

Introduction to the Light-Field Camera

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Outline

1. Preface
2. Image Rendering
3. Light-Field History
4. Plenoptic 1.0
5. Plenoptic 2.0
6. Different Light-Field Camera
7. Conclusion

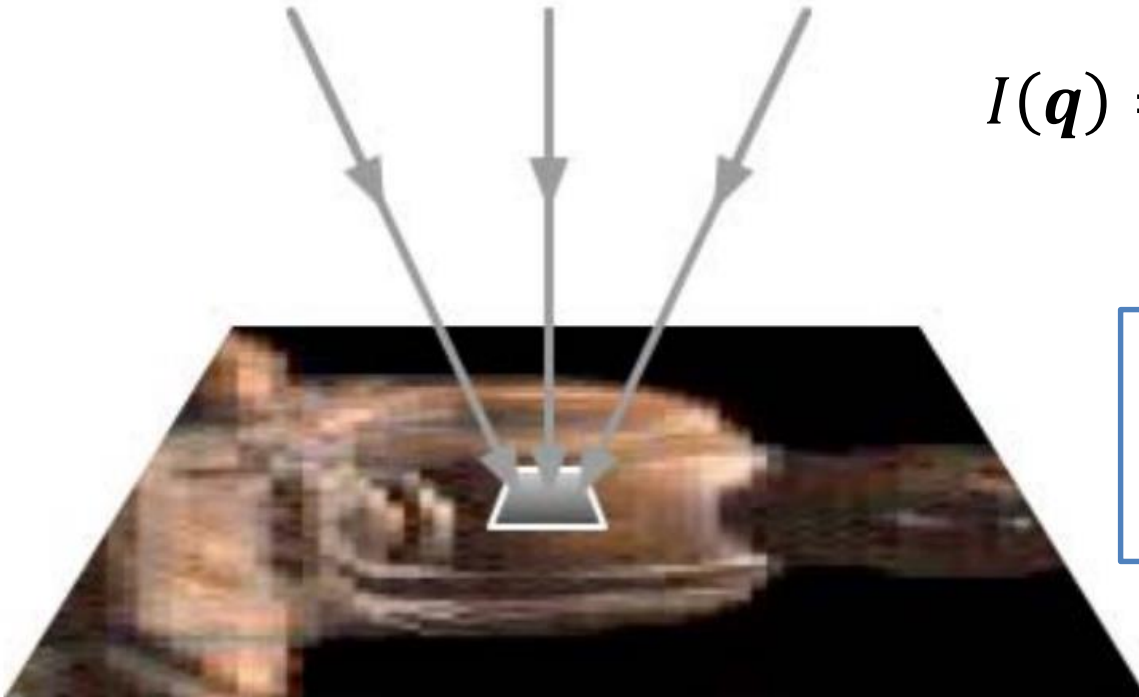
Preface – What is Light-Field Camera?

1. Website: <https://www.lytro.com/>
2. Property: Refocusing, change orientation, display photo in 3D



Image Rendering

- A tradition image is formed by integrating rays from every direction at each pixel.

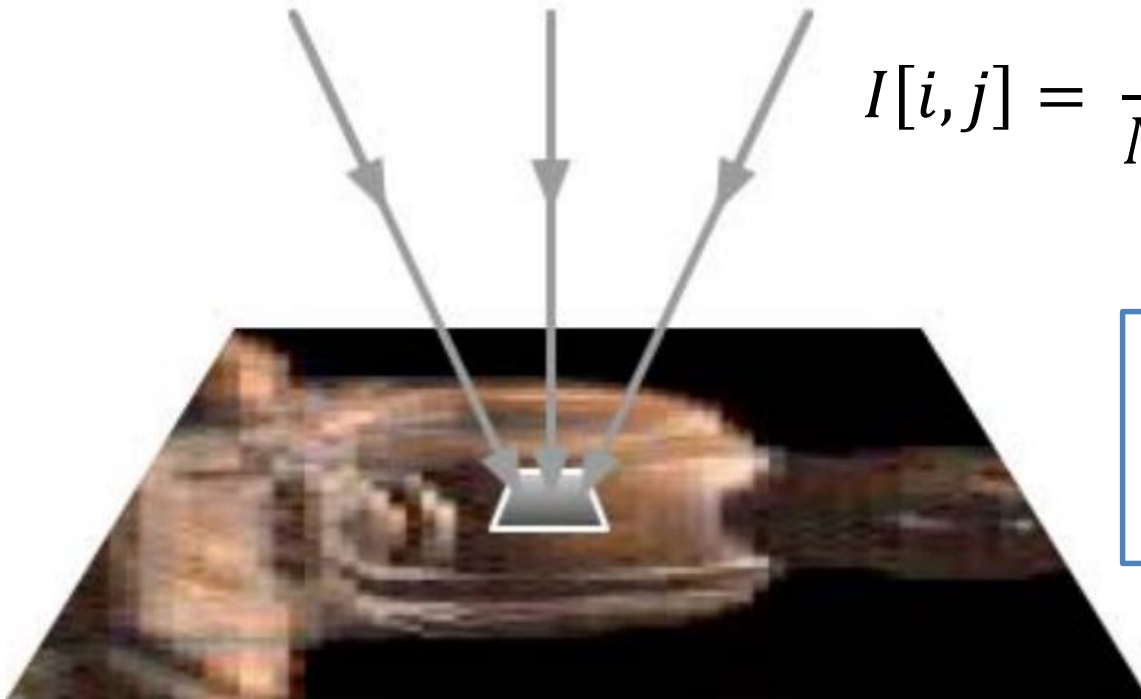


$$I(\mathbf{q}) = \int_{\mathbf{p}} r(\mathbf{q}, \mathbf{p}) d\mathbf{p}$$

\mathbf{q} : position ($\in R^2$)
 \mathbf{p} : direction ($\in R^2$)
 $r(\mathbf{q}, \mathbf{p})$: radiance
 $I(\mathbf{q})$: pixel value

Image rendering

- A tradition image is formed by integrating rays from every direction at each pixel.

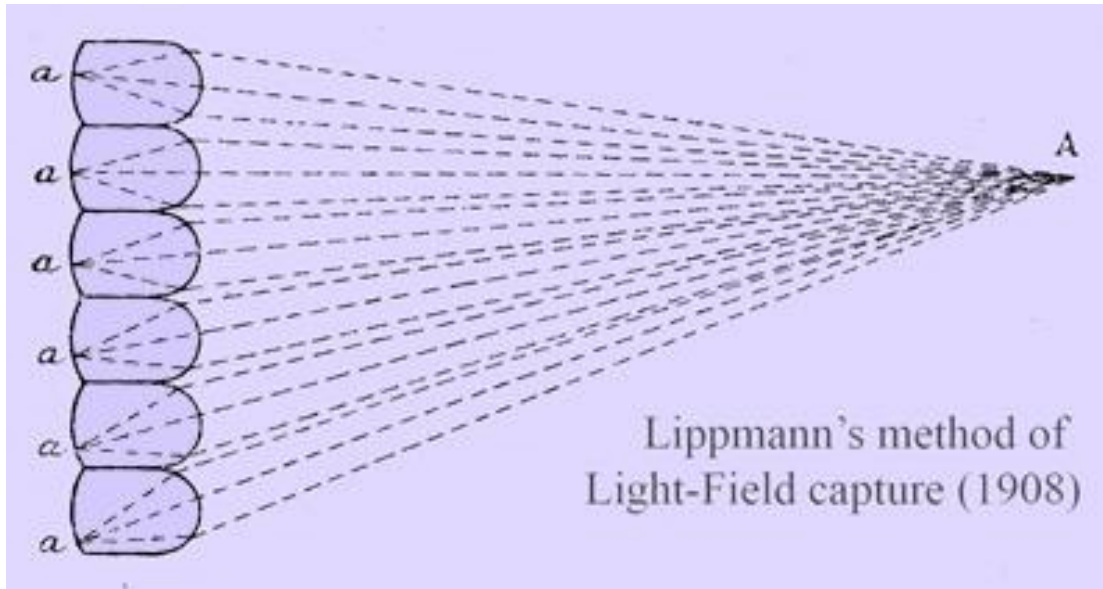


$$I[i, j] = \frac{1}{N^2} \sum_m \sum_n r[i, j, m, n]$$

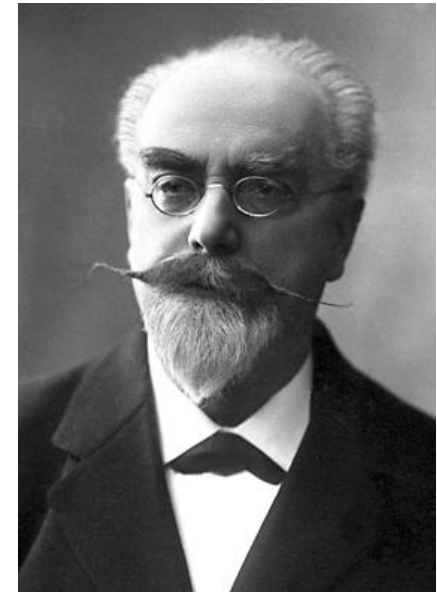
i, j : position
 m, n : direction
 $r(i, j, m, n)$: radiance
 $I[i, j]$: pixel value

Light-Field History

- The first light-field camera – 1908 Lippmann's Integral Photographs



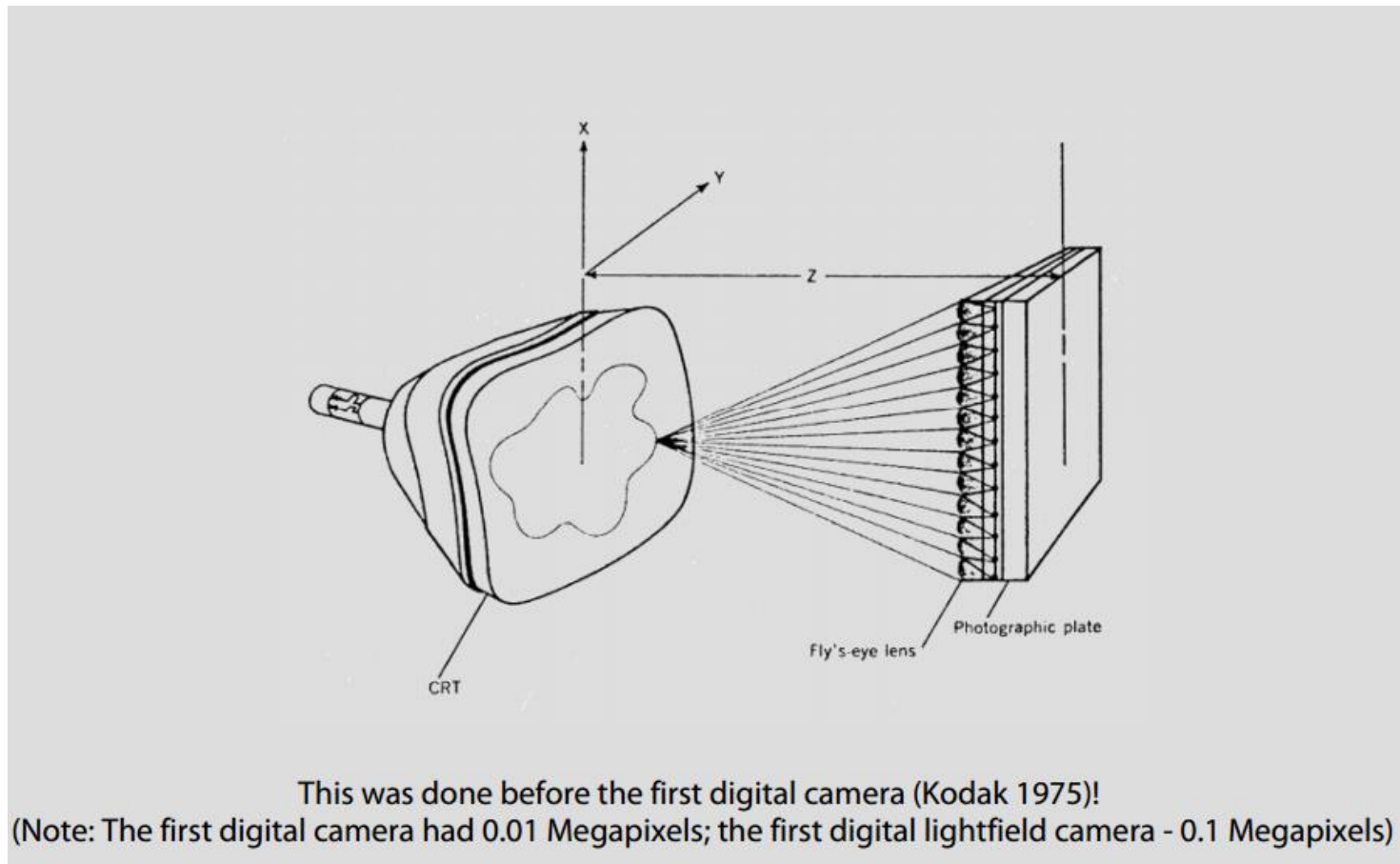
Lippmann's Integral Photographs



Lippmann

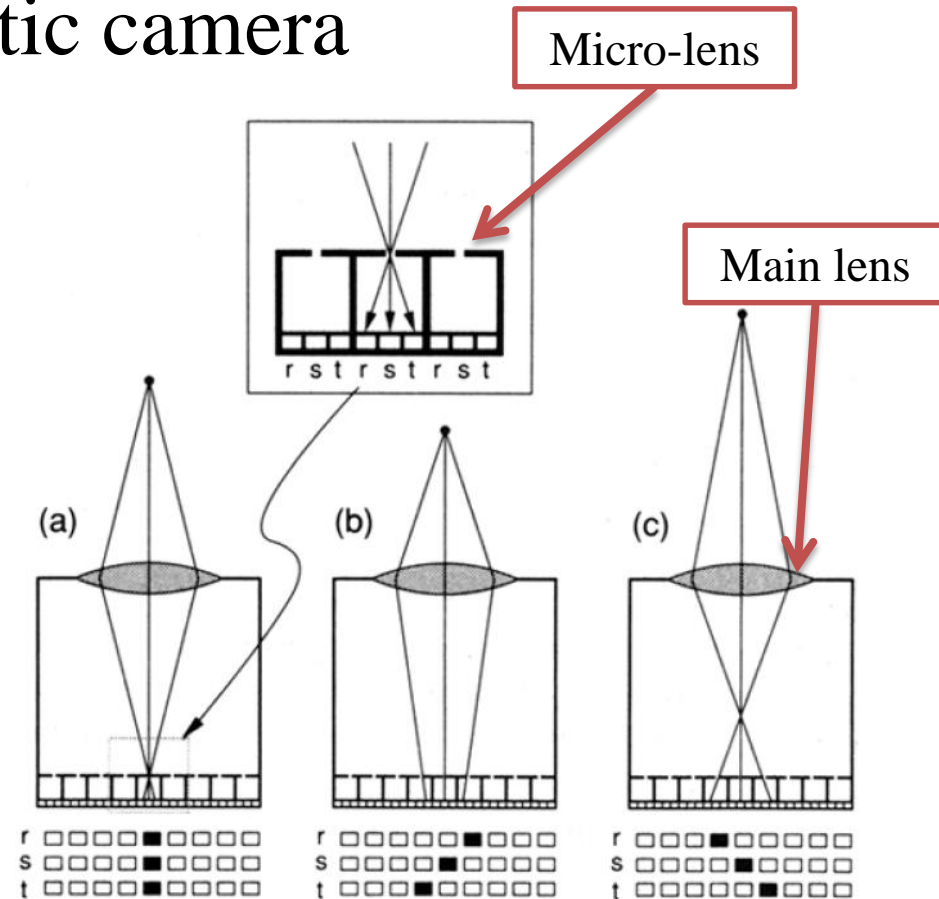
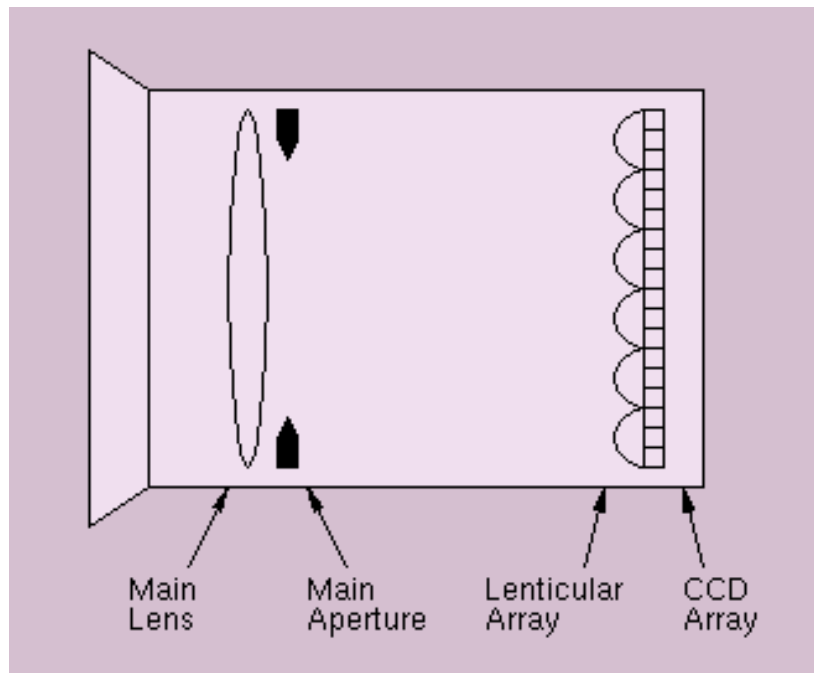
Light-Field History

- 1968 Chutjian (First Digital Light-Field)



Light-Field History

- 1992 Adelson - Plenoptic camera

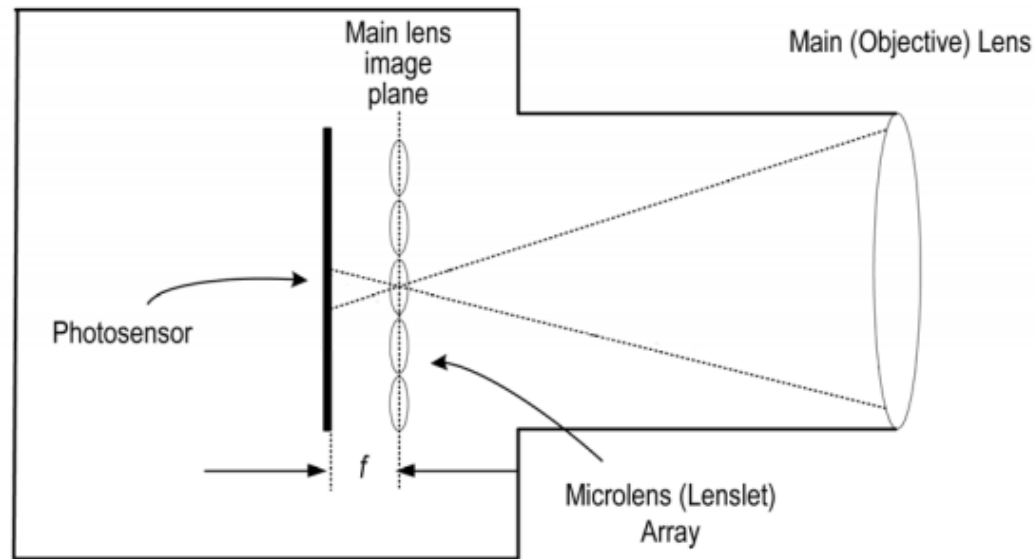


[1] Adelson, E. H., Wang, J. Y. "Single lens stereo with a plenoptic camera". *IEEE TPAMI*, 14(2), 99-106, 1992.

Plenoptic 1.0

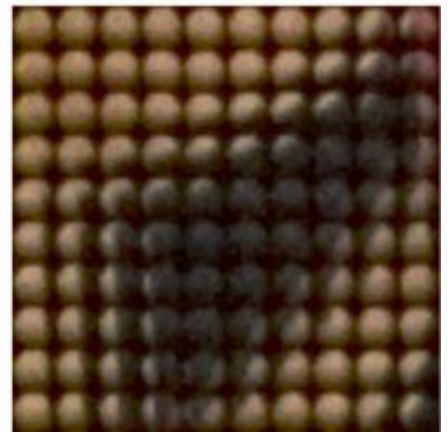
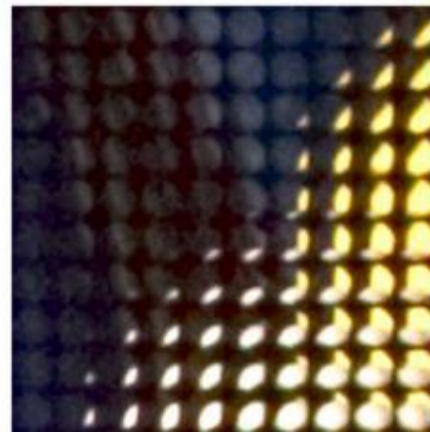
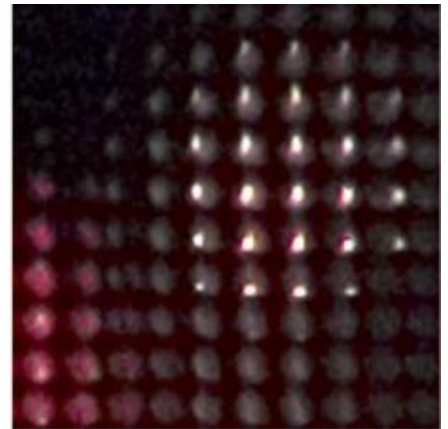
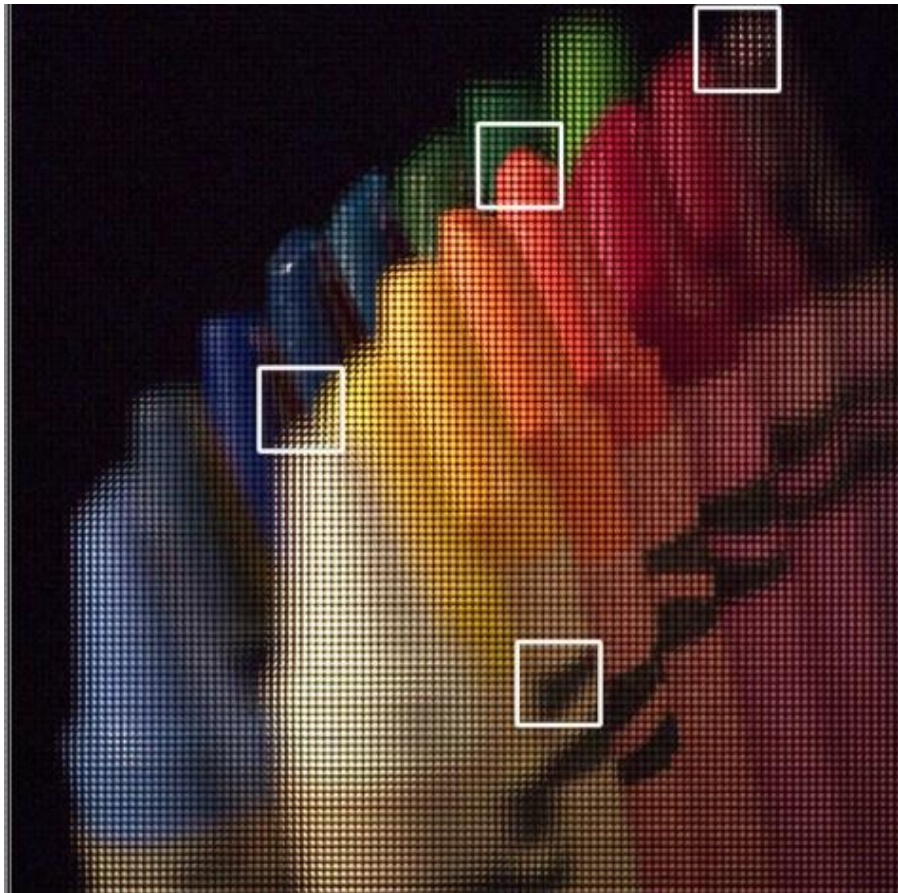
- Main lens focused on micro-lens, micro-lens focused on infinity

Conventional plenoptic camera



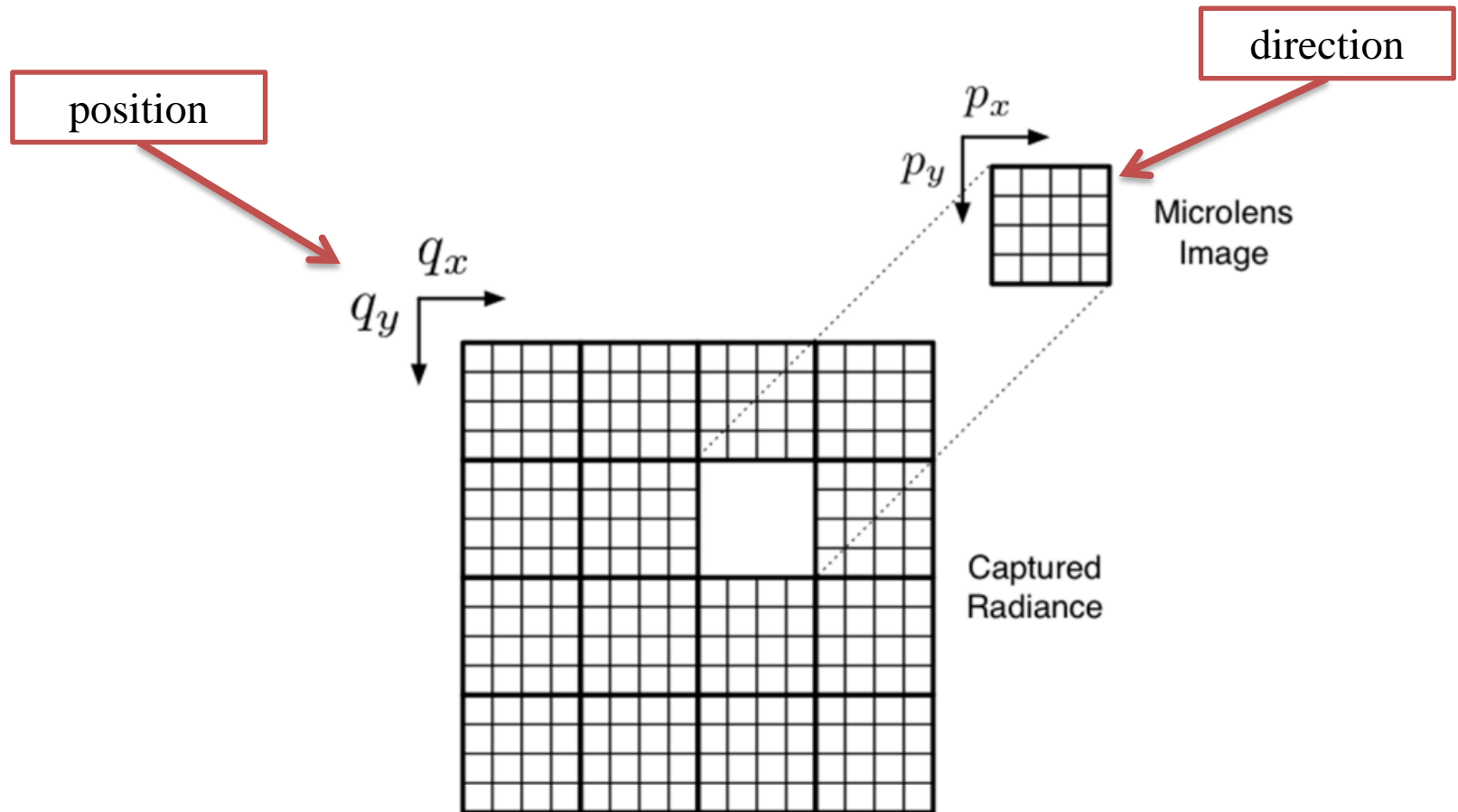
Plenoptic 1.0

- Raw data



Plenoptic 1.0

- Plenoptic image is a flat 2D array of 2D arrays



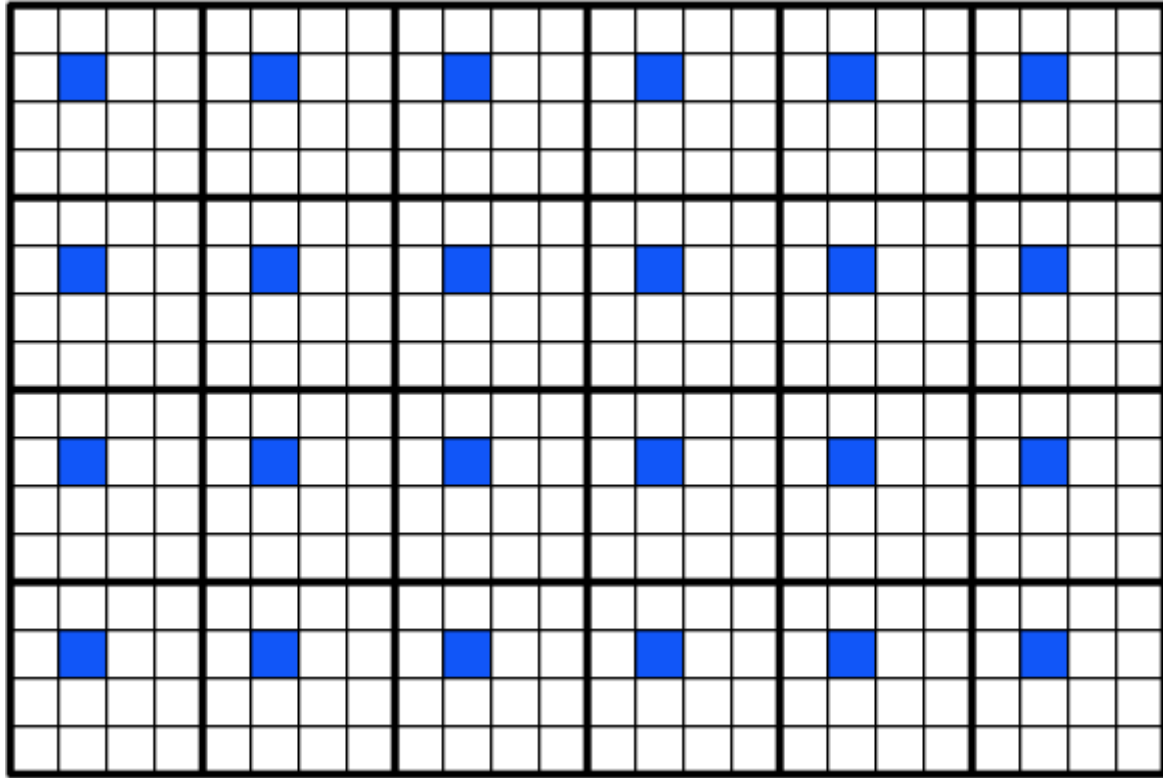
Plenoptic 1.0 - Rendering

- Light-field rendering



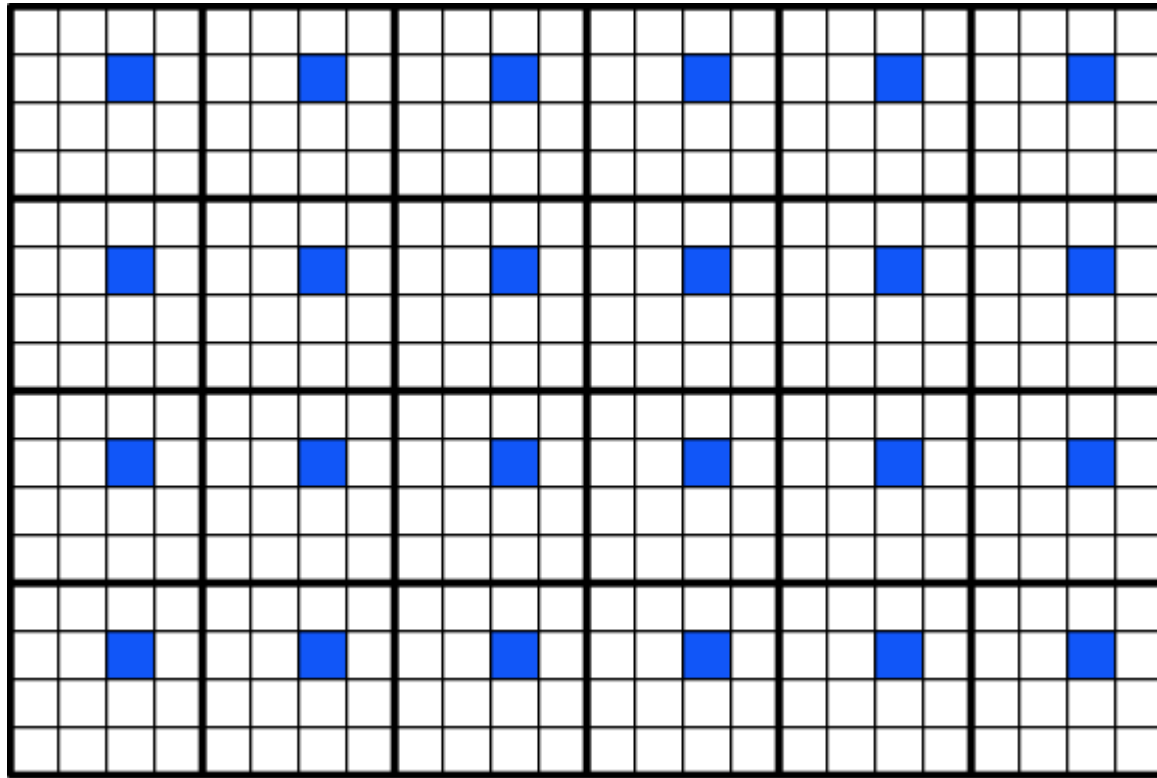
Plenoptic 1.0 - Rendering

- Render different viewpoint



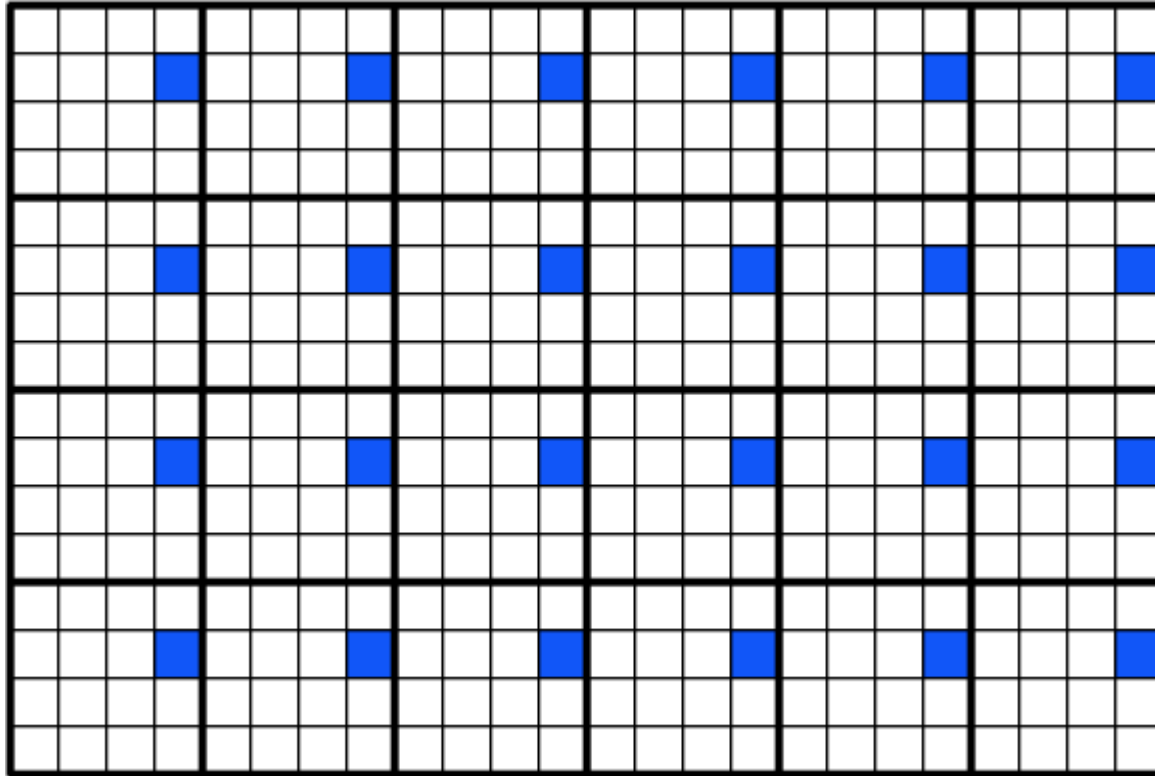
Plenoptic 1.0 - Rendering

- Render different viewpoint



Plenoptic 1.0 - Rendering

- Render different viewpoint



Plenoptic 1.0 - Rendering

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Plenoptic 1.0 - Rendering

- Render different viewpoint



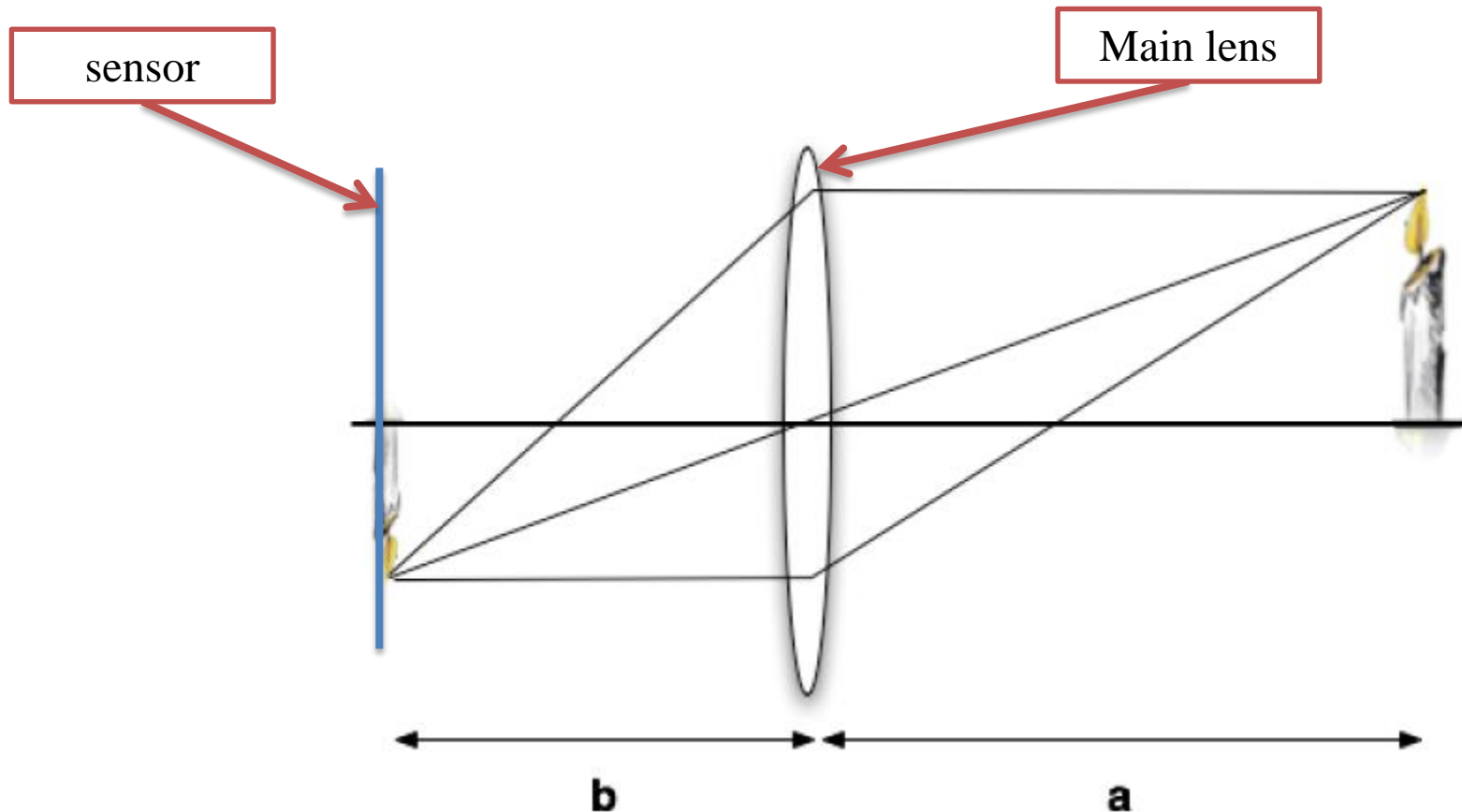
Plenoptic 1.0 - Rendering

- Render different viewpoint



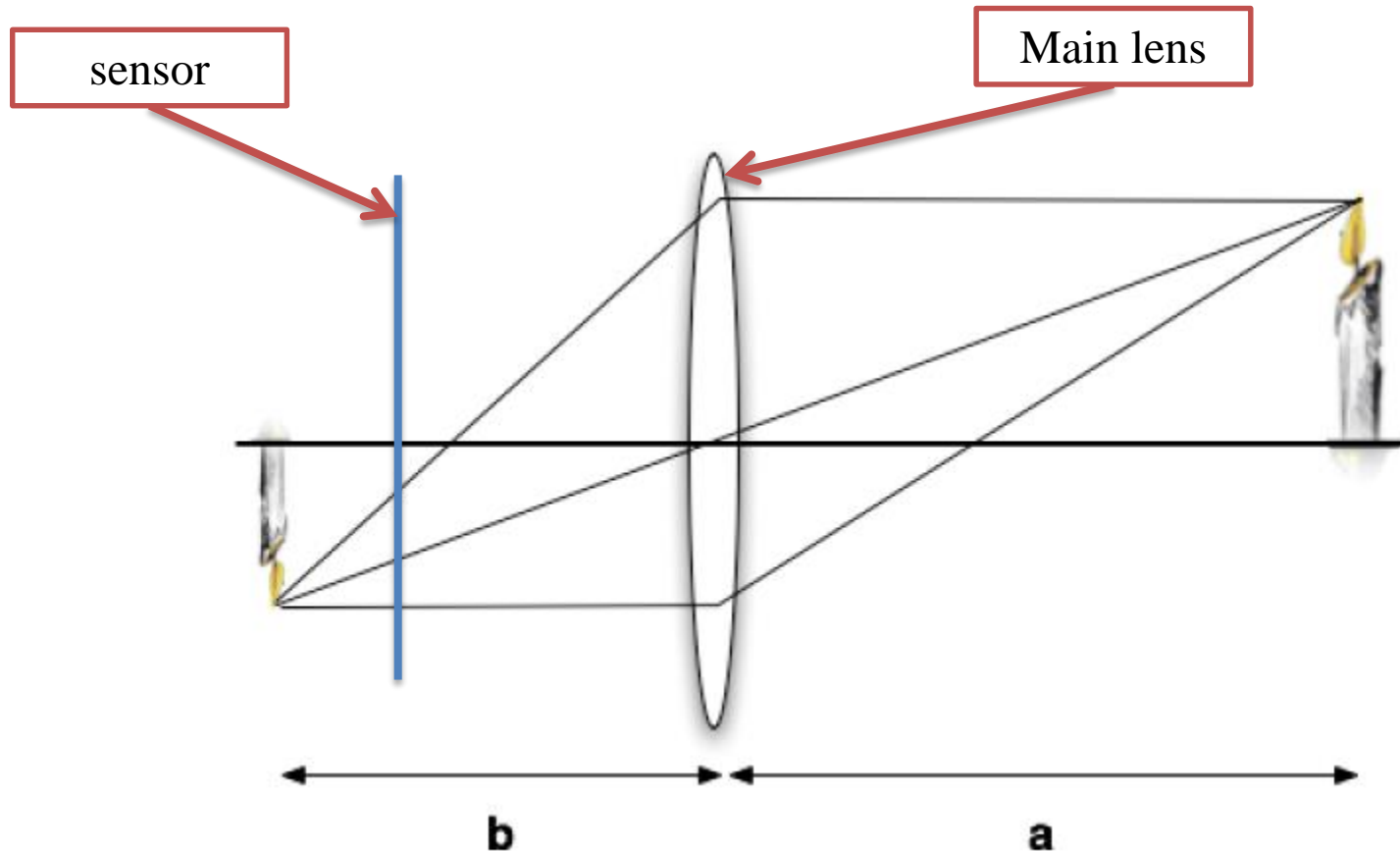
Plenoptic 1.0 - Refocusing

- Change the distance from the lens to the sensor



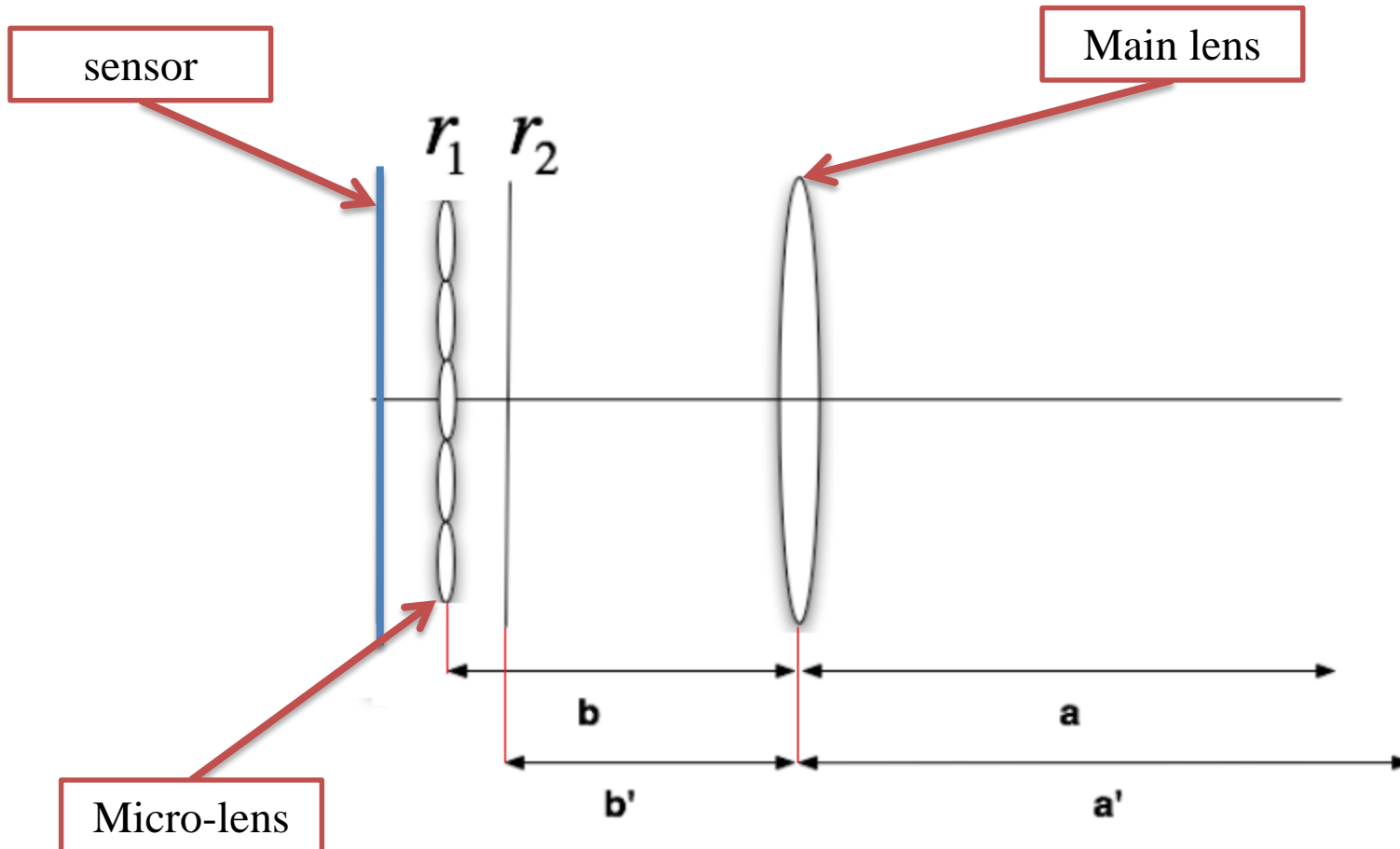
Plenoptic 1.0 - Refocusing

- Change the distance from the lens to the sensor



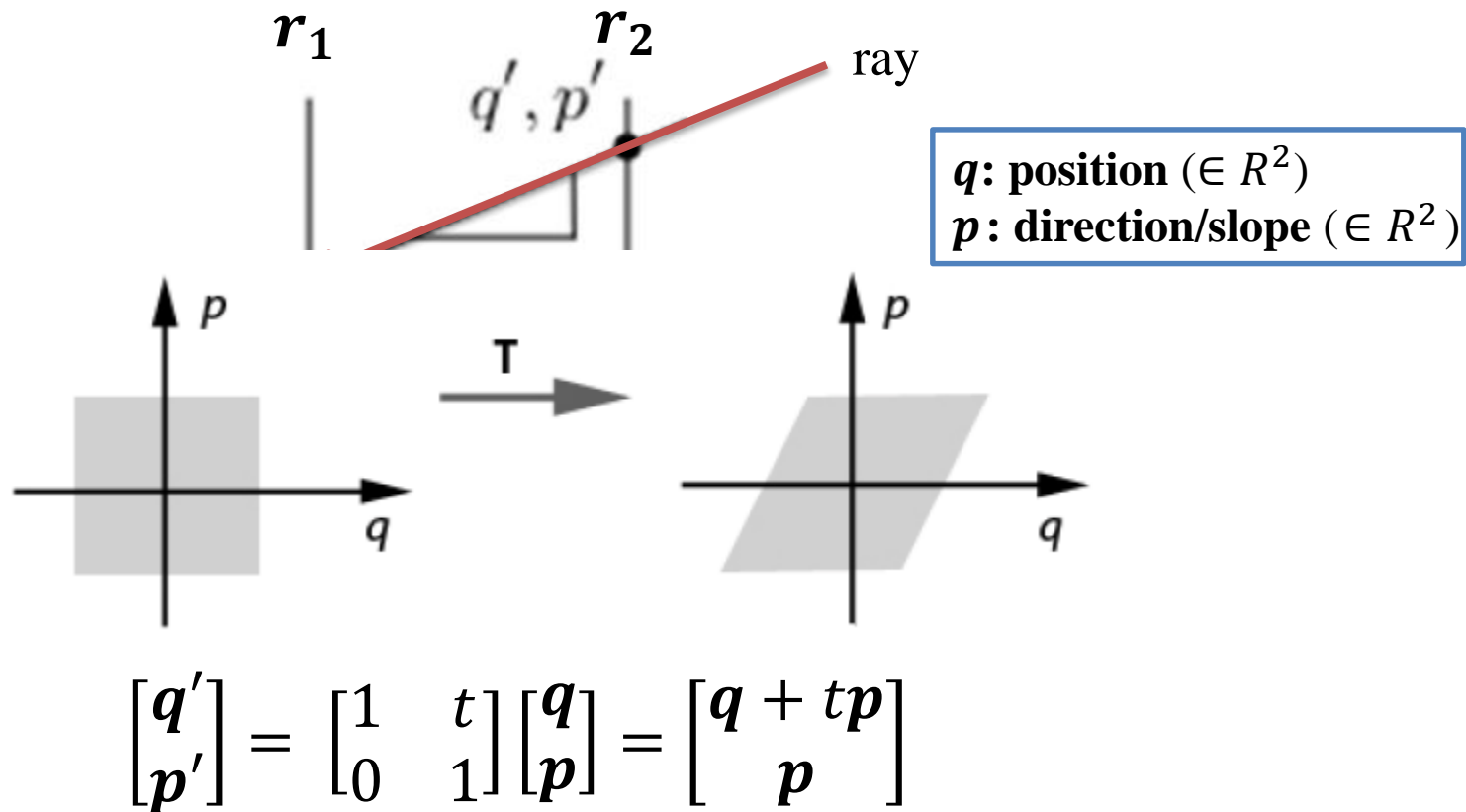
Plenoptic 1.0 - Refocusing

- We capture radiance r_1 . How to compute r_2 ?



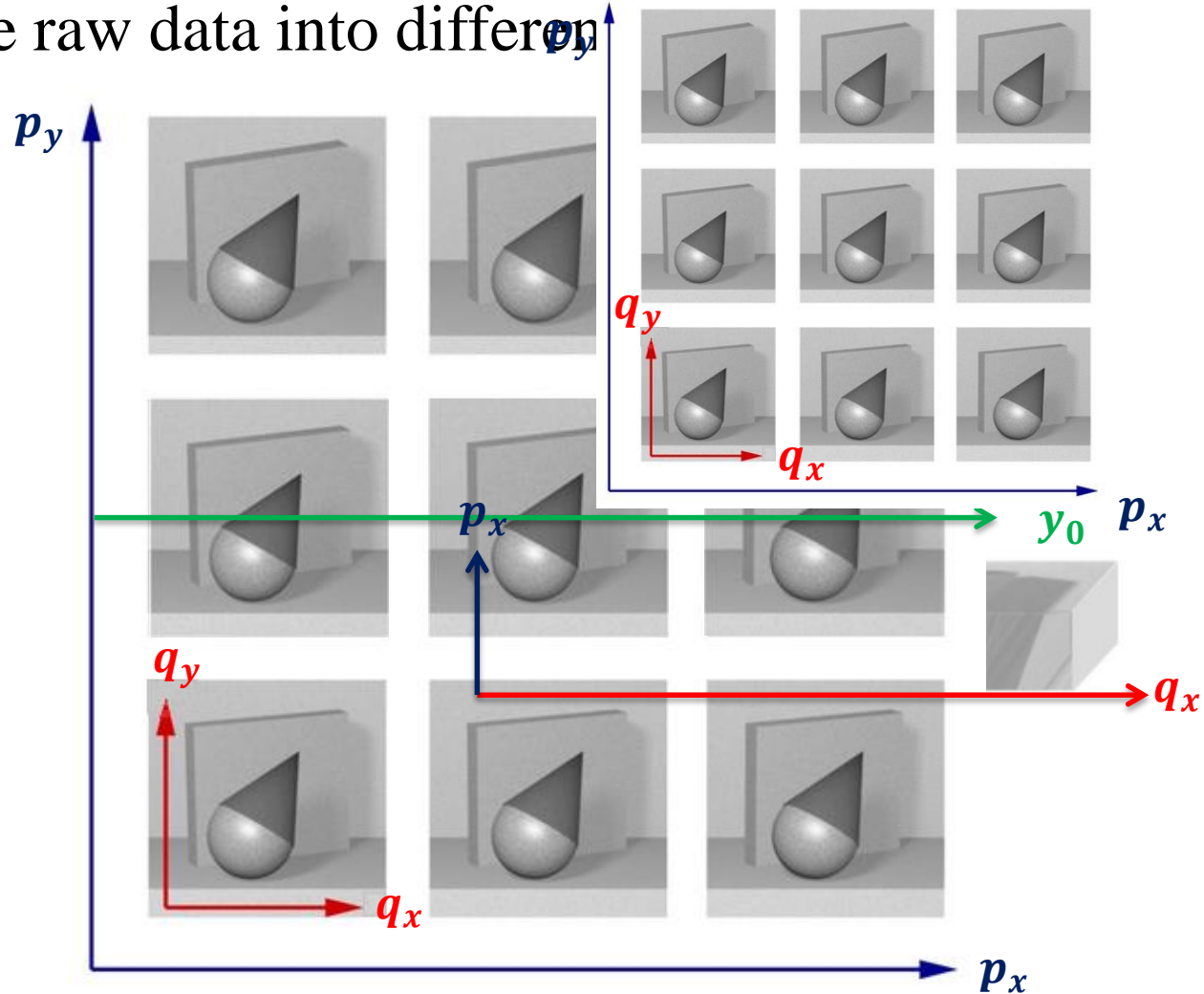
Plenoptic 1.0 - Refocusing

- Ray travels distance t through space
- Refocusing is shearing transform: $r'(\mathbf{q}', \mathbf{p}') = r(\mathbf{q} + t\mathbf{p}, \mathbf{p})$



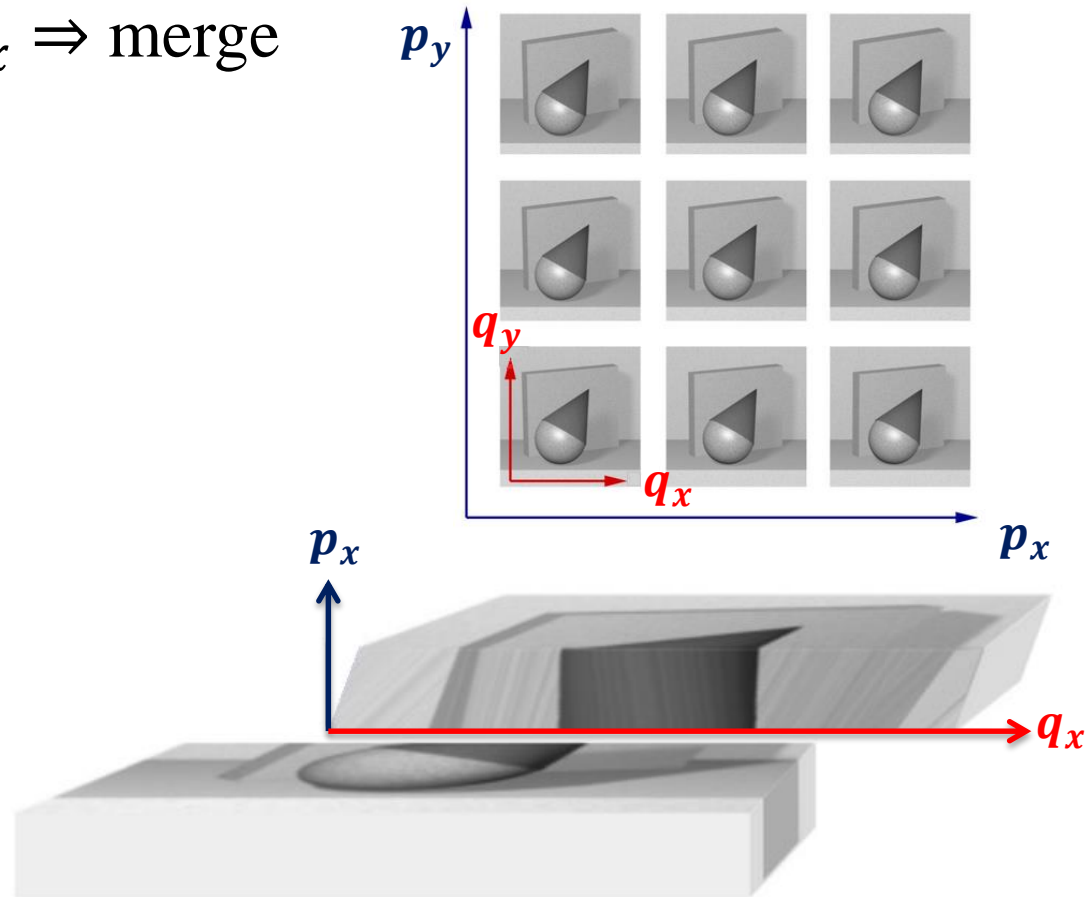
Plenoptic 1.0 - Refocusing

- Separate raw data into different **by**



Plenoptic 1.0 - Refocusing

- Shearing in $q_x \Rightarrow$ merge



Plenoptic 1.0 - Refocusing



Plenoptic 1.0 - Refocusing

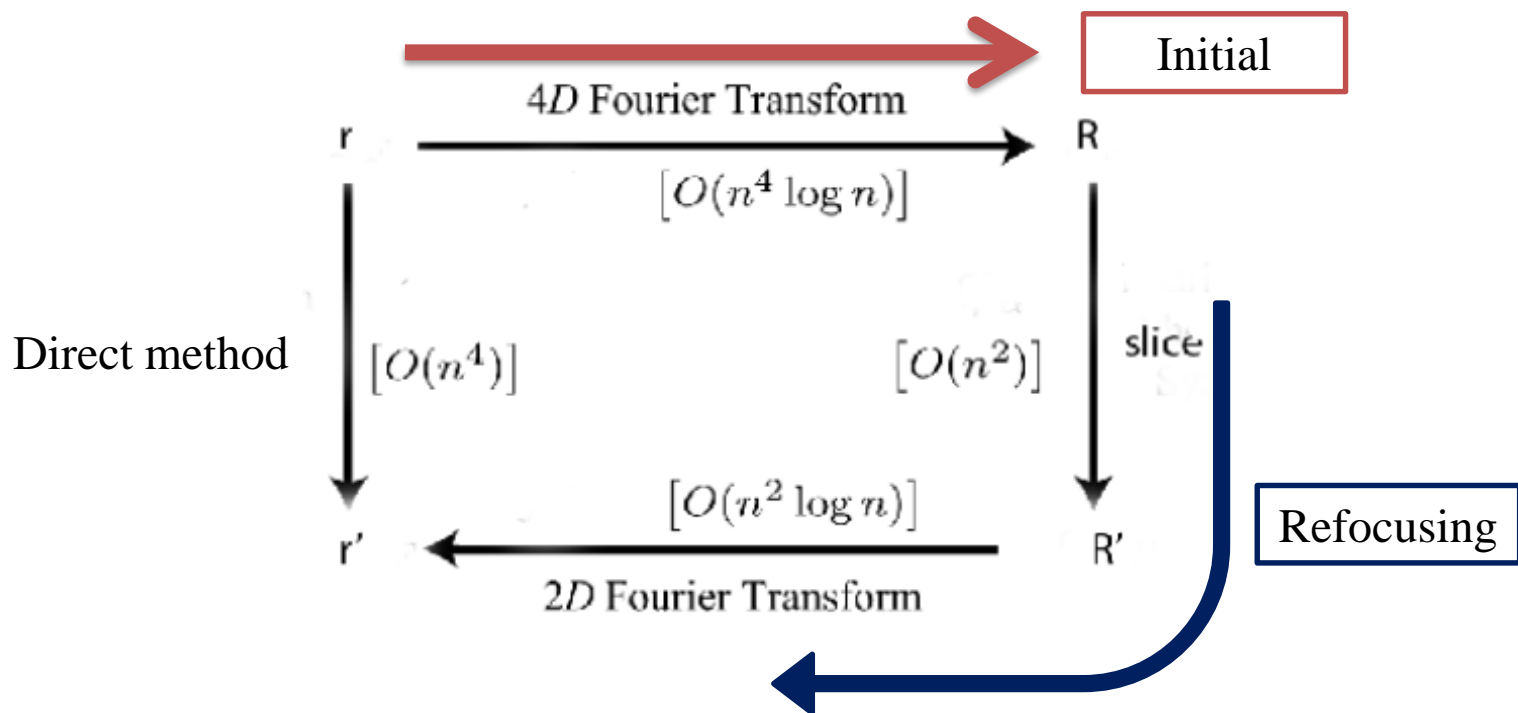


Plenoptic 1.0 - Refocusing



Plenoptic 1.0 - Refocusing

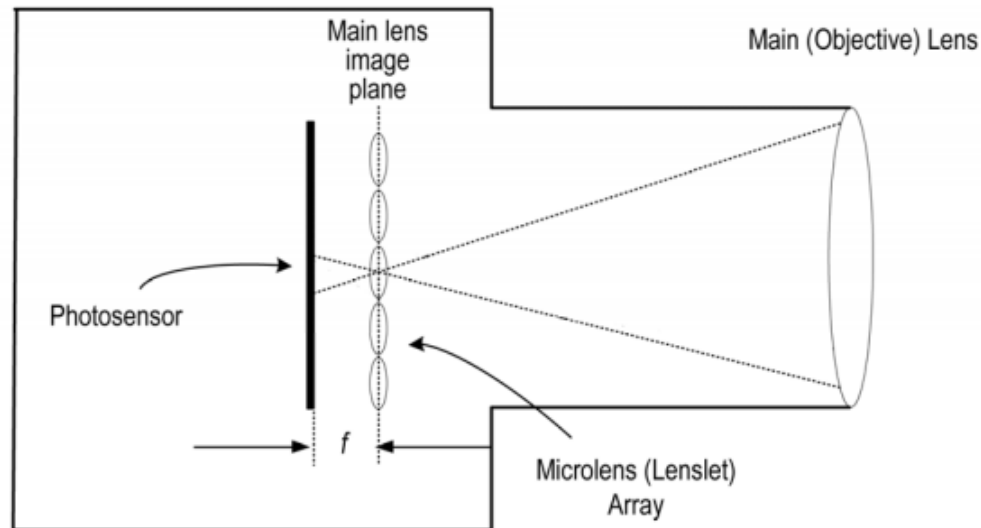
- Direct refocusing in the spatial domain requires $O(N^4)$ operations for each refocused image
- Ren Ng proposed the Fourier slice refocusing method:



Is Plenoptic 1.0 good enough?

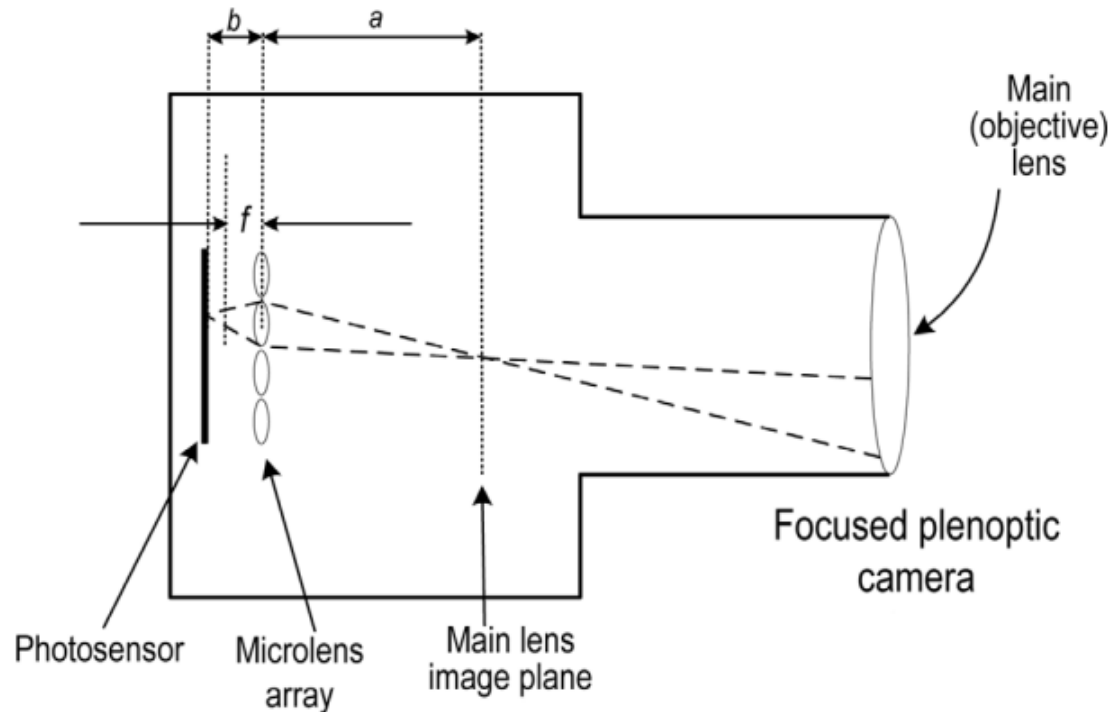
- Micro-lenses images are defocused relative to main lens image
- Low resolution

Conventional plenoptic camera



Plenoptic 2.0

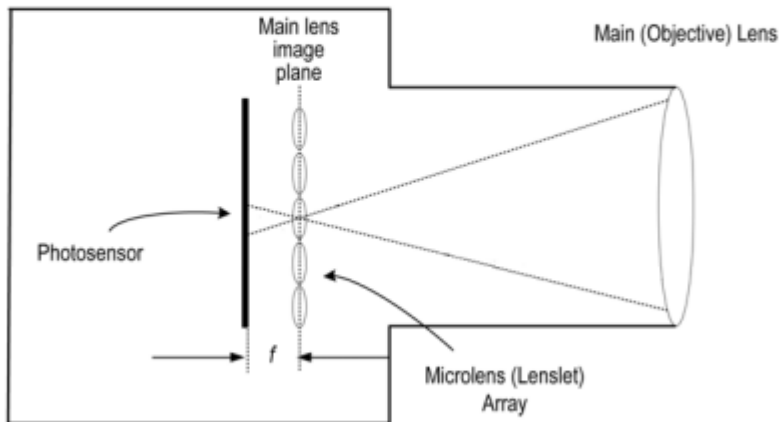
- Lumsdaine and Georgiev 2008: Micro-lenses satisfy the lens equation, and exactly focused on the main lens image.



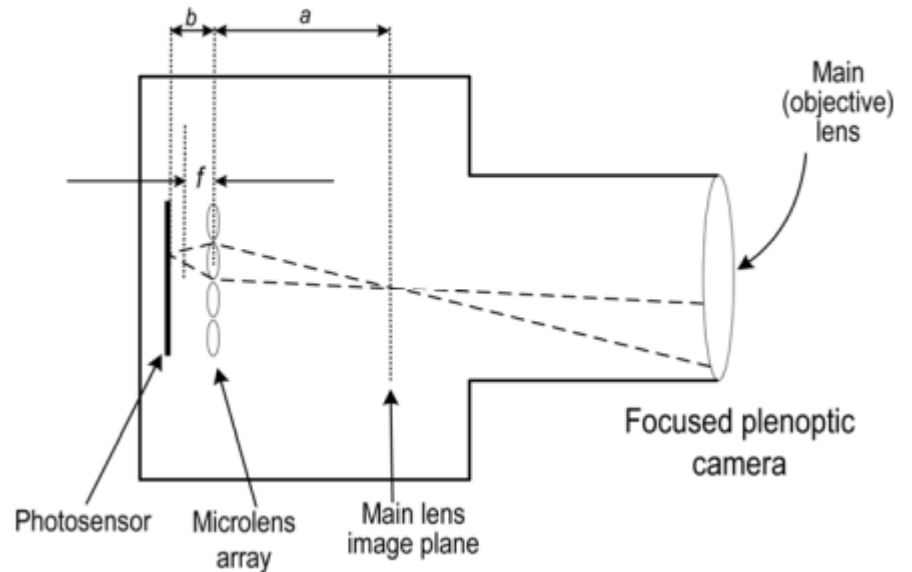
Comparison

► Plenoptic Camera (1.0)

Conventional plenoptic camera

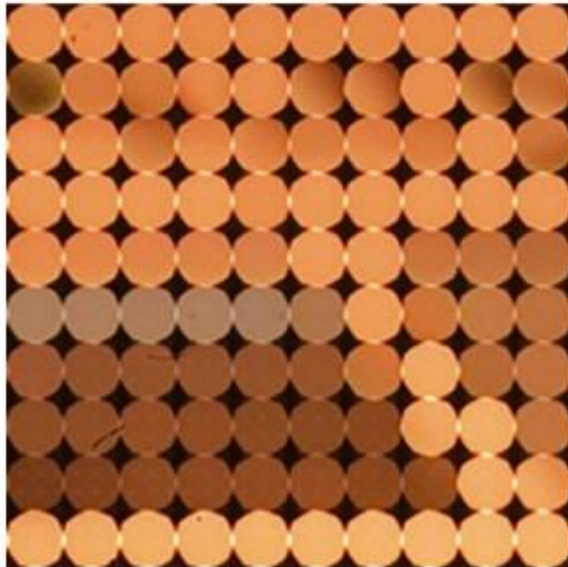


► Focused Plenoptic Camera (2.0)

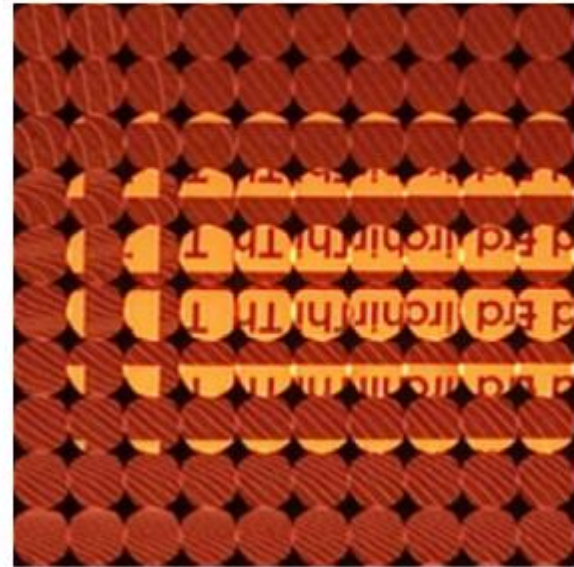


Comparison

- ▶ Plenoptic Camera
Blurry microimages



- ▶ Focused Plenoptic Camera
Sharp and inverted microimages

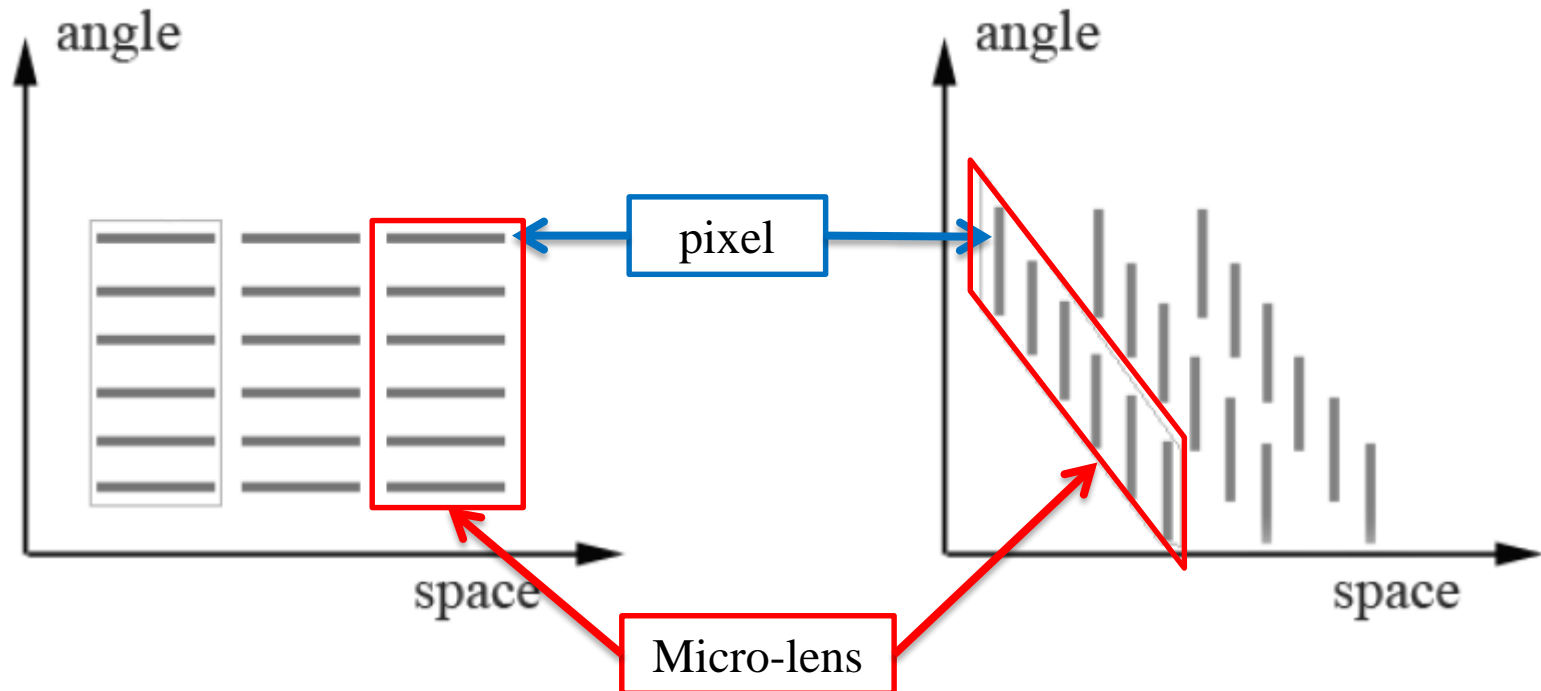


Comparison

- Resolution analysis

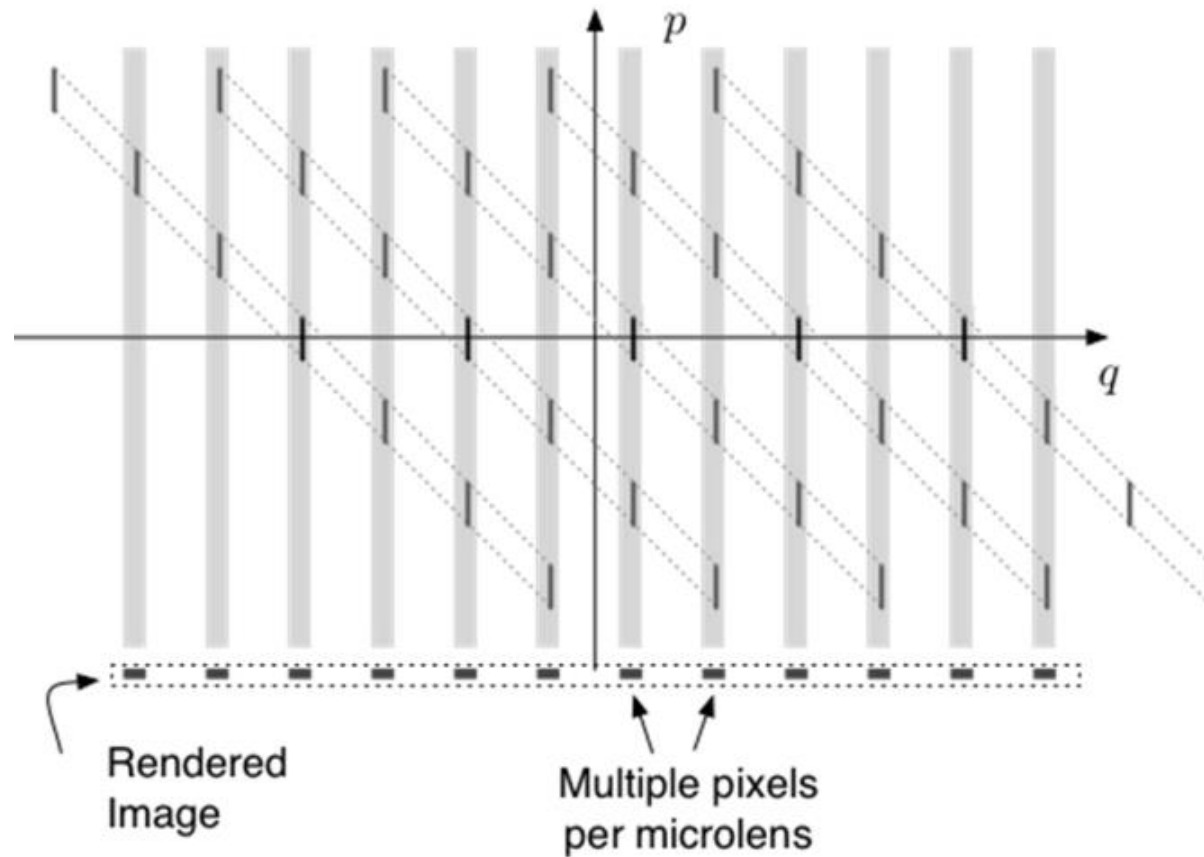
- Plenoptic 1.0

- Plenoptic 2.0



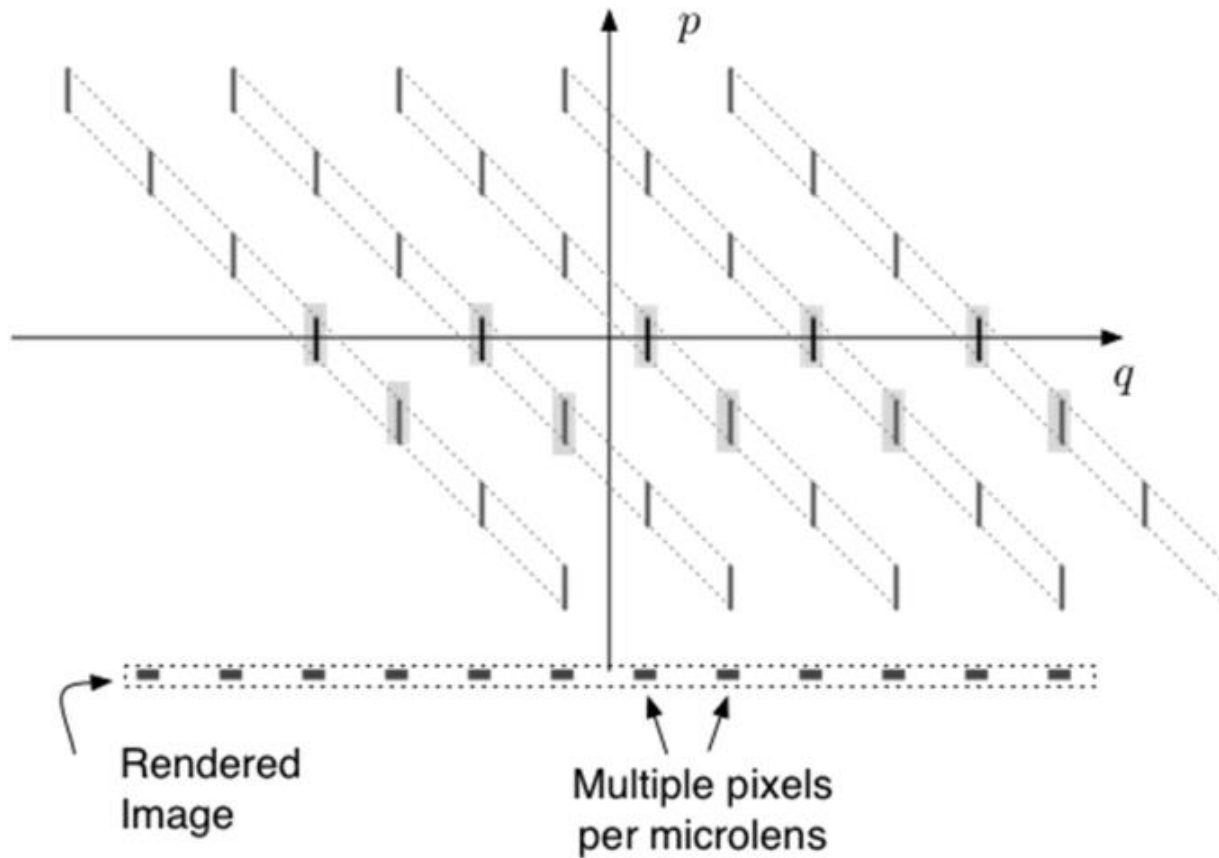
Plenoptic 2.0

- Rendering full aperture image



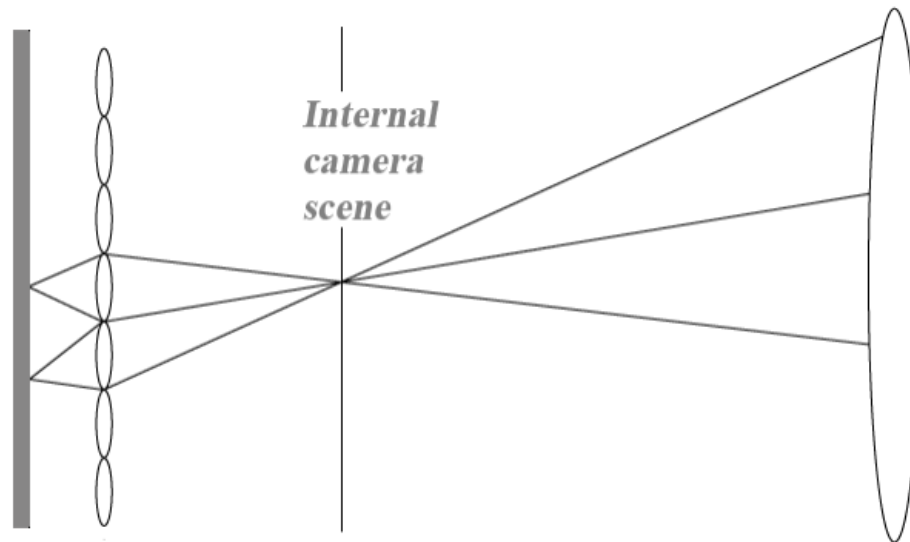
Plenoptic 2.0

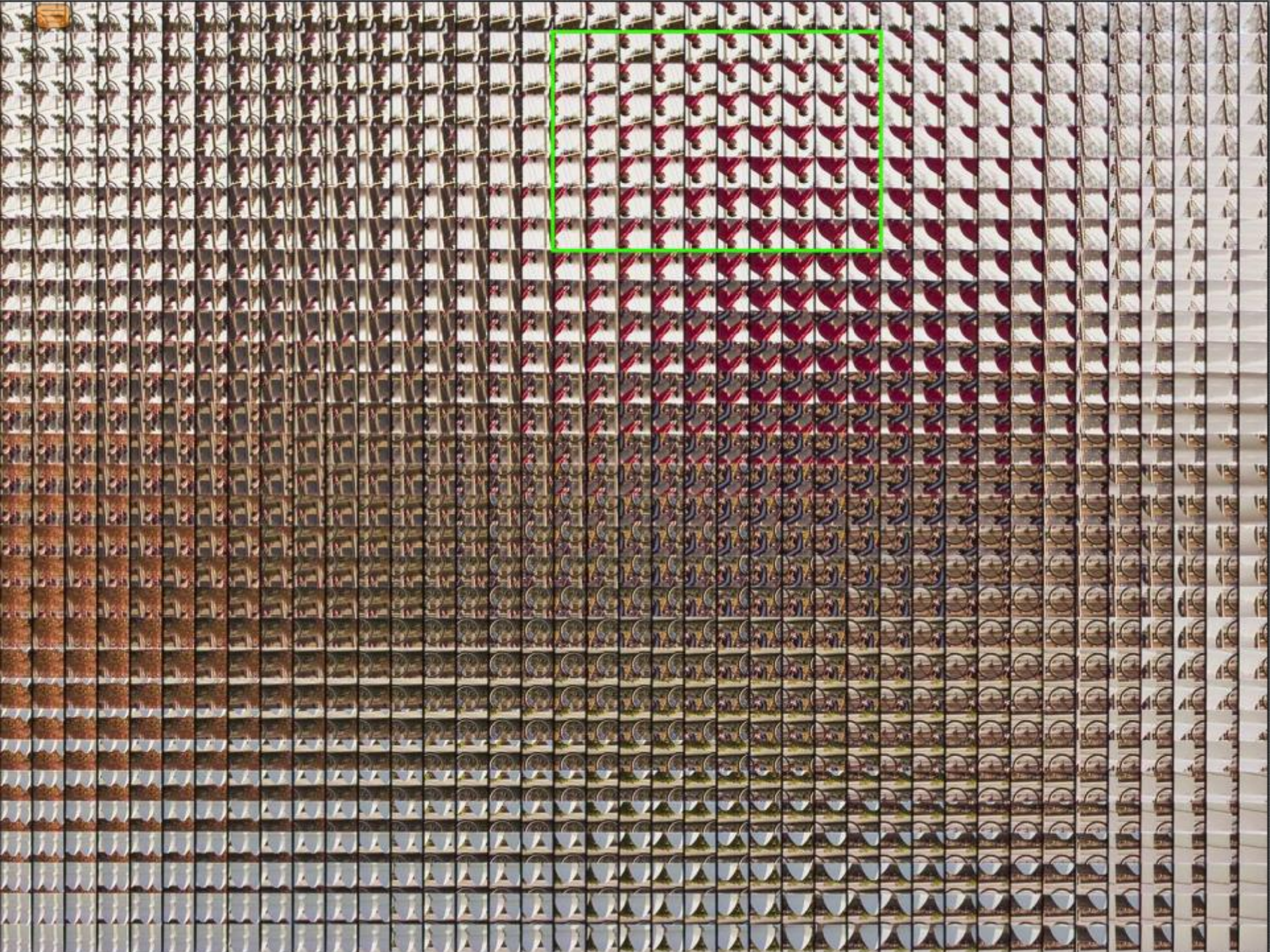
- Rendering one view

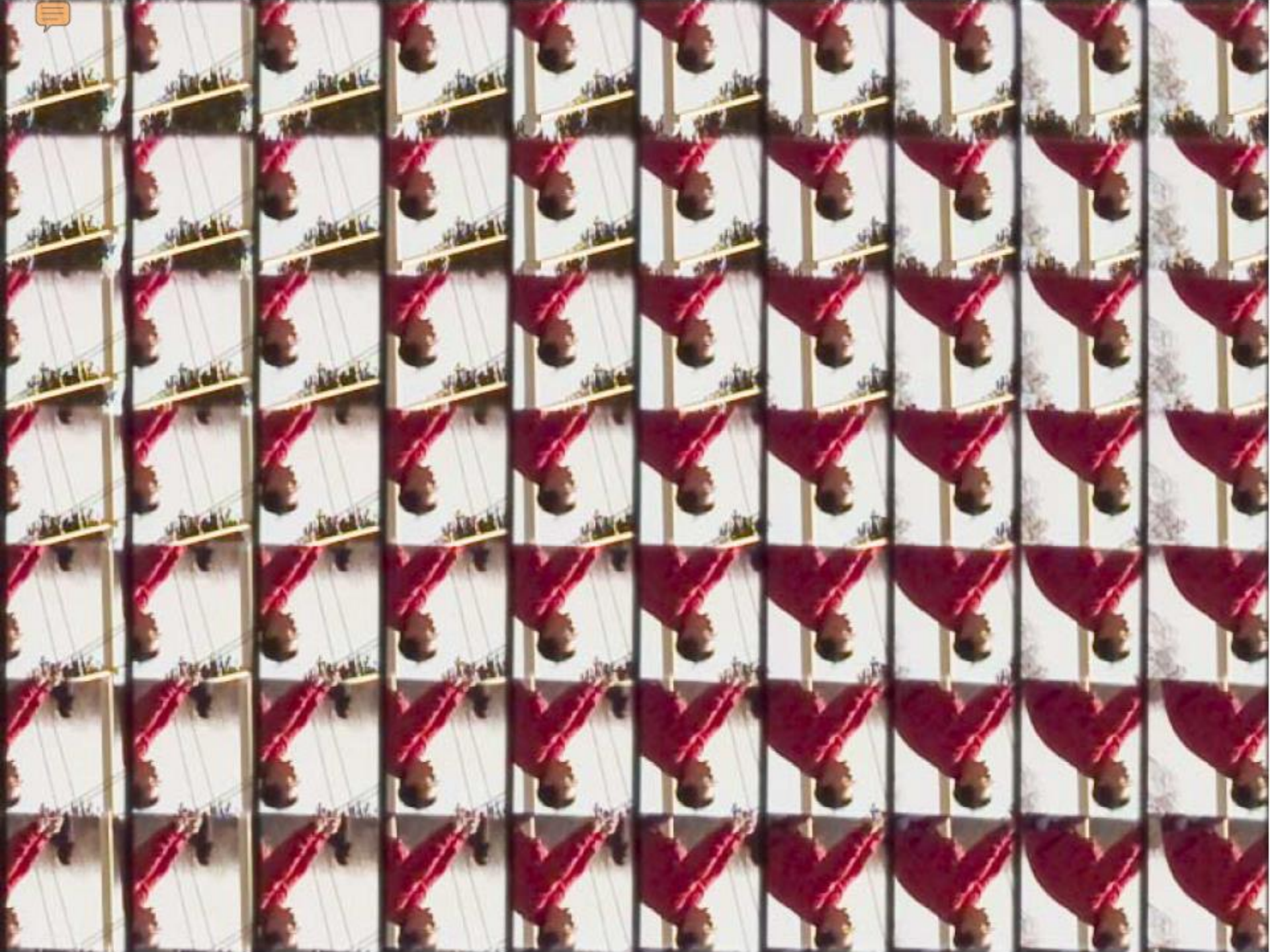


Plenoptic 2.0

- Advantage of plenoptic 2.0:
 1. Decouple resolution from the number of micro-lenses
 2. Free to choose spatial-angular trade-off point
 3. Each micro-lens is observing the scene as a slightly shifted camera \Rightarrow good for super-resolution











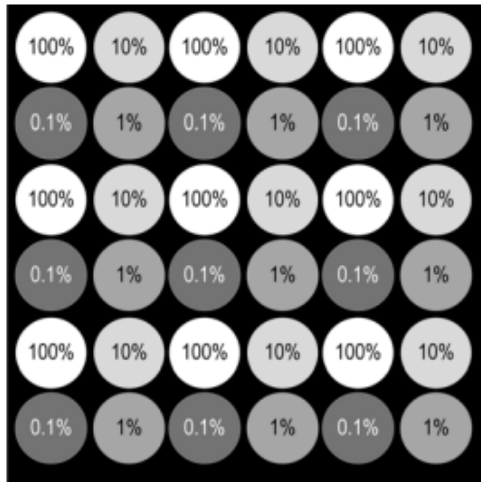
Super-resolution

- Plenoptic 1.0 result

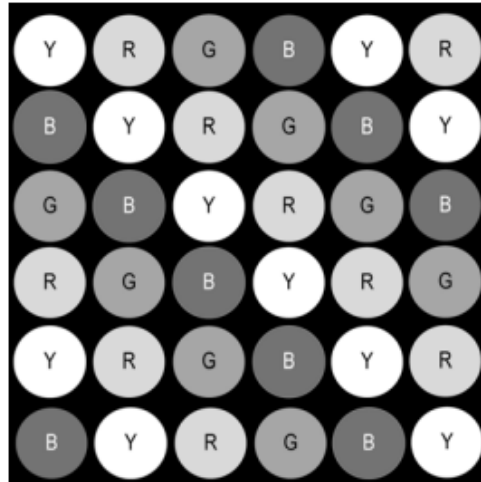


Other application

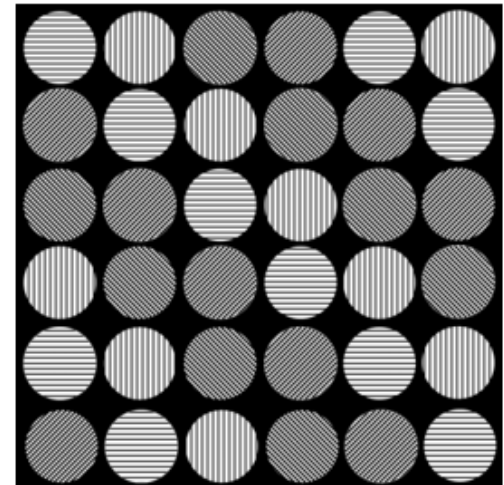
- We can put different filters on different micro-lenses



1000 X increase
in dynamic range



12-color imaging
with RGB sensor



sampling four
linear polarizations

Different Light-Field Camera

- Lytro – the first hand-held light-field camera
- Plenoptic 1.0, resolution = 1080 x 1080 pixels (1.2M)
- Software can run both on MAC and Windows



Red Hot
16GB
750 Pictures
\$499.00



Electric Blue
8GB
350 Pictures
\$399.00



Graphite
8GB
350 Pictures
\$399.00



Seaglass
8GB
350 Pictures
\$399.00



Moxie Pink
8GB
350 Pictures
\$399.00

Different Light-Field Camera

- Raytrix – target at industrial and scientific application
- Resolution from 1M to 3M
- Precise per-pixel depth information



Raytrix-R5



Raytrix-R11



Raytrix-R29



Raytrix-RX

Different Light-Field Camera

- Nokia Pelican Imaging – implement on smart phone



[4] Venkataraman, Kartik, et al. "PiCam: an ultra-thin high performance monolithic camera array." *ACM Transactions on Graphics (TOG)* 32.6 (2013): 166.

Conclusion

- What we have talked about:
 1. The basic image rendering idea
 2. The history of light-field camera
 3. Property of Plenoptic camera 1.0
 - Micro-lens focused on infinity
 - Rendering and refocusing
 4. Property of Plenoptic camera 2.0
 - Micro-lens focused on main lens image
 - Higher flexibility, suitable for super-resolution
 5. Different kinds of light-field camera

