Computer Vision

Spring 2006 15-385,-685

Instructor: S. Narasimhan

Wean 5403

T-R 3:00pm – 4:20pm

Image Formation and Optics

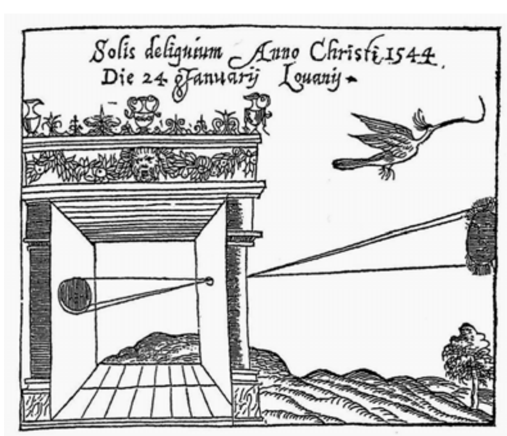
Lecture #2

Topics to be Covered

- Brief History of Images
- Pinhole and Perspective Projection
- Approximations to Perspective Projection
- Image Formation using Lenses
- Lens related issues

A Brief History of Images

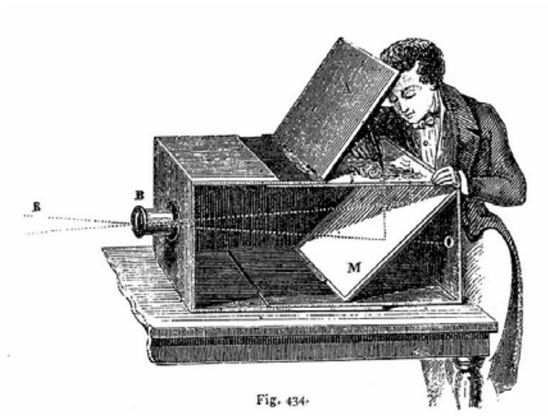
1544



Camera Obscura, Gemma Frisius, 1544

A Brief History of Images

- 1558
- 1568



Lens Based Camera Obscura, 1568

A Brief History of Images

- 1558
- 1568
- 1837

Still Life, Louis Jaques Mande Daguerre, 1837

A Brief History of Images

Silicon Image Detector, 1970

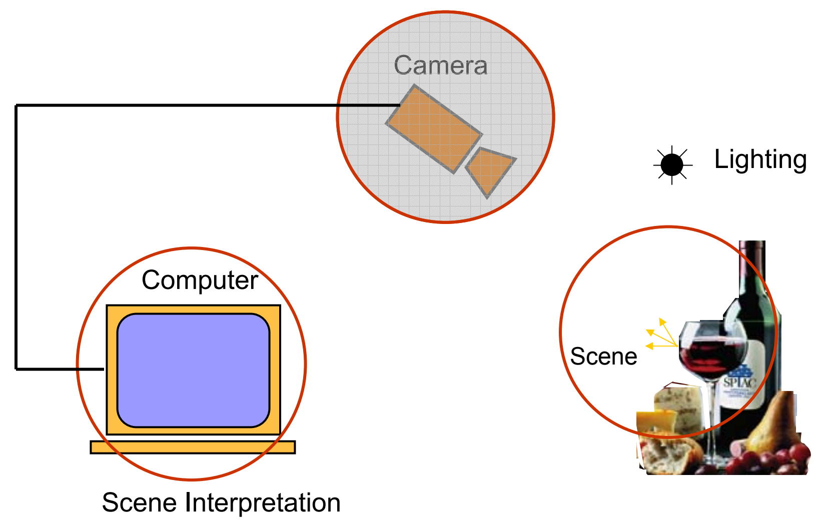
1558
1568
1837
1970

A Brief History of Images

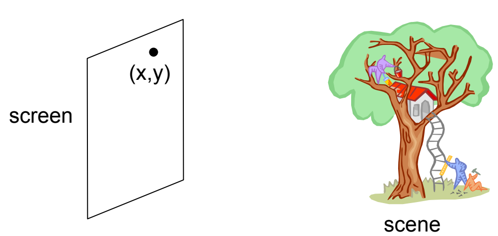
Digital Cameras

1558
1568
1837
1970
1995

Components of a Computer Vision System

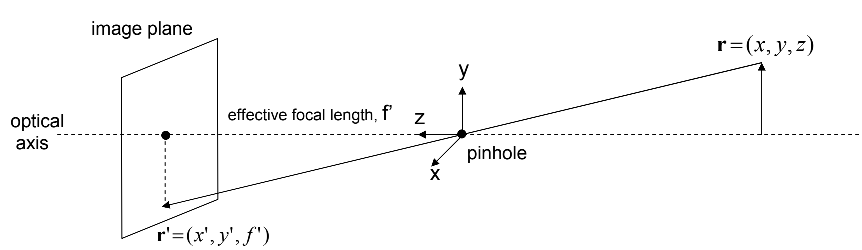


Pinhole and the Perspective Projection



Is an image being formed on the screen?

YES! But, not a “clear” one.

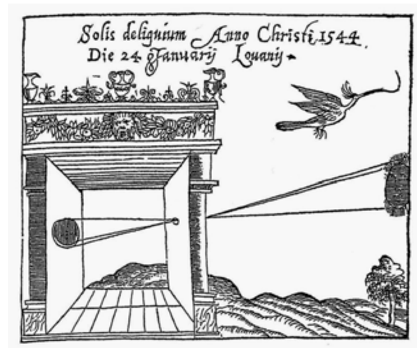


$$\frac{\mathbf{r}'}{f'} = \frac{\mathbf{r}}{z} \quad \Rightarrow \quad \frac{x'}{f'} = \frac{x}{z} \quad \frac{y'}{f'} = \frac{y}{z}$$

Pinhole Camera

• Basically a pinhole camera is a box, with a tiny hole at one end and film or photographic paper at the other.

• Mathematically: out of all the light rays in the world, choose the set of light rays passing through a point and projecting onto a plane.



Pinhole Photography

©Charlotte Murray Untitled, 4" x 5" pinhole photograph, 1992

Image Size inversely proportional to Distance

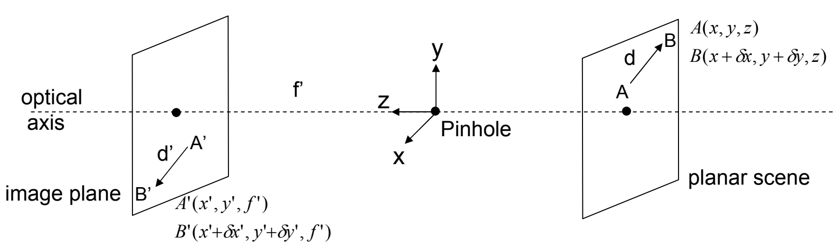
Reading: http://www.pinholeresource.com/

Pinhole Photography

Wide Field of View and Sharp Image

©Clarissa Carnell, *Stonehenge*, 5" x 7" Gold Toned Printing-Out Paper Pinhole Photograph, 1986

Magnification



From perspective projection:

$$\frac{x'}{f'} = \frac{x}{z} \qquad \frac{y'}{f'} = \frac{y}{z}$$

$$\frac{x'+\delta x'}{f'} = \frac{x+\delta x}{z} \qquad \frac{y'+\delta y'}{f'} = \frac{y+\delta y}{z}$$

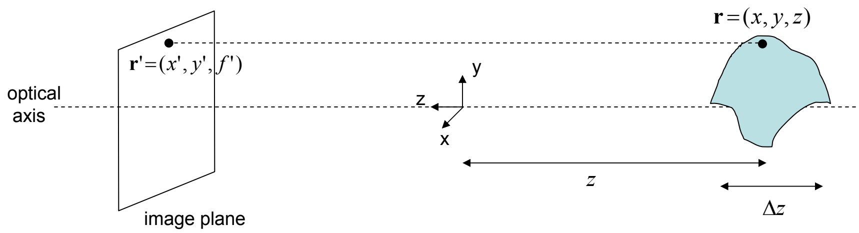
Magnification:

$$m = \frac{d'}{d} = \frac{\sqrt{(\delta x')^2 + (\delta y')^2}}{\sqrt{(\delta x)^2 + (\delta y)^2}} = \frac{f'}{z}$$

$$\frac{Area_{image}}{Area_{scene}} = m^2$$

Orthographic Projection

- Magnification: $x' = m\ x \qquad y' = m\ y$
- When m = 1, we have orthographic projection



- This is possible only when $z >> \Delta z$
- In other words, the range of scene depths is assumed to be much smaller than the average scene depth.

But, how do we produce non-inverted images?

Better Approximations to Perspective Projection

(NALWA)

- Weak-Perspective

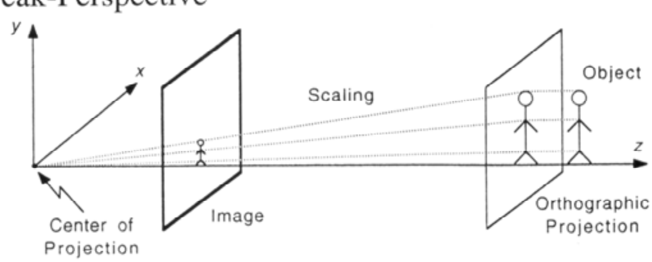


Figure 2.8 Approximation of perspective projection by orthographic projection. Perspective projection onto a plane can be approximated by orthographic projection, followed by scaling, when (1) the object dimensions are small compared to the distance of the object from the center of projection, and (2) compared to this distance, the object is close to the straight line that passes through the center of projection and is orthogonal to the image plane (this line is the z-axis here).

Better Approximations to Perspective Projection

- Para-Perspective

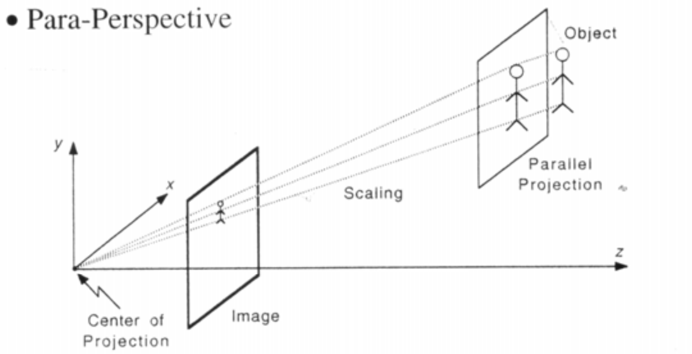


Figure 2.9 Approximation of perspective projection by parallel projection. *Parallel projection* onto a plane is a generalization of orthographic projection in which all the object points are projected along a set of parallel straight lines that may or may not be orthogonal to the projection plane. Perspective projection onto a plane can be approximated by parallel projection, followed by scaling, whenever the object dimensions are small compared to the distance of the object from the center of projection. The direction of parallel projection in such an approximation is along the "average direction" of perspective projection.

Problems with Pinholes

- Pinhole size (aperture) must be "very small" to obtain a clear image.
- However, as pinhole size is made smaller, less light is received by image plane.
- If pinhole is comparable to wavelength λ of incoming light, DIFFRACTION blurs the image!
- Sharpest image is obtained when:

  pinhole diameter $d = 2\sqrt{f'\lambda}$

  Example: If *f' = 50mm,*

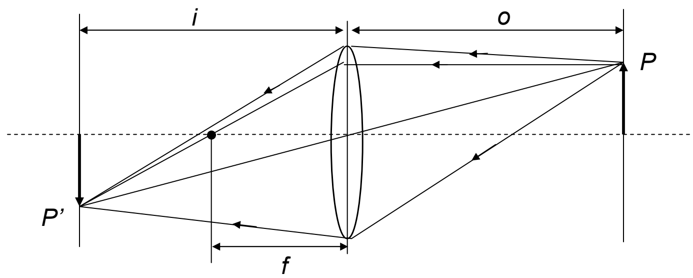
  = *600nm* (red),

  d = 0.36mm

Fig. 5.96 The pinhole camera. Note the variation in image clarity as the hole diameter decreases. [Photos courtesy Dr. N. Joel, UNESCO.]

Image Formation using Lenses

- Lenses are used to avoid problems with pinholes.
- Ideal Lens: Same projection as pinhole but gathers more light!

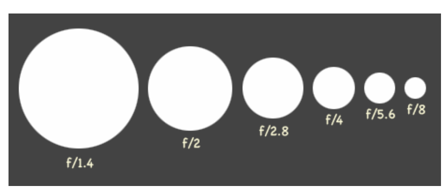


- Gaussian Thin Lens Formula: $\frac{1}{i} + \frac{1}{o} = \frac{1}{f}$
- f is the focal length of the lens – determines the lens's ability to refract light
- f different from the effective focal length f' discussed before!

Aperture, F-Number

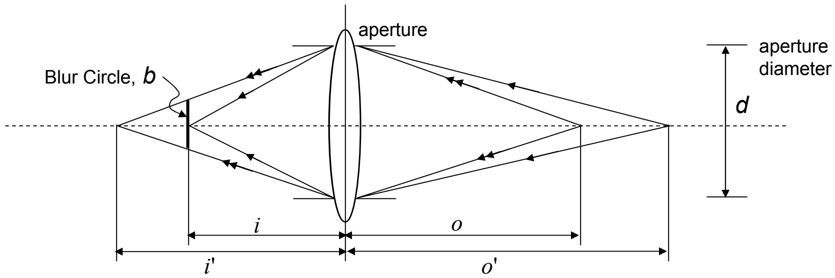
- Aperture : Diameter ***D*** of the lens that is exposed to light.
- F-Number **(f/#):**

$$f/\# = \frac{f}{D},$$



- For example, if ***f*** is 16 times the pupil diameter, then **f/#=f/16.**
- The greater the **f/#**, the less light per unit area reaches the image plane.
- f-stops represent a convenient sequence of f/# in a geometric progression.

Focus and Defocus



- Gaussian Law:

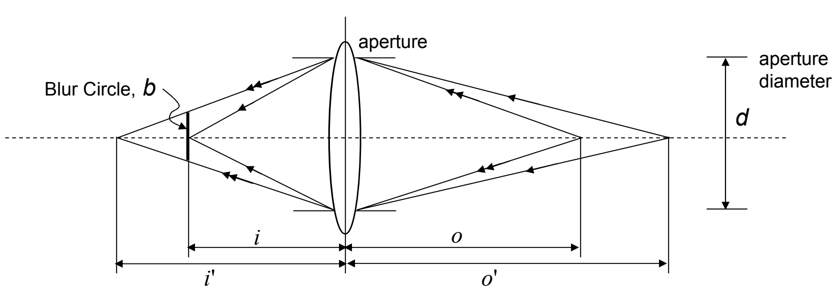
$$\frac{1}{i}+\frac{1}{o}=\frac{1}{f}$$

$$\frac{1}{i'}+\frac{1}{o'}=\frac{1}{f}$$

$$\Rightarrow \quad (i'-i)=\frac{f}{(o'-f)}\frac{f}{(o-f)}(o-o')$$

- In theory, only one scene plane is in focus.

Circle of Confusion



- Blur Circle Diameter ***b*** : Derive using similar triangles

$$b=\frac{d}{i'}(i'-i)$$

Depth of Field

- Range of object distances over which image is <u>sufficiently well</u> focused.
- Range for which *blur circle* is less than the resolution of the sensor.

http://images.dpchallenge.com/images_portfolio/27920/print_preview/116336.jpg

Depth of Field

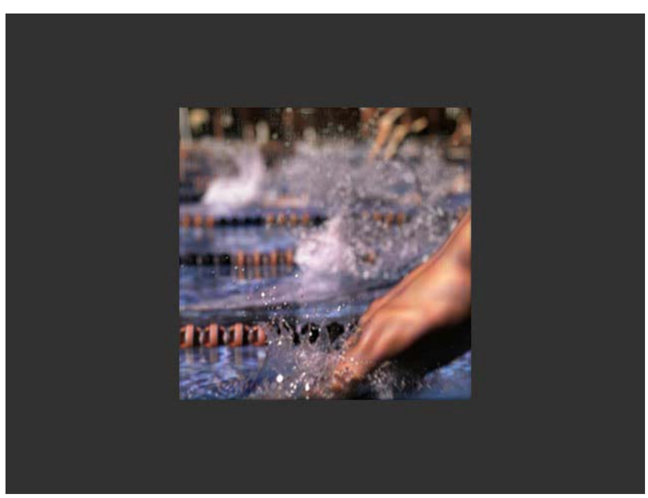
Both near and farther scene areas are blurred

Controlling Depth of Field

Increase Aperture, decrease Depth of Field

www.cambridgeincolour.com/.../depth-of-field.htm

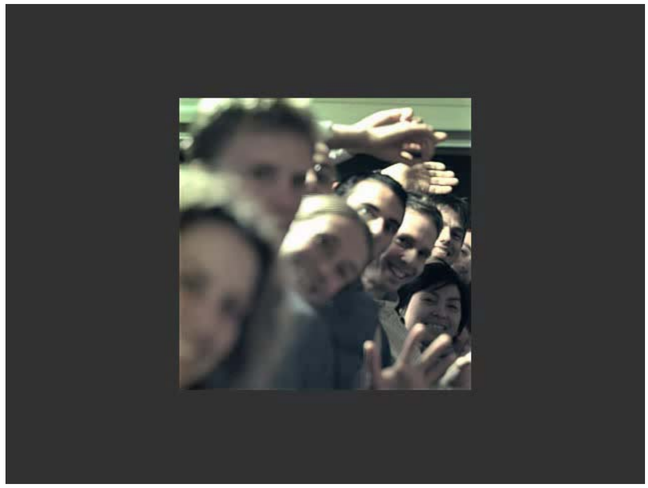
Light Field Camera – Digital Refocusing



Use a microlens array in front of the CCD/Film

Ted Adelson, Wang, MIT; Ren Ng, Marc Levoy, Pat Hanrahan, Stanford

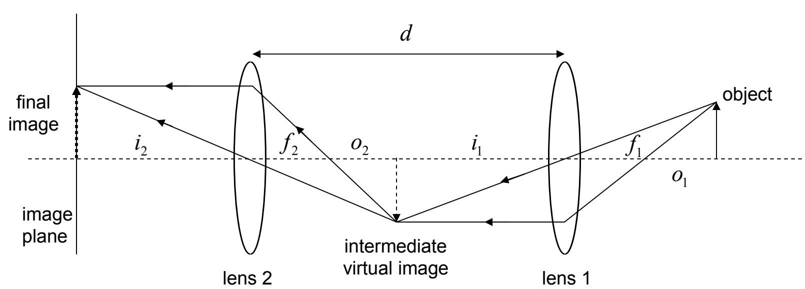
Light Field Camera – Digital Refocusing



Use a microlens array in front of the CCD/Film

Ted Adelson, Wang, MIT; Ren Ng, Marc Levoy, Pat Hanrahan, Stanford

Optics of a Two Lens System



- Rule : Image formed by first lens is the object for the second lens.
- Main Rays : Ray passing through focus emerges parallel to optical axis.
  Ray through optical center passes un-deviated.
- Magnification: $m = \dfrac{i_2}{o_2}\dfrac{i_1}{o_1}$

Exercises: What is the combined focal length of the system?
What is the combined focal length if d = 0?

Lens Vignetting

- Usually brighter at the center and darker at the periphery.

Reading: http://www.dpreview.com

Chromatic Abberations

Reading: http://www.dpreview.com

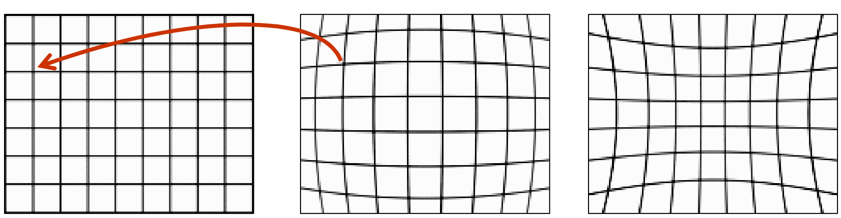
Lens Glare

• Stray interreflections of light within the optical lens system.

• Happens when very bright sources are present in the scene.

Reading: http://www.dpreview.com

Radial Lens Distortions



No Distortion Barrel Distortion Pincushion Distortion

• Radial distance from Image Center:

$$r_u = r_d + k_1 r_d^3$$

Correcting Radial Lens Distortions

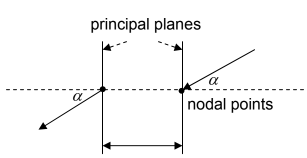
Before

After

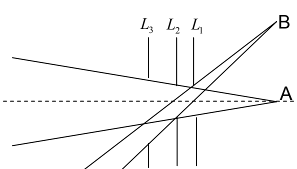
http://www.grasshopperonline.com/barrel_distortion_correction_software.html

Common Lens Related Issues - Summary

Compound (Thick) Lens

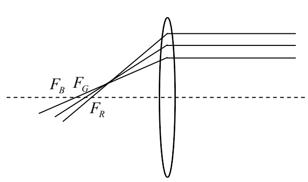


Vignetting



more light from A than B !

Chromatic Abberation



Lens has different refractive indices
for different wavelengths.

Radial and Tangential Distortion

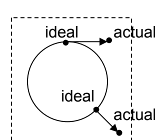
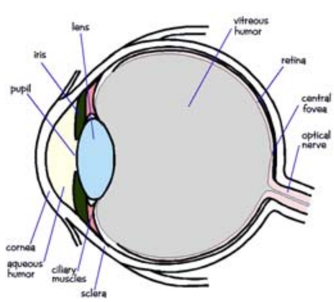


image plane

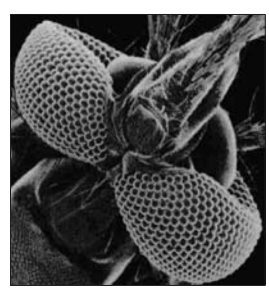
Next Class

- Image Sensing
- Horn, Chapter 2

Biological Cameras



Human Eye



Mosquito Eye