Modeling Light

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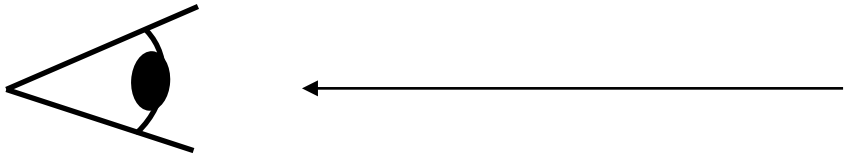
CS194: Image Manipulation & Computational Photography
Alexei Efros, UC Berkeley, Fall 2018

What is light?

Electromagnetic radiation (EMR) moving along rays in space

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



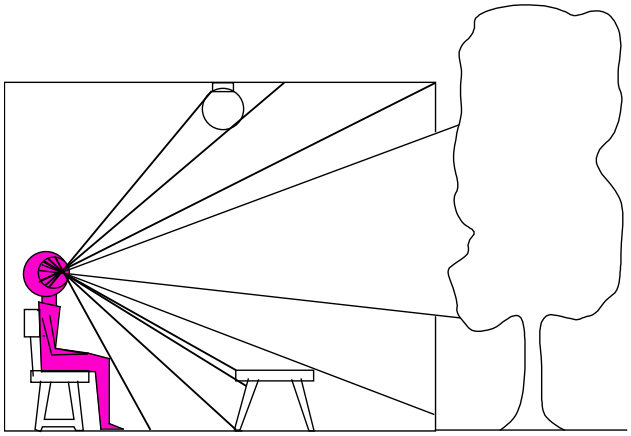
Light:

- Travels far
- Travels fast
- Travels in straight lines
- Interacts with stuff
- Bounces off things
- Is produced in nature
- Has lots of energy

-- Steve Shafer

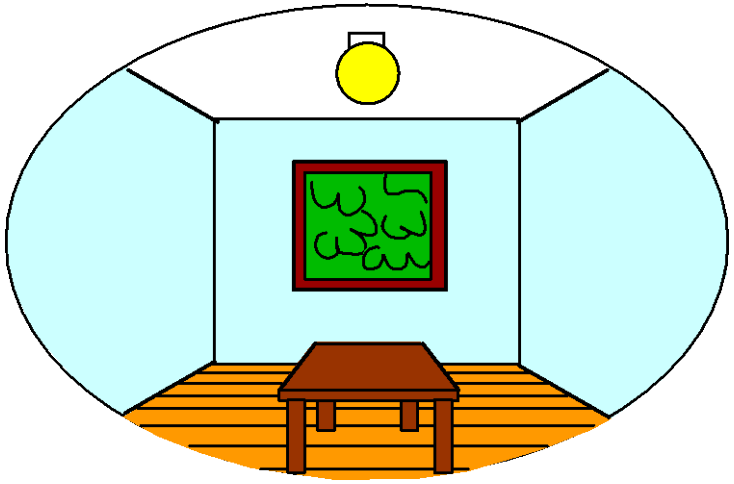
What do we see?

3D world



Point of observation

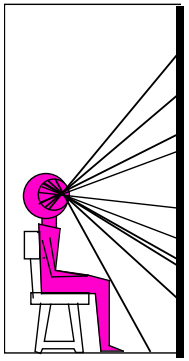
2D image



Figures © Stephen E. Palmer, 2002

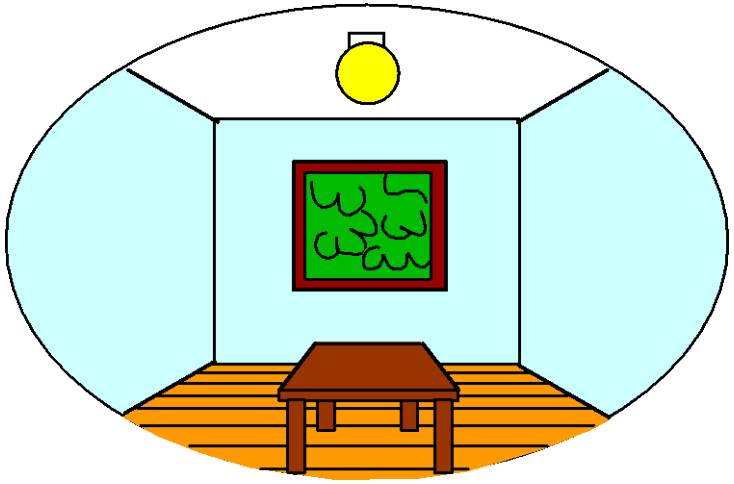
What do we see?

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

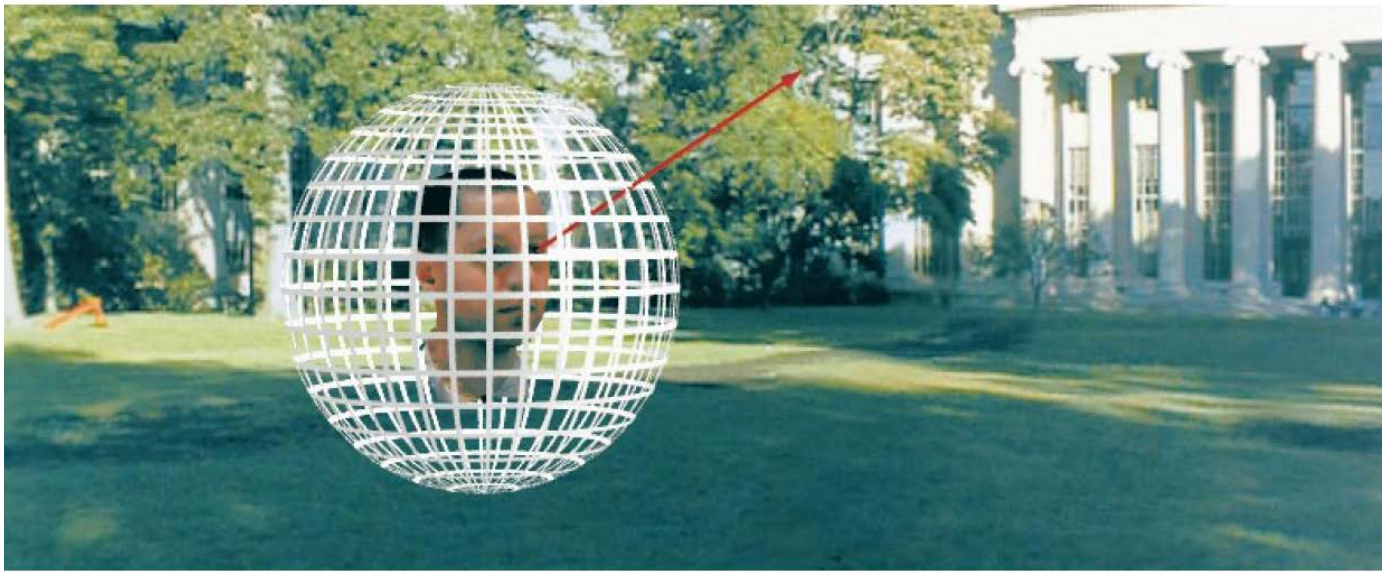


Figure by Leonard McMillan

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 <u>everything</u> that he can see…

Grayscale snapshot

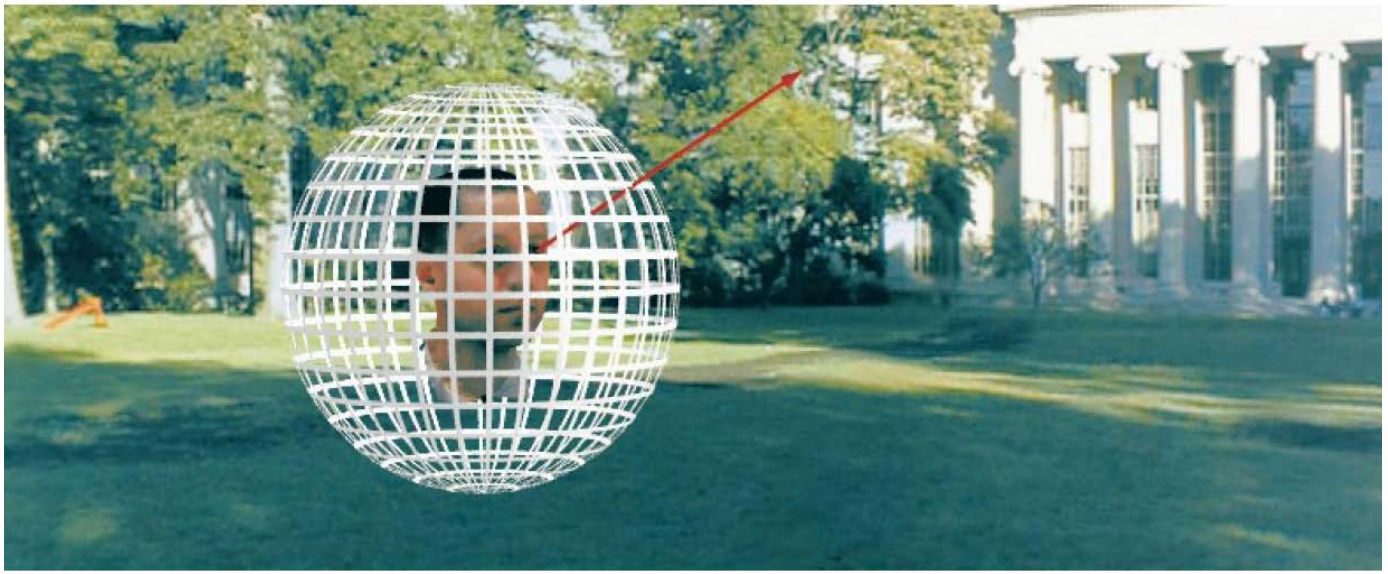
$$P(\theta,\phi)$$

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

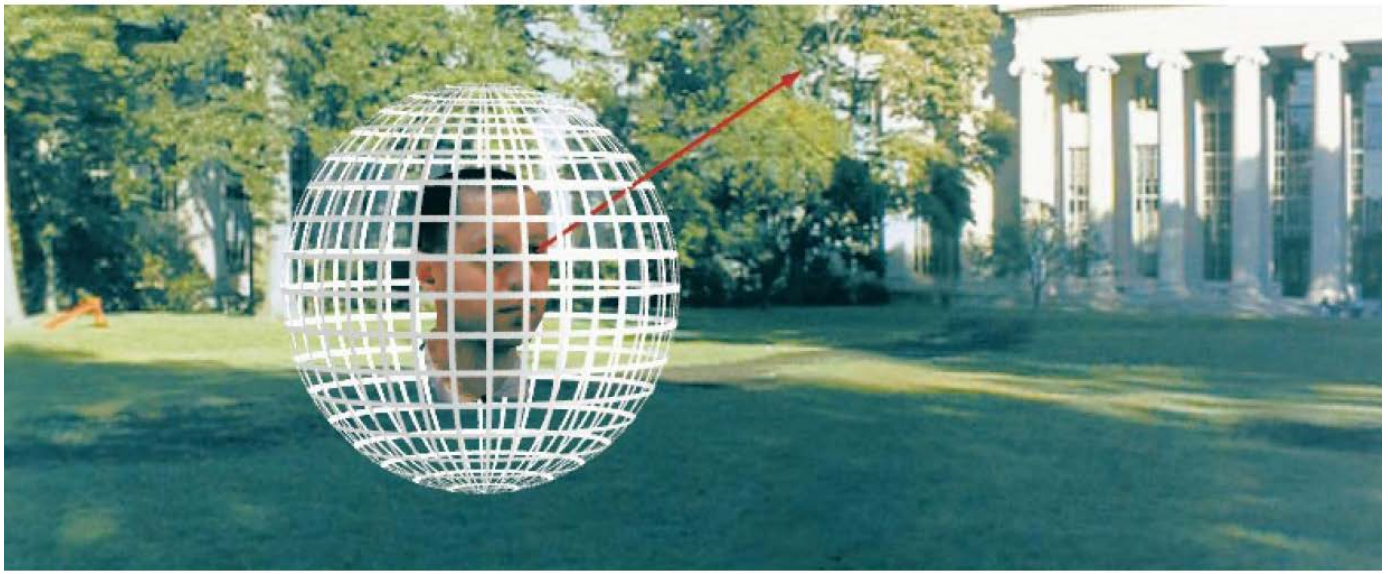


$$P(\theta,\phi,\lambda)$$

is intensity of light

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

A movie

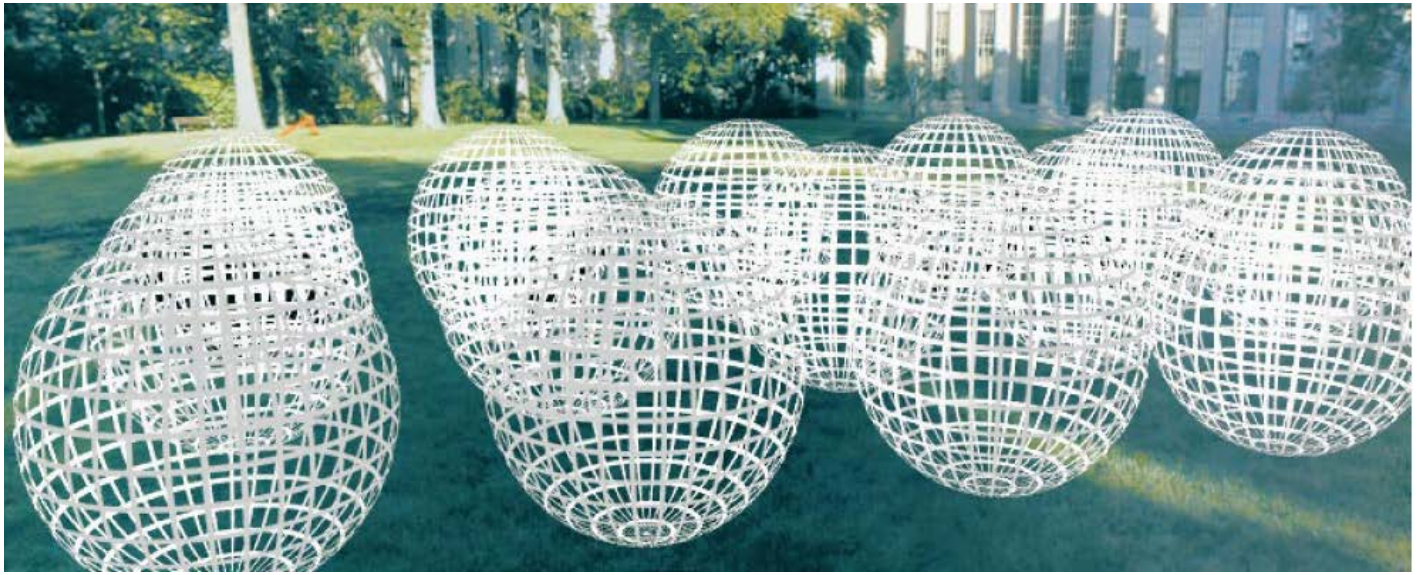


$$P(\theta,\phi,\lambda,t)$$

is intensity of light

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

Holographic movie

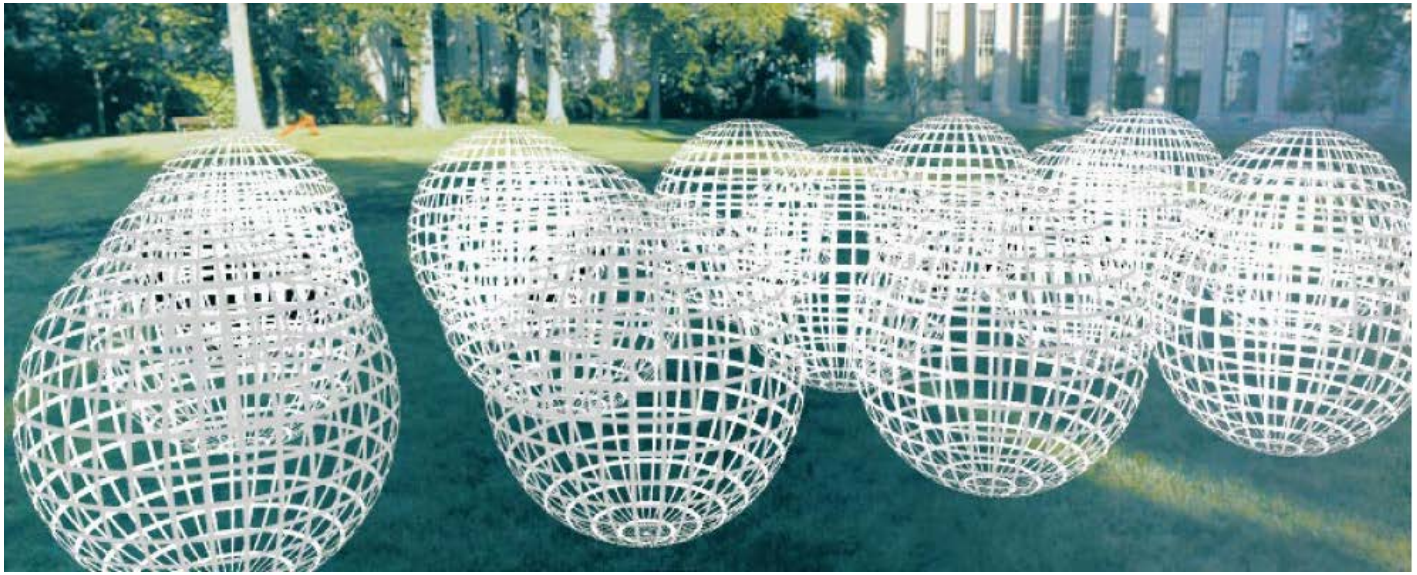


$$P(\theta,\phi,\lambda,t,V_X,V_Y,V_Z)$$

is intensity of light

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

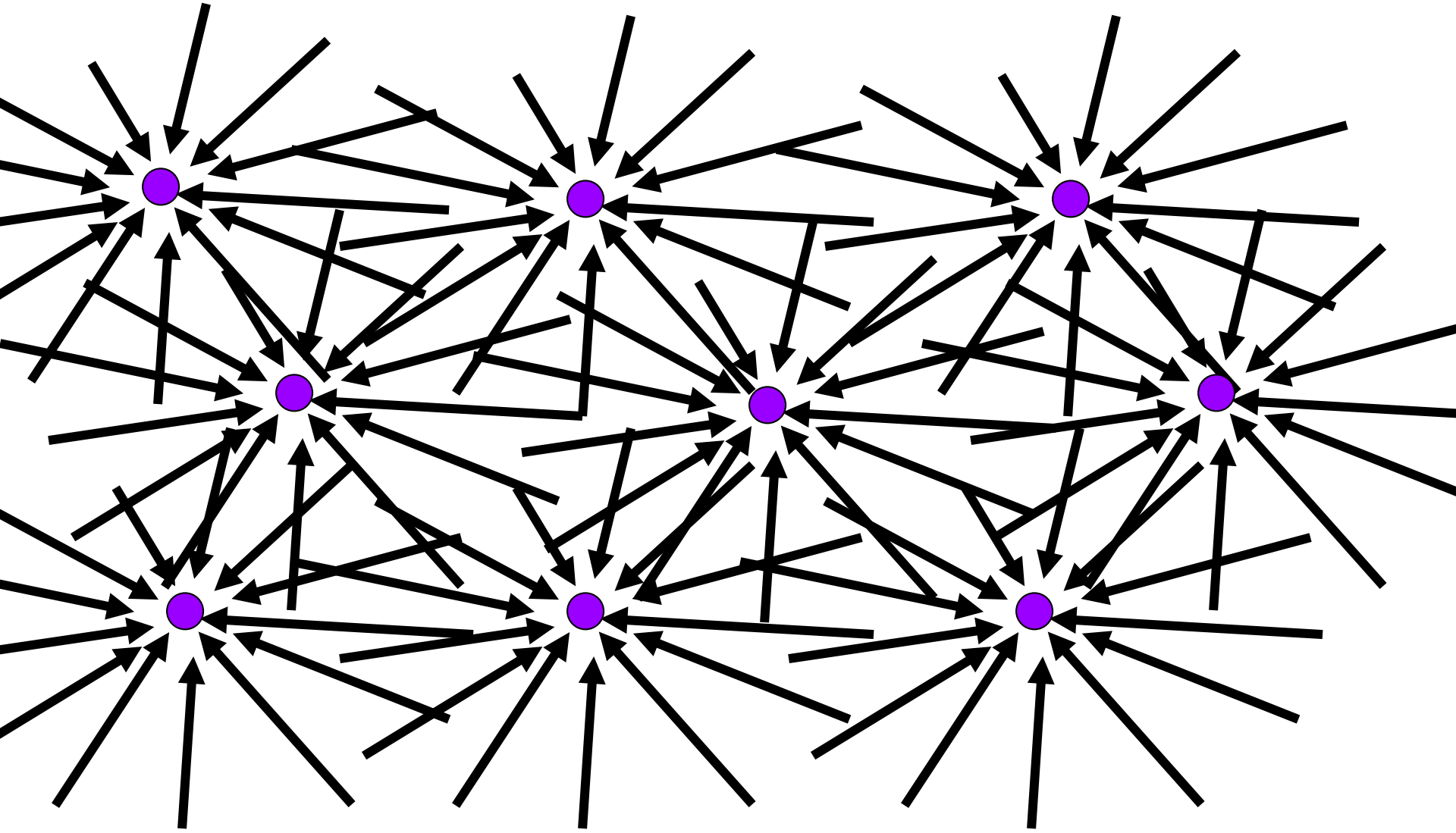
The Plenoptic Function



$$P(\theta,\phi,\lambda,t,V_X,V_Y,V_Z)$$

- 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

Model geometry or just capture images?

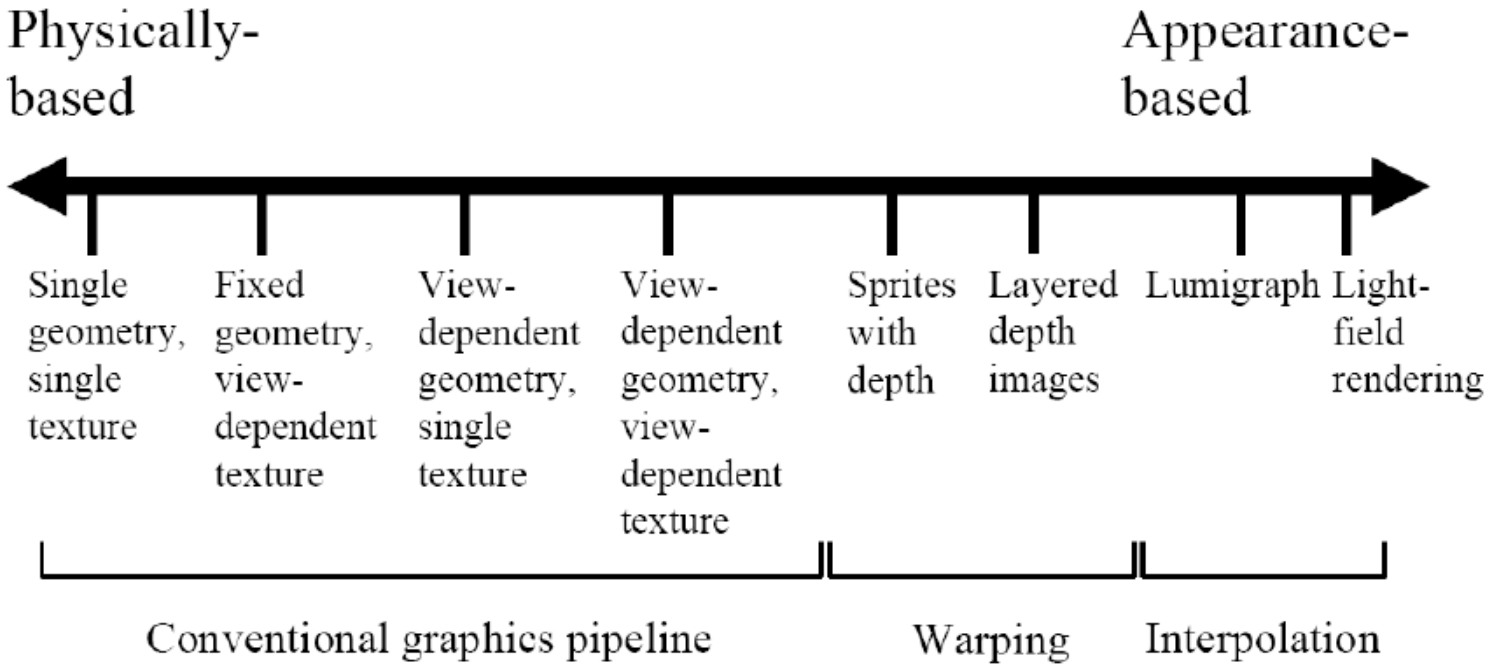
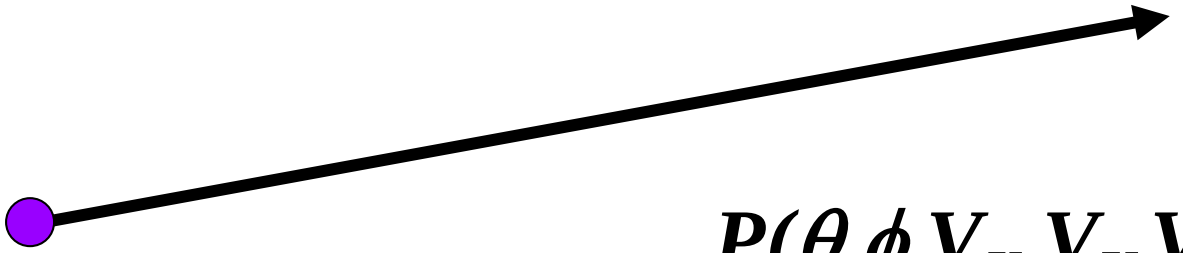


Figure 13.11: *The geometry-image continuum in image-based rendering (Kang* et al. *2000). Representations on the left end of the spectrum use more detailed geometry and simpler image representations, while representations and algorithms on the right use more images and less geometry.*

Ray

Let’s not worry about time and color:

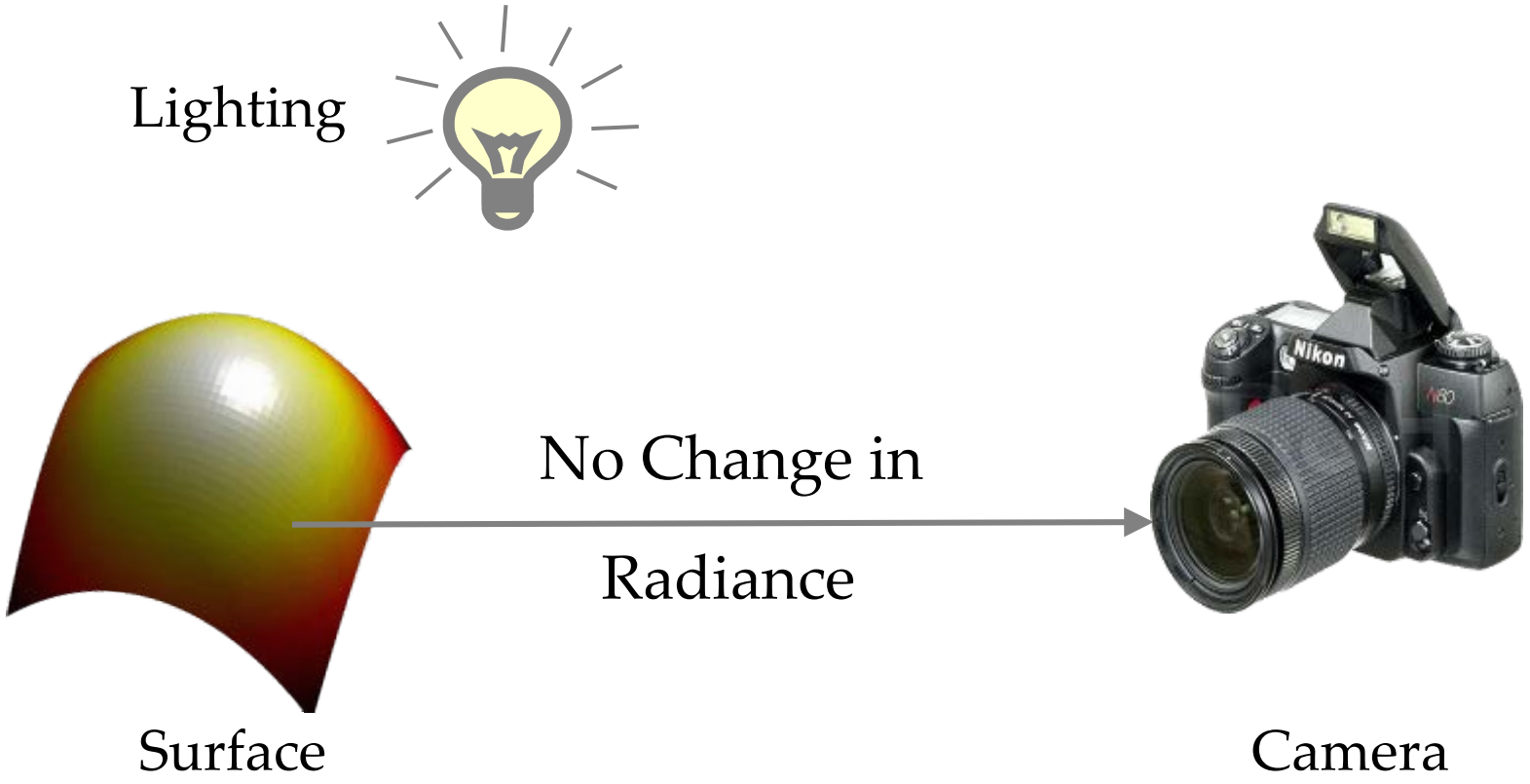


$P(\theta,\phi,V_X,V_Y,V_Z)$

5D

- 3D position
- 2D direction

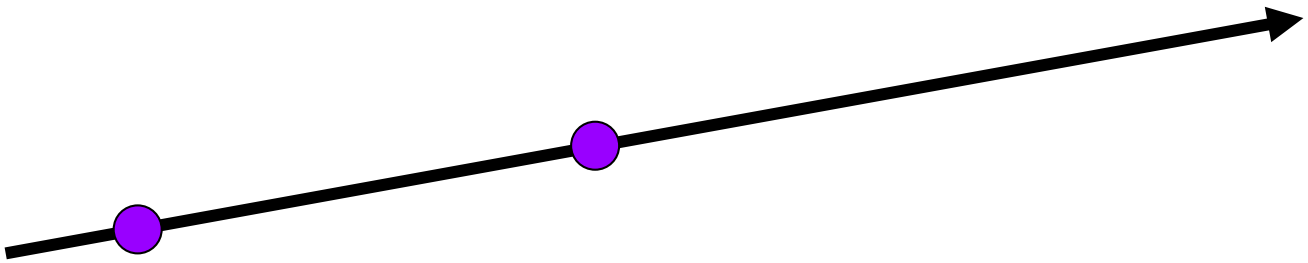
How can we use this?



Ray Reuse

Infinite line

- Assume light is constant (vacuum)



4D

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

Only need plenoptic surface

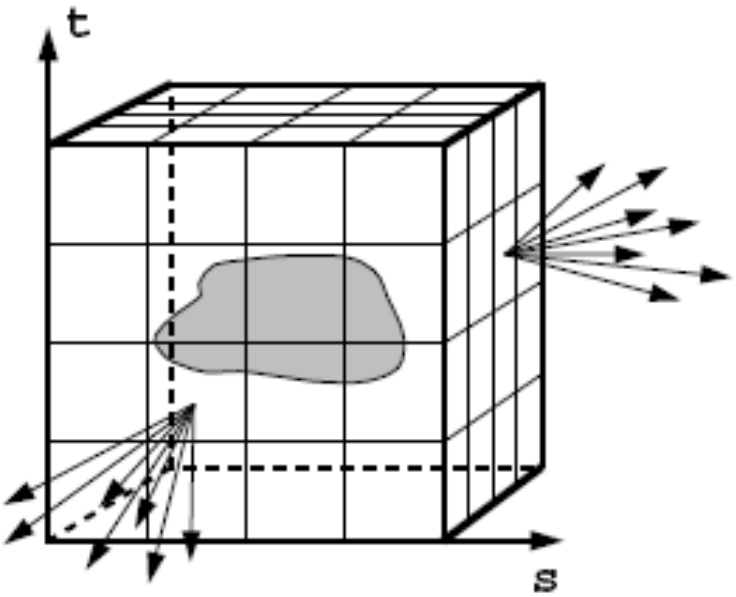
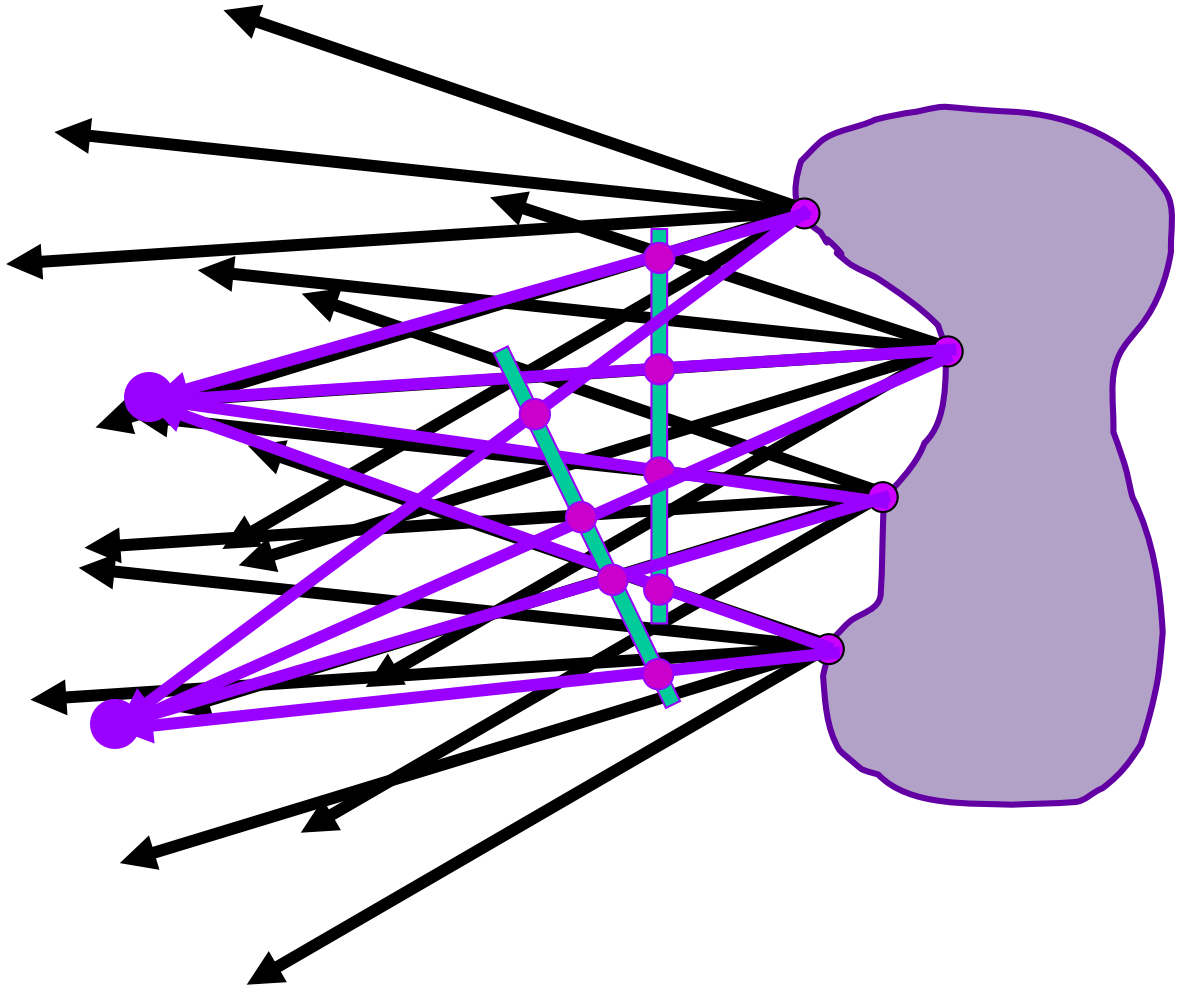


Figure 1: The surface of a cube holds all the radiance information due to the enclosed object.

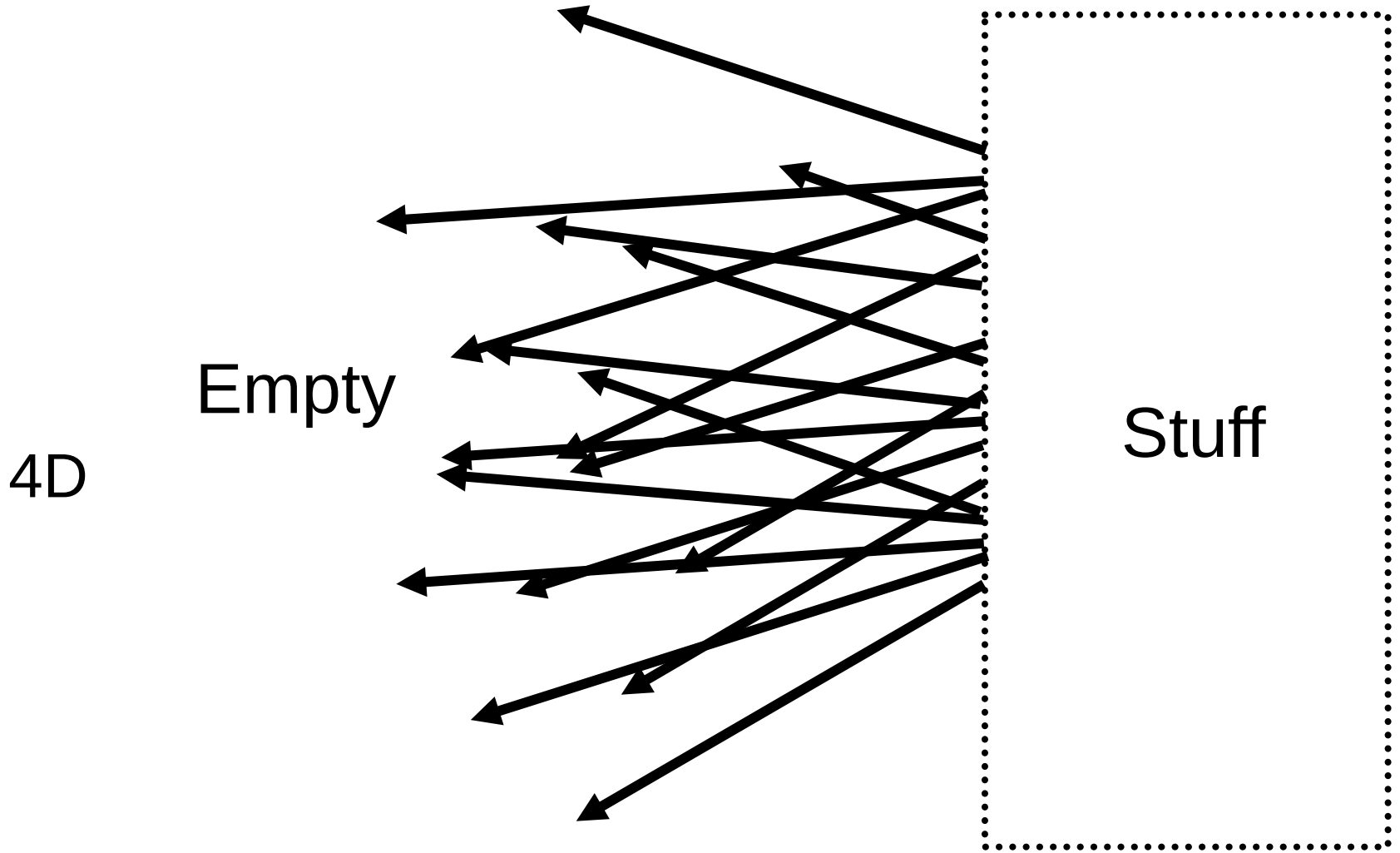
Synthesizing novel views



Slide by Rick Szeliski and Michael Cohen

Lumigraph / Lightfield

Outside convex space



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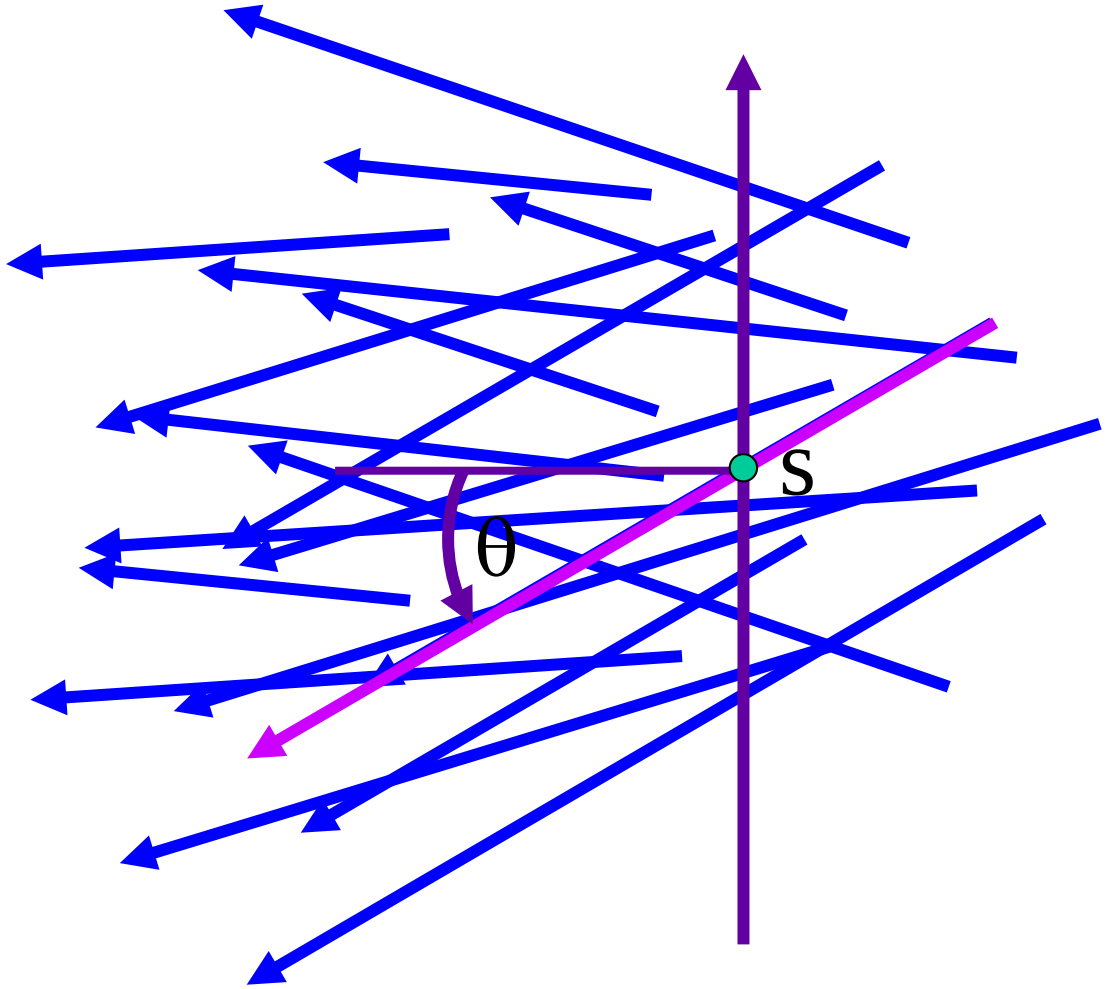
Lumigraph - Organization

2D position

2D direction



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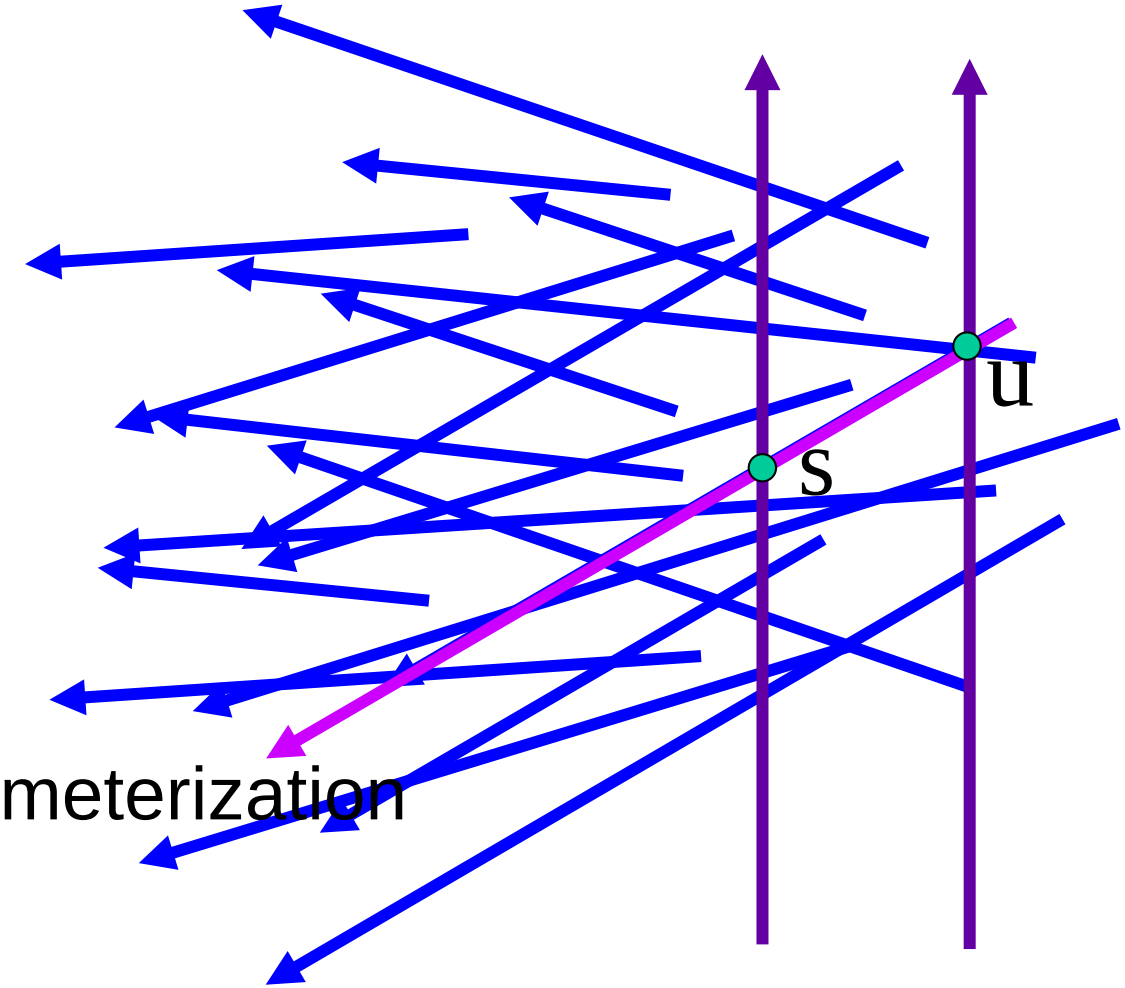
Lumigraph - Organization

2D position

2D position

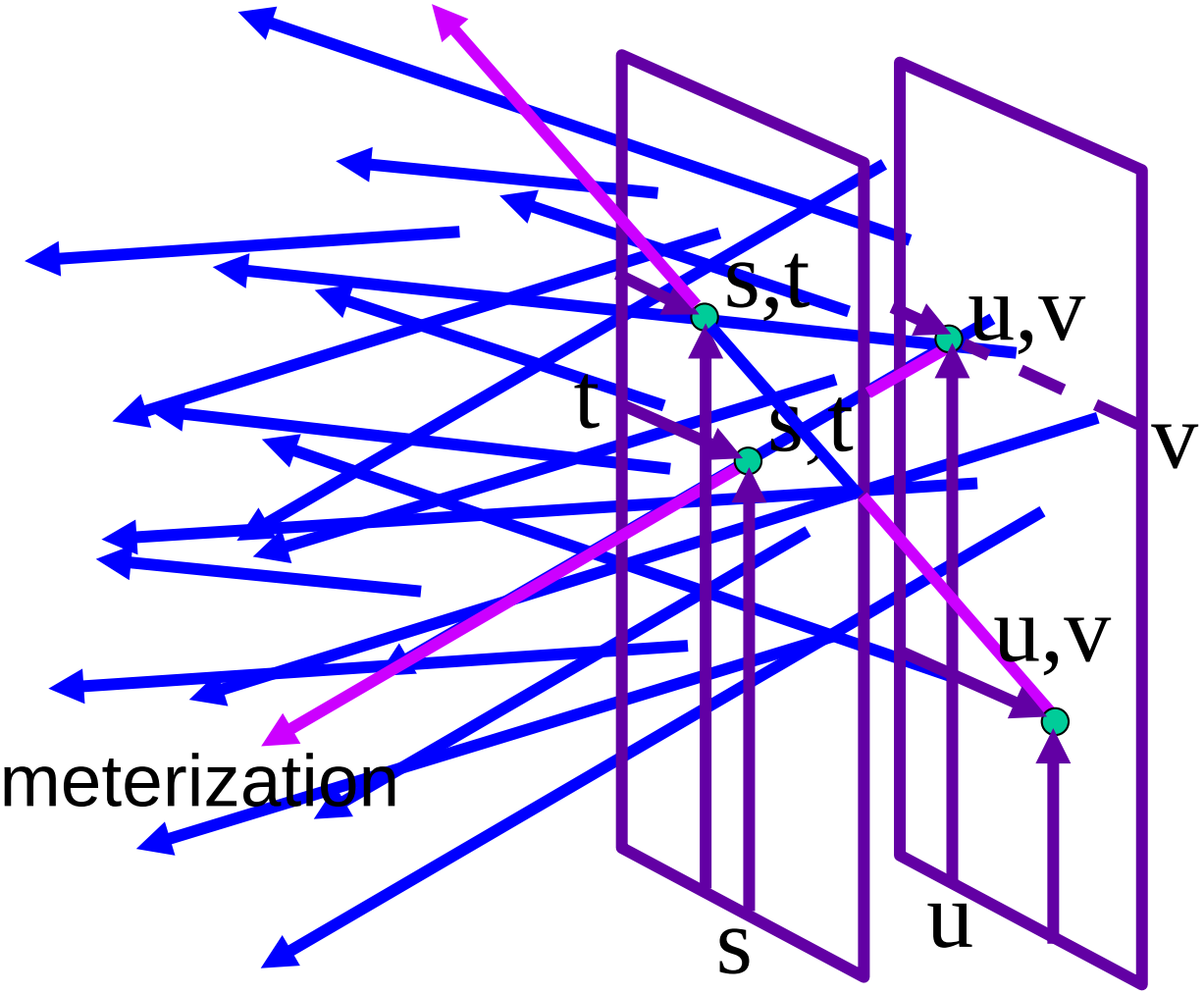


2 plane parameterization

Lumigraph - Organization

2D position

2D position



2 plane parameterization

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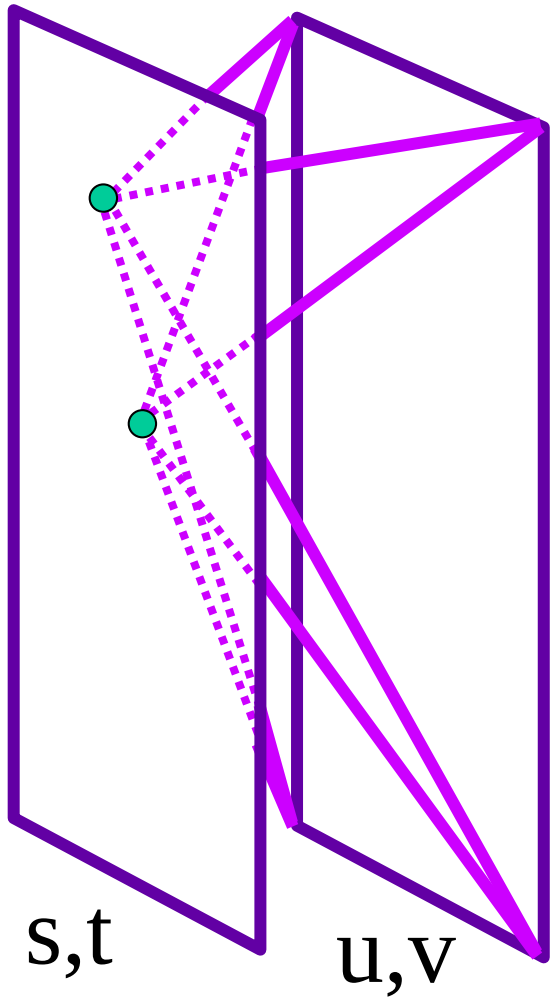
Lumigraph - Organization

Hold s,t constant

Let u,v vary

An image



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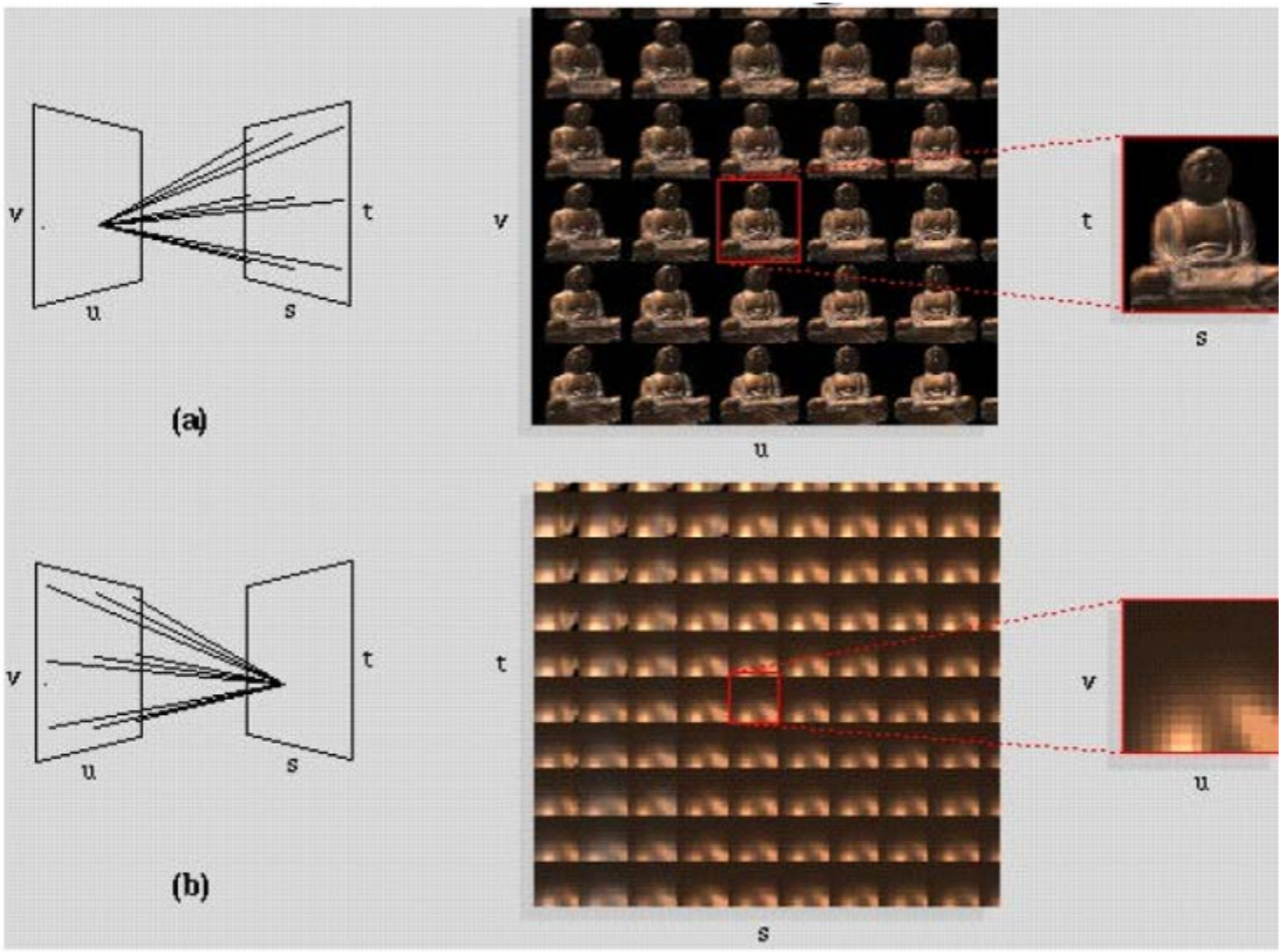
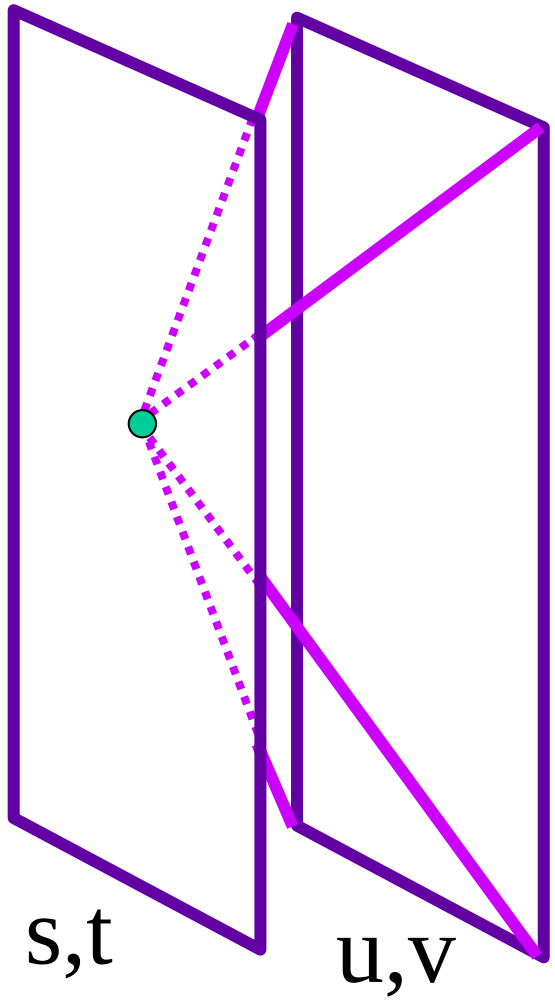
Lumigraph / Lightfield



Lumigraph - Capture

Idea 1

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



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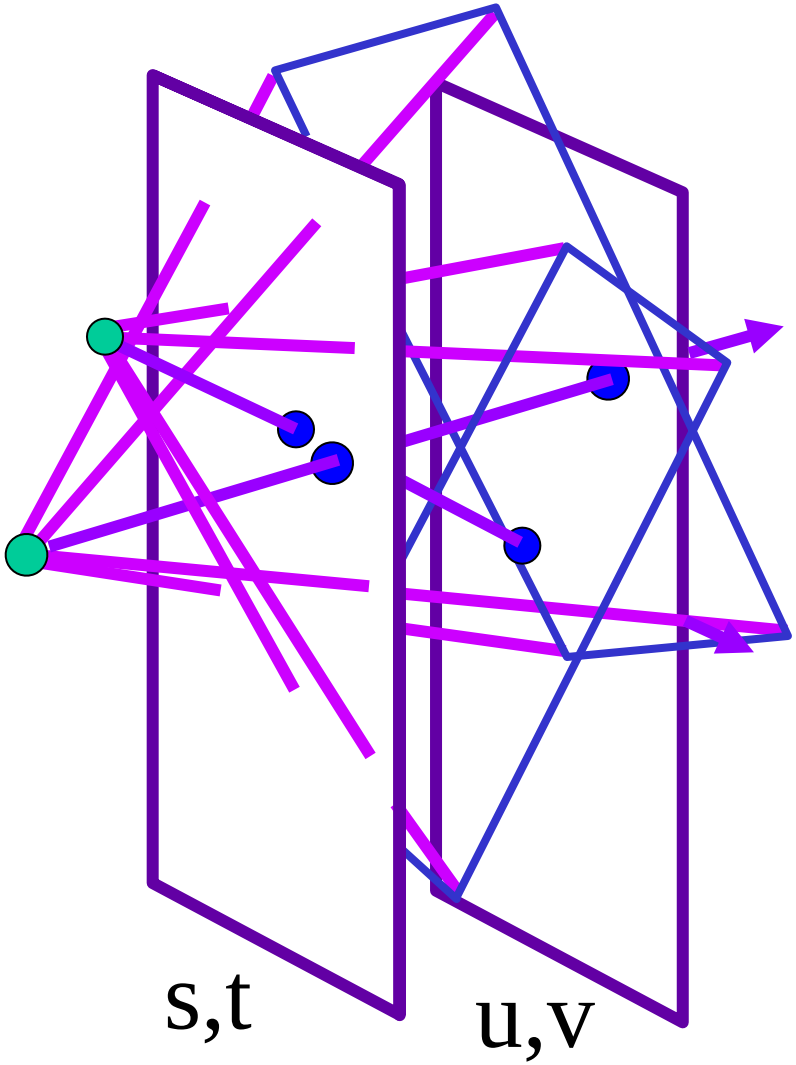
Lumigraph - Capture

Idea 2

- Move camera anywhere
- Rebinning
  - see Lumigraph paper



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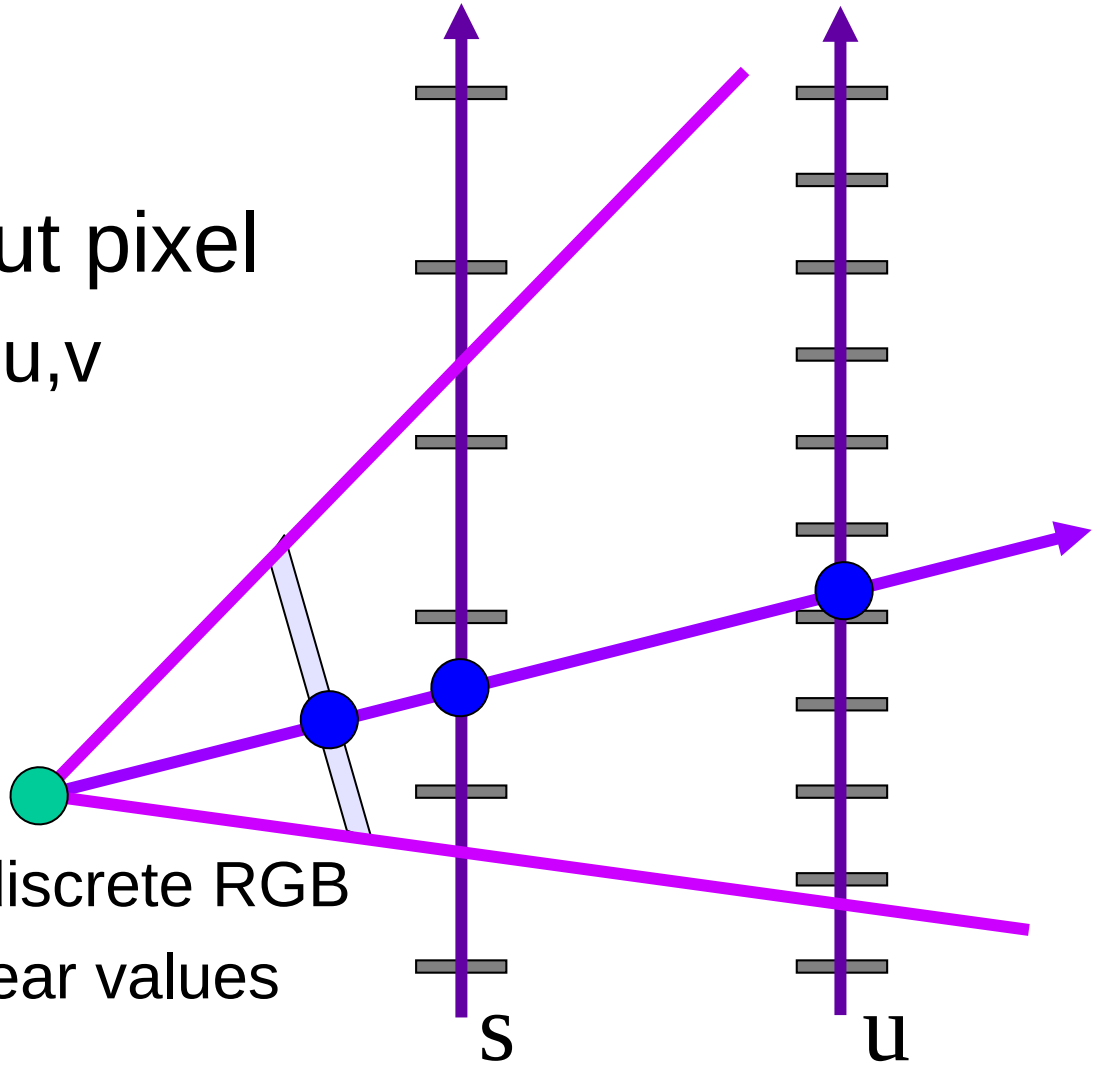
Novel View Synthesis

- For each output pixel
  - determine s,t,u,v
  - either
    - use closest discrete RGB
    - interpolate near values



Slide by Rick Szeliski and Michael Cohen

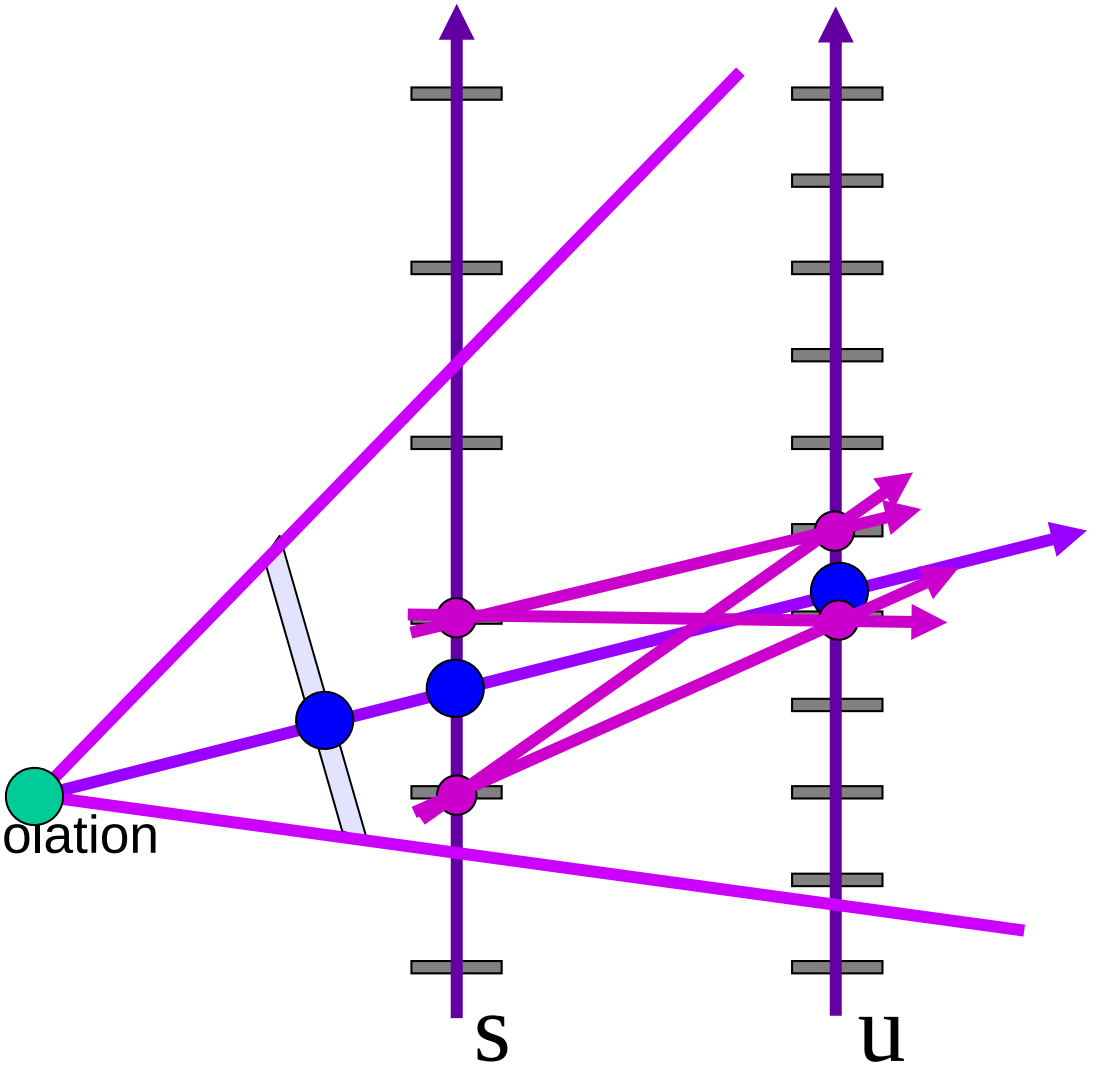
Interpolation

Nearest

- closest s
- closest u
- draw it

Blend 16 nearest

- quadrilinear interpolation



Slide by Rick Szeliski and Michael Cohen

Stanford multi-camera array

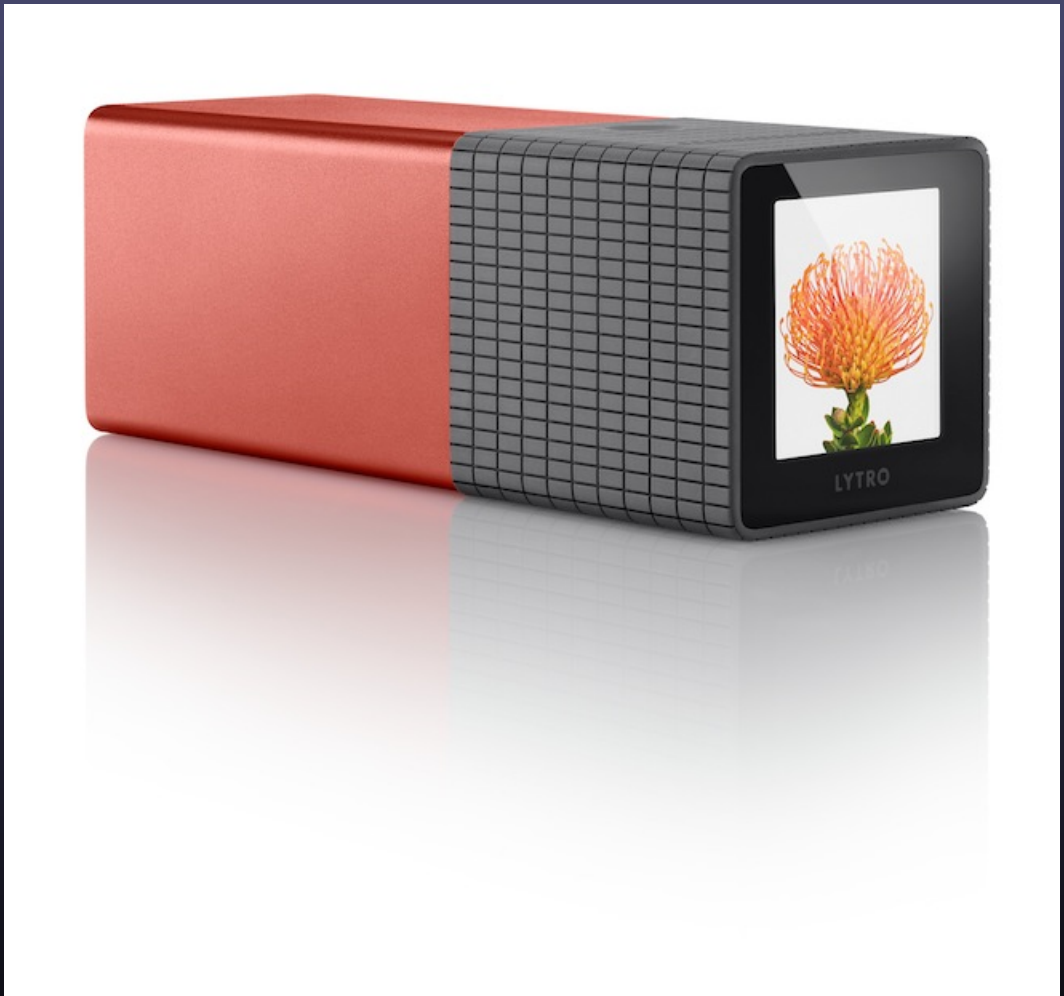
- 640 × 480 pixels × 30 fps × 128 cameras

- 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

On sale now: lytro.com



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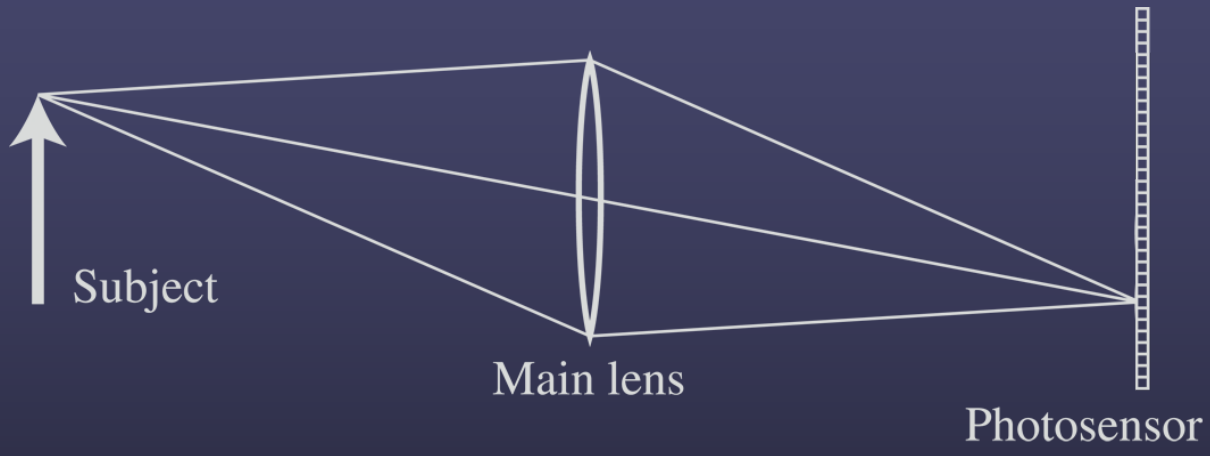
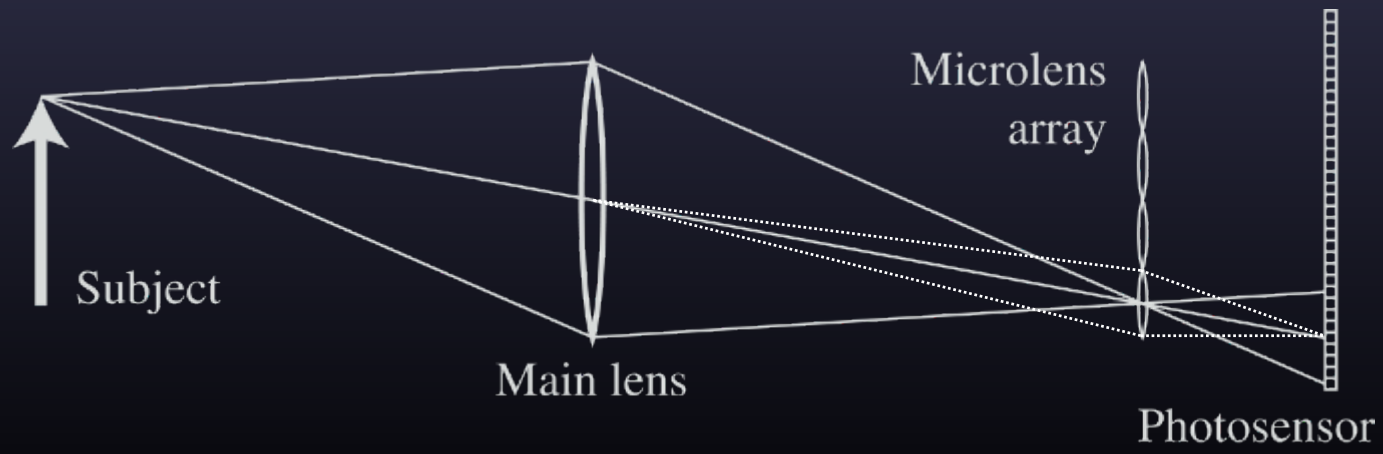
Conventional versus light field camera





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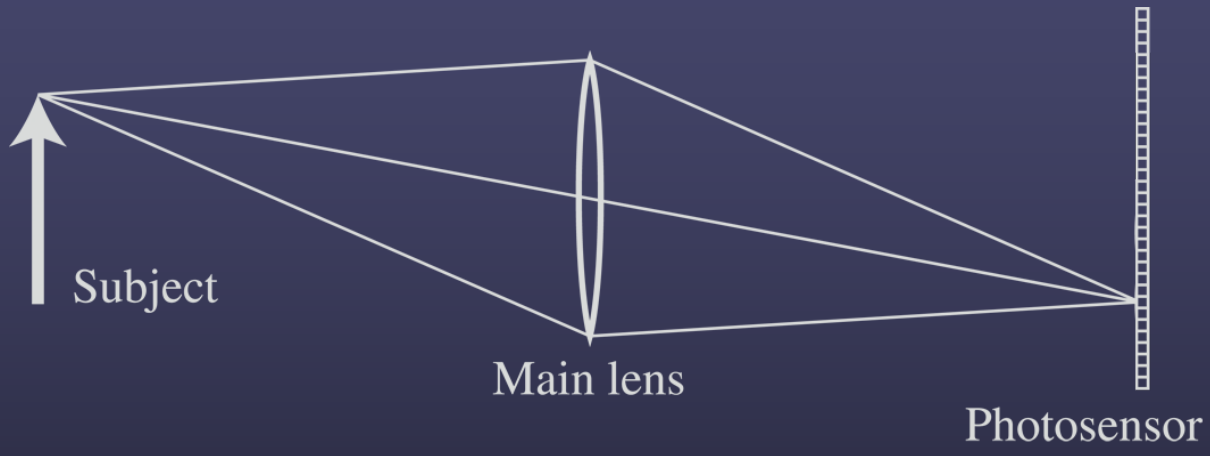
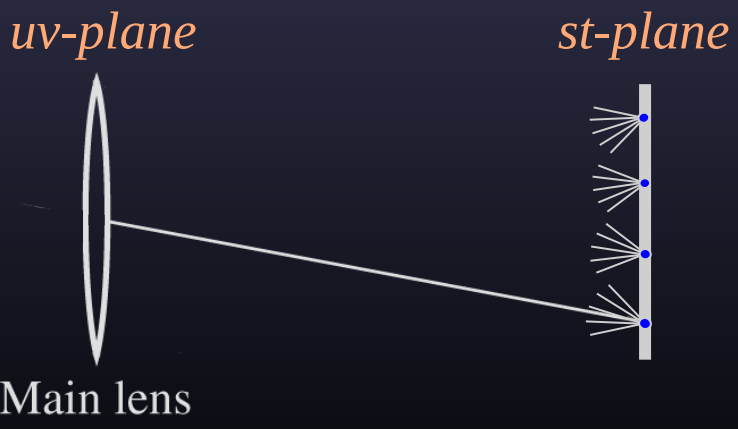
Conventional versus light field camera





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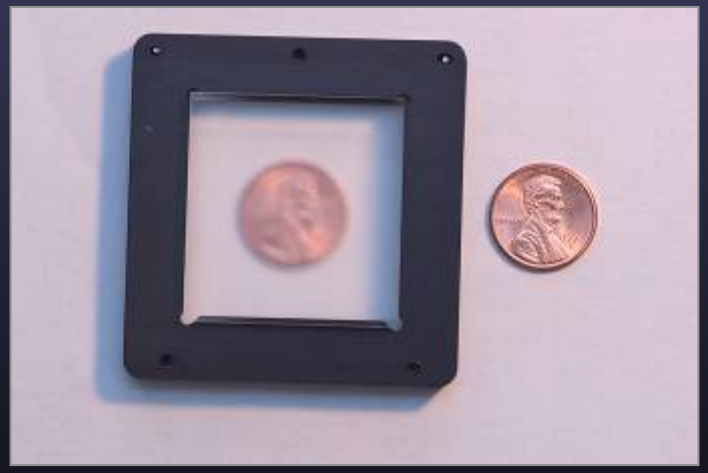
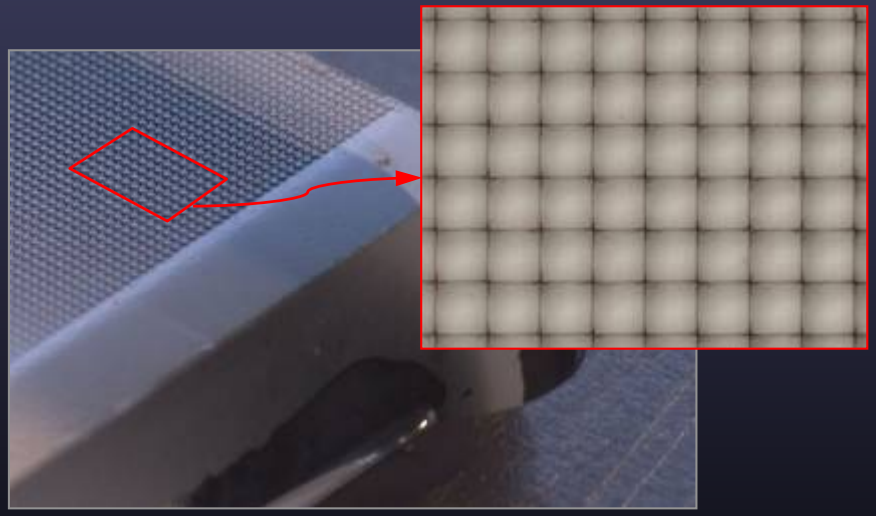
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor

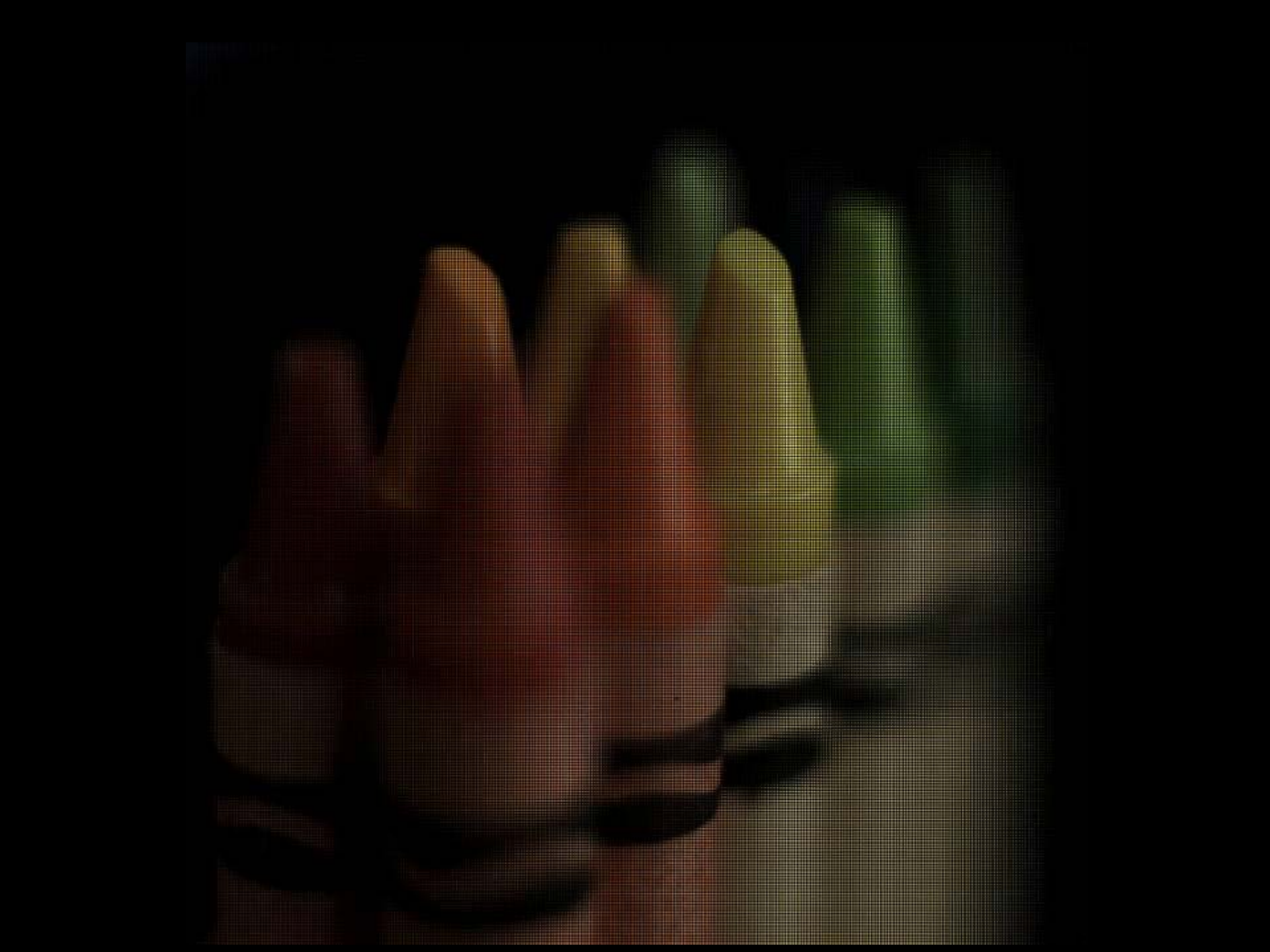


Adaptive Optics microlens array

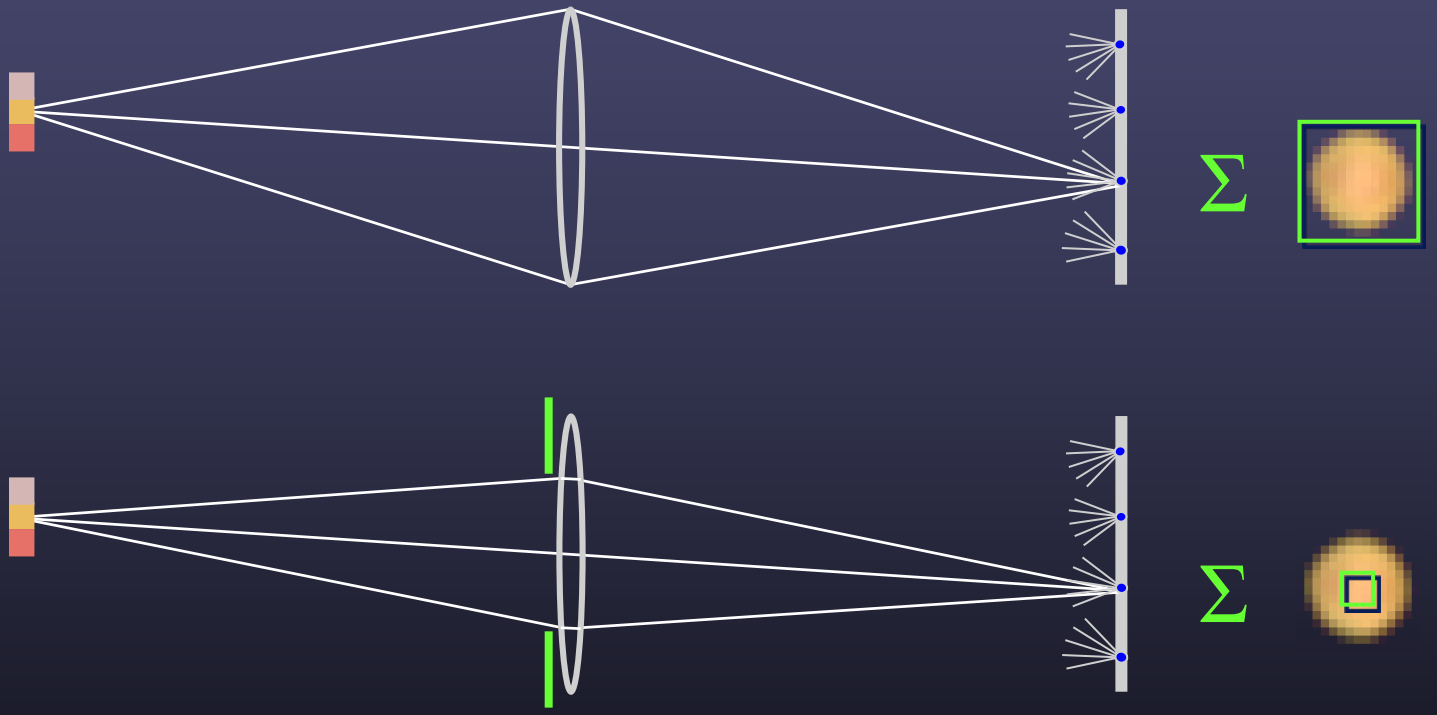


125µ square-sided microlenses

- *4000 × 4000 pixels ÷ 292 × 292 lenses = 14 × 14 pixels per lens*



Digitally stopping-down



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

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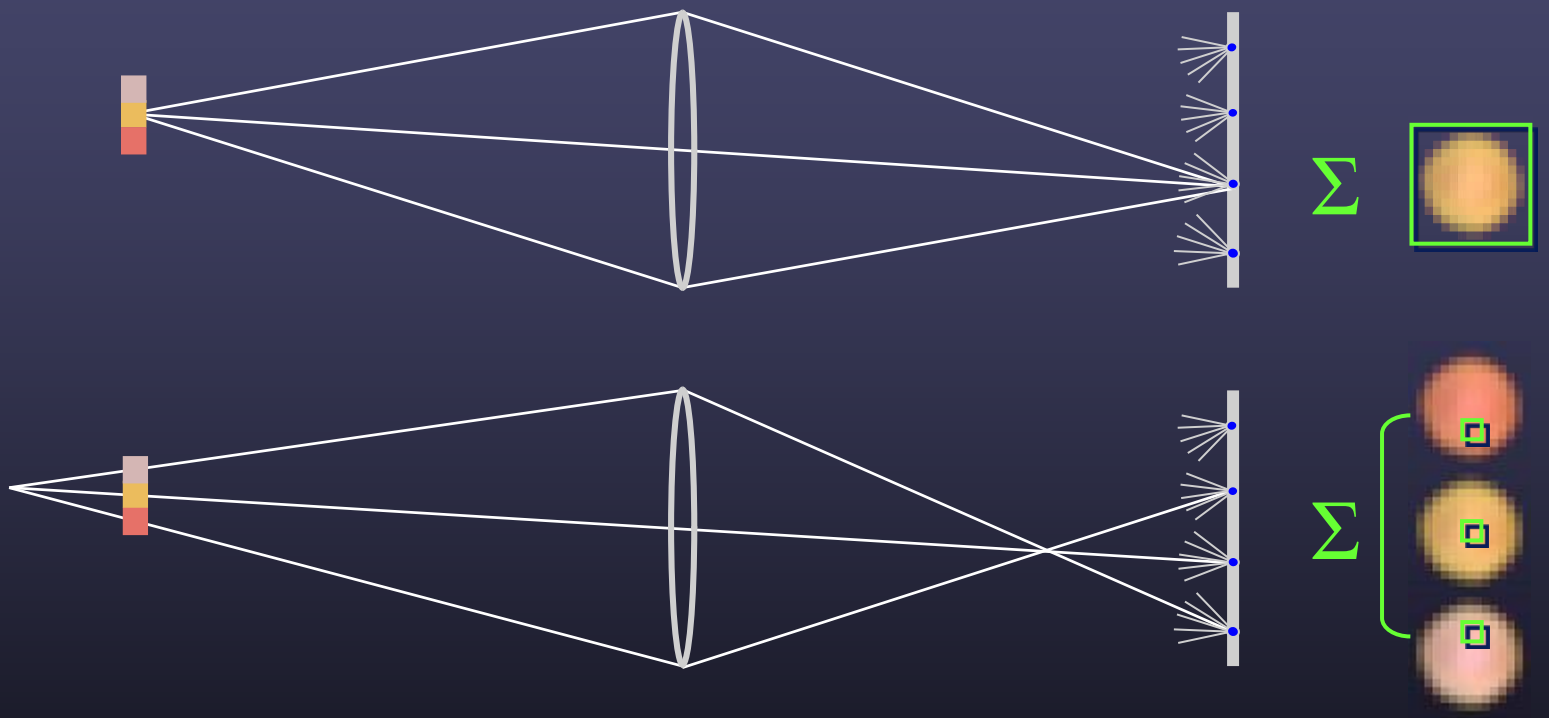
Digital refocusing



- refocusing = summing windows extracted from several microlenses

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Example of digital refocusing

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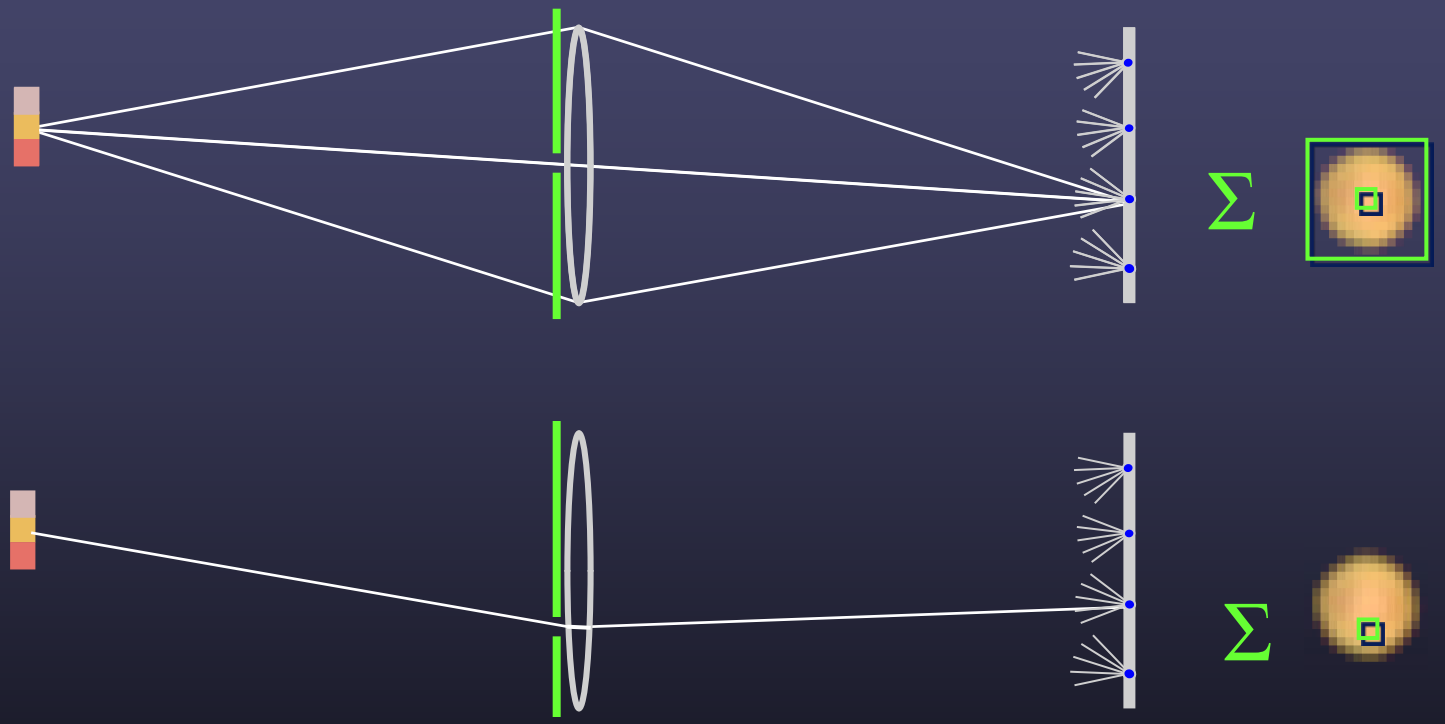
Digitally moving the observer



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

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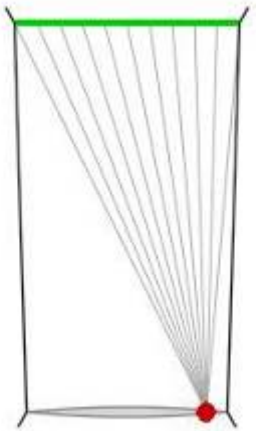
Example of moving the observer



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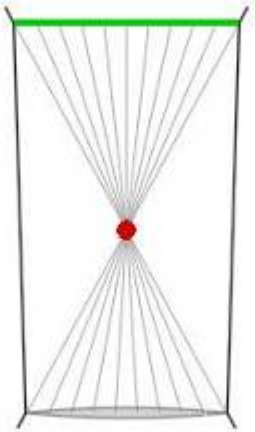
Moving backward and forward



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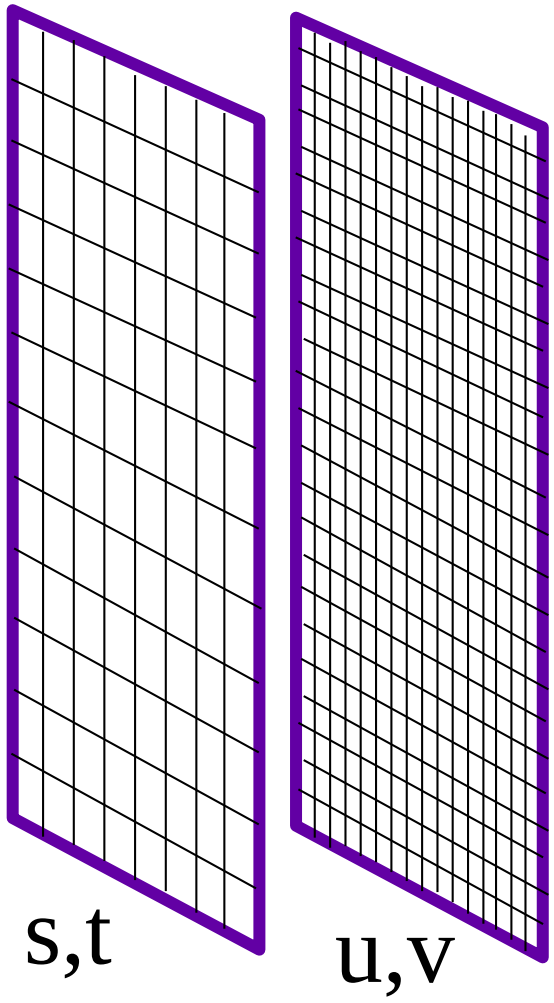
3D Lumigraph

One row of s,t plane

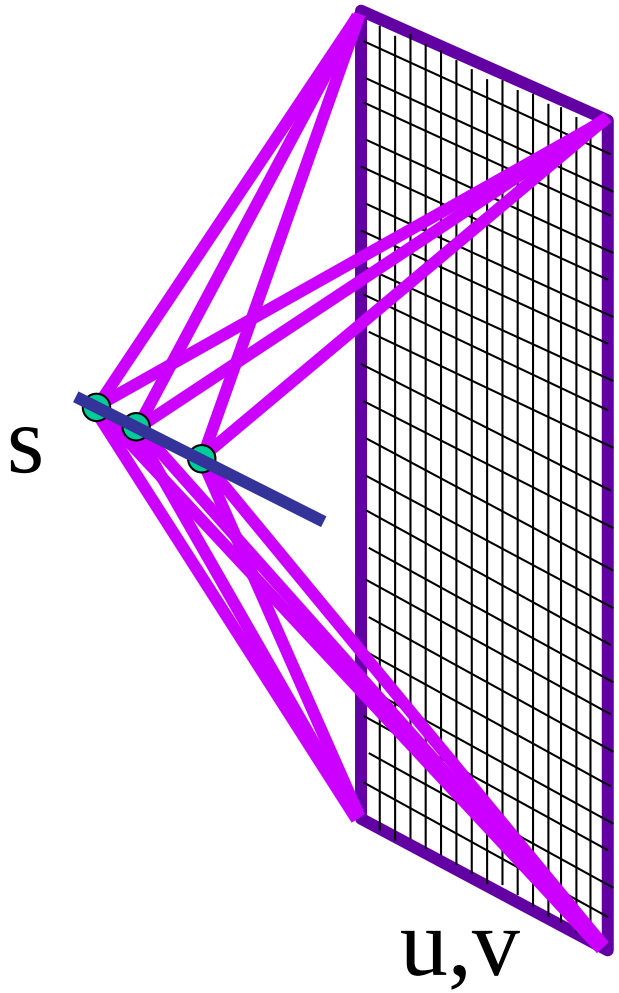
- i.e., hold t constant



3D Lumigraph

One row of s,t plane

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

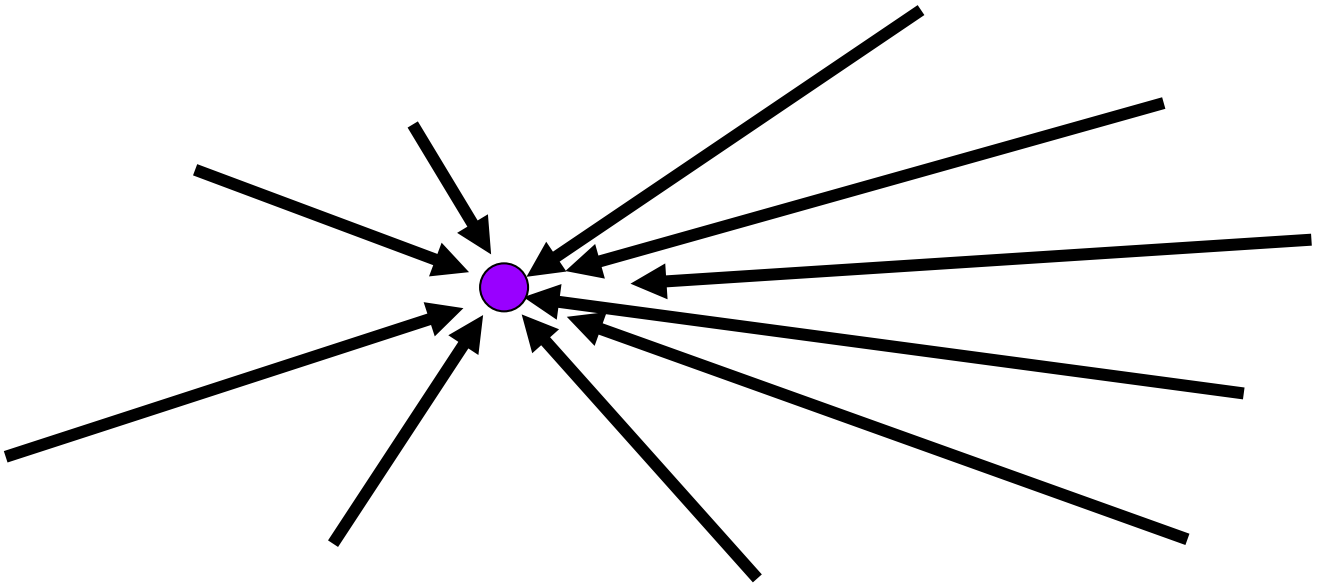


P(x,t)

by David Dewey

2D: Image

What is an image?

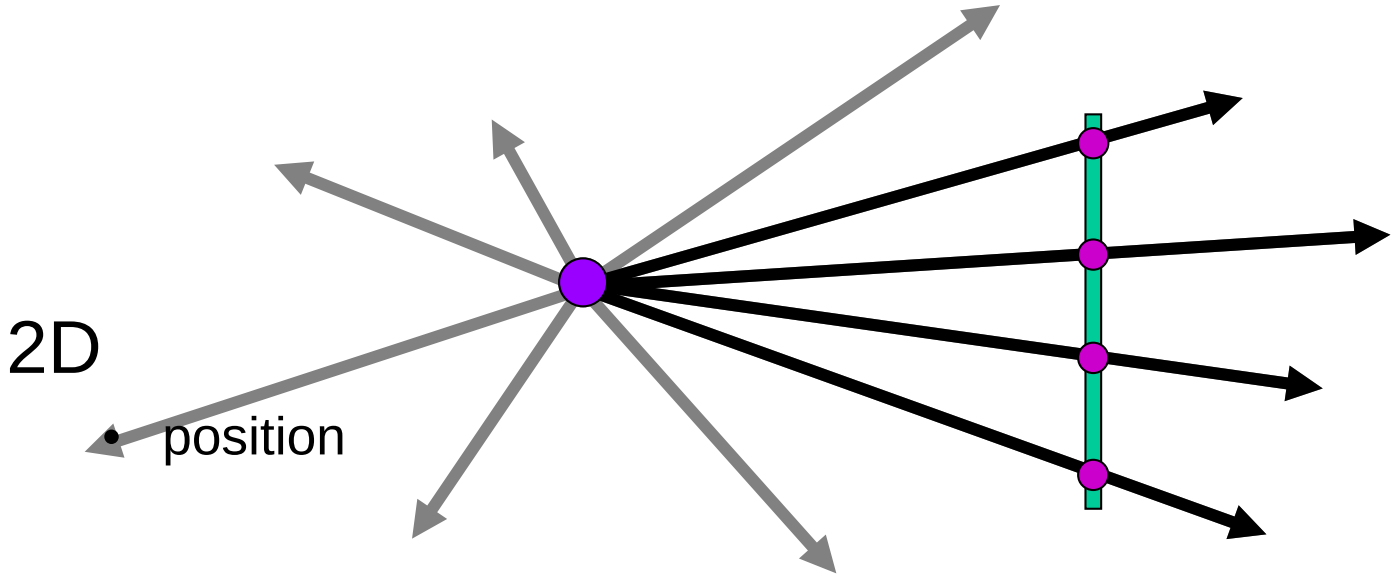


All rays through a point

- 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 ponorama

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

Where is the geometry???

Other ways to sample Plenoptic Function

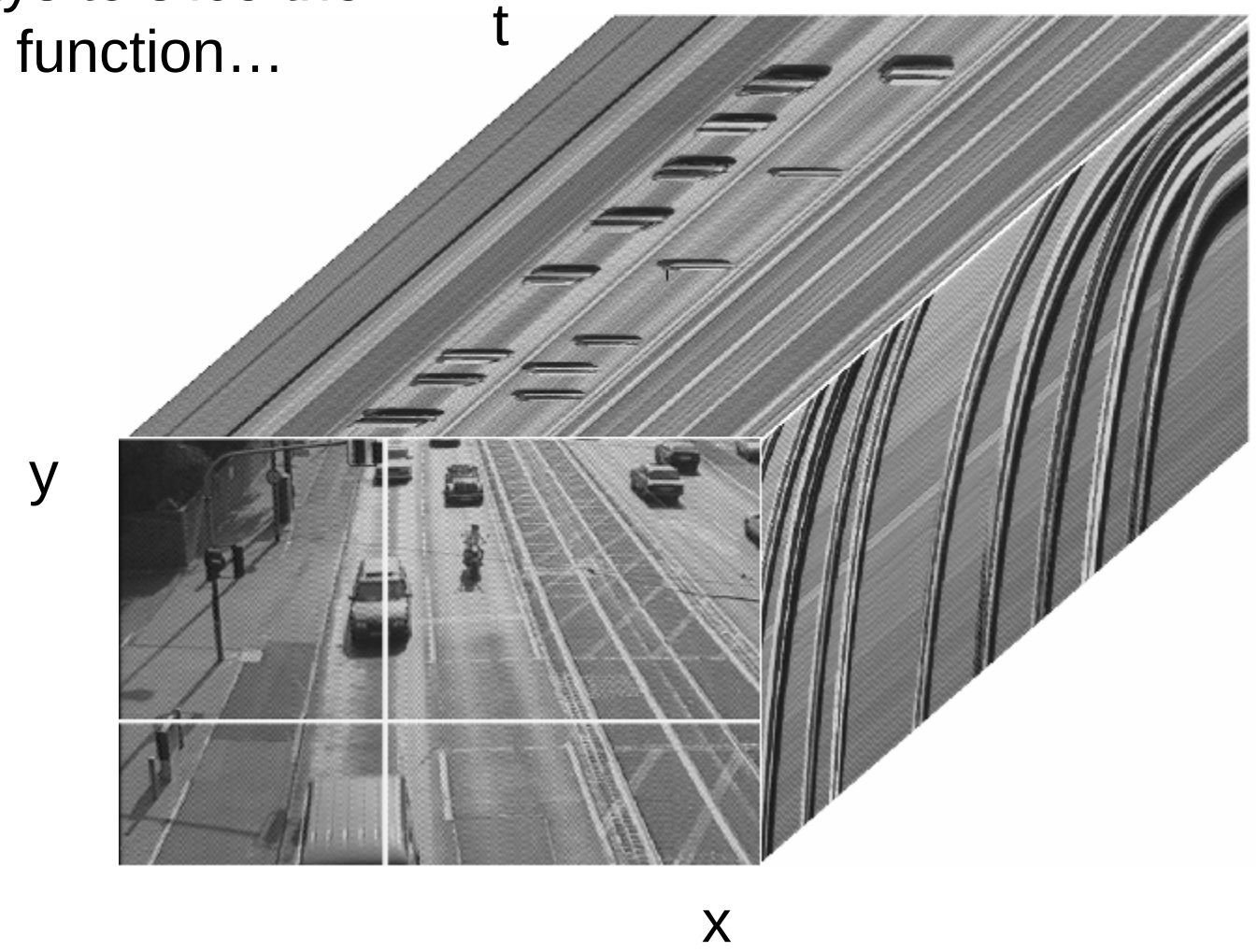
Moving in time:

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

Claude Monet, Haystacks studies

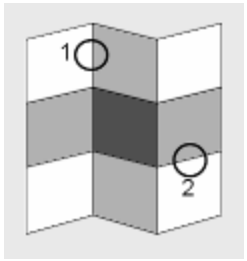
Space-time images

Other ways to slice the plenoptic function…

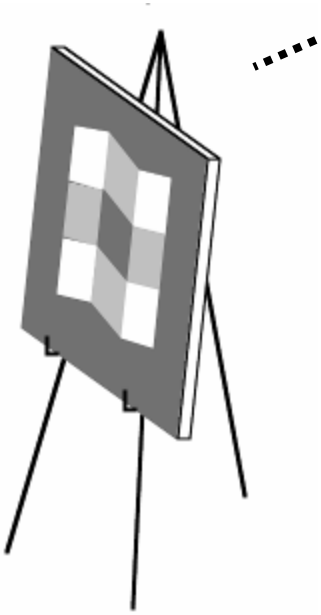


The “Theatre Workshop” Metaphor

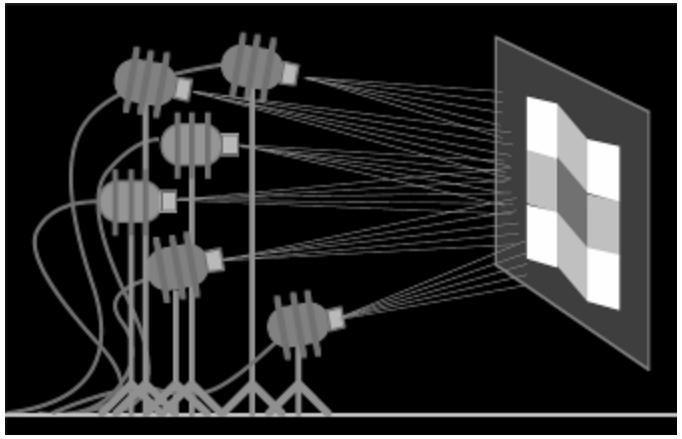
(Adelson & Pentland,1996)



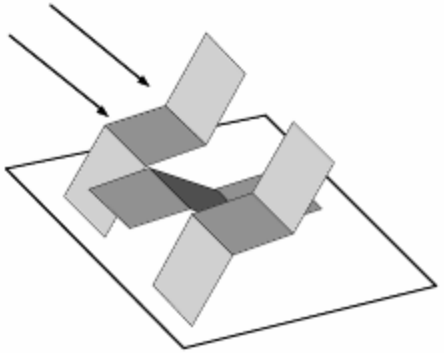
desired image



Painter



Lighting Designer



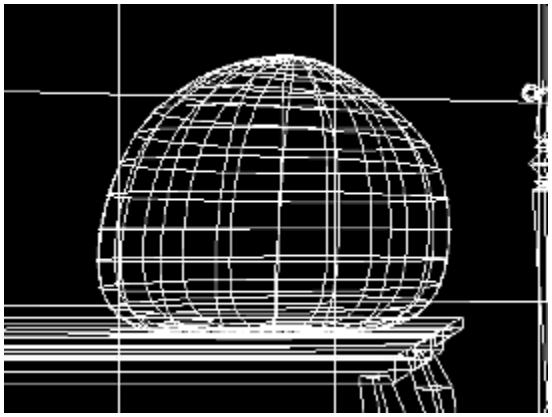
Sheet-metal worker

Painter (images)

Lighting Designer (environment maps)

Show Naimark SF MOMA video
https://www.youtube.com/watch?v=bMDr_CFFgWE

Sheet-metal Worker (geometry)



Let surface normals do all the work!

https://www.youtube.com/watch?v=J_IACmVfP60

… working together

clever Italians

Want to minimize cost

Each one does what’s easiest for him

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