CSCE 448/748 - Computational Photography

Light Fields

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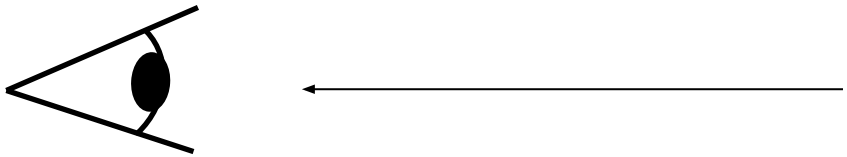
Many slides from Alexei Efros, James Hays, Mark Levoy, and Sen et al.

What is light?

Electromagnetic radiation (EMR) moving along rays in space

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

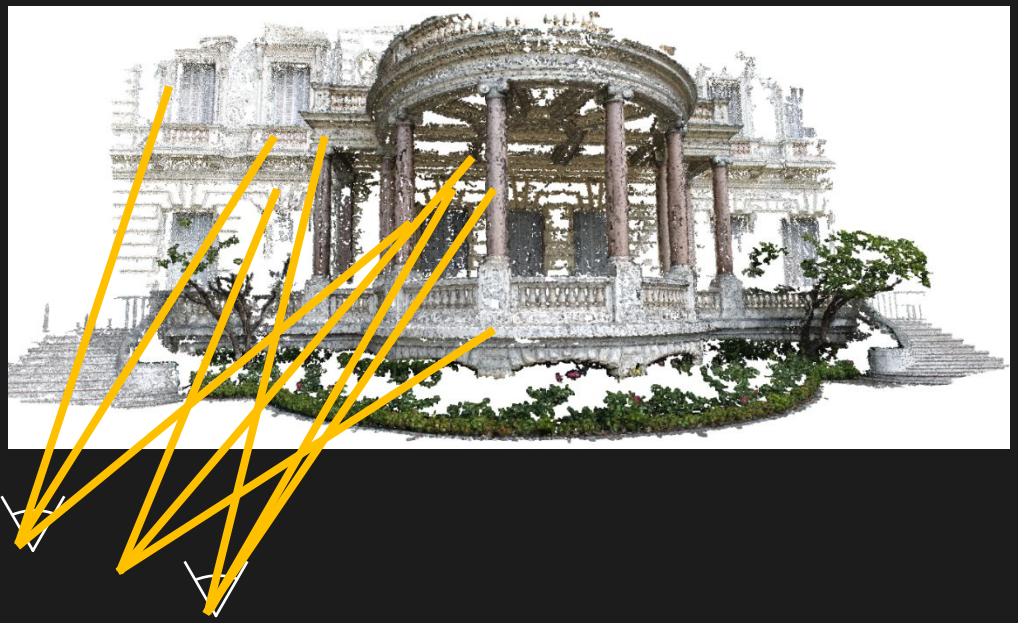


Useful things:

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

Light field

Scene



Light Field

The Plenoptic Function

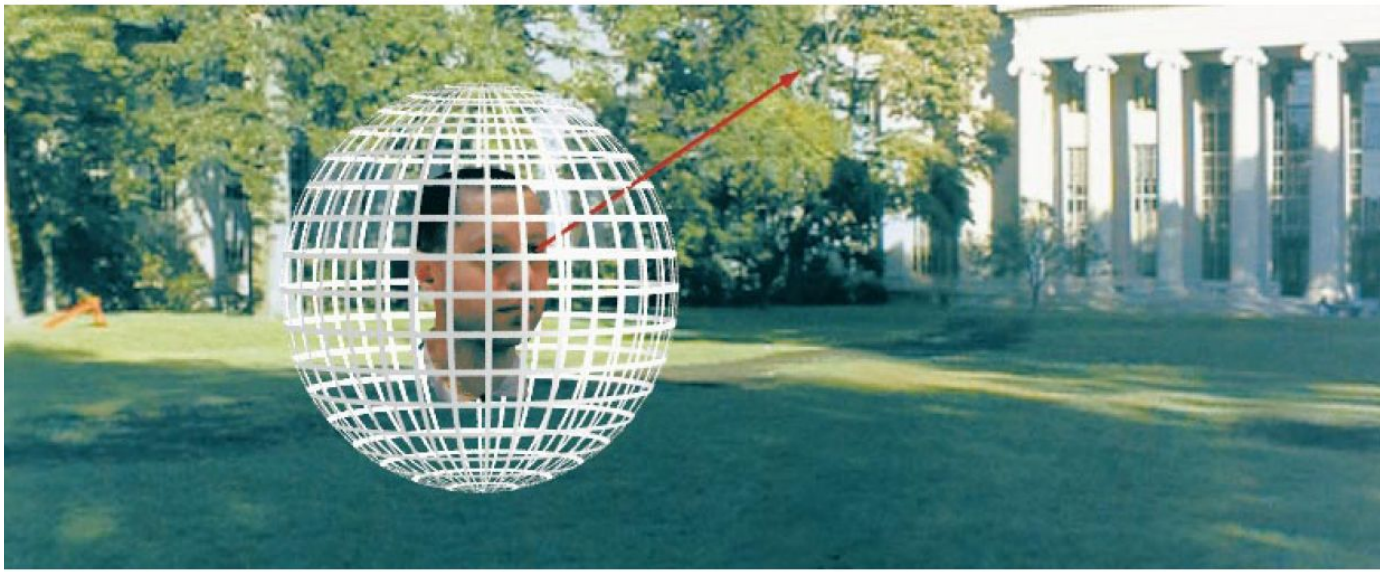
Figure by Leonard McMillan

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



$P(\theta, \varphi)$ is intensity of light

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

Color snapshot

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

is intensity of light

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

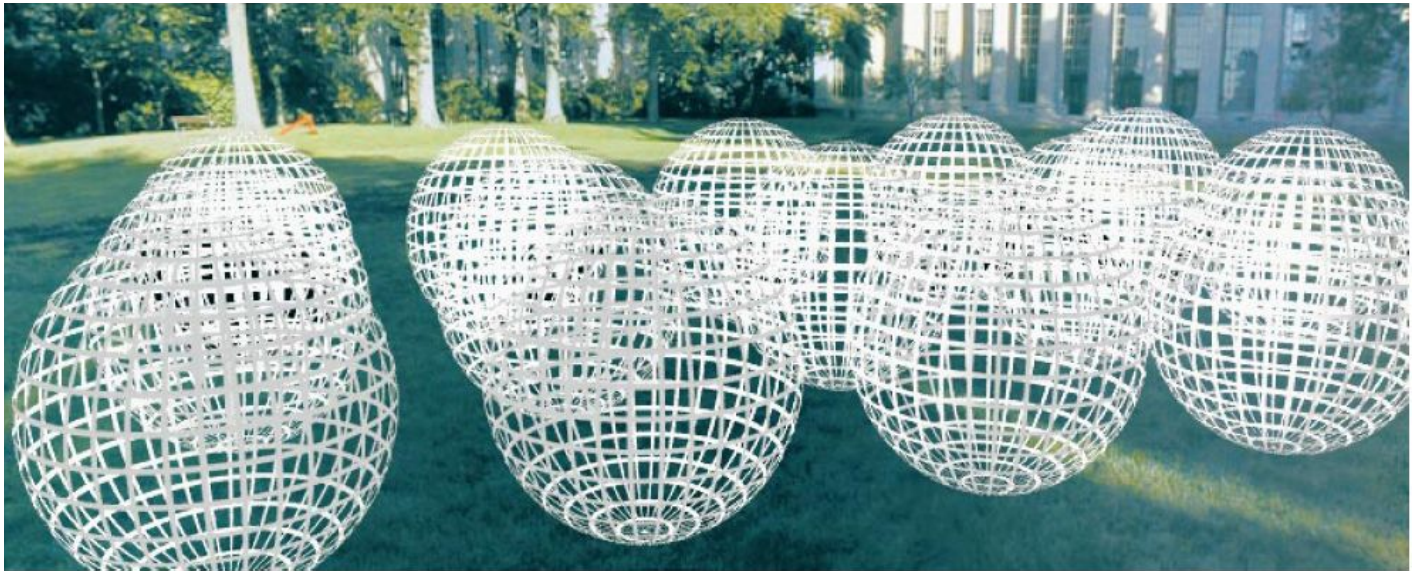
A movie

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

is intensity of light

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

Holographic movie

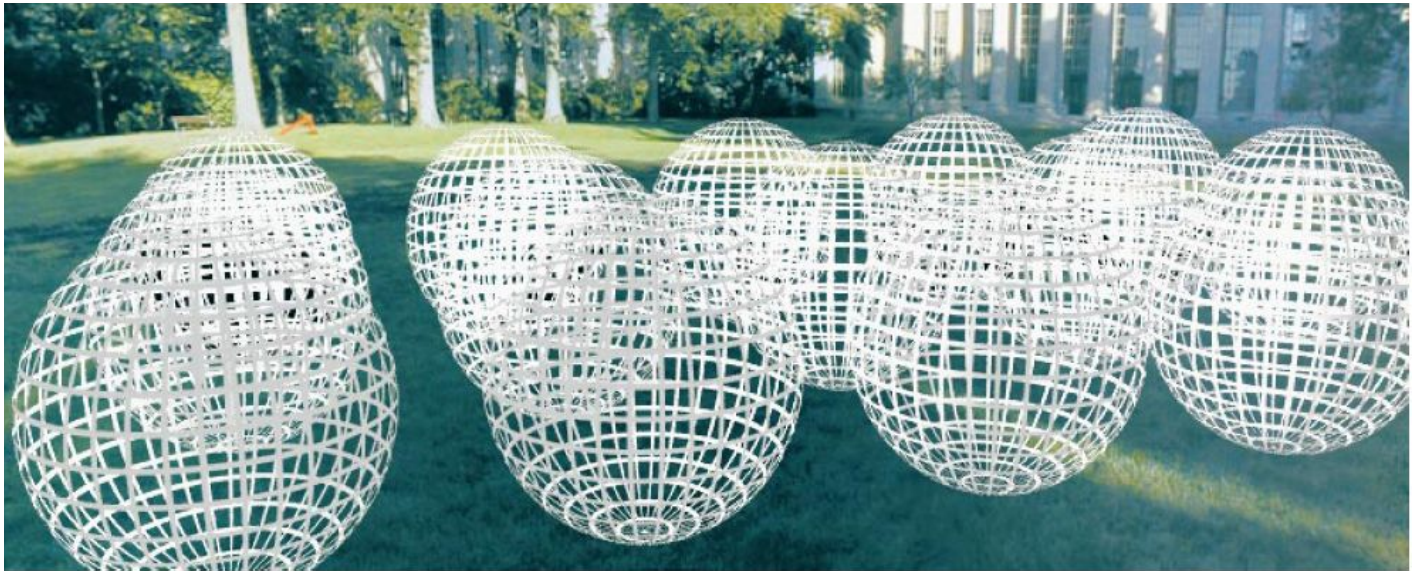


$$P(\theta,\varphi,\lambda,t,V_X,V_Y,V_Z)$$

is intensity of light

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

The Plenoptic Function

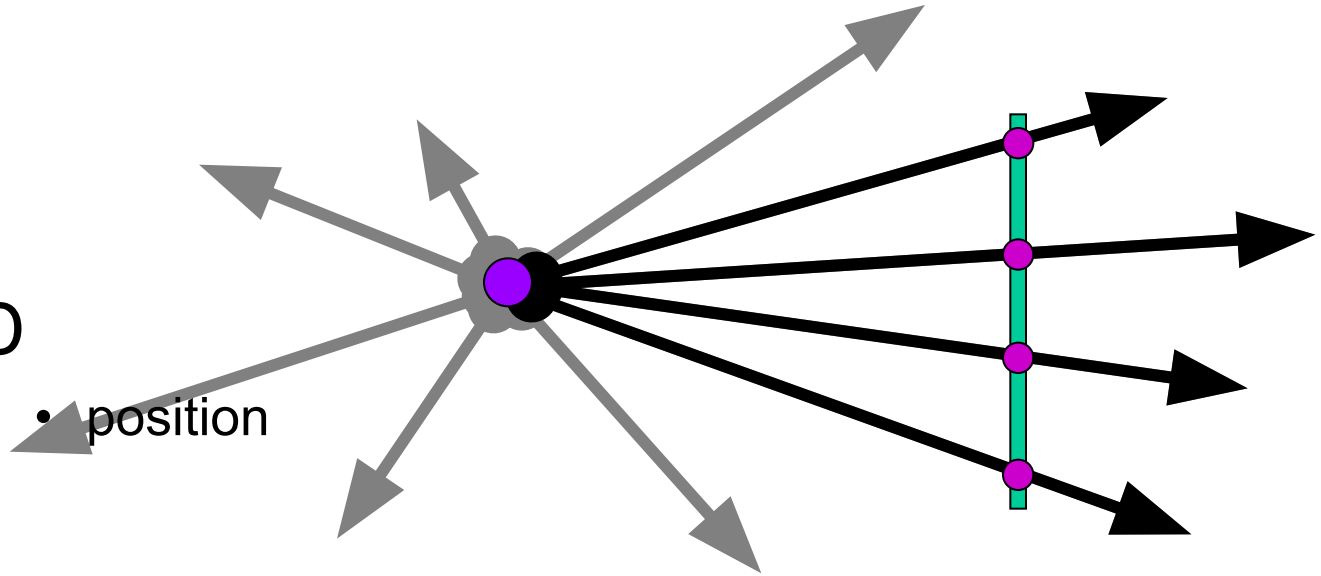


$$P(\theta,\varphi,\lambda,t,V_X,V_Y,V_Z)$$

- 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…

Image

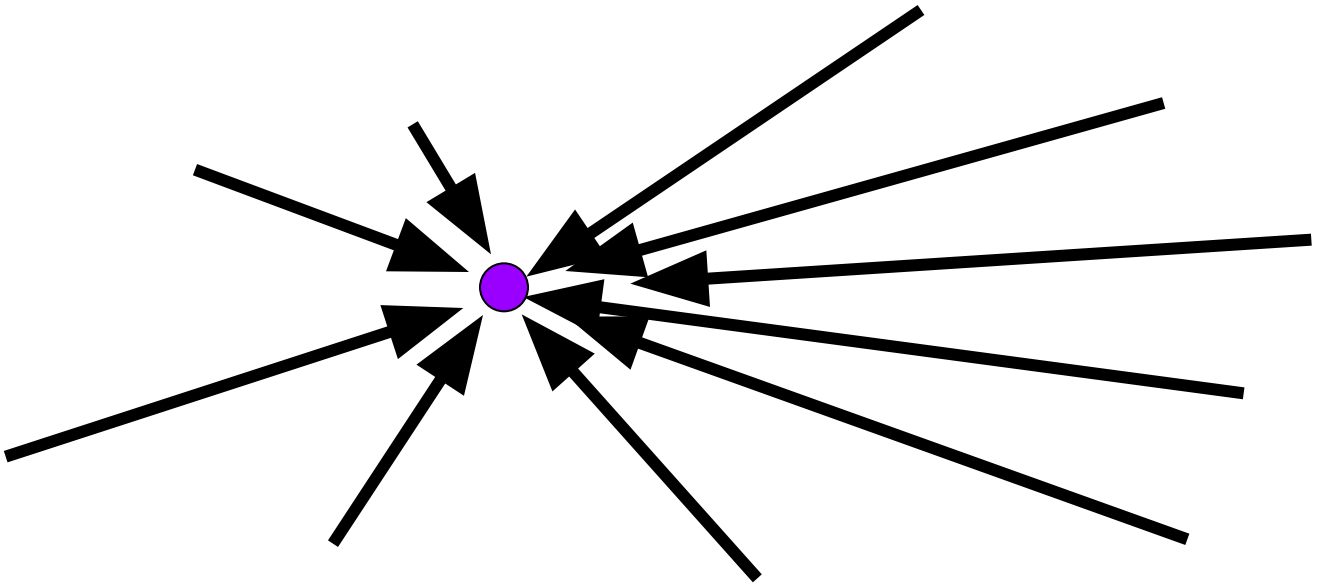
Image plane



2D

- position

2D: Image



All rays through a point

- Panorama?

Slide by Rick Szeliski and Michael Cohen

Spherical Panorama

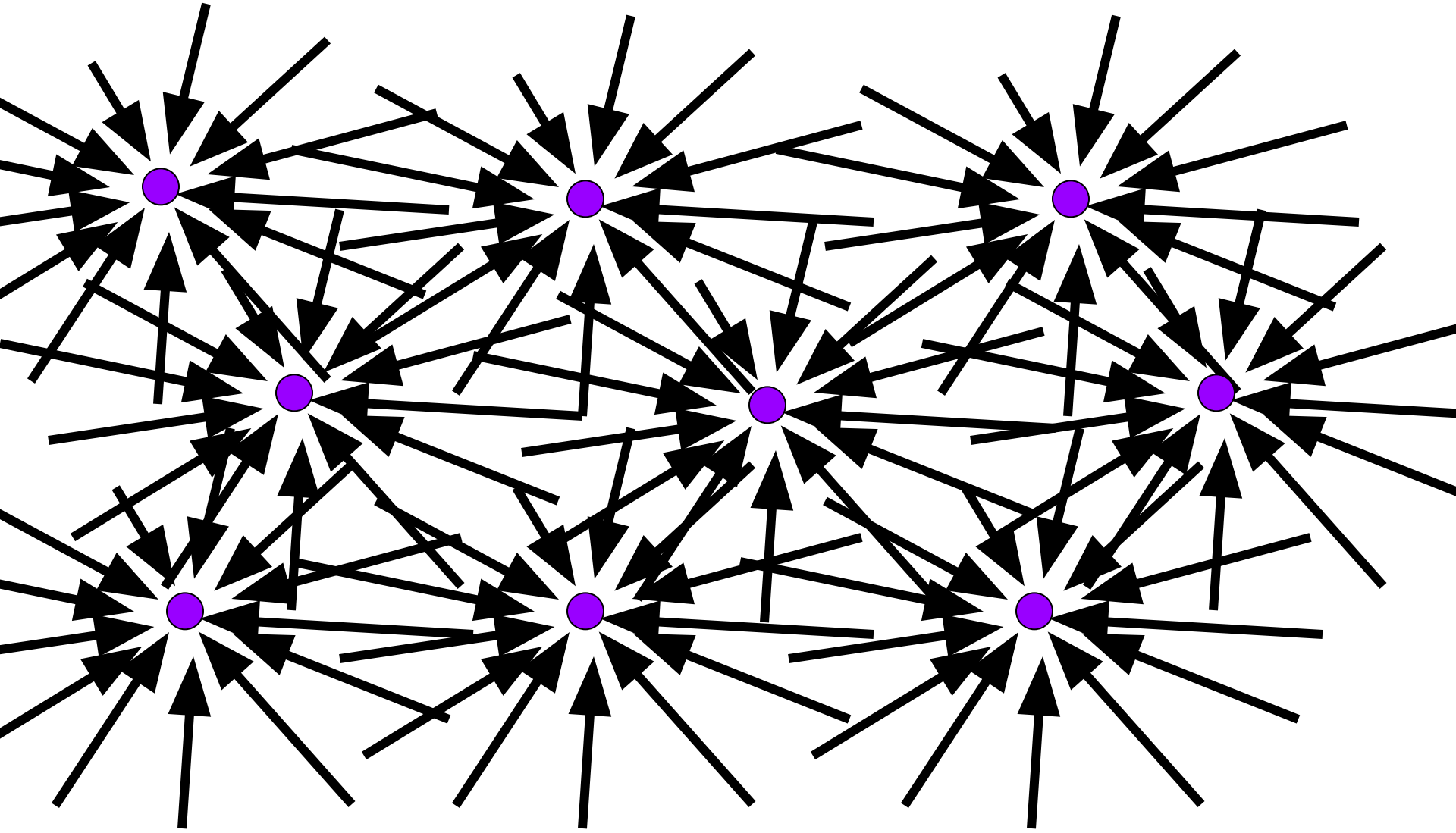
See also: 2003 New Years Eve

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

All light rays through a point form a ponorama

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

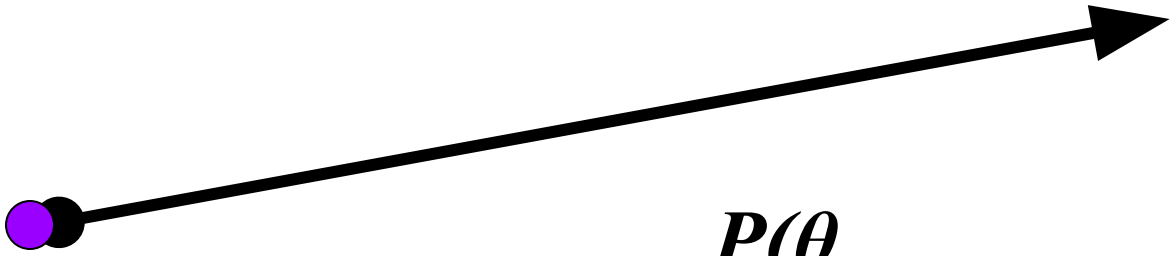
Sampling Plenoptic Function (top view)



Just lookup – Google Street View

Ray

Let's not worry about time and color:



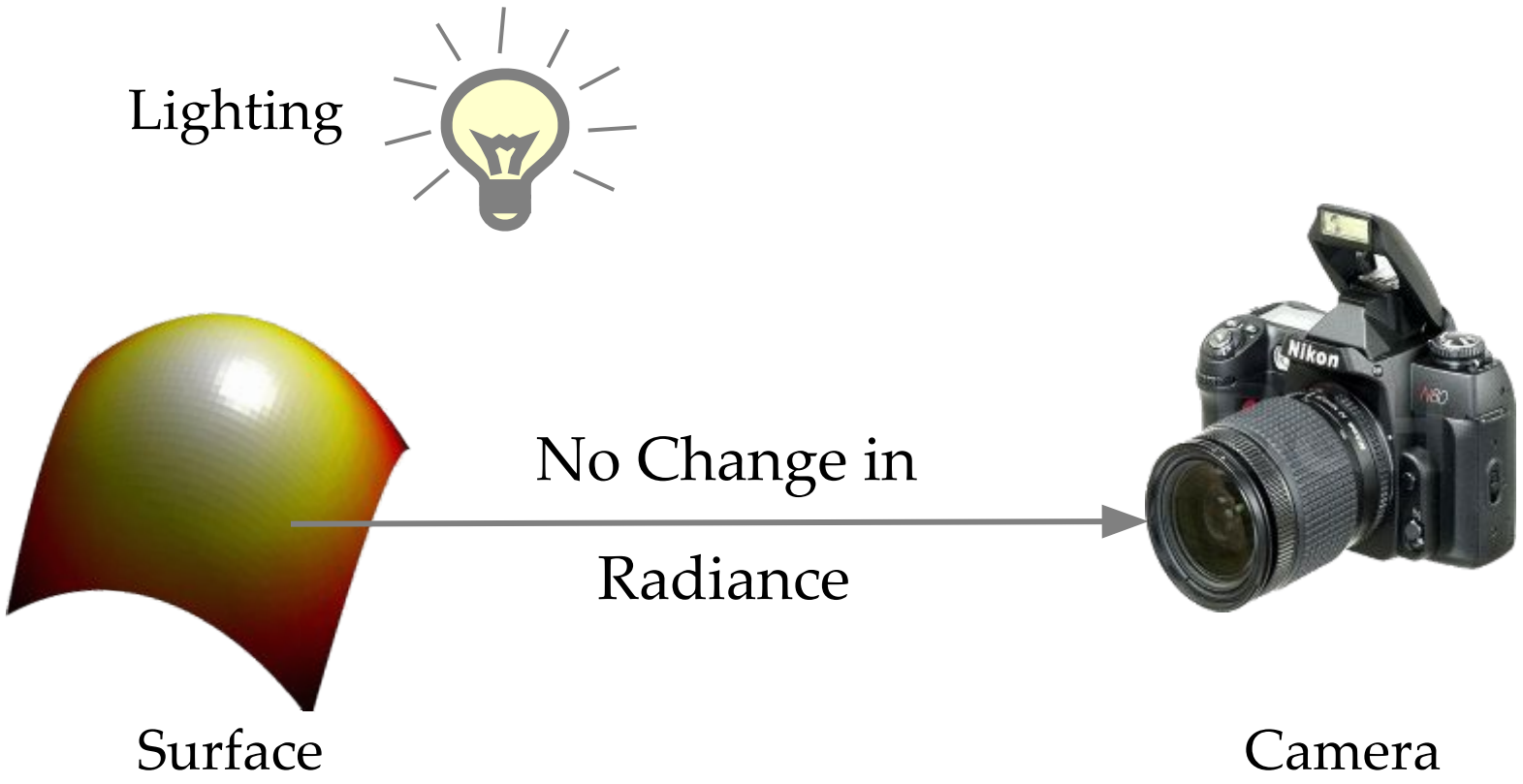
5D

- 3D position
- 2D direction

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

Slide by Rick Szeliski and Michael Cohen

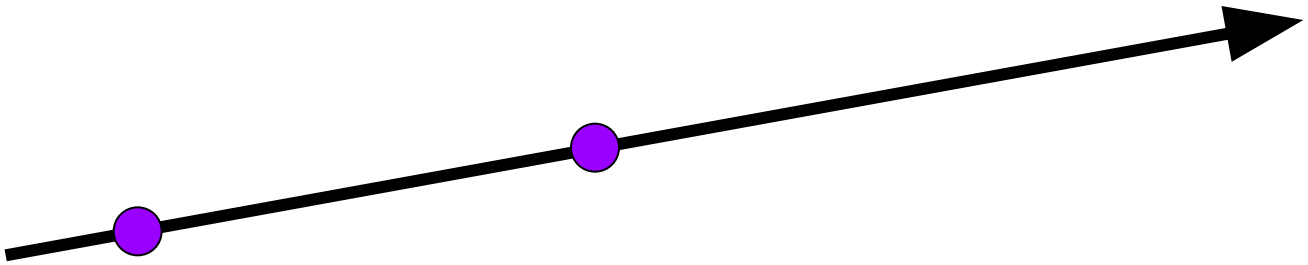
How can we use this?



Ray Reuse

Infinite line

- Assume light is constant (vacuum)

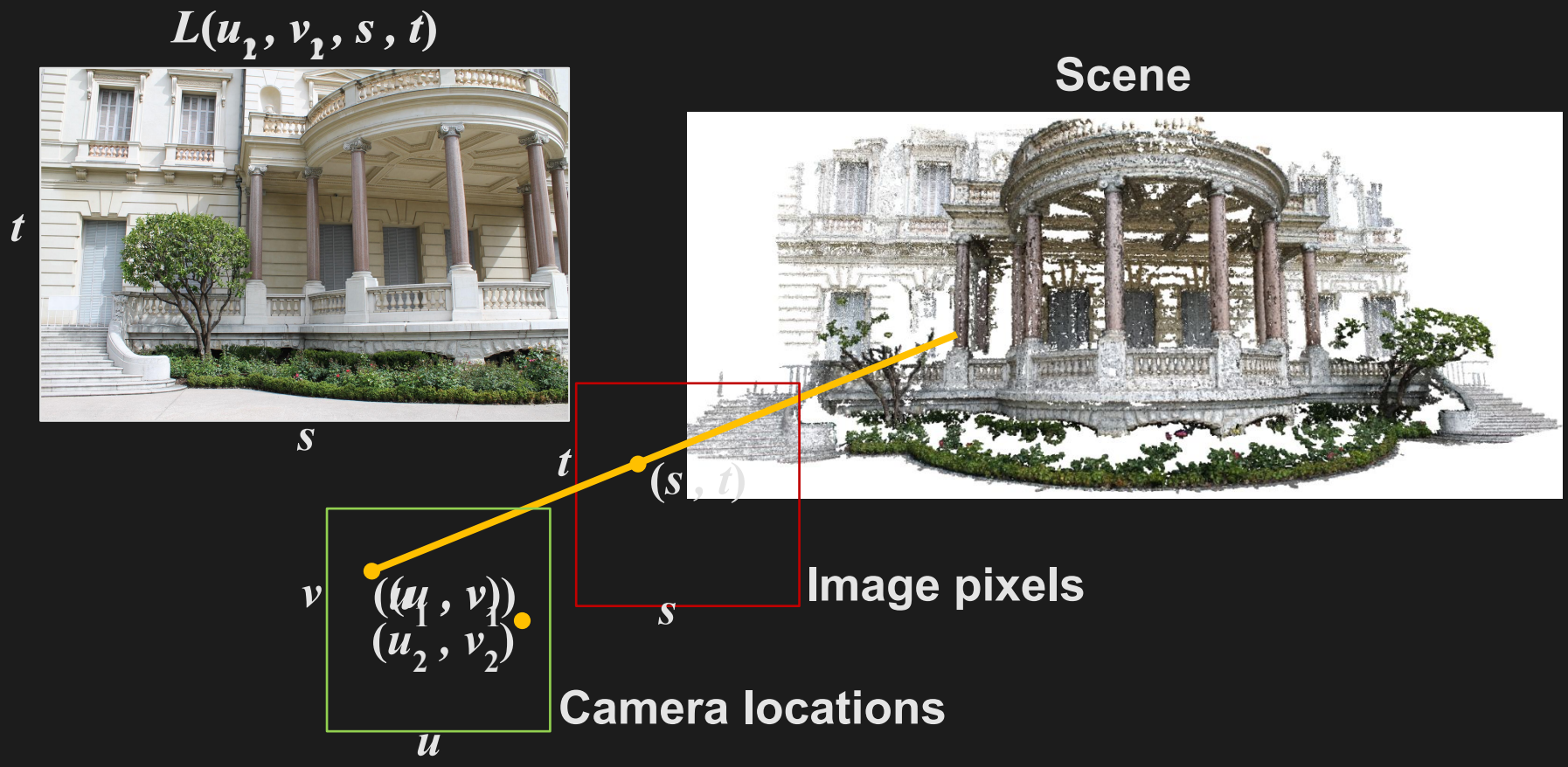


4D

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

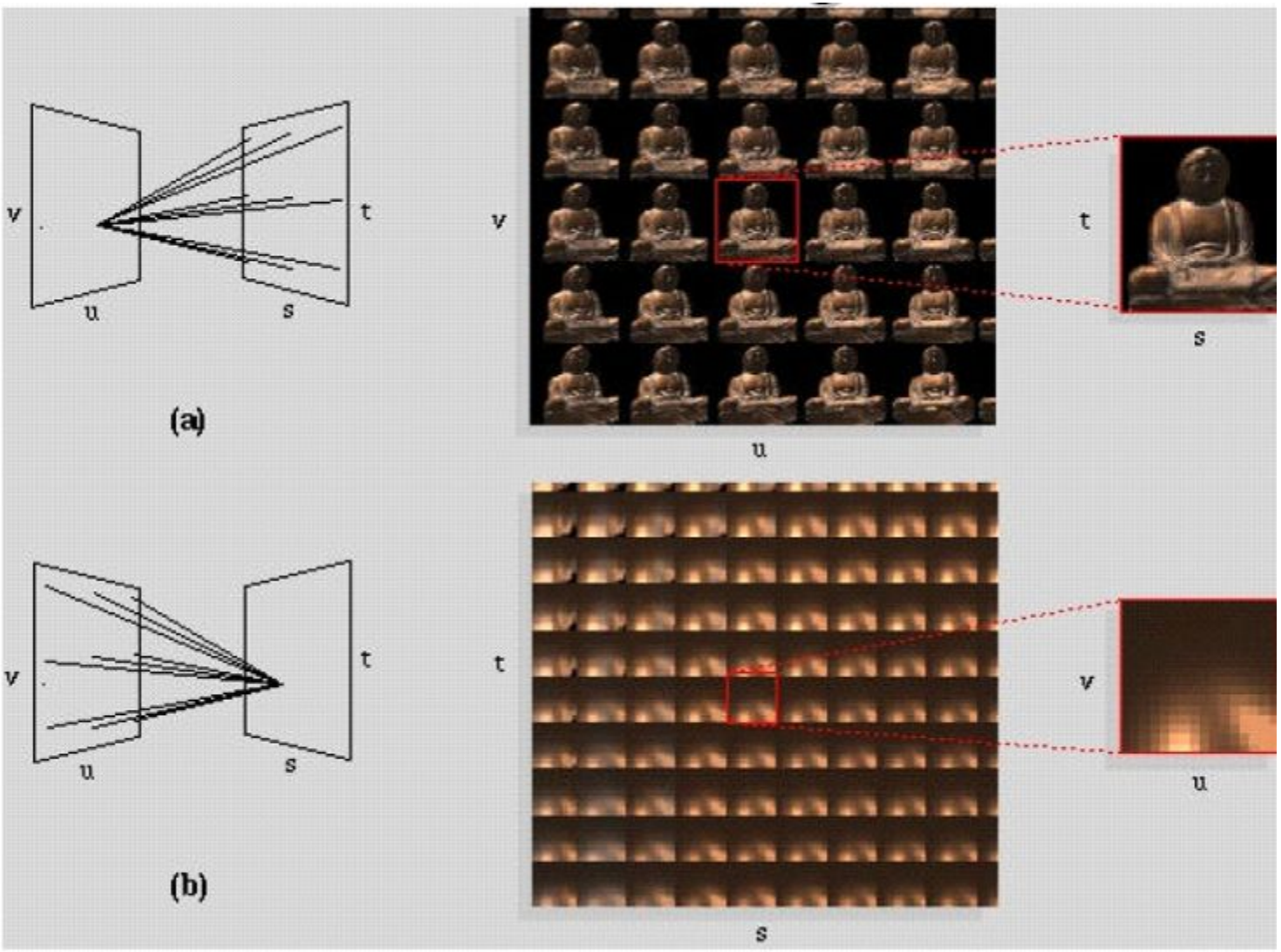
Slide by Rick Szeliski and Michael Cohen

Light field


$L(u_1, v_1, s, t)$
t
s
Scene
t
(s, t)
s
v
(u_1, v_1)
(u_2, v_2)
u
Image pixels
Camera locations
4D Light Field

Capturing process

Lumigraph / Lightfield



Stanford multi-camera array

- 640 × 480 pixels × 30 fps × 128 cameras

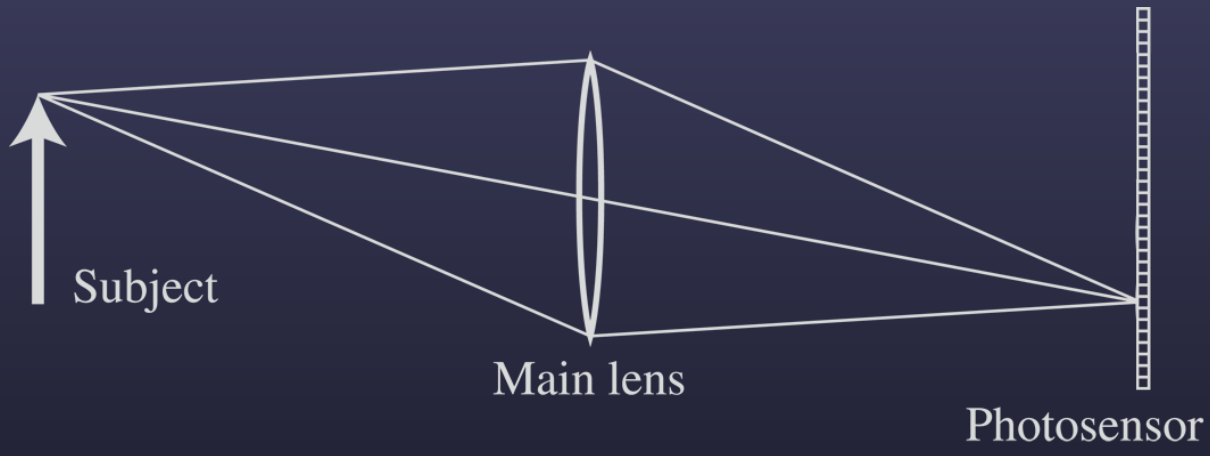
- synchronized timing
- continuous streaming
- flexible arrangement

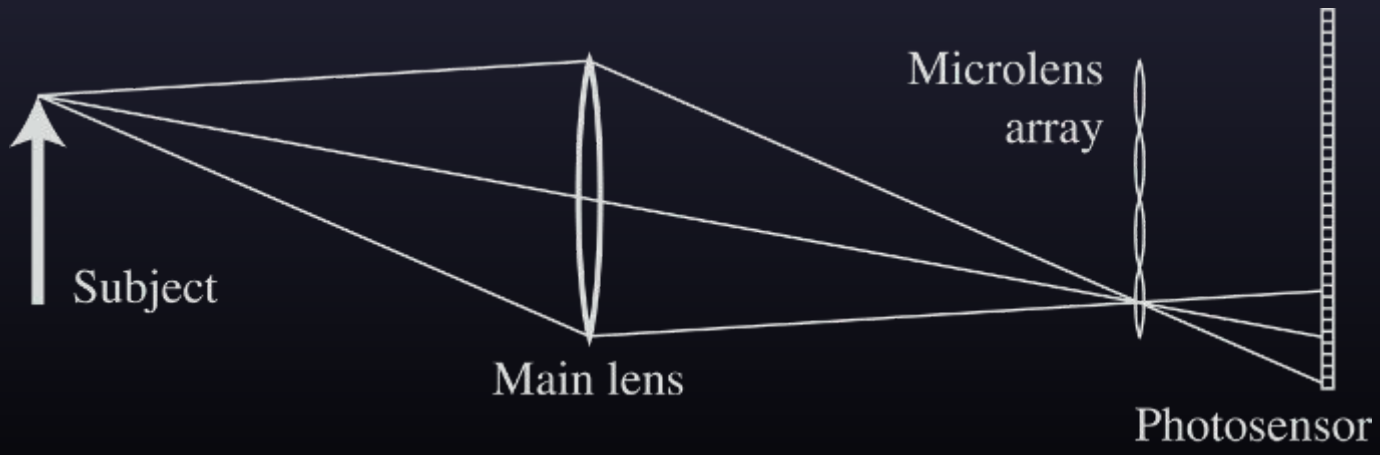
Light field photography using a handheld plenoptic camera

Commercialized as Lytro

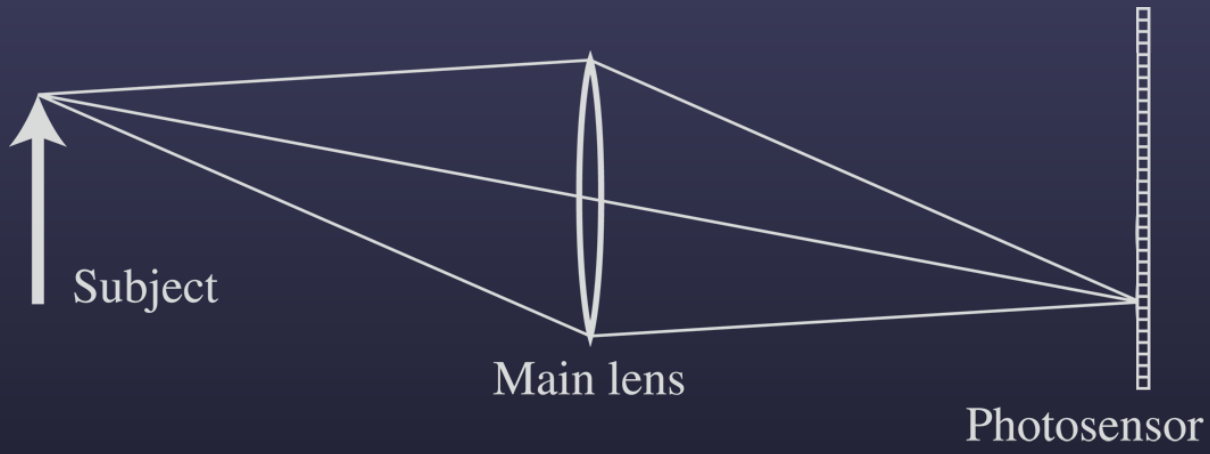
Ren Ng, Marc Levoy, Mathieu Brédif,
Gene Duval, Mark Horowitz and Pat Hanrahan

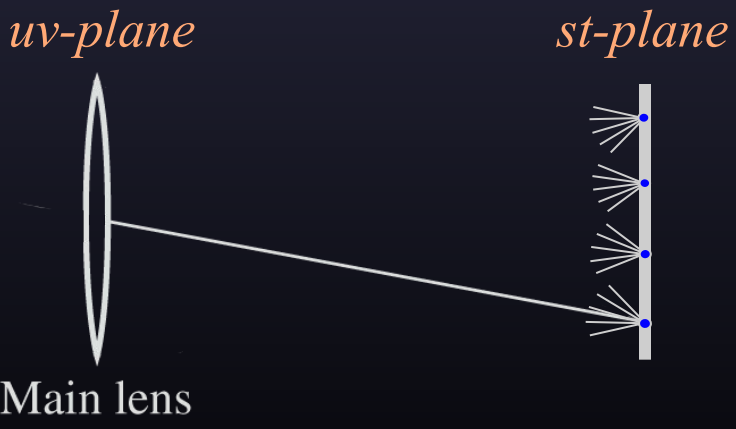
Conventional versus light field camera





Conventional versus light field camera

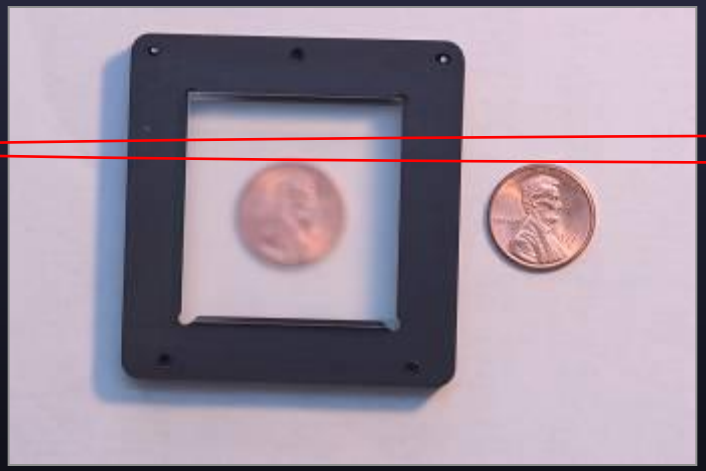




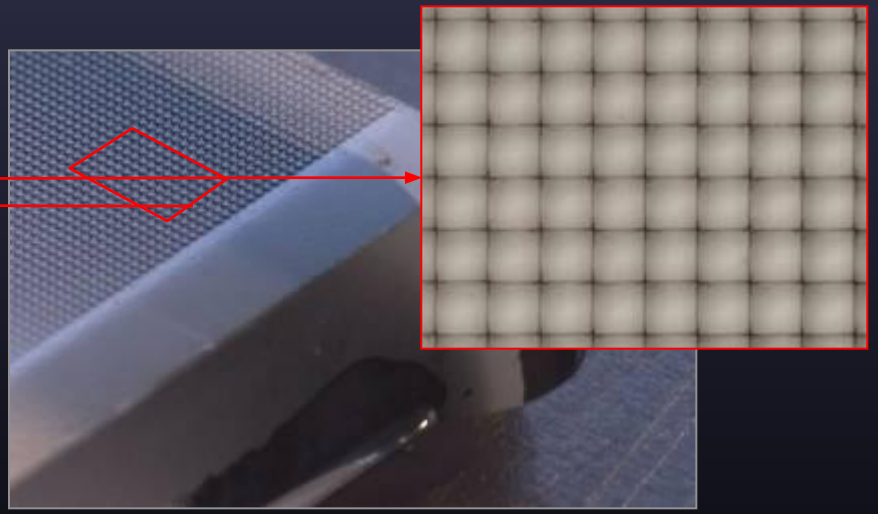
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor



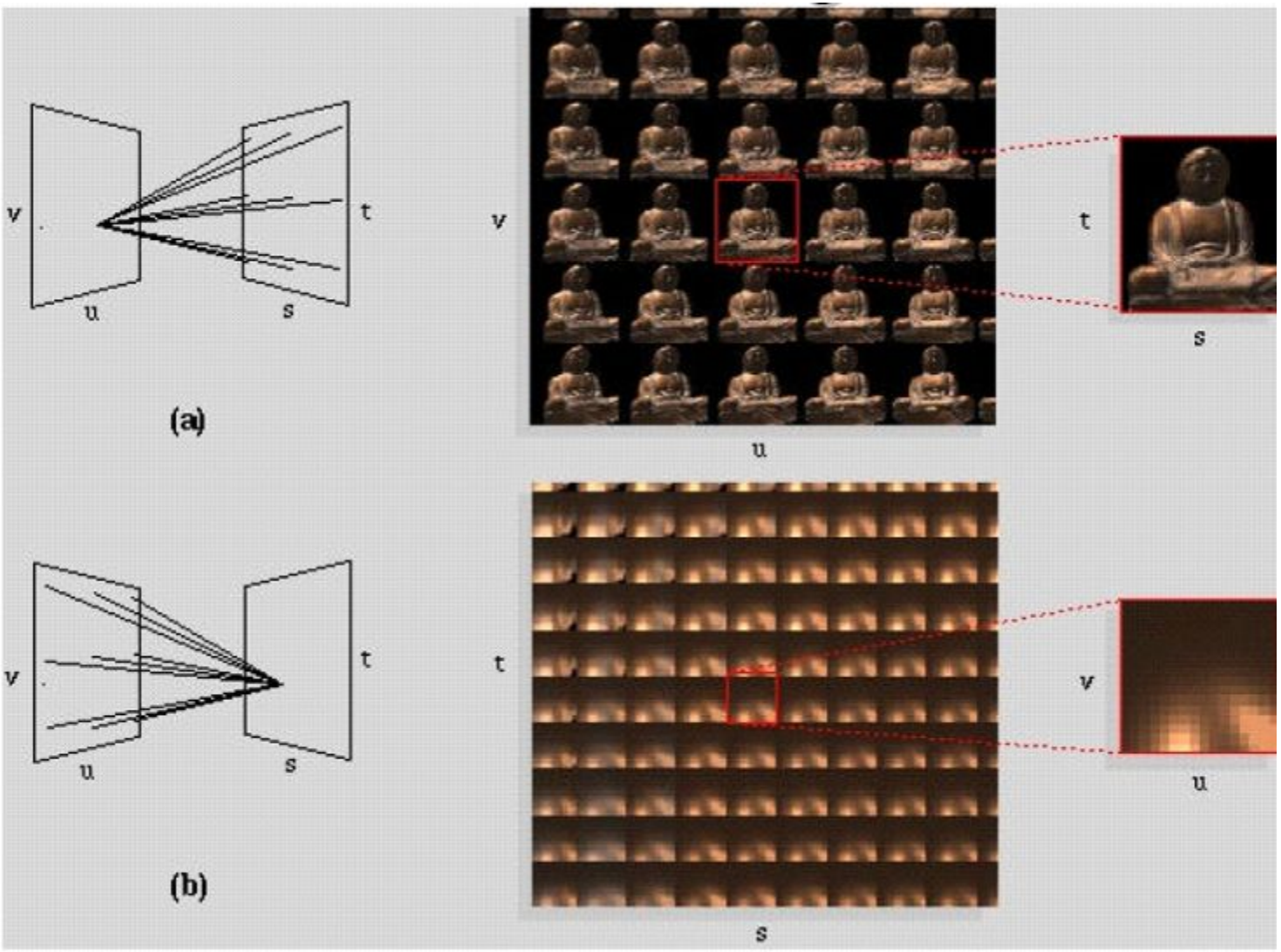
Adaptive Optics microlens array

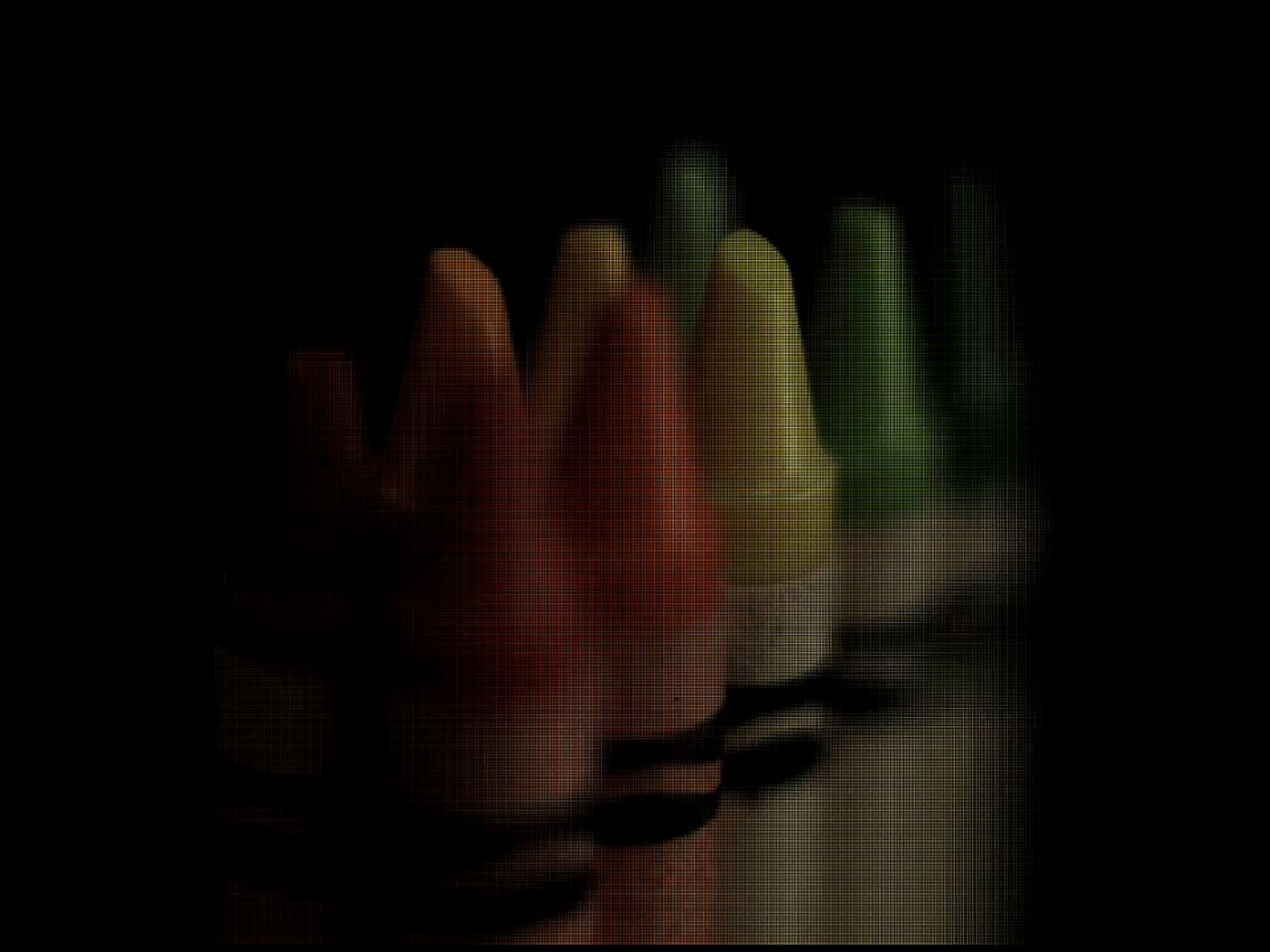


125µ square-sided microlenses

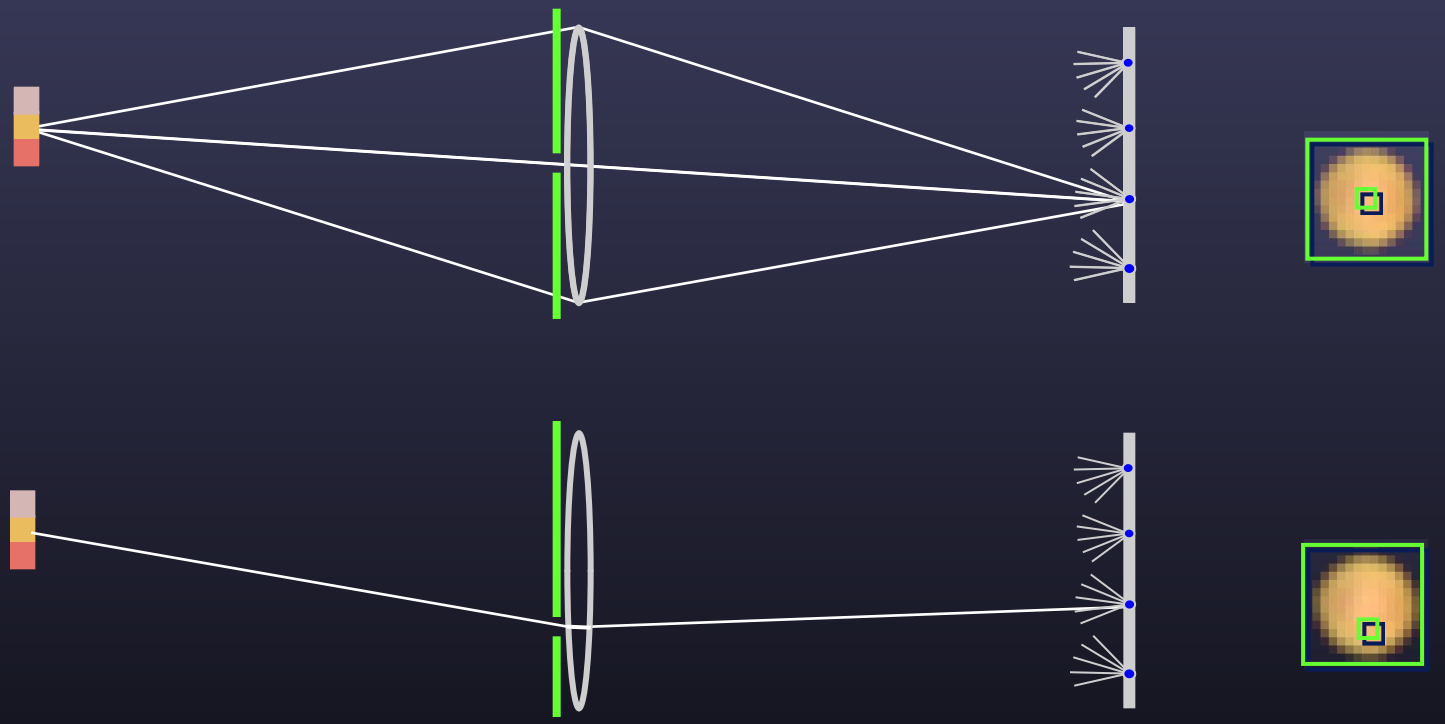
- *4000 × 4000 pixels ÷ 292 × 292 lenses = 14 × 14 pixels per lens*

Lumigraph / Lightfield



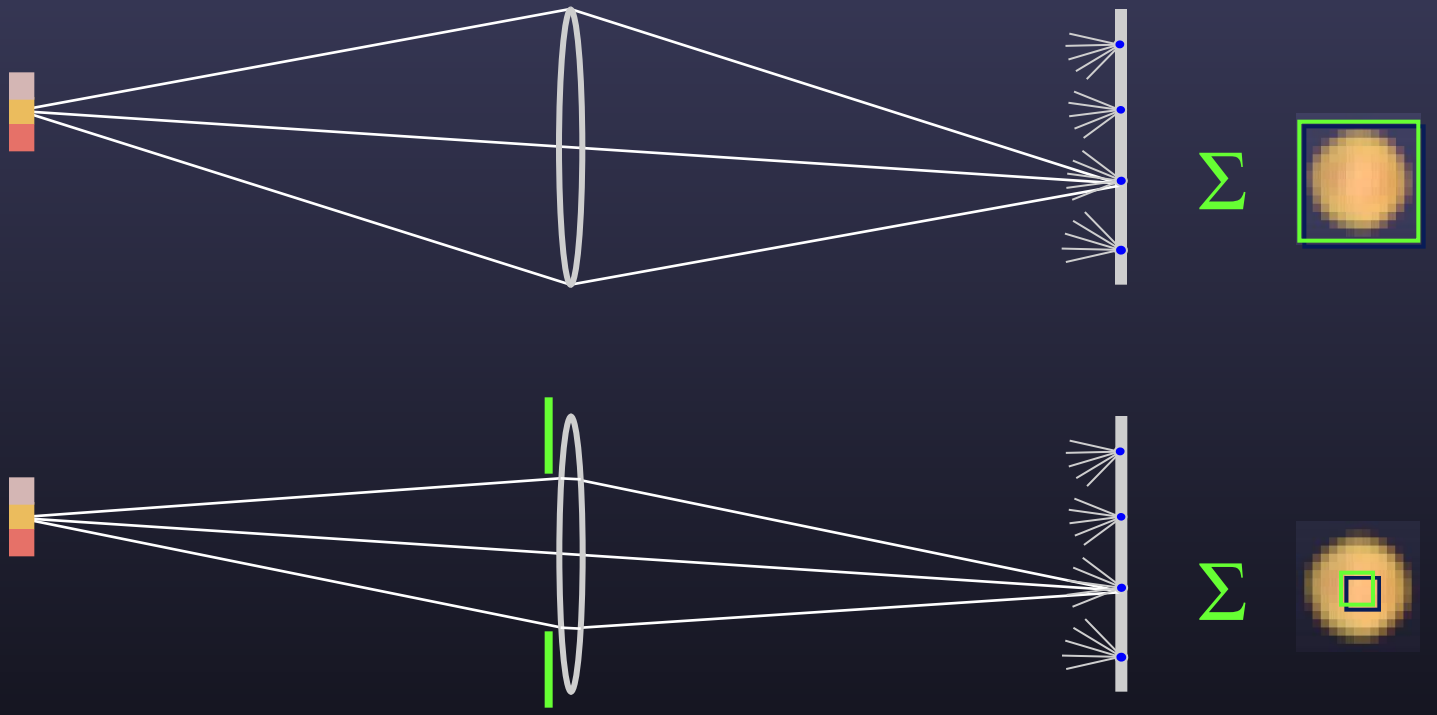


Digitally moving the observer



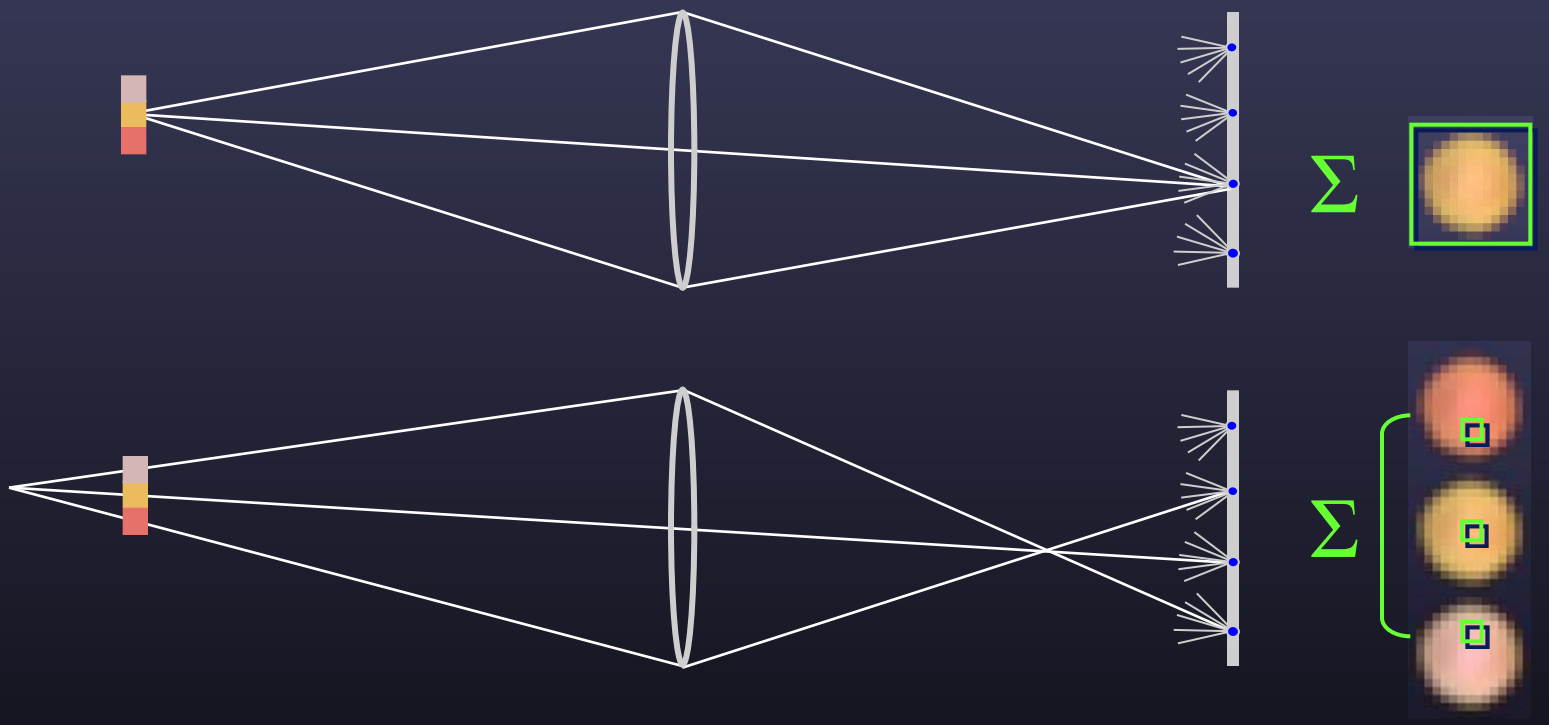
- moving the observer = moving the window we extract from the microlenses

Digitally stopping-down (aperture change)



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

Digital refocusing



- refocusing = summing windows extracted from several microlenses

Example of digital refocusing

Example of moving the observer