The Focused Plenoptic Camera

“Lightfield photographers, focus your cameras!”
Karl Marx
Comparison

- Plenoptic Camera (1.0)
  - Conventional plenoptic camera
  - Main lens image plane
  - Photosensor
  - MicroLens (Lenslet) Array

- Focused Plenoptic Camera (2.0)
  - Focused plenoptic camera
Comparison

- Plenoptic Camera
  - Blurry microimages

- Focused Plenoptic Camera
  - Sharp and inverted microimages
Why Inverted?

Like a telescope with multiple eyepieces.
Lightfield Rendering (Small Part of Scene)
Focused Plenoptic Rendering: 500X Better!
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:

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

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
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!
Extended Modes
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

- 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
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
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).