Computational Camera & Photography:

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MIT Media Lab

http:// CameraCulture . info/

Plan for Today

- Computational Illumination
- Introduction to Lightfields
- Assignment #2: Optics
  - A: Virtual Optical Bench
  - B: Lightfields
- Check Wiki for Reading Material
  - Pl edit, add URLs, figures, comments etc
- Everyone on comp-cam mailing list?
- Listeners: Pl send a topic you would like to present (15-20 mins)
- Youtube videos on camera tutorial (DoF etc)
  http://www.youtube.com/user/MPTutor

Final Project Ideas

- User interaction device
  - Camera based
  - Illumination based
  - Photodetector or line-scan camera
- Capture the invisible
  - Tomography for internals
  - Structured light for 3D scanning
  - Fluorescence for transparent materials
- Cameras in different EM/other spectrum
  - Wifi, audio, magnetic, haptic, capacitive
  - Visible Thermal IR segmentation
  - Thermal IR (emotion detection, motion detector)
  - Multispectral camera, discriminating (camel-sand)
- Illumination
  - Multi-flash with lighfield
  - Schielren photography
  - Strobing and Colored strobing
- External non-imaging sensor
  - Camera with gyro movement sensors, find identity of user
  - Cameras with GPS and online geo-tagged photo collections
  - Interaction between two cameras (with lasers on-board)
- Optics
  - Lightfield
  - Coded aperture
  - Bio-inspired vision
- Time
  - Time-lapse photos
  - Motion blur

Sample Final Projects

- Schlieren Photography
  - (Best project award + Prize in 2008)
- Camera array for Particle Image Velocimetry
- BiDirectional Screen
- Looking Around a Corner (theory)
- Tomography machine
- ..
- ..

Auto Focus

- Contrast method compares contrast of images at three depths,
  if in focus, image will have high contrast, else not

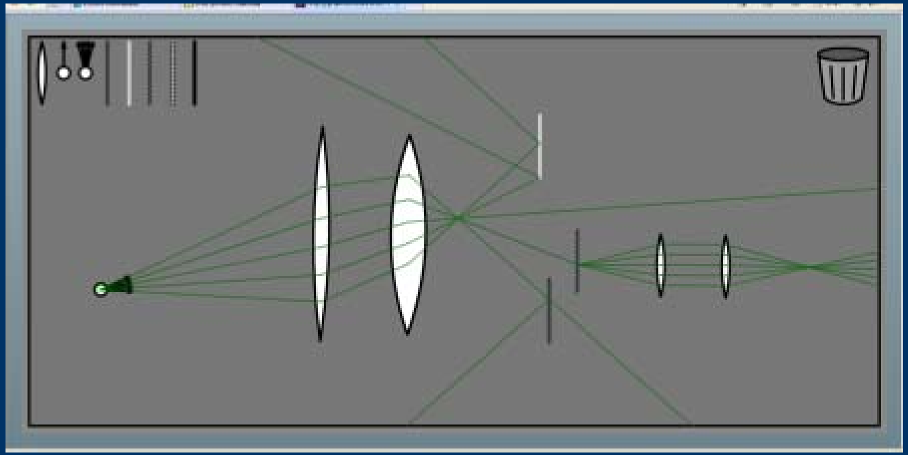
- Phase methods compares two parts of lens at the sensor plane,
  if in focus, entire exit pupil sees a uniform color, else not
- - assumes object has diffuse BRDF

Homeworks

- Submit to class website
  - Commented Source code
  - Input images and output images PLUS intermediate results
  - CREATE a webpage and send me a link
- Ok to use online software
  - HDRshop
- Update results on Flickr (group) page

Second Homework: Option A

- Extending Andrew Adam's Virtual Optical Bench



- (a) Create new optical bench
  - Ability to add new elements
- (b) Form images
  - Integrate light from multiple rays
  - Show image effects (DoF, LF etc)

Synthetic aperture videography

Vaish, V., et al. "Using Plane + Parallax for Calibrating Dense Camera Arrays." *Proceedings of CVPR 2004*.

Second HW (b): Lightfield Photography

- Translate camera and take photos
- Show refocussing and see-thru effects
  - http://lightfield.stanford.edu/lfs.html

- Part 1
  - Create images with plane of focus at different depth
  - Create images with variable depth of field (just use fewer images)
  - Create see-thru effects (just small depth of field)
  - Find depth using max-contrast operator

- Part 2
  - Images with SLANTED plane of focus
  - See-thru effect by elminating foreground color pixels
  - Extra credit: Create new bokeh (point spread function)

- Use high depth complexity, colorful, point specular (sphere) objects

Second HW (c): Lightfield Photography

- Do ALL in software using Virtual Optical Bench
- Translate camera and take photos
- Show refocussing and see-thru effects
  - http://lightfield.stanford.edu/lfs.html

- Part 1
  - Create images with plane of focus at different depth
  - Create images with variable depth of field (just use fewer images)
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- Part 2
  - Images with SLANTED plane of focus
  - See-thru effect by elminating foreground color pixels
  - Extra credit: Create new bokeh (point spread function)

- Use high depth complexity, colorful, point specular (sphere) objects

Computational Illumination, Part 2

- What are annoyances in photography ?

- Why CCD camera behaves retroreflective?

- Youtube videos on camera tutorial (DoF etc)
  http://www.youtube.com/user/MPTutor

Poll

- When:
- Google Earth Live? Why?
- Commercially exploited pervasive recording?

http://www.youtube.com/watch?v=_J7qE6frzz8

http://www.newscientist.com/article/dn17854-live-video-makes-google-earth-cities-bustle.html

Measuring Light

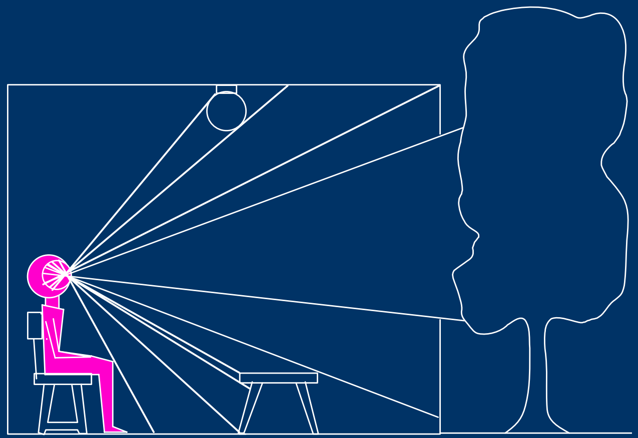
I say that if the front of a building—or any open piazza or field—which is illuminated by the sun has a dwelling opposite to it, and if, in the front which does not face that sun, you make a small round hole, all the illuminated objects will project their images through that hole and be visible inside the dwelling on the opposite wall which may be made white; and there, in fact, they will be upside down, and if you make similar openings in several places in the same wall you will have the same result from each. Hence the images of the illuminated objects are all everywhere on this wall and all in each minutest part of it.

- (The notebooks of Leonardo da Vinci)

Next several slides by Ashok Veeraraghavan

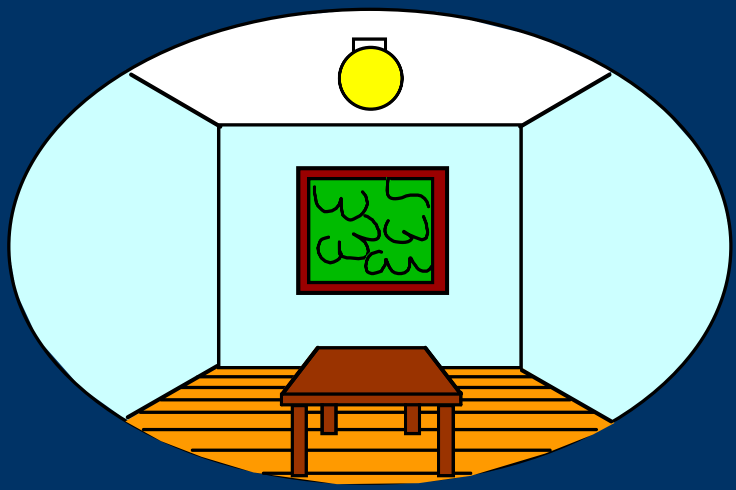
What do we see?

3D world



Point of observation

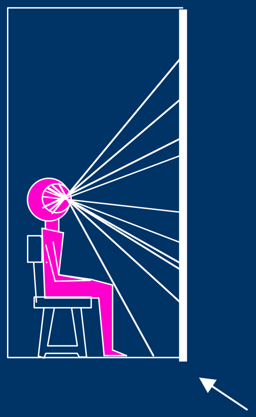
2D image



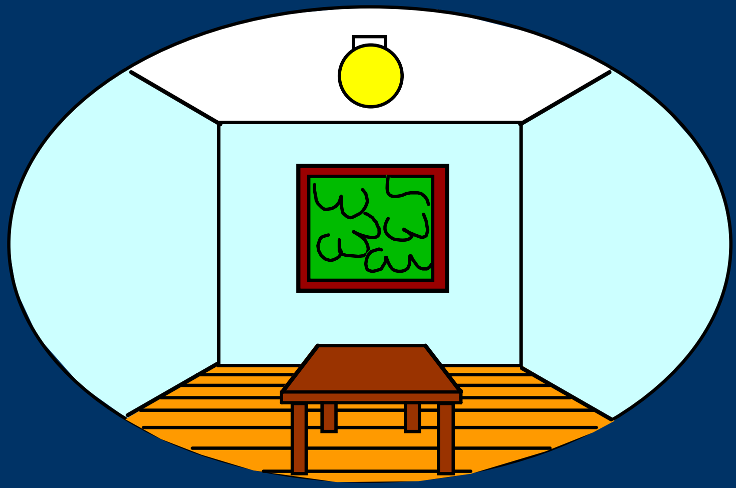
Images courtesy of Stephen E. Palmer. Used with permission.

What do we see?

3D world



2D image



Images courtesy of Stephen E. Palmer. Used with permission.

The Plenoptic Function

Figure removed due to copyright restrictions.

- Q: What is the set of all things that we can ever see?
- A: The Plenoptic Function (Adelson & Bergen)

- Let's start with a stationary person and try to parameterize everything that he can see…

Grayscale snapshot

Figure removed due to copyright restrictions.

$$P(\theta,\phi)$$

- is intensity of light
  - Seen from a single view point
  - At a single time
  - Averaged over the wavelengths of the visible spectrum
- (can also do *P(x,y),* but spherical coordinate are nicer)

Color snapshot

Figure removed due to copyright restrictions.

$$P(\theta,\phi,\lambda)$$

- is intensity of light
  - Seen from a single view point
  - At a single time
  - As a function of wavelength

A movie

Figure removed due to copyright restrictions.

$$P(\theta,\phi,\lambda,t)$$

- is intensity of light
  - Seen from a single view point
  - Over time
  - As a function of wavelength

Holographic movie

Figure removed due to copyright restrictions.

$$P(\theta, \phi, \lambda, t, V_X, V_Y, V_Z)$$

- is intensity of light
  - Seen from ANY viewpoint
  - Over time
  - As a function of wavelength

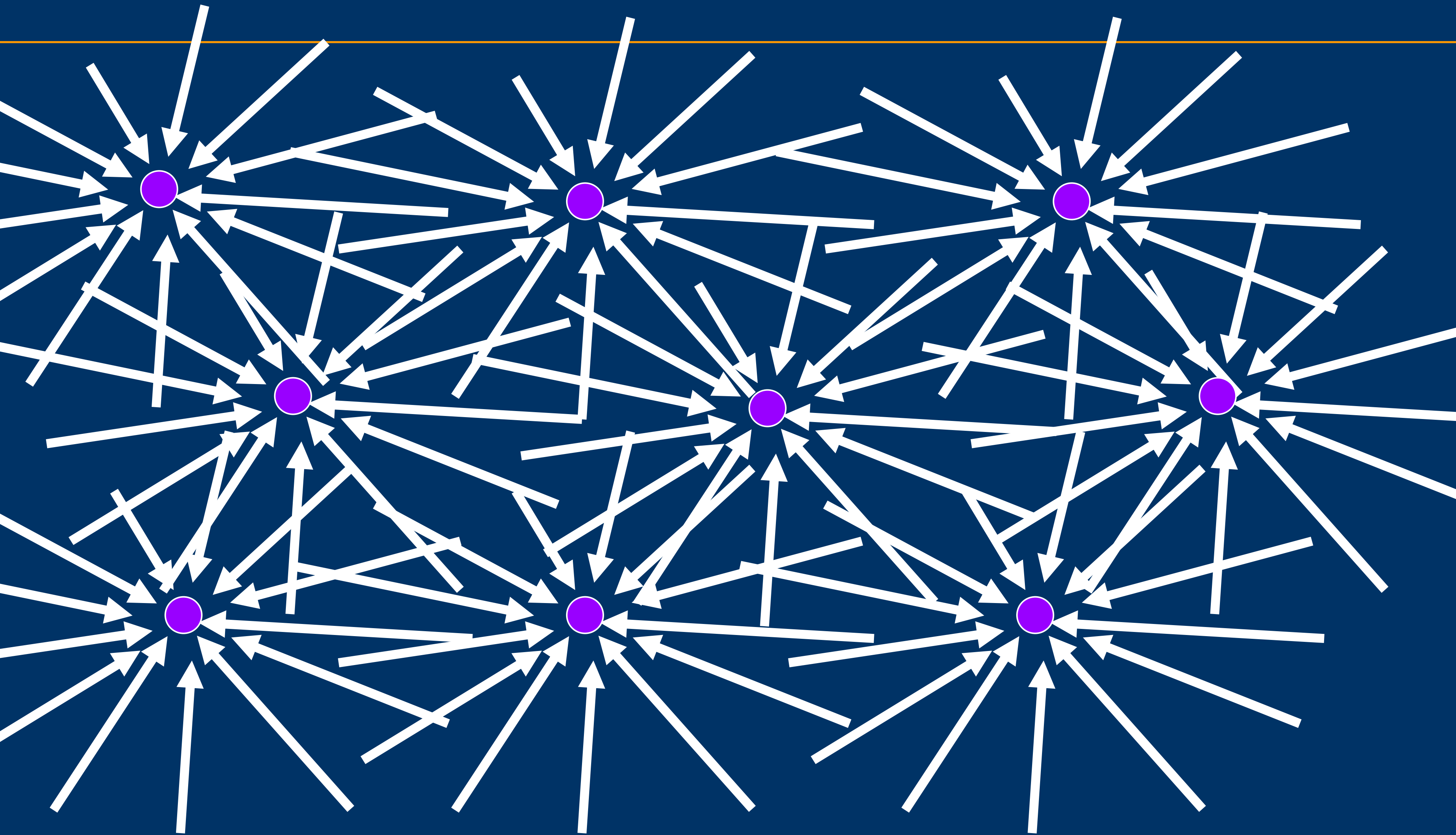
The Plenoptic Function

Figure removed due to copyright restrictions.

$$P(\theta,\phi,\lambda,t,V_X,V_Y,V_Z)$$

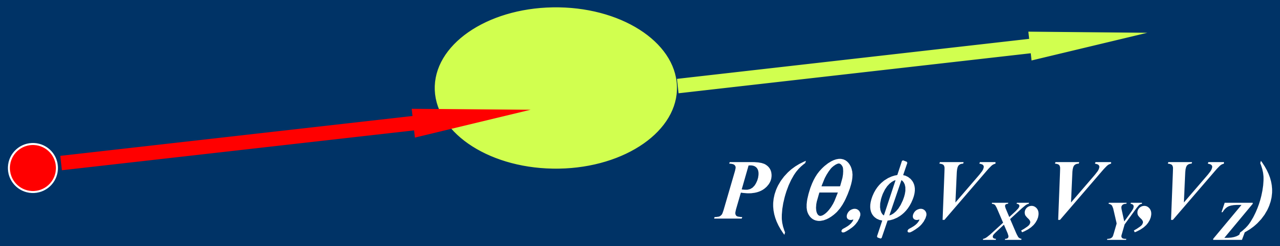
- Can reconstruct every possible view, at every moment, from every position, at every wavelength
- Contains every photograph, every movie, everything that anyone has ever seen.

Sampling Plenoptic Function (top view)



Ray

- Let's not worry about time and color:



- 5D
  - 3D position
  - 2D direction

Ray

- No Occluding Objects

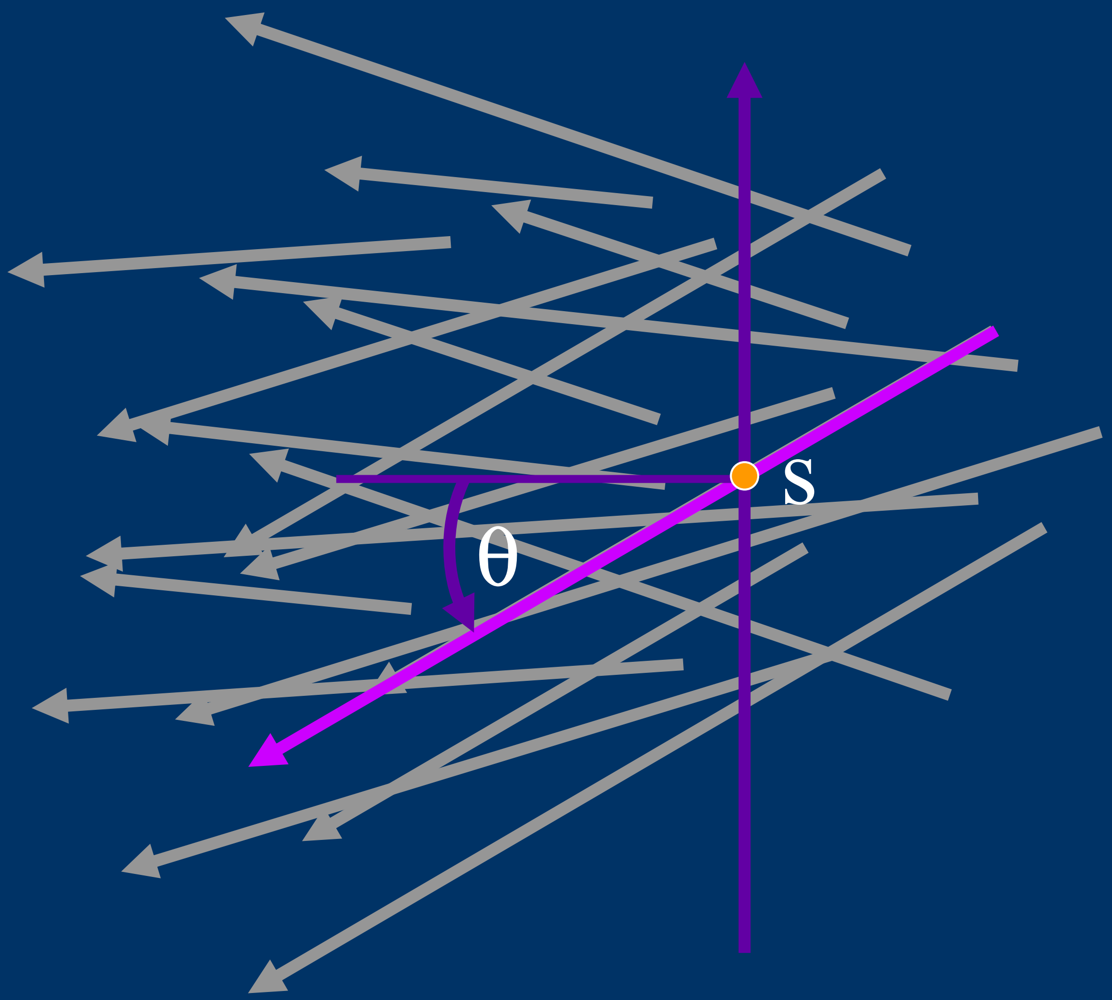
$$P(\theta, \phi, V_X, V_Y, V_Z)$$

- 4D
  - 2D position
  - 2D direction

- The space of all lines in 3-D space is 4D.

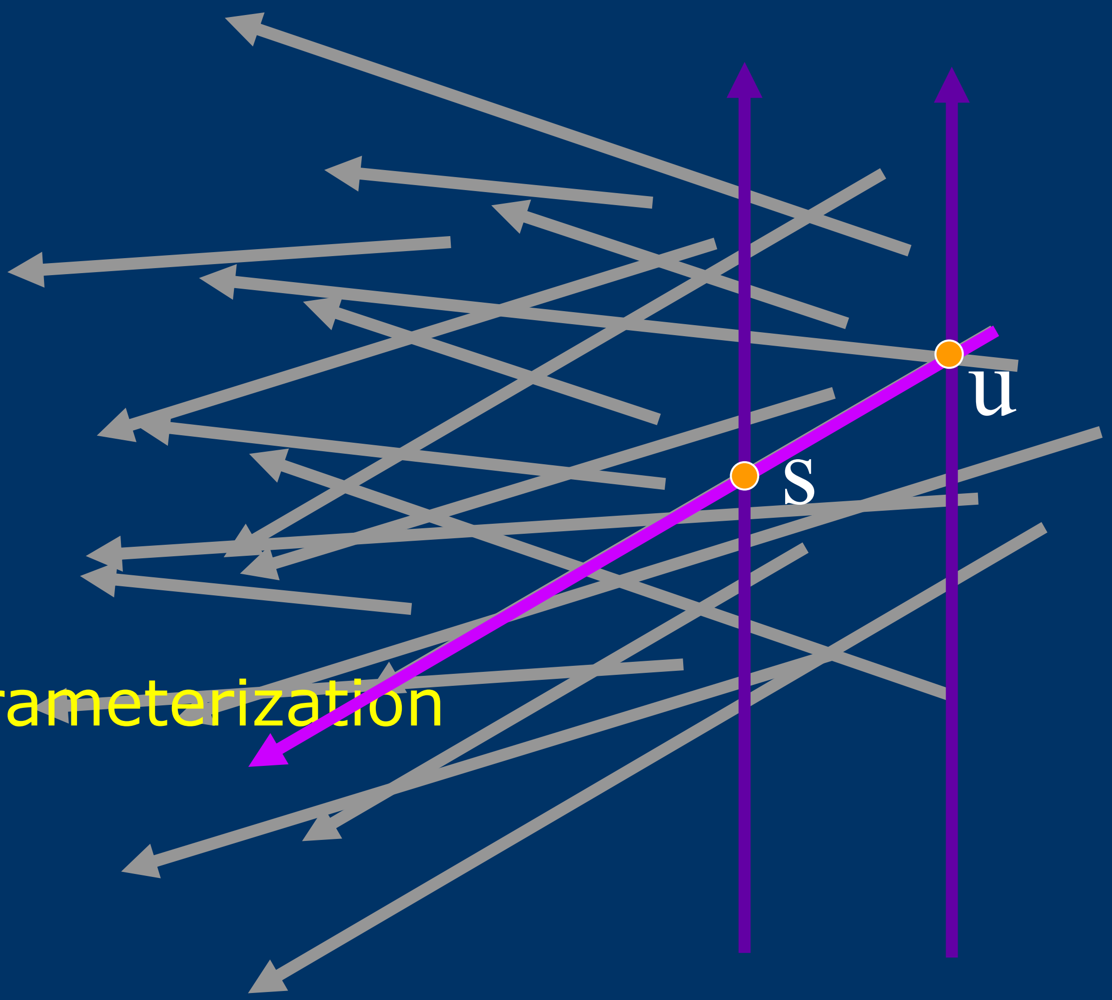
Lumigraph/Lightfield - Organization

- 2D position
- 2D direction



Lumigraph - Organization

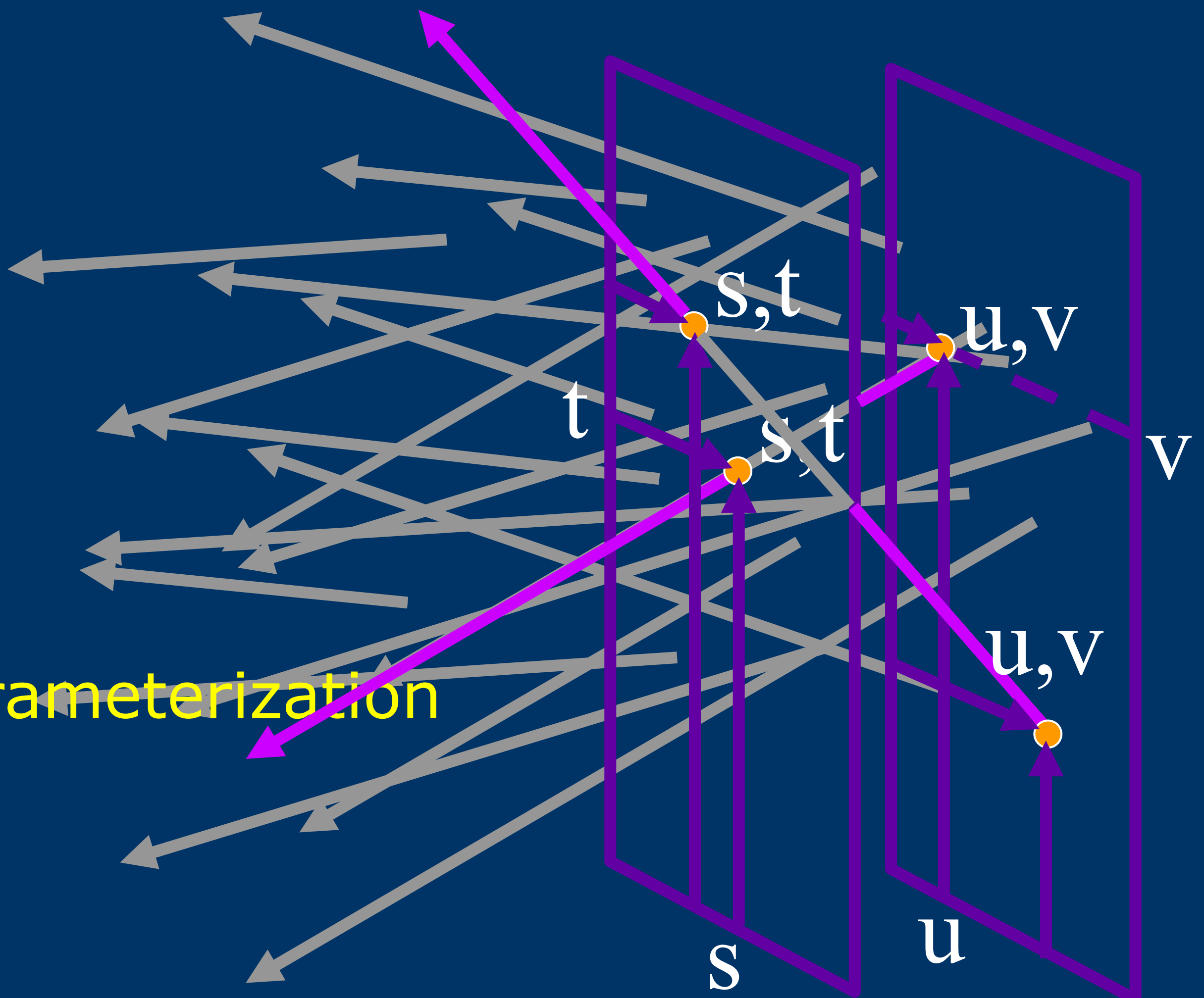
- 2D position
- 2D position
- 2 plane parameterization



Slide by Rick Szeliski and Michael Cohen

Lumigraph - Organization

- 2D position
- 2D position



- 2 plane parameterization

Courtesy of Rick Szeliski and Michael Cohen. Used with permission.

Slide by Rick Szeliski and Michael Cohen

Various images removed due to copyright restrictions.

http://graphics.stanford.edu

Reducing Glare

Conventional Photo

After removing outliers

Glare Reduced Image

Raskar, R., et al. “Glare Aware Photography: 4D Ray Sampling for Reducing Glare Effects of Camera Lenses.” *Proceedings of SIGGRAPH 2008*.

Enhancing Glare

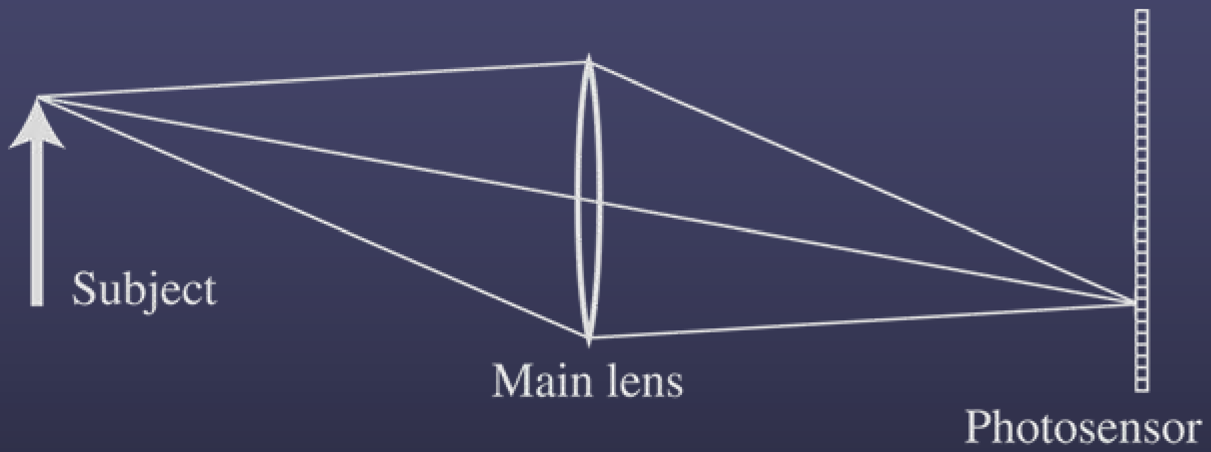
Conventional Photo

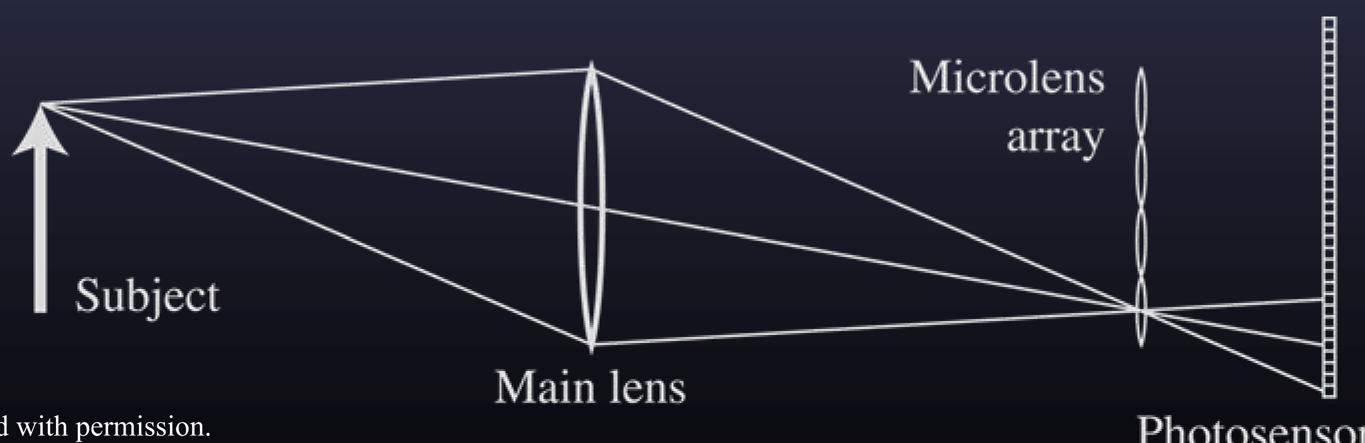
Glare Enhanced Image

Raskar, R., et al. “Glare Aware Photography: 4D Ray Sampling for Reducing Glare Effects of Camera Lenses.” *Proceedings of SIGGRAPH 2008*.

Lego gantry for capturing light fields
(built by Andrew Adams)

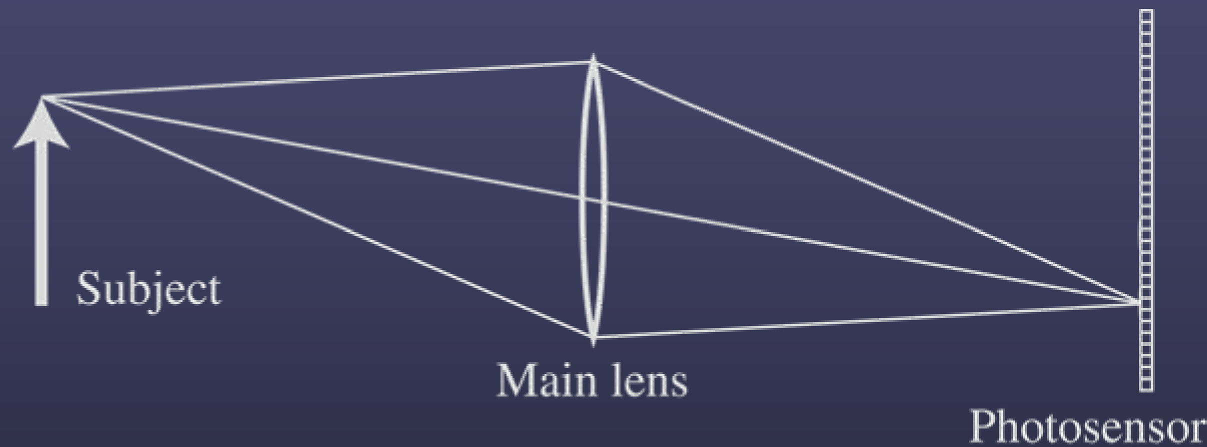
Conventional versus plenoptic camera

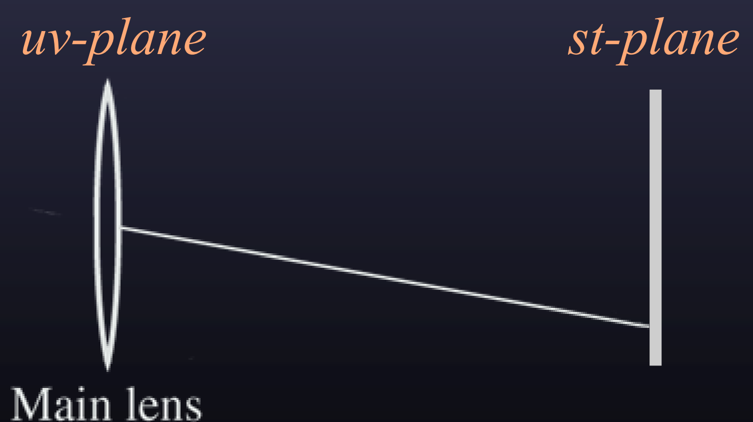




Courtesy of Ren Ng. Used with permission.

Conventional versus plenoptic camera



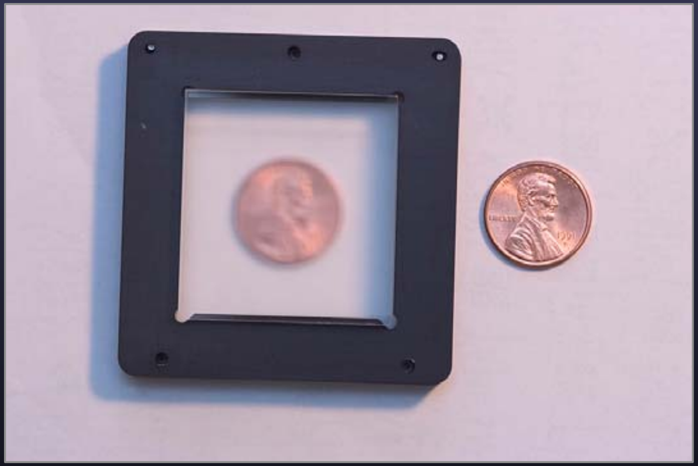


Courtesy of Ren Ng. Used with permission.

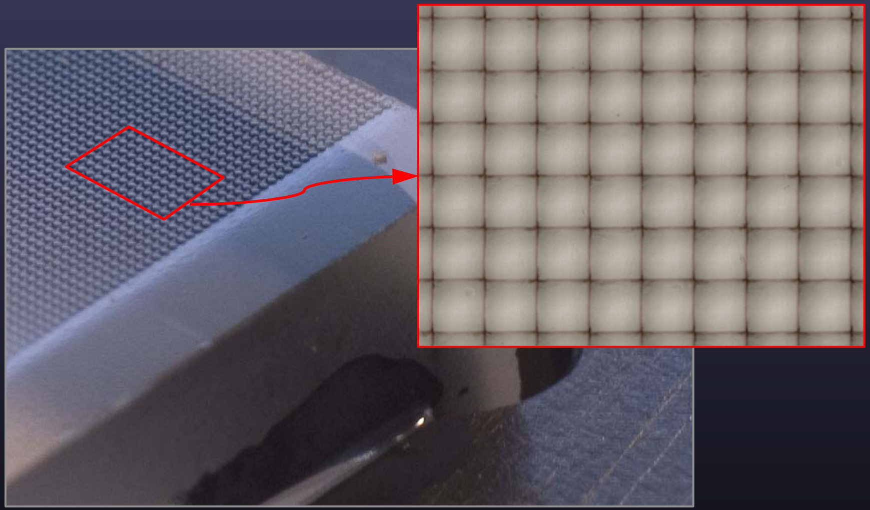
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor



Adaptive Optics microlens array



125μ square-sided microlenses

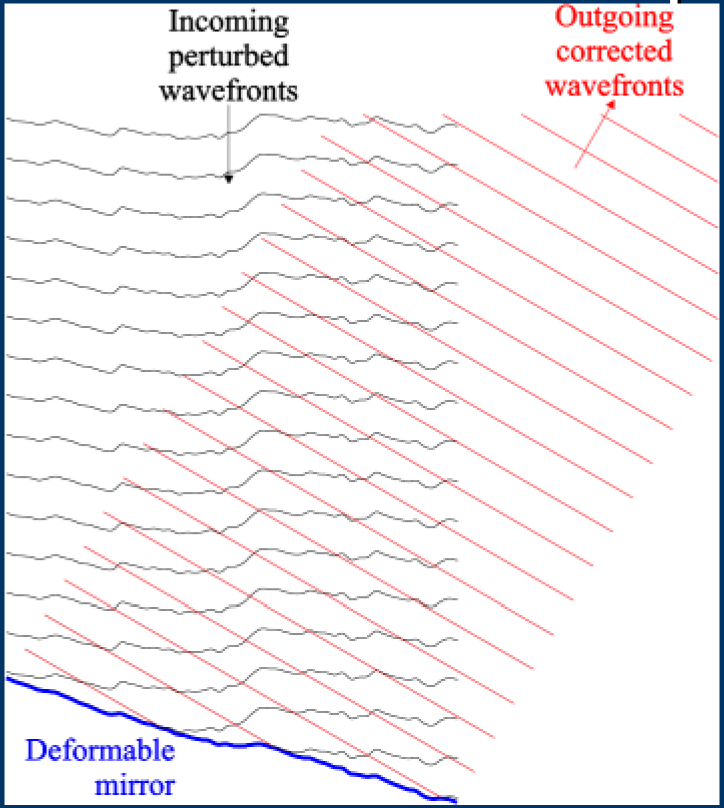
4000×4000 *pixels* $\div$ 292×292 *lenses* $=$ 14×14 *pixels per lens*

Example of digital refocusing

Courtesy of Ren Ng. Used with permission.

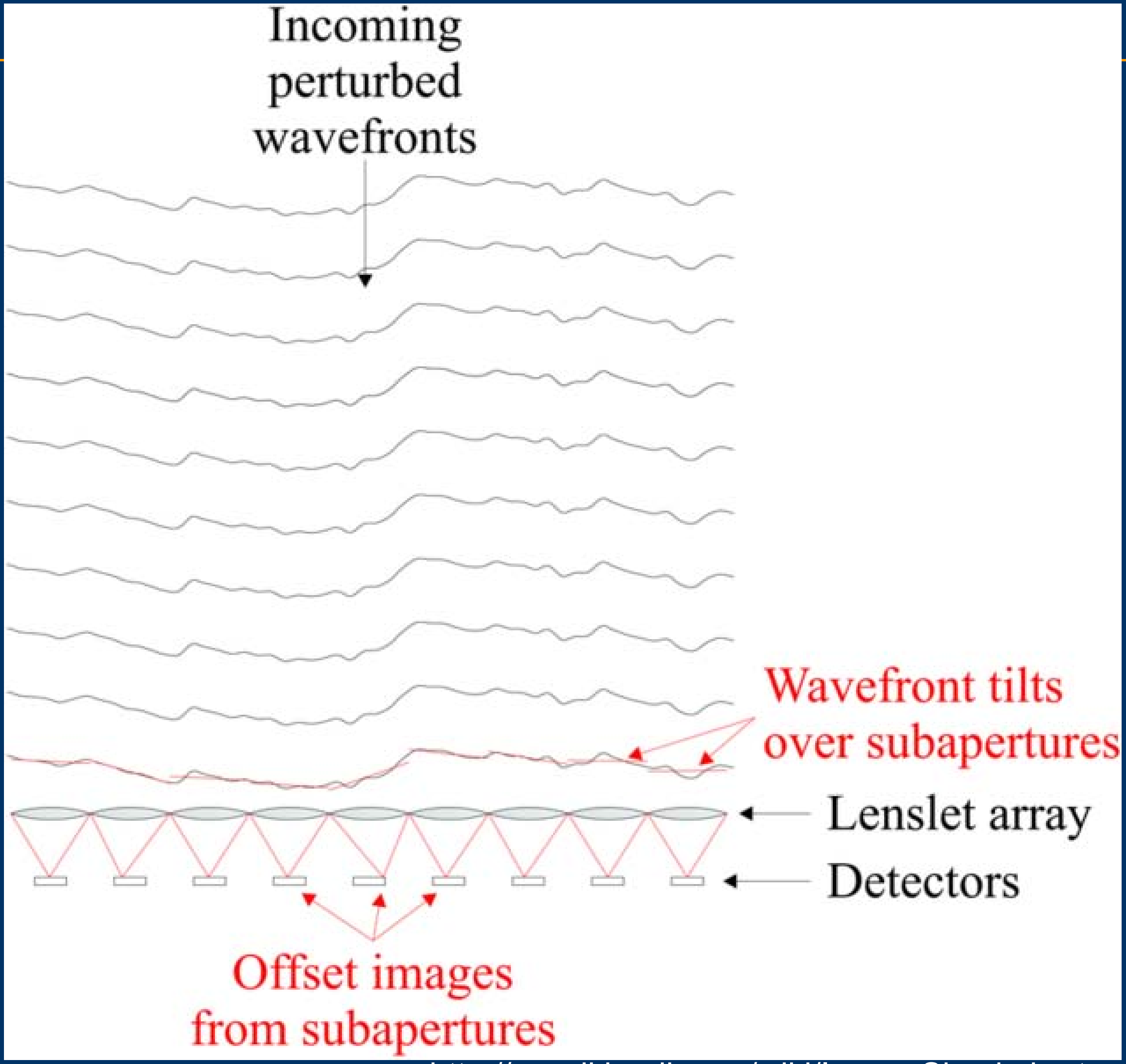
Adaptive Optics

- A deformable mirror can be used to correct wavefront errors in an astronomical telescope



http://en.wikipedia.org/wiki/Image:Adaptive_optics_correct.png

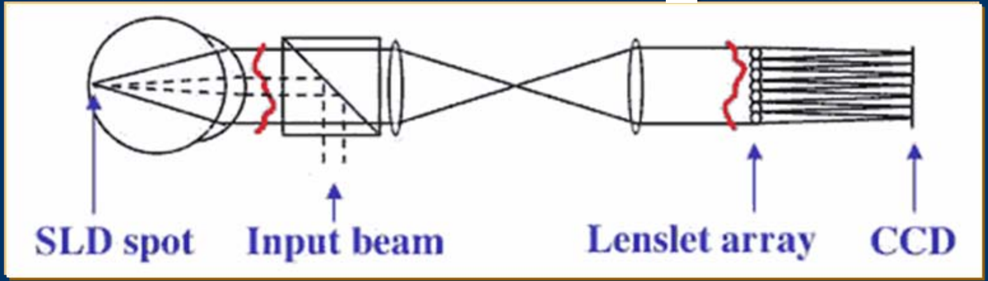
Shack Hartmann wavefront sensor (commonly used in Adaptive optics).

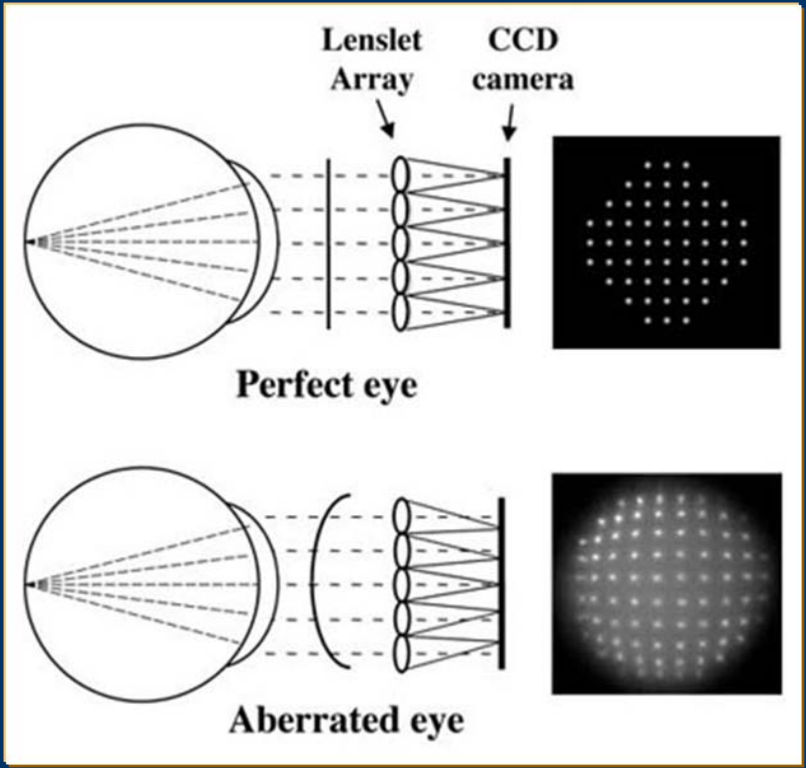


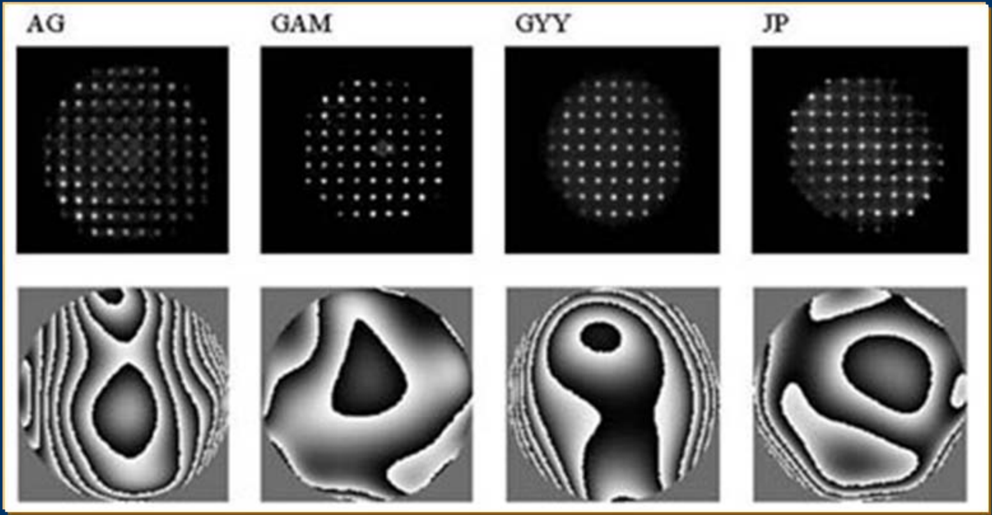
http://en.wikipedia.org/wiki/Image:Shack_hartmann.png

Measuring shape of wavefront = Lightfield Capture

- http://www.cvs.rochester.edu/williamslab/r_shackhartmann.html







The spots formed on the CCD chip for the eye will be displaced because the wavefront will hit each lenslet at an angle rather than straight on.

DoF Depends on aperture

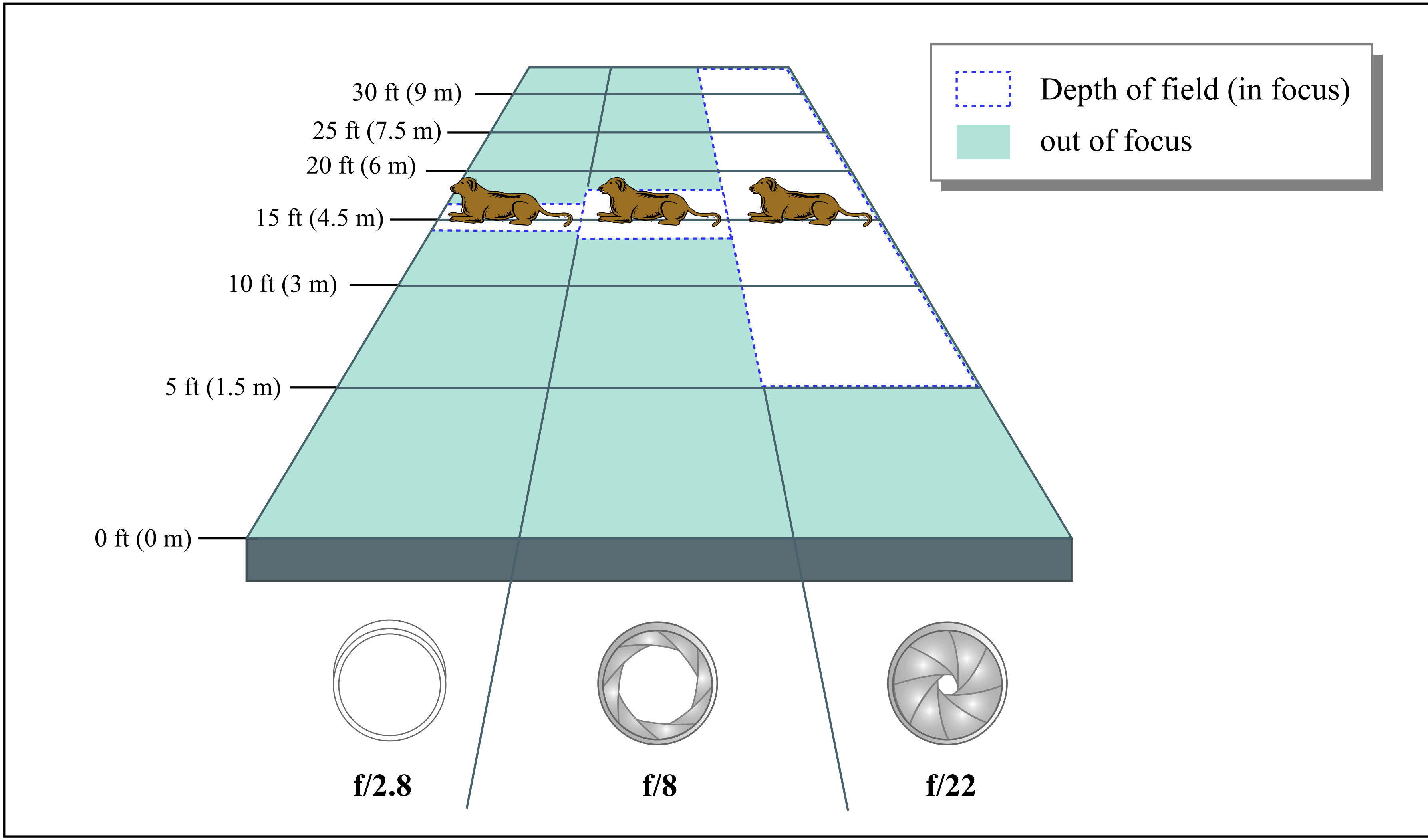


Figure by MIT OpenCourseWare.

Depends on focusing distance

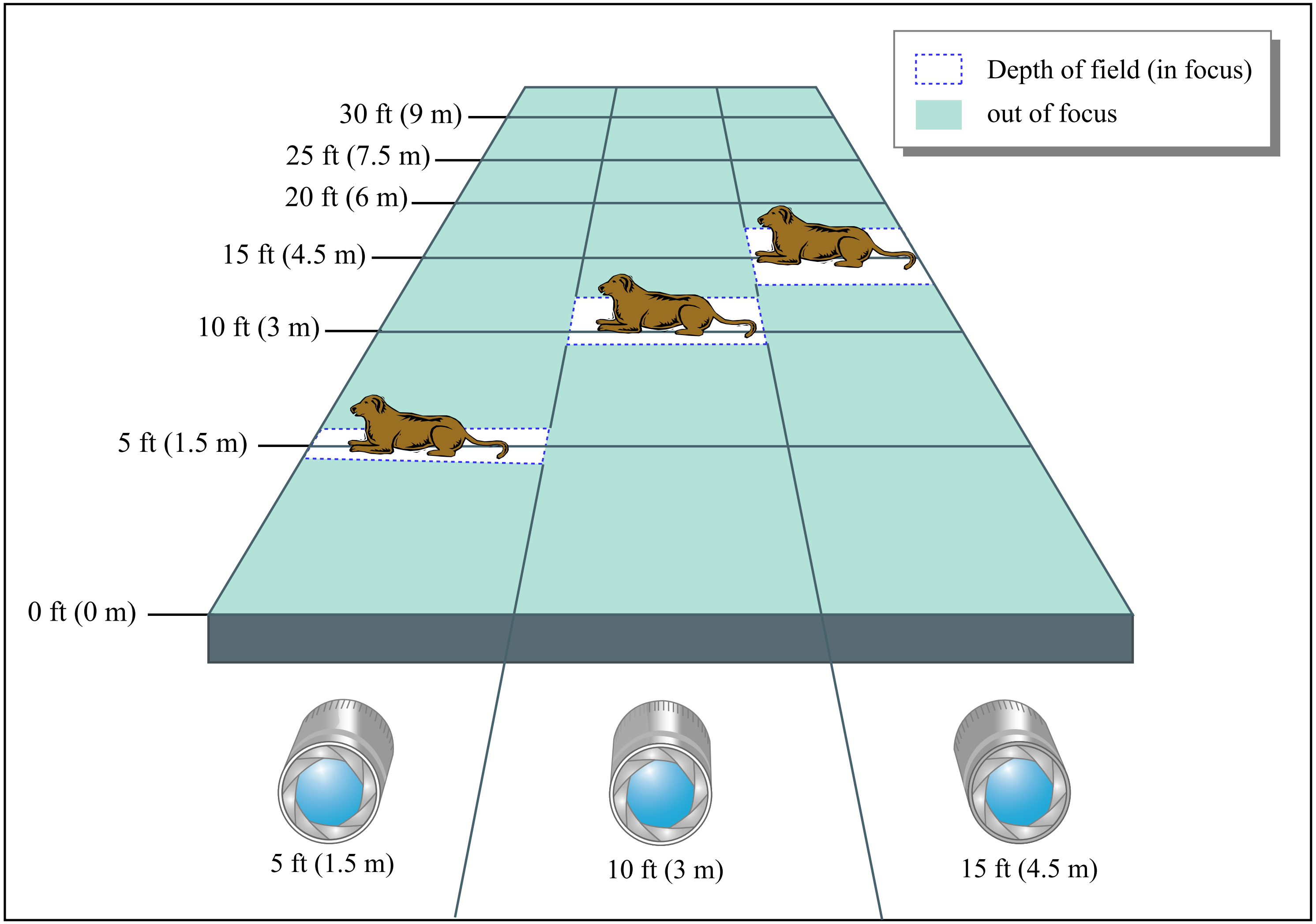


Figure by MIT OpenCourseWare.

Depends on focal length

- **Remember definition of f stop = diameter/focus length**

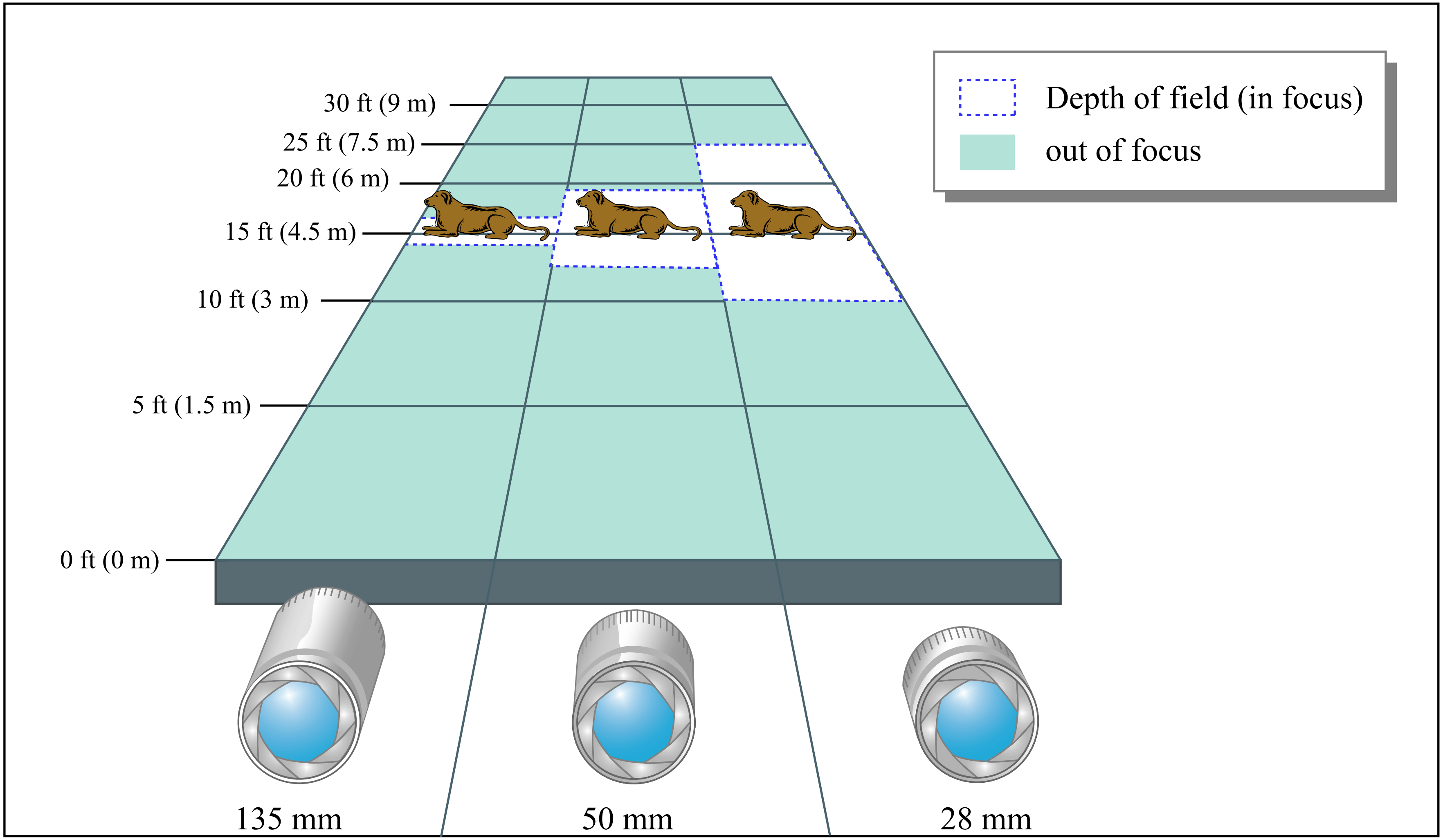
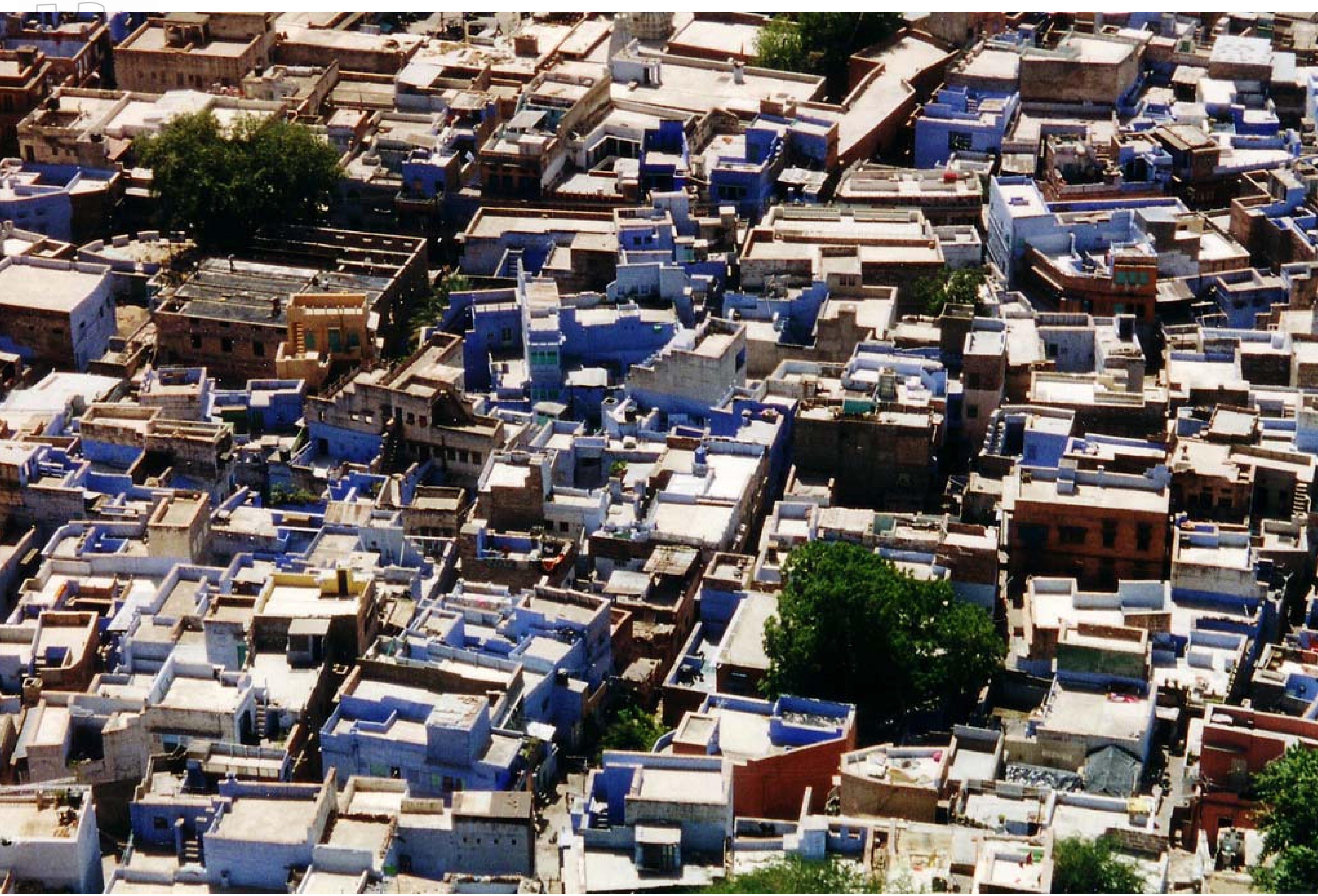


Figure by MIT OpenCourseWare.

Courtesy of paul_goyette on Flickr.



Courtesy of paul_goyette on Flickr.

Scheimpflug principle

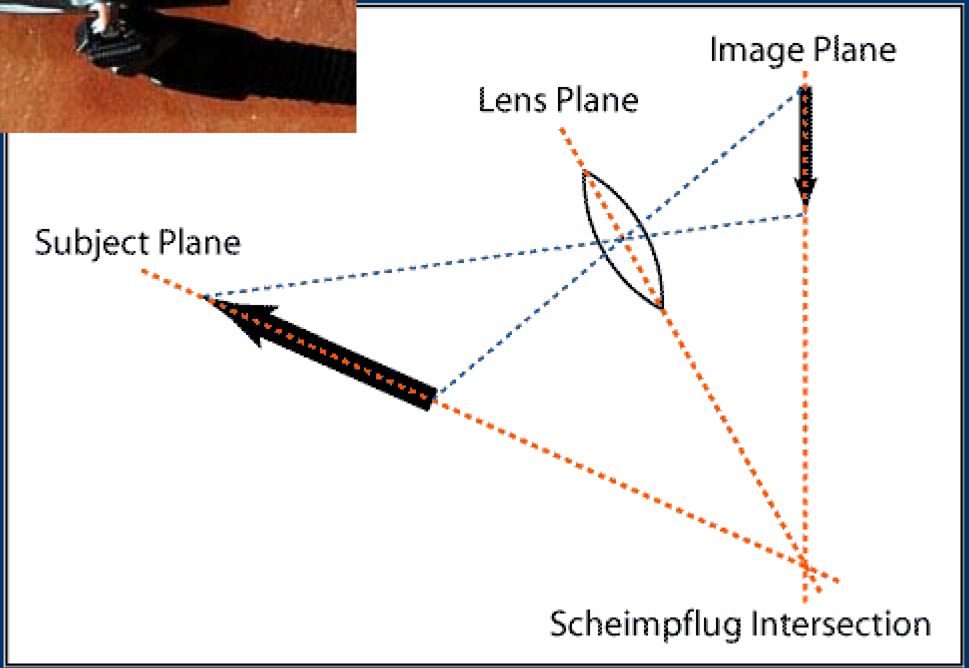


Image: Wikipedia, public domain.

How do we see the world?

Sequence of 7 slides removed due to copyright restrictions.
1) Diagram of light rays from object to film
2) Put pinhole camera into the lightpath
3, 4) Images demonstrating the blurring effects of aperture size
5, 6) Diagrams showing how lens gathers light
7) Diagram showing the "in focus" and "circle of confusion" effects of a lens.
See Figure 5.109 in Hecht, Eugene. *Optics*. Addison-Wesley, 2002, p.199.

Slide by Steve Seitz

Material not covered

- Lens basics
  - Concave, convex, refraction, Snells law
- Appearance
  - Depth of field, zoom etc
- Lens artifacts
  - Radial distortion, coma, astigmatism
- Please refer to Siggraph course videos/slides

- Does an out of focus image get dark?
- Does a zoomed in image get dark?
- Why CCD camera behaves retroreflective?
- How does auto-focus work?

Anti-Paparazzi Flash

Image removed due to copyright restrictions.
See Berzon, Alexandra. "The Anti-Paparazzi Flash."
New York Times, December 11, 2005.

The anti-paparazzi flash: 1. The celebrity prey. 2. The lurking photographer. 3. The offending camera is detected and then bombed with a beam of light. 4. Voila! A blurry image of nothing much.

- Anti-Paparazzi Flash

Auto Focus

- Contrast method compares contrast of images at three depths,
  if in focus, image will have high contrast, else not

- Phase methods compares two parts of lens at the sensor plane,
  if in focus, entire exit pupil sees a uniform color, else not
- - assumes object has diffuse BRDF

Lens = Pin-holes + Prisms

- Sum up images from different pin-holes
- Ray matrix operations

Sub-Aperture = Pin-hole + Prism

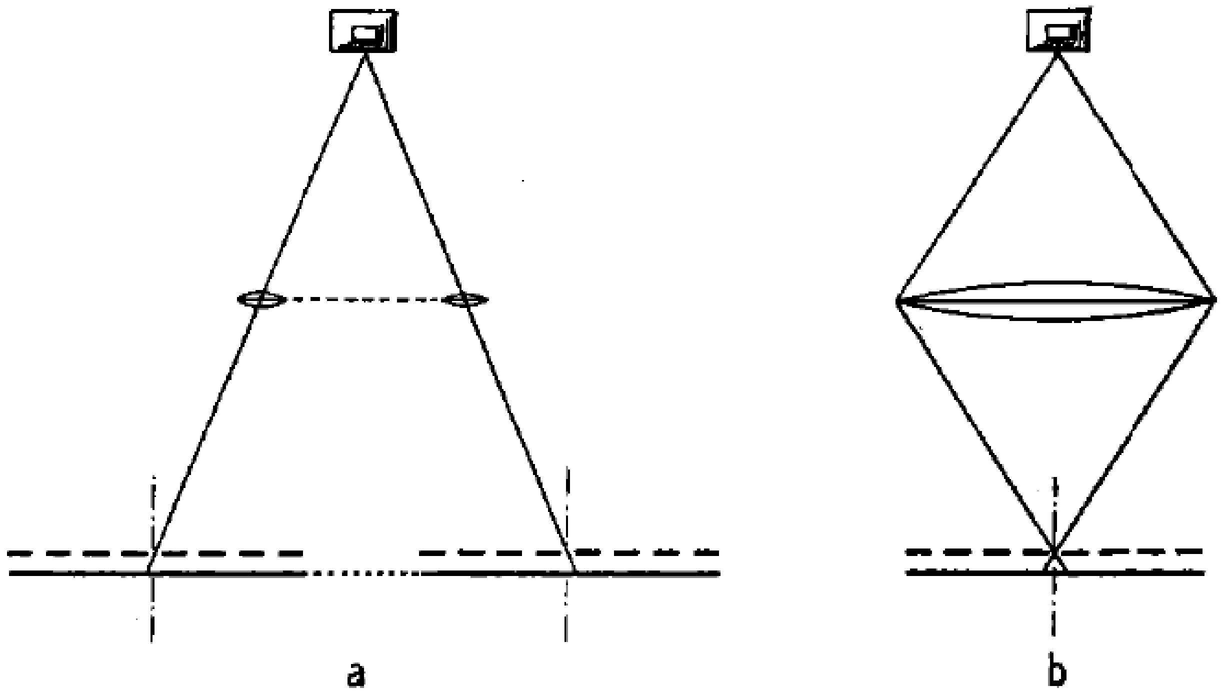


FIG. 1. *Two methods of making parallax panoramagram negatives. (a) A moving lens exposing a sensitive plate behind a grating slightly separated from it; lens, grating and plate being maintained in line during the exposure. (b) A large stationary lens, projecting an image on a stationary plate through a grating slightly separated from it.*

Ives, Herbert. E. *JOSA* 20, no. 6 (1930): 332-340. doi:10.1364/JOSA.20.000332

Ives 1930

vertical axis than is called for by the simple formula above developed. This correction, which is roughly proportional to the cosine of the angle between nn' and the sensitive surface, and so is of importance only for

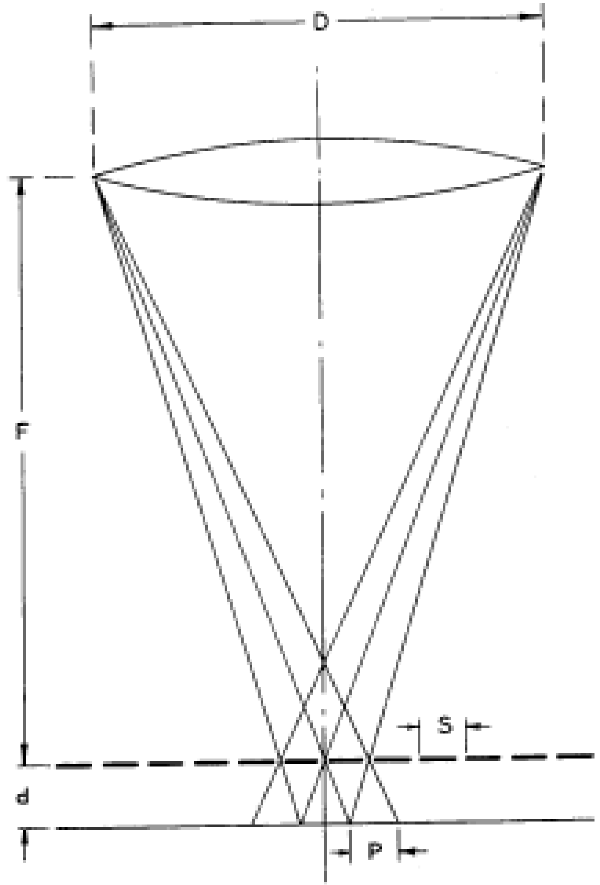
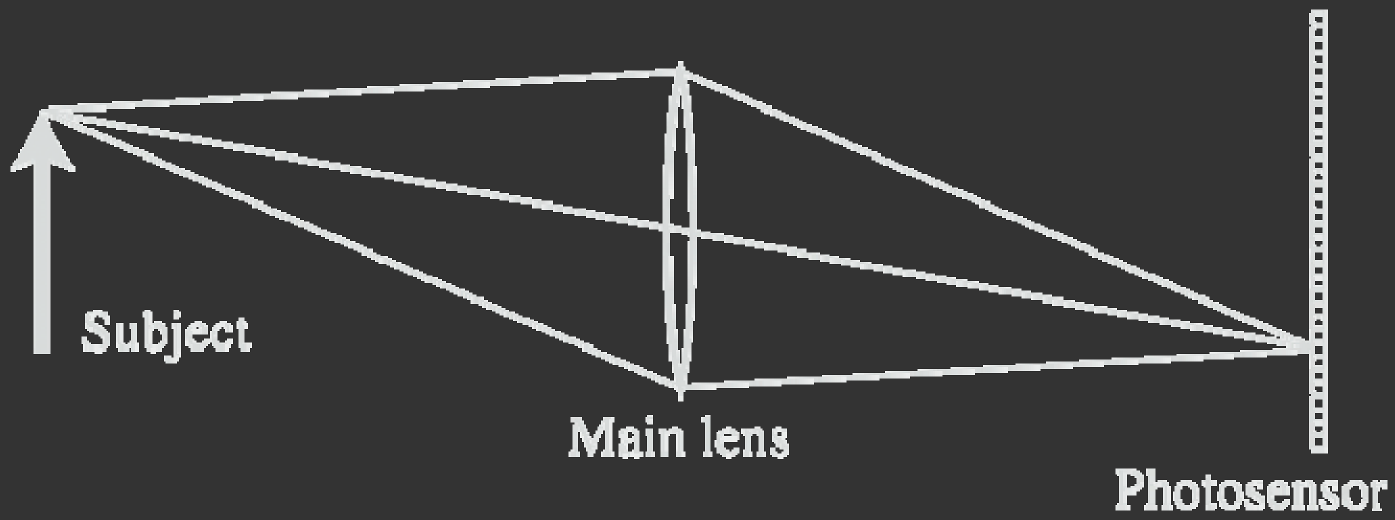


FIG. 4. Determination of separation of grating and plate as function of grating spacing, lens diameter and focal distance.

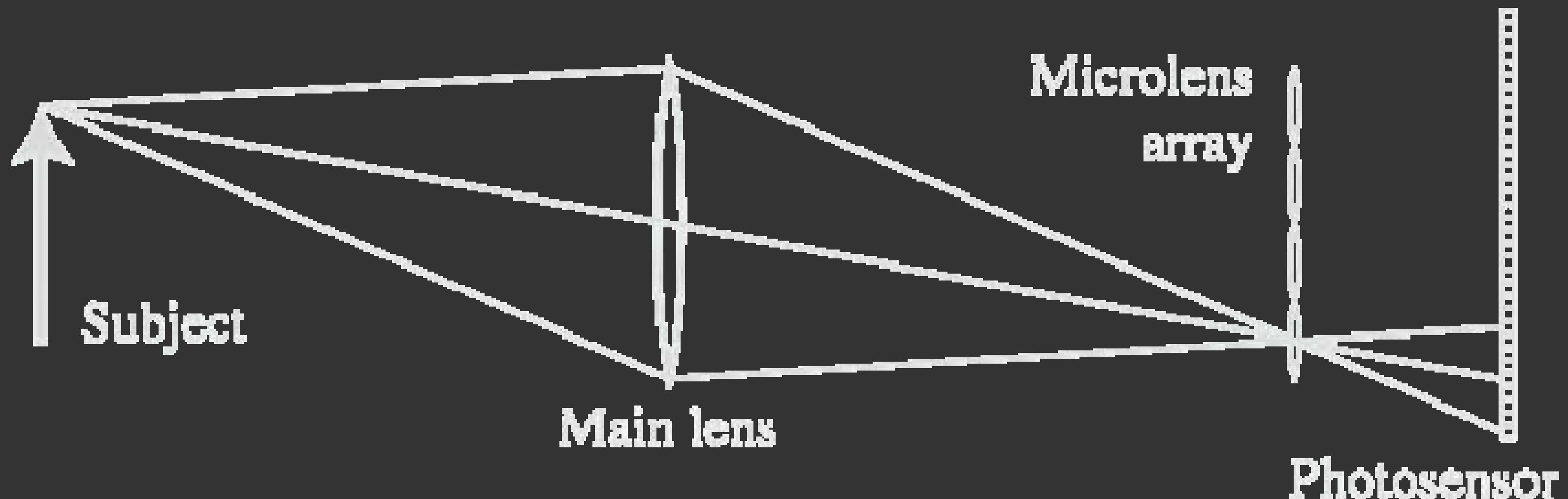
large angles, also varies with the angle of observation. A diameter of taking lens and size of picture can theoretically be attained such that this second order correction will fail. The slightly greater magnification of the viewing grating called for over the amount given by the

Ives, Herbert. E. *JOSA* 20, no. 6 (1930): 332-340. doi:10.1364/JOSA.20.000332

Light Field Inside a Camera



Lenslet-based Light Field camera

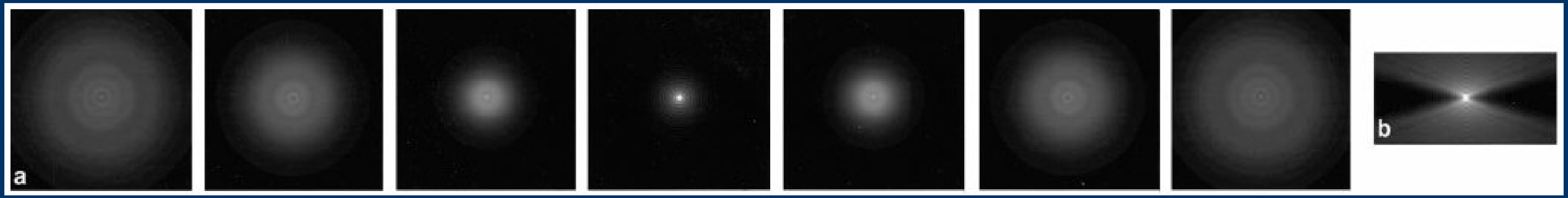


[Adelson and Wang, 1992, Ng et al. 2005]

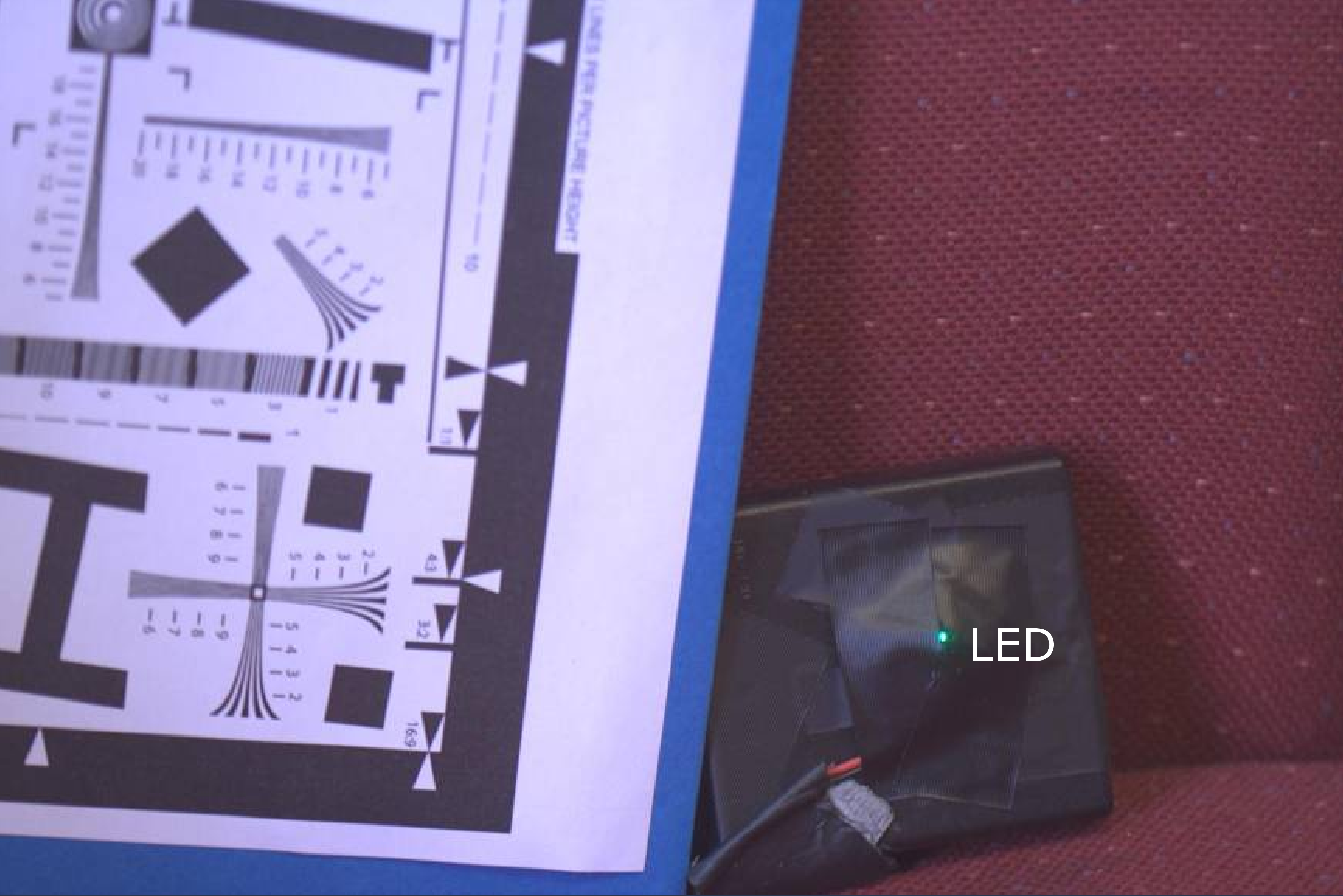
Light Fields

- What are they?
- What are the properties?
- How to capture?
- What are the applications?

- Focus stack ..
- object * PSF → focus stack



McNally, J. G., et al. "Three-Dimensional Imaging by Deconvolution Microscopy." *Methods* 19, no. 3 (Nov. 1999): 373-385.



In Focus Photo

Out of Focus Photo: Open Aperture

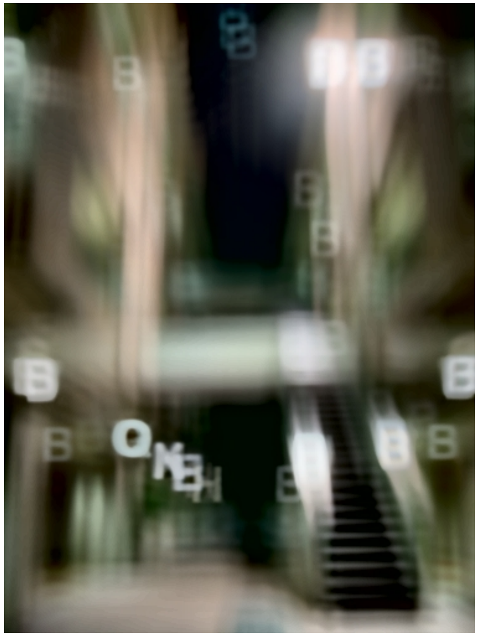
Coded Aperture Camera

The aperture of a 100 mm lens is modified

Insert a coded mask with chosen binary pattern

Rest of the camera is unmodified

Out of Focus Photo: Coded Aperture



Modeling and Synthesis of Aperture Effects in Cameras

Douglas Lanman, Ramesh Raskar, and Gabriel Taubin

Computational Aesthetics 2008
20 June, 2008

Slides removed due to copyright restrictions.
See this paper and associated presentation at
http://mesh.brown.edu/dlanman/research.html

Light field photography and microscopy

Marc Levoy

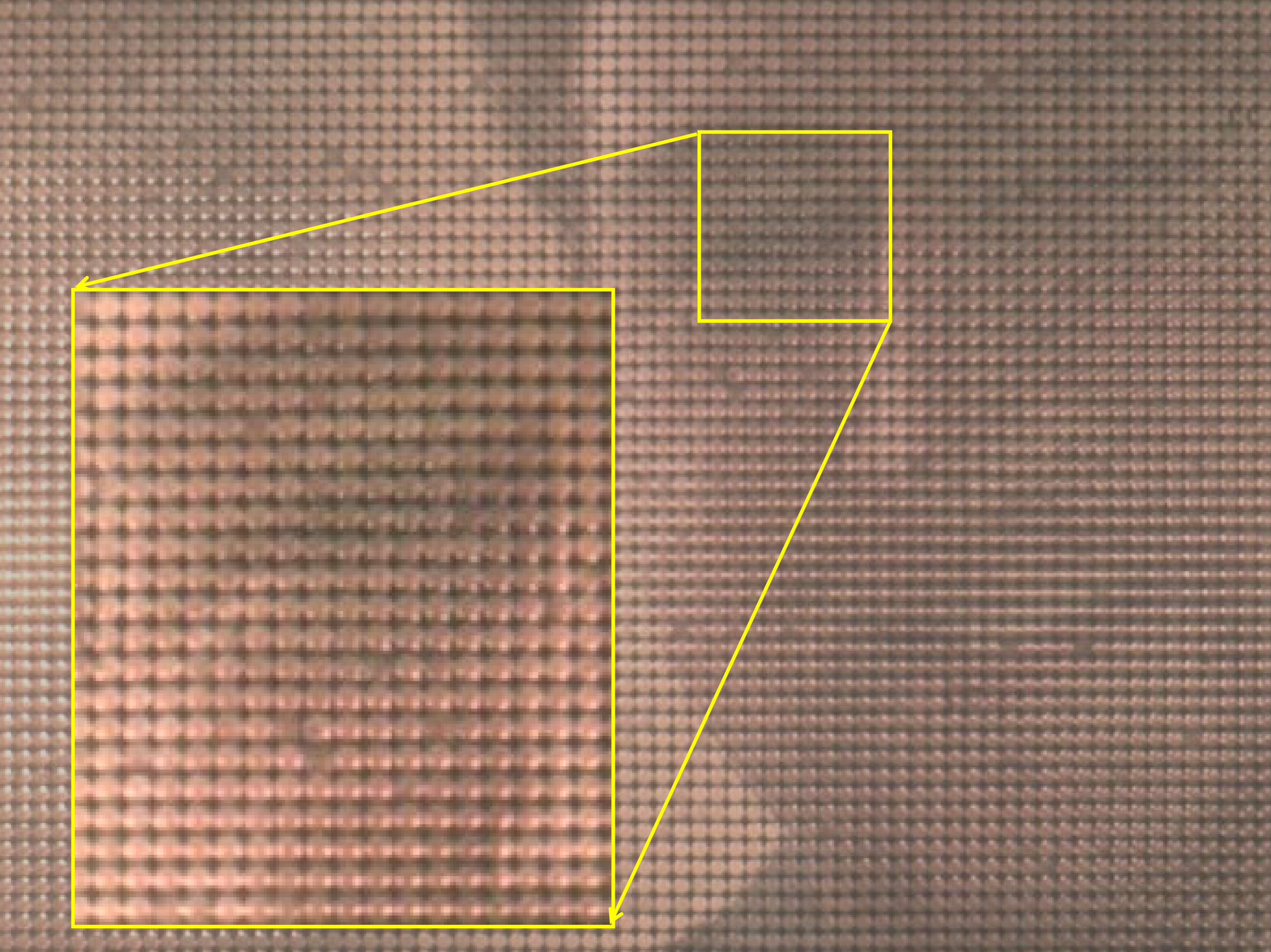
Computer Science Department
Stanford University

Slides removed due to copyright restrictions.
A public version of this talk may be downloaded at
http://graphics.stanford.edu/talks/microscopy-public-apr09.pdf

Lens Glare Reduction

[Raskar, Agrawal, Wilson, Veeraraghavan SIGGRAPH 2008]

Glare/Flare due to camera lenses reduces contrast



Reducing Glare

Conventional Photo

After removing outliers

Glare Reduced Image

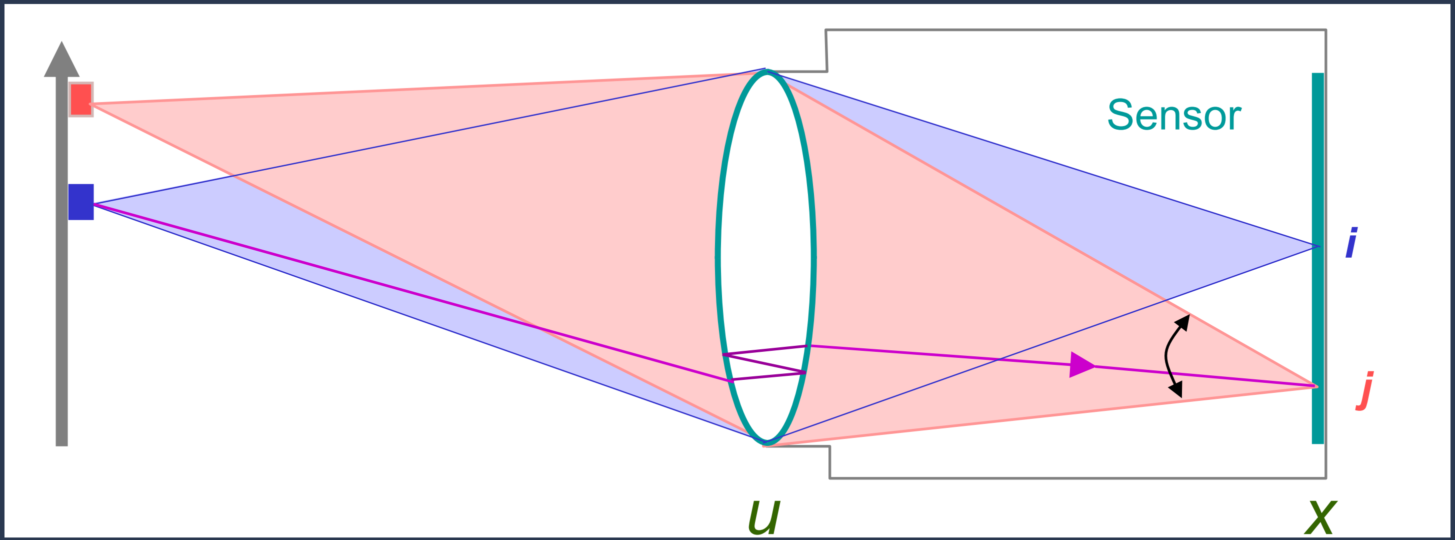
Enhancing Glare

Conventional Photo

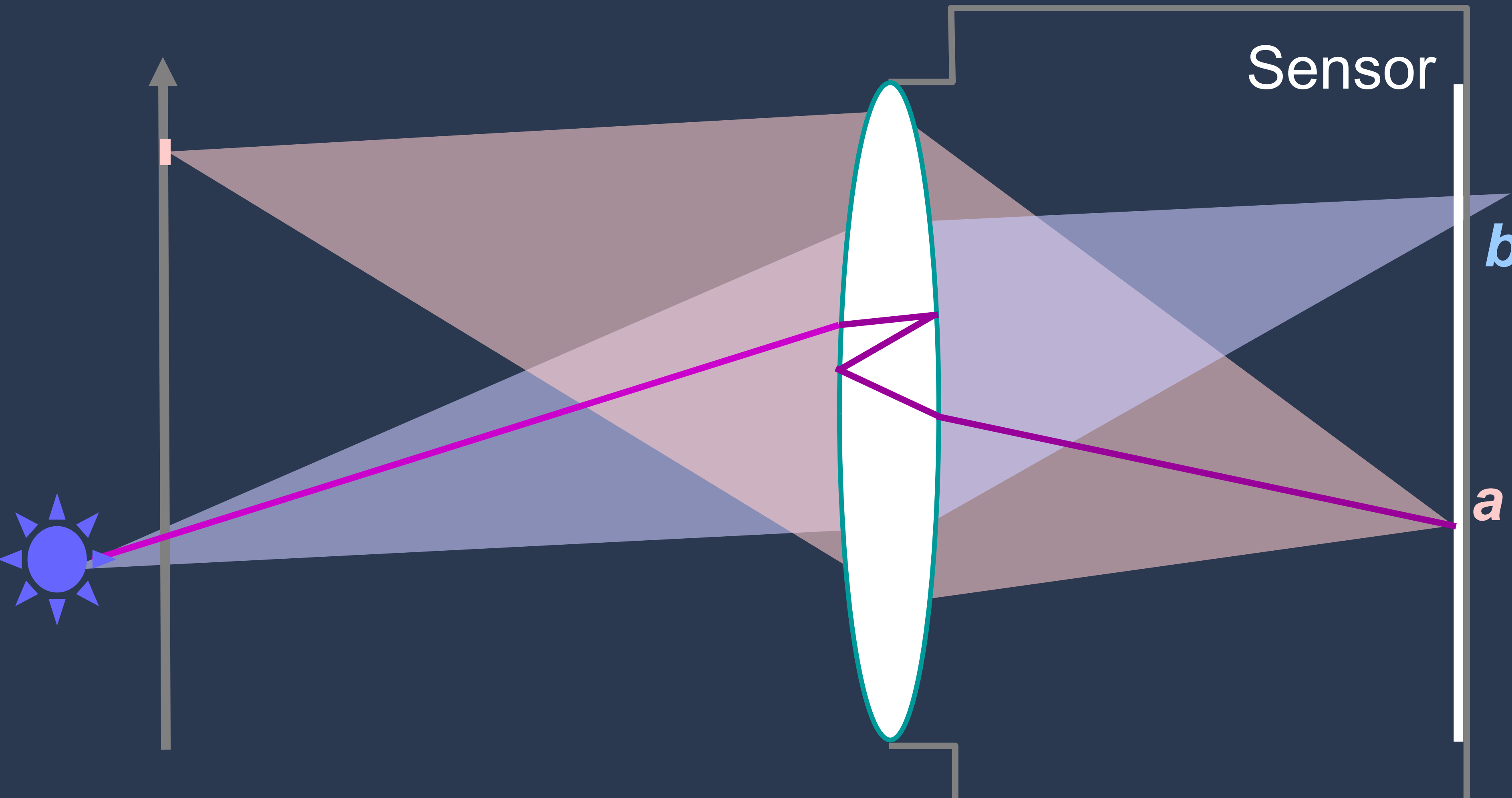
Glare Enhanced Image

Glare = low frequency noise in 2D

- But is high frequency noise in 4D
- Remove via simple outlier rejection

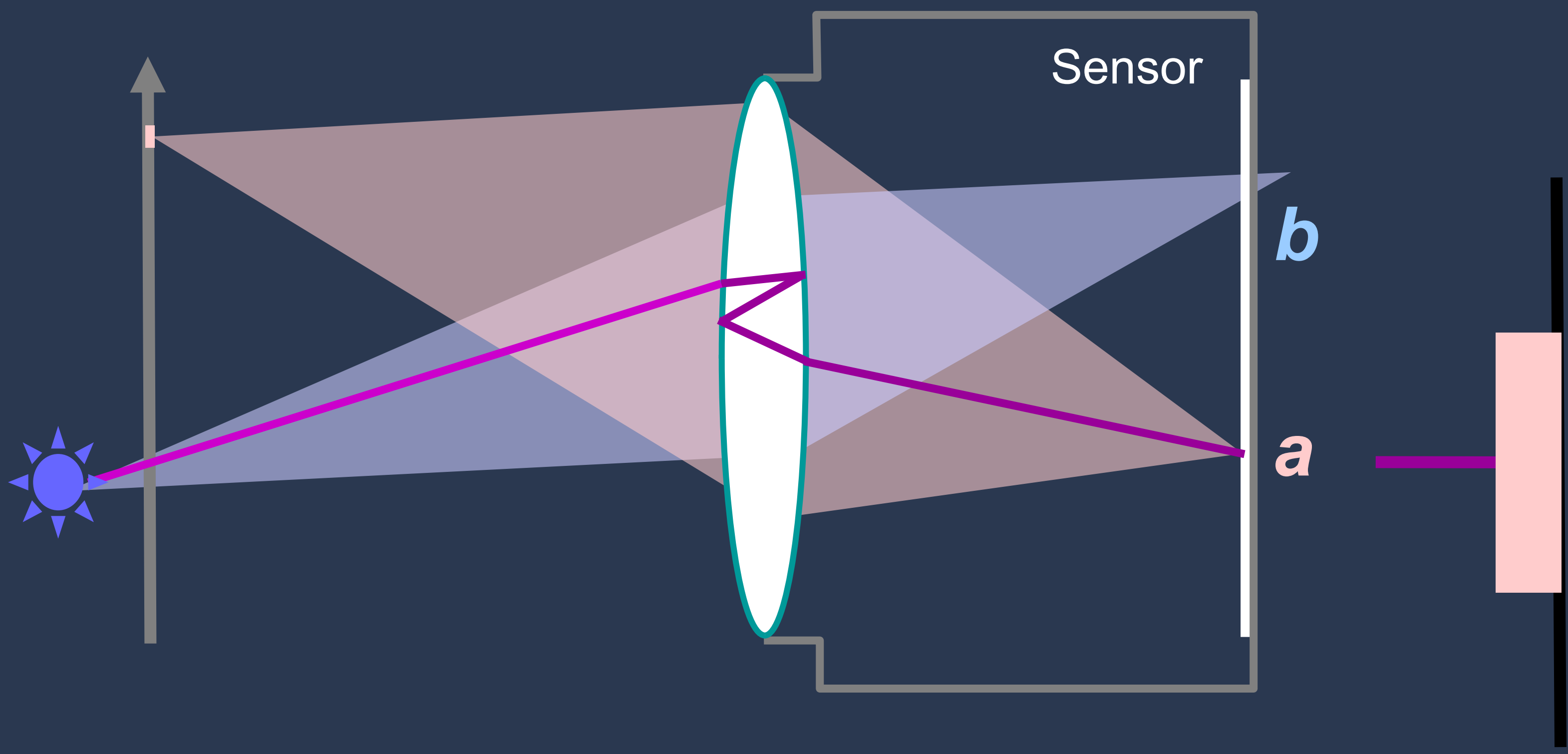


Glare due to Lens Inter-Reflections



Effects of Glare on Image

- Hard to model, Low Frequency in 2D
- But reflection glare is outlier in 4D ray-space

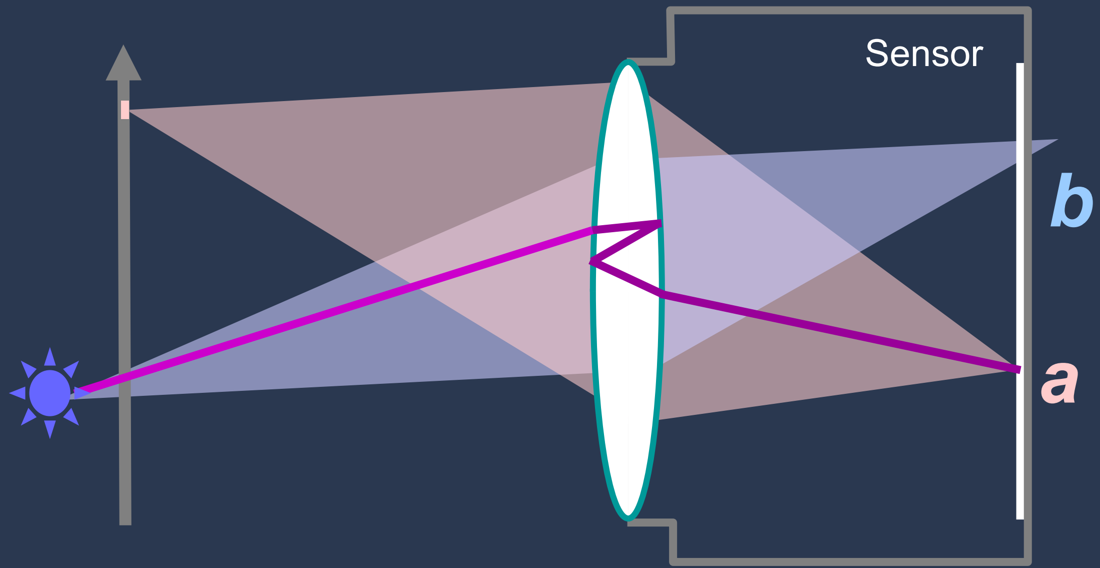


Lens Inter-reflections

Raskar, R., et al. "Glare Aware Photography: 4D Ray Sampling for Reducing Glare Effects of Camera Lenses." *Proceedings of SIGGRAPH 2008.*

Key Idea

- Lens Glare manifests as low frequency in 2D Image
- But Glare is highly view dependent
  - manifests as outliers in 4D ray-space
- Reducing Glare == Remove outliers among rays

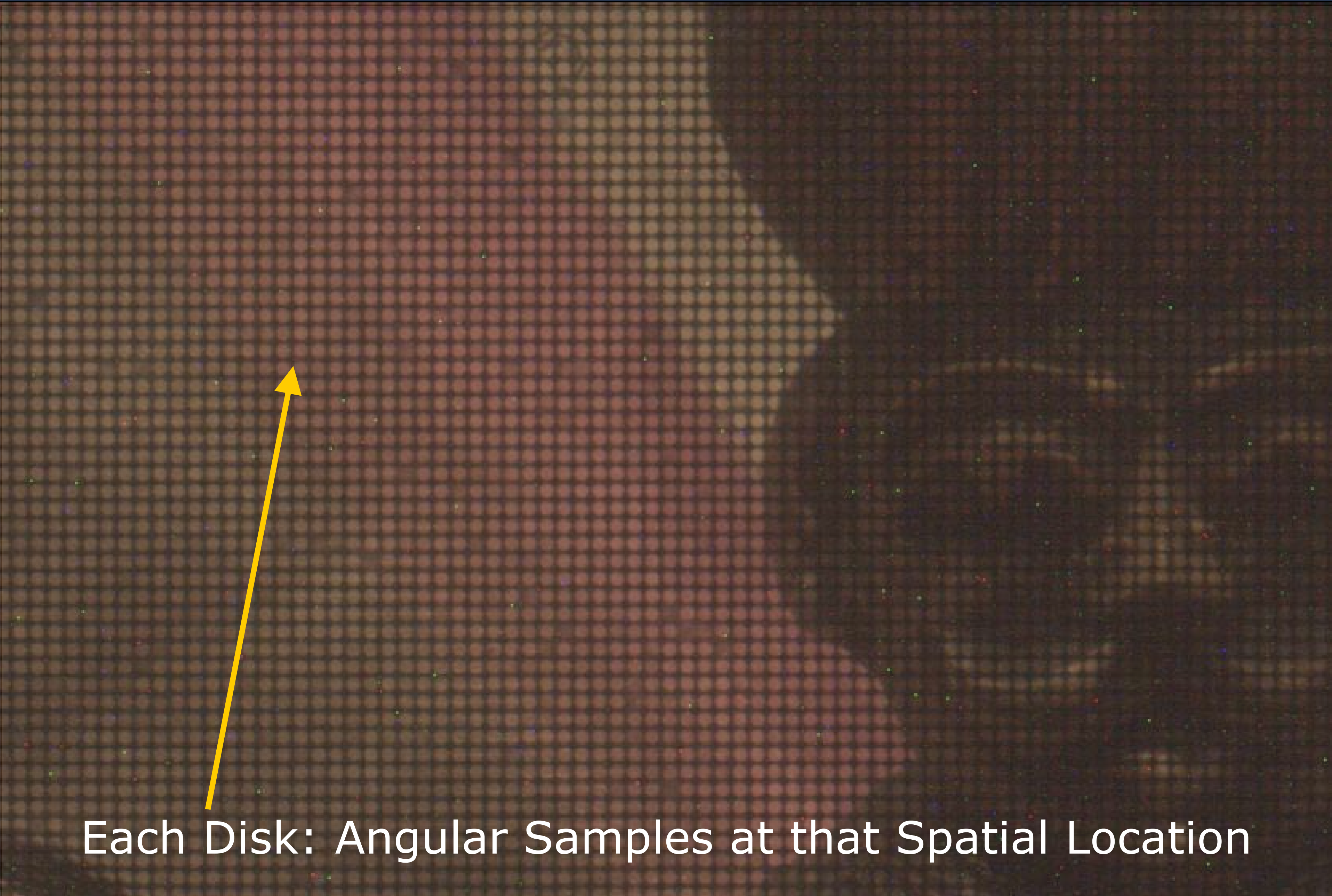


Reducing Glare using a Light Field Camera


Captured Photo: LED off


Captured Photo: LED On

No Glare



With Glare


v
u
y
x

Sequence of Sub-Aperture Views

Average of all the
Light Field views

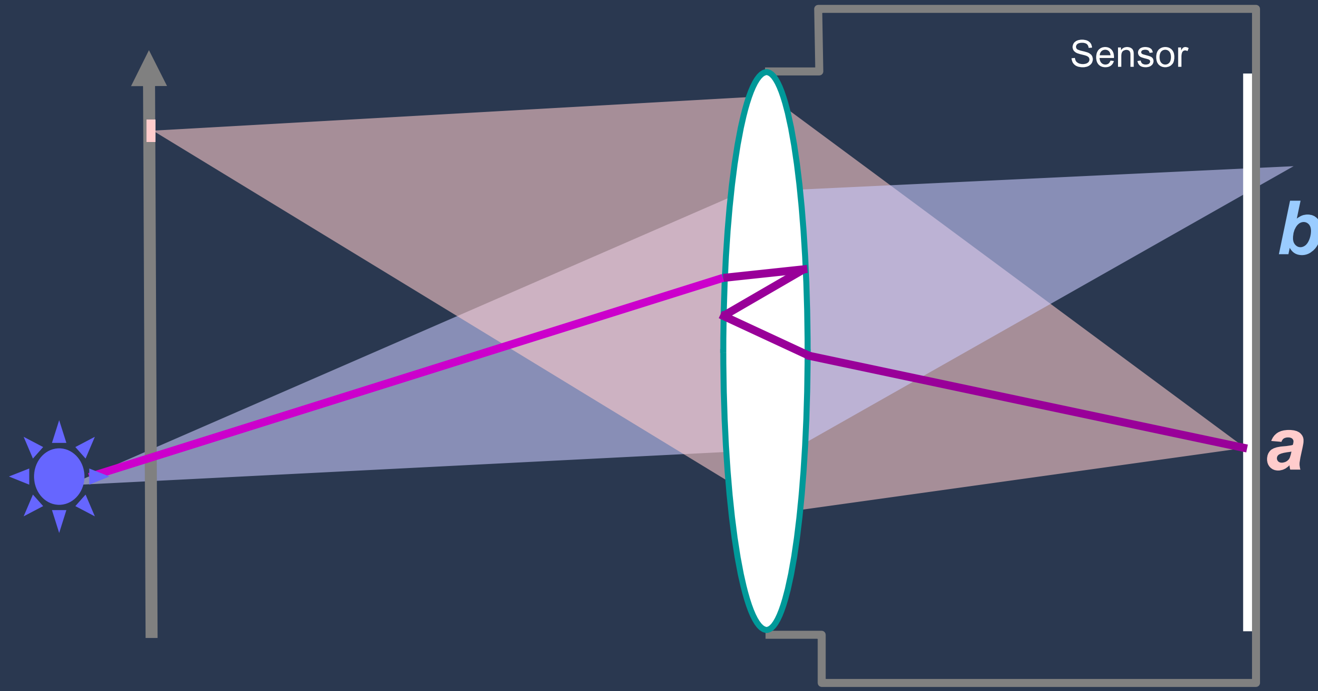
Low Res Traditional
Camera Photo

One of the
Light Field views

Glare Reduced Image

Key Idea

- Reducing Glare == Remove outlier among angular samples



Light Fields

- What are they?
- What are the properties?
- How to capture?
- What are the applications?

Light Field Applications

- Lens effects
  - Refocussing
  - New aperture setting
  - All in focus image

- Geometric
  - Estimate depth
  - (Create new views)
  - Synthetic aperture (Foreground/background)
  - (Insert objects)

- Statistical
  - Lens glare
  - Specular-diffuse

- Note:
  - LF not required, 4D sampling sufficient
  - Similar HD analysis also works for motion, wavelength, displays

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