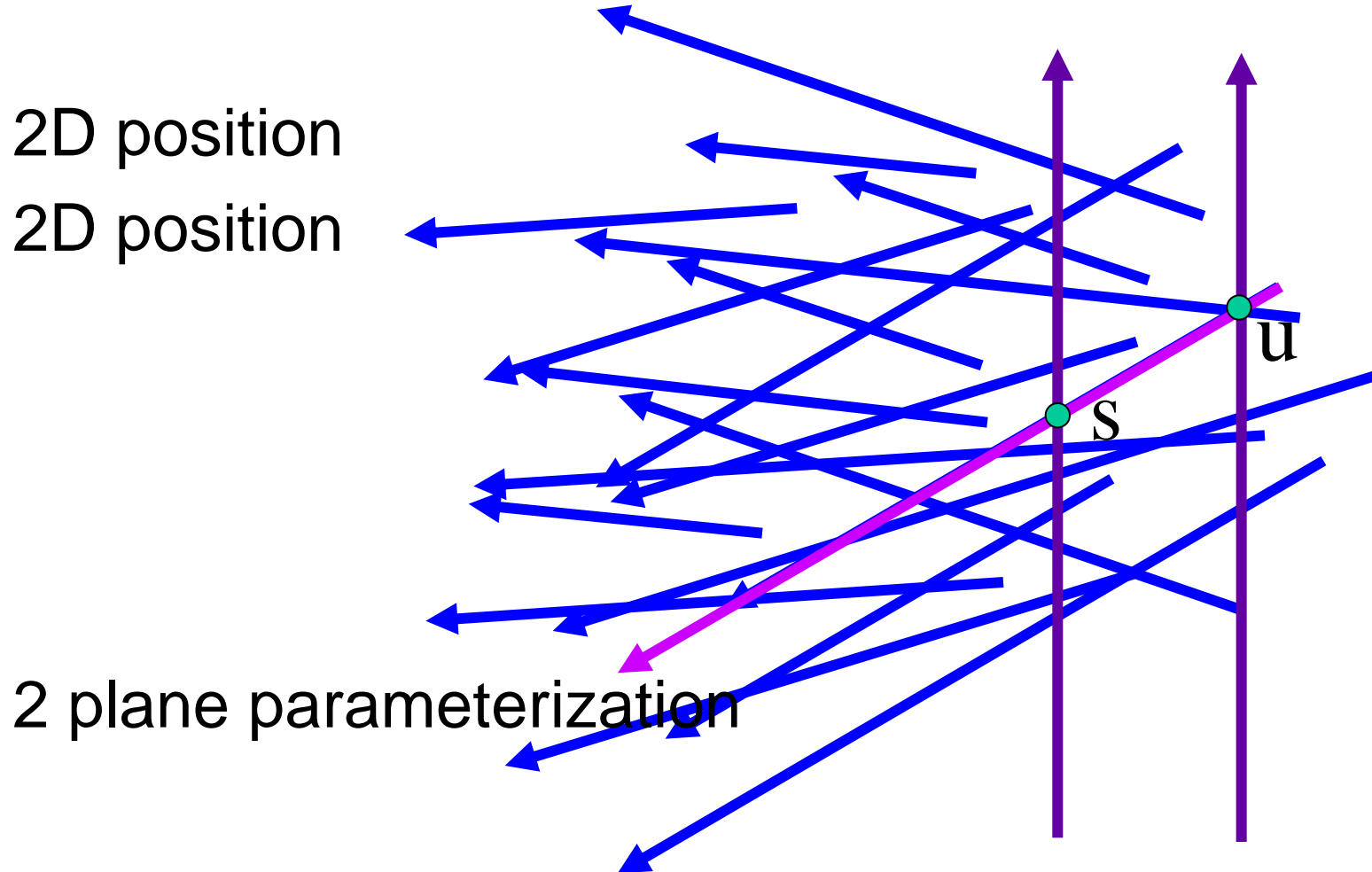
Lumigraph - Organization

2D position

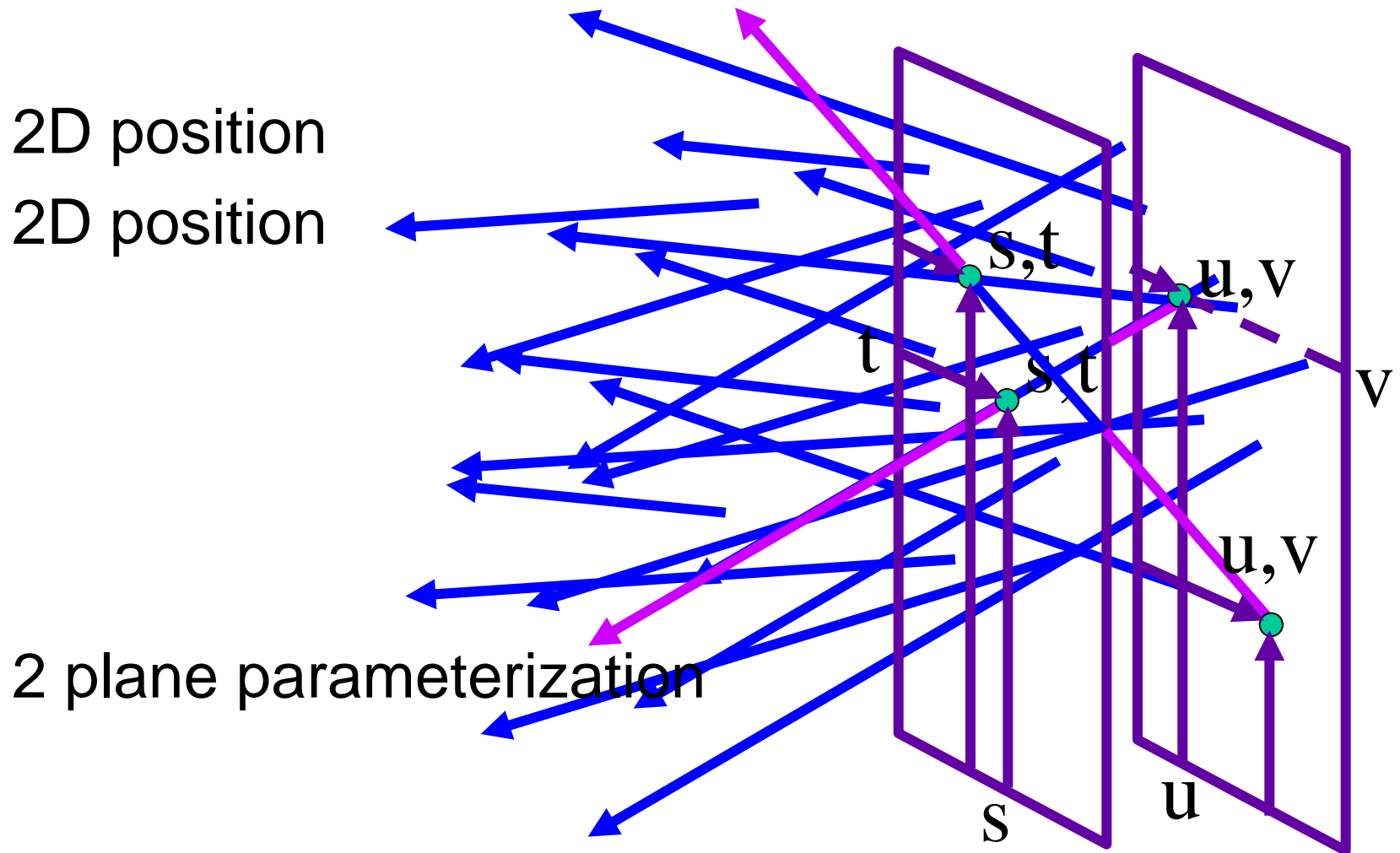
2D direction



Lumigraph - Organization



Lumigraph - Organization

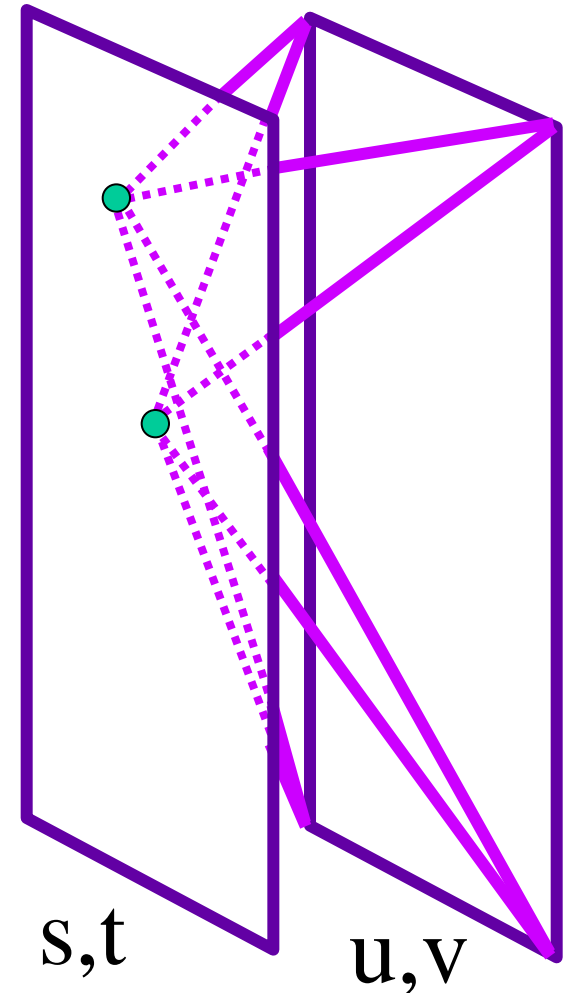


Lumigraph - Organization

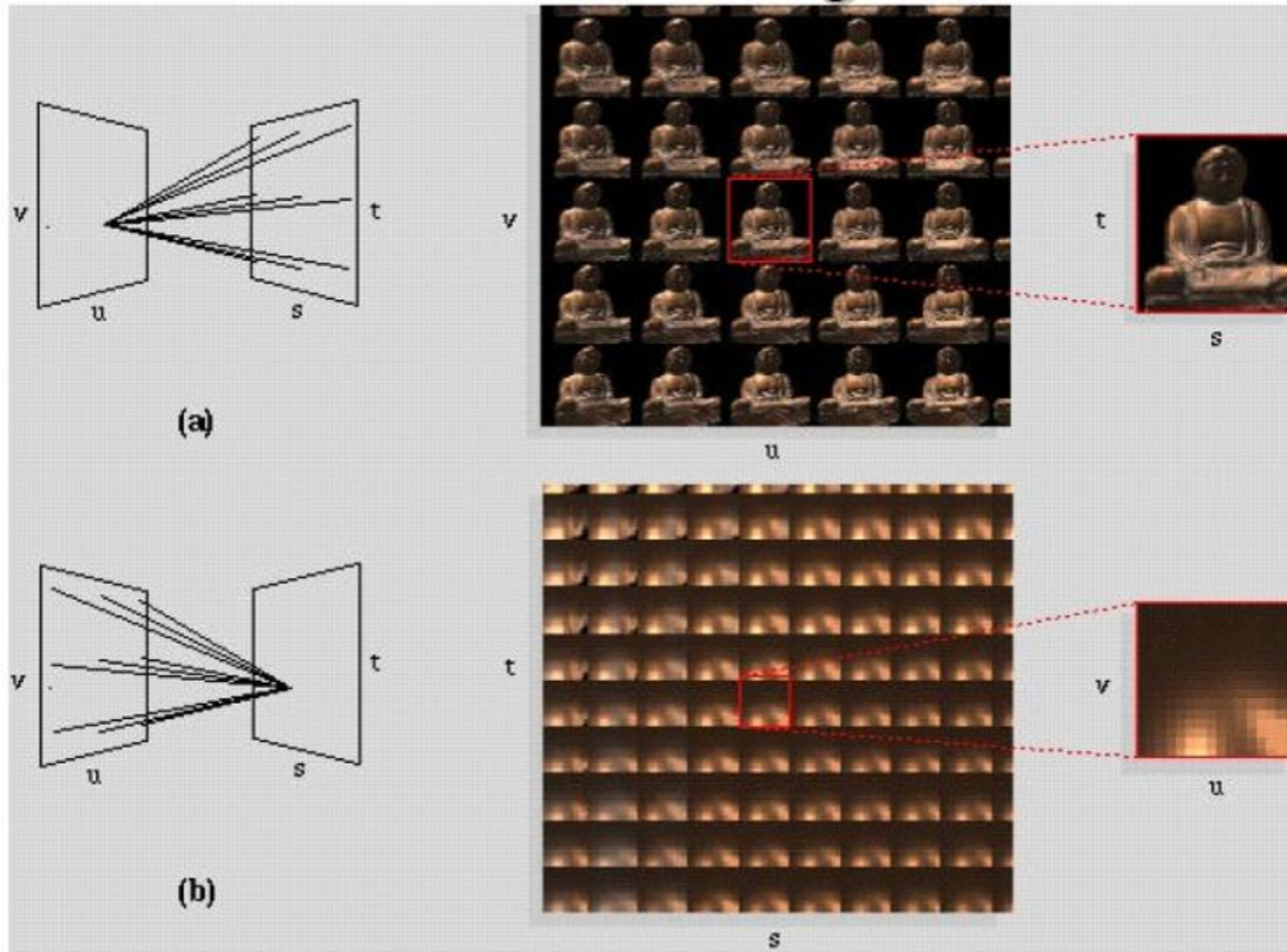
Hold s, t constant

Let u, v vary

An image



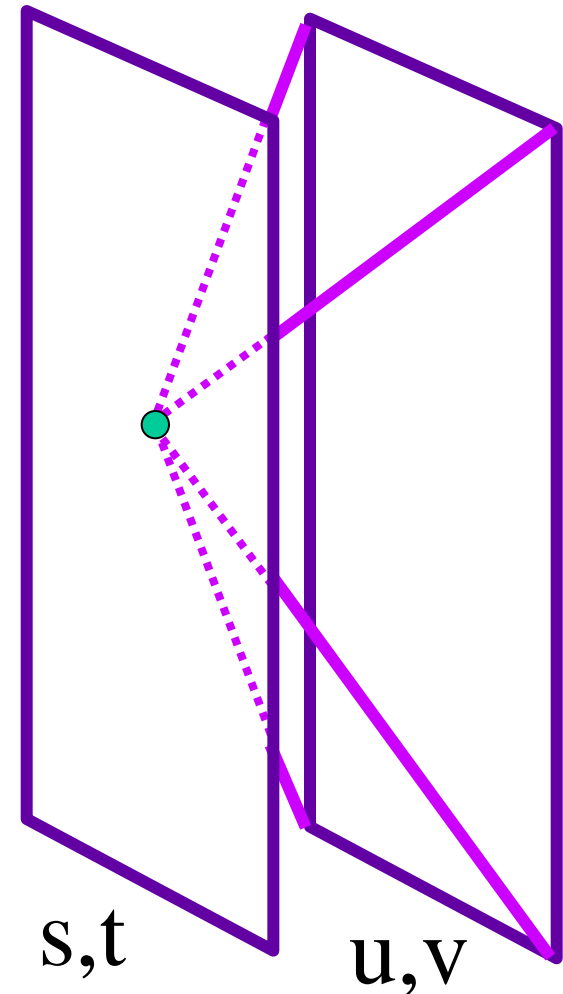
Lumigraph / Lightfield



Lumigraph - Capture

Idea 1

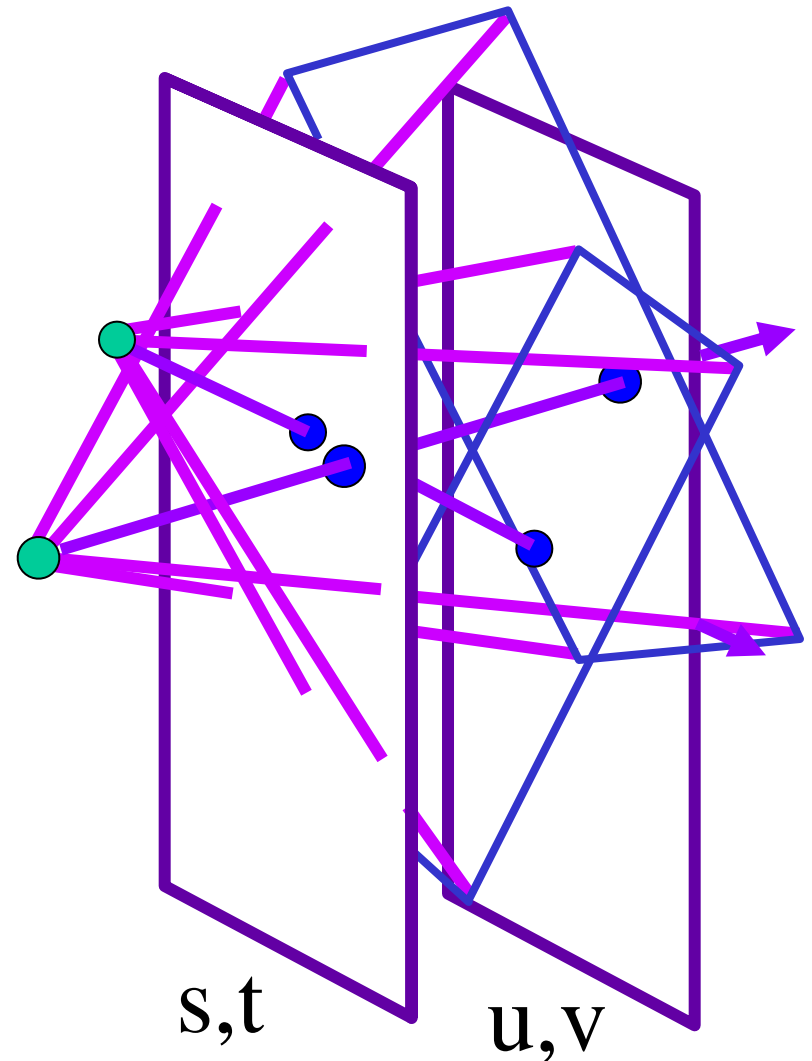
- Move camera carefully over s, t plane
- Gantry
 - see Lightfield paper



Lumigraph - Capture

Idea 2

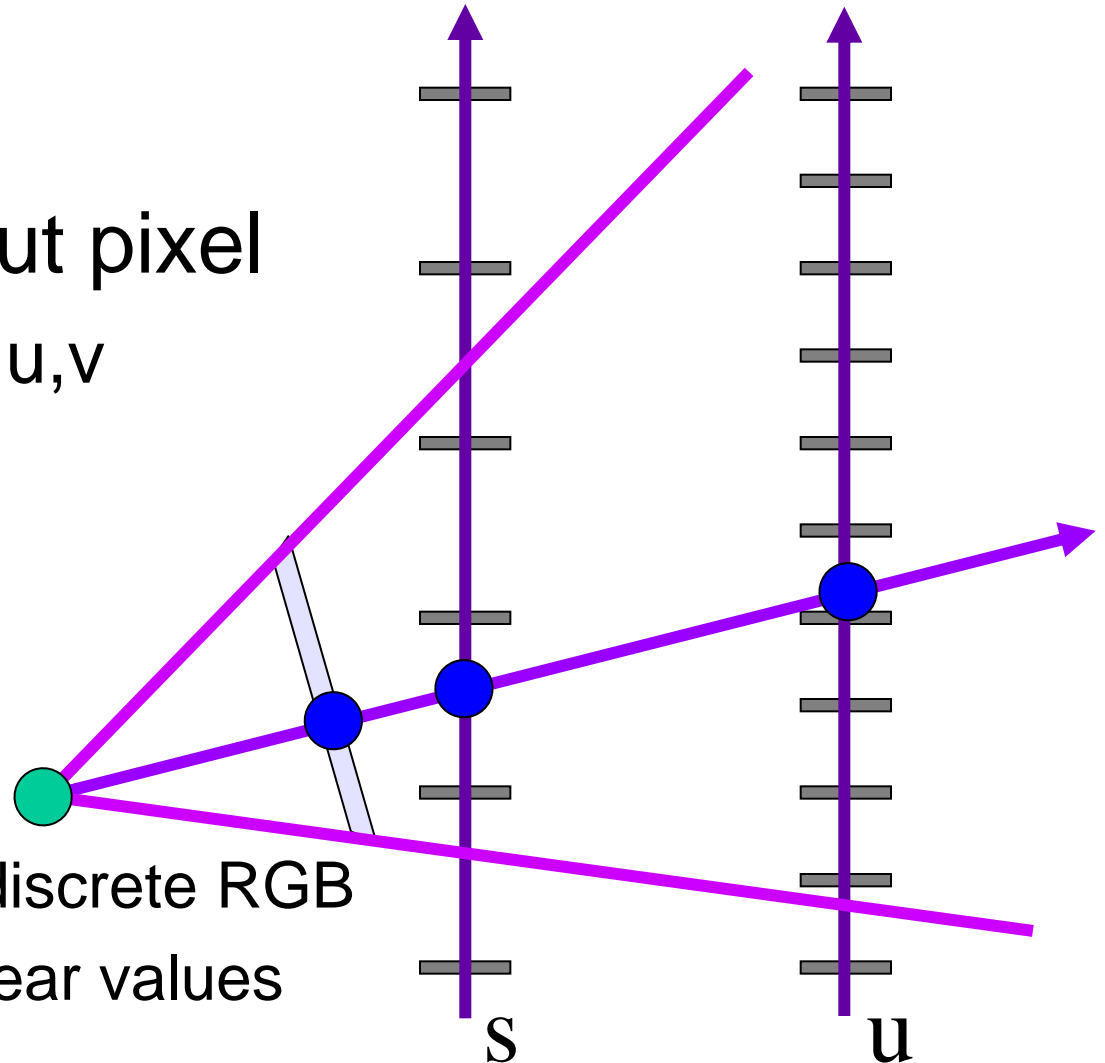
- Move camera anywhere
- Rebinning
 - see Lumigraph paper



Lumigraph - Rendering

- For each output pixel
 - determine s, t, u, v

- either
 - use closest discrete RGB
 - interpolate near values



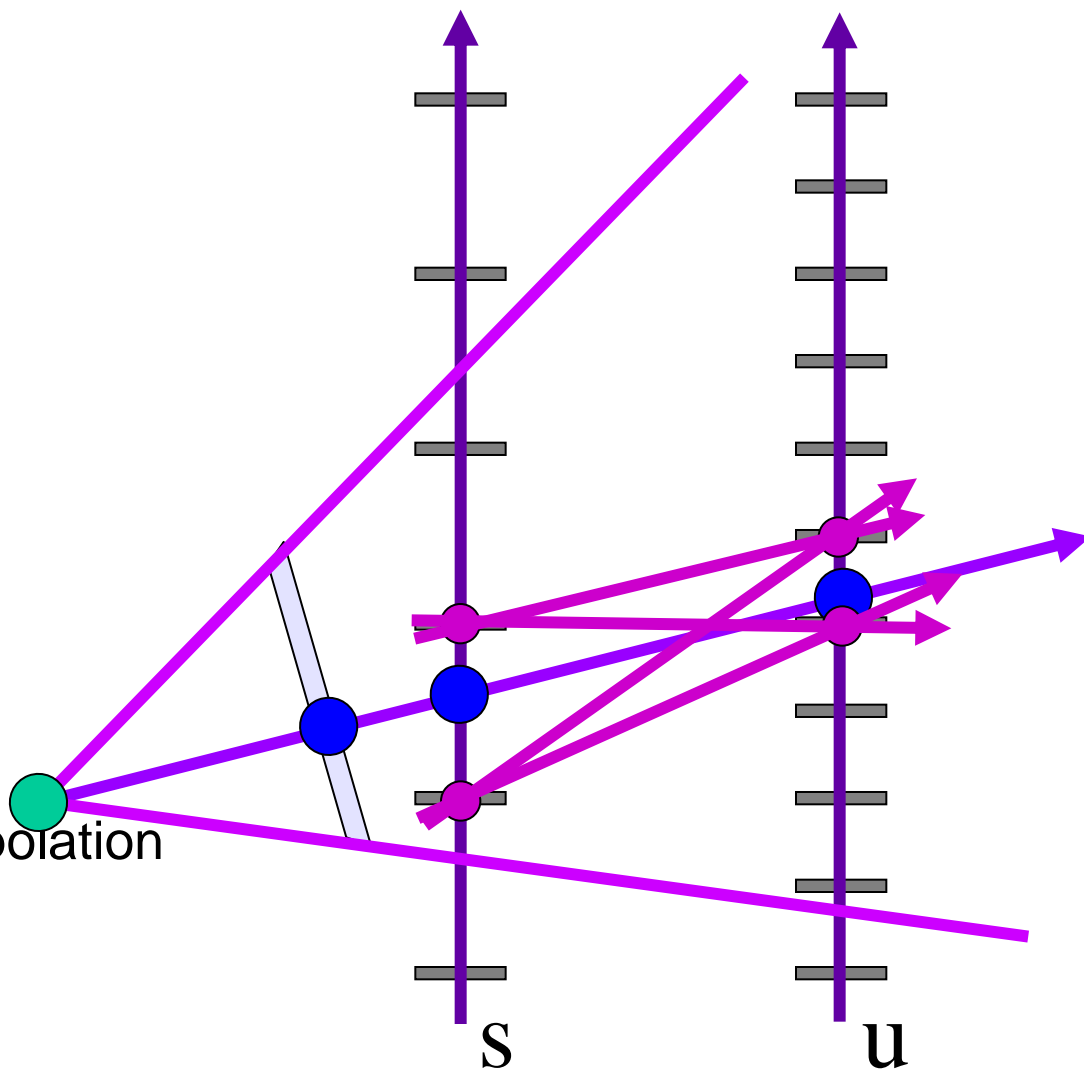
Lumigraph - Rendering

Nearest

- closest s
- closest u
- draw it

Blend 16 nearest

- quadrilinear interpolation



Stanford multi-camera array



- 640 480 pixels
30 fps 128 cameras
- synchronized timing
- continuous streaming
- flexible arrangement

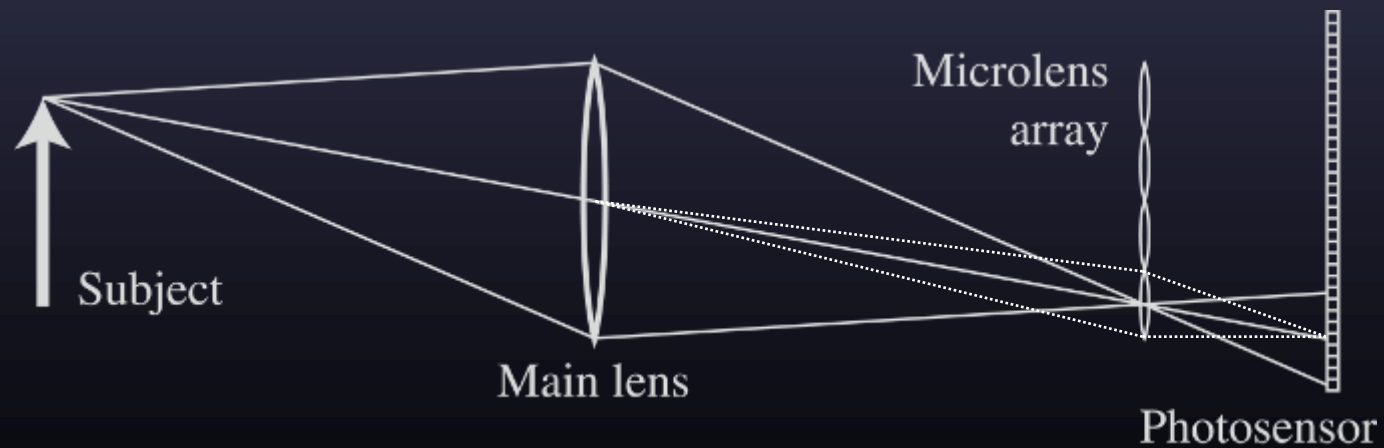
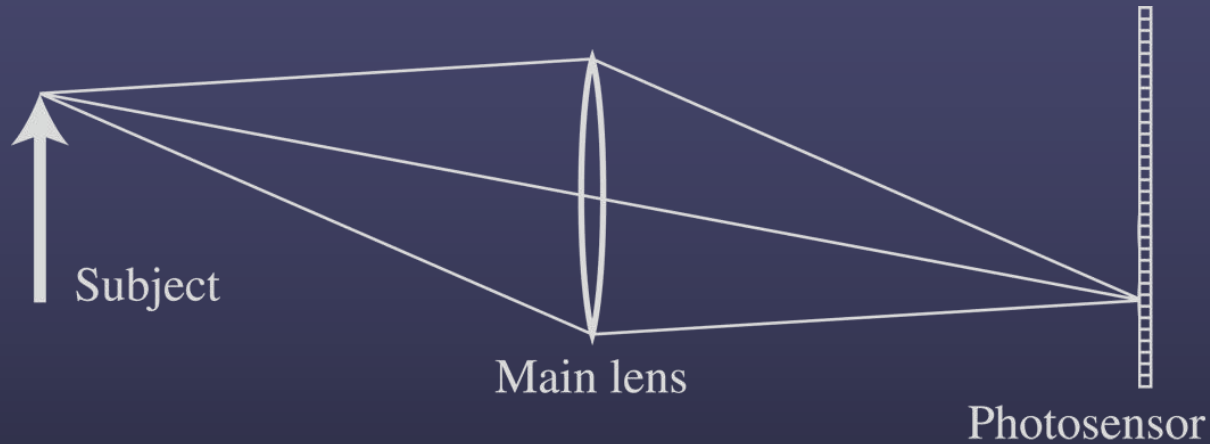


Light field photography using a handheld plenoptic camera

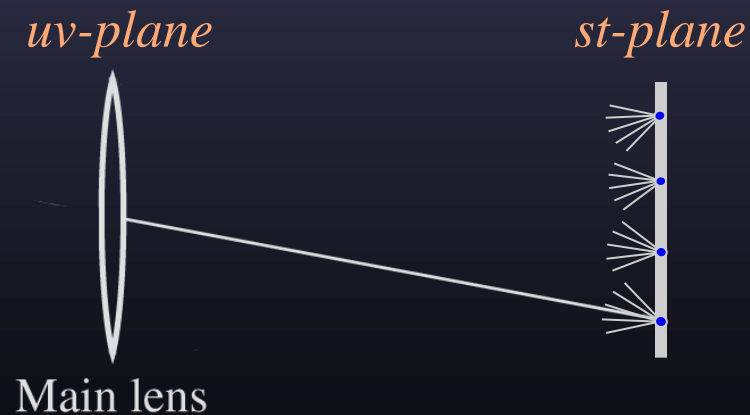
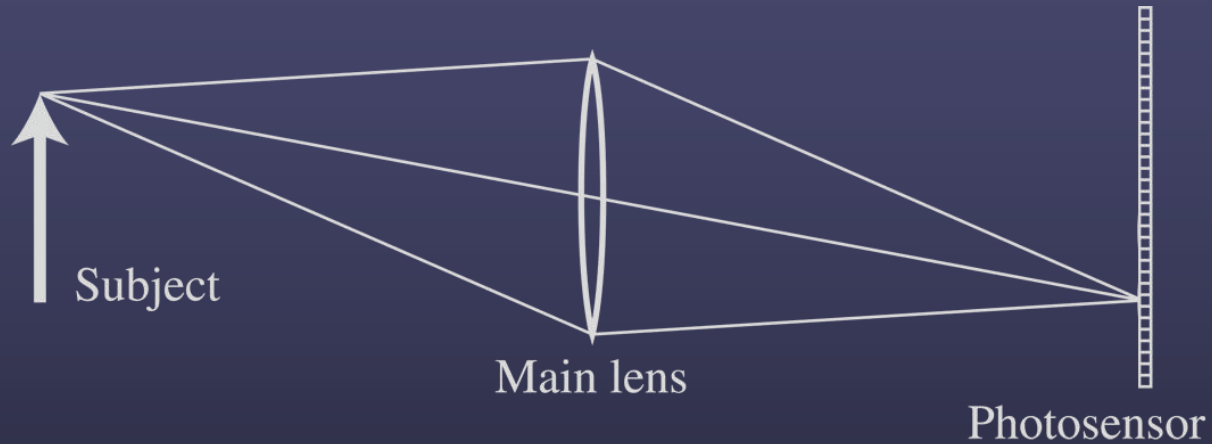
*Ren Ng, Marc Levoy, Mathieu Brédif,
Gene Duval, Mark Horowitz and Pat Hanrahan*



Conventional versus light field camera



Conventional versus light field camera



Prototype camera



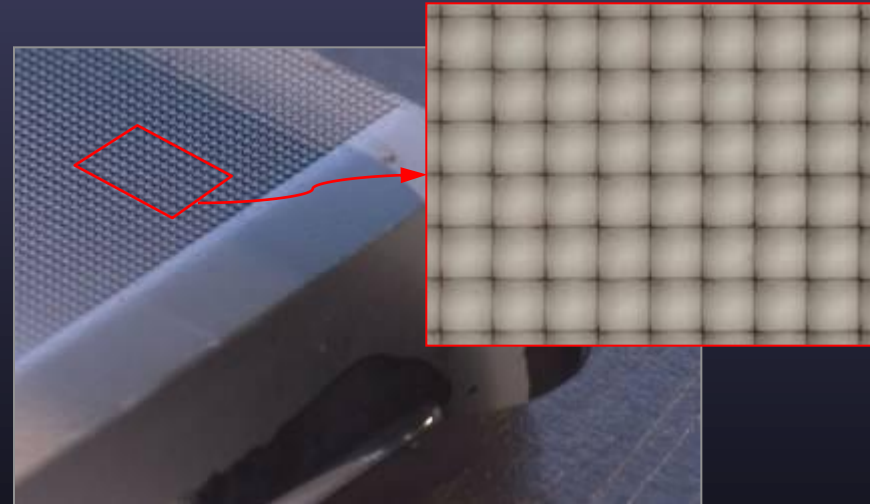
Contax medium format camera



Kodak 16-megapixel sensor

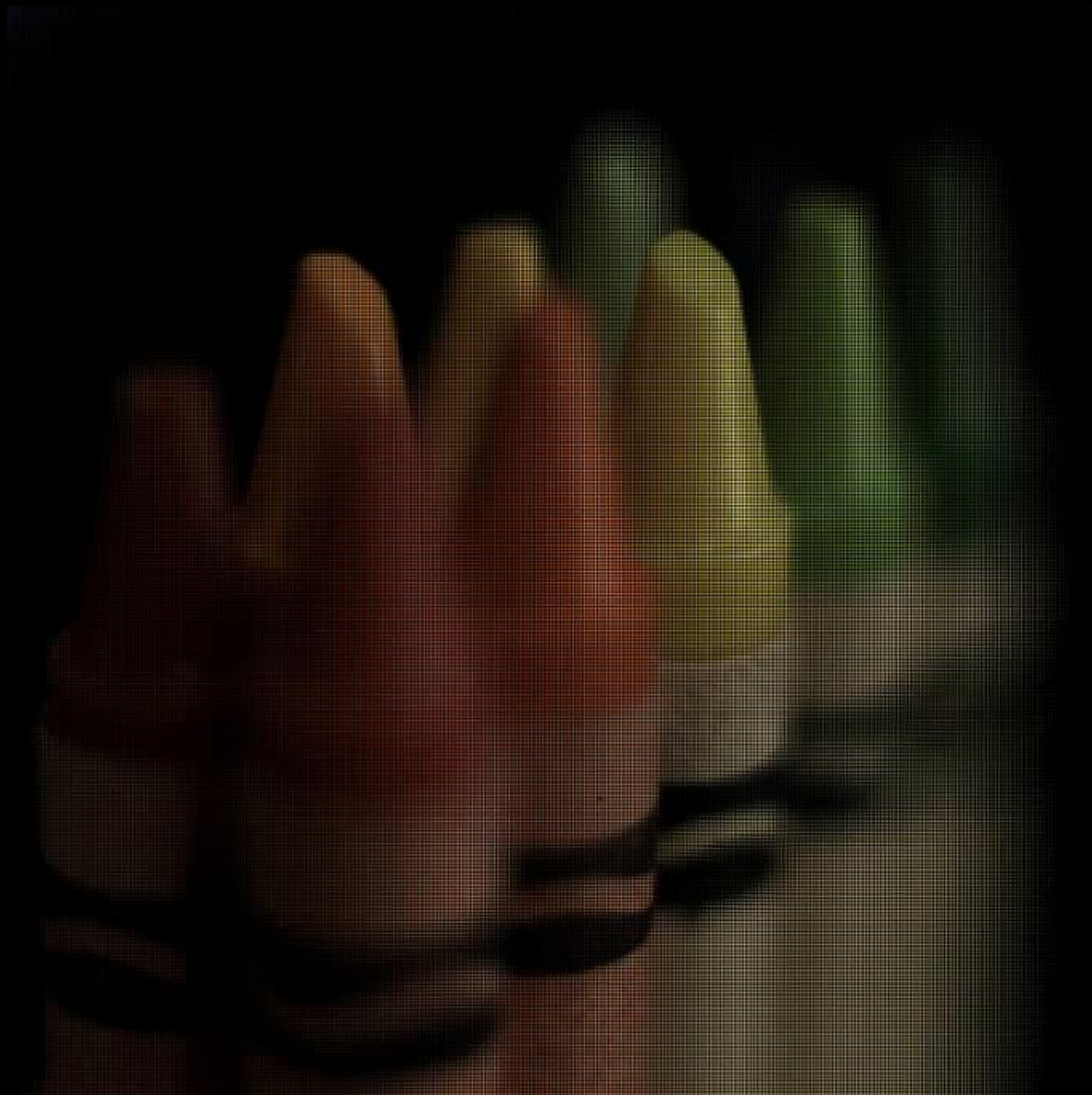


Adaptive Optics microlens array

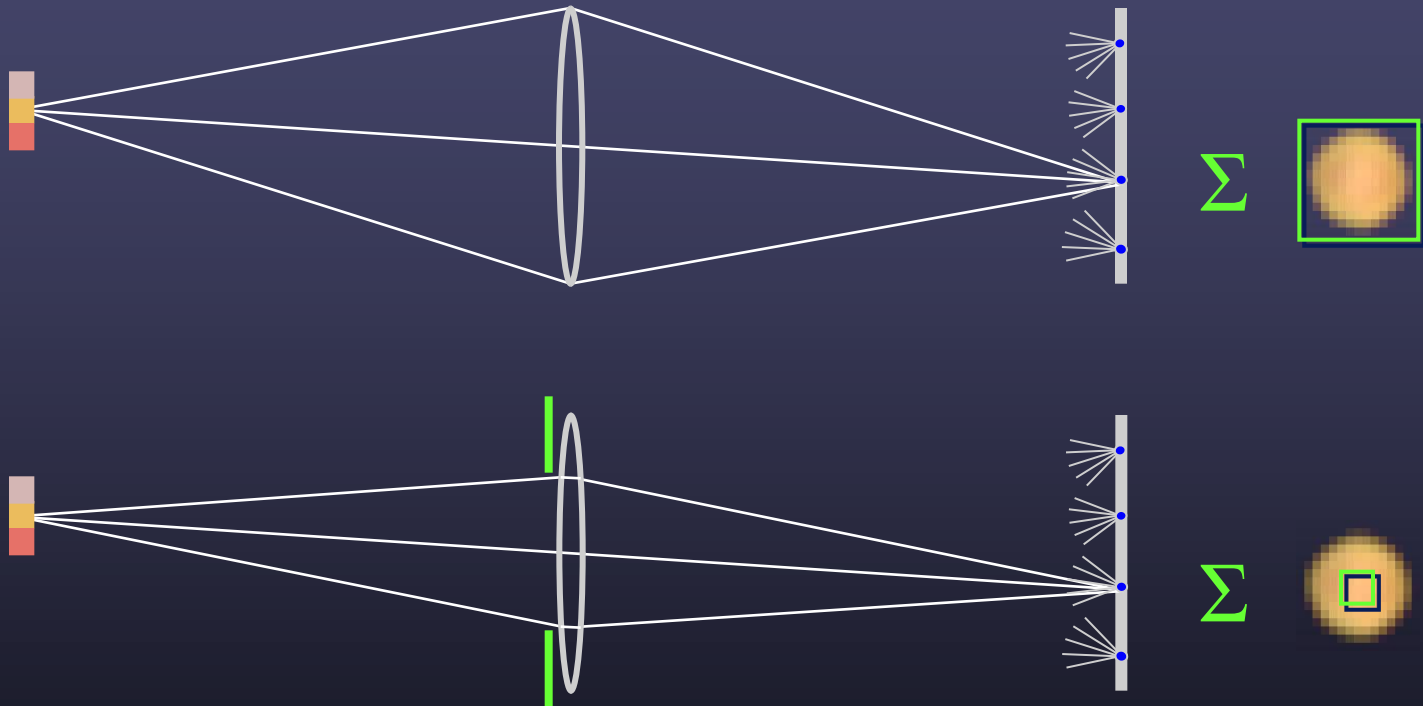


125μ square-sided microlenses

- 4000 4000 pixels 292 292 lenses = 14 14 pixels per lens

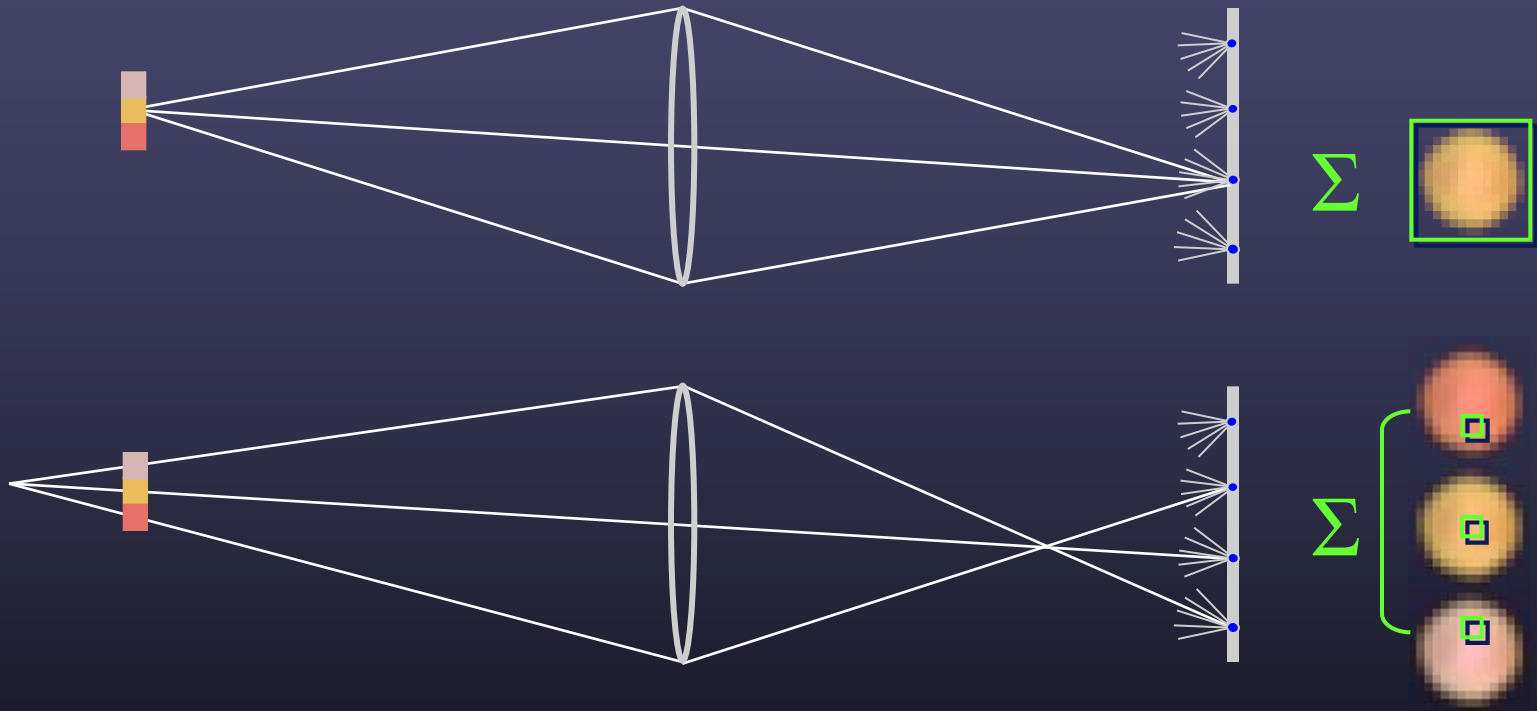


Digitally stopping-down



- stopping down = summing only the central portion of each microlens

Digital refocusing

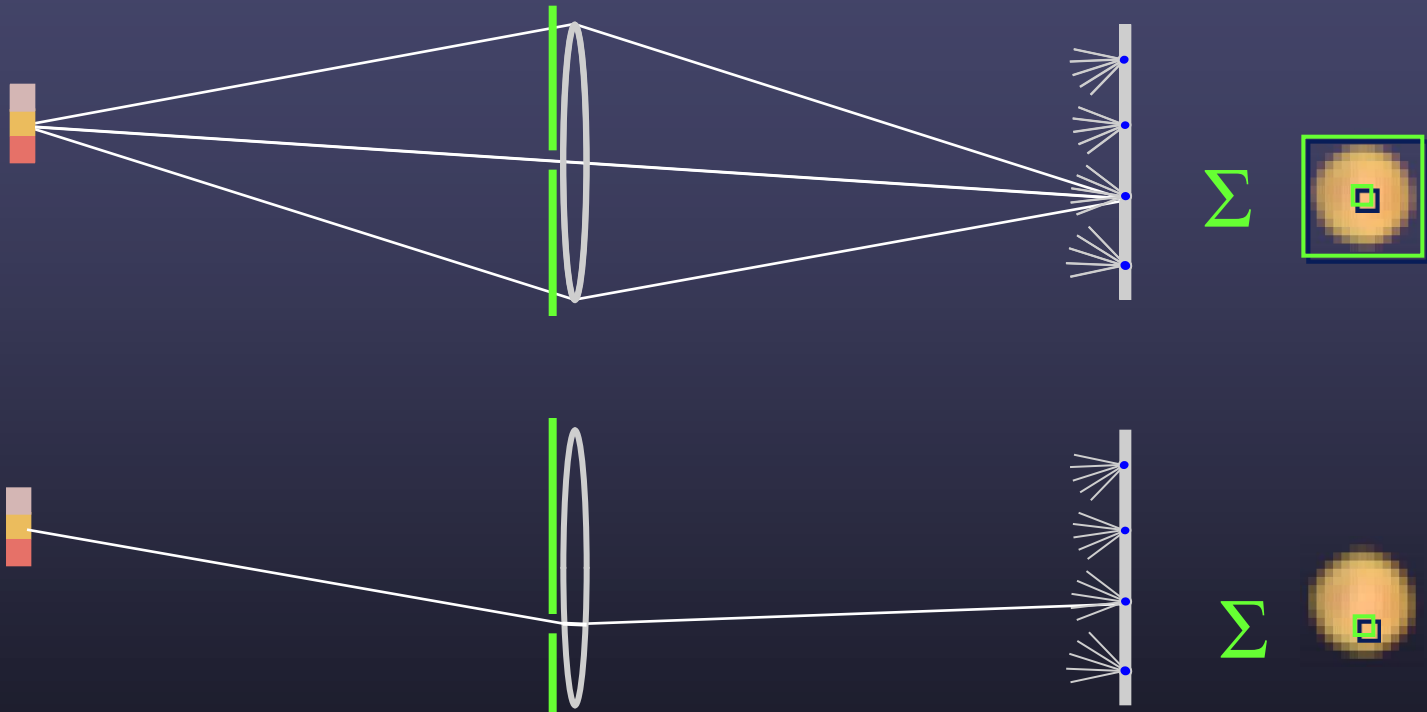


- refocusing = summing windows extracted from several microlenses

Example of digital refocusing

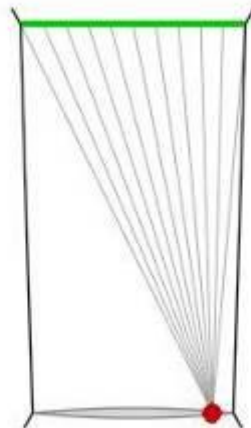


Digitally moving the observer

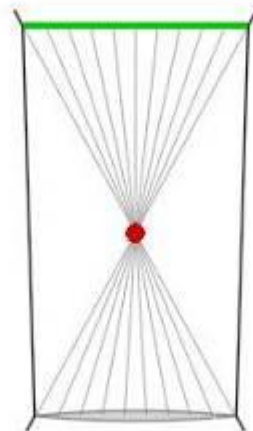


- moving the observer = moving the window we extract from the microlenses

Example of moving the observer



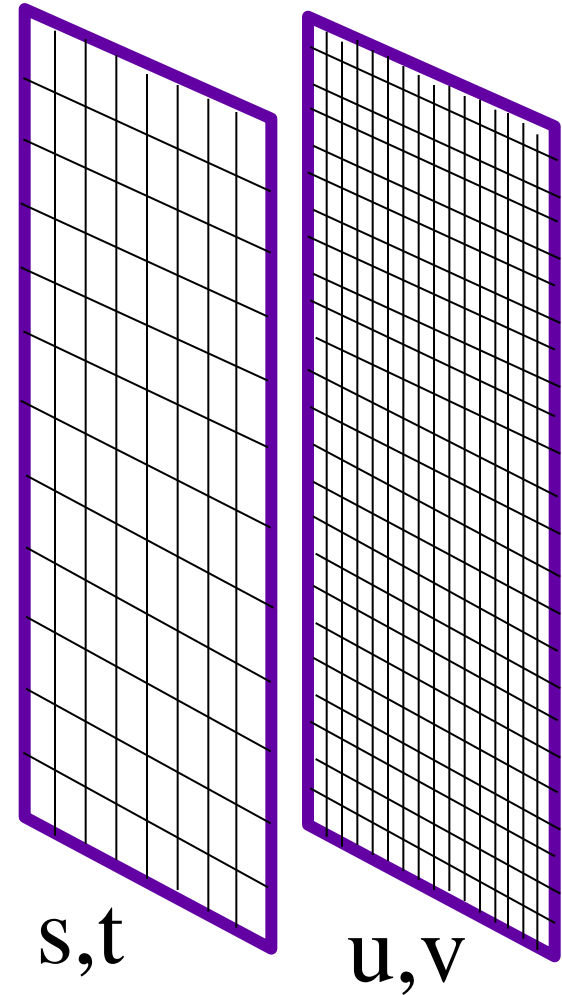
Moving backward and forward



3D Lumigraph

One row of s,t plane

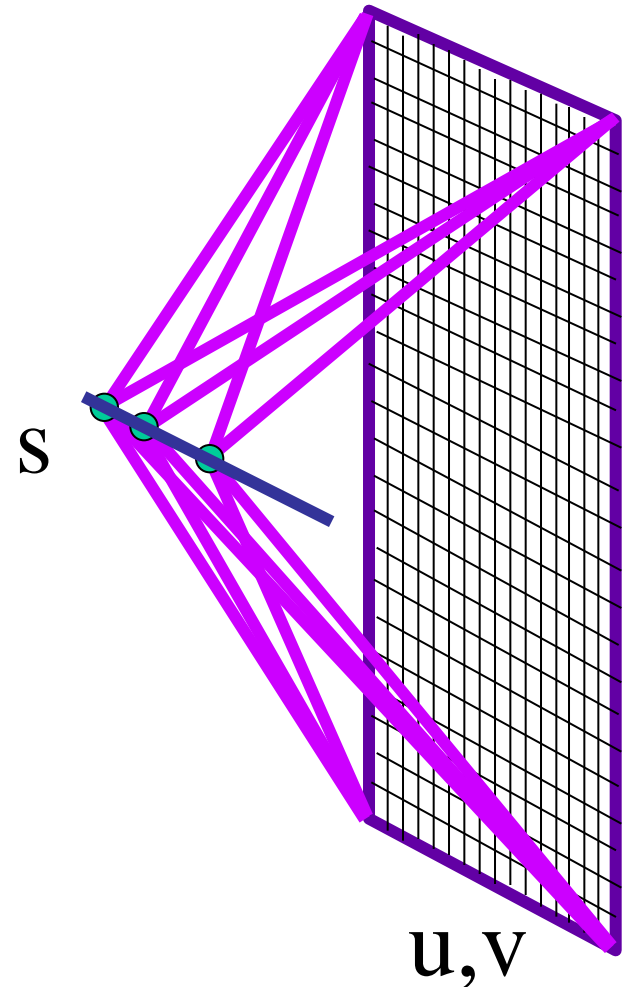
- i.e., hold t constant



3D Lumigraph

One row of s,t plane

- i.e., hold t constant
- thus s, u, v
- a “row of images”



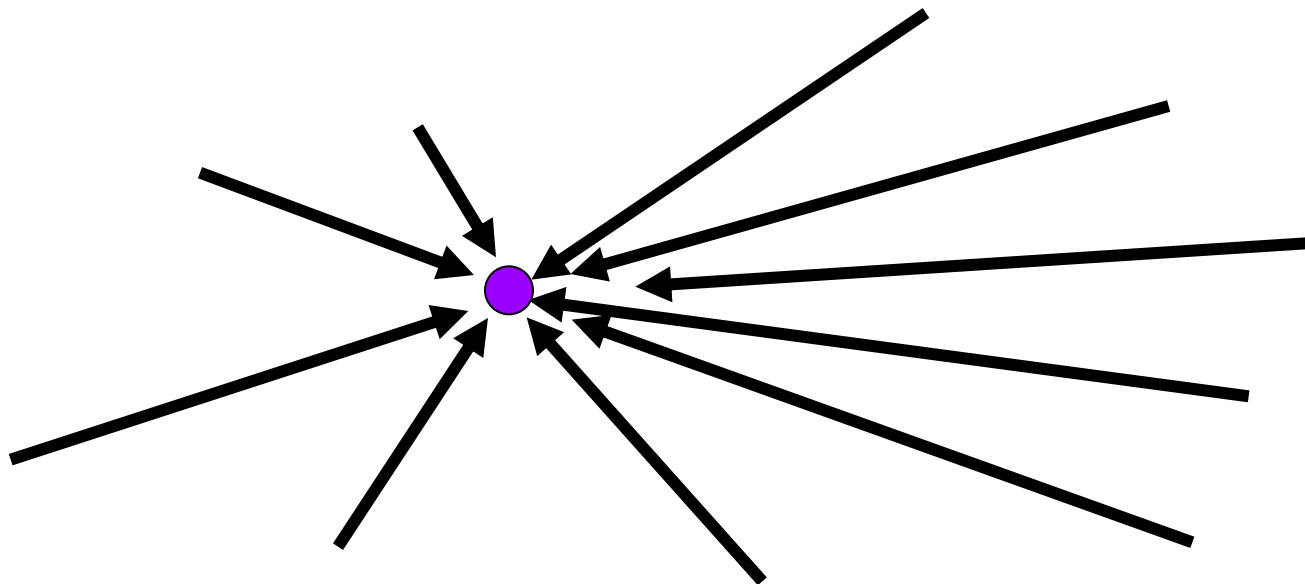


$P(x,t)$

by David Dewey

2D: Image

What is an image?

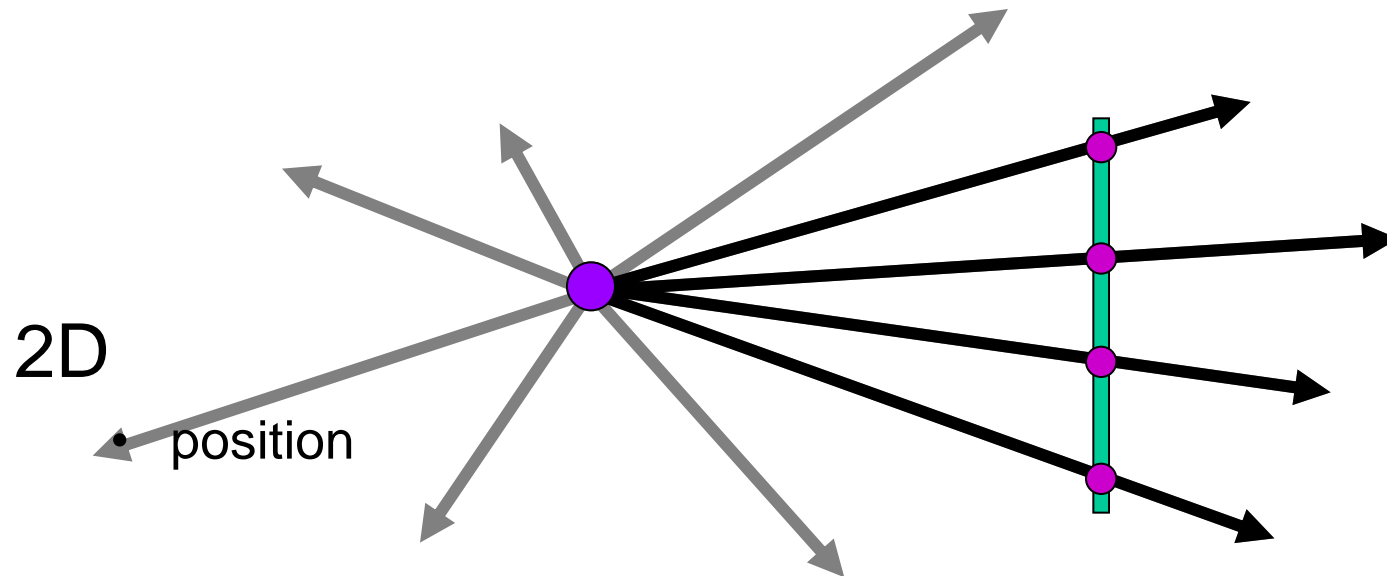


All rays through a point

- Panorama?

Image

Image plane



Spherical Panorama



See also: 2003 New Years Eve

<http://www.panoramas.dk/fullscreen3/f1.html>

All light rays through a point form a panorama

Totally captured in a 2D array -- $P(\theta, \phi)$

Where is the geometry???

Other ways to sample Plenoptic Function

Moving in time:

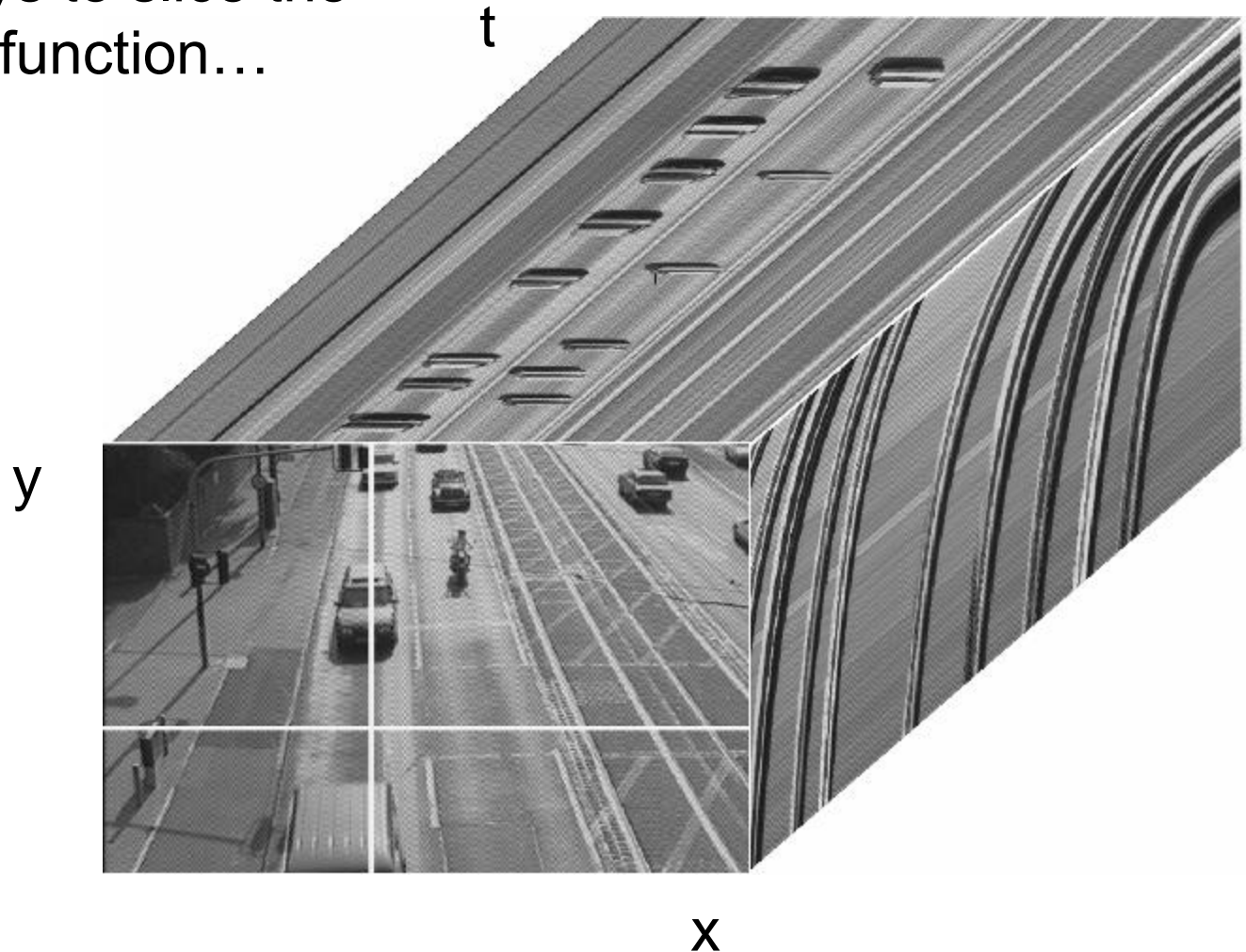
- Spatio-temporal volume: $P(\theta, \phi, t)$
- Useful to study temporal changes
- Long an interest of artists:



Claude Monet, Haystacks studies

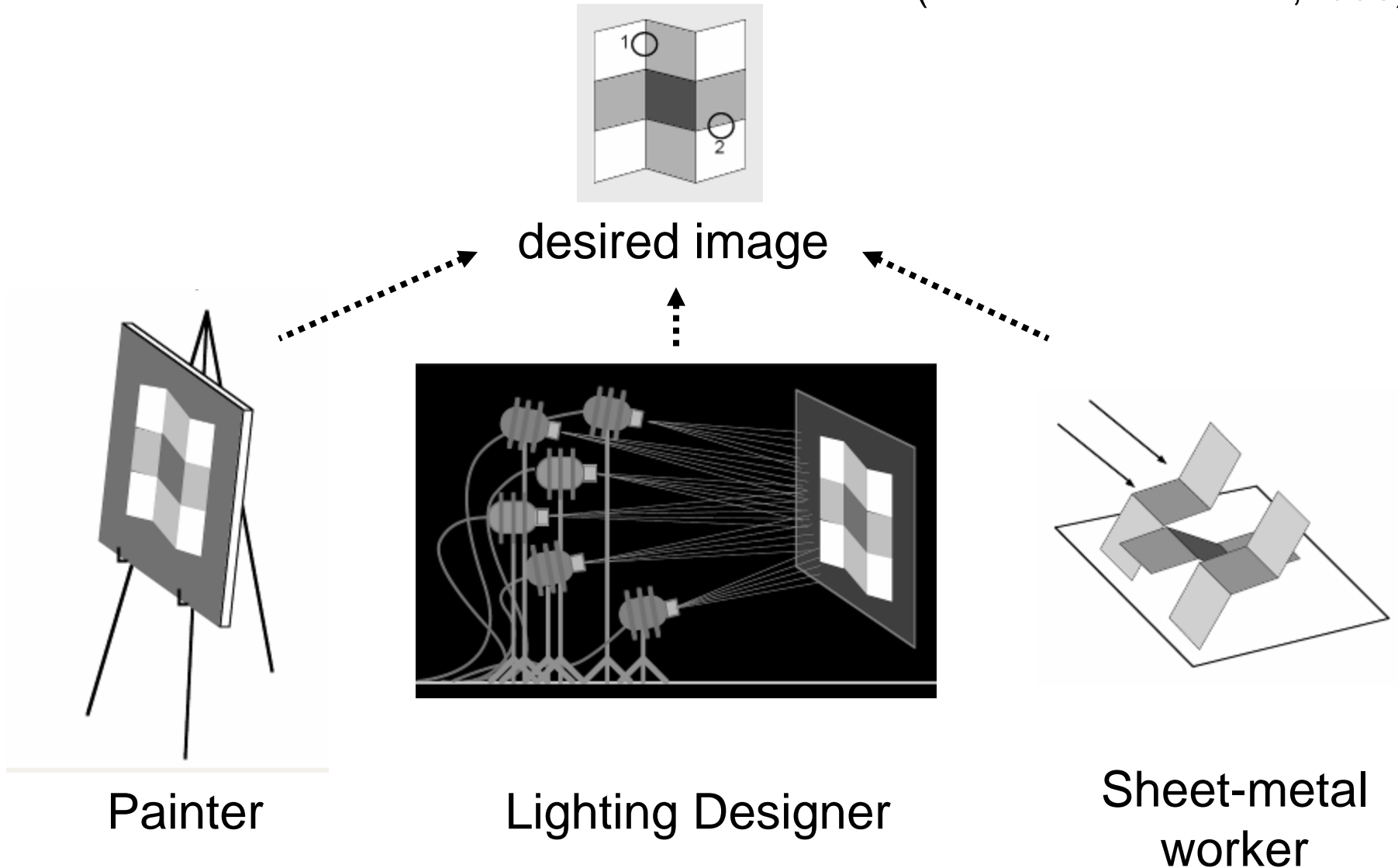
Space-time images

Other ways to slice the
plenoptic function...



The “Theatre Workshop” Metaphor

(Adelson & Pentland, 1996)



Painter (images)



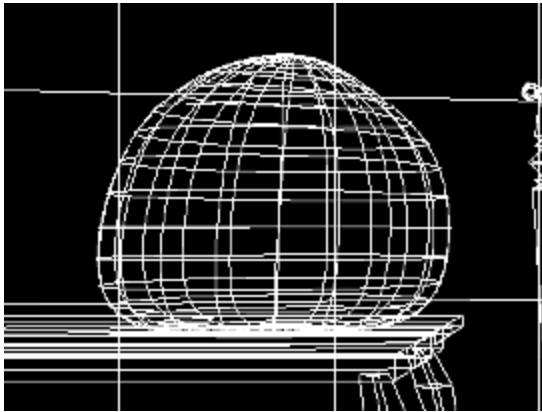
Lighting Designer (environment maps)



Show Naimark SF MOMA video

<http://www.debevec.org/Naimark/naimark-displacements.mov>

Sheet-metal Worker (geometry)



Let surface normals do all the work!

... working together



clever Italians

Want to minimize cost

Each one does what's easiest for him

- Geometry – big things
- Images – detail
- Lighting – illumination effects