Announcement

 A total of 5 (five) late days are allowed for projects.

Image Formation





Digital Camera



The Eye

Alexei Efros' slide

Image Formation



Let's design a camera

 Idea 1: put a piece of film in front of an object
 Do we get a reasonable image?

Pinhole Camera



- Add a barrier to block off most of the rays
 - This reduces blurring
 - The opening known as the **aperture**
 - How does this transform the image?

Camera Obscura



- The first camera
 - 5th B.C. Aristotle, Mozi (Chinese: 墨子)
 - How does the aperture size affect the image?

http://en.wikipedia.org/wiki/Pinhole_camera

Shrinking the aperture



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

Shrinking the aperture



0.35 mm



0.15 mm

0.07 mm

Shrinking the aperture

Sharpest image is obtained when:

$$d = 2\sqrt{f\lambda}$$

d is diameter,

f is distance from hole to film λ is the wavelength of light, all given in metres.

Example: If f = 50mm,

 $\lambda = 600nm$ (red),

d = 0.36mm





Pinhole cameras are popular

Google

pinhole c	inhole camera				
	Google Search	I'm Feeling Lucky			



Jerry Vincent's Pinhole Camera

Impressive Images





Jerry Vincent's Pinhole Photos

What's wrong with Pinhole Cameras?

• Low incoming light => Long exposure time => Tripod

KODAK Film or Paper	Bright Sun	Cloudy Bright
TRI-X Pan	1 or 2 seconds	4 to 8 seconds
T-MAX 100 Film	2 to 4 seconds	8 to 16 seconds
KODABROMIDE Paper, F2	2 minutes	8 minutes

http://www.kodak.com/global/en/consumer/education/lessonPlans/pinholeCamera/pinholeCanBox.shtml

What's wrong with Pinhole Cameras





People are ghosted

What's wrong with Pinhole Cameras





People become ghosts!

Pinhole Camera Recap

- 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 of incoming light, *DIFFRACTION* effects blur the image!

What's the solution?



- A lens focuses light onto the film
 - There is a specific distance at which objects are "in focus"
 - other points project to a "circle of confusion" in the image
 - Changing the shape of the lens changes this distance

Thin lens optics

- Simplification of geometrical optics for well-behaved lenses
- All parallel rays converge to one point on a plane located at the focal length f



All rays going through the center are not deviated
 Hence same perspective as pinhole



Frédo Durand's slide

Demo!

-http://blue.utb.edu/pdukes/PhysApplets/ThinLens/lens&mirror/lensDemo.html



Frédo Durand's slide

Similar triangles everywhere!





Frédo Durand's slide





Film camera



Film camera



Still Life, Louis Jaques Mande Daguerre, 1837

Before Film was invented



Lens Based Camera Obscura, 1568

Silicon Image Detector





Silicon Image Detector, 1970

Digital camera



- A digital camera replaces film with a sensor array
- Each cell in the array is a light-sensitive diode that converts photons to electrons

SLR (Single-Lens Reflex)

- Reflex (R in SLR) means that we see through the same lens used to take the image.
- Not the case for compact cameras



SLR view finder



Compound Lens System



- Rule : Image formed by first lens is the object for the second lens.
- If $d \approx 0$, the combined focal length f is

$$f = \frac{f_1 f_2}{f_1 + f_2}$$

Srinivasa Narasimhan' s slide

Field of View (FoV) vs Focal Length



Canon EF-S 60mm f/2.8 Canon EF C 100mm f/2.8 1

Canon EF 180mm f/3.5

Field of View (FoV) vs Focal Length



24mm



50mm



135mm



Frédo Durand's slide

Field of View (FoV) vs Focal Length



Question: How does FoV change when we focus on closer objects?

Depth of Field

Large aperture opening



Changing the aperture size affects depth of field. A smaller aperture increases the range in which the object is approximately in focus

Aperture

- Aperture is the diameter of the lens opening, usually specified by f-stop, f/D, a fraction of the focal length.
 - f/2.0 on a 50mm means that the aperture is 25mm
 - f/2.0 on a 100mm means that the aperture is 50mm

- When a change in f-stop occurs, the light is either doubled or cut in half.
- Lower f-stop, more light (larger lens opening)
- Higher f-stop, less light (smaller lens opening)



F-stop



Blur Circle Diameter :
$$b = \frac{d}{i'}(i'-i) \approx \frac{d}{f}(i'-i)$$

 f -stop: $\# = \frac{f}{d}$

F-stop



Canon EF-S 60mm f/2.8 Canon EF C 100mm f/2.8 1

Canon EF 180mm f/3.5

Exposure

- Two main parameters:
 - Aperture (in f stop)
 - shutter speed (in fraction of a second)

See http://www.photonhead.com/simcam/

Effects of shutter speeds

• Slower shutter speed => more light, but more motion blur



• Faster shutter speed freezes motion



So far, we've only talked about monochrome sensors. Color imaging has been implemented in a number of ways:

- Field sequential
- Multi-chip
- Color filter array
- X3 sensor

Field sequential





Field sequential







Field sequential



Prokudin-Gorskii (early 1900's)













http://www.loc.gov/exhibits/empire/

Prokudin-Gorskii (early 1990's)



Multi-chip





Color filters can be manufactured directly onto the photodetectors.

Color filter array



Color filter arrays (CFAs)/color filter mosaics

Color filter array

R	G	в
R	G	в
R	G	в
R	G	в

W

G

W

G

Cy

Ye

Cy

Ye

Ye

Cy

Ye

Cy

G

W

G

W

R	G	в	G
R	G	В	G
R	G	В	G
R	G	В	G

Stripes

G

Су

Mg

Cy

Mg

Ye

G

Ye

R

G

R

G

G

В

G

В

R

G

R

G

G

В

G

В

Mg

Ye

G

Ye

Mosaics

G

Cy

Mg

Cy

Ye	G	Су	G
Ye	G	Су	G
Ye	G	Су	G
Ye	G	Су	G

Kodak DCS620x



Color filter arrays (CFAs)/color filter mosaics

Why CMY CFA might be better



Bayer's pattern





R	G	R	G	R	G	R
11	12	13	14	15	16	17
G	в	G	В	G	в	G
21	22	23	24	25	26	27
R	G	R	G	R	G	R
31	32	33	34	35	36	37
G	В	G	В	G	В	G
41	42	43	44	45	46	47
R	G	R	G	R	G	R
51	52	53	54	55	56	57
G	B	G	B	G	B	G
61	62	63	64	65	66	67
R	G	R	G	R	G	R
71	72	73	74	75	76	77

Median-based interpolation (Freeman)

- 1. Linear interpolation
- 2. Median filter on color differences

Demosaicking CFA's

Median-based interpolation (Freeman)







original



linear interpolation





Reconstruction (G=R+filtered difference)

Demosaicking CFA's







Bilinear









Generally, Freeman's is the best, especially for natural images.

Foveon X3 sensor

- light penetrates to different depths for different wavelengths
- multilayer CMOS sensor gets 3 different spectral sensitivities 400 700



Color filter array





YungYu Chuang's slide

green

X3 technology







green

blue

OUTPUT YungYu Chuang's slide

Foveon X3 sensor



Bayer CFA

X3 sensor

Cameras with X3





Sigma SD10, SD9

Polaroid X530

Sigma SD9 vs Canon D30

