

Light Fields

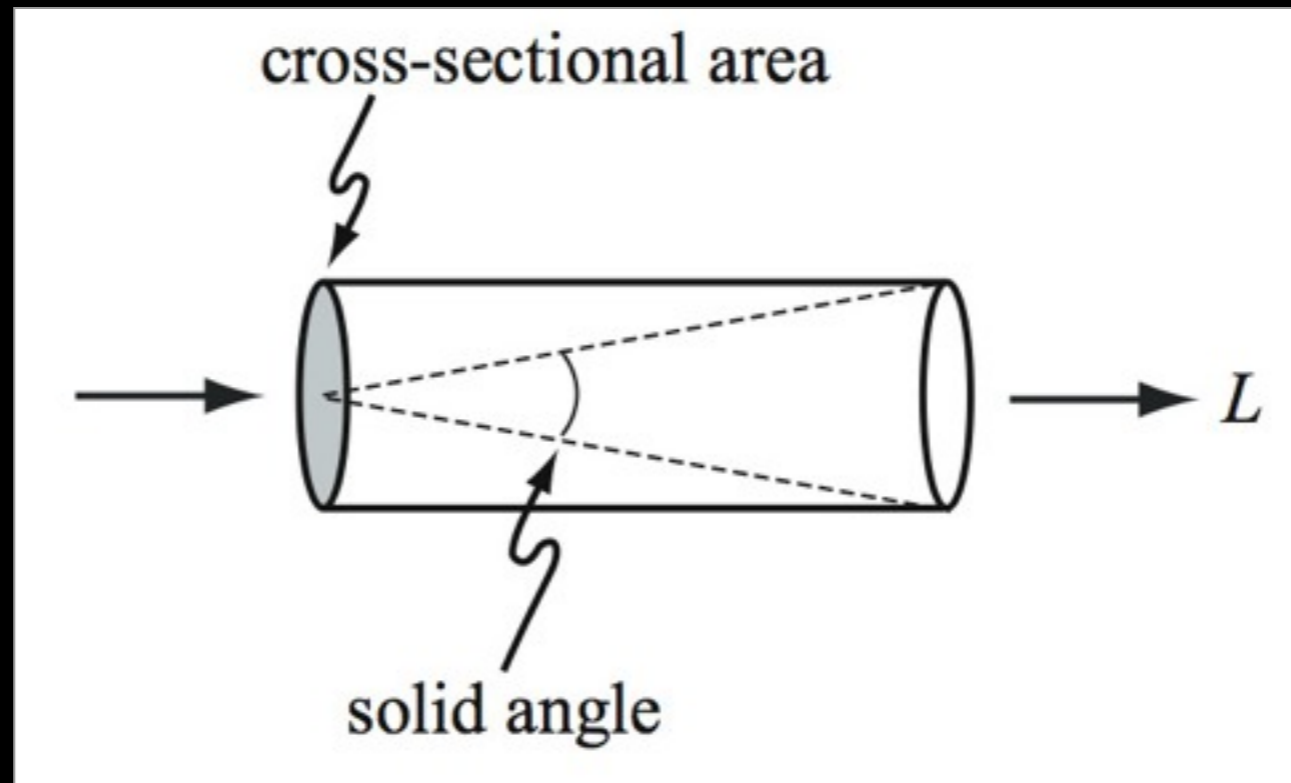
Slides stolen from Marc Levoy by David Jacobs
CS 478 Winter 2012

Outline

- Definition
- Capture and Rendering
 - Parameterization Strategies
 - Creation and Display
 - Devices
 - Sampling
- 3D Reconstruction
- Other Applications

The scalar light field

Radiance as a function of position and direction in a static scene with fixed illumination.

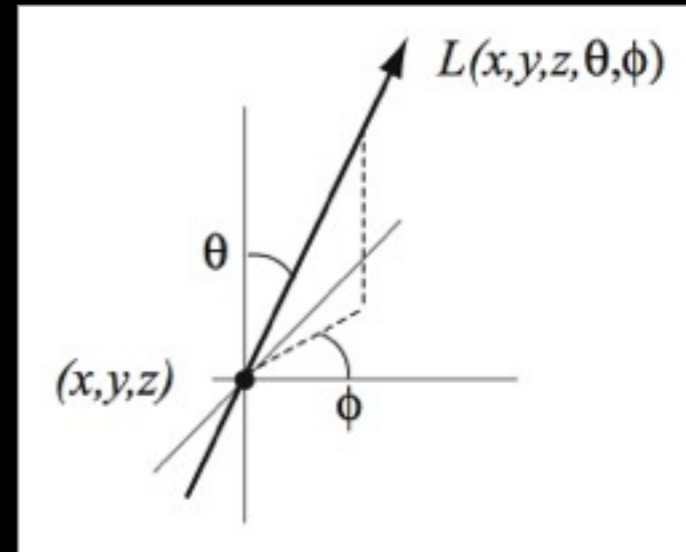


L is radiance in watts/(m²steradians)

Dimensionality

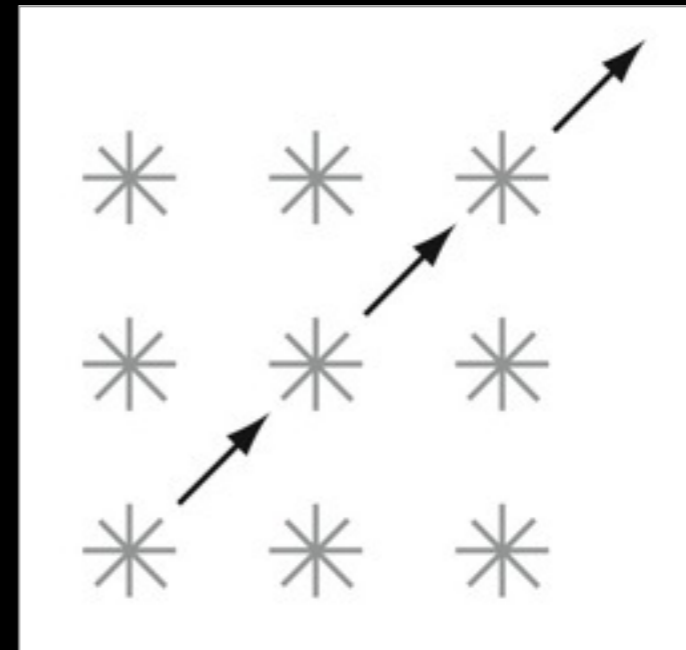
- In general
⇒ 5D function
“plenoptic function”
[Adelson 1991]

$$L(x,y,z,\theta,\phi)$$



- In “free space”
⇒ 4D function
“the light field”
[Moon 1981]

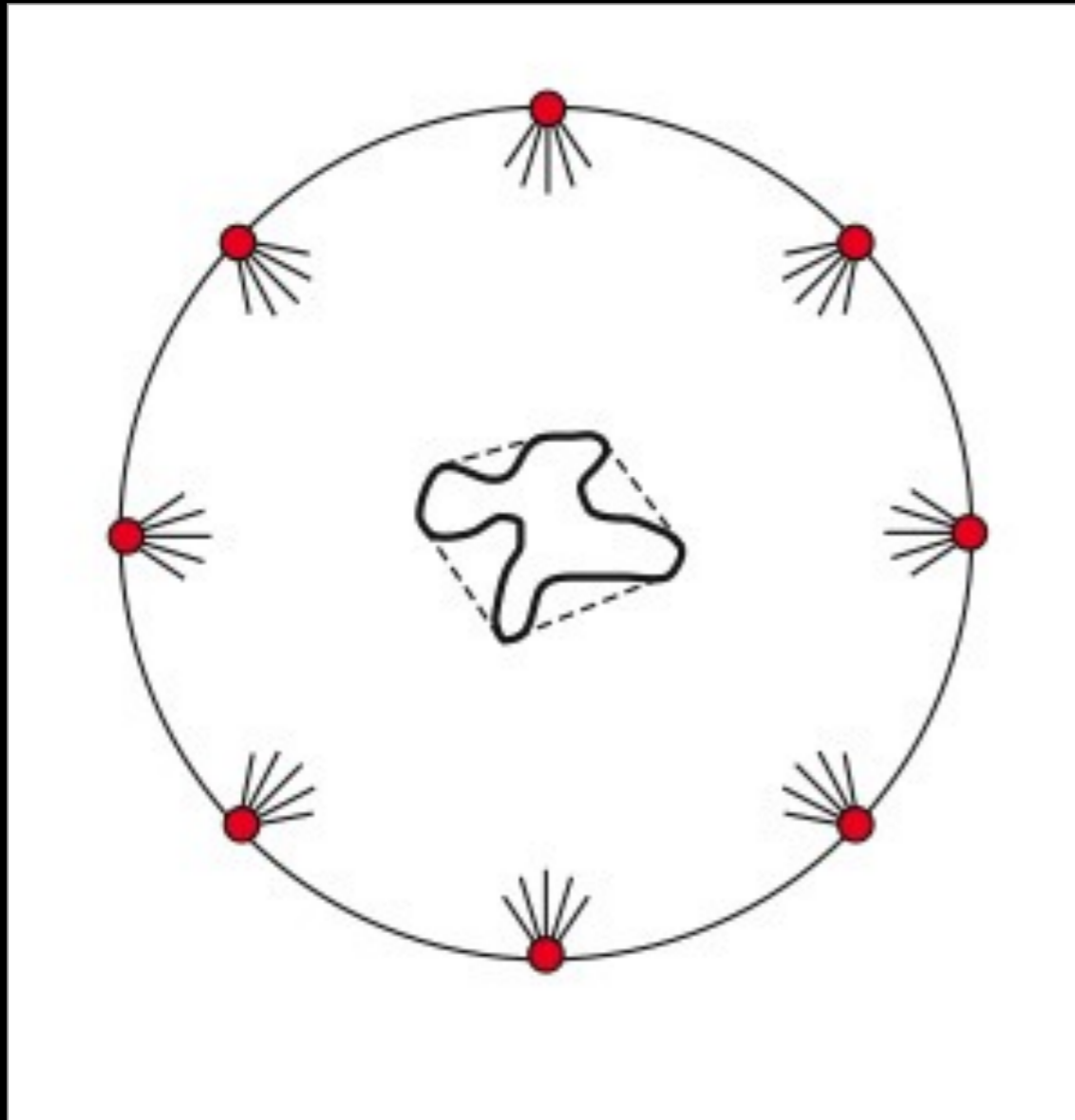
$$L(\dots?)$$



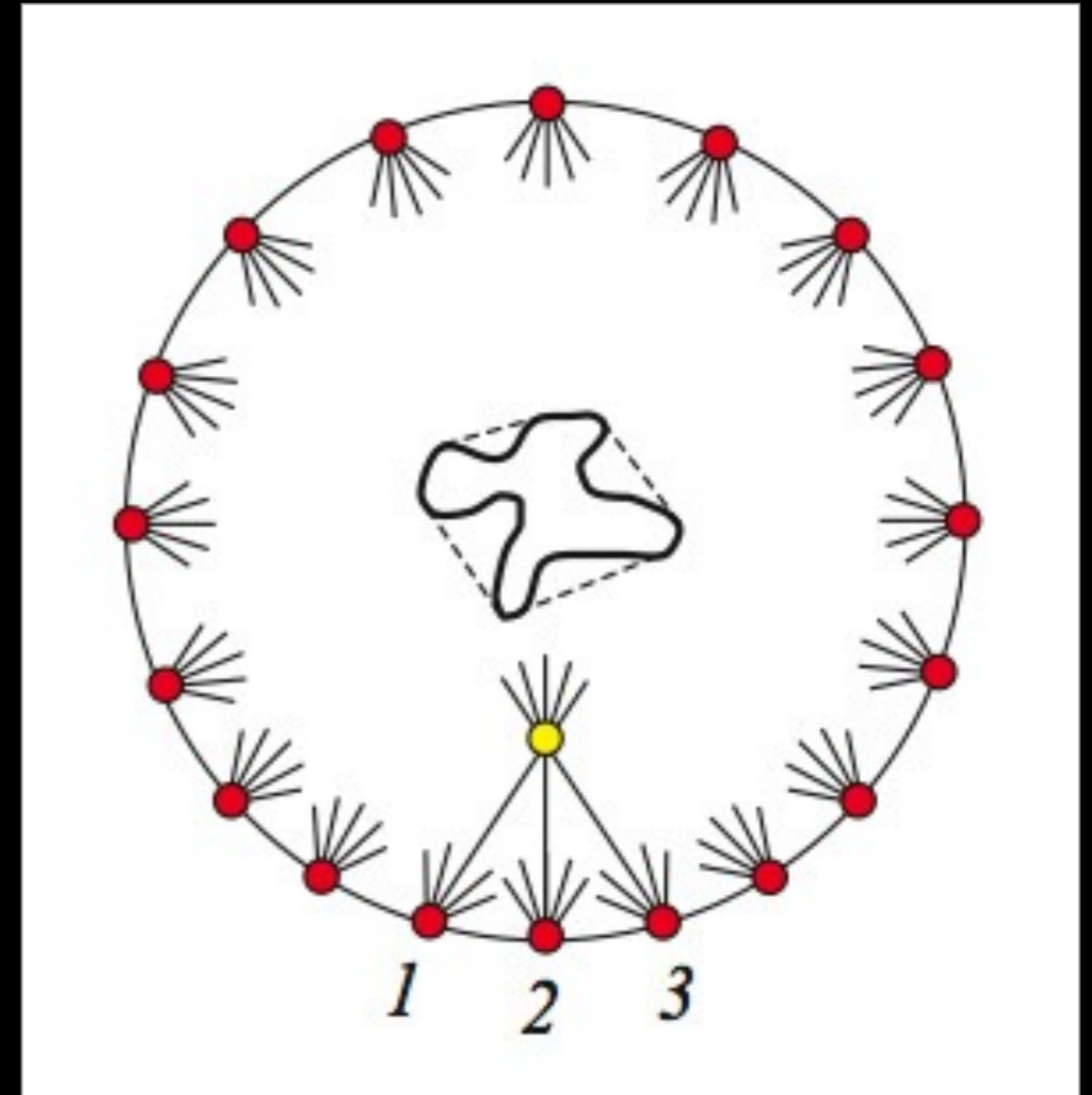
The free-space assumption

- The 3D space outside a compact object
- The 3D space inside an uncluttered environment

Rendering Lightfields



flipbook animation
(QuickTime VR)
[Chen 1995]



rebinning the rays
to create new views
[Levoy 1996]

QuickTime VR Object Movie



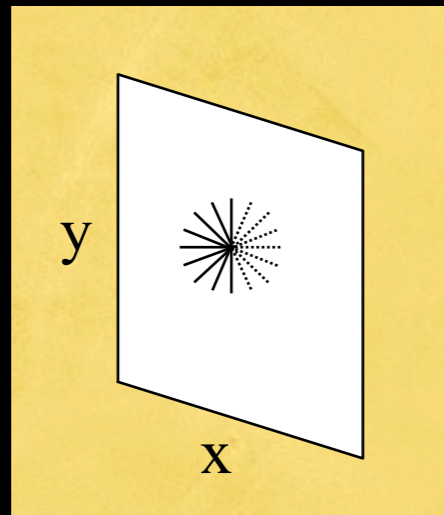
<http://www.csuchico.edu/tlp/info/projects/skull/>

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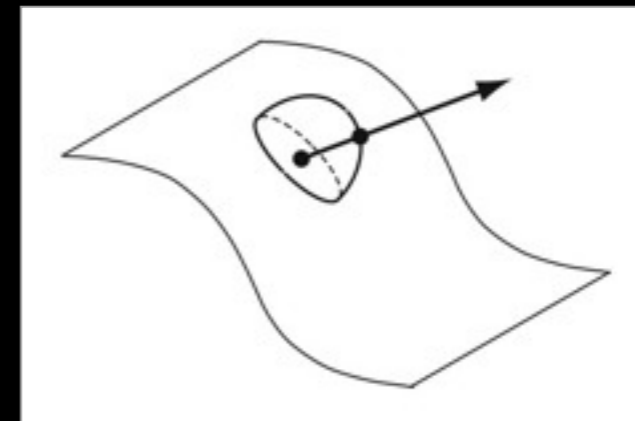
Parameterization Strategies

Point-on-plane + direction
(or point-on-surface + direction)



$$L(x,y,\theta,\phi)$$

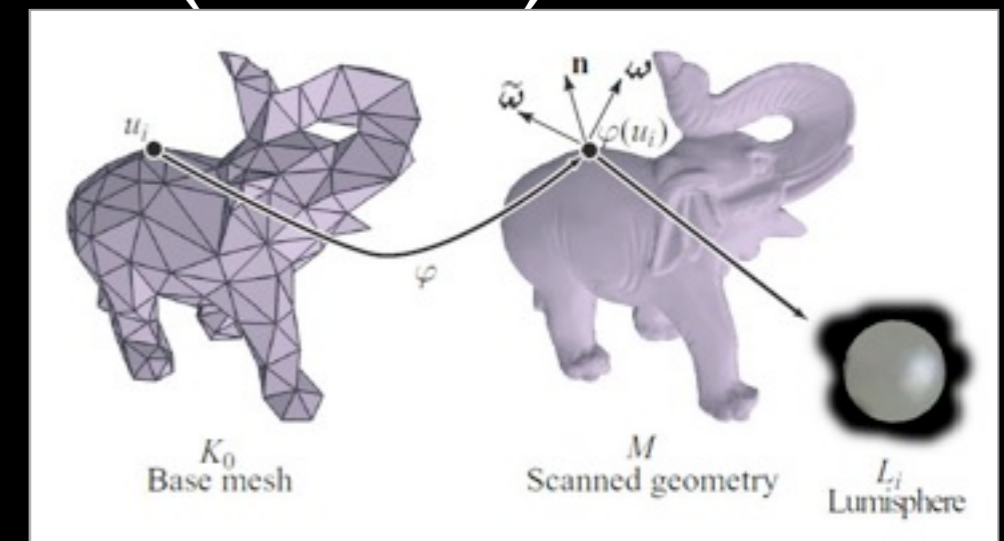
or



$$L(u,v,\theta,\phi)$$

Good for representing a
light field at a surface

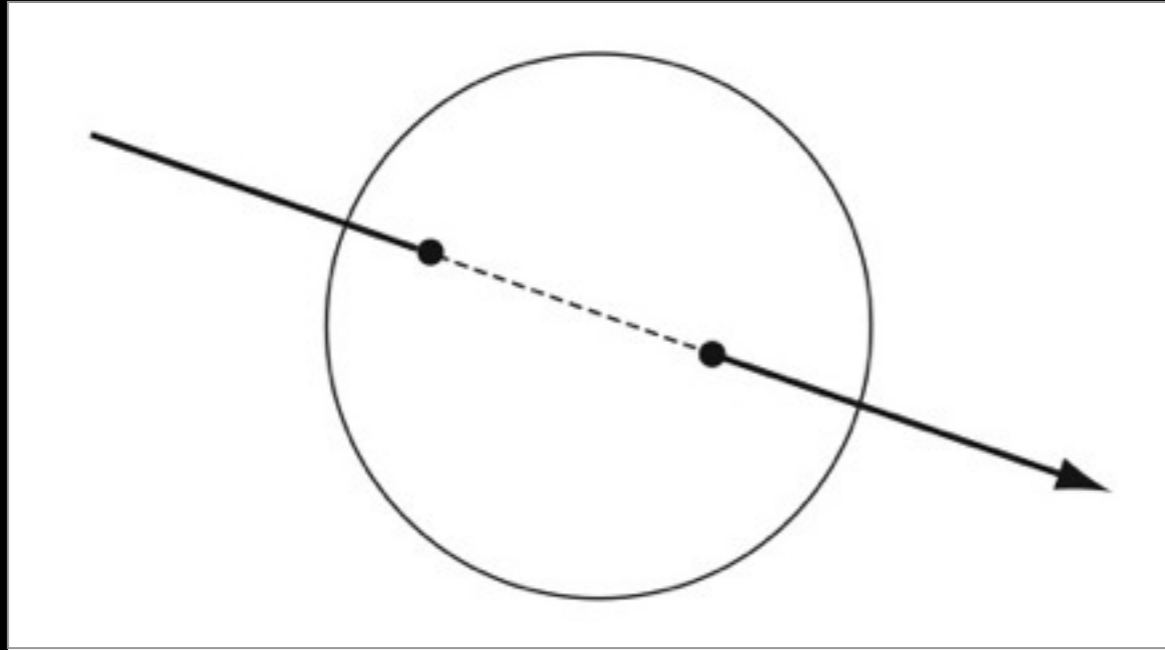
Bad for display (requires trigonometry)



[Wood 2000]

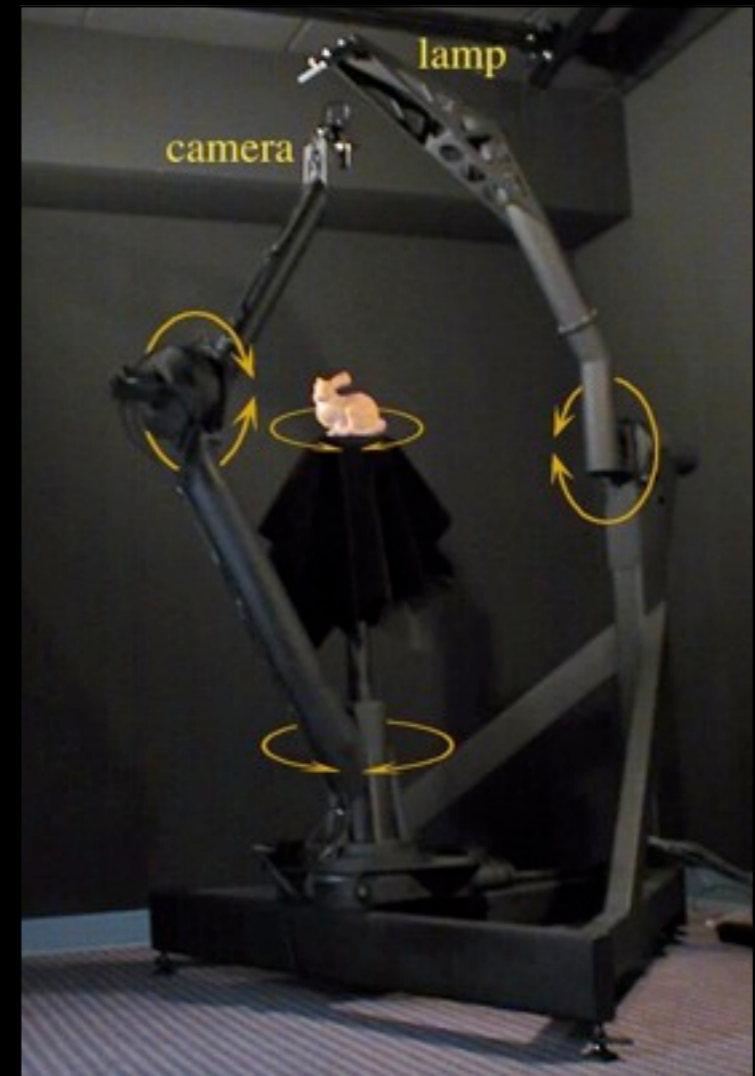
Parameterization Strategies

Chords of a sphere



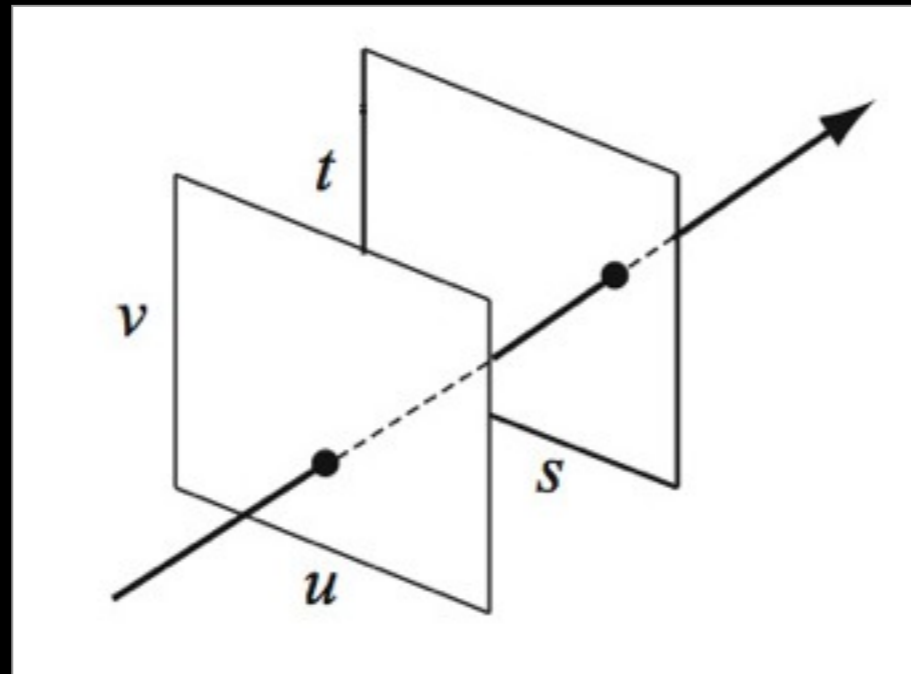
$$L(\theta_1, \Phi_1, \theta_2, \Phi_2)$$

Easy to get uniform sampling of light-field
Useful for spherical gantries



Parameterization Strategies

Two plane parameterization (“light slab”)

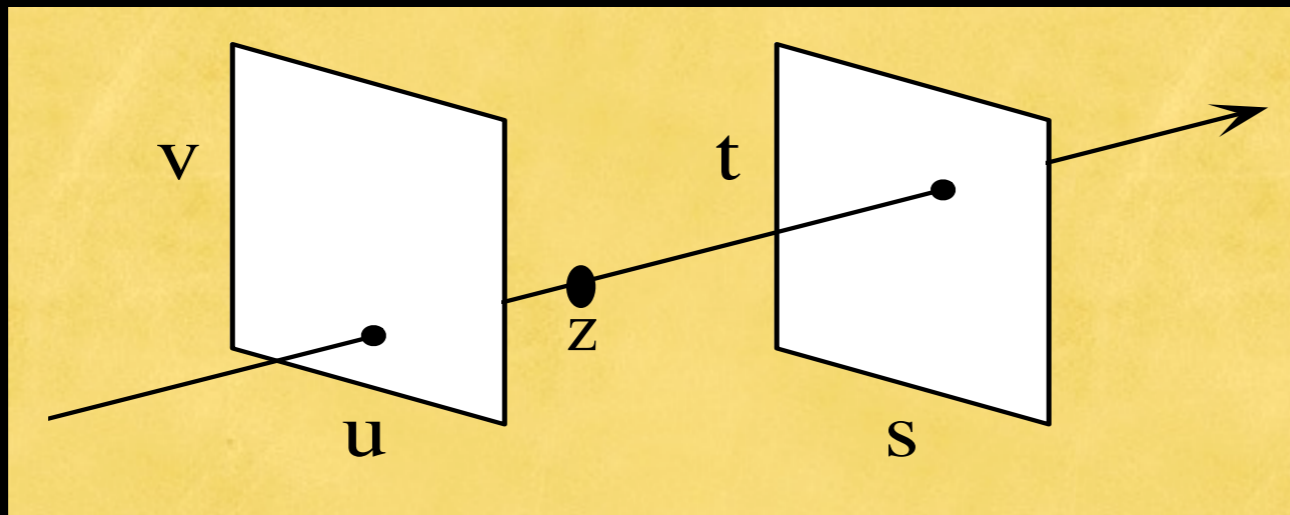


$L(u,v,s,t)$

- Uses projective geometry
 - One plane at $\infty \Rightarrow$ array of orthographic images
 - Fast, incremental display

Aside: Plenoptic Parameterization

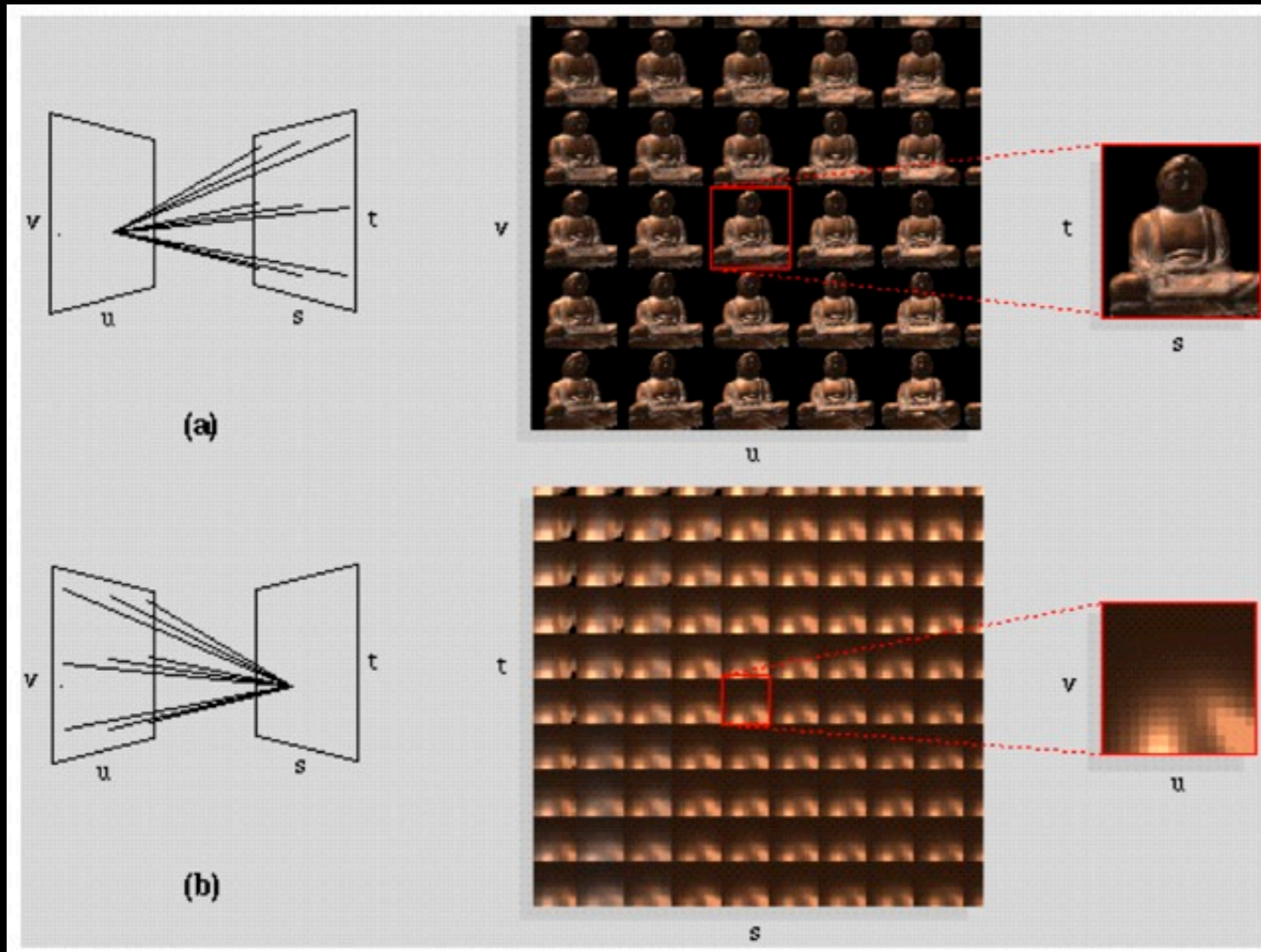
Two plane ray field



$L(u,v,s,t,z)$

- Multiple colors along a single line
- Alternative to $L(x,y,z,\theta,\phi)$
- Similar to the ZZ-buffer [Salesin 1990]

Representing in 2D



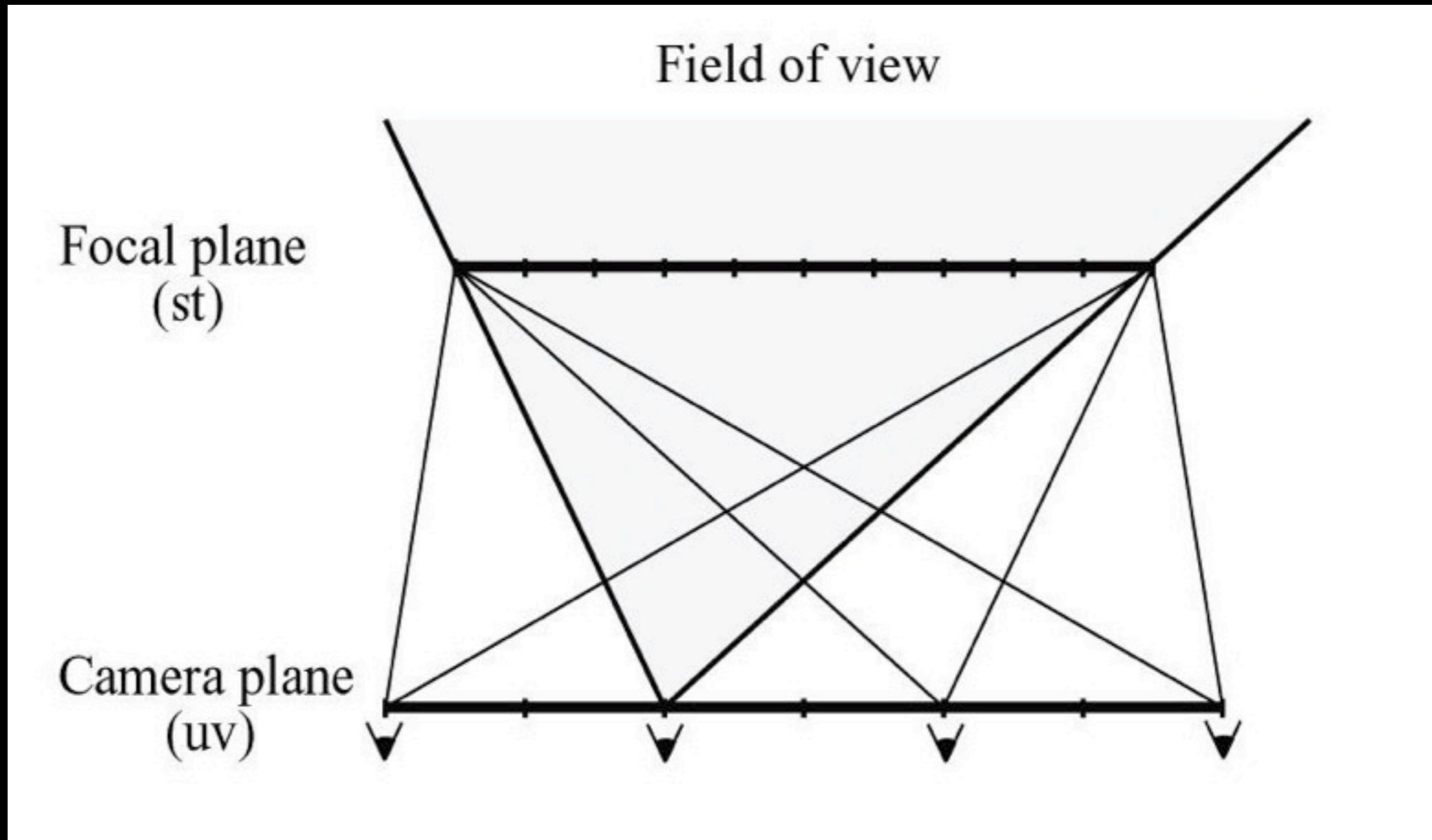
An array of
perspective views

or

An array of
reflectance maps

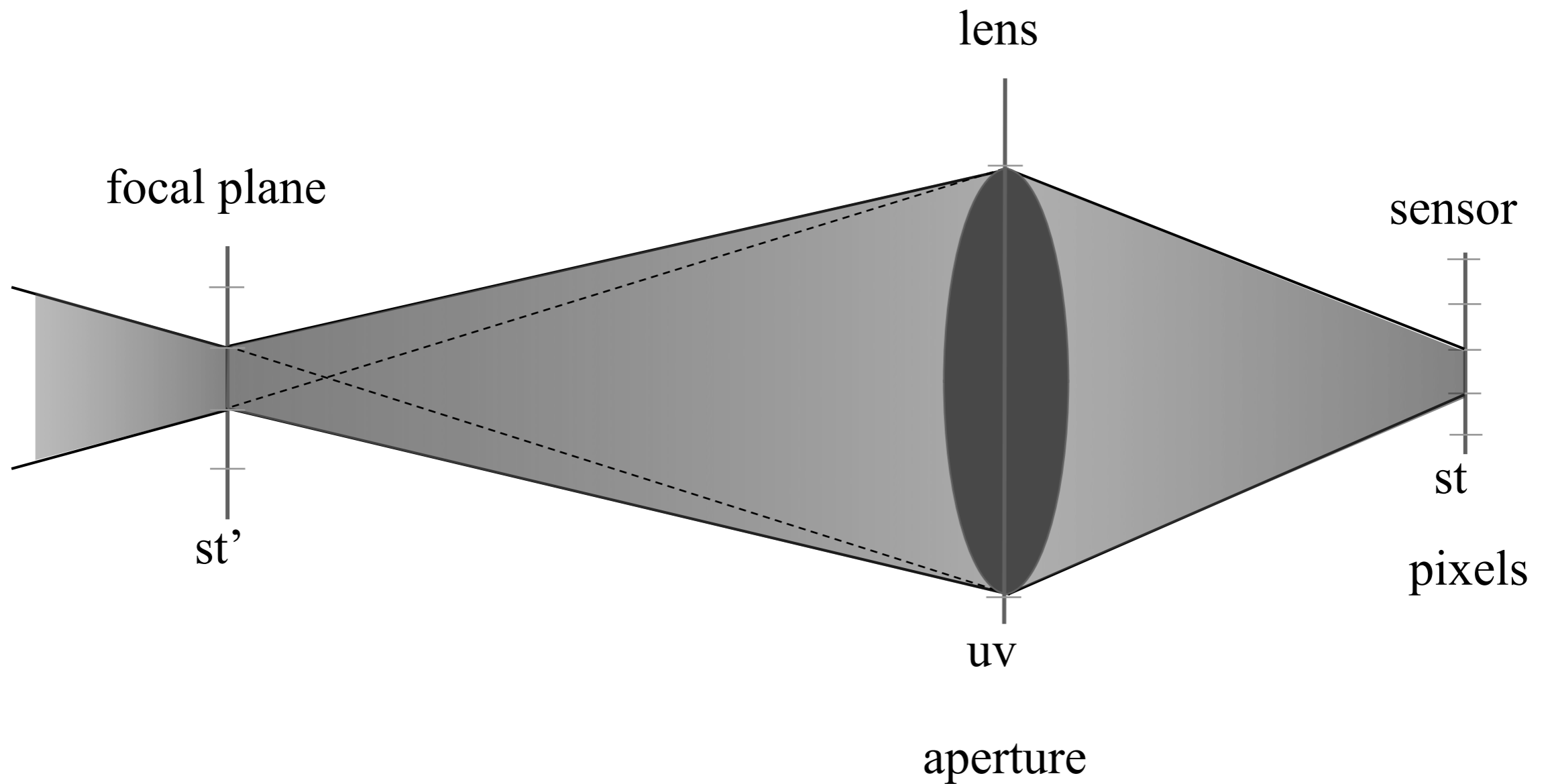
Depends on where the object
is relative to the two planes

Synthesizing a light slab

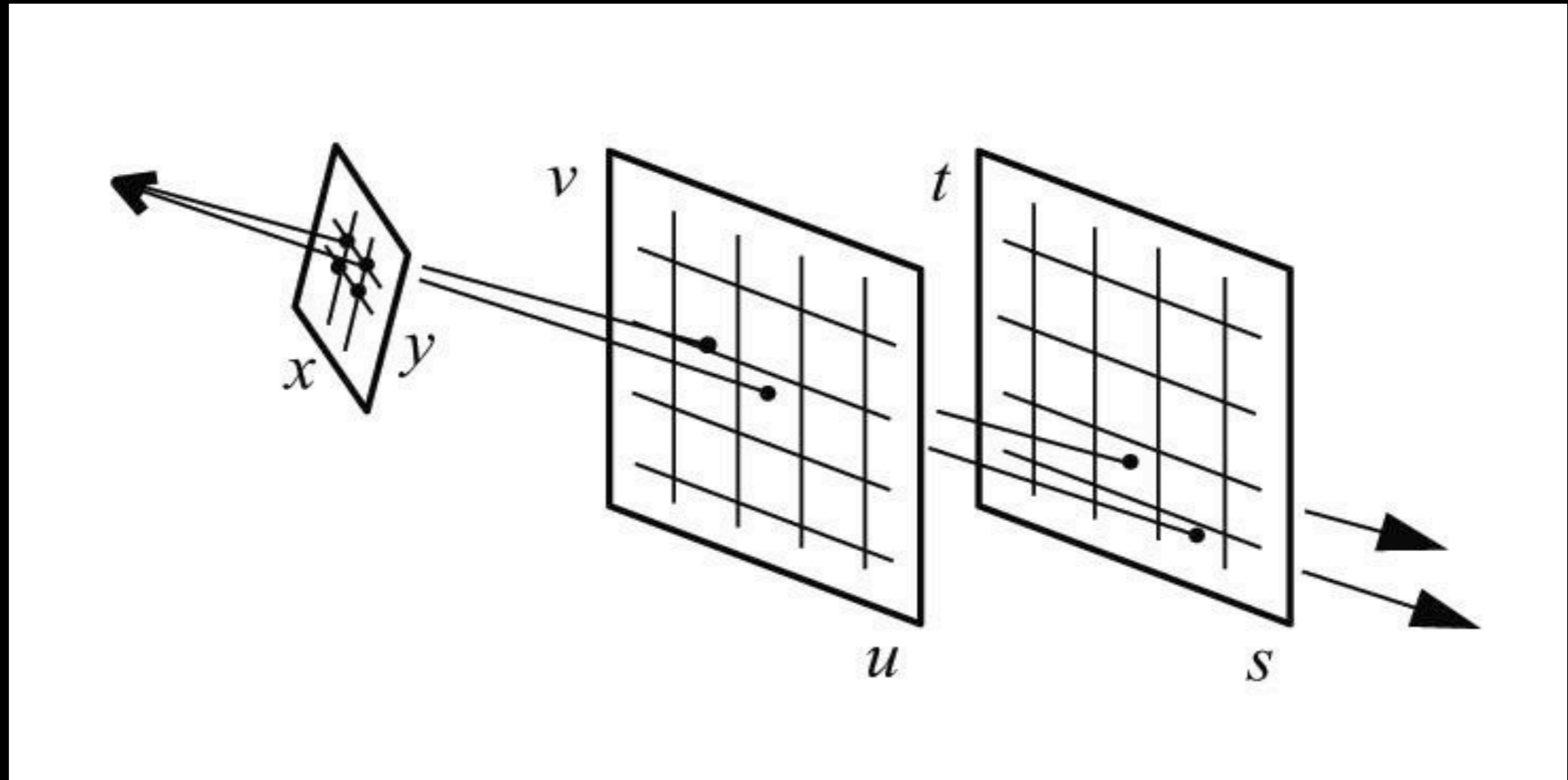


Note each view is an off-axis perspective (or just cropped)

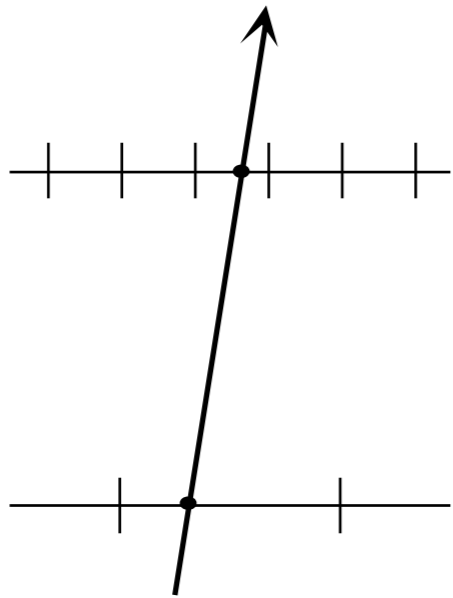
(Ordinary) camera geometry



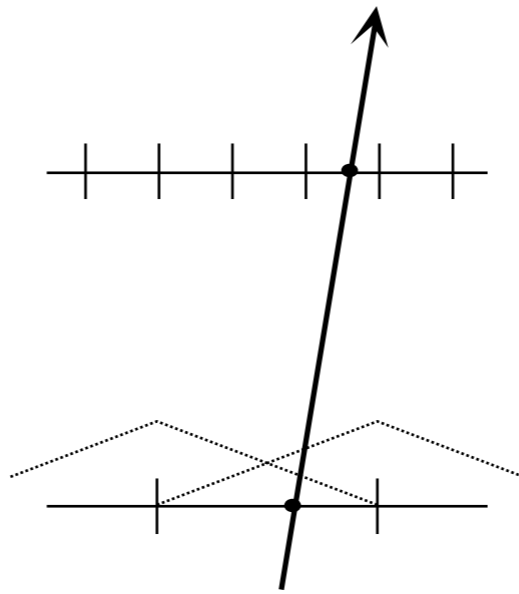
Displaying a light field



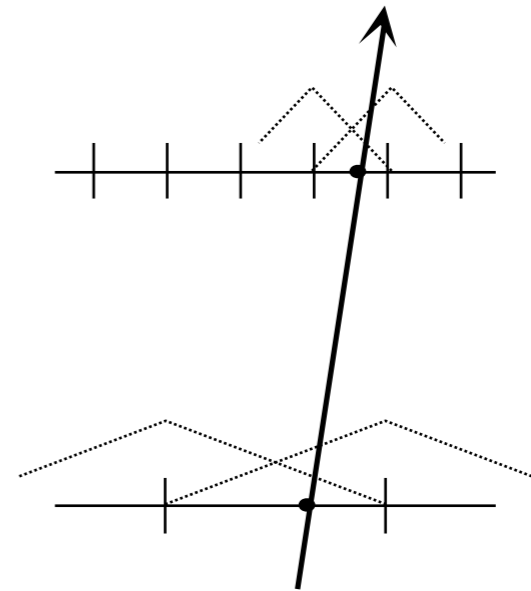
Interpolation for display



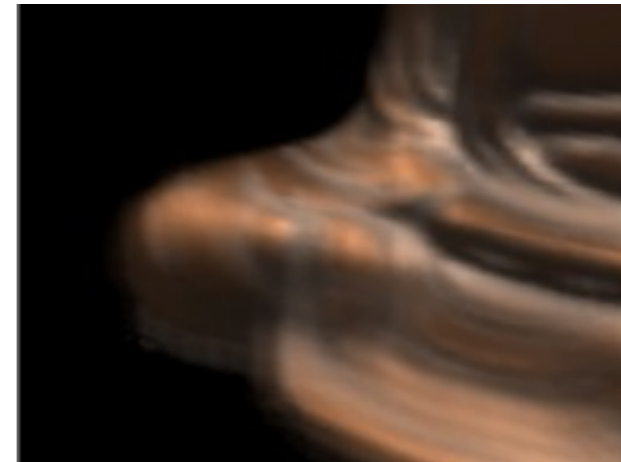
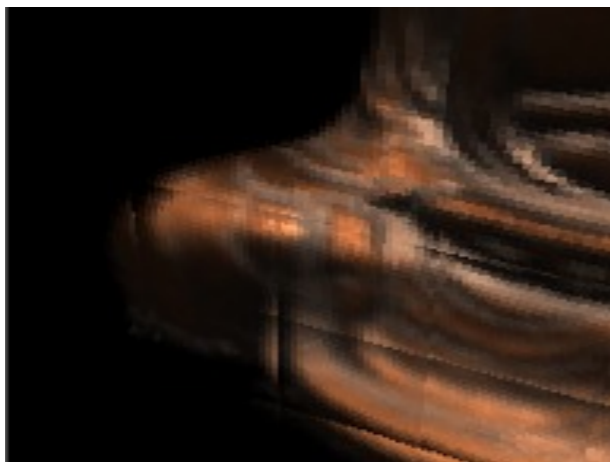
point sample



uv bilerp



uv and st bilerp

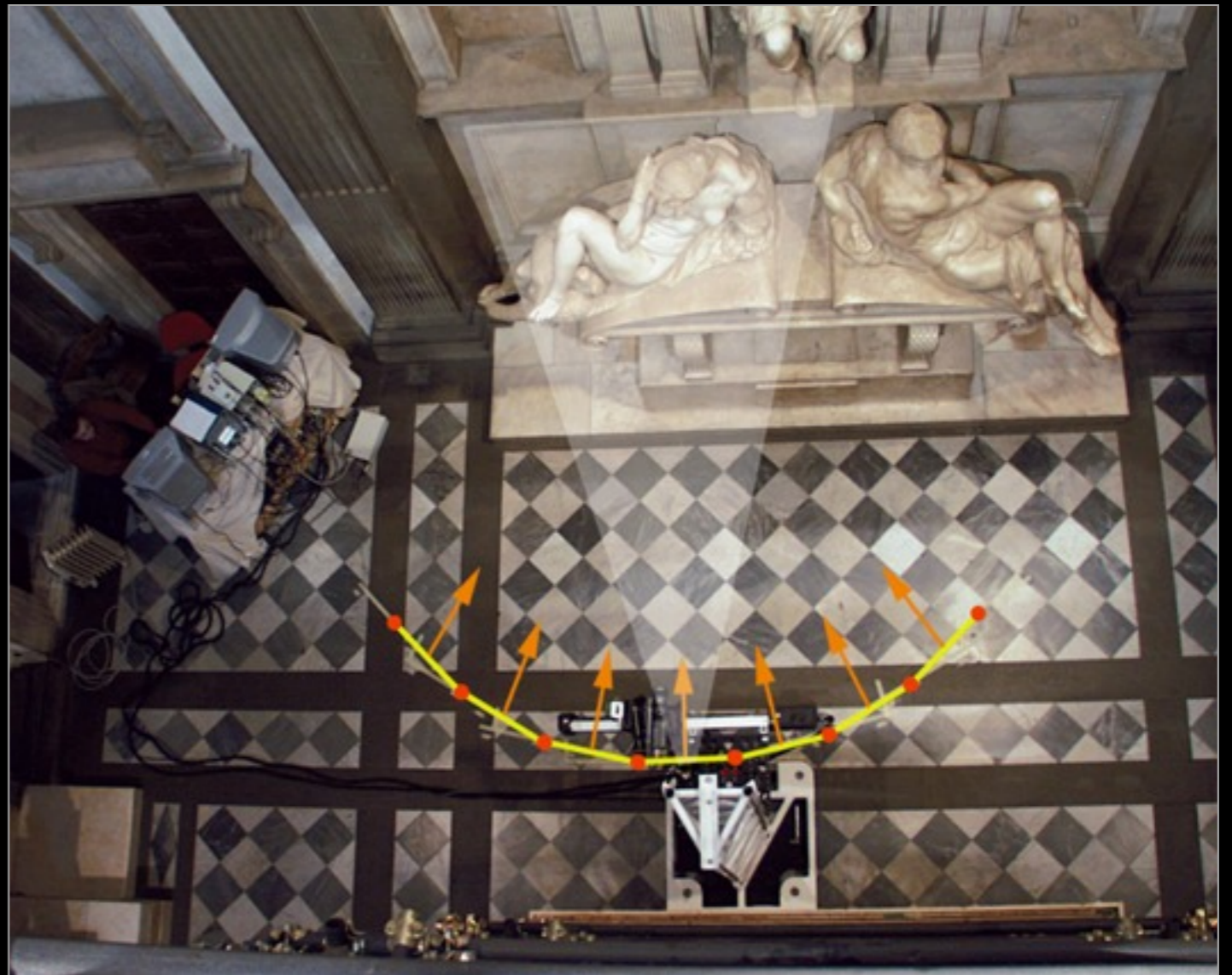


Acquisition in Practice



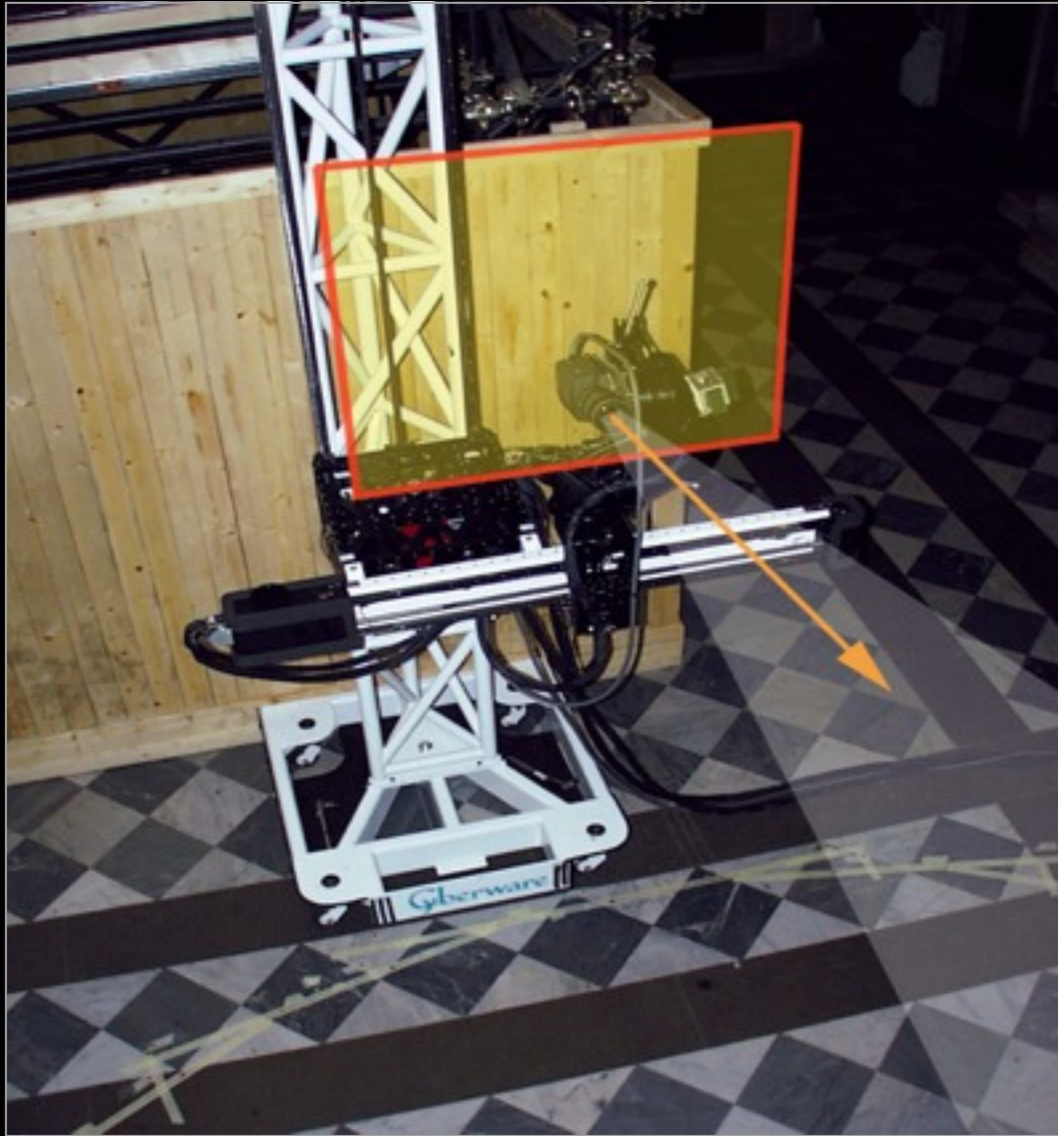
Night (Medici Chapel)

Capturing the light field

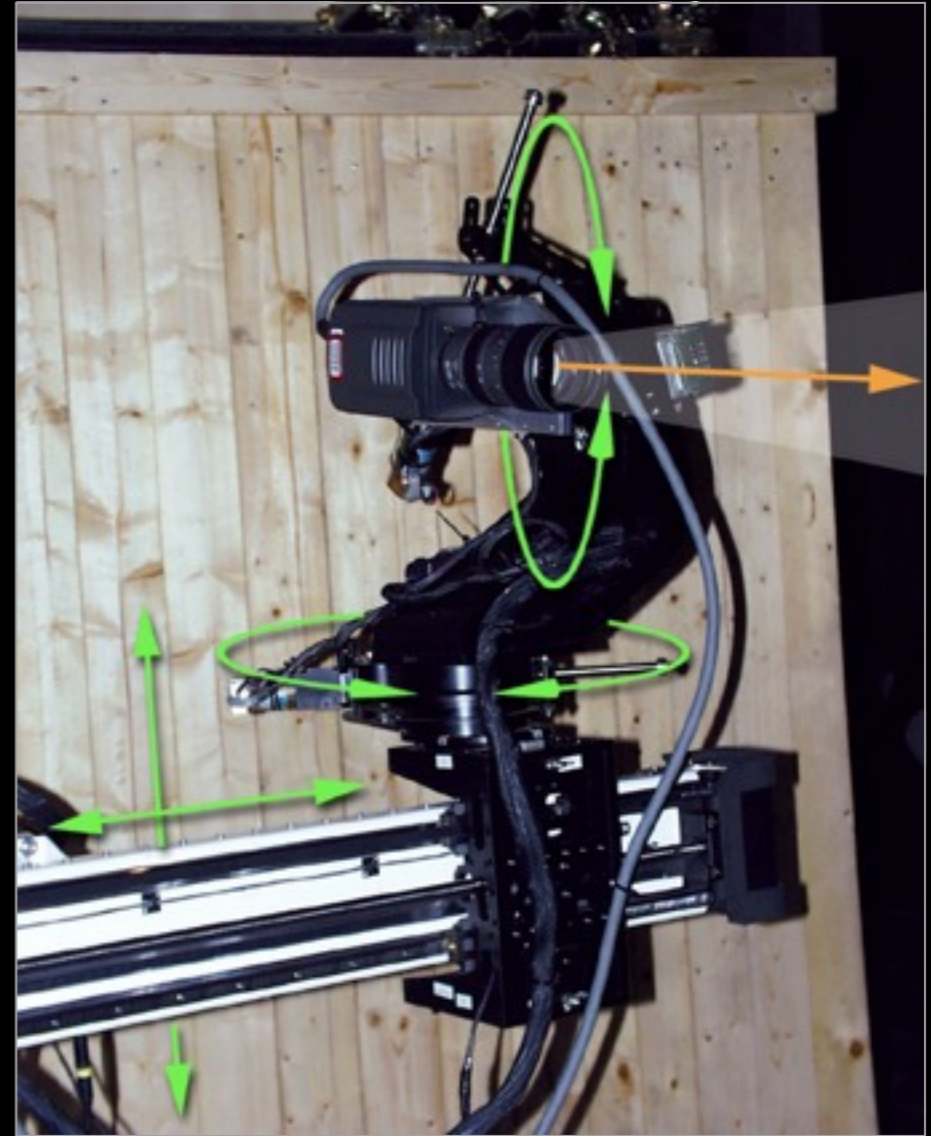


7 light slabs,
each 70cm x 70cm

Capturing the light field



each slab contained 56 x 56 images spaced 12.5mm apart



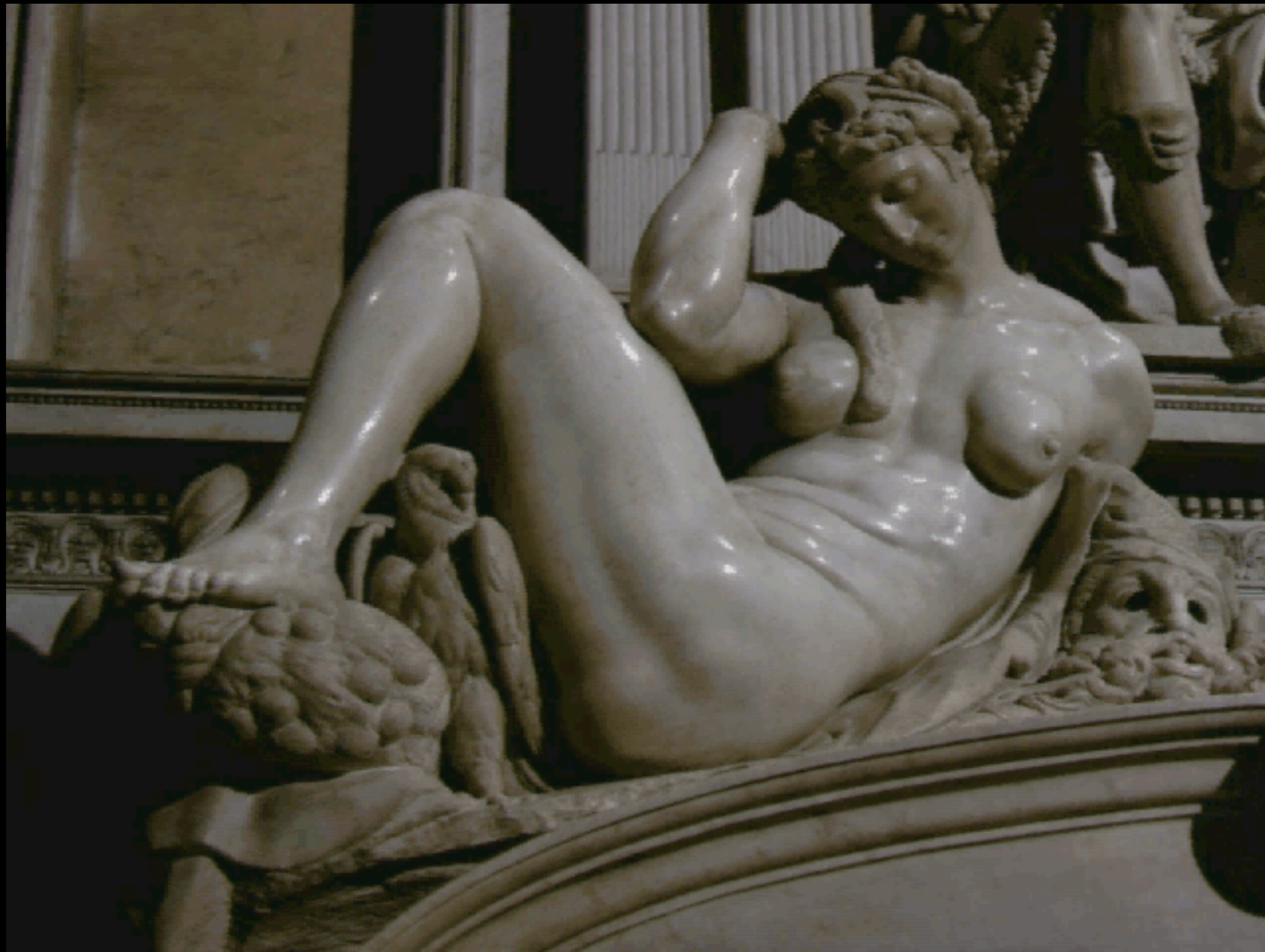
the camera was always aimed at the center of the statue

Statistics about the light field

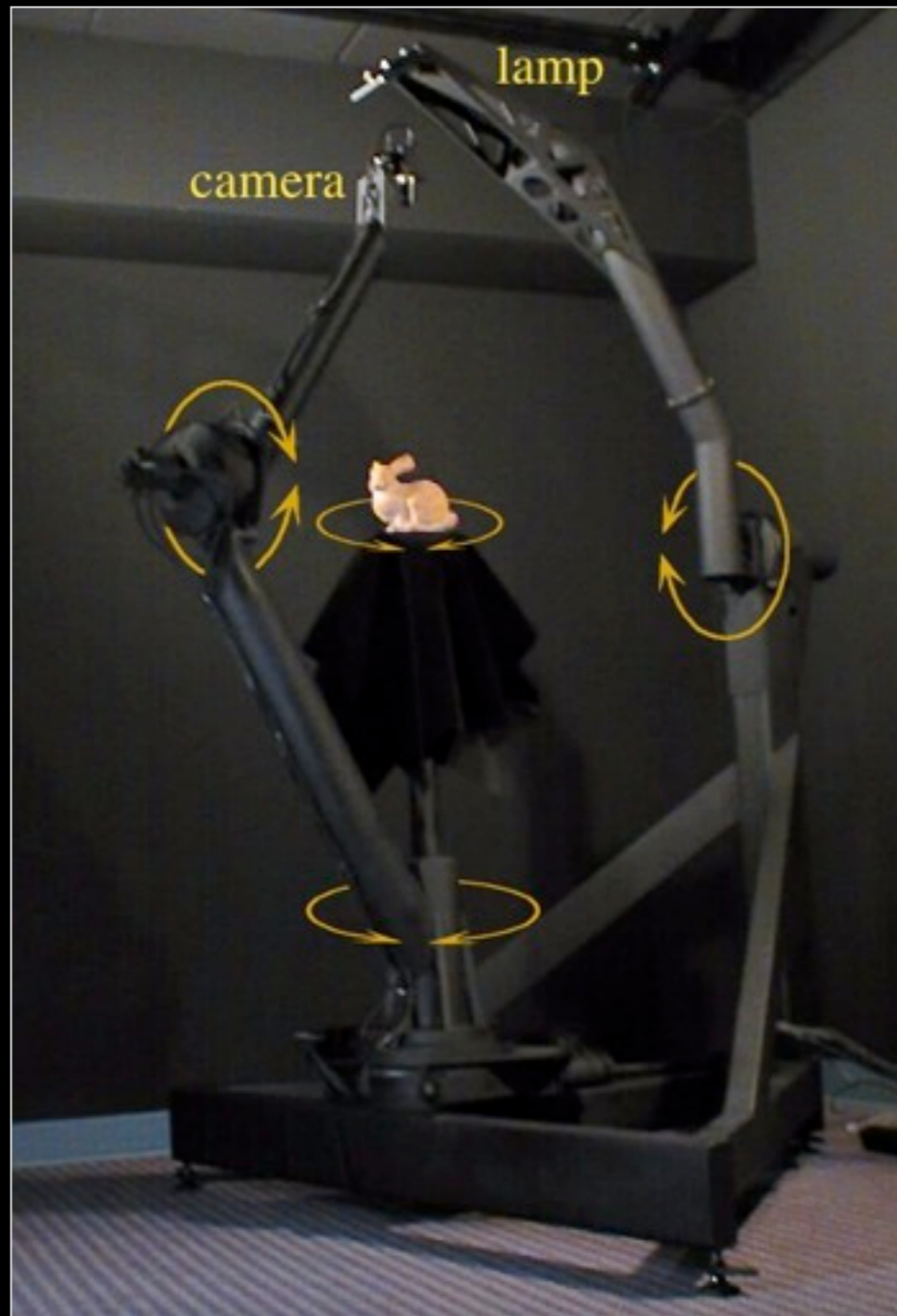
- 392 x 56 images
- 1300 x 1000 pixels each
- 96 gigabytes (uncompressed)
- 35 hours of shooting (over 4 nights)
- also acquired a 0.29 mm 3D model of statue
 - data still hasn't been calibrated and aligned!



One row of light field slab



Other light field capture devices



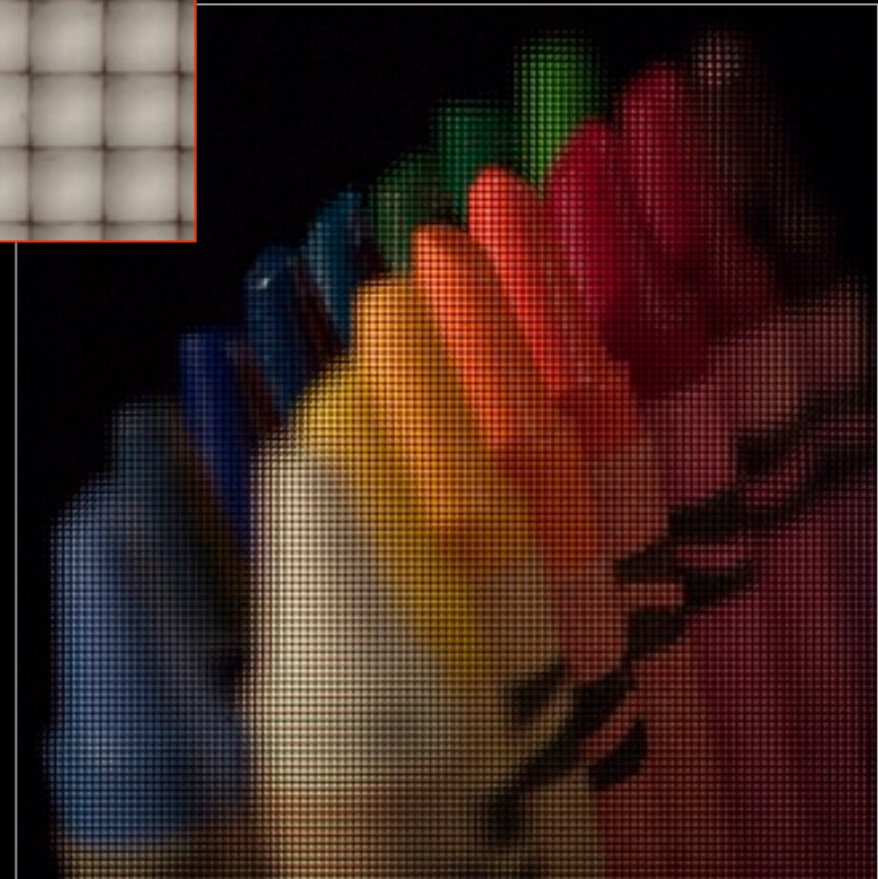
- Stanford spherical gantry [Levoy 2002]
- MIT camera array [Yang 2002]
- CMU camera array [Zhang 2004]
- MSR/China concentric mosaics [Shum 2000]
- Stanford camera array [Wilburn 2005]
- Ren Ng's plenoptic camera [Ng 2005]

Stanford Spherical Gantry

Handheld plenoptic camera

[Ng 2005]

- array of microlenses behind the main lens
- requires modifying the camera



Lytro lightfield camera

[Lytro (AKA Ng) 2012]



Adobe light field camera

[Georgeiv 2006]

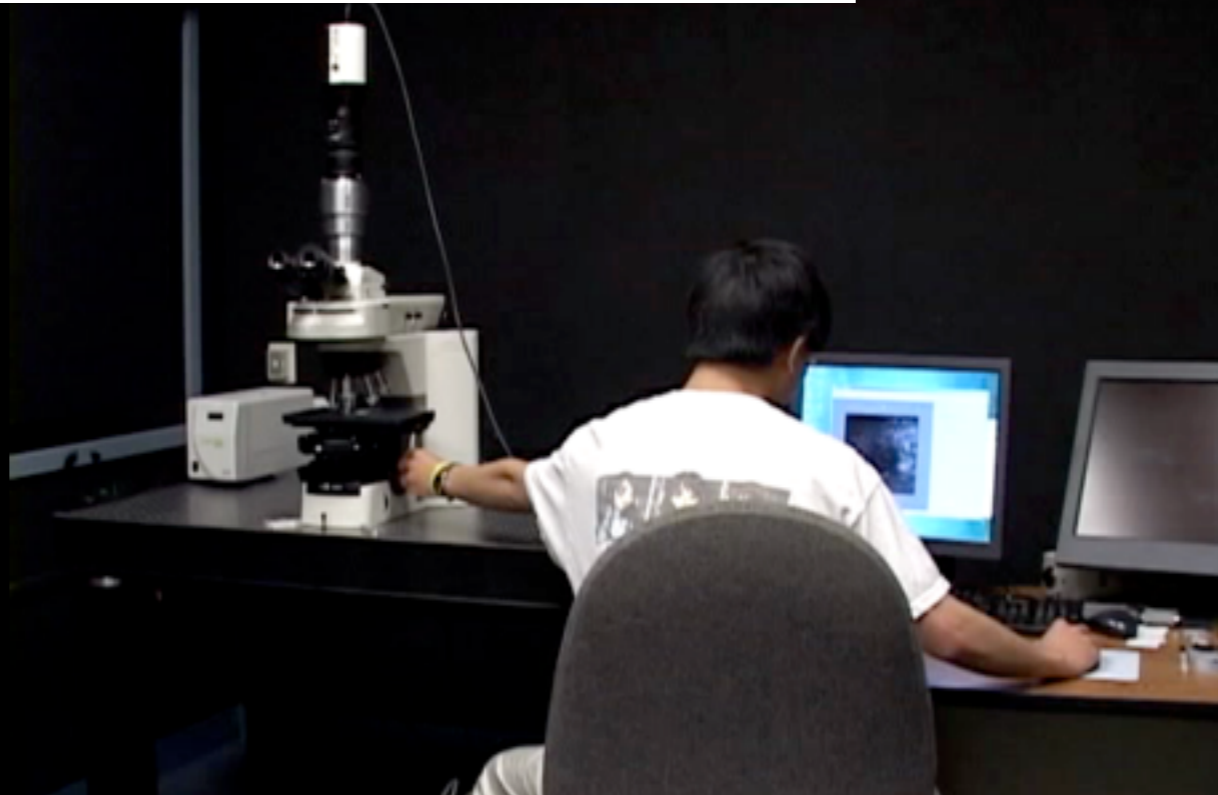
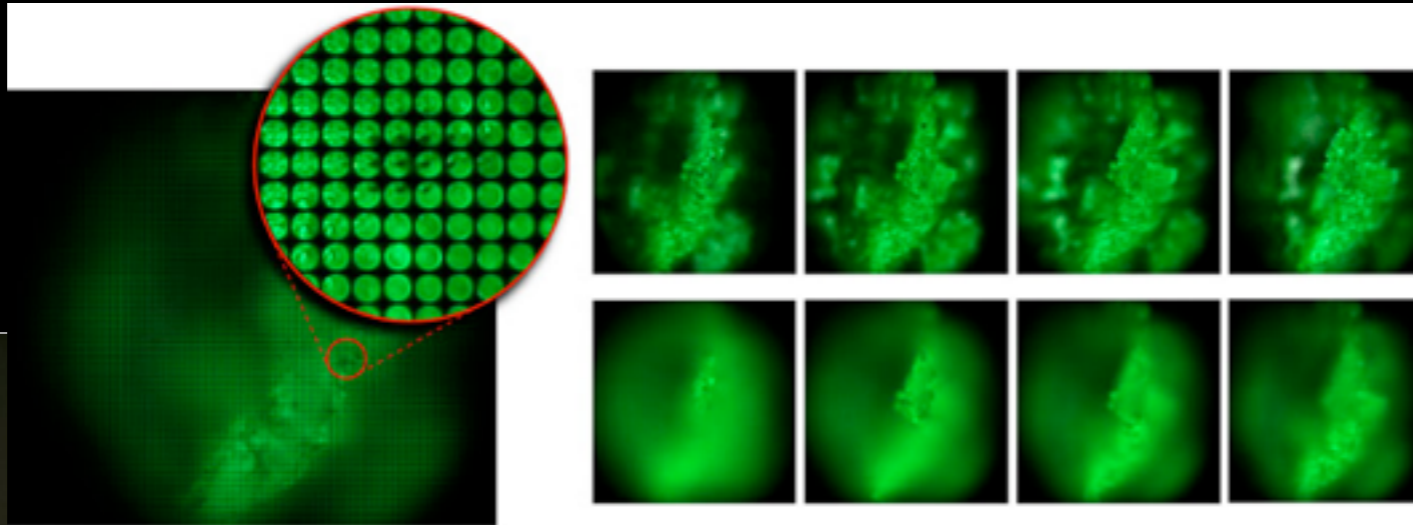
- array of lenslets outside the main lens
- each lenslet must be well-corrected



Light field microscope

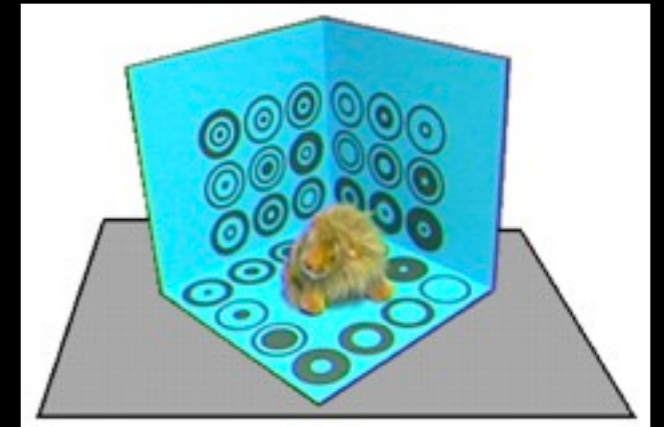
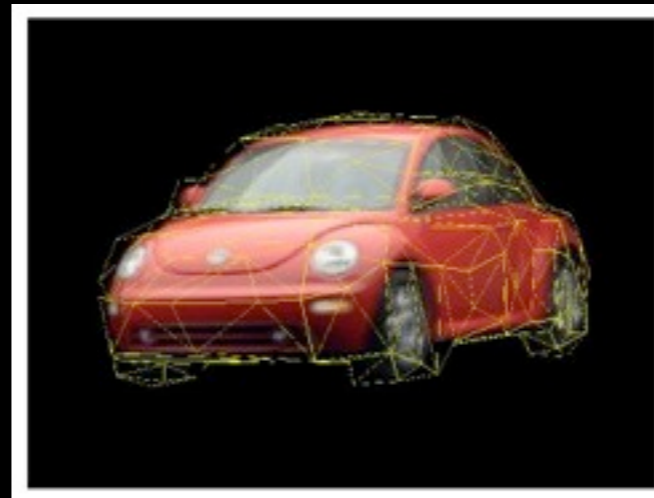
[Levoy 2006]

- array of microlenses behind a microscope objective
- allows oblique views, refocusing, 3D reconstruction



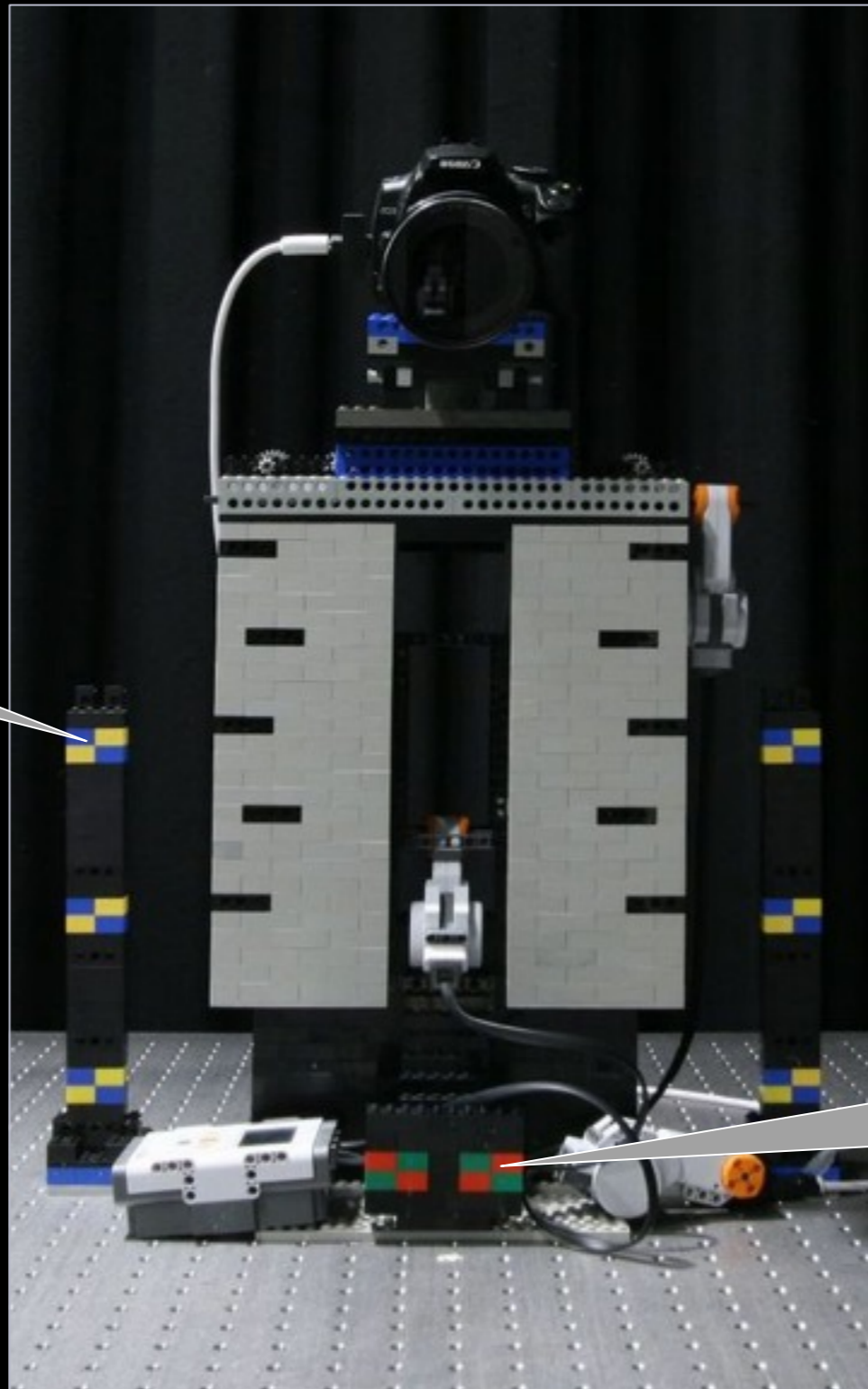
Capturing unstructured light fields using a handheld video camera

- video camera and calibration target [Gortler 1996]
- markerless capture [Buehler 2001]
- interactive capture [Davis 2012]



Lego gantry for capturing light fields

(built by Andrew Adams)



calibration
point

plane + parallax
[Vaish 2004]

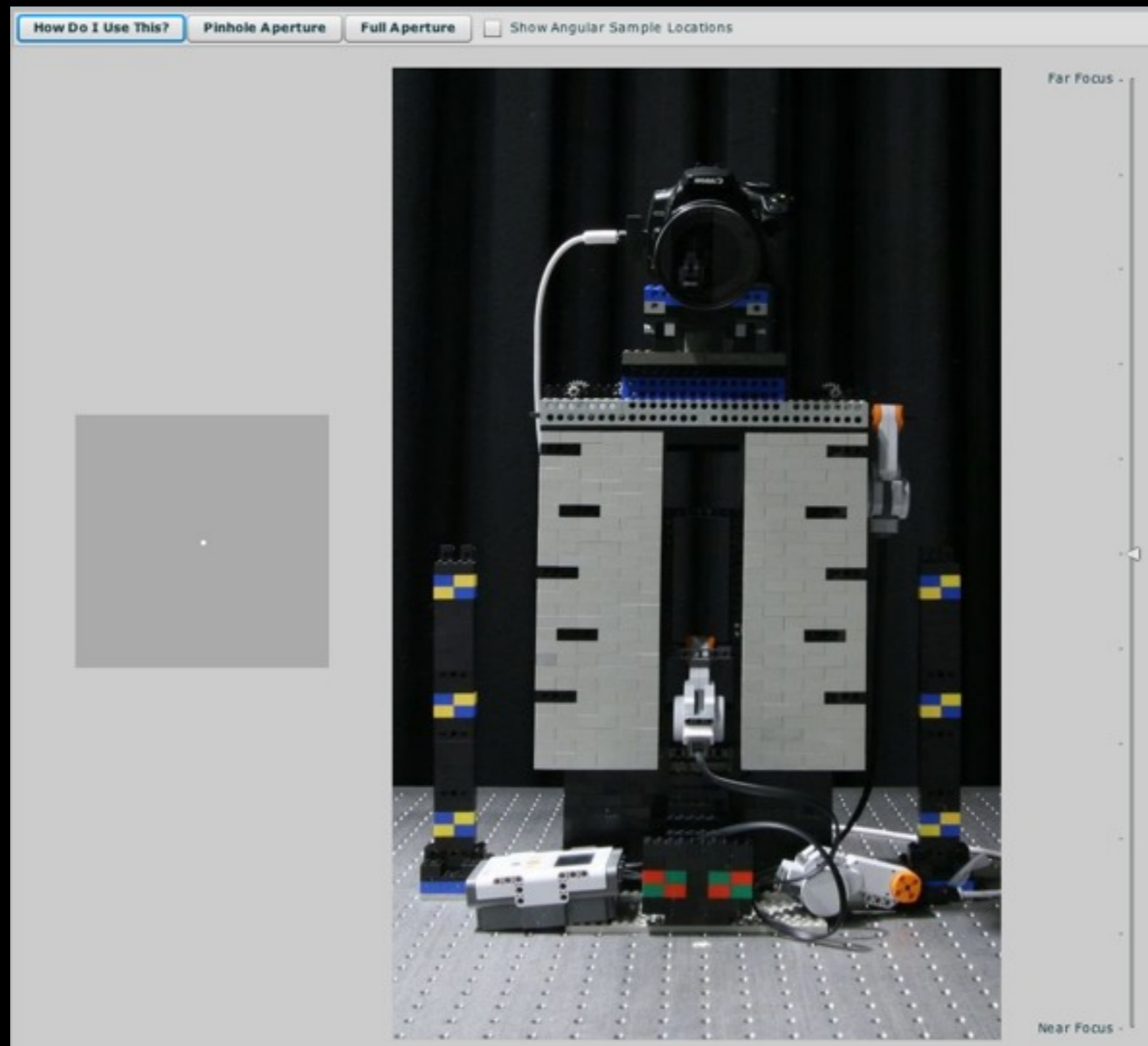
Flash-based viewer for light fields

(written by Andrew Adams)



Try it yourself at <http://lightfield.stanford.edu/>

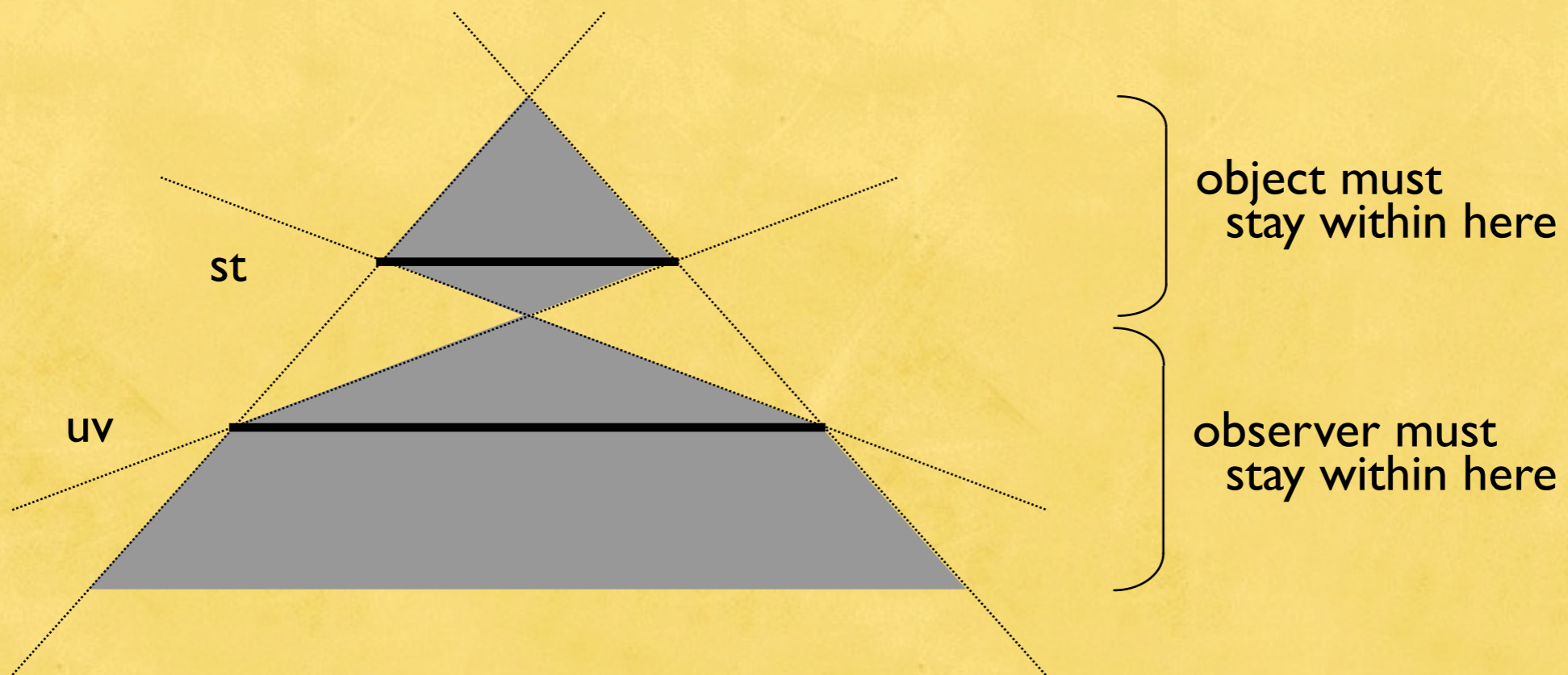
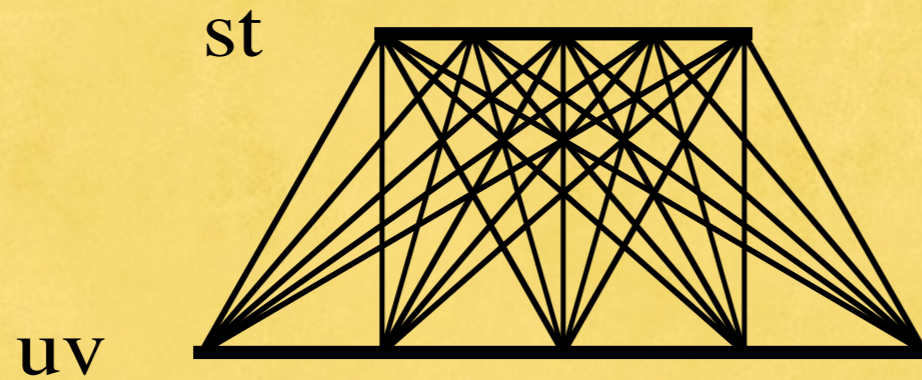
The Lego gantry captures a light field of itself



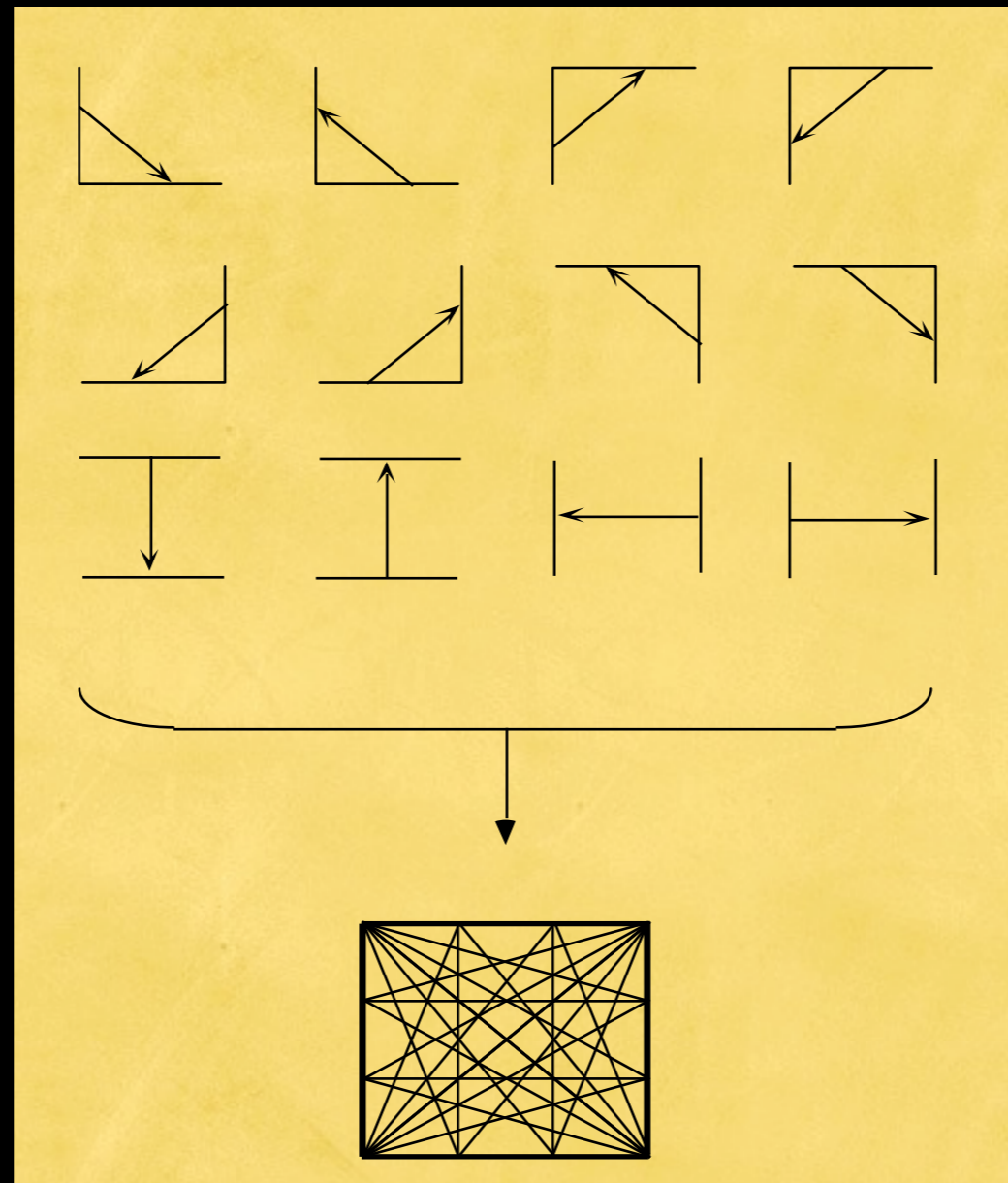
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The coverage of a light field



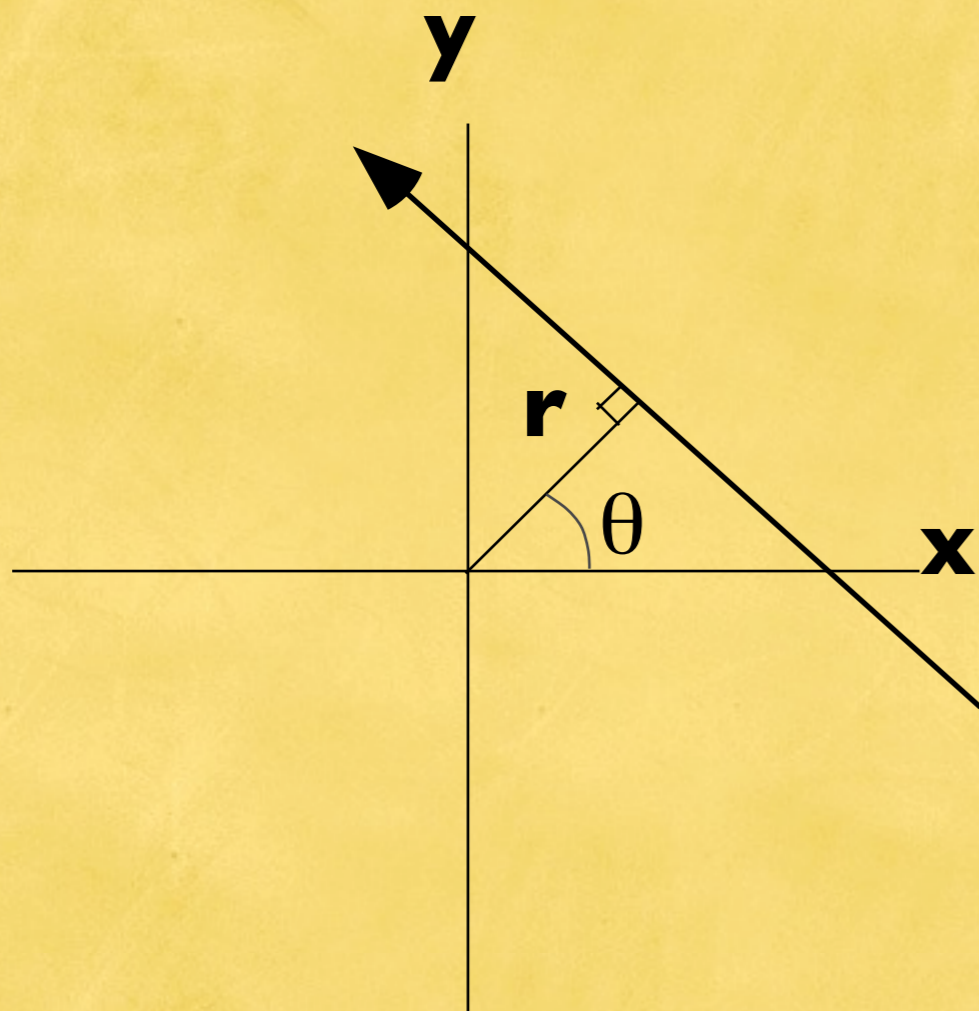
An omni-directional light field



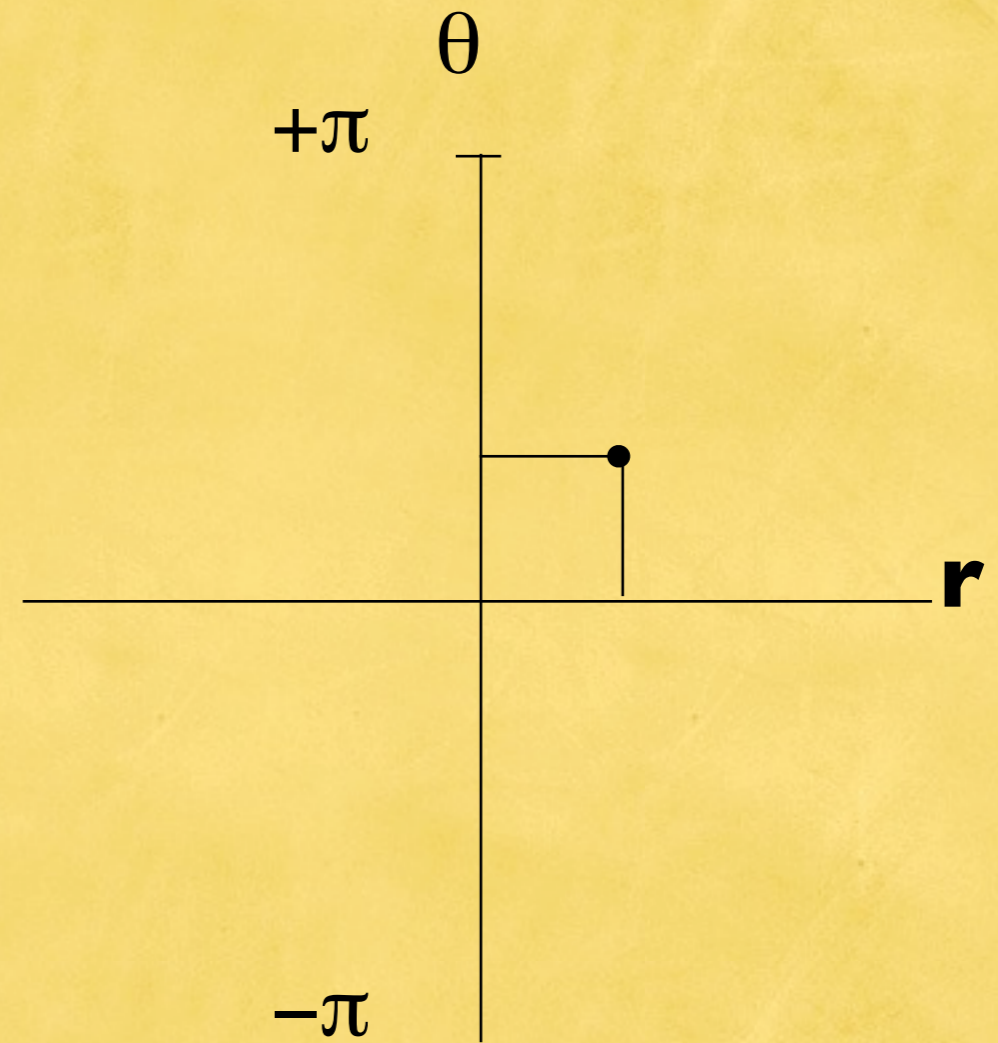
object can fill square

observer can stand anywhere outside square

Line space interpretation



point space



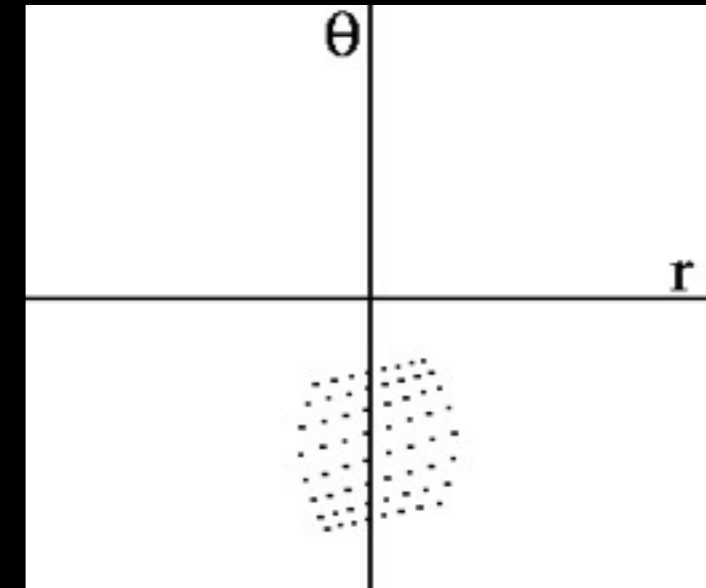
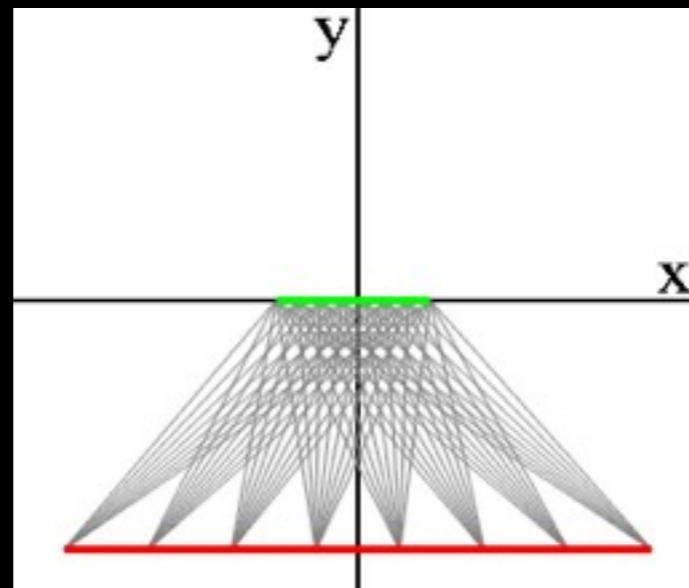
line space

Using line space to visualize ray coverage

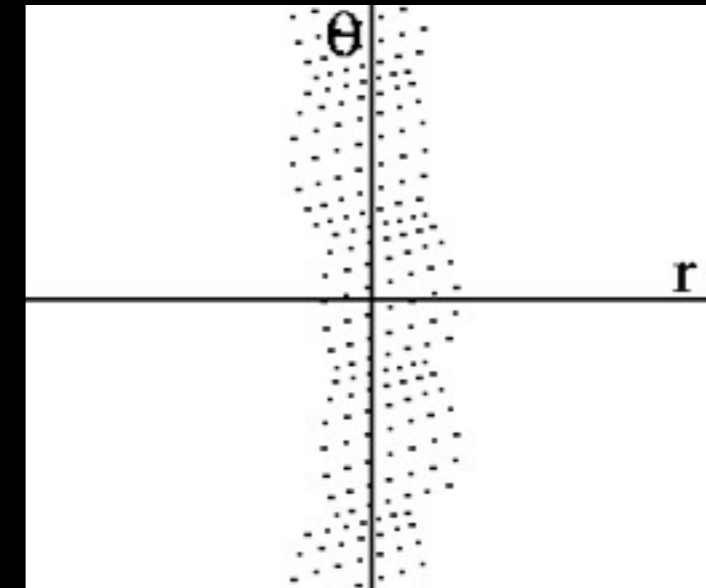
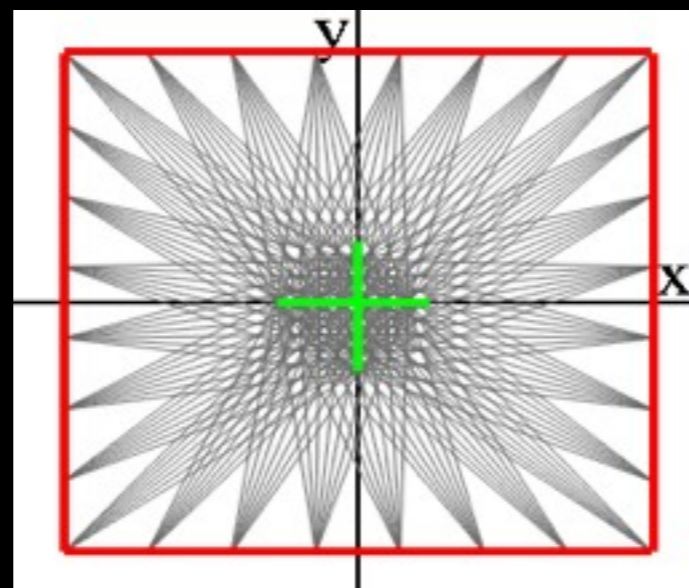
point space

line space

one slab



four slabs

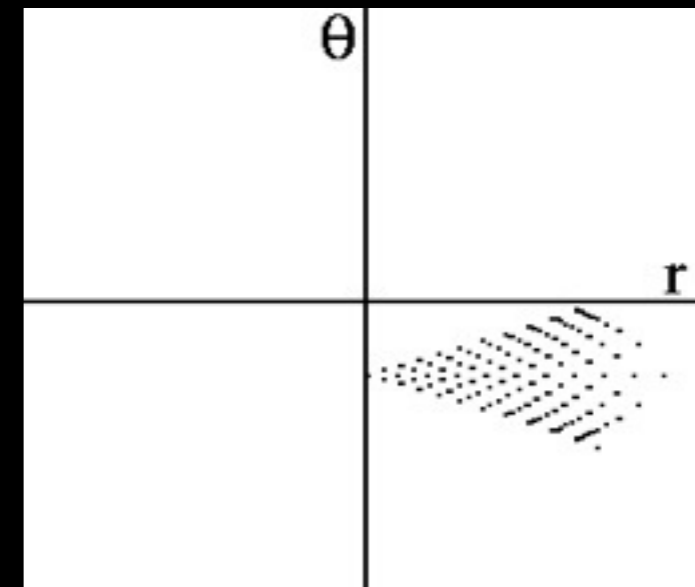
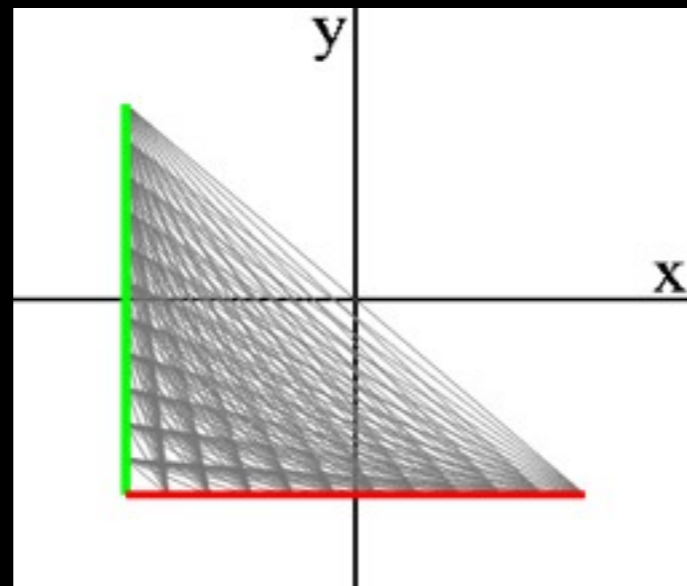


Using line space to visualize sampling uniformity

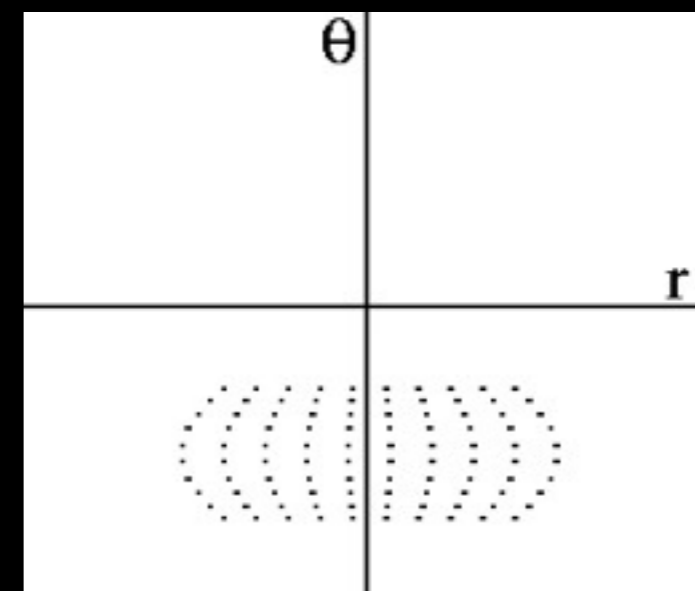
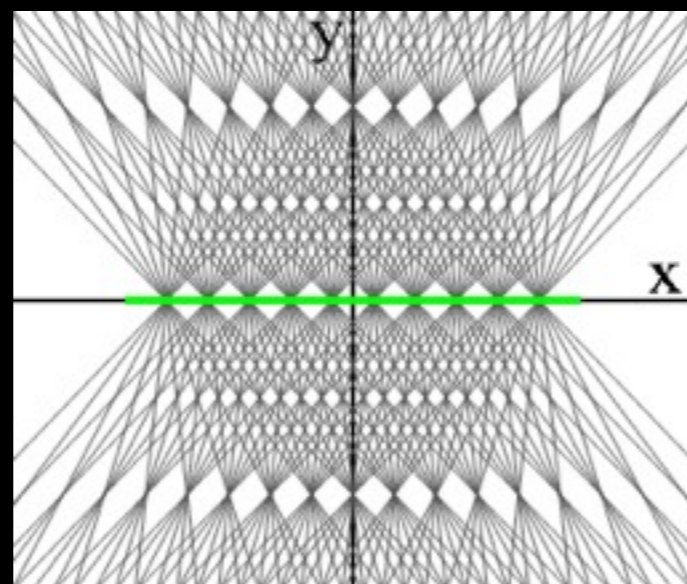
point space

line space

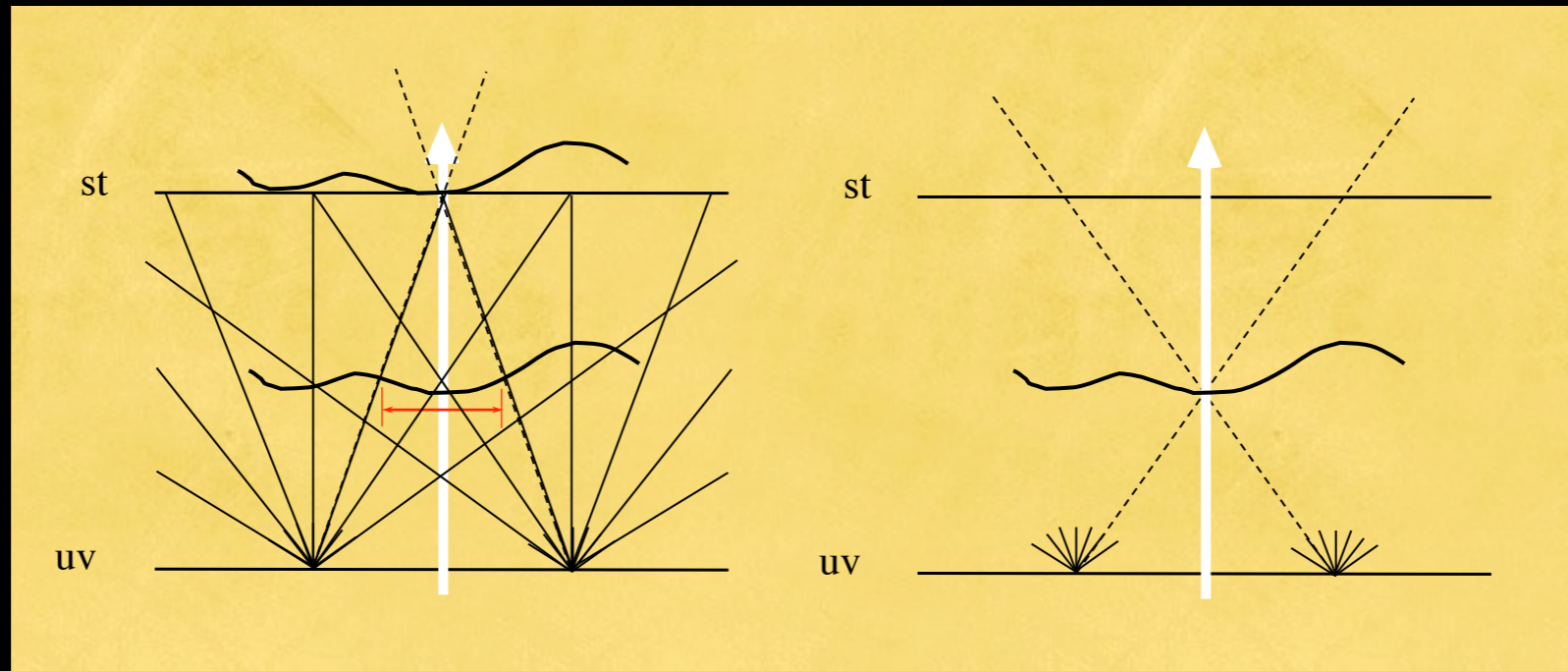
corner



orthographic



Disparity artifacts in light fields



disparity depends on density of samples in the light field and range of depths in the scene

[Levoy 1996]

if the depth of a surface is known, a better set of rays can be extracted, reducing disparity

[Gortler 1996]

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3D reconstruction from light fields



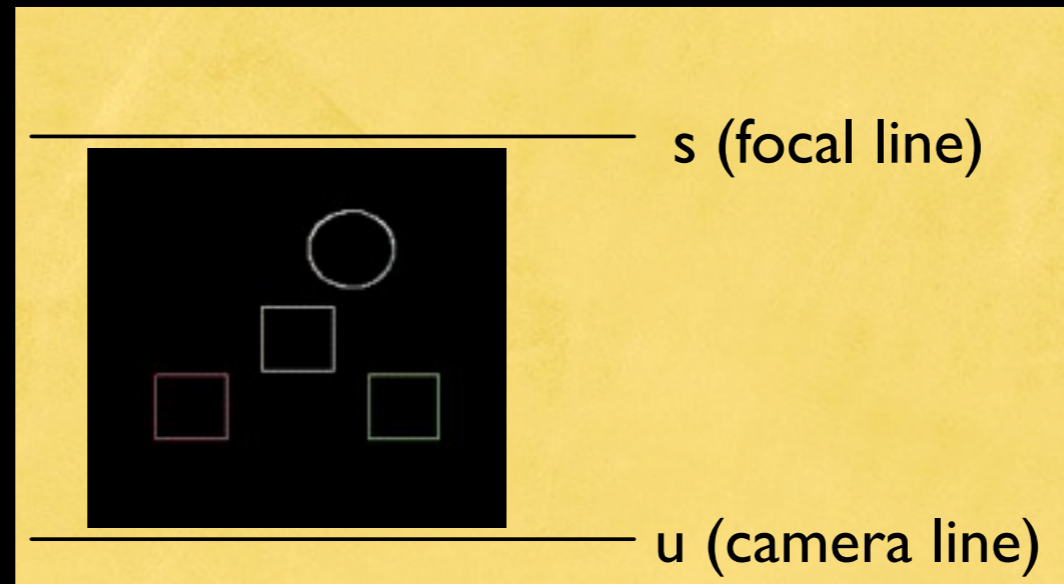
light field



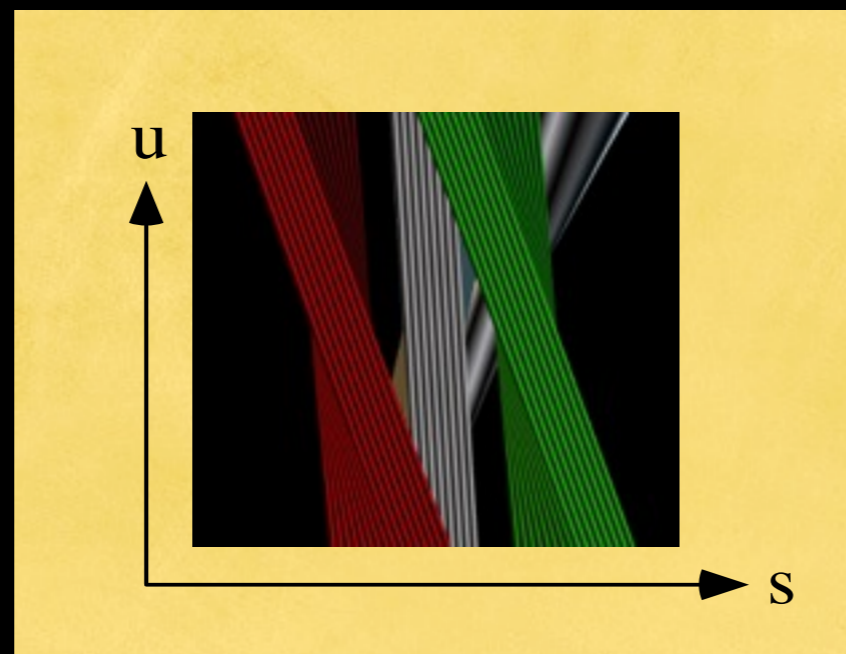
synthetic focal sequence

Vision algorithms interpreted in line space

flatland scene

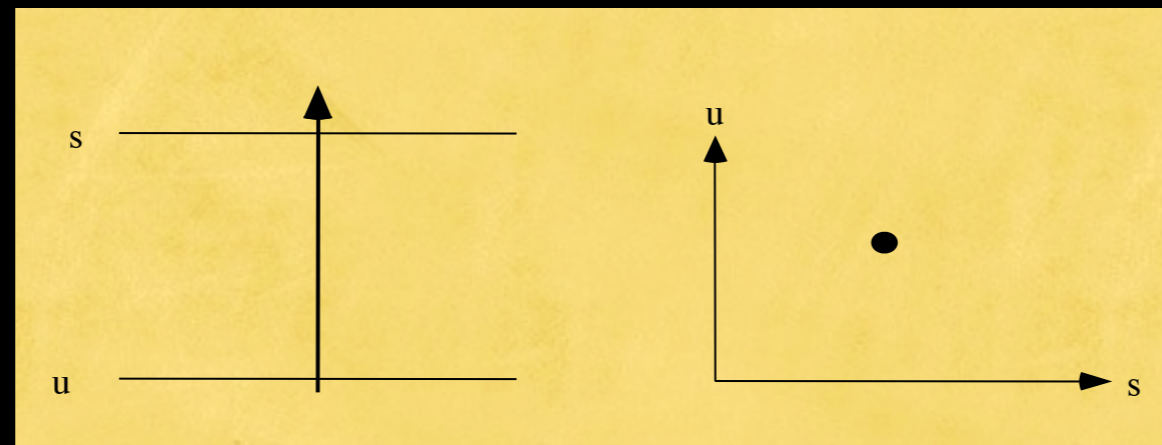


flatland light field (a.k.a. epipolar image) [Bolles 1987]

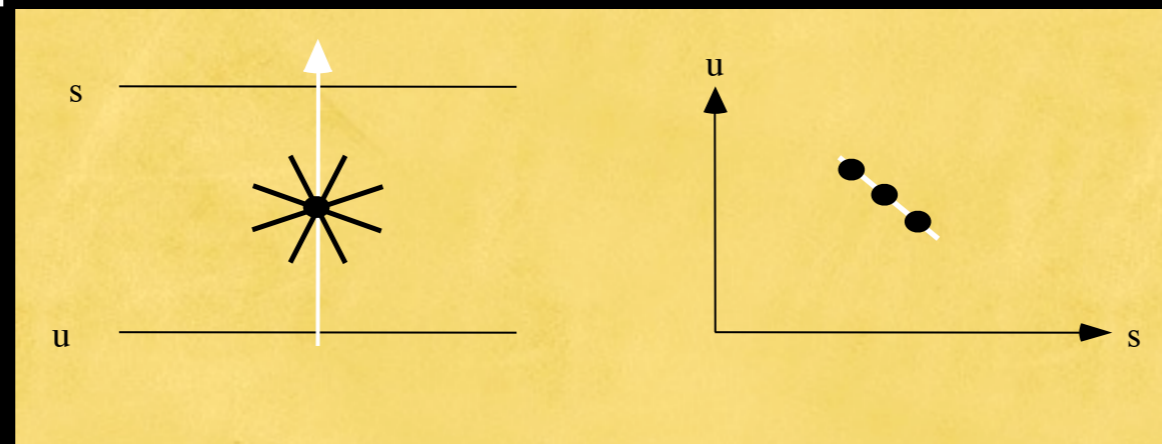


Line space dualities

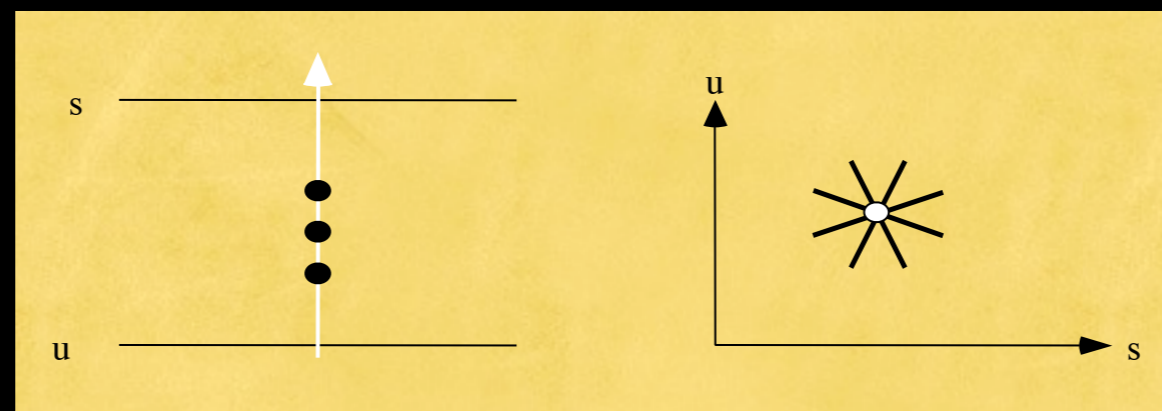
a line



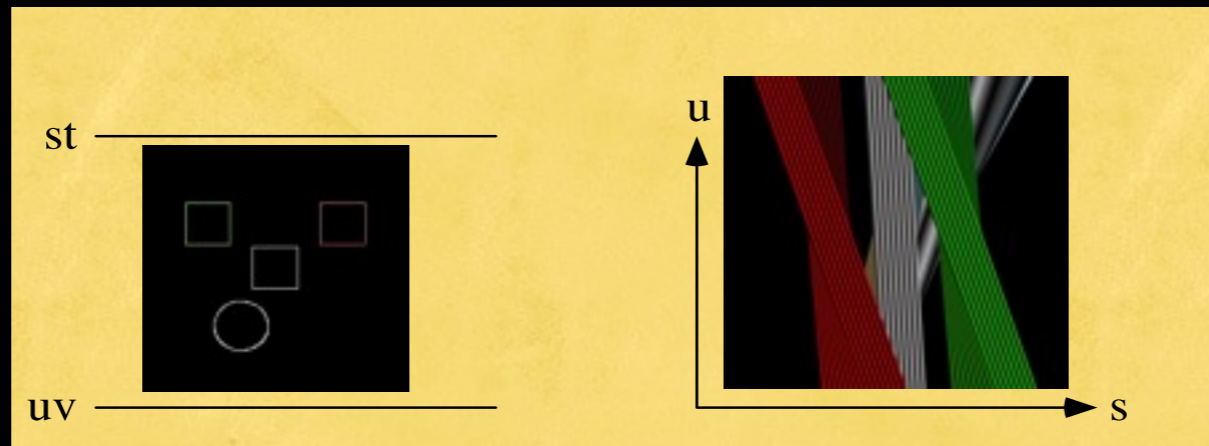
lines through a point



points on a line



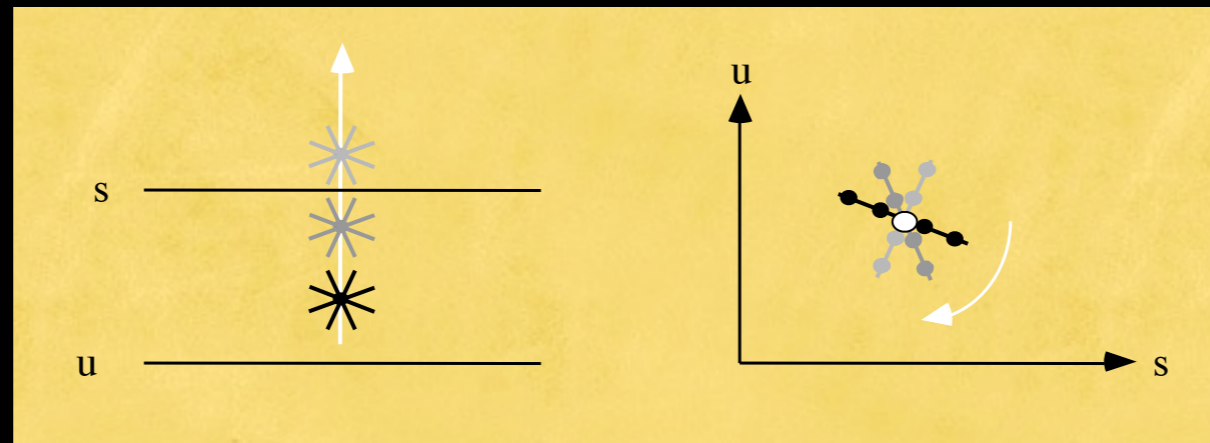
Shape from stereo versus shape from focus



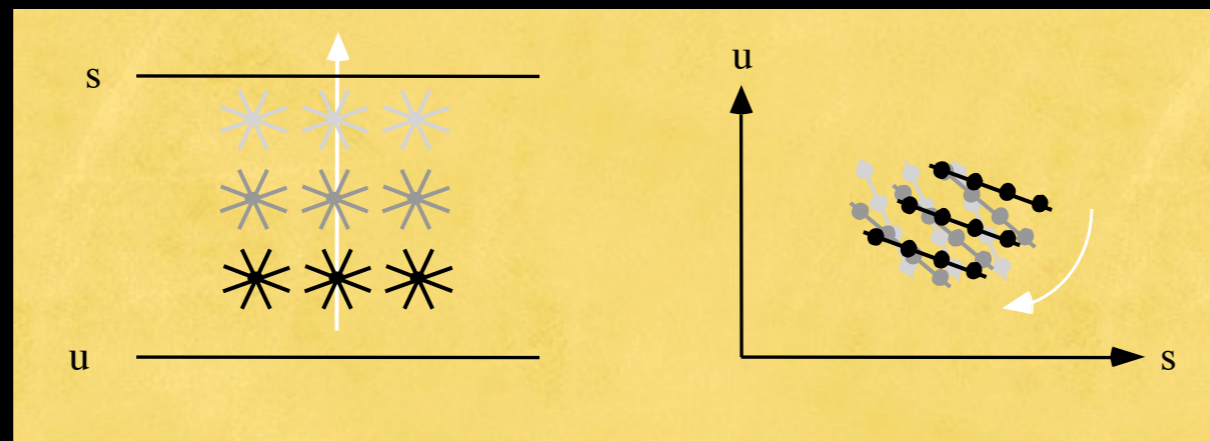
scene

light field

shape from stereo



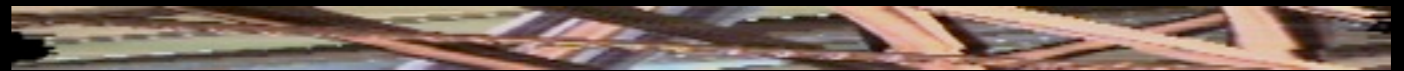
shape from focus



Shape from focus example



rectified camera images



slice of epipolar volume at scanline 119



synthetic focus sequence

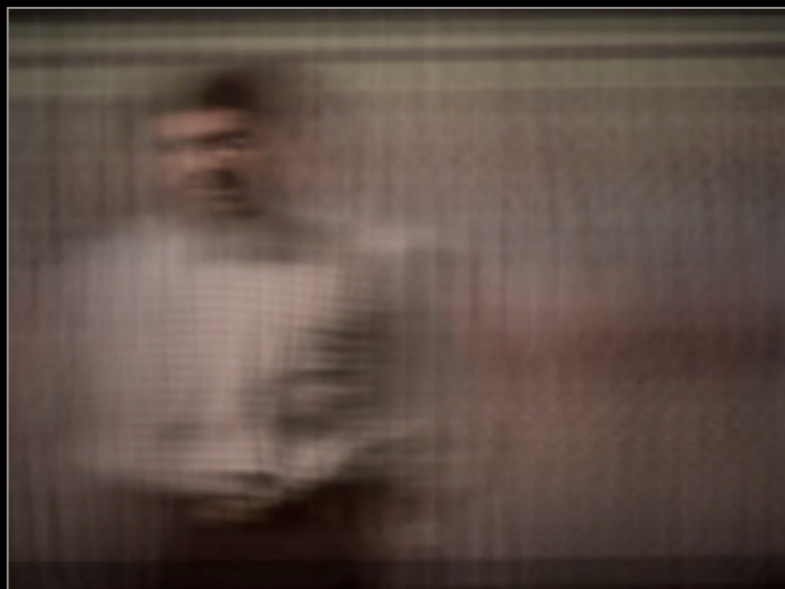


slice at scanline 261

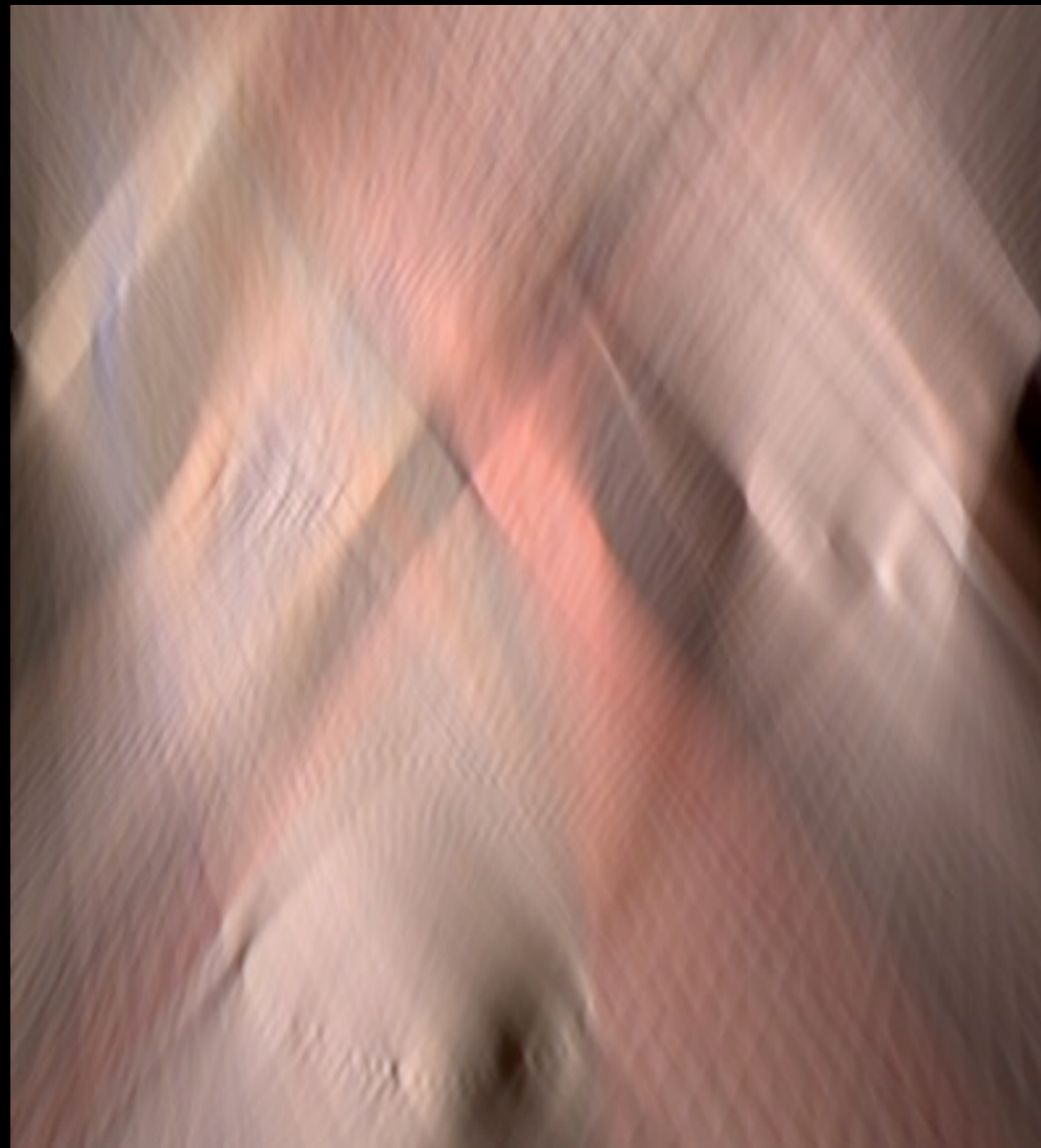
Shape from focus example



rectified camera images



synthetic focus sequence

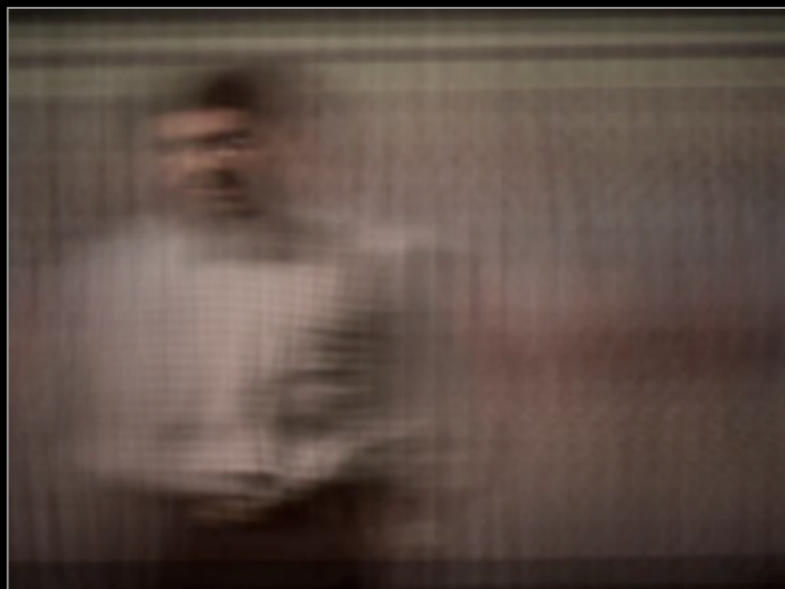


one scanline with different focal distances,
i.e. one slice from a focal stack

Shape from focus example



rectified camera images



synthetic focus sequence

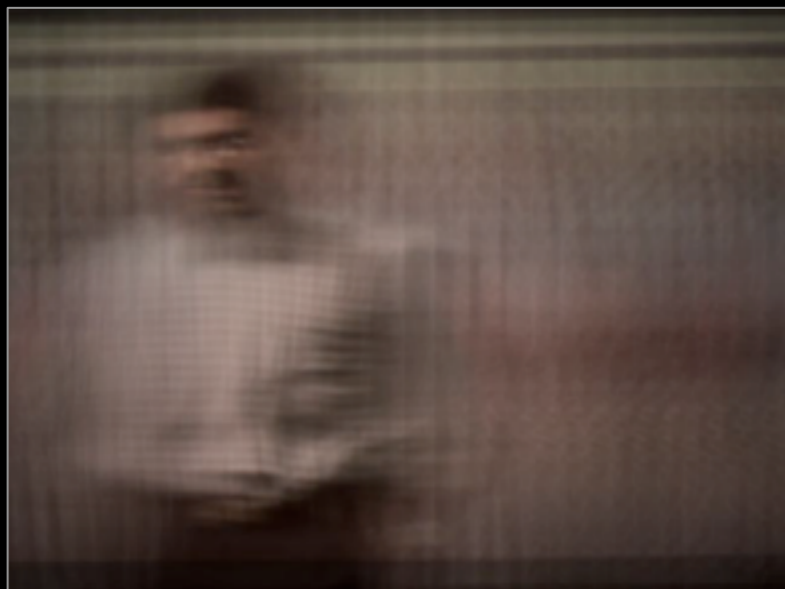


one scanline with different focal distances,
i.e. one slice from a focal stack

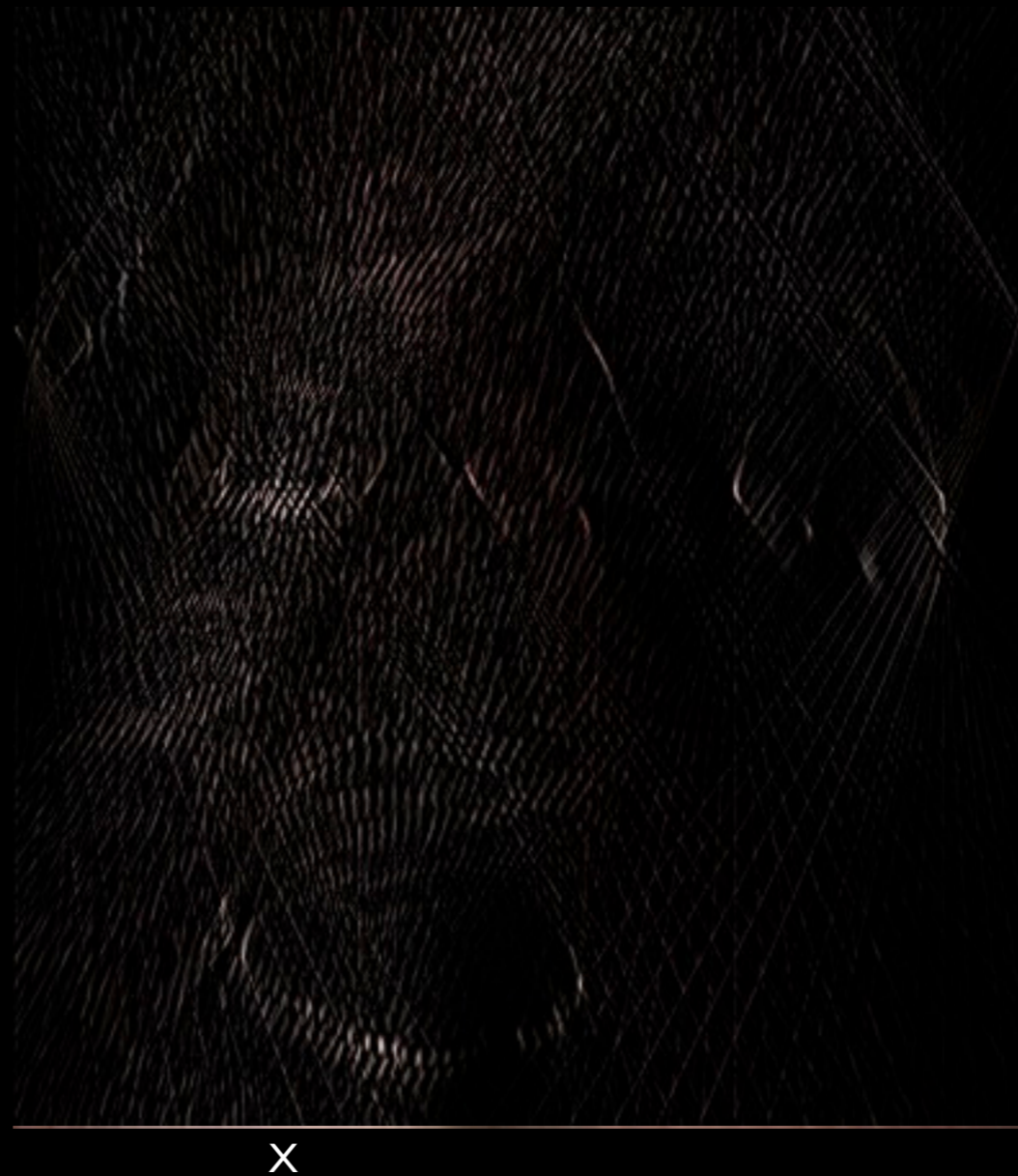
Shape from focus example



rectified camera images



synthetic focus sequence



after applying
x-sharpness
operator

one scanline with different focal distances,
i.e. one slice from a focal stack

Which is better: stereo or focus?

stereo

fails on heavily occluded scenes

focus

fails on surfaces with linear ramp shading

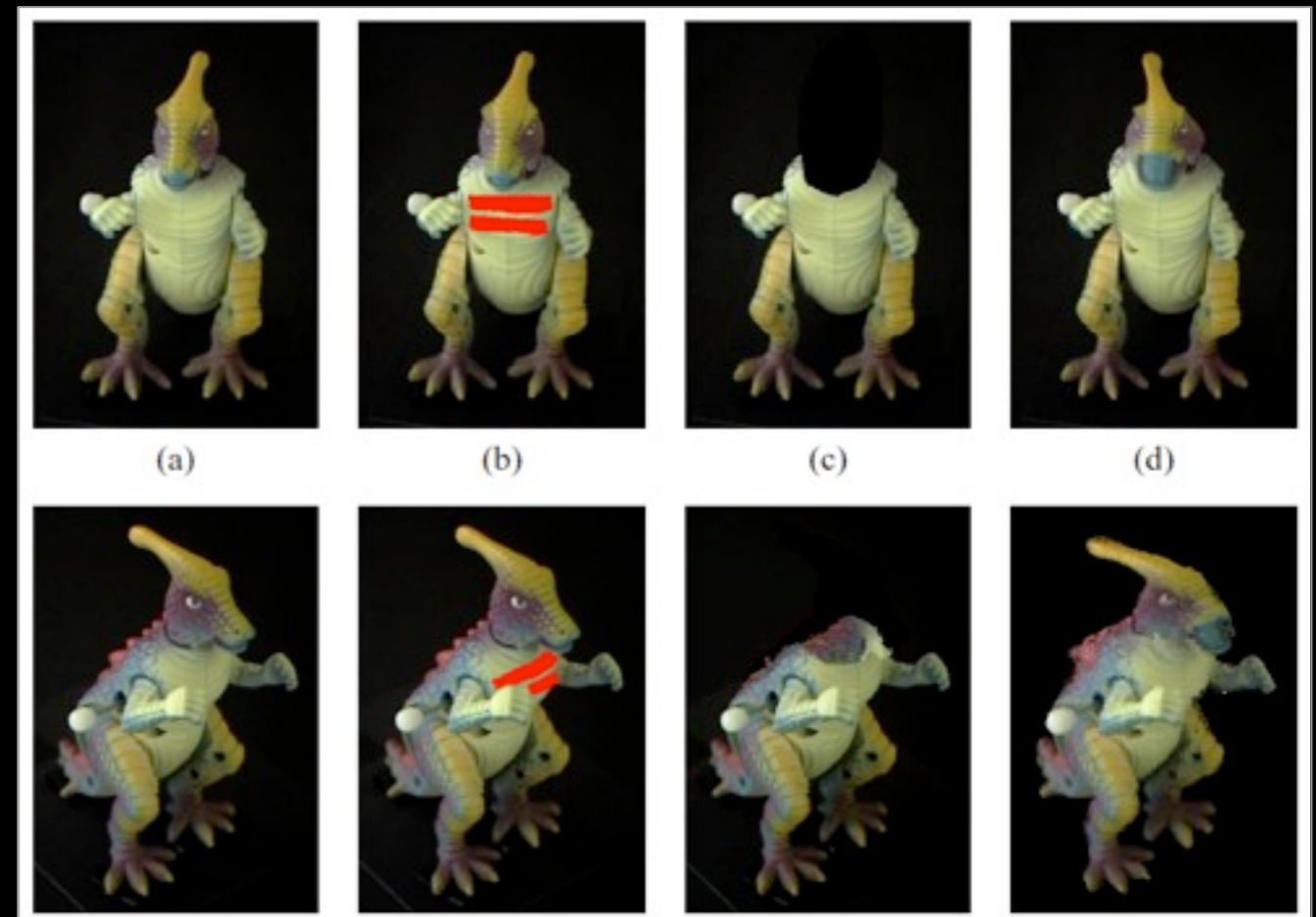
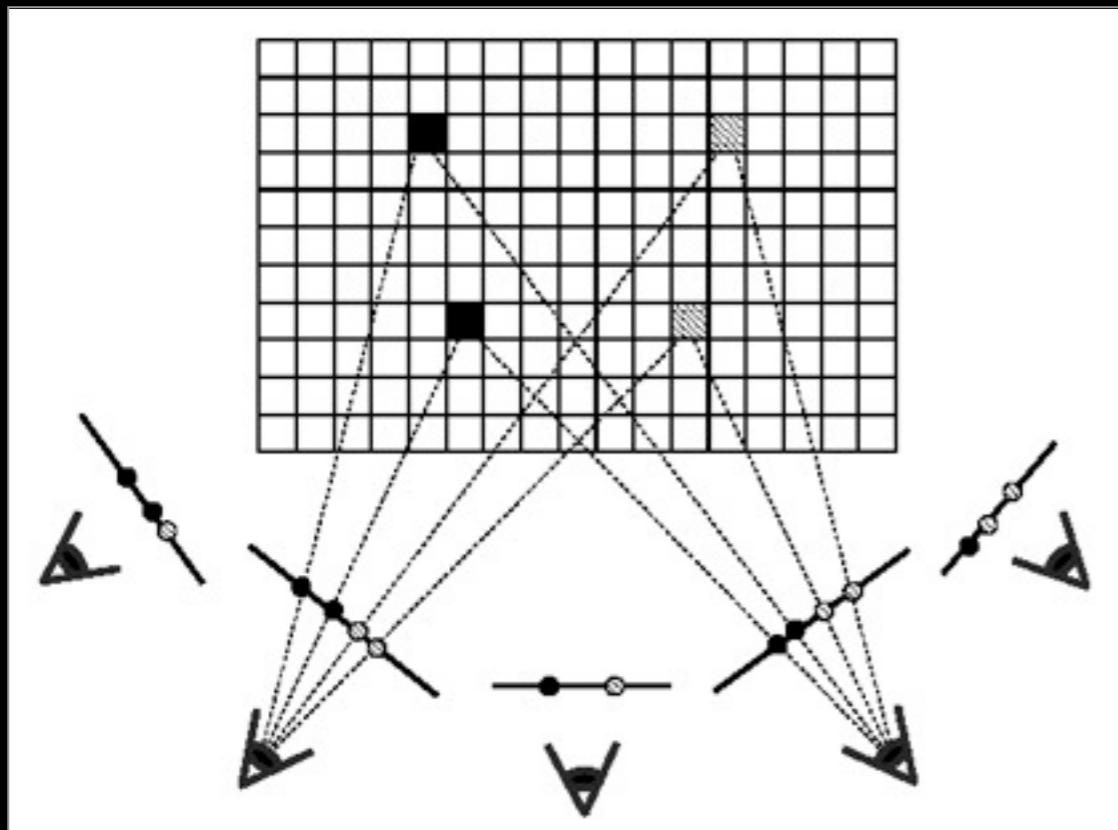
hybrid?

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Plenoptic image editing

[Seitz 1998]



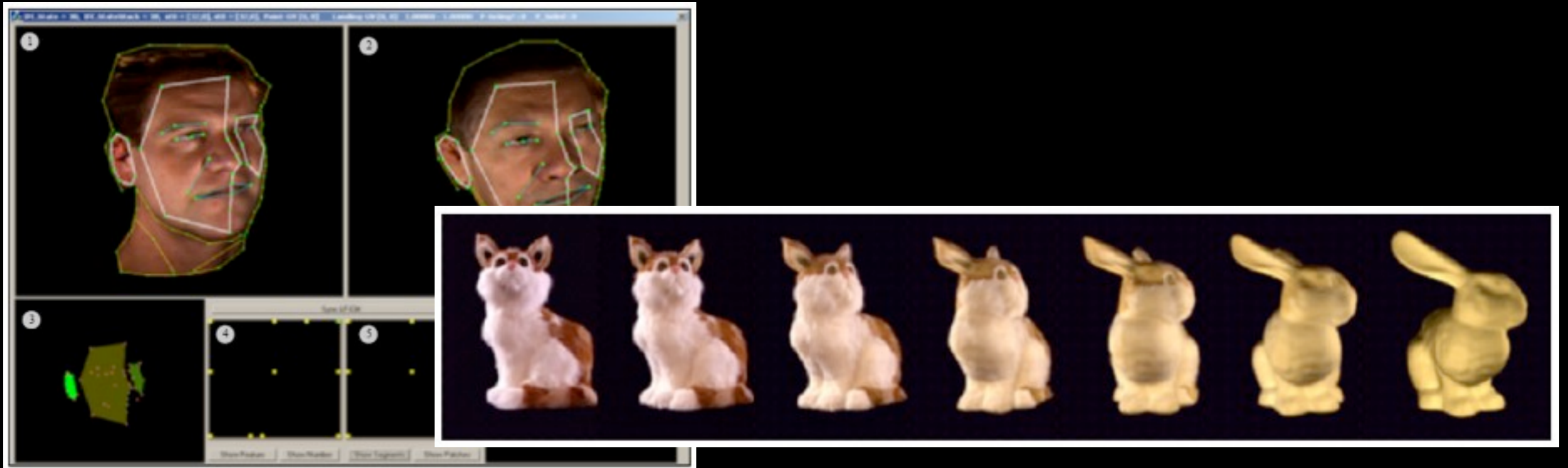
use color consistency constraints [Seitz 1997] to obtain voxel model
store mapping between pixels in images and voxels in model
for each pixel changed during editing

change corresponding voxel

change corresponding pixels in all other views

Light field morphing

[Zhang et al., SIGGRAPH 2002]



UI for specifying feature polygons
and their correspondences

sample morph

feature correspondences = 3D model

Autostereoscopic display of light fields

[Isaksen 2000]

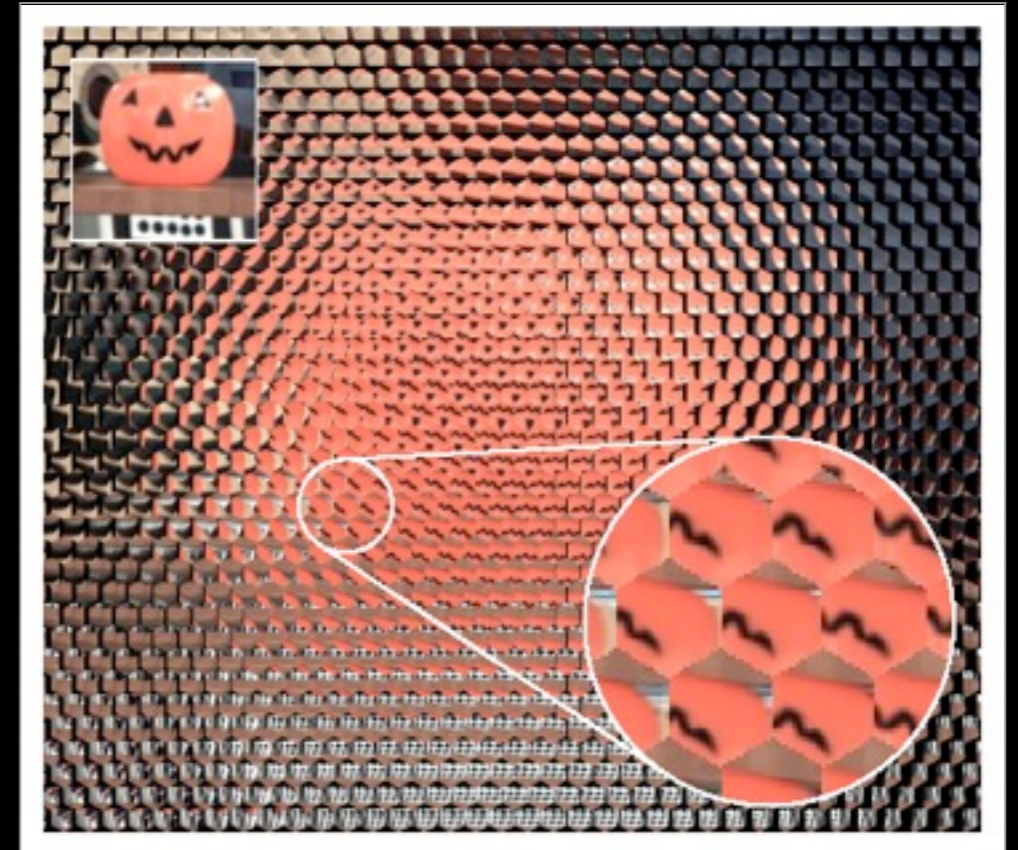
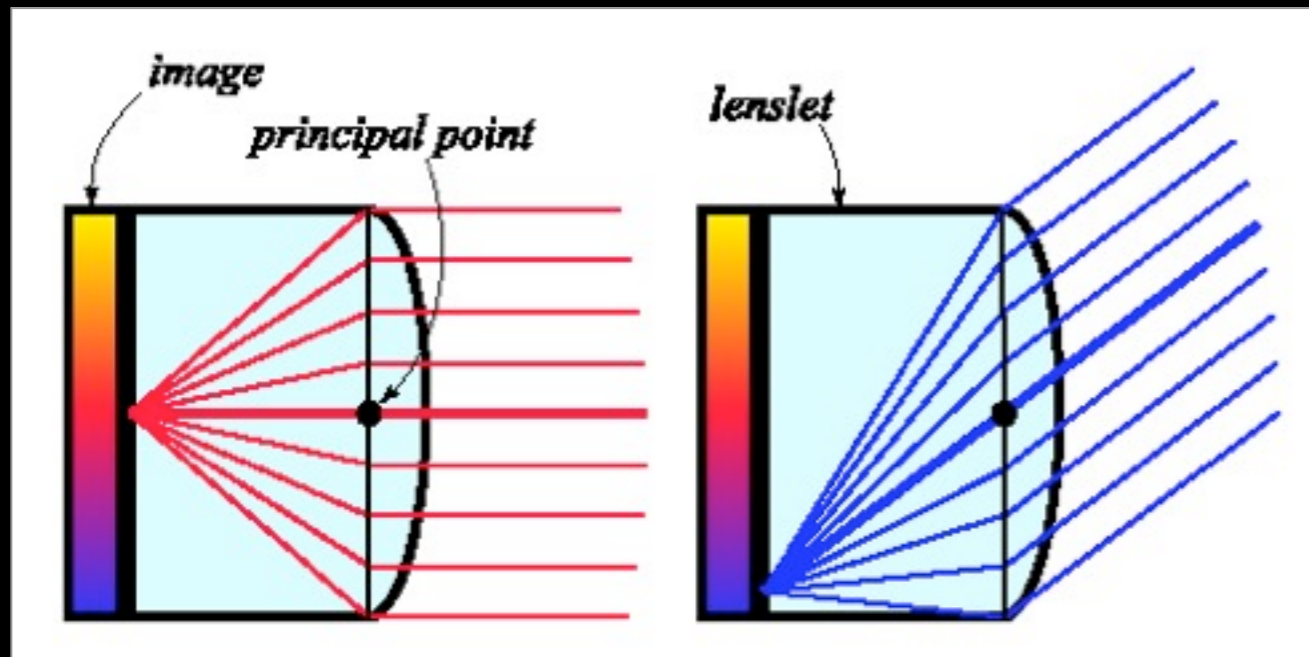


image is at focal distance of lenslet \Rightarrow collimated rays

spatial resolution \sim # of lenslets in the array

angular resolution \sim # of pixels behind each lenslet

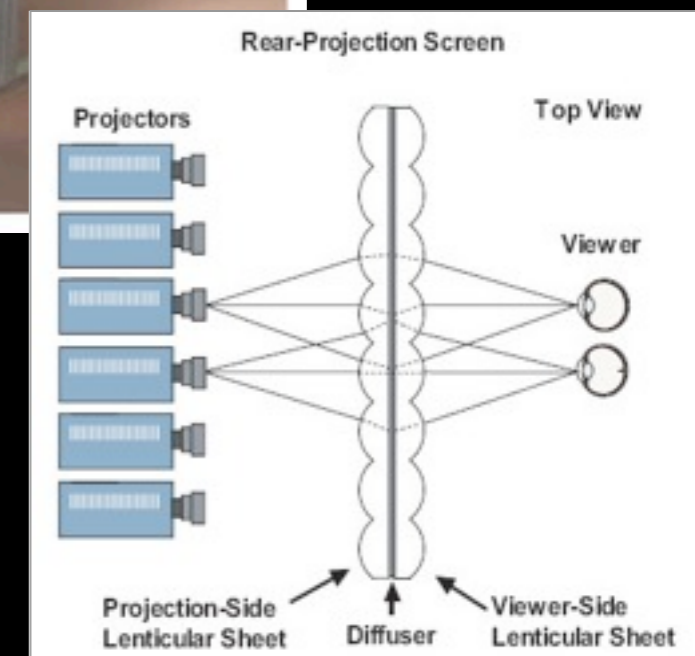
each eye sees a different sets of pixels \Rightarrow stereo

Autostereoscopic display of light fields

[Matusik 2004]



16 cameras, 16 projectors
spatial resolution \sim # of pixels in projector
angular resolution \sim # of projectors
of lenslets is unimportant



Tomographic Image Synthesis

[Wetzstein 2011]



2-6 attenuating layers of plastic

spatial resolution \sim printer resolution

angular resolution \sim variable, 10° works well

Slide credits

- ◆ Gershun, A., "The Light Field", Moscow, 1936. Translated by P. Moon and G. Timoshenko in *Journal of Mathematics and Physics*, Vol. XVIII, MIT, 1939, pp. 51–151.
- ◆ Adelson, E.H., Bergen, J.R., "The plenoptic function and the elements of early vision," In *Computation Models of Visual Processing*, MIT Press, 1991.
- ◆ Moon, P., Spencer, D.E., *The Photic Field*, MIT Press, 1981.
- ◆ Chen, S.E., Williams, L., "View interpolation for image synthesis," *Proc. SIGGRAPH 1995*.
- ◆ Levoy, M., Hanrahan, P., "Light Field Rendering," *Proc. SIGGRAPH 1996*.
- ◆ Wood, D.N. et al., "Surface Light Fields for 3D Photography," *Proc. SIGGRAPH 2000*.
- ◆ Salesin, D., Stolfi, J., "Rendering CSG Models with a ZZ-Buffer," *Proc. SIGGRAPH 1990*.
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