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)
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 \( A^{-1} = \begin{bmatrix}
-\frac{a}{b} & 0 \\
1/f & -\frac{b}{a} \\
\end{bmatrix} \)
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
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!
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
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 lightfield rendering (plenoptic 1.0).