Pinhole camera

- Captures **pencil of rays** - all rays through a single point: aperture, center of projection, focal point, camera center
- The image is formed on the **image plane**

### Shrink the aperture

- Why not make the aperture as small as possible?
  - Less light gets through
  - Diffraction effects

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**Campus of Massachusetts, Amherst**

**January 28, 2016**

**Instructor: Subhransu Maji**
Adding a lens

• A lens focuses light on to the film
  • Thin lens model:
    - Rays passing through the center are not deviated (pinhole projection model still holds)

Slide by F. Durand

Thin lens formula

• What is the relation between the focal length ($f$), the distance of the object from the optical center ($D$) and the distance at which the object will be in focus ($D'$)?

image plane  lens  object

Slide by F. Durand
Thin lens formula

\[ \frac{1}{D'} + \frac{1}{D} = \frac{1}{f} \]

Any point satisfying the thin lens equation is in focus

Depth of Field

DOF is the distance between the nearest and farthest objects in a scene that appear acceptably sharp in an image.

Miniature faking

"Jodhpur rooftops" by Paul Goyette

Miniature faking

http://www.wallcoo.net/photography/Tilt-shift_Photography_Wallpapers_1920x1080/wallpapers/1600x900/Tallinn_old_town_1920x1080.html
Miniature faking

http://www.wallcoo.net/photography/Tilt-shift_Photography_Wallpapers_1920x1080/wallpapers/1366x768/Tilt_Shift_Wallpaper_20_by_leiyagami.html

Changing the aperture size affects the depth of field

- A smaller aperture increases the range in which the object is approximately in focus
- But small aperture reduces the amount of light — need to increase the exposure for contrast
- Pinhole camera has an infinite depth of field

Controlling depth of field

Pinhole glasses

- Your eye has a lens which is out of focus — adding a pinhole makes the aperture small so everything stays in focus!
- You can make one with your own hand!
Field of view

• Field of view (FOV) depends on the focal length and the size of the camera retina

\[ \phi = \tan^{-1} \left( \frac{d}{2f} \right) \]

Larger focal length = smaller FOV

Field of view, focal length

Large FOV, small \( f \) — Camera close to the car

\( \tan(\phi) \times 2f = d \)

\( \sim (\phi) \times 2f = d \)

Small FOV, large \( f \) — Camera far from the car
Same effect for faces

- wide-angle (short focus)
- standard
- telephoto (long focus)

Approximating an orthographic camera

The dolly zoom
- Continuously adjusting the camera focal length while the camera moves away from (or towards) the subject
- Also called as “Vertigo shot” or the “Hitchcock shot”

Example of dolly zoom from Goodfellas
Example of dolly zoom from La Haine
Lens flaws: Chromatic aberration

- Lens have different refractive indices (Snell’s law) for different wavelengths: causes color fringing

![Near lens center and near lens outer images](image)

Lens flaws: Spherical aberration

- Spherical lenses don’t focus light perfectly (thin lens model)
  - Rays farther from the optical axis are focused closer

![Spherical aberration diagram](image)

Lens flaws: Vignetting

- Reduction of image brightness in the periphery

![Vignetting diagram](image)

Lens flaws: Radial distortion

- Caused by asymmetry of lenses
  - Deviations are most noticeable near the periphery

![Radial distortion examples](image)

http://parkingandyou.com

http://clanegesselphotography.blogspot.com
Real photographic lens

- Many uses: cameras, telescopes, microscopes, etc
  - Fixed focal length
  - Adjustable zoom

Example of a prime lens - Carl Zeiss Tessar

Example of a zoom lens - Nikkor 28-200 mm zoom lens, extended to 200 mm at left and collapsed to 28 mm focal length at right.


Measuring light

- Photographic film — strip of transparent plastic film base coated on one side with a gelatin emulsion containing light-sensitive materials
- Creates a latent image when exposed to light for short duration
- Films are then chemically developed to form a photograph
- **Question:** how do we get color?

Early color photography

- Sergey Prokudin-Gorskii (1863-1944)
- Photographs of the Russian empire (1909-1916)

Only problem!

- Homework 1: fix this by aligning the channels
Fix one channel (say red). For the homework we will assume that channels are only translated, i.e., no rotation, scaling, etc.

For each shift: \( x \in (-15,15), y \in (-15,15) \)
- Measure similarity, e.g. angle between the vectors (reshape image to a vector)
- Pick the shift that maximizes similarity
- Repeat for the blue channel

A digital camera replaces the film with a sensor array
- Each cell in the array is a light-sensitive diode that converts photons to electrons
- Two common types
  - Charge Coupled Device (CCD)
  - Complementary Metal Oxide Semiconductor (CMOS)

Basic idea for alignment

Digital camera

Color sensing in the camera

Demosaicing

Why more green?
Interpolation

![Image](gt)

**nearest neighbor**
- copy one of your neighbors
- ? ← gl

![Image](gl)

**linear interpolation**
- average values of your neighbors
- ? ← (gt+gl+gr+gb)/4

![Image](gb)

**adaptive gradient**
- average based on local structure
- if |gt-gb| > |gl-gr|
- ? ← (gl+gr)/2
- else
- ? ← (gt+gb)/2

Similarly for the blue and red channels

**Homework 1:** implement nearest neighbor

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Problem with demosaicing: color moiré

![Image](Problem with demosaicing: color moiré)

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The cause of color moiré

![Image](The cause of color moiré)

Fine black and white detail in the image scene is misinterpreted as color information

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Historic milestones

- **Pinhole model:** Mozi (470-390 BCE), Aristotle (384-322 BCE)
- **Principles of optics (including lenses):** Alhacen (965-1039 CE)
- **Camera obscura:** Leonardo da Vinci (1452-1519), Johann Zahn (1631-1707)
- **First photo:** Joseph Nicephore Niepce (1822)
- **Daguerréotypes:** first widely used photographic process (1839)
- **Photographic film:** Eastman (1889)
- **Cinema:** Lumière Brothers, 1895
- **Color Photography:** Lumière Brothers, 1908
- **Television:** Baird, Farnsworth, Zworykin, 1920s
- **First consumer camera with CCD:** Sony Mavica (1981)
- **First fully digital camera:** Kodak DCS100 (1990)
First digitally scanned photo

- 1957, 176x176 pixels


More reading & thought problems

- Richard Szeliski's book, Sections 2.2.3 - 2.3.2