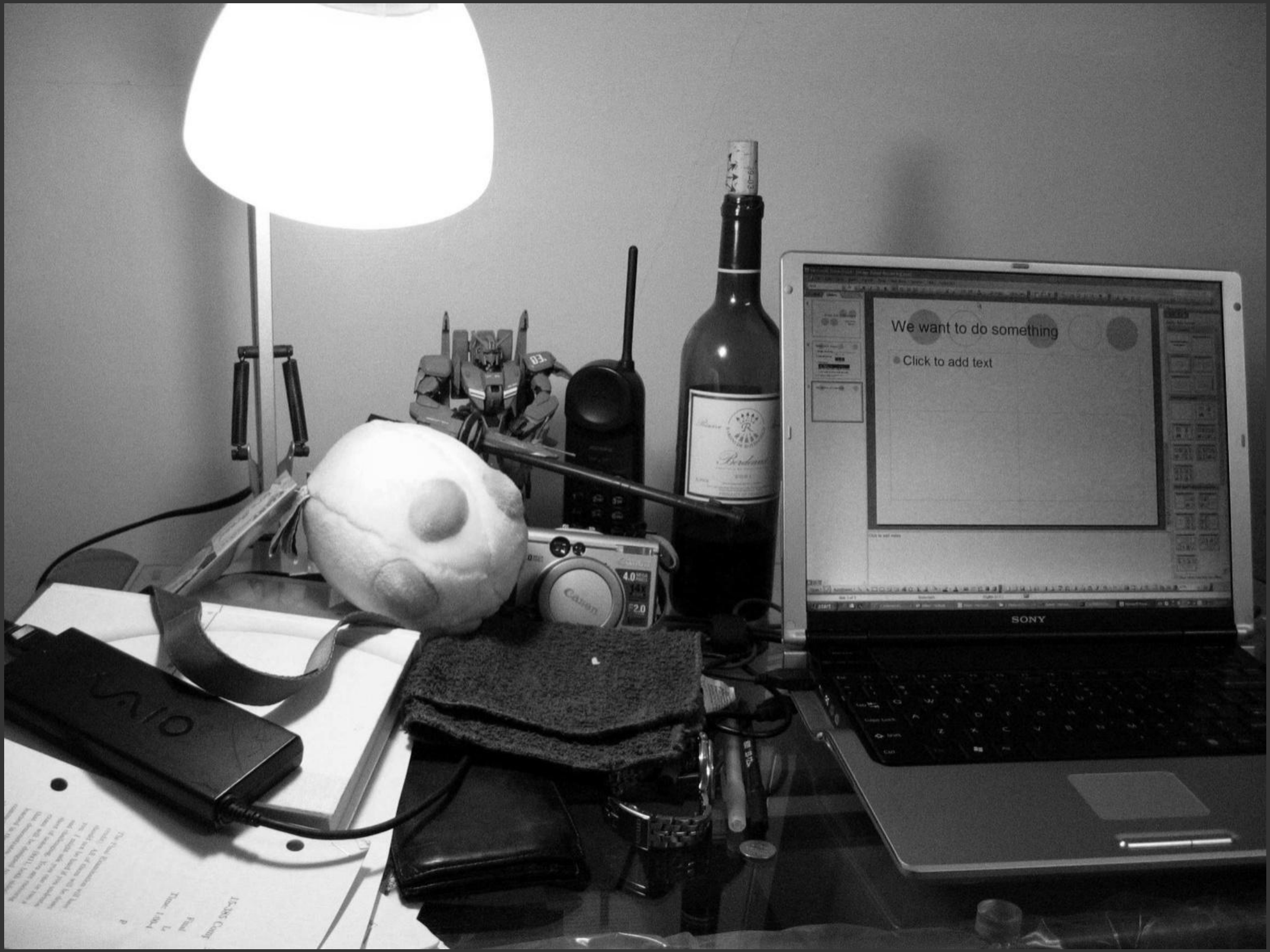
Light Field

Modeling a desktop

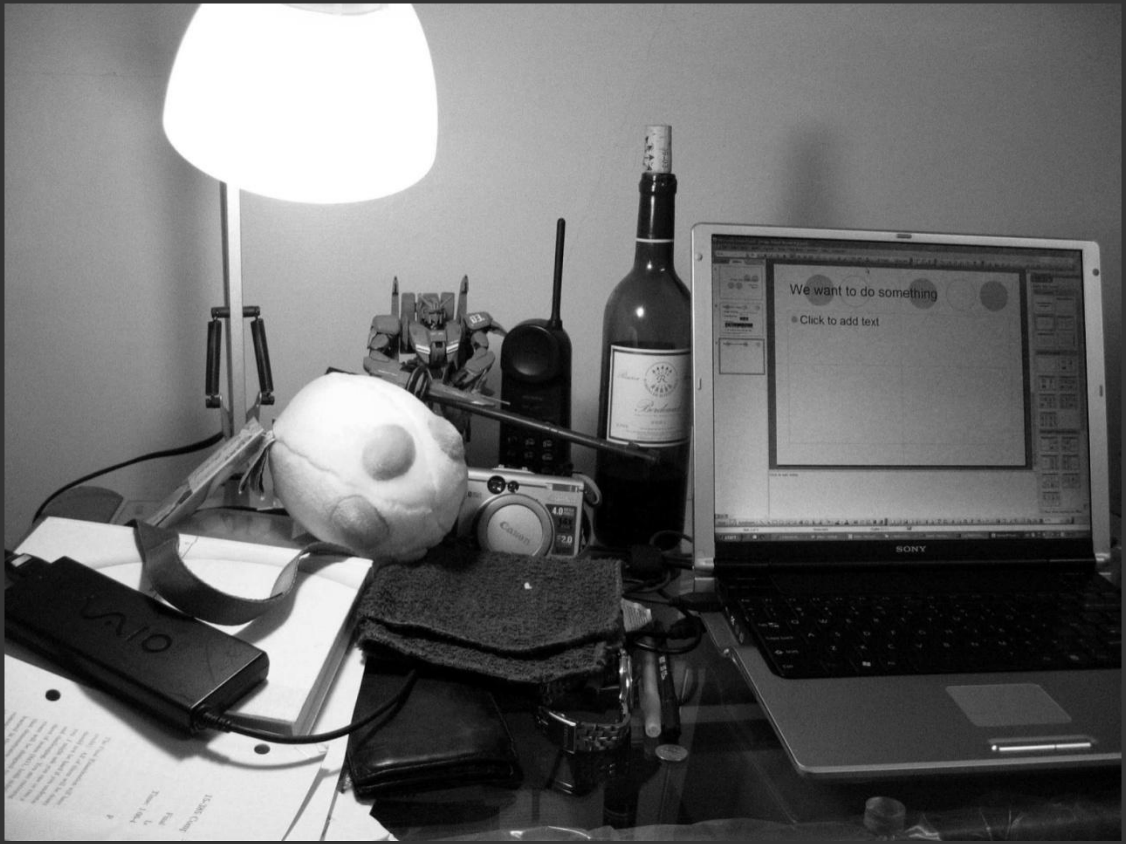



Réserve
Bordeaux
2001


Backspace
Enter

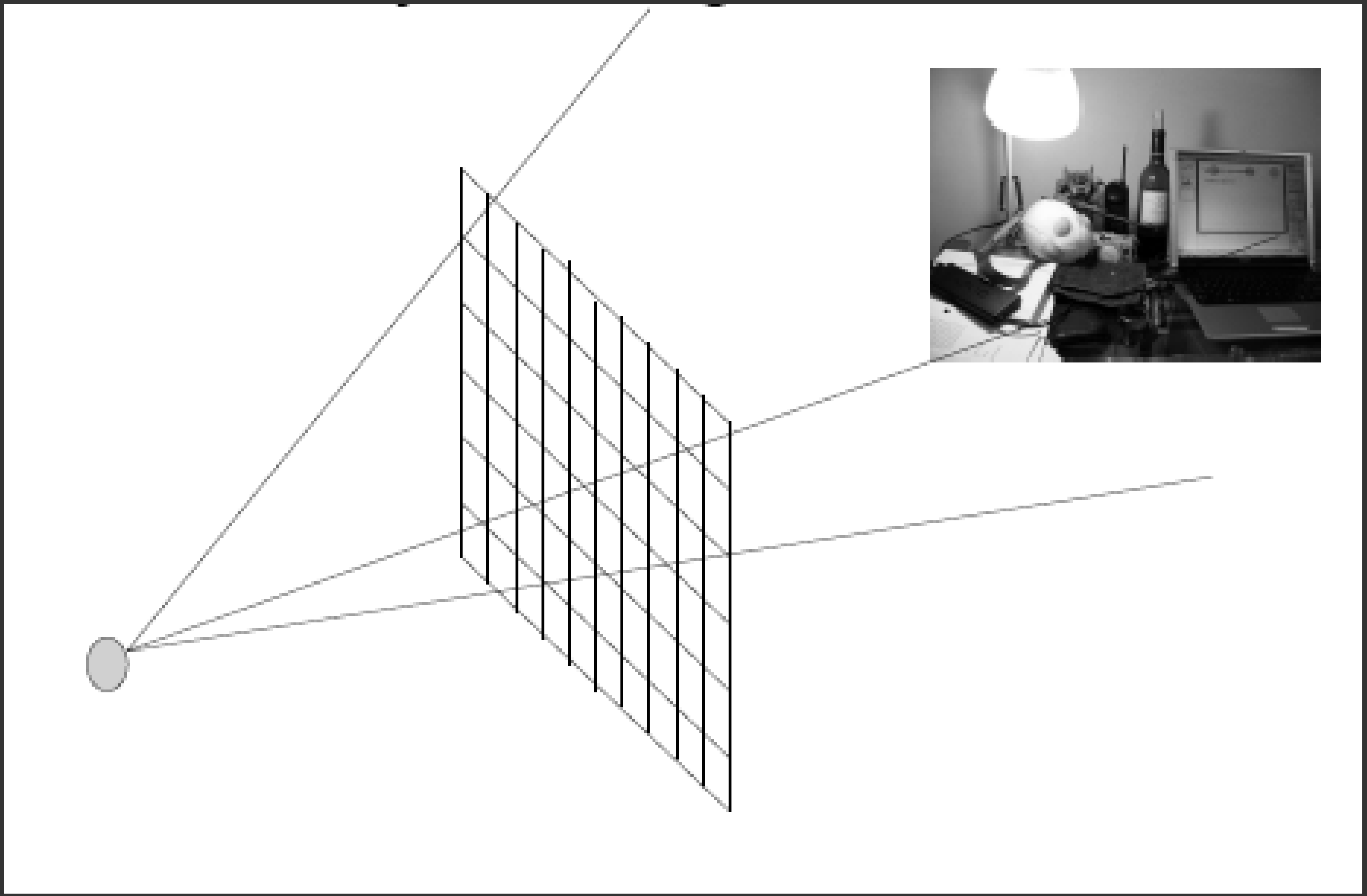
Image Based Rendering

- Fast Realistic Rendering without 3D models

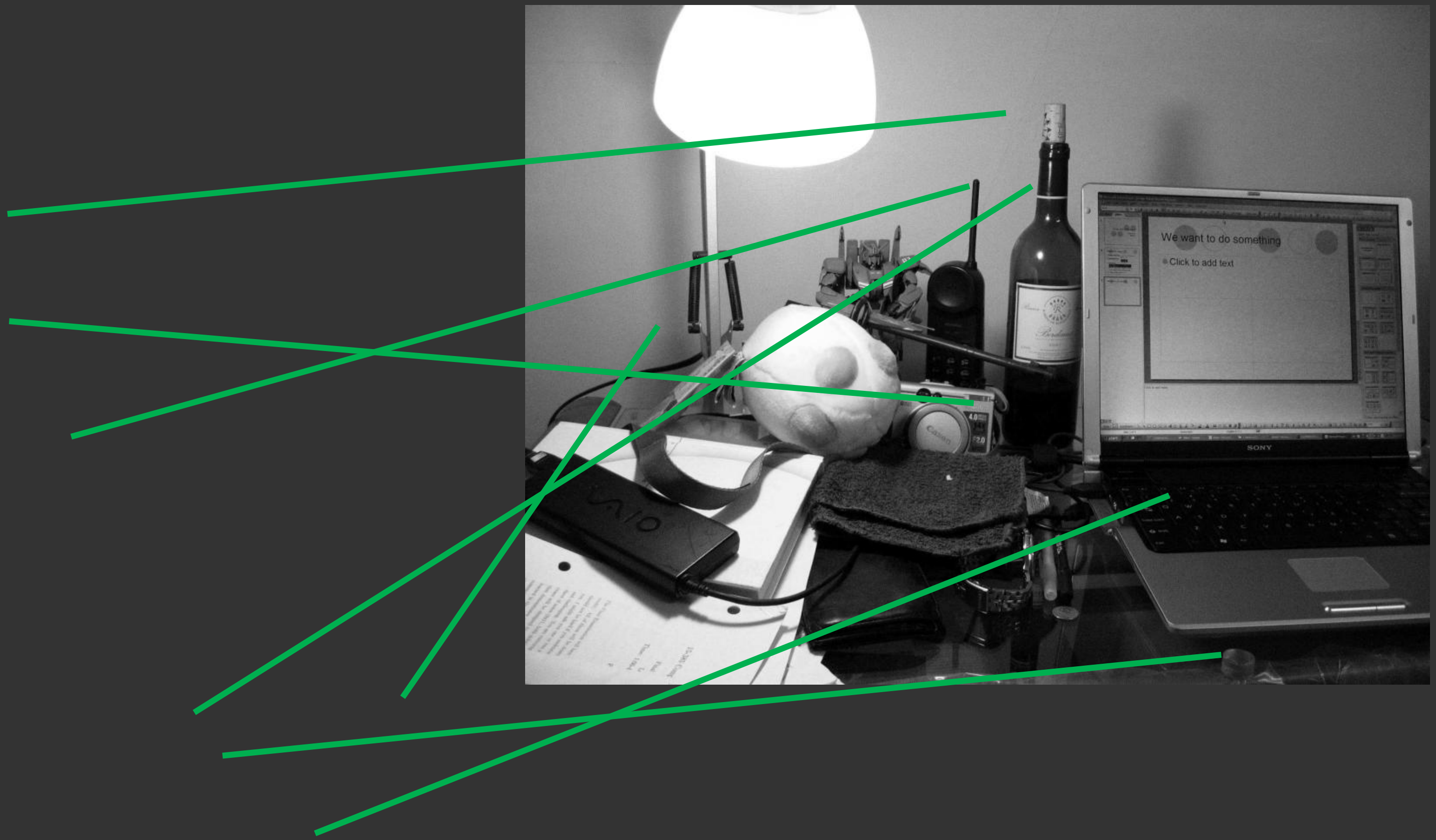


Start from Ray Tracing

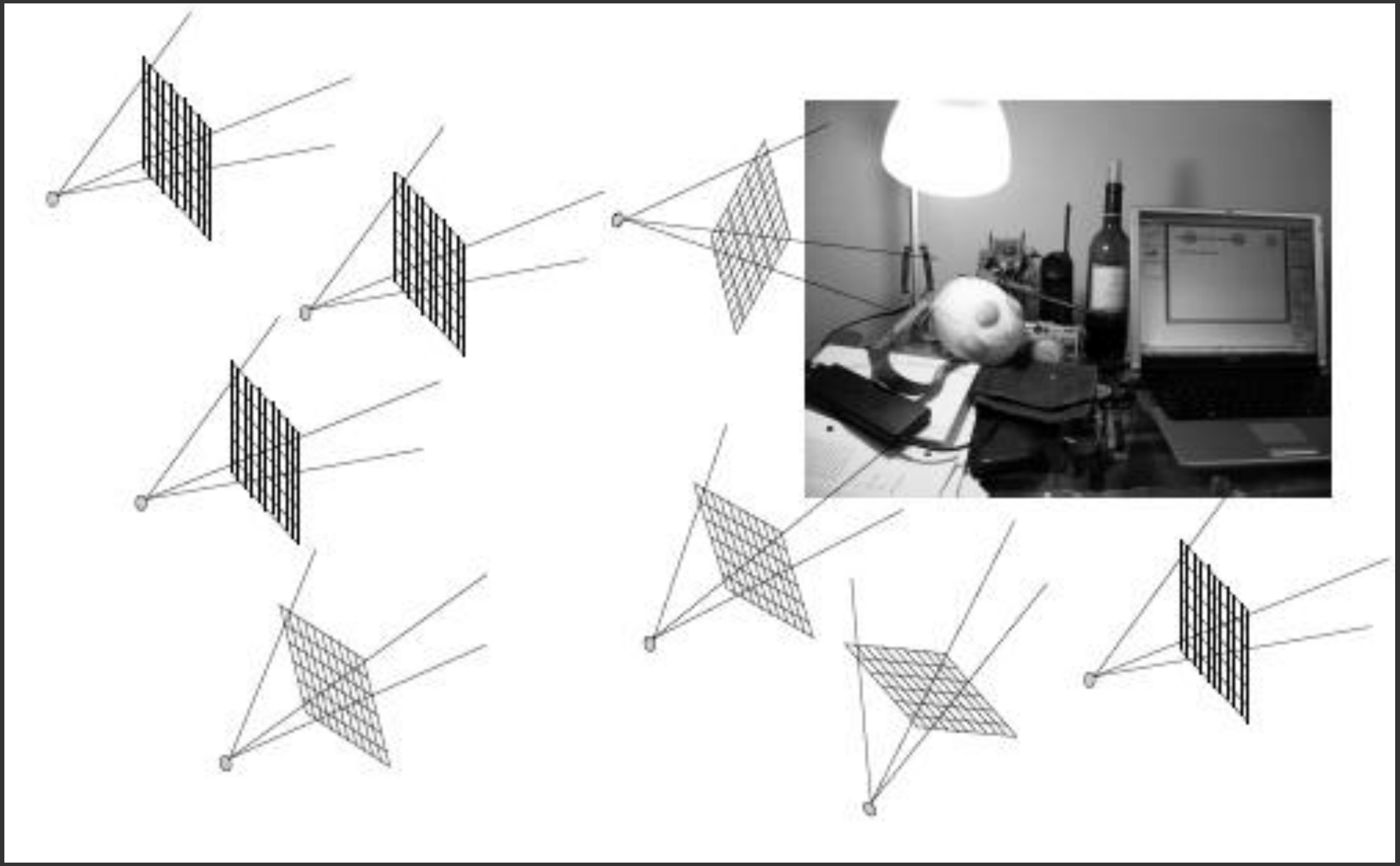
- Rendering is about computing color along each ray



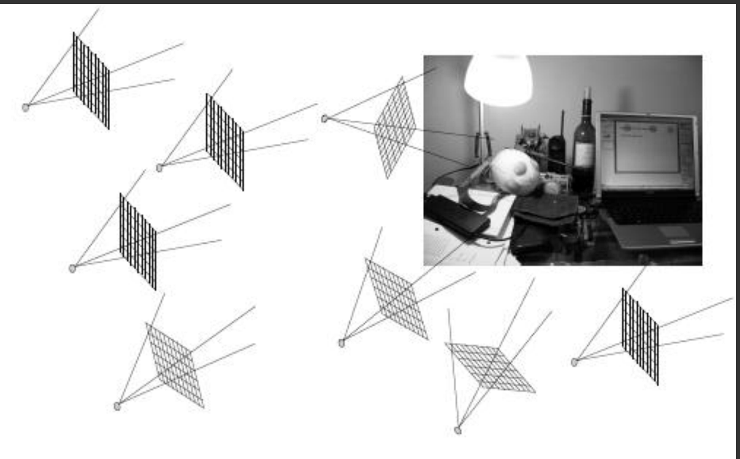
Sampling Rays

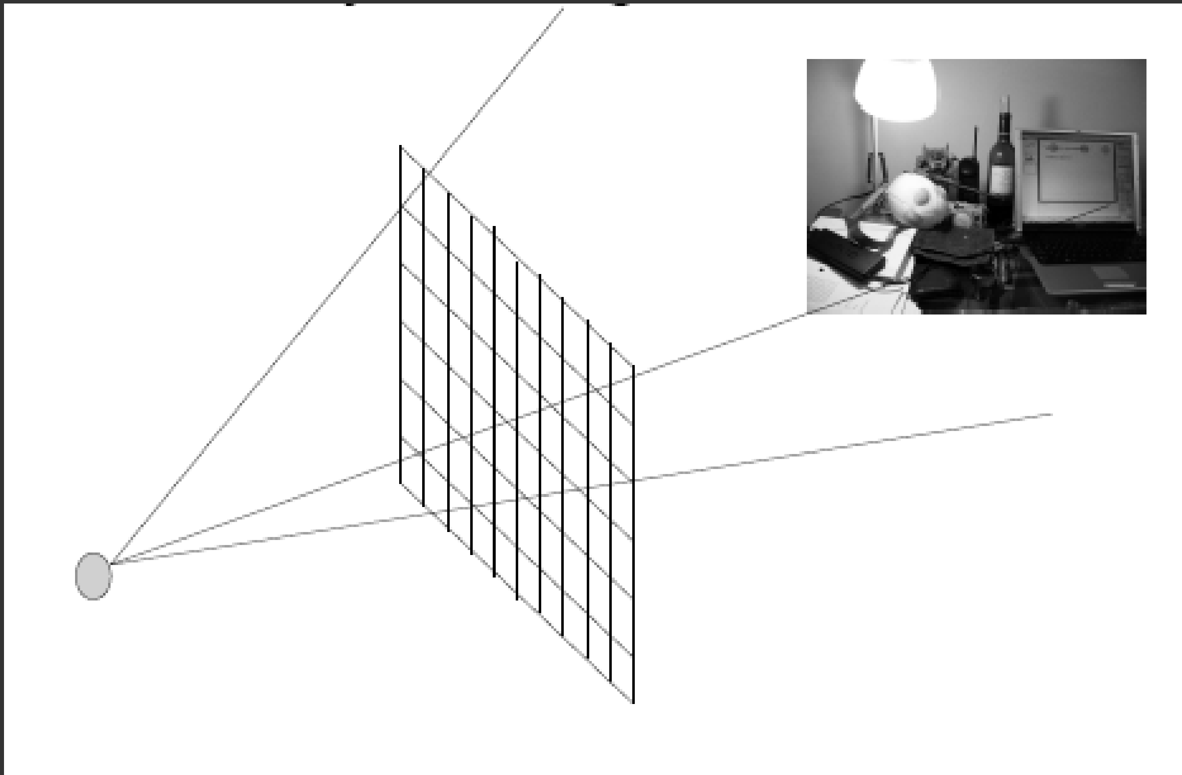


Sampling Rays by Taking Pictures



Rendering as Ray Resampling

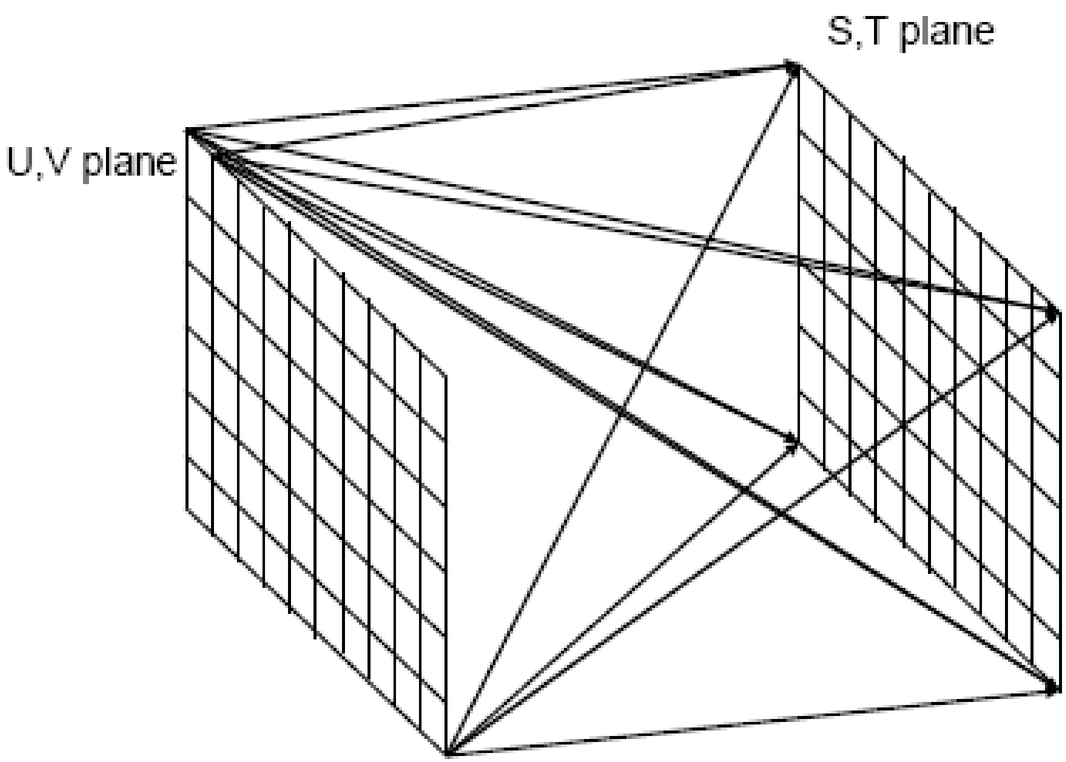


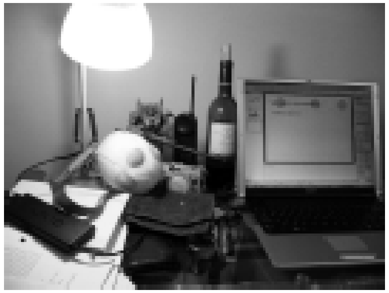


Ray space

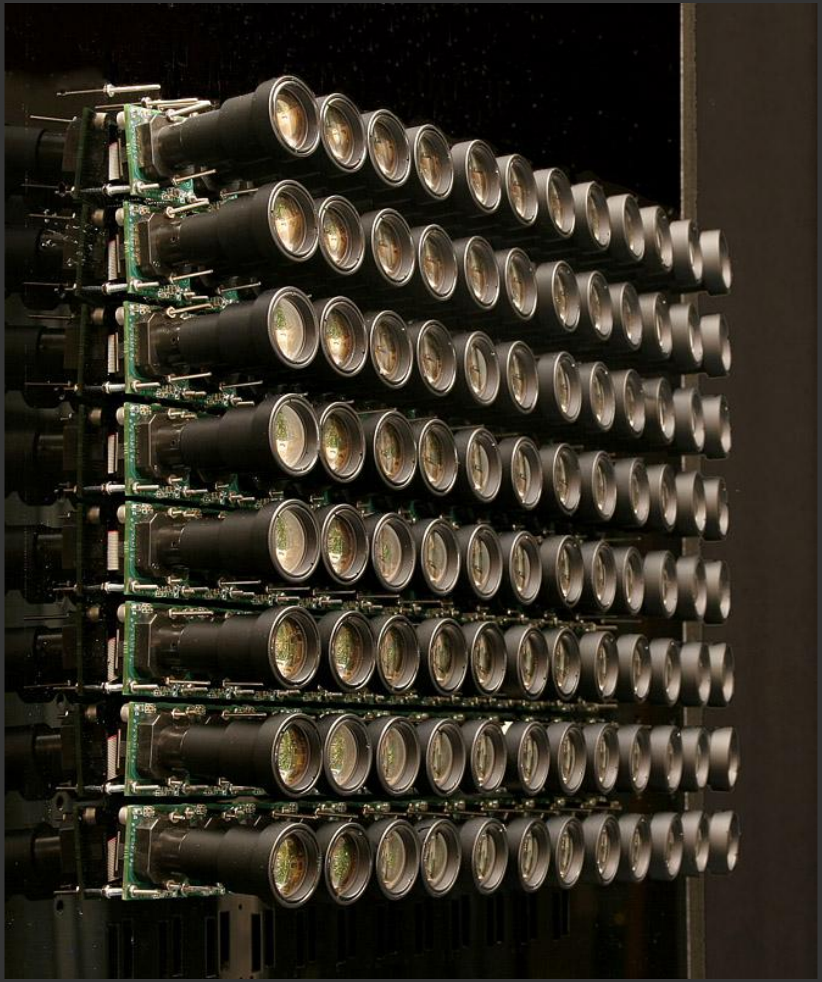
- How to parameterize the ray space
- How to sample and resample rays

Two Plane Parameterization



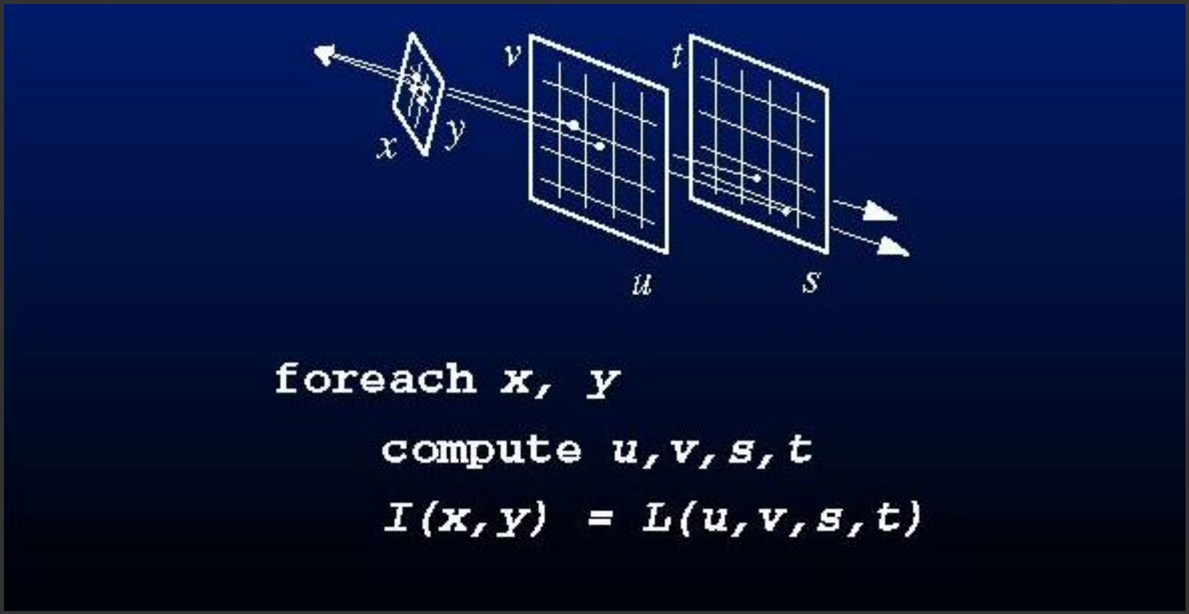


Stanford Camera Array



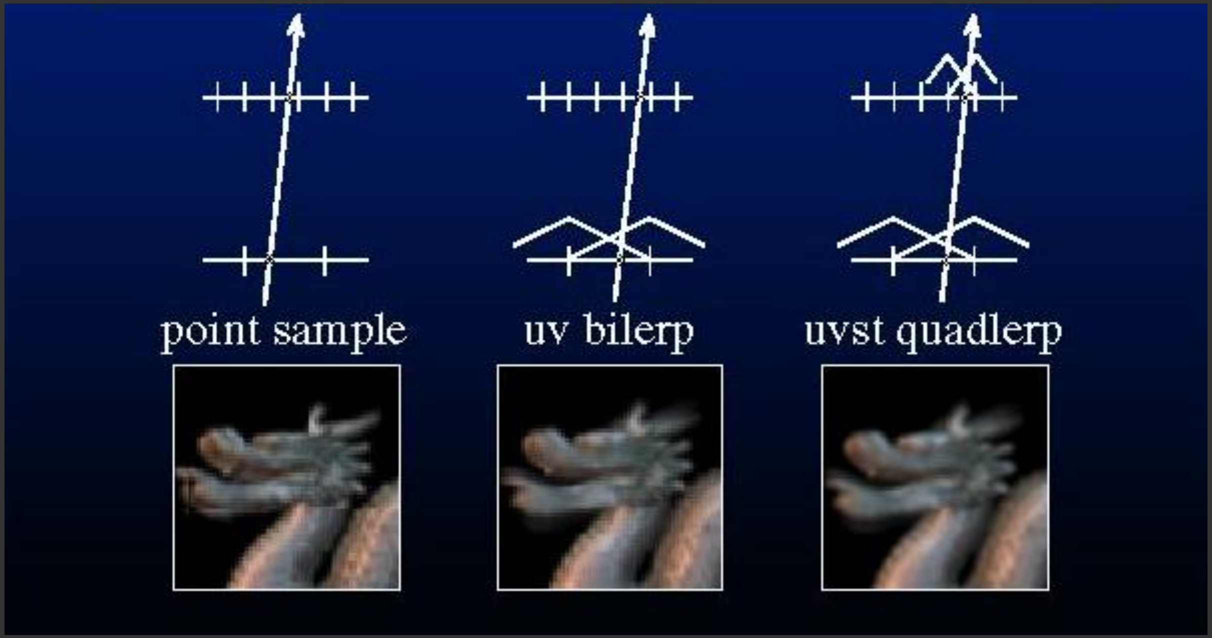
Light Field Rendering

- Very Fast

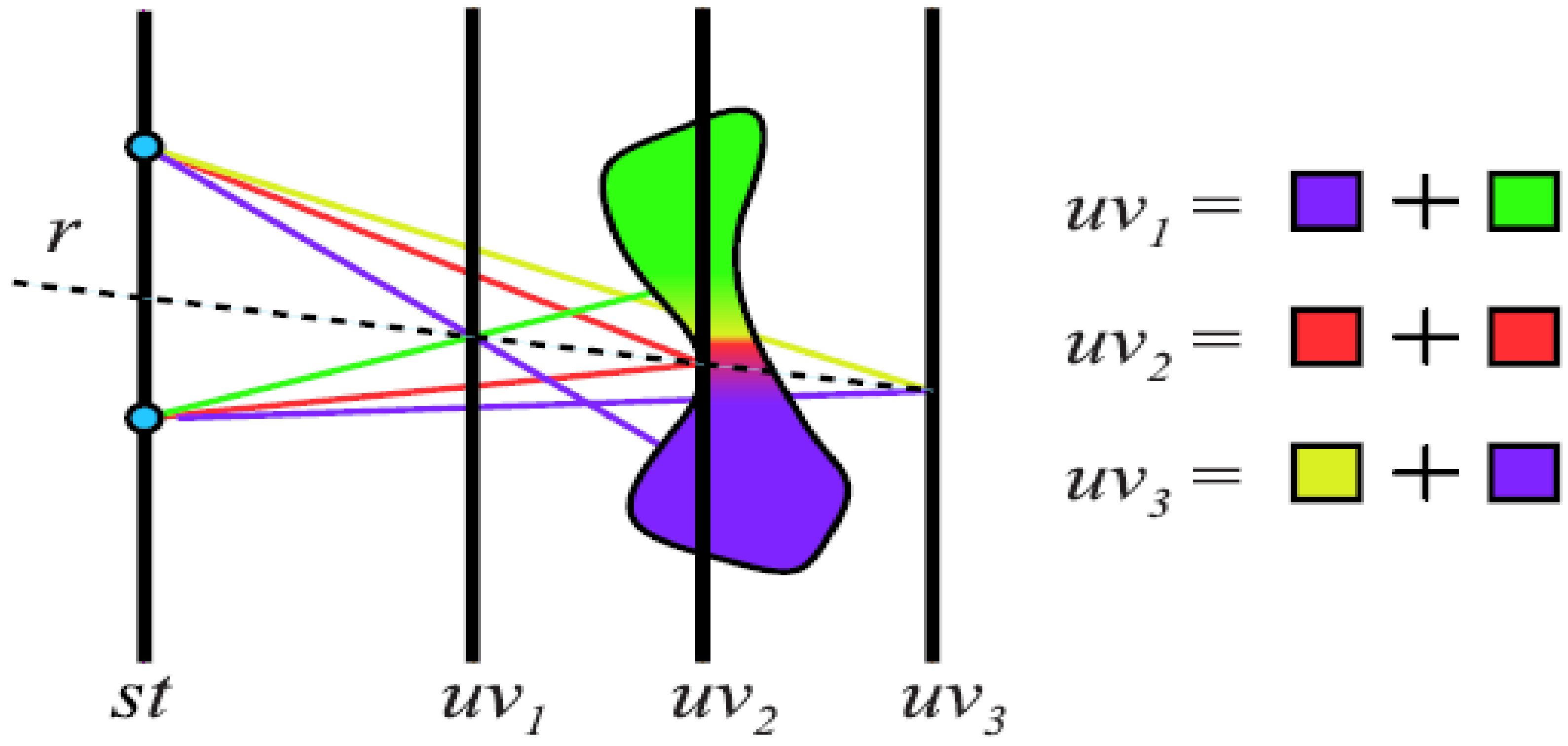


Light Field Rendering

- 4D interpolation

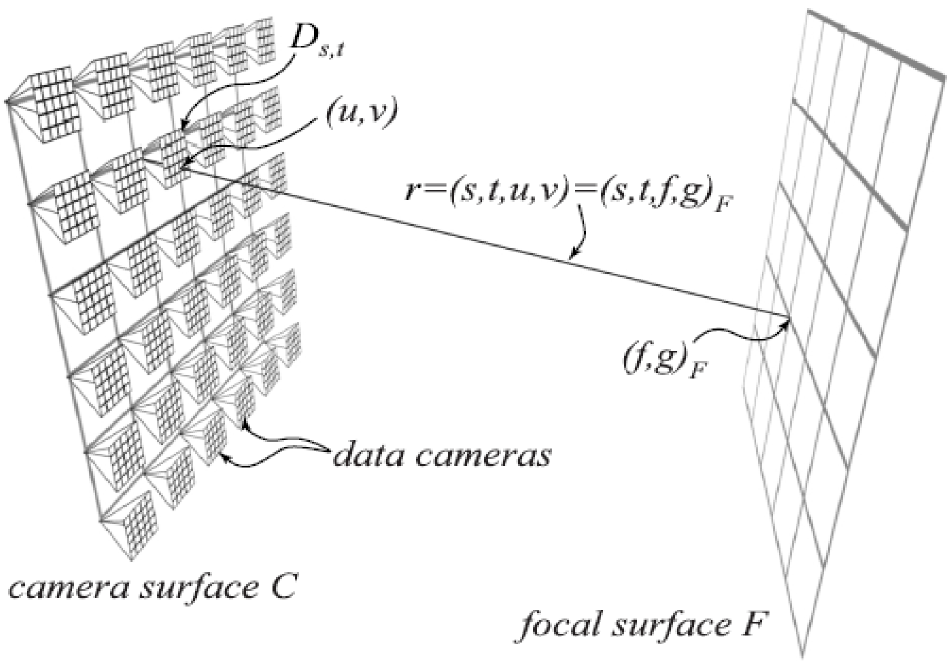


Dynamic Reparameterized Light Fields



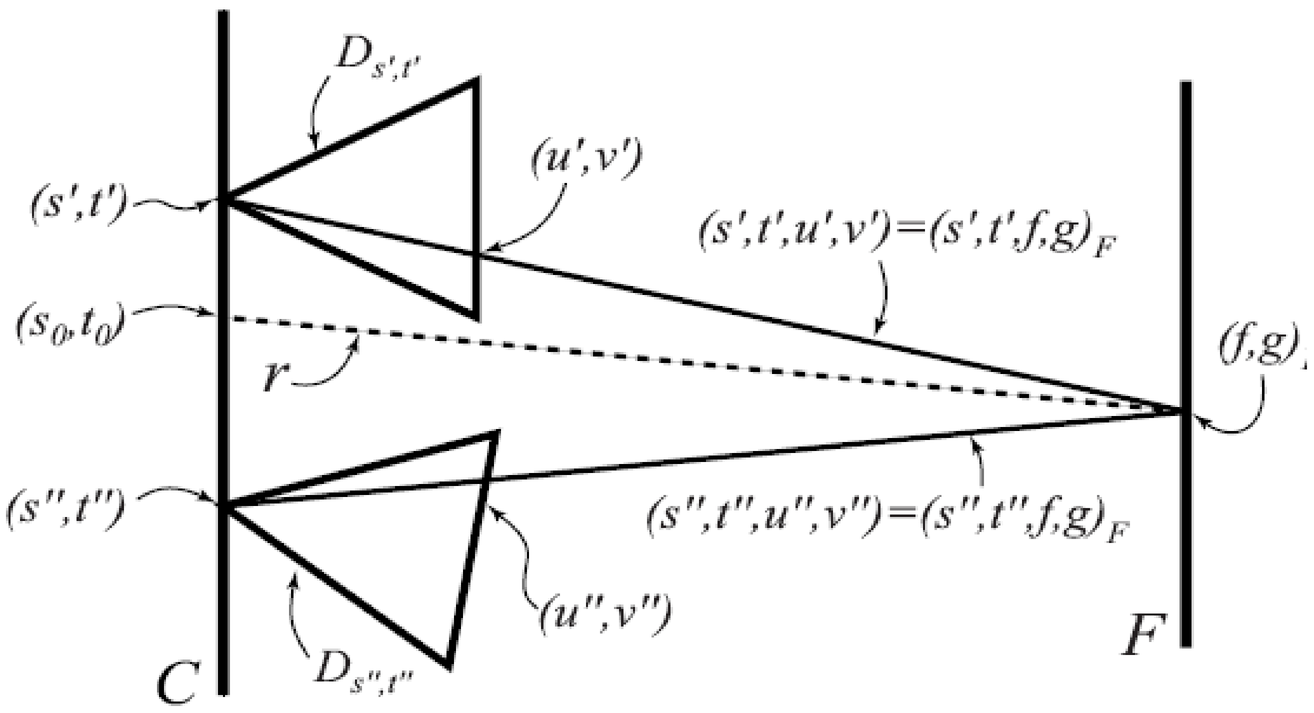
Dynamic Reparameterized Light Fields

- Move to desired new focal surface
- Create a new 4D space with new focal surface
- Recove ray with Reparameterization
- $(u, v, s, t) \Rightarrow (u, v, f, g)_F$



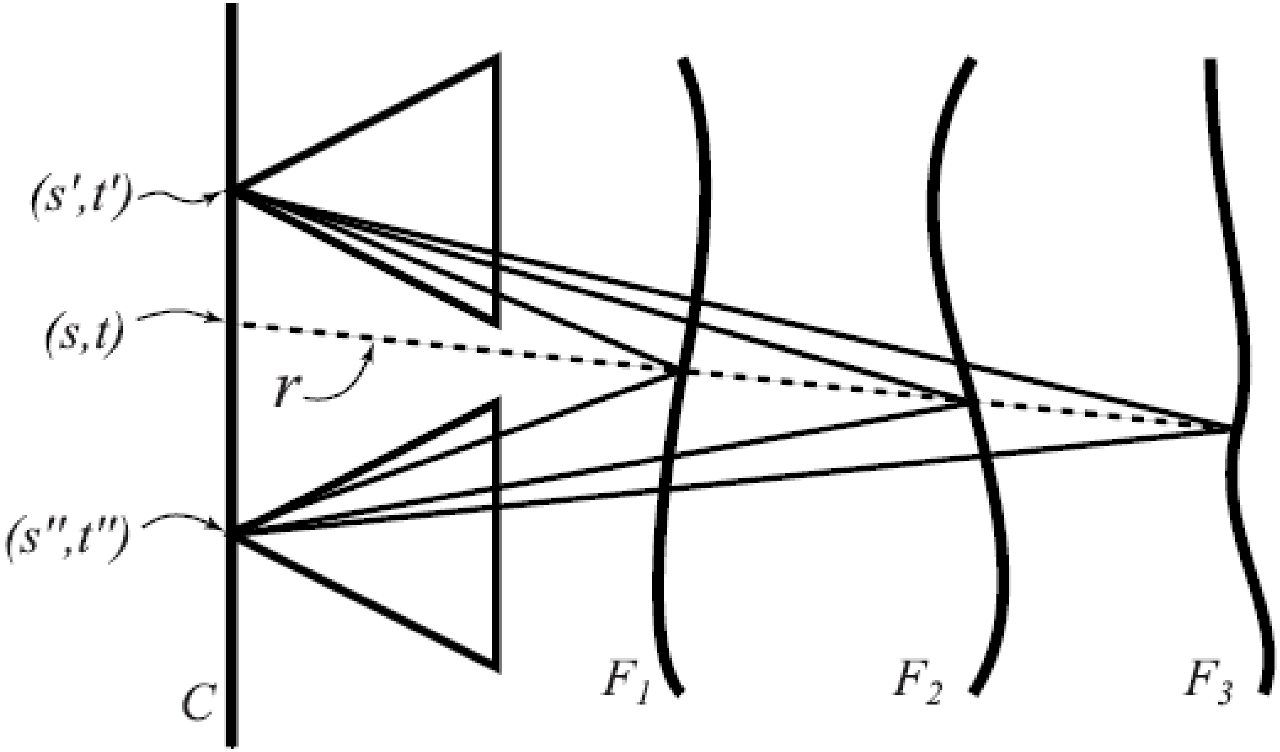
Dynamic Reparameterized Light Fields

- Recover ray r
- Resample from ray (s', t', f, g) and (s'', t'', f, g)
- Interpolation, reconstruction with filter, … , etc



Dynamic Reparameterized Light Fields

- Change the shape of focal surface
- Gives focus on 3D object rather than planes



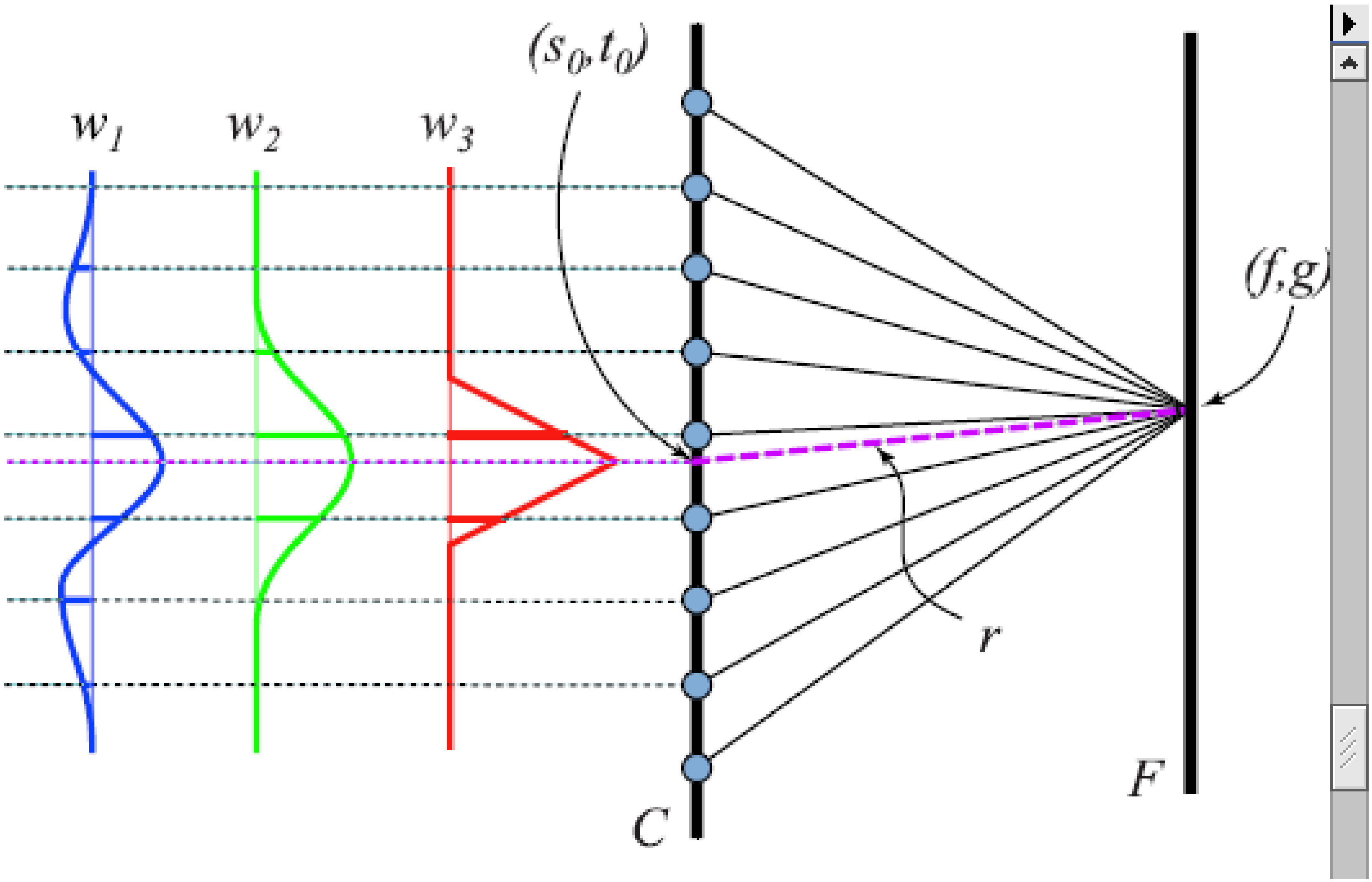
Dynamic Reparameterized Light Fields

Dynamic Reparameterized Light Fields

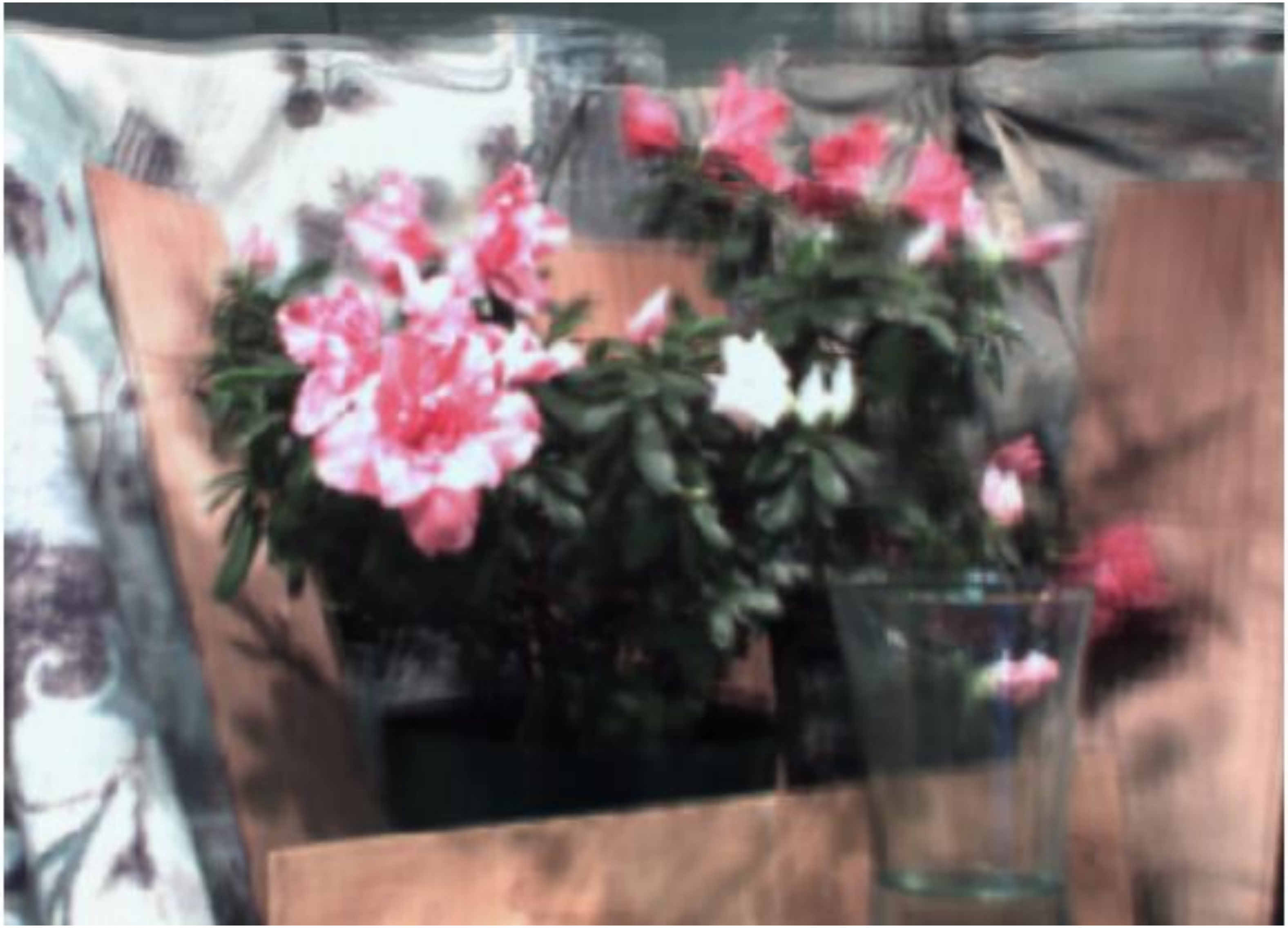
Variable Apertures

- Also can generate variable aperture
- Aperture
  - Control amount of light
  - Control depth of fields
- Aperture Filter:
  - Control how many cameras are used to resample a required ray
  - Larger apertures produce images with narrow range of focus

Aperture Filters



Variable Apertures

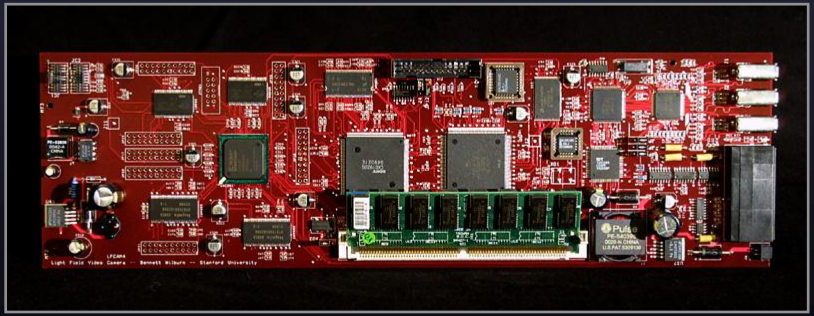


Variable Apertures

Stanford multi-camera array

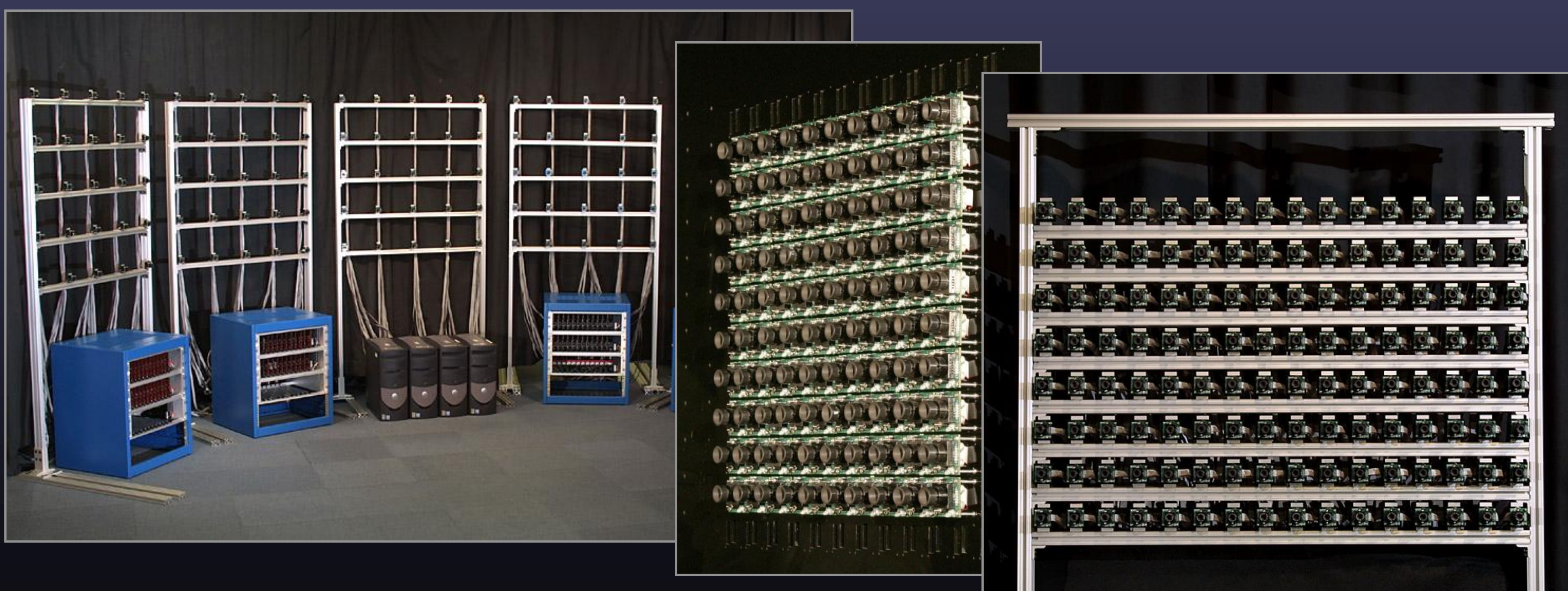
- 640 480 pixels
  30 fps 128 cameras

- synchronized timing
- continuous streaming
- flexible arrangement

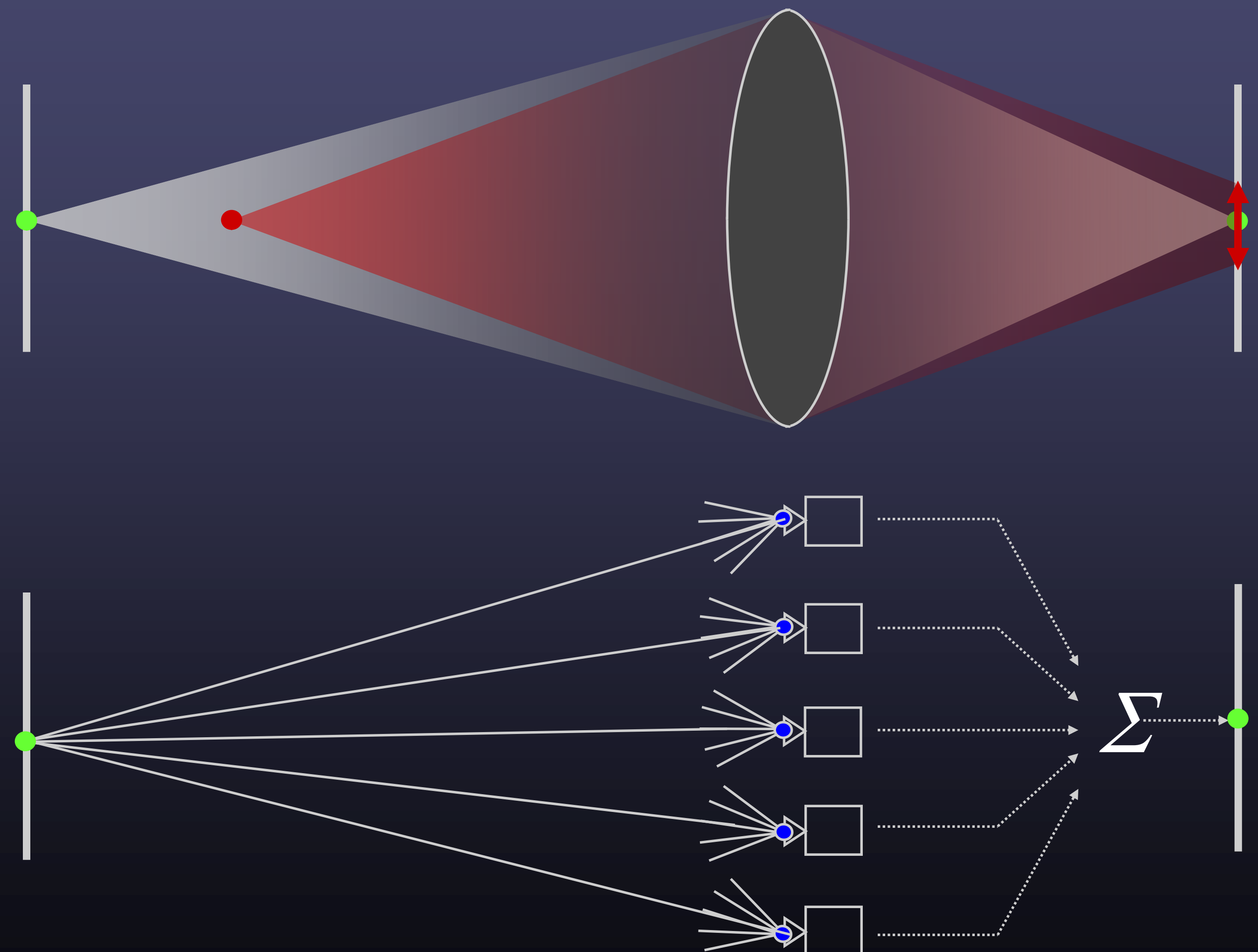


Ways to use large camera arrays

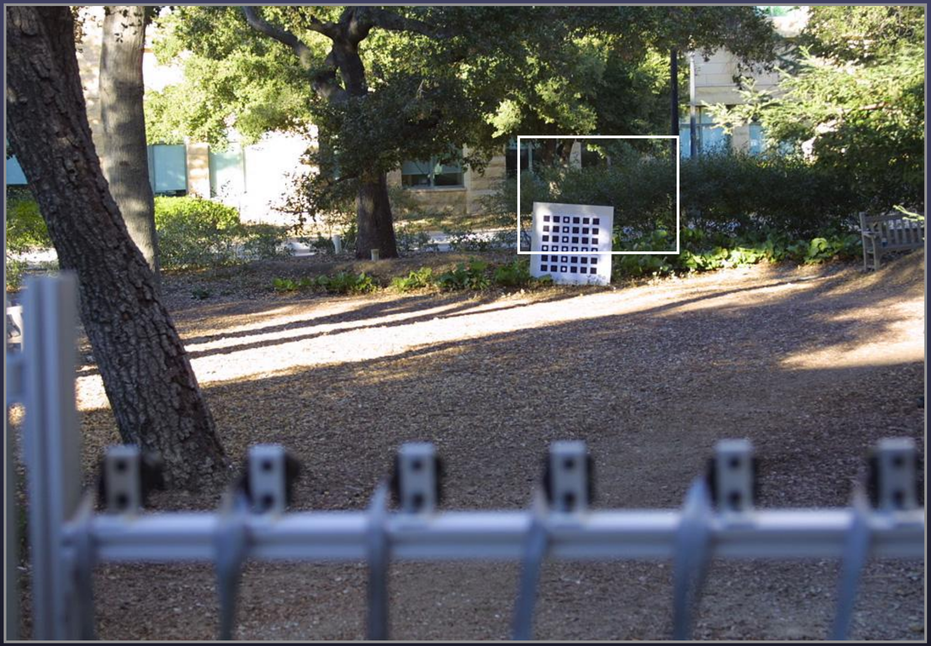
- widely spaced → light field capture
- tightly packed → high-performance imaging
- intermediate spacing → synthetic aperture photography



Intermediate camera spacing: synthetic aperture photography

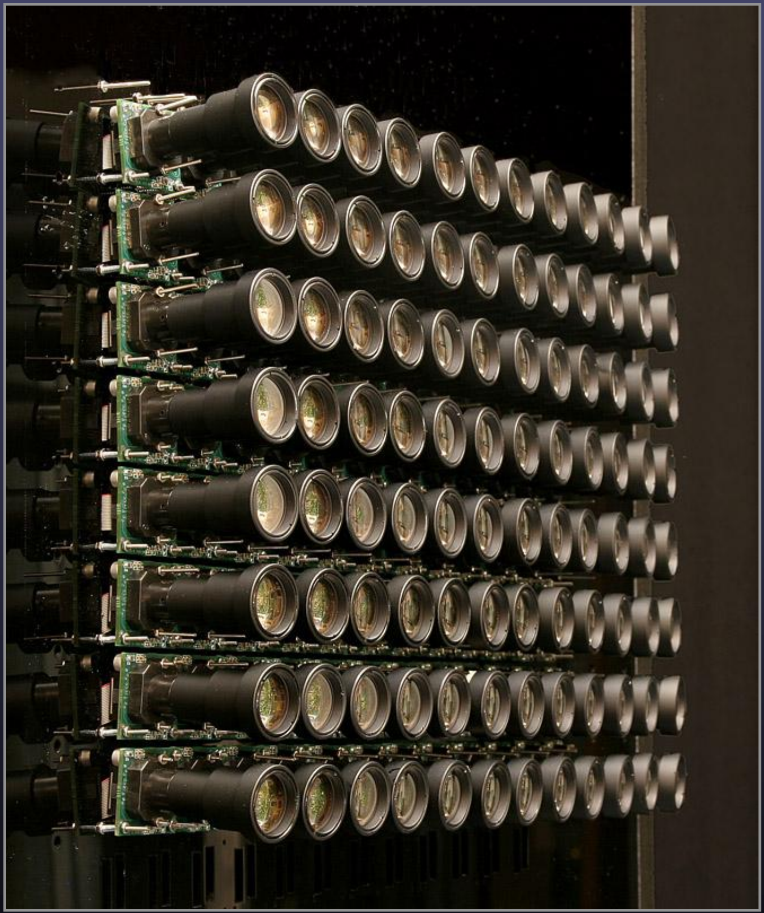


Example using 45 cameras
[Vaish CVPR 2004]



Tiled camera array

Can we match the image quality of a cinema camera?



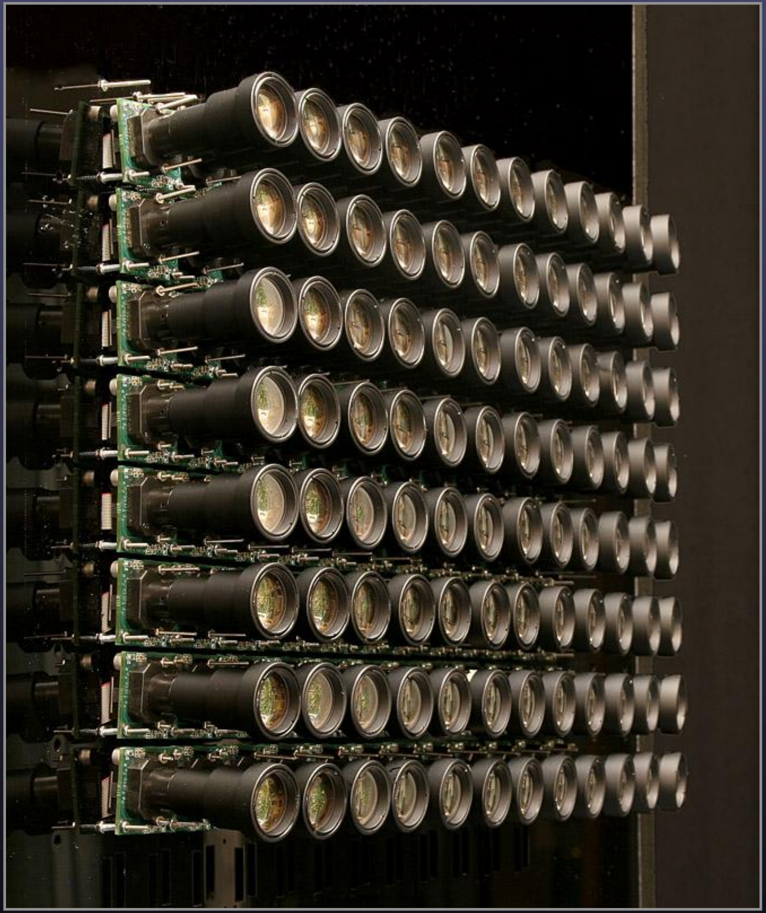
- world’s largest video camera
- no parallax for distant objects
- poor lenses limit image quality
- seamless mosaicing isn’t hard

Tiled panoramic image
(before geometric or color calibration)

Tiled panoramic image
(after calibration and blending)

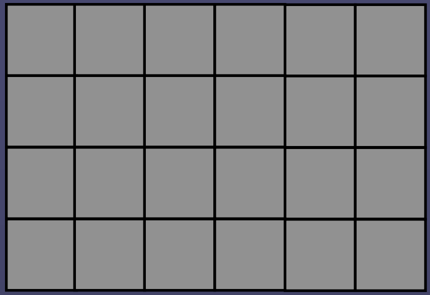
Tiled camera array

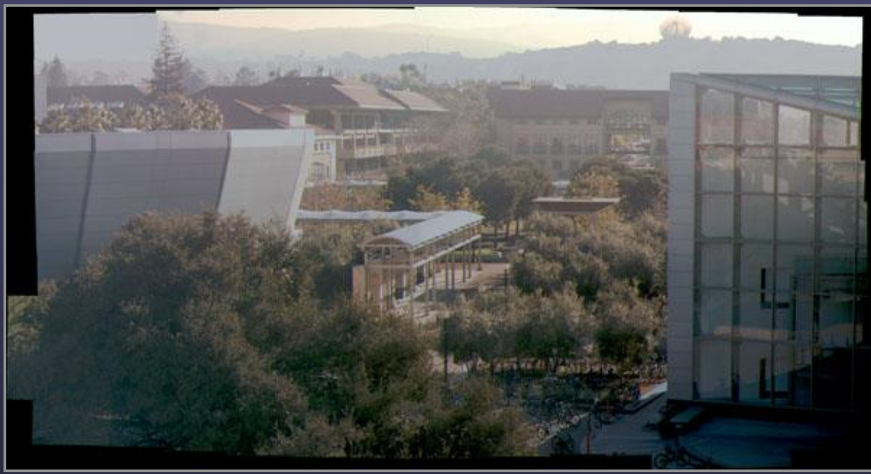
Can we match the image quality of a cinema camera?



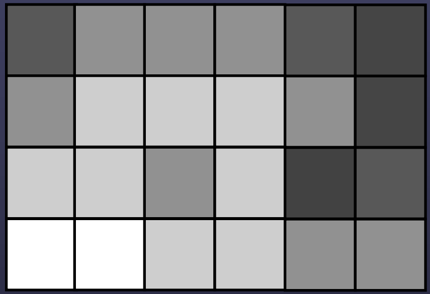
- world's largest video camera
- no parallax for distant objects
- poor lenses limit image quality
- seamless mosaicing isn't hard
- per-camera exposure metering
- HDR within and between tiles

same exposure in all cameras

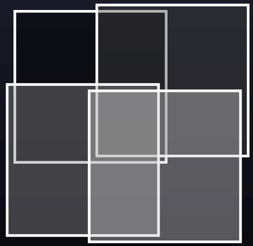


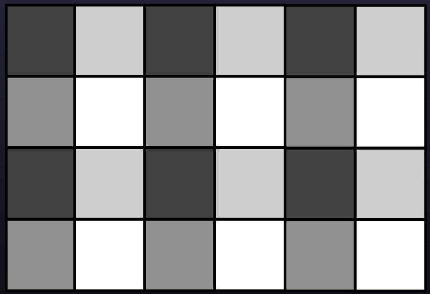


individually metered



checkerboard of exposures



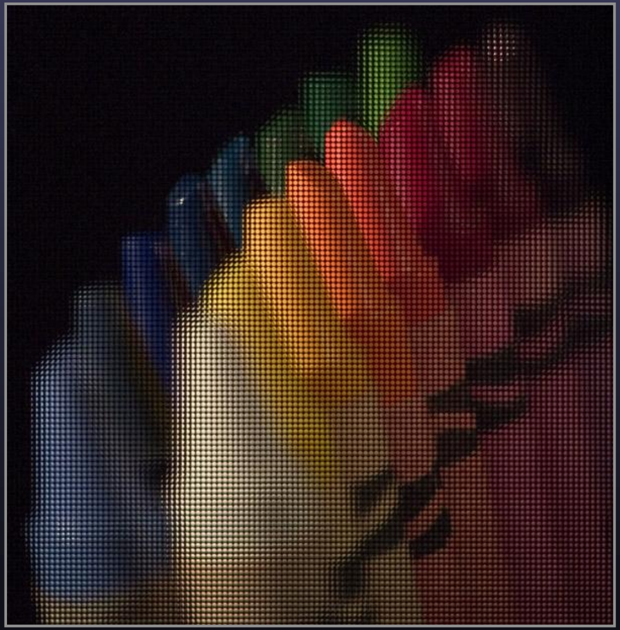


High-performance photography as multi-dimensional sampling

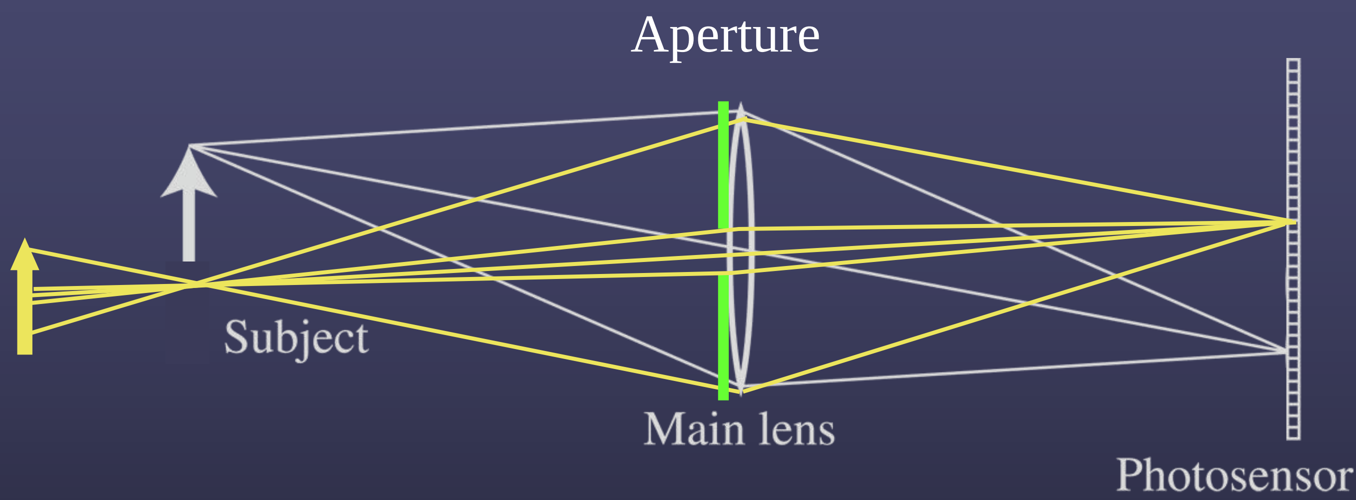
- spatial resolution
- field of view
- frame rate
- dynamic range
- bits of precision
- depth of field
- focus setting
- color sensitivity

Light field photography using a handheld plenoptic camera

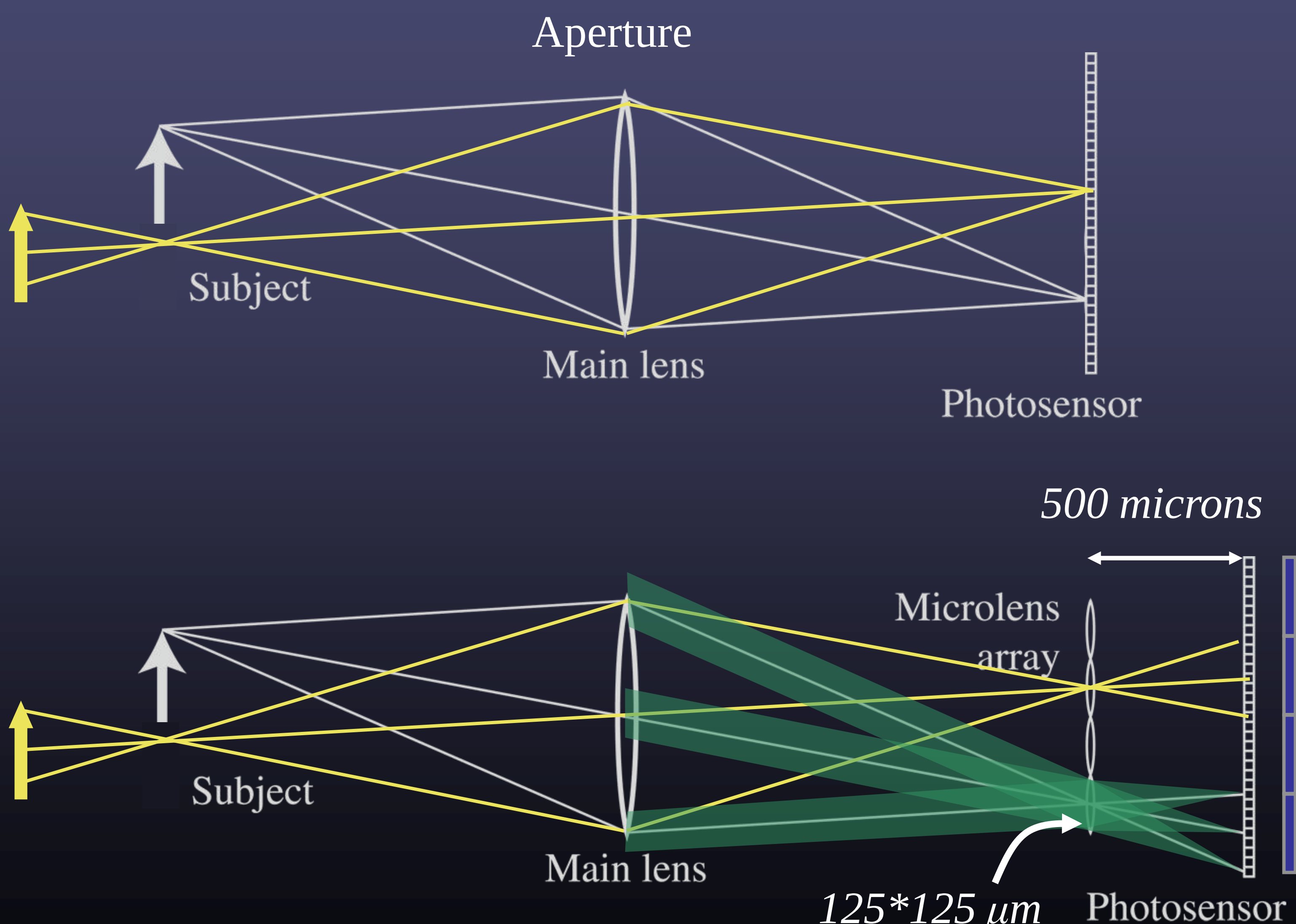
Ren Ng, Marc Levoy, Mathieu Brédif,
Gene Duval, Mark Horowitz and Pat Hanrahan
Stanford University



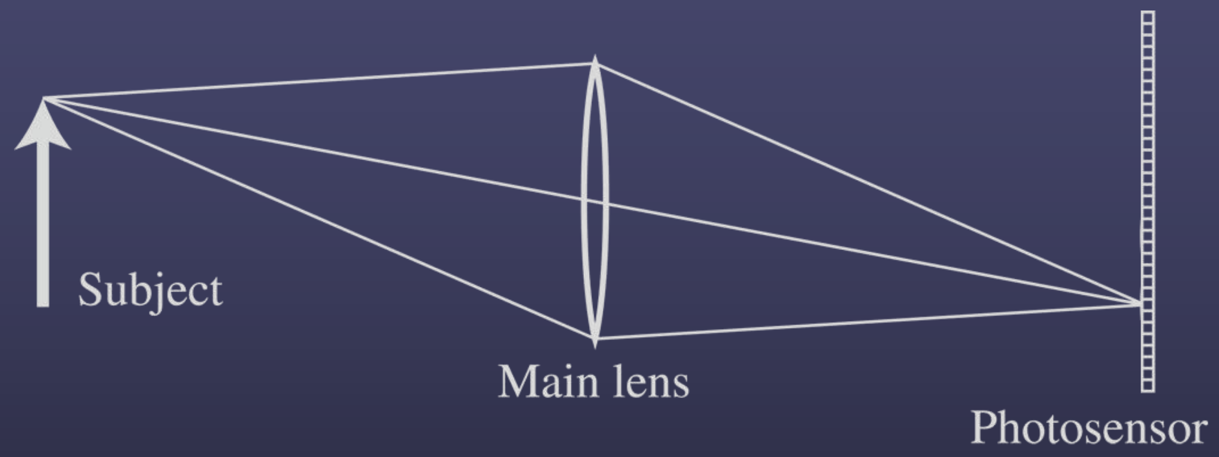
What's wrong with conventional cameras?

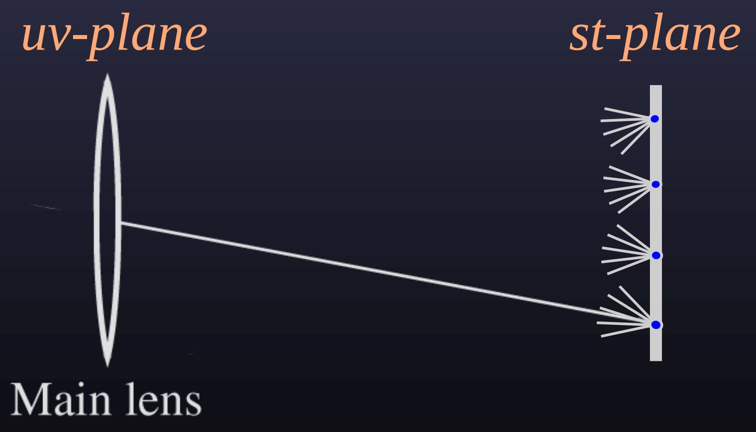


Capture the light field inside a camera

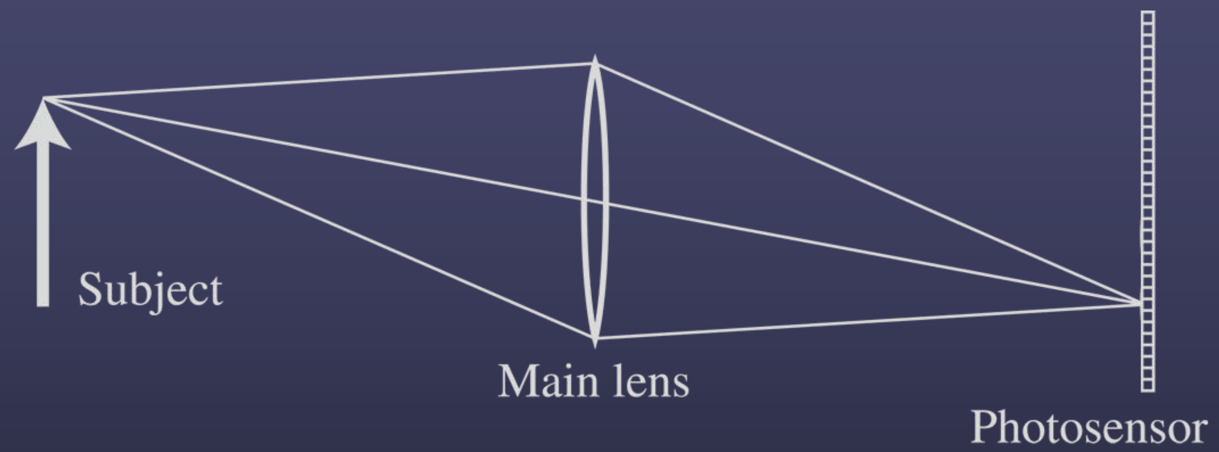


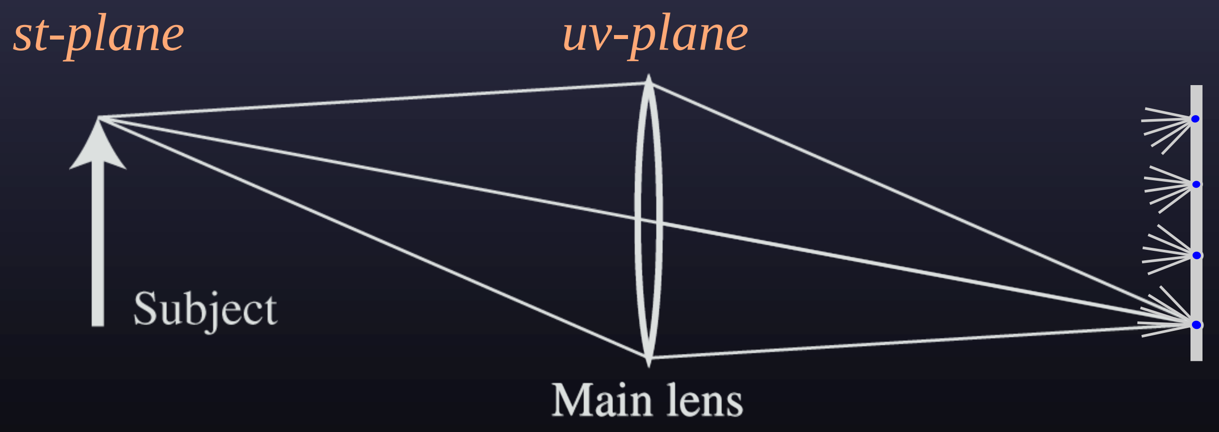
Conventional versus light field camera





Conventional versus light field camera

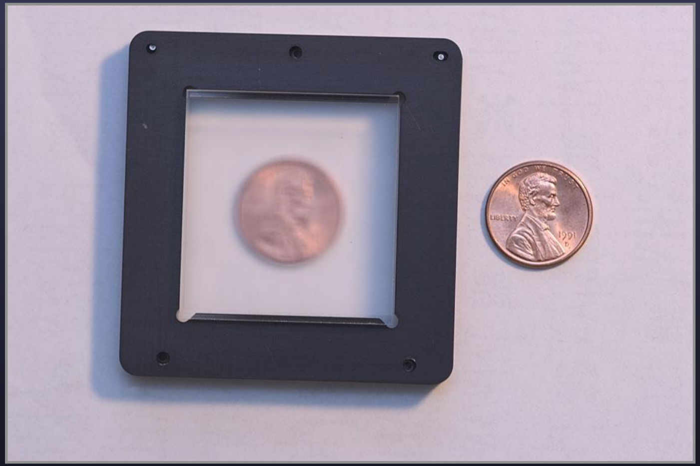




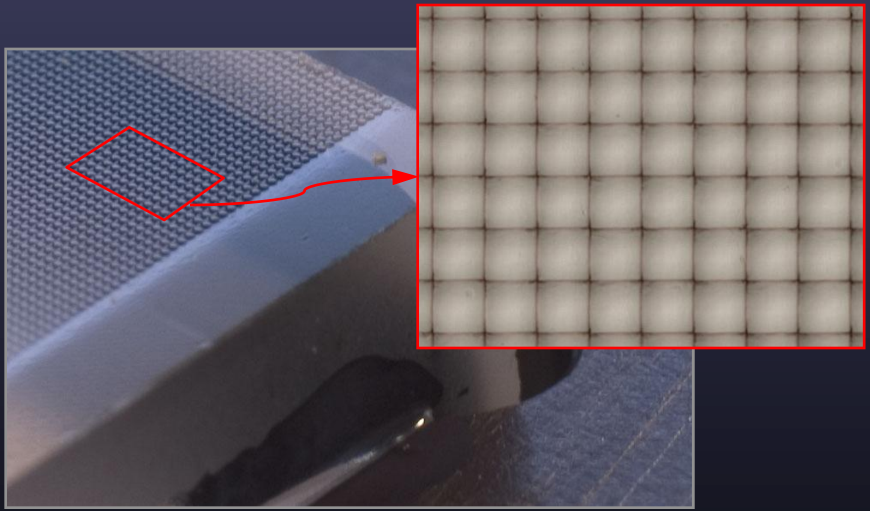
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor



Adaptive Optics microlens array

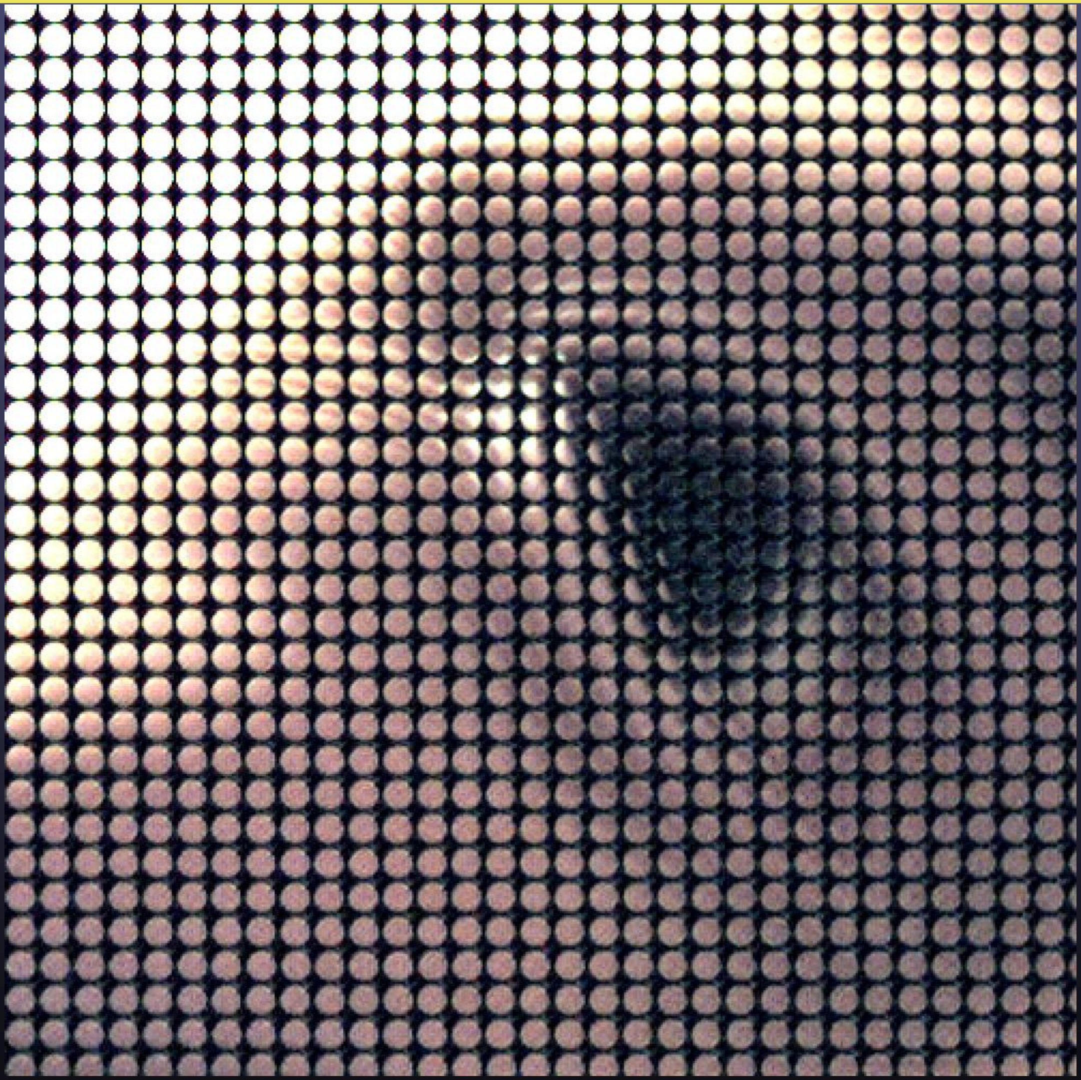


125µ square-sided microlenses

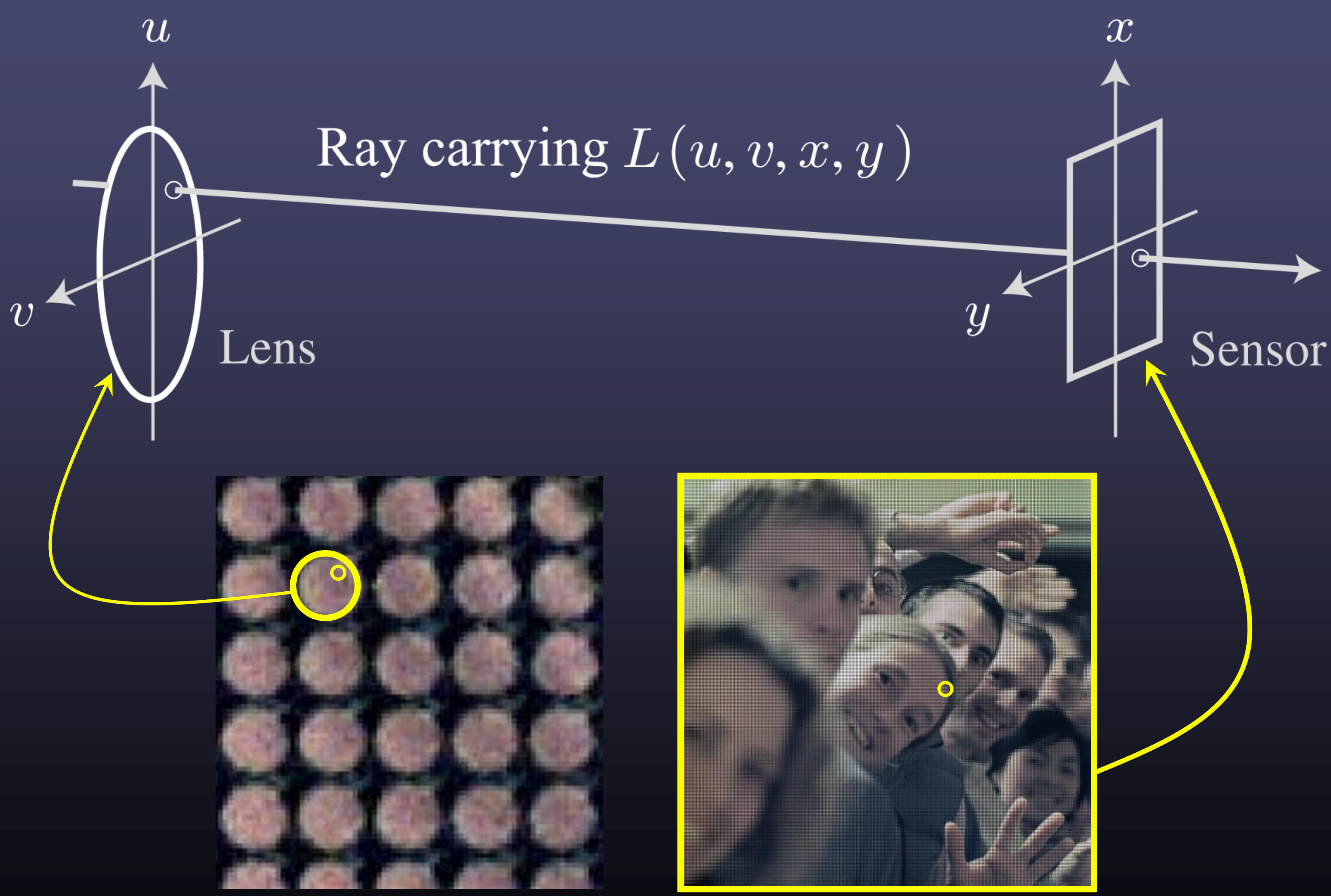
4000   4000 pixels   292   292 lenses = 14   14 pixels per lens

Light Field in a Single Exposure

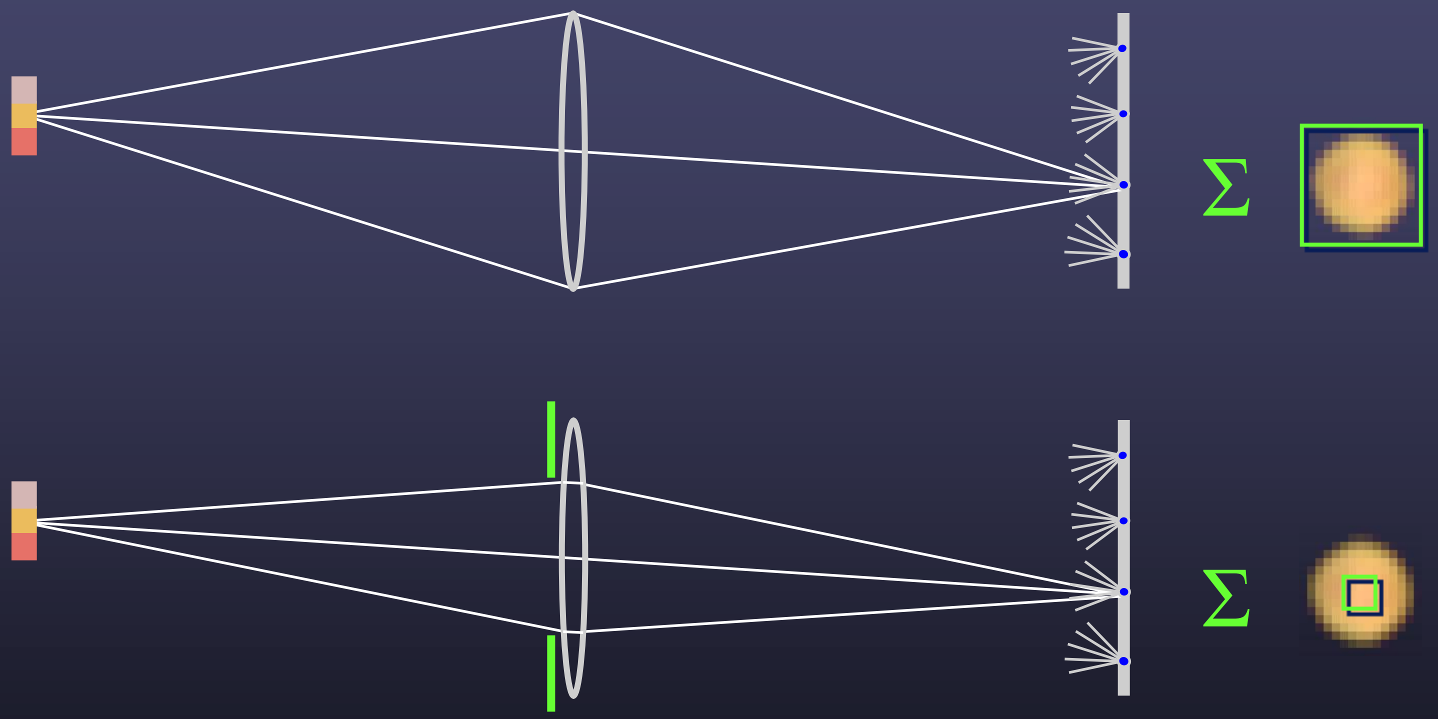
Light Field in a Single Exposure



Light field inside a camera body

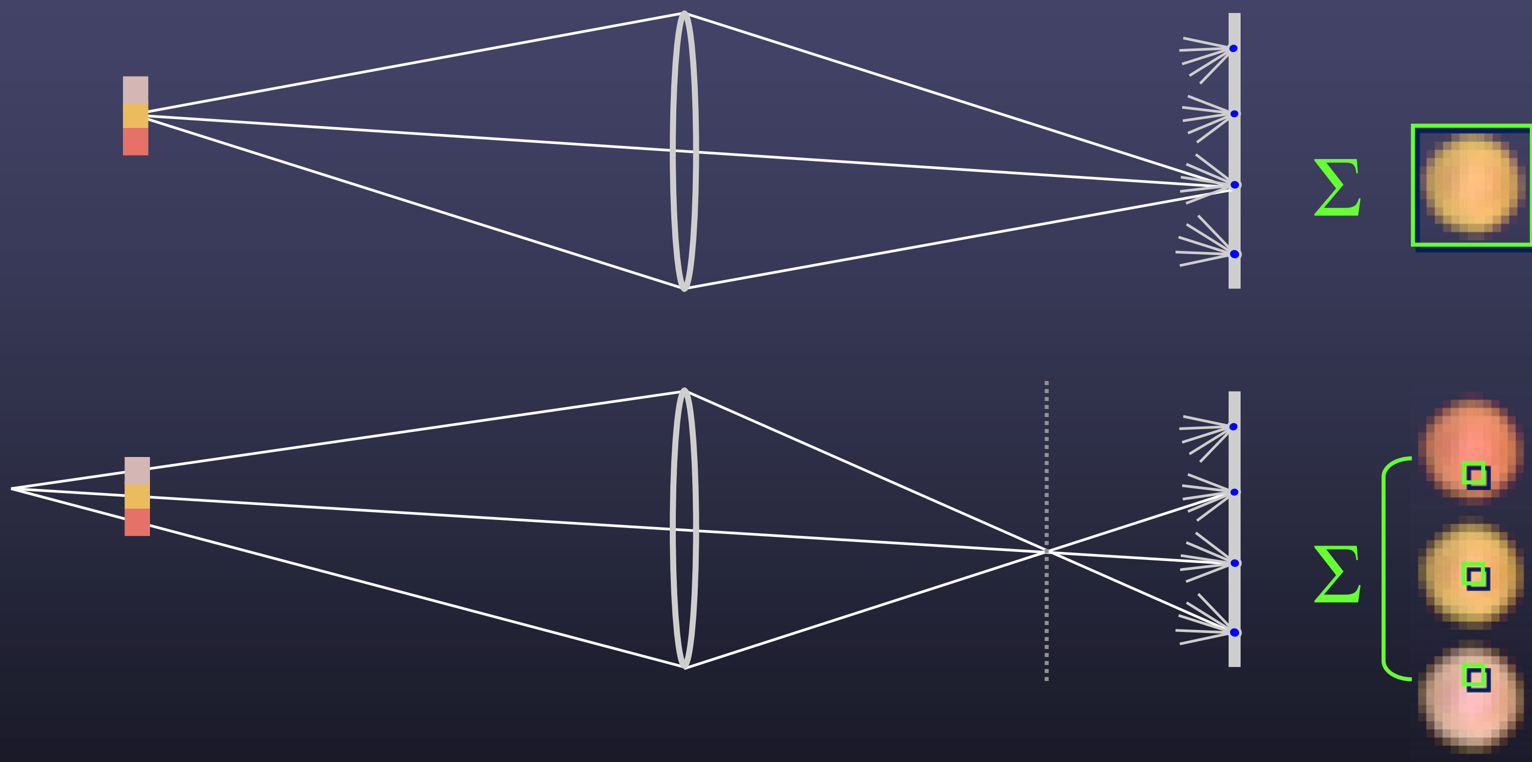


Digitally stopping-down



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

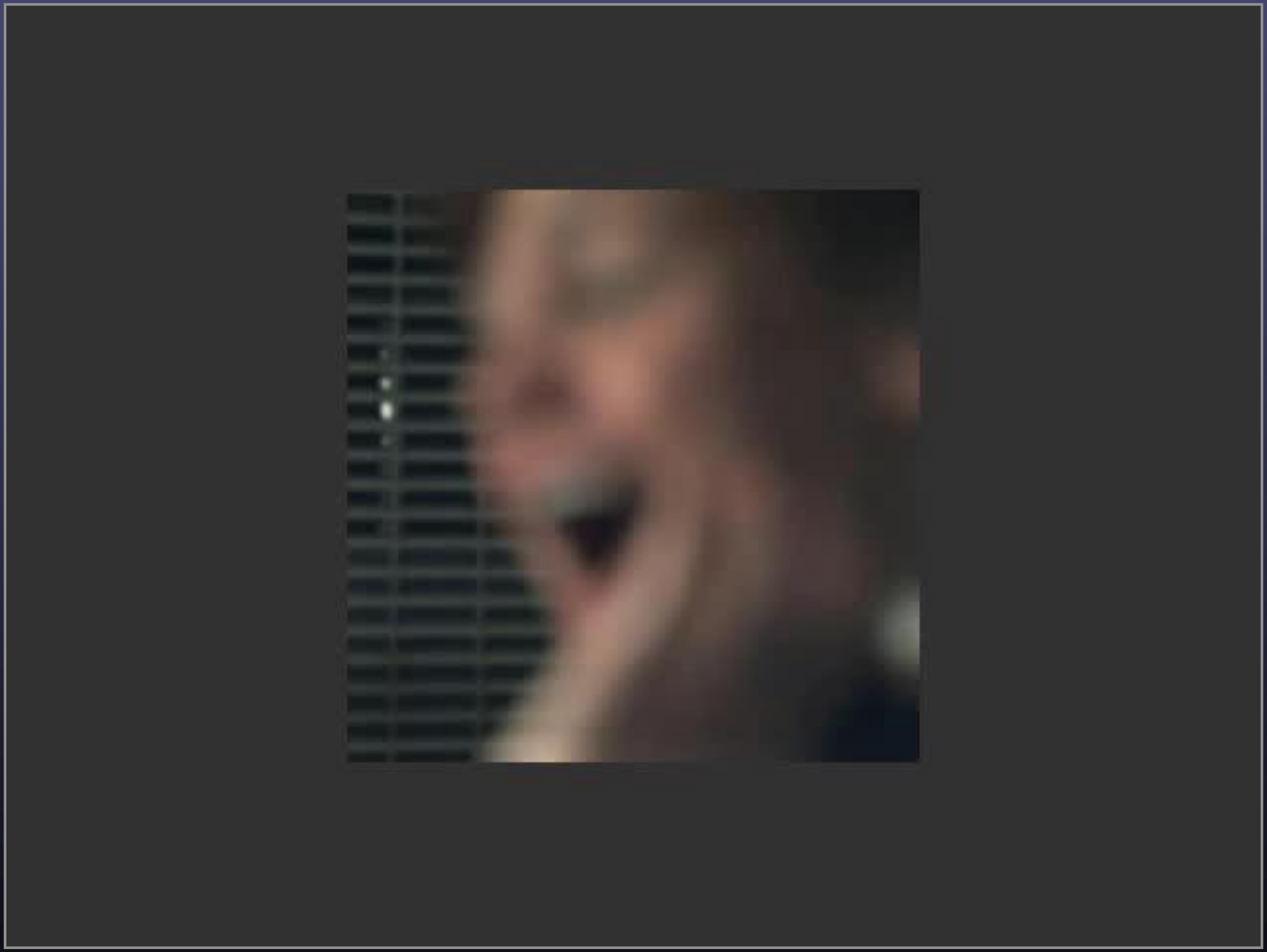
Digital refocusing



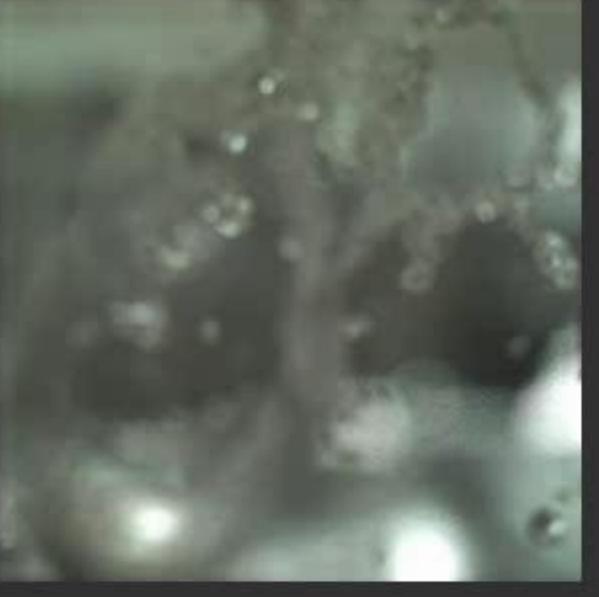
- refocusing = summing windows extracted from several microlenses

Example of digital refocusing

Refocusing portraits



Action photography

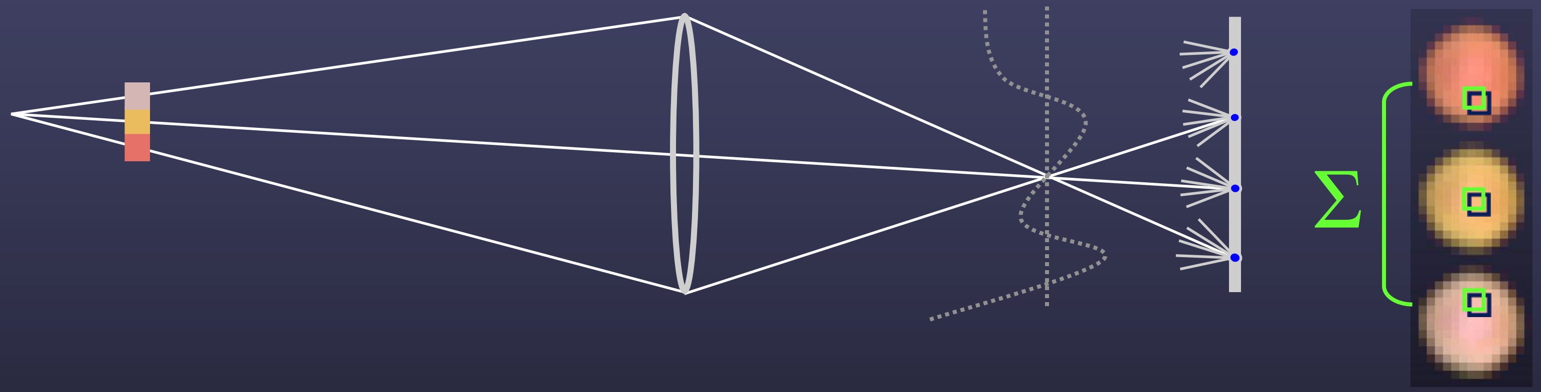


Focusing through a splash of water

Extending the depth of field

conventional photograph, main lens at *f* / 4 | conventional photograph, main lens at *f* / 22

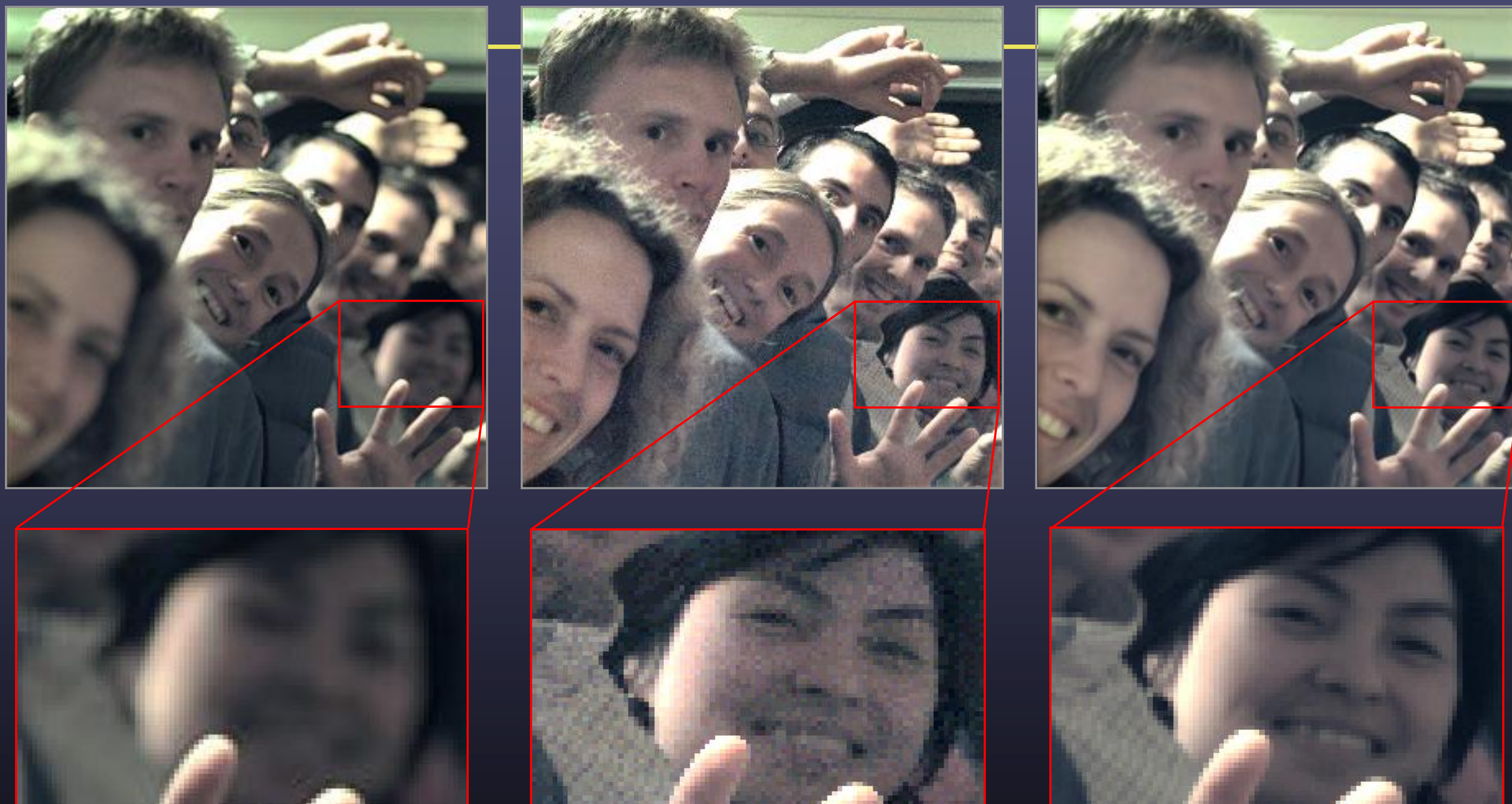
Scene-dependent focal plane



Depth from focus problem

Interactive solution [Agarwala 2004]

Extending the depth of field



conventional photograph, main lens at *f* / 4

conventional photograph, main lens at *f* / 22

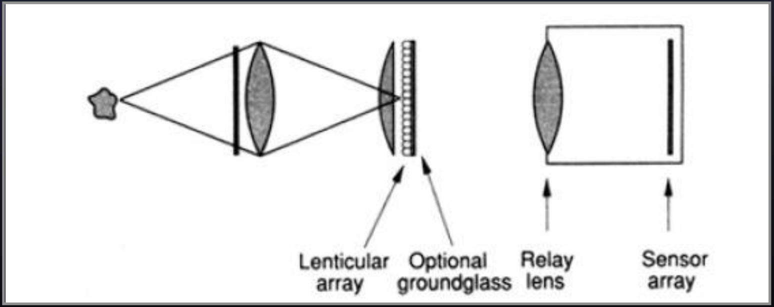
light field, main lens at *f* / 4, after all-focus algorithm [Agarwala 2004]

A digital refocusing theorem

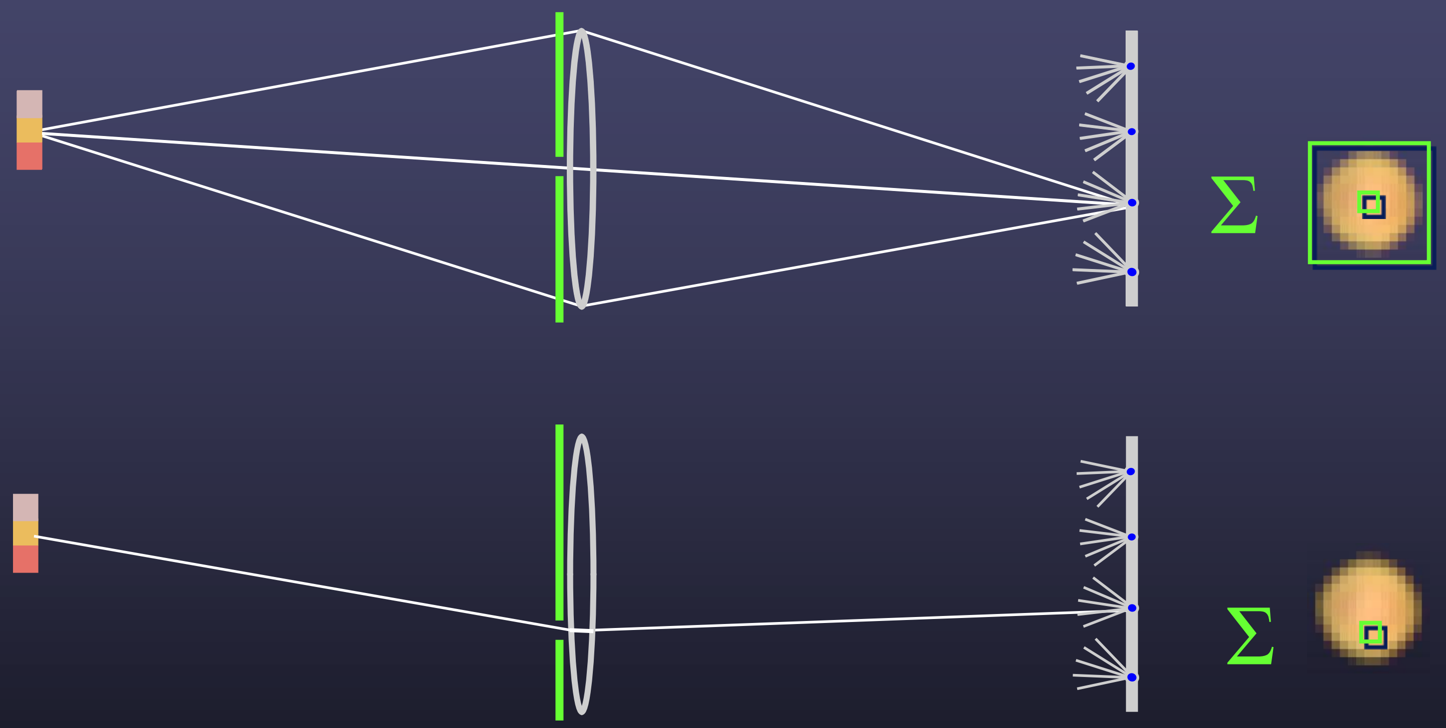
- an *f* / N light field camera, with P P pixels under each microlens, can produce views as sharp as an *f* / (N P) conventional camera
- these views can be focused anywhere within the depth of field of the *f* / (N P) camera

Prior work

- integral photography
  - – microlens array + film
  - – application is autostereoscopic effect
- [Adelson 1992]
  - – proposed this camera
  - – built an optical bench prototype using relay lenses
  - – application was stereo vision, not photography

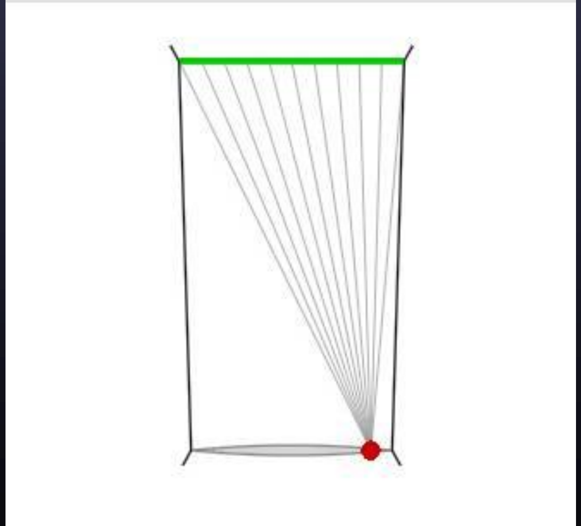


Digitally moving the observer

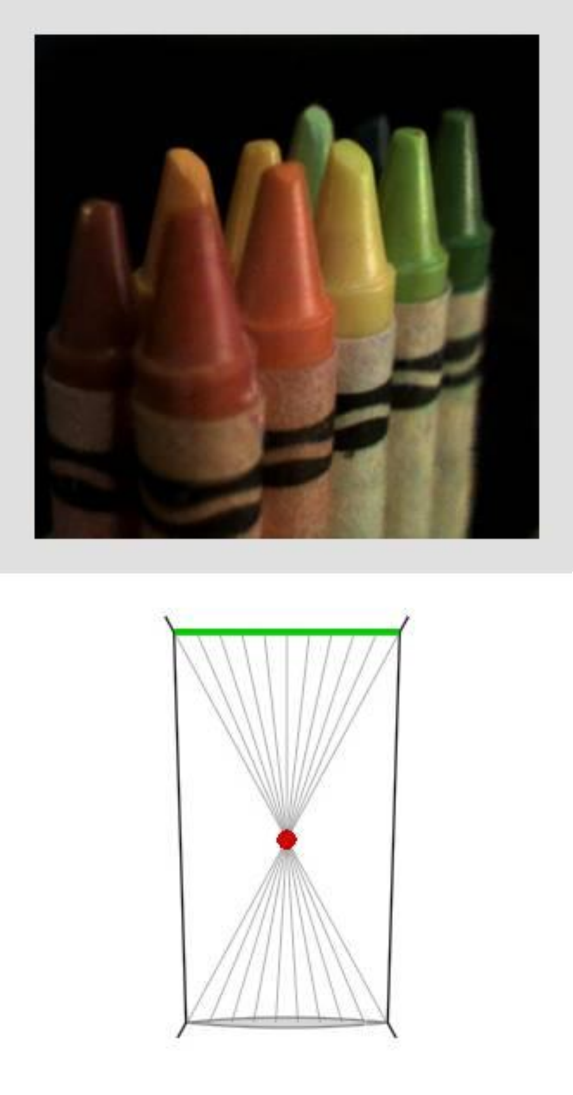


- moving the observer = moving the window we extract from the microlenses

Example of moving the observer



Moving backward and forward



Implications

- cuts the unwanted link between exposure (due to the aperture) and depth of field
- trades off (excess) spatial resolution for ability to refocus and adjust the perspective
- sensor pixels should be made even smaller, subject to the diffraction limit

  36mm 24mm 2.5μ pixels = 266 megapixels

  20K 13K pixels

  4000 2666 pixels 20 20 rays per pixel
- Application in microscope