Lens Array/ Camera Array
Light field photography and microscopy

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Geometric Components of the pencil of ray lights

**ANGULAR COORDINATES**

\[ I = P(\Theta_v, \Phi_v, E_x, E_y, E_z, t, \lambda) \]

- \( E = (E_x, E_y, E_z) \)
  - Viewpoint
- \( V = (\Theta_v, \Phi_v) \)
  - Direction of the ray light passing through the Viewpoint

**CARTESIAN COORDINATES**

\[ I = P(x, y, E_x, E_y, E_z, t, \lambda) \]

- Commonly used in machine vision
Lumigraph / Lightfield
High performance imaging using large camera arrays

Bennett Wilburn, Neel Joshi, Vaibhav Vaish, Eino-Ville Talvala, Emilio Antunez, Adam Barth, Andrew Adams, Mark Horowitz, Marc Levoy

(Proc. SIGGRAPH 2005)
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
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
Spacetime aperture shaping

- shorten exposure time to freeze motion $\rightarrow$ dark
- stretch contrast to restore level $\rightarrow$ noisy
- increase (synthetic) aperture to capture more light $\rightarrow$ decreases depth of field
• center of aperture: few cameras, long exposure → high depth of field, low noise, but action is blurred

• periphery of aperture: many cameras, short exposure → freezes action, low noise, but low depth of field
Light field photography using a handheld plenoptic camera

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

(Proc. SIGGRAPH 2005 and TR 2005-02)
Conventional versus light field camera
Conventional versus light field camera

Subject → Main lens → Photosensor

st-plane

Subject → Main lens → Photosensor

uv-plane
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor

Adaptive Optics microlens array

125μ square-sided microlenses

\[ 4000 \times 4000 \text{ pixels} \div 292 \times 292 \text{ lenses} = 14 \times 14 \text{ pixels per lens} \]
A digital refocusing theorem

- an $f/N$ light field camera, with $P \times P$ pixels under each microlens, can produce views as sharp as an $f/(N \times P)$ conventional camera

- or -

- it can produce views with a shallow depth of field ($f/N$) focused anywhere within the depth of field of an $f/(N \times P)$ camera
Example of digital refocusing
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]
Digitally moving the observer

• moving the observer = moving the window we extract from the microlenses
Example of moving the observer
Moving backward and forward