Cameras

Digital Visual Effects

Yung-Yu Chuang

with slides by Fredo Durand, Brian Curless, Steve Seitz and Alexei Efros
Announcements

- Do subscribe the mailing list
- Check out scribes from past years
Put a piece of film in front of an object.
Pinhole camera

Add a barrier to block off most of the rays.
- It reduces blurring
- The pinhole is known as the aperture
- The image is inverted
Shrinking the aperture

Why not making the aperture as small as possible?

- Less light gets through
- Diffraction effect
Shrinking the aperture
High-end commercial pinhole cameras

$200~$700
Adding a lens
Lenses

Thin lens equation: \[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \]
Thin lens formula

Similar triangles everywhere! \[ \frac{y'}{y} = \frac{D'}{D} \]
Thin lens formula

Similar triangles everywhere!

\[ \frac{y'}{y} = \frac{D'}{D} \]

\[ \frac{y'}{y} = \frac{(D'-f)}{f} \]
The focal length $f$ determines the lens’s ability to bend (refract) light. It is a function of the shape and index of refraction of the lens.
Adding a lens

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
- Thin lens applet:
  http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html
Zoom lens

Nikon 28-200mm zoom lens.

simplified zoom lens in operation
Field of view vs focal length

Gaussian Lens Formula: \[
\frac{1}{i} + \frac{1}{o} = \frac{1}{f}
\]

Field of View: \[\alpha = 2\arctan\left(\frac{w}{2i}\right) \approx 2\arctan\left(\frac{w}{2f}\right)\]

Example: \(w = 30\text{mm}, f = 50\text{mm} \Rightarrow \alpha \approx 33.4^\circ\)

Slides from Li Zhang
Focal length in practice

- 24mm
- 50mm
- 135mm

Illustration showing the comparison of different focal lengths with corresponding angles of view.
Distortion

- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviations are most noticeable for rays that pass through the edge of the lens
Correcting radial distortion

from Helmut Dersch
Vignetting

more light from A than B!
Vignetting

more light from A than B!

Goldman & Chen ICCV 2005

Slides from Li Zhang
Chromatic Aberration

Lens has different refractive indices for different wavelengths.

Special lens systems using two or more pieces of glass with different refractive indexes can reduce or eliminate this problem.

http://www.dpreview.com/learn/?/Glossary/Optical/chromatic_aberration_01.htm

Slides from Li Zhang
Exposure = aperture + shutter speed

- Aperture of diameter D restricts the range of rays (aperture may be on either side of the lens)
- Shutter speed is the amount of time that light is allowed to pass through the aperture
Exposure

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

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

- Faster shutter speed freezes motion

From Photography, London et al.
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)
Depth of field

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

[Diagram showing the relationship between the sensor, lens, diaphragm, point in focus, and object with texture.]
Depth of field

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

From Photography, London et al.
Exposure

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

• Reciprocity
  The same exposure is obtained with an exposure twice as long and an aperture area half as big
  - Hence square root of two progression of f stops vs. power of two progression of shutter speed
  - Reciprocity can fail for very long exposures

From Photography, London et al.
Reciprocity

- Assume we know how much light we need
- We have the choice of an infinity of shutter speed/aperture pairs

- What will guide our choice of a shutter speed?
  - Freeze motion vs. motion blur, camera shake

- What will guide our choice of an aperture?
  - Depth of field, diffraction limit

- Often we must compromise
  - Open more to enable faster speed (but shallow DoF)
Exposure & metering

- The camera metering system measures how bright the scene is.
- In Aperture priority mode, the photographer sets the aperture, the camera sets the shutter speed.
- In Shutter-speed priority mode, photographers set the shutter speed and the camera deduces the aperture.
- In Program mode, the camera decides both exposure and shutter speed (middle value more or less).
- In Manual mode, the user decides everything (but can get feedback).
Pros and cons of various modes

• Aperture priority
  - Direct depth of field control
  - Cons: can require impossible shutter speed (e.g. with f/1.4 for a bright scene)

• Shutter speed priority
  - Direct motion blur control
  - Cons: can require impossible aperture (e.g. when requesting a 1/1000 speed for a dark scene)
    • Note that aperture is somewhat more restricted

• Program
  - Almost no control, but no need for neurons

• Manual
  - Full control, but takes more time and thinking
Sensitivity (ISO)

- Third variable for exposure
- Linear effect (200 ISO needs half the light as 100 ISO)
- Film photography: trade sensitivity for grain

Digital photography: trade sensitivity for noise

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<th>Camera Type</th>
<th>ISO</th>
<th>Example</th>
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<tr>
<td>Nikon D2X</td>
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Summary in a picture

(source: hamburgerfotospots.de)
Demo

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

scene

aperture & shutter

table with

motor

film
A digital camera replaces film with a sensor array.

Each cell in the array is a light-sensitive diode that converts photons to electrons.
CCD v.s. CMOS

- CCD is less susceptible to noise (special process, higher fill factor)
- CMOS is more flexible, less expensive (standard process), less power consumption
Sensor noise

- Blooming
- Diffusion
- Dark current
- Photon shot noise
- Amplifier readout noise
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

1. Prism
2. Mirror (flipped for exposure)
3. Film/sensor
4. Light from scene
5. Mirror (when viewing)
6. Lens
7. Your eye

Diagram of an SLR view finder showing the path of light from the scene through the lens, prism, mirror, and film/sensor to the viewer's eye.
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 1900’s)
Multi-chip

wavelength dependent
Embedded color filters

Color filters can be manufactured directly onto the photodetectors.
Color filter array

Kodak DCS620x

Color filter arrays (CFAs)/color filter mosaics
Why CMY CFA might be better
Color filter array

Color filter arrays (CFAs)/color filter mosaics

Bayer pattern
Bayer’s pattern
Demosaicking CFA’s

bilinear interpolation

\[ G_{44} = \frac{G_{34} + G_{43} + G_{45} + G_{54}}{4} \]
\[ R_{44} = \frac{R_{33} + R_{35} + R_{53} + R_{55}}{4} \]

original

input

linear interpolation
Demosaicking CFA’s

<table>
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Constant hue-based interpolation (Cok)

Hue: \((R/G, B/G)\)

Interpolate G first

\[
\begin{align*}
R_{44} &= \frac{G_{33} R_{33} + G_{35} R_{35} + G_{53} R_{53} + G_{55} R_{55}}{4} \\
B_{33} &= \frac{G_{22} B_{22} + G_{24} B_{24} + G_{42} B_{42} + G_{44} B_{44}}{4}
\end{align*}
\]
Demosaicking CFA’s

Median-based interpolation (Freeman)

1. Linear interpolation
2. Median filter on color differences
Demosaicking CFA’s

Median-based interpolation (Freeman)

original

input

linear interpolation

color difference
(e.g. G-R)

median filter
(kernel size 5)

Reconstruction
(G=R+filtered difference)
Demosaicking CFA’s

### Gradient-based interpolation (LaRoche-Prescott)

1. **Interpolation on G**

\[
\alpha = \text{abs}\left[ \frac{(B_{42} + B_{46})}{2} - B_{44} \right] \\
\beta = \text{abs}\left[ \frac{(B_{24} + B_{64})}{2} - B_{44} \right]
\]

\[
G_{44} = \begin{cases} \\
\frac{G_{43} + G_{45}}{2} & \text{if } \alpha < \beta \\
\frac{G_{34} + G_{54}}{2} & \text{if } \alpha > \beta \\
\frac{G_{43} + G_{45} + G_{34} + G_{54}}{4} & \text{if } \alpha = \beta
\end{cases}
\]
## Demosaicking CFA’s

### Gradient-based interpolation (LaRoche-Prescott)

2. Interpolation of color differences

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<td>G 64</td>
<td>R 65</td>
<td>G 66</td>
<td>R 67</td>
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\[
R_{34} = \frac{(R_{33}-G_{33}) + (R_{35}-G_{35})}{2} + G_{34},
\]

\[
R_{43} = \frac{(R_{33}-G_{33}) + (R_{53}-G_{53})}{2} + G_{43},
\]

\[
R_{44} = \frac{(R_{33}-G_{33}) + (R_{35}-G_{35}) + (R_{53}-G_{53}) + (R_{55}-G_{55})}{4} + G_{44}.
\]
Demosaicking CFA’s

bilinear  Cok  Freeman  LaRoche
Demosaicking CFA’s

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
**Color filter array**

Mosaic Capture

In conventional systems, color filters are applied to a single layer of photodetectors in a tiled mosaic pattern.

The filters let only one wavelength of light—red, green or blue—pass through to any given pixel, allowing it to record only one color.

As a result, mosaic sensors capture only 25% of the red and blue light, and just 50% of the green.

red  green  blue  output
X3 technology

A Foveon® X3™ image sensor features three separate layers of photodetectors embedded in silicon. Since silicon absorbs different colors of light at different depths, each layer captures a different color. Stacked together, they create full-color pixels. As a result, only Foveon X3 image sensors capture red, green and blue light at every pixel location.
Foveon X3 sensor

Bayer CFA

X3 sensor
Cameras with X3

Sigma SD10, SD9

Polaroid X530
Sigma SD9 vs Canon D30
Color processing

- After color values are recorded, more color processing usually happens:
  - White balance
  - Non-linearity to approximate film response or match TV monitor gamma
White Balance

warmer +3

automatic white balance
White Balance

illumination

reflectance

perception
Color constancy

What color is the dress?
Color constancy
Human vision is complex
AutoFocus

- Active
  - Sonar
  - Infrared
- Passive
Digital camera review website

- A cool video of digital camera illustration
- http://www.dpreview.com/
Camcorder

Control Panel

VCR Unit
Interlacing

without interlacing  with interlacing
Deinterlacing

blend

weave
Deinterlacing

Discard (even field only or odd field only)

Progressive scan
Hard cases
Computational cameras

MAS.541
Thu 9a-12p
Room 9-057
Computational Camera:
Google Glass, Microsoft
Kinect and Apps
More emerging cameras
References

- http://electronics.howstuffworks.com/autofocus.htm
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- http://www.100fps.com/