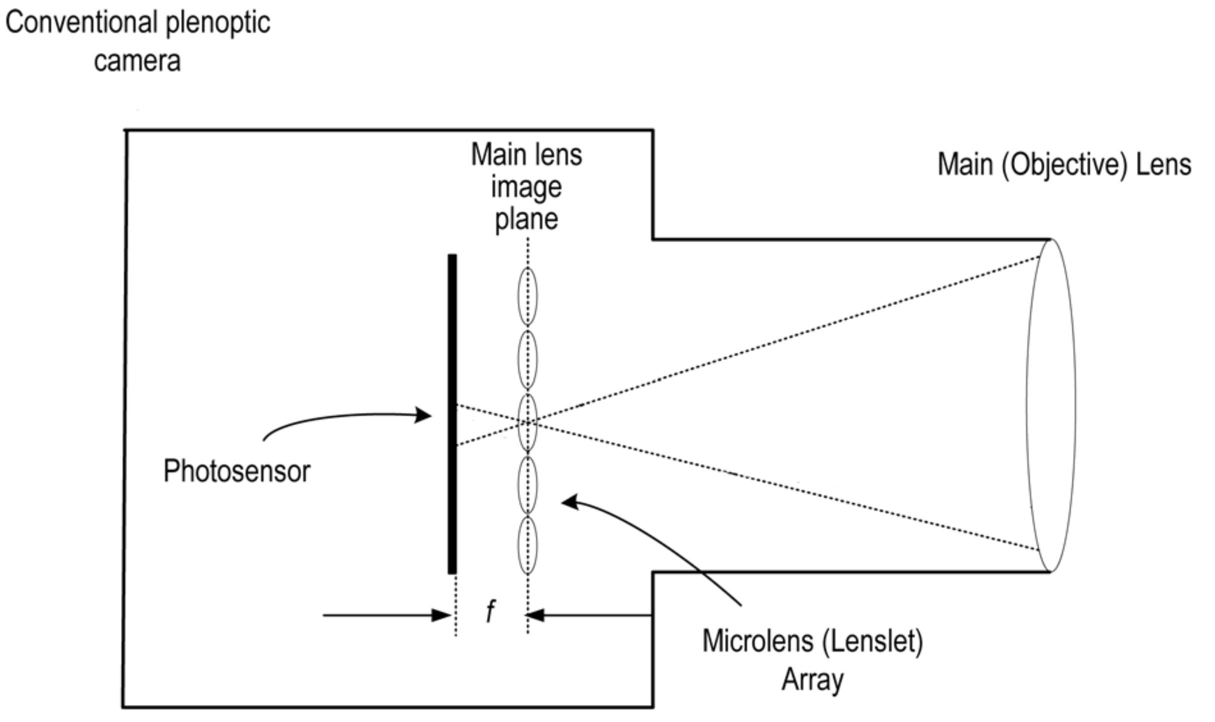
The Focused Plenoptic Camera

"Lightfield photographers, focus your cameras!"
Karl Marx

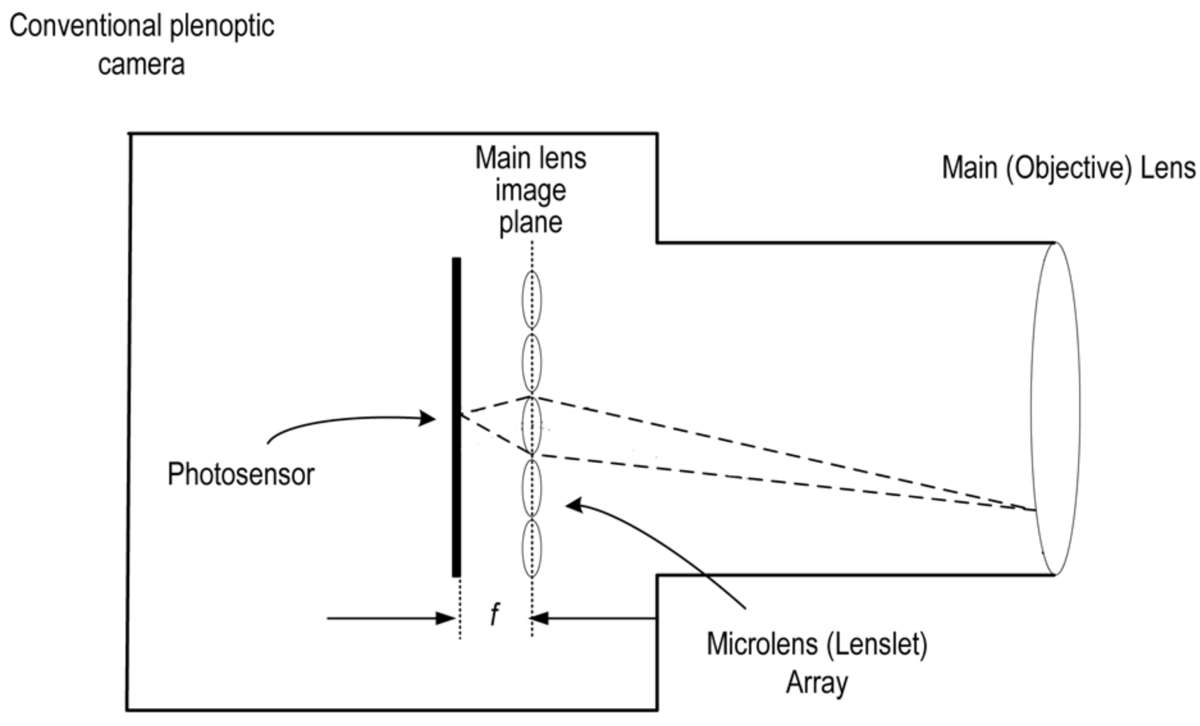
Plenoptic Camera, Adelson 1992

- Main lens focused on microlenses



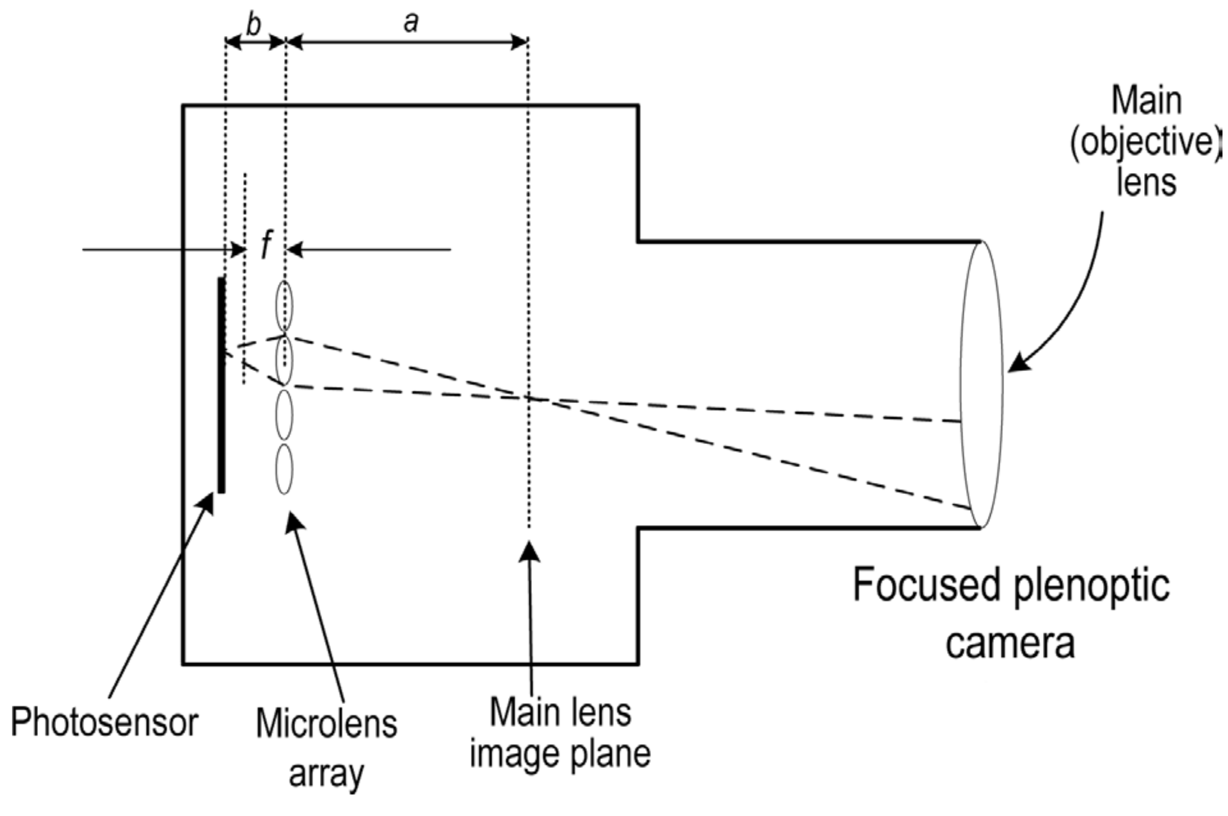
Plenoptic Camera, Adelson 1992

- Microlenses focused on infinity



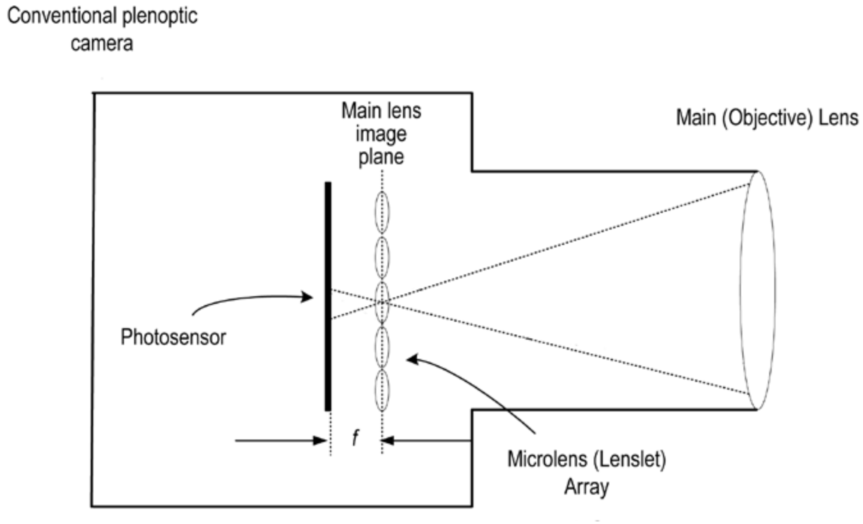
Focused Plenoptic Camera

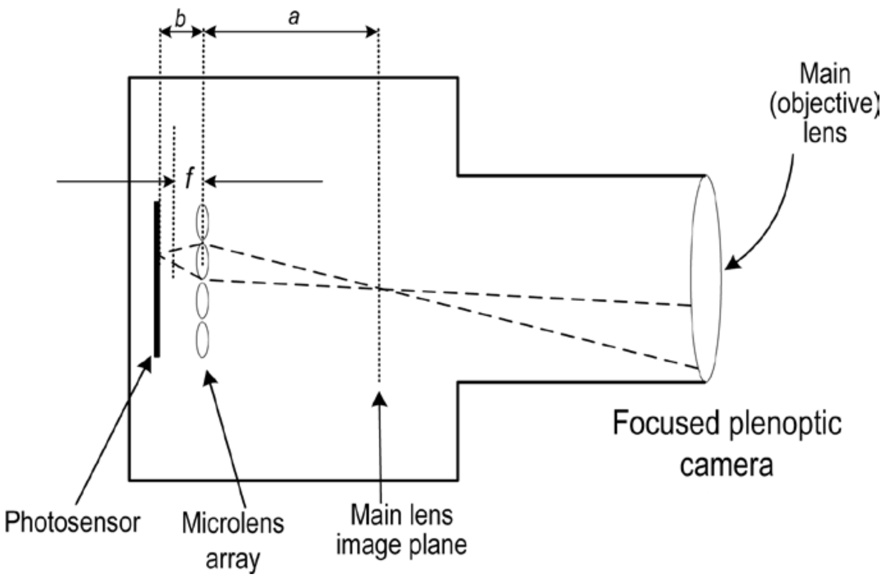
- Microlenses focused on main lens image



Comparison

- Plenoptic Camera (1.0)
- Focused Plenoptic Camera (2.0)

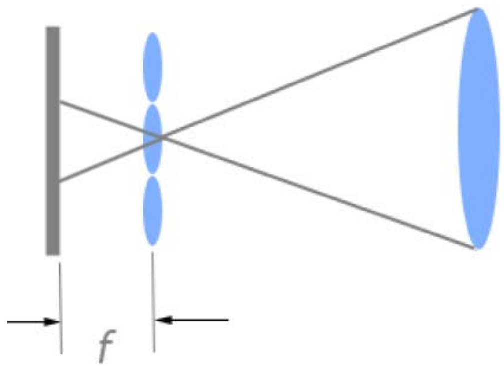




Adobe

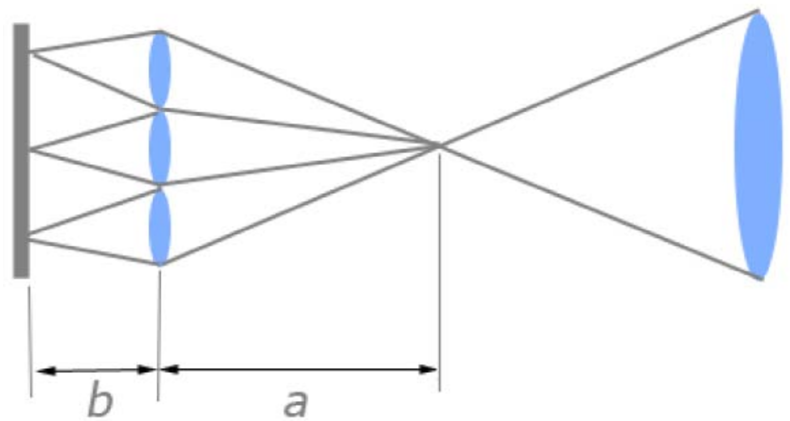
Comparison

- Plenoptic Camera



Microlenses focused at infinity. Completely defocused relative to main lens image.

- Focused Plenoptic Camera

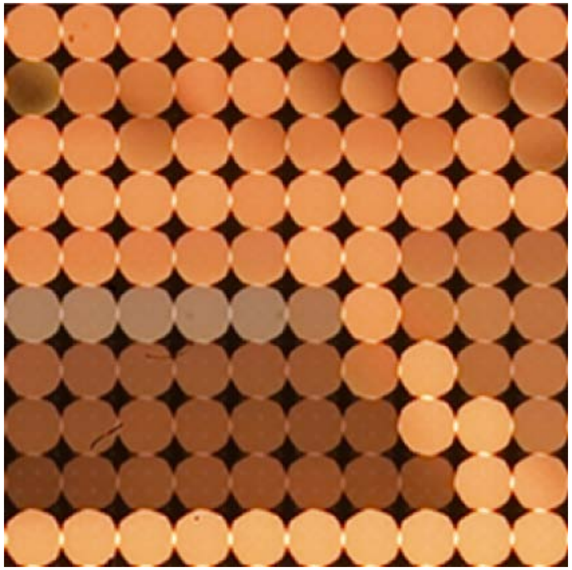


Microlenses satisfy the lens equation. Exactly focused on the main lens image.

Comparison

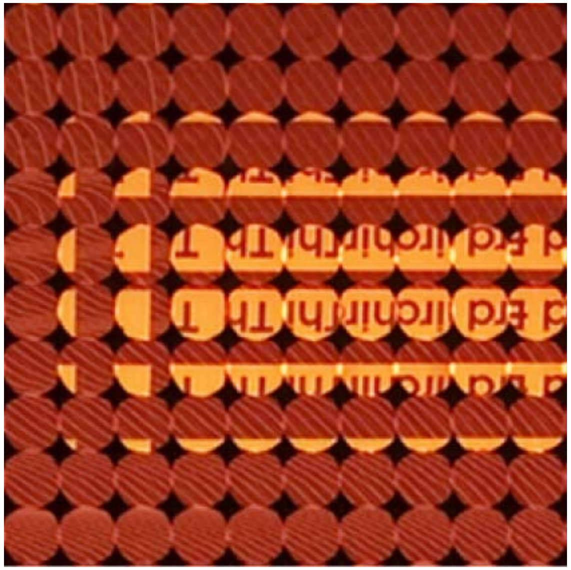
- Plenoptic Camera

  Blurry microimages



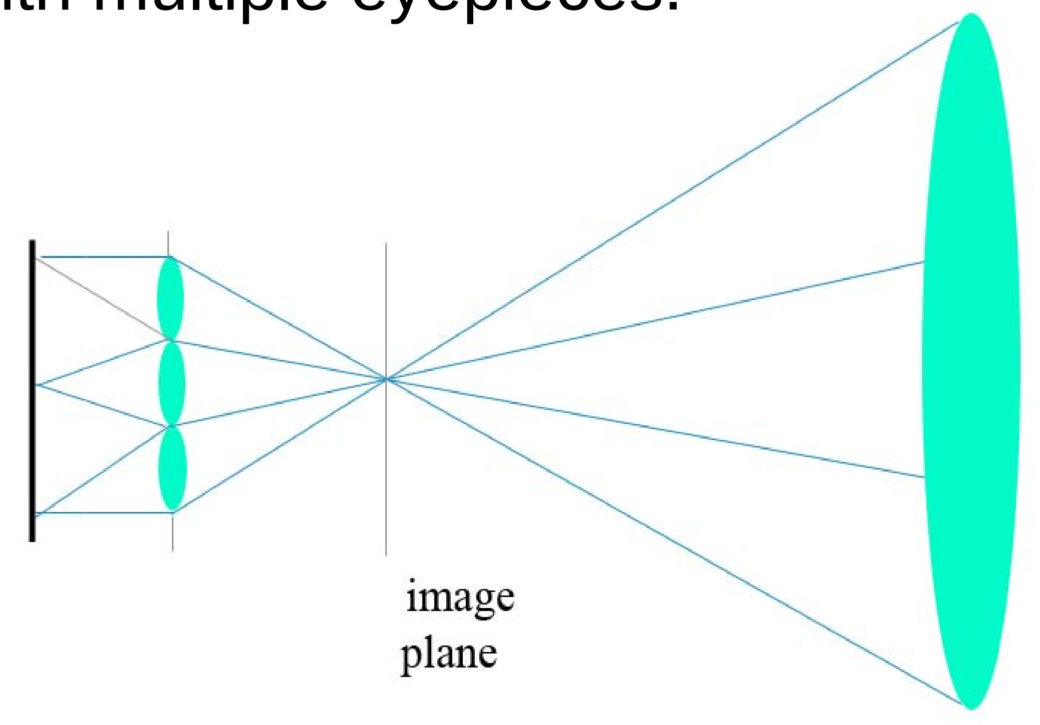
- Focused Plenoptic Camera

  Sharp and inverted microimages



Why Inverted?

- What is the condition for exact focusing with main lens image shifted from the plane of microlenses?
- **Answer:** Simple relay imaging! This is like a telescope with multiple eyepieces.



Lightfield Rendering Small Part of Scene

Full Resolution Rendering: 500X Improvement!

Resolution Analysis

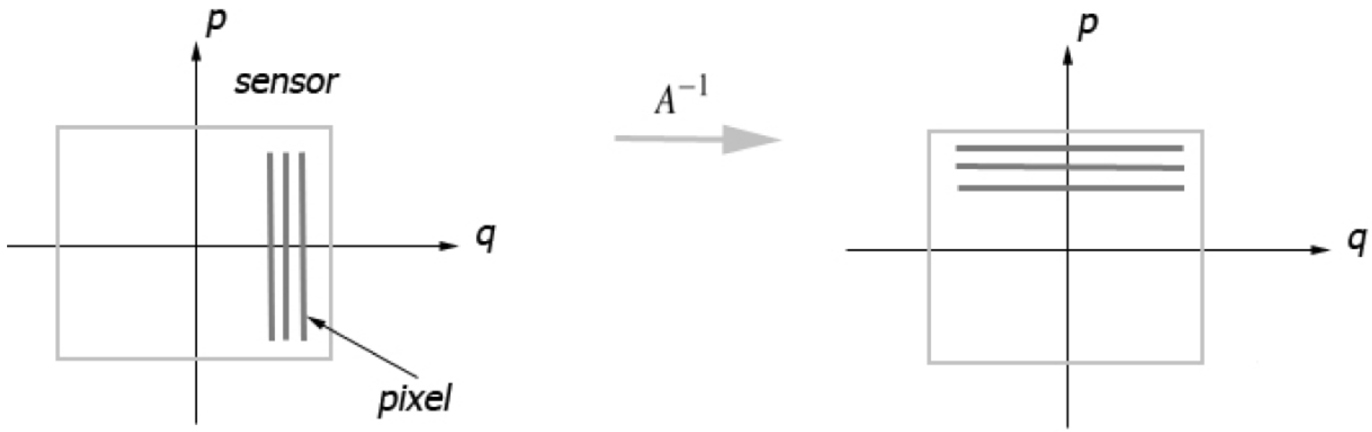
- Why do we have so much higher resolution in 2.0?
- Because the camera is focused:
  - The main lens creates radiance r(x) at its image plane.
  - Plenoptic 1.0 and 2.0 sample this radiance differently.
- For one microcamera, the optical transfer matrix is A.
- Radiance on the sensor: $r'(x) = r(A^{-1}x)$
- (continue)

Resolution Analysis

- For Plenoptic 1.0 the transfer matrix is:

$$A = \begin{bmatrix} 1 & f \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -\frac{1}{f} & 1 \end{bmatrix} = \begin{bmatrix} 0 & f \\ -\frac{1}{f} & 1 \end{bmatrix}$$

Inverse matrix $A^{-1} = \begin{bmatrix} 1 & -f \\ \frac{1}{f} & 0 \end{bmatrix}$



Resolution Analysis

- Rotation of each pixel to 90 degrees in optical phase space causes the low spatial resolution of 1.0 camera.
- For Plenoptic 2.0 the transfer matrix is:

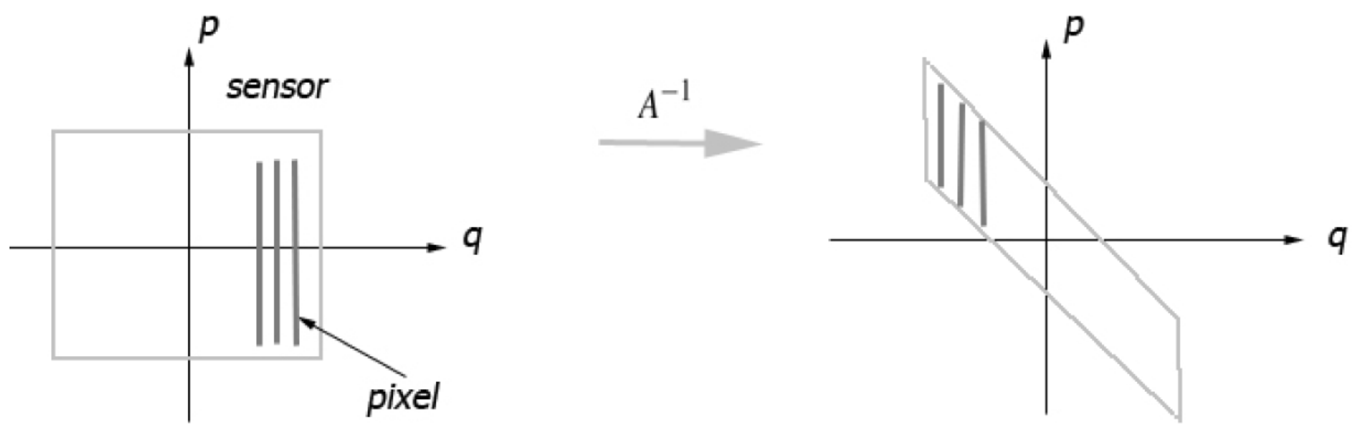
$$A = \begin{bmatrix} 1 & b \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -\frac{1}{f} & 1 \end{bmatrix} \begin{bmatrix} 1 & a \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} -\frac{b}{a} & 0 \\ -\frac{1}{f} & -\frac{a}{b} \end{bmatrix}$$

Inverse matrix $$A^{-1} = \begin{bmatrix} -\frac{a}{b} & 0 \\ \frac{1}{f} & -\frac{b}{a} \end{bmatrix}$$

Resolution analysis

- For Plenoptic 2.0 There is **no rotation**, just shear:

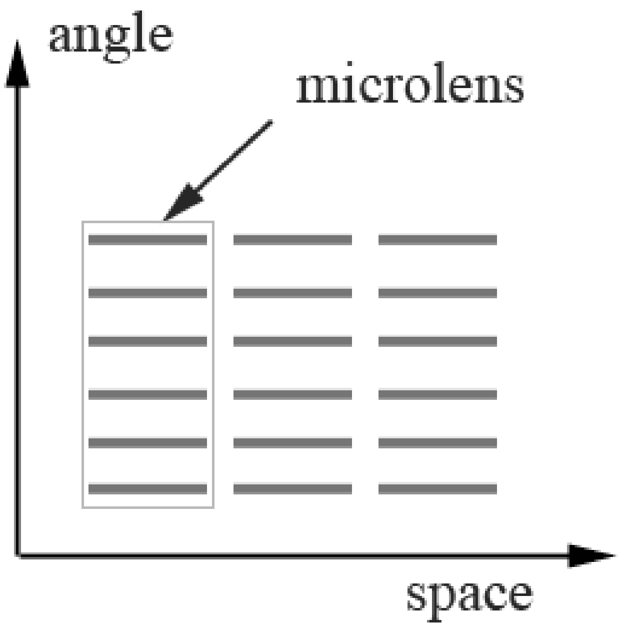
$$A^{-1} = \begin{bmatrix} -\frac{a}{b} & 0 \\ \frac{1}{f} & -\frac{b}{a} \end{bmatrix}$$



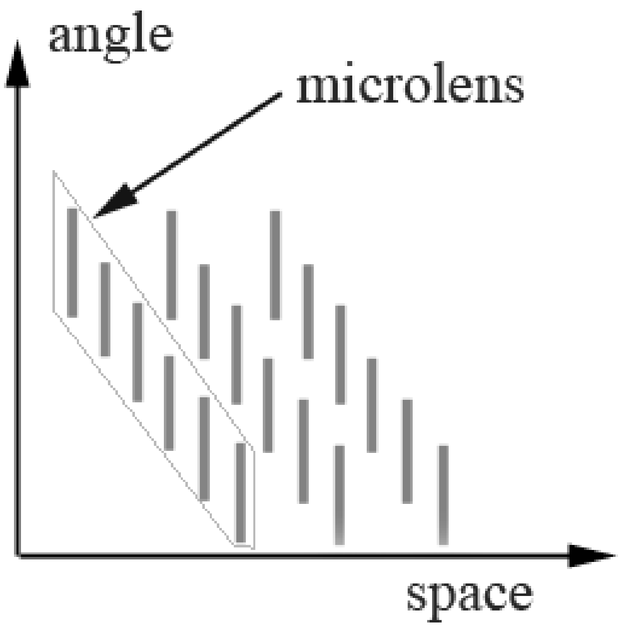
- Pixels remain "vertical". *b/a* of the sensor resolution.

Resolution analysis

- Plenoptic 1.0



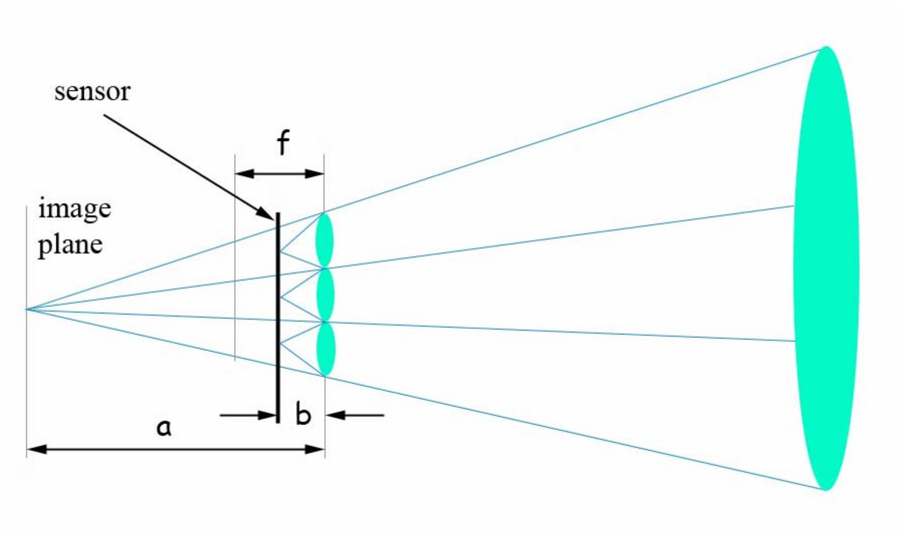
- Plenoptic 2.0



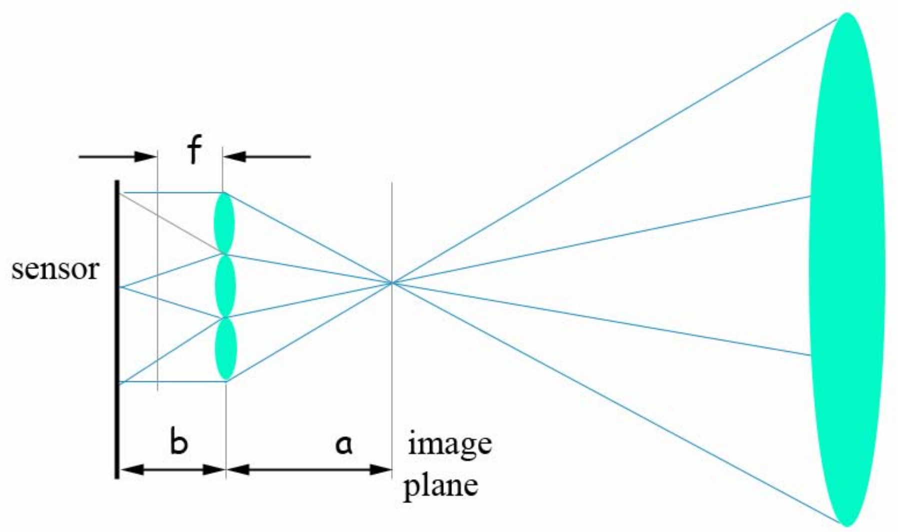
Adobe

Two Ways of Focusing

- Galilean Telescopic Array

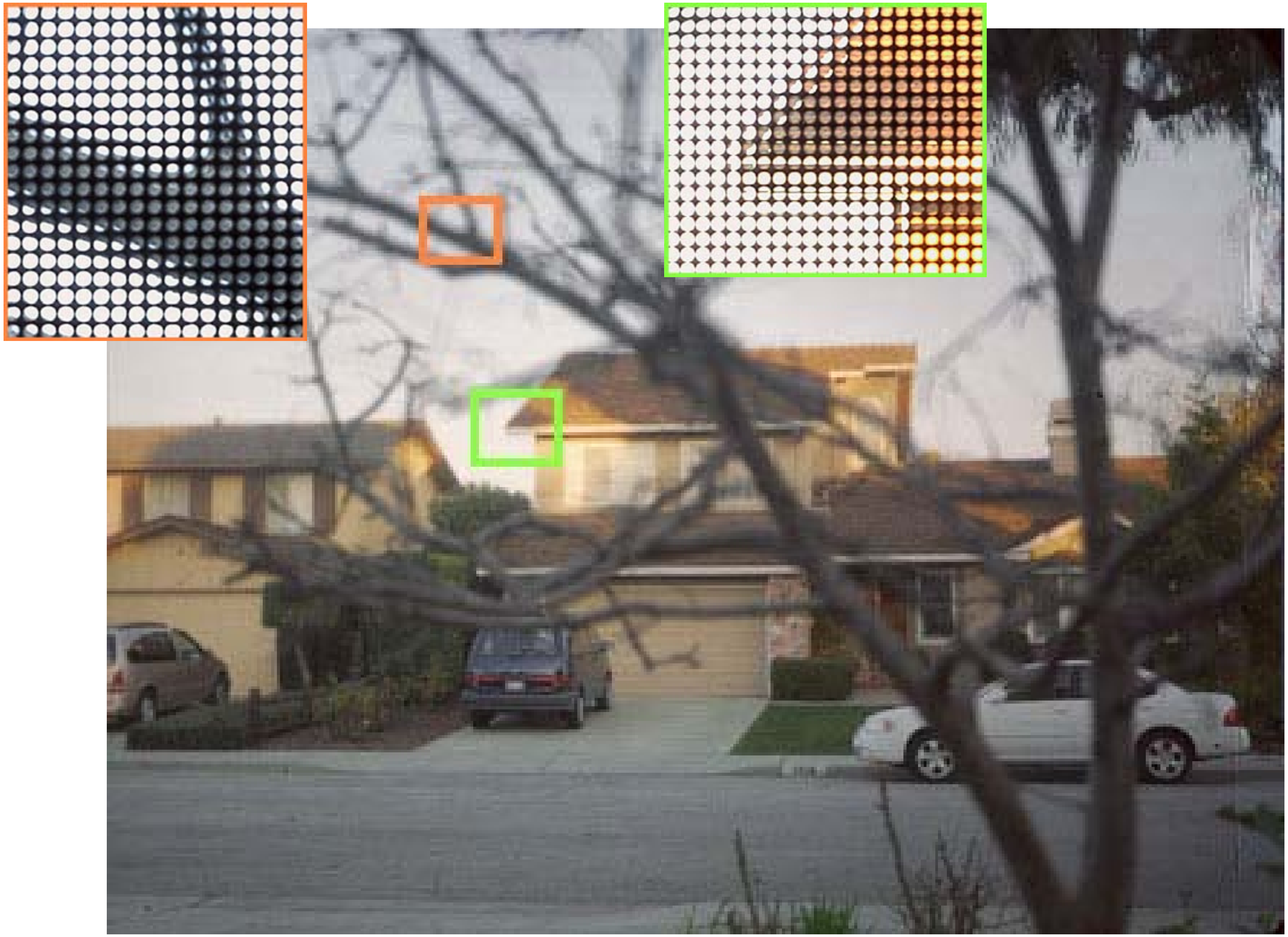


- Keplerian Telescopic Array



(Proposed by Galileo and Kepler 400 years ago)

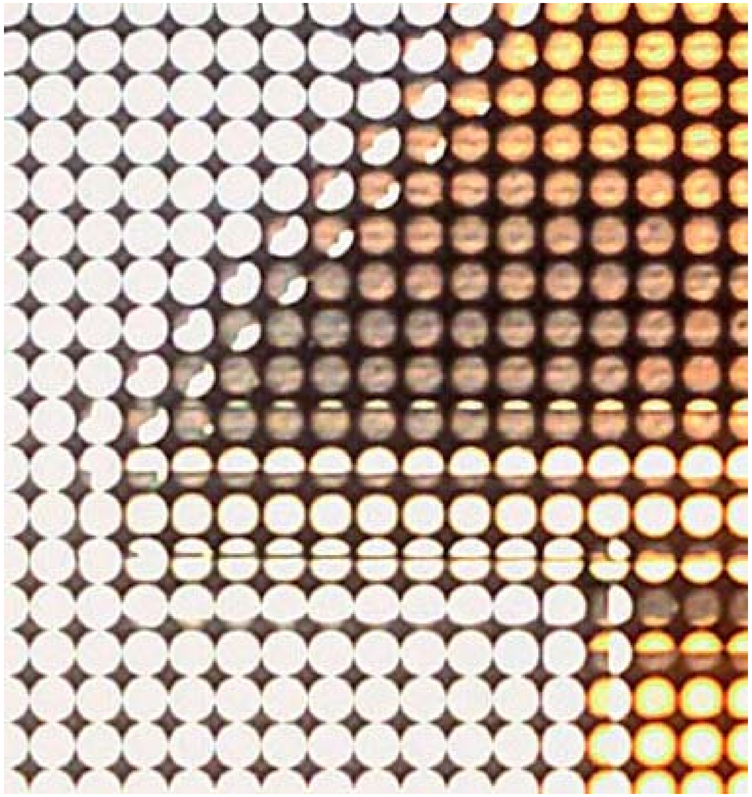
Two Ways of Focusing



Two Ways of Focusing

- Gaililean Imaging

- Keplerian Imaging



Plenoptic 2.0 Refocusing

Plenoptic 2.0 Refocusing

Plenoptic 2.0 Refocusing

Plenoptic 2.0 Resolution

- Plenoptic 2.0 sampling is more flexible:
  - Decouples resolution from number of microlenses.
  - Free to choose the spatial-angular tradeoff point.

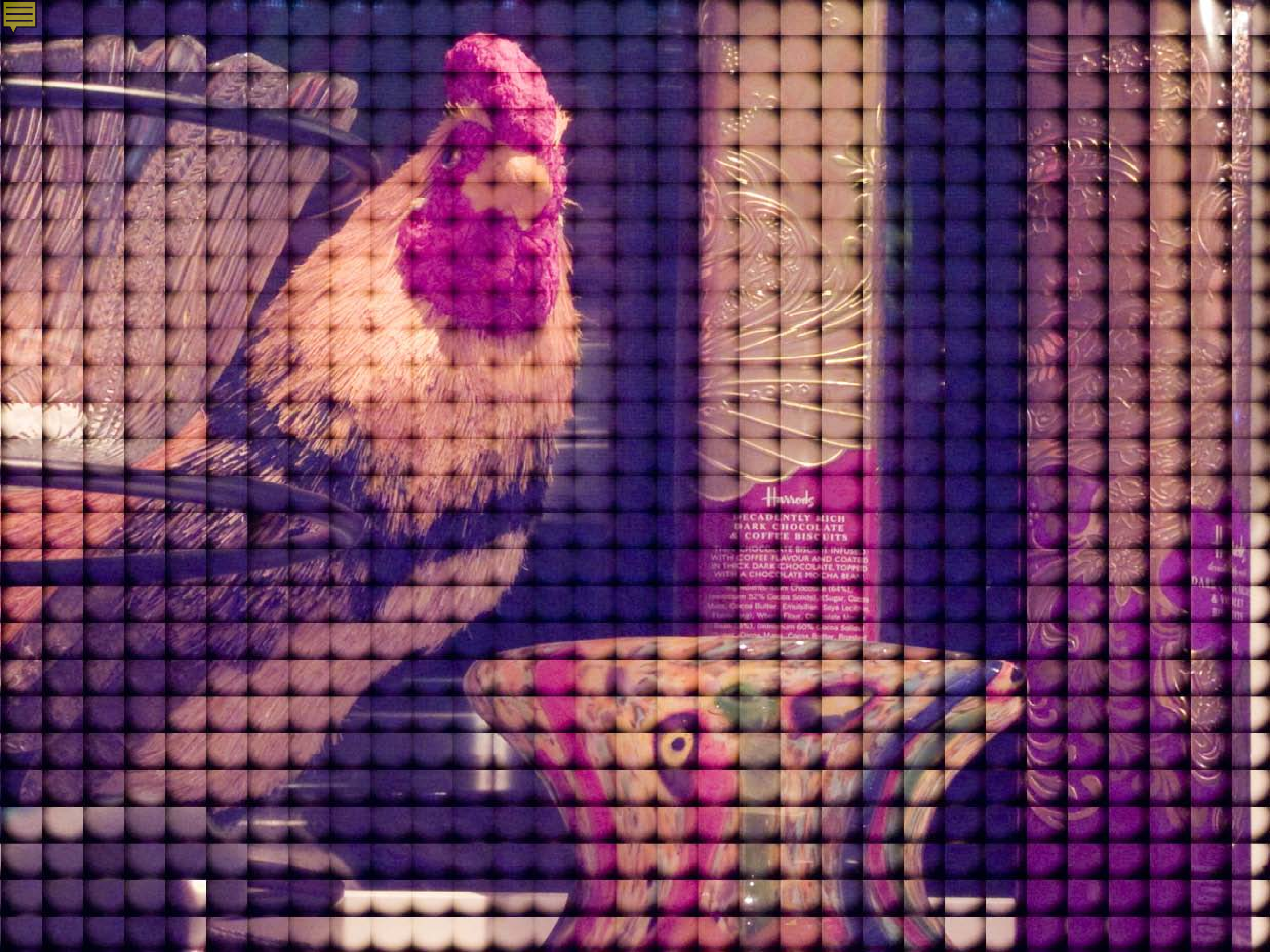
- We can actually reach very low angular resolution not possible with traditional plenoptic camera (because edge effects would introduce noise).
  - Stereo 3D.

- Up to b/a of the sensor resolution can be achieved!
- This is up to 100%, i.e. full sensor resolution!

Full Sensor Resolution Plenoptic Camera

- Demonstrating image capture with a plenoptic camera and rendering at full sensor resolution:

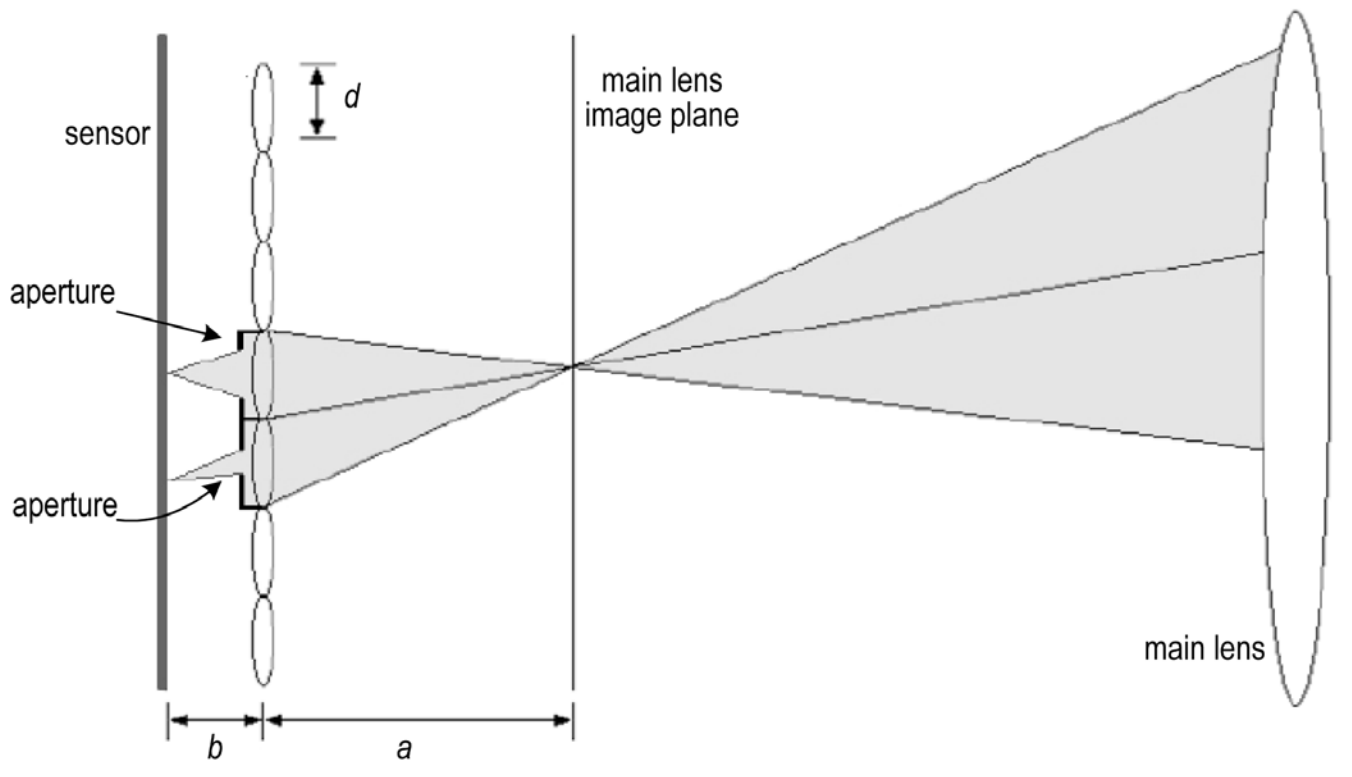
- 39 megapixel capture
- 39 megapixel rendering


Harrods
DARK CHOCOLATE
& COFFEE BISCUITS
WITH COFFEE FLAVOUR AND COATED

Plenoptic HDR Camera

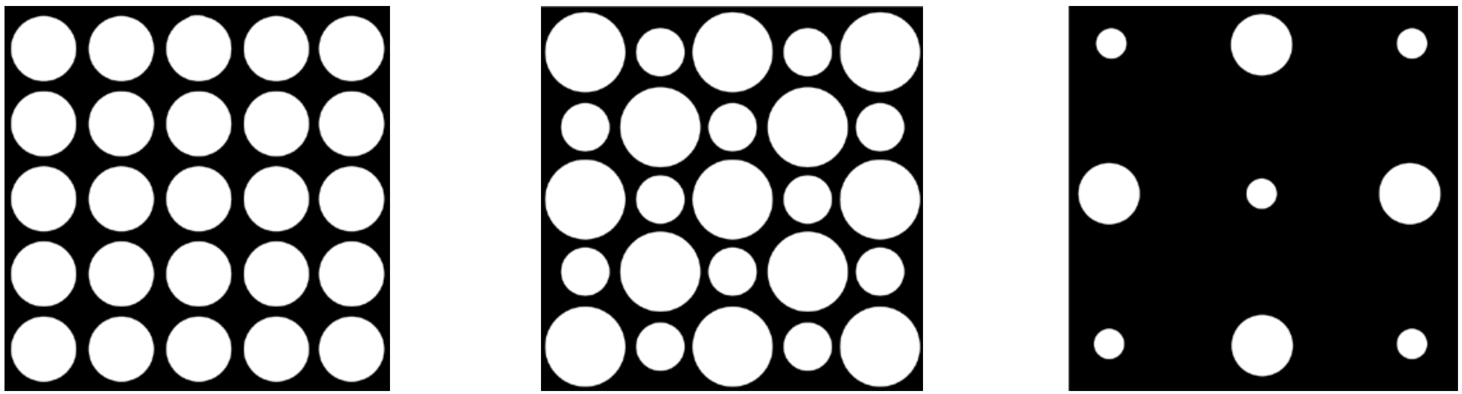
HDR with Plenoptic Camera 2.0

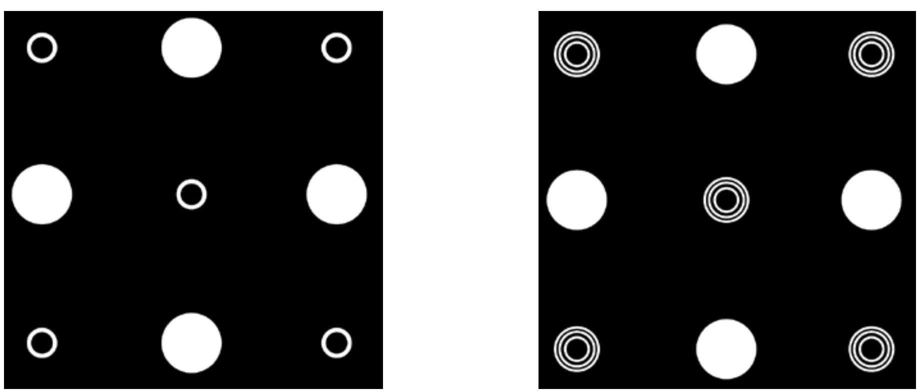
- Each point is seen multiple times in different microlenses
- We can put different apertures on different microlenses



HDR with Plenoptic Camera 2.0

- We can put different apertures on different microlenses

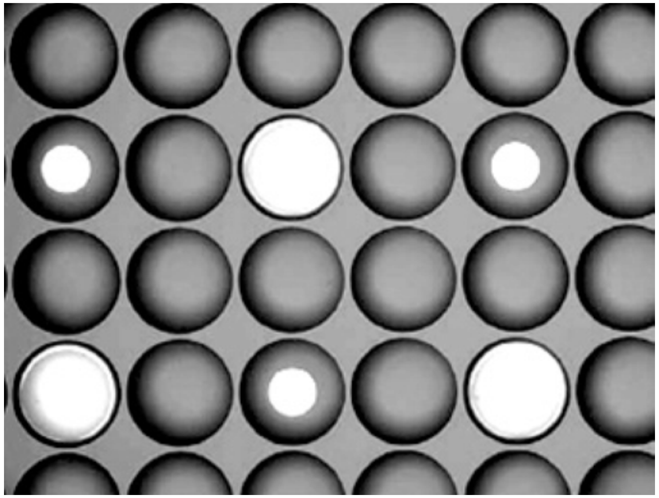




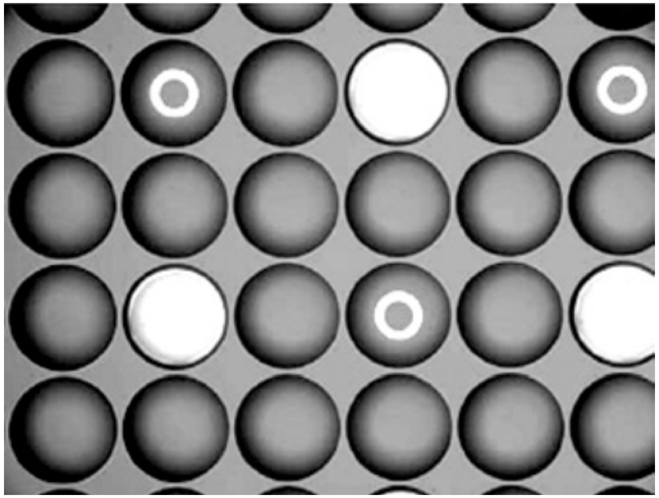
← Fresnel zones as aperture

HDR with Plenoptic Camera 2.0

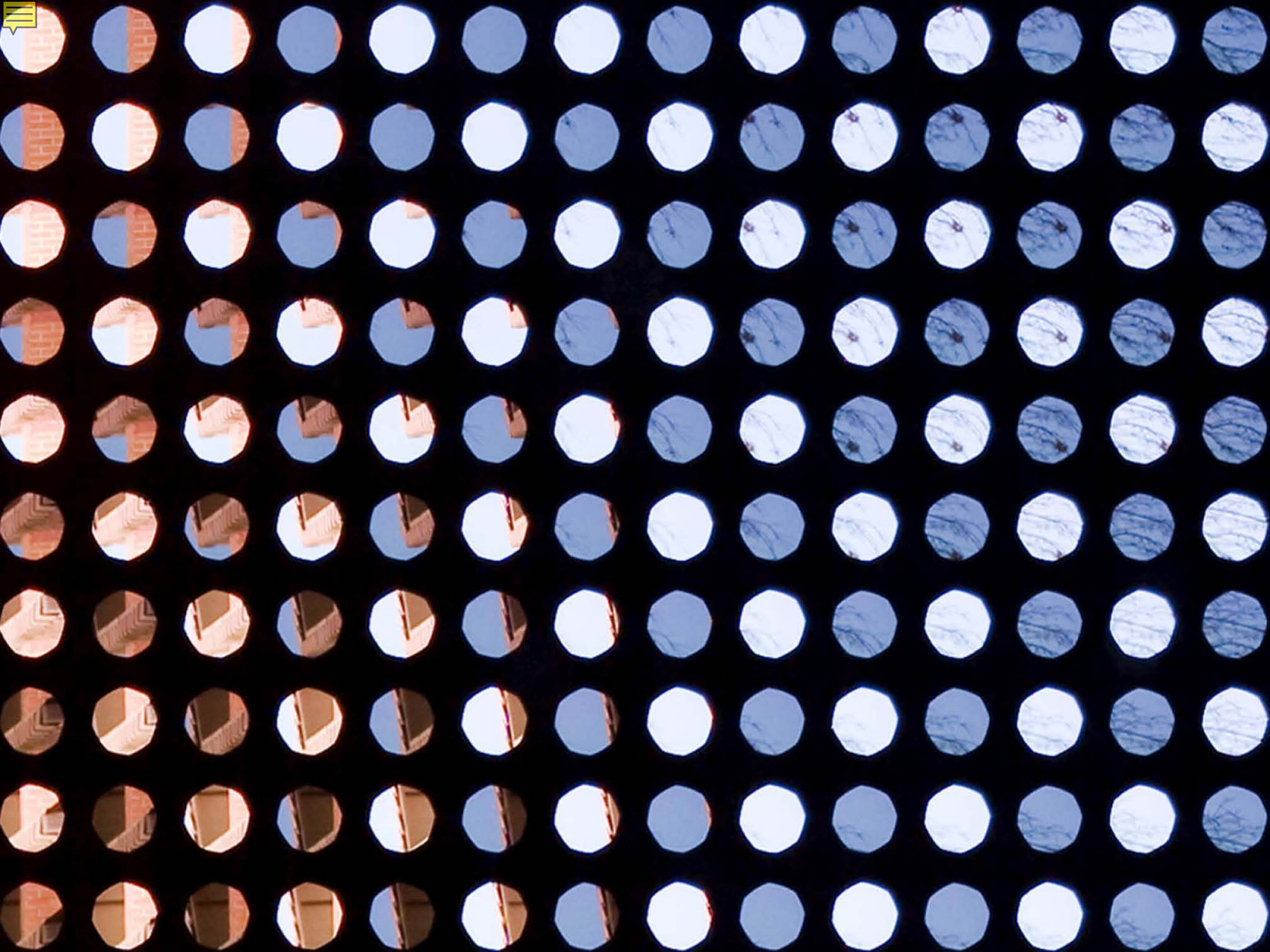
- Two of our microlens arrays under the microscope



4 times reduction of aperture



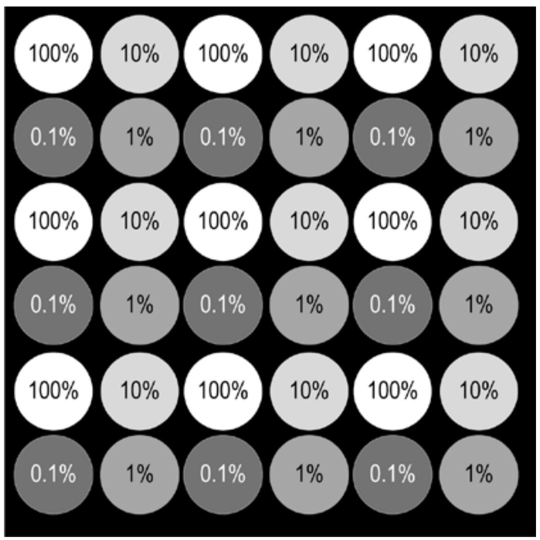
8 times reduction of aperture

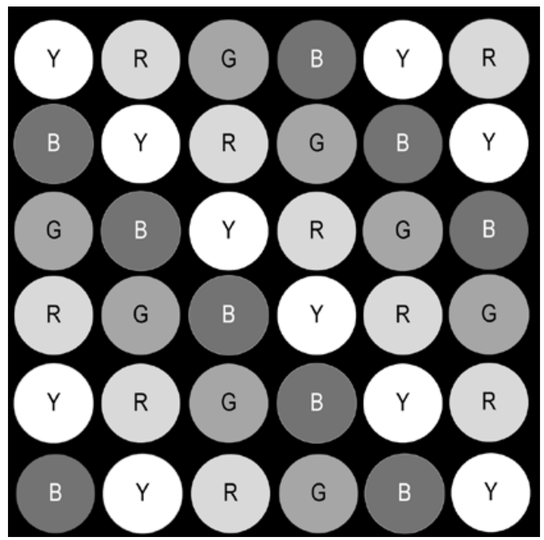


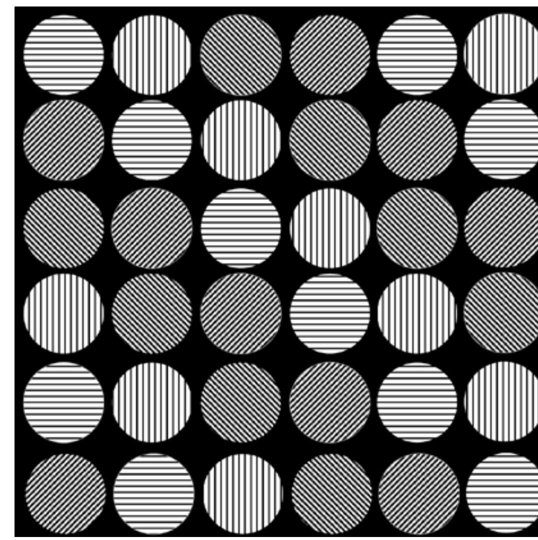
HDR with Plenoptic Camera 2.0

- We can put different filters on different microlenses:

Neutral density, color (for spectral imaging), polarization.







1000 X increase in dynamic range

12-color imaging with RGB sensor

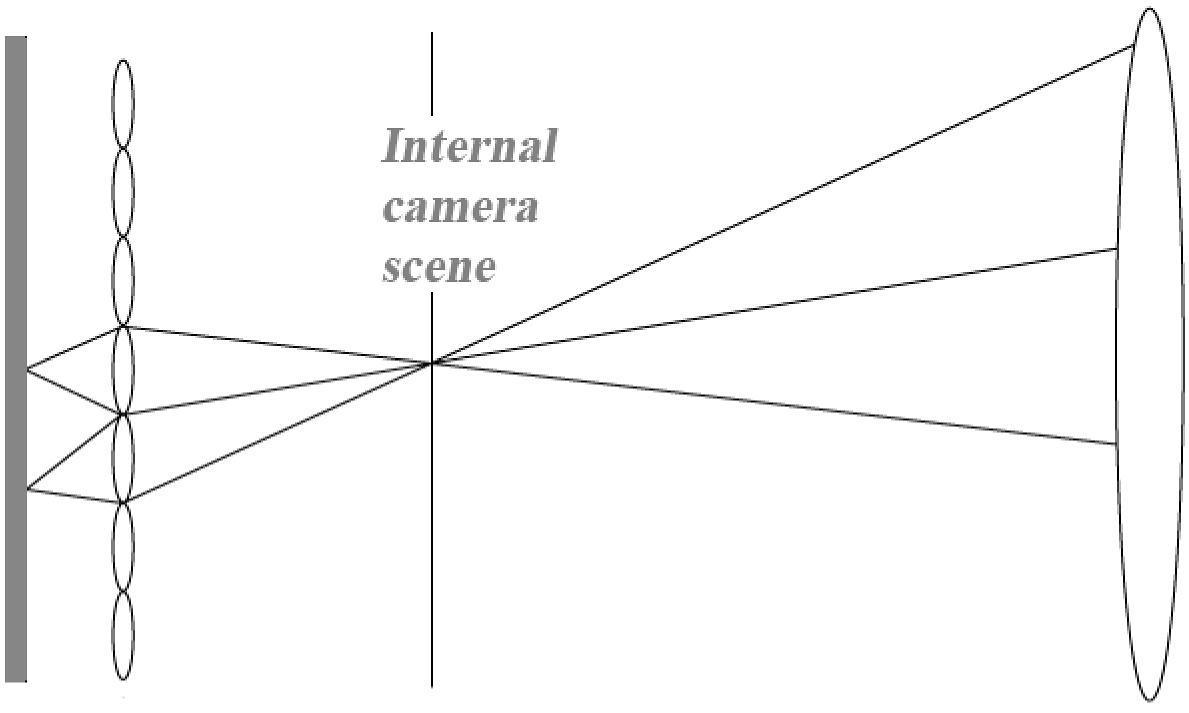
sampling four linear polarizations

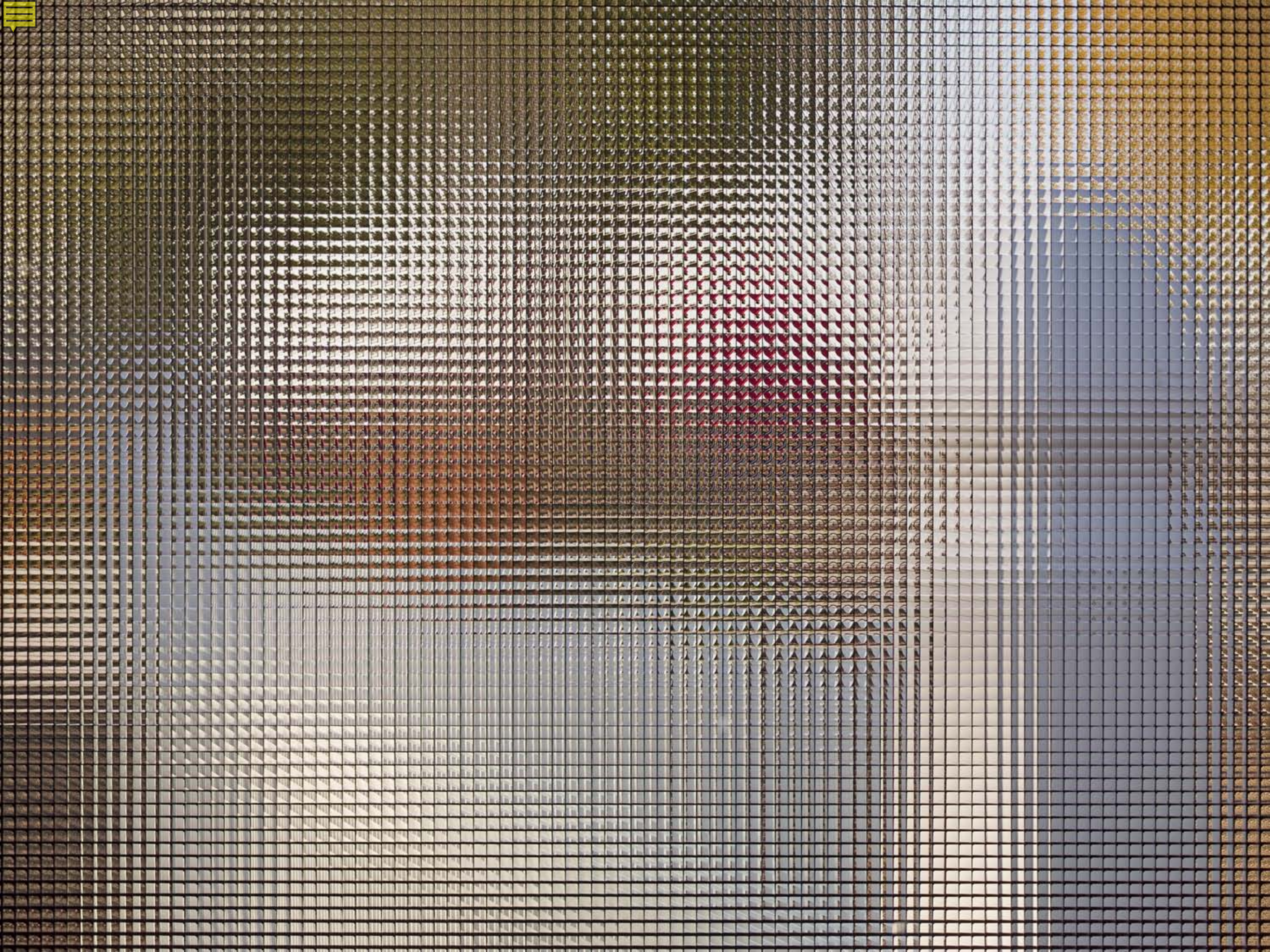
Adobe

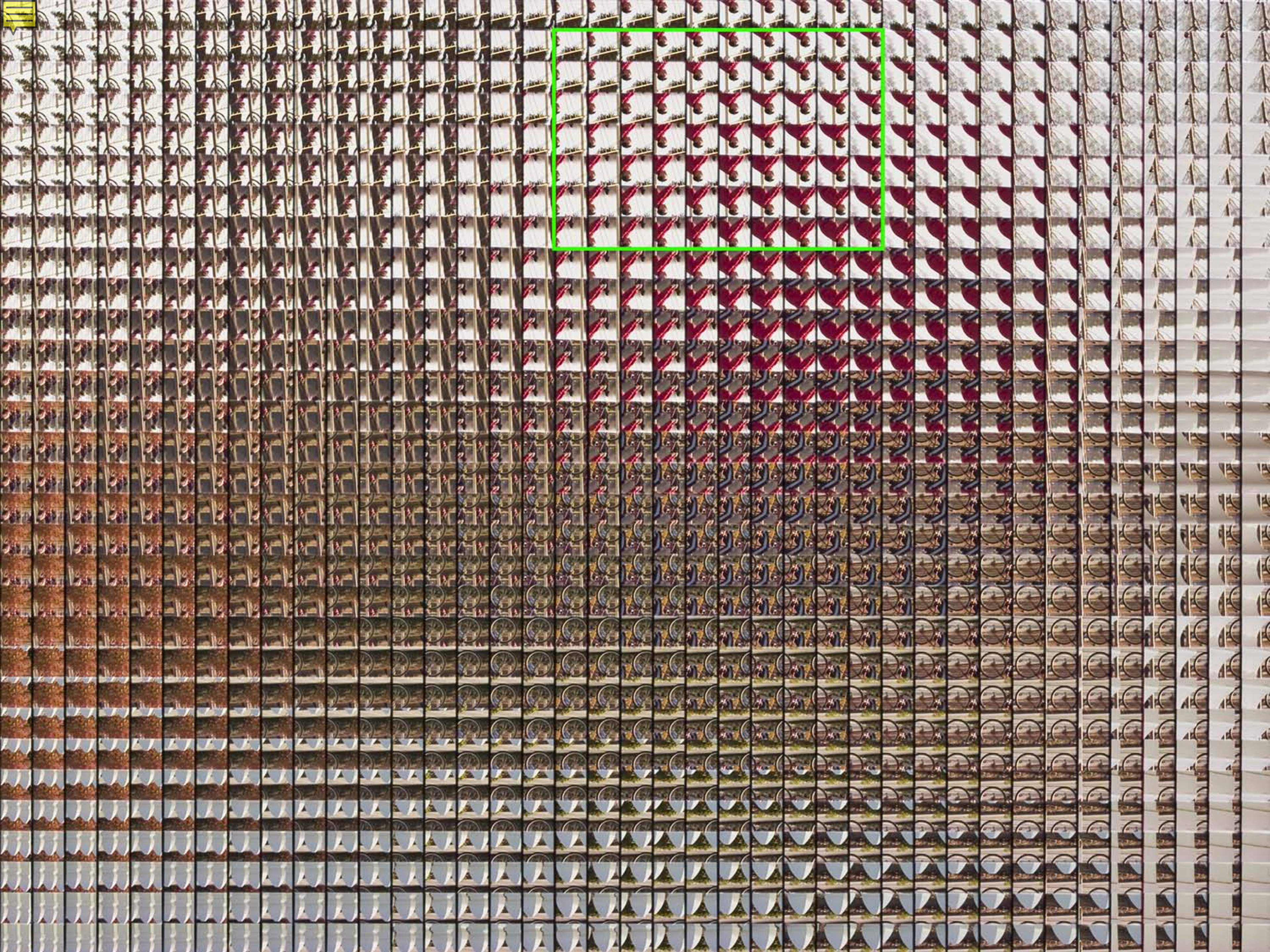
Plenoptic Superresolution Camera

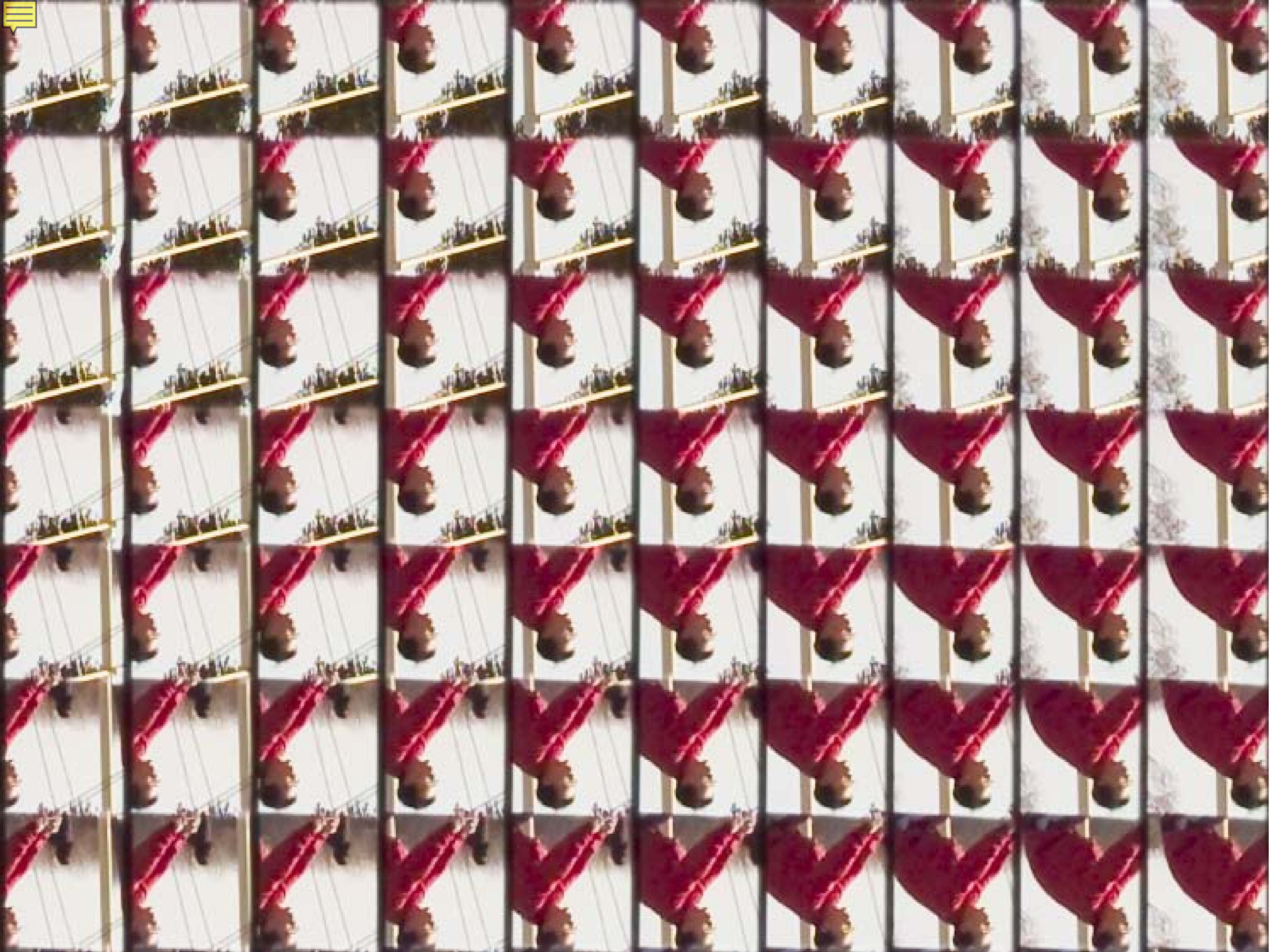
Superresolution with Plenoptic Camera 2.0

- Each microlens is observing the scene as a slightly shifted camera. We can compute the subpixel shift based on camera parameters. Then, superresolve.

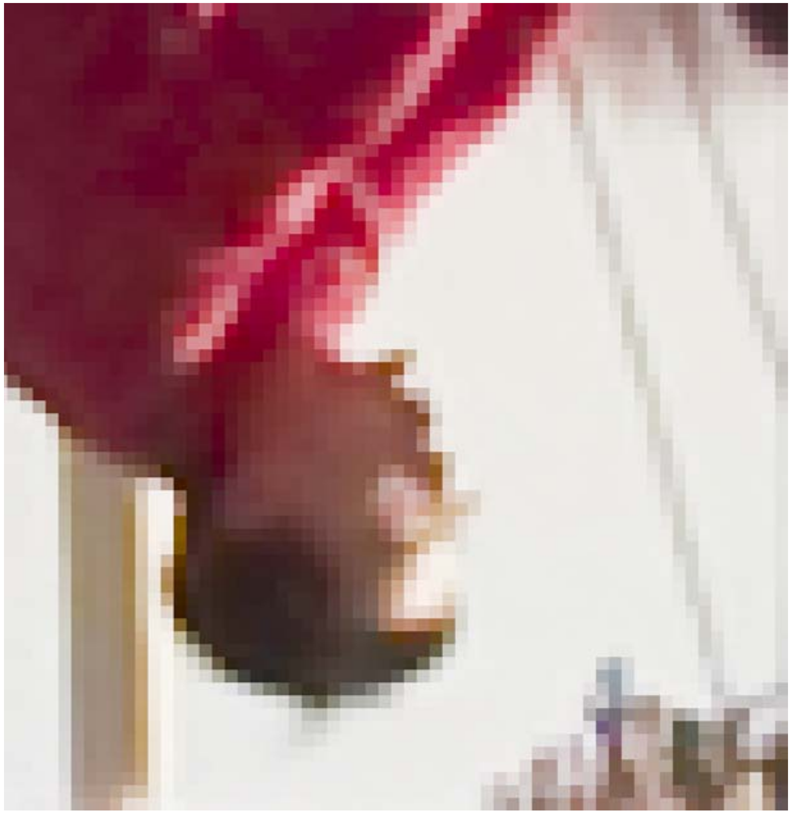






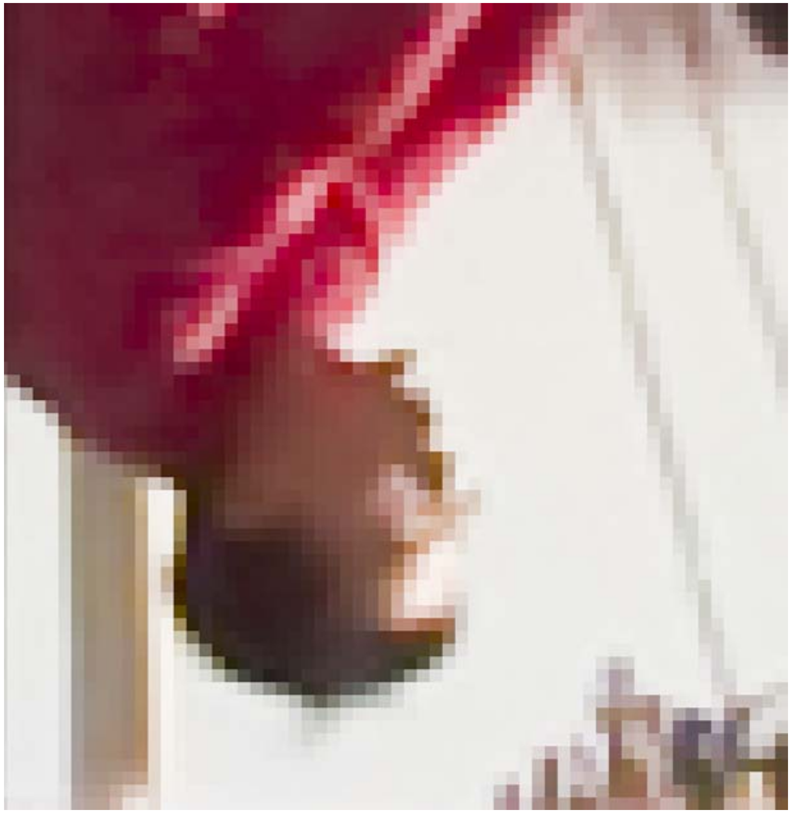


Superresolution with Plenoptic Camera 2.0



- Observe the subpixel shift

Superresolution with Plenoptic Camera 2.0



- Observe the subpixel shift

Superresolution with Plenoptic Camera 2.0

- Compare same image with traditional lifgtfield rendering (plenoptic 1.0).

Adobe