Today:
- Pinhole camera
- Film camera
- Digital camera
- Sensor types
- Signal chain
- Demo project

Let’s build a camera...
Camera trial #1

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 make the aperture as small as possible?
- Less light gets through
- Diffraction effect
Diffraction

Camera Obscura

Drawing from "The Great Art of Light and Shadow"
Jesuit Athanasius Kircher, 1646.
High-end commercial pinhole cameras


Adding a 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

Lenses

Thin lens equation: \( \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \)

- Any object point satisfying this equation is in focus
- Thin lens applet: [http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html](http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html)
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 light is allowed to pass through the aperture

Aperture

- Aperture is usually specified by f-stop, f/D. 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.


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

Film camera

from Helmut Dersch
History of Camera Development

• Many pinhole-type cameras dating back to the 11th century
• Joseph Niépce recorded the first photograph in 1826, using a photo-sensitive silver/chalk mixture
• Development of recording mediums more responsive to light: wet plates, dry plates
• George Eastman introduces photographic film in 1885, and debuts the “Kodak” camera in 1888 – a cheap and easy to operate camera that began to popularize cameras
• Oskar Barnack developed the Leica camera in 1925, which popularized 35mm film standard
• Ihagee introduced the first single-lens reflex camera, Exakta, in 1933, allowing photographers to view image “through the lens”
• Auto-focus developed in the Konica C35AF in 1977

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
History of Digital Camera Development

• Began with charged couple device (CCD) cameras that recorded to analog media
  • Steve Sasson produced the first for Kodak in 1973
  • Solid state CCD that recorded output onto cassette tape
  • Resolution: 10,000 pixels, or 0.01 megapixels
• First practical use in 1984, for journalism
  • Canon RC-701 recorded images onto “video floppies”
  • During 1984 Olympics images could be transmitted via telephone lines, and image quality was acceptable for newsprint
• JPEG image compression standard introduced in 1988
• First true digital camera: Fuji DS-1P debuted in 1988, recording a computerized image file to onboard memory
• First camera with live image feed to LCD: Casio QV-10 in 1995
• First “professional” digital SLR camera natively designed: 2.74MP Nikon D1 in 1999
• First affordable “consumer” digital SLR: 6MP Canon Digital Rebel 300D in 2003 - $1000

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

CCD

CMOS
Sensor noise

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

Color

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
Field sequential
Field sequential

Prokudin-Gorskii (early 1890’s)

http://www.loc.gov/exhibits/empire/
Prokudin-Gorskii (early 1890’s)

Multi-chip

wavelength dependent
Embedded color filters

Color filters can be manufactured directly onto the photodetectors.

Microlens and Color Filter
Color Filter Response

Human Eye
Silicon

Wavelength (nm)

Relative response

Color filter array

Stripes

R G B
R G B
R G B
R G B

Y R G
Y R G
Y R G
Y R G

Cy W
Cy W
Cy W
Cy W

Ye G
Ye G
Ye G
Ye G

G B
G B
G B
G B

Mg G
Mg G
Mg G
Mg G

Cy Ye
Cy Ye
Cy Ye
Cy Ye

Ye G
Ye G
Ye G
Ye G

Cy W
Cy W
Cy W
Cy W

Mosaics

Kodak DCS620x

Color filter arrays (CFAs)/color filter mosaics
Color filter array

Color filter arrays (CFAs)/color filter mosaics

Bayer’s pattern
Design of a DSLR

When DSLR is not Capturing Image

The photographic lens located in front of the camera directs lights into the camera body. Light is then reflected by the mirror to the pentaprism and finally travels to the viewfinder where photographers can observe the scene. Notice that the mirror is flipped down and the shutter covers the image sensor from recording lights.

Design of a DSLR

When Capturing an Image

The image capturing process starts when the shutter release button is pressed. Notice the mirror is flipped up from its original position, allowing light to travel to the sensor area. The shutter that covers the image sensor is now fully opened, and the image sensor is exposed under light and will be capturing the image.
All cameras, film or digital, work the same:

Photons are projected onto a photo-sensitive plane which records the light information.

By confining light to only photons which pass through a certain point, we begin to resolve “detail.”
**Input:**
Light «photons»

**Output:**
Electrical signals
Many electrons
Voltage: High
Implication: Many photons detected, bright exposure
Result: bright image

Few electrons
Voltage: Low
Implication: Few photons detected, dark exposure
Result: dark image

Max electrons
Voltage: Max
Implication: Max photons detected, brightest exposure
Result: White image

No electrons
Voltage: Zero
Implication: No photons detected, darkest exposure
Result: Black image
**Problem:**

Since the sensor only records light intensity, we can’t differentiate between colors!

Thus, imaging sensors only record in black and white

**Solution:**

Color filtering, the most common form being the Bayer filter

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1) Designates individual photosites to be either red, green, or blue (RGB)
2) Respective color filters are placed over each photosite
3) Thus, only the light energy corresponding to that color’s wavelength reaches the sensor
4) Thus the sensor can interpret the energy recorded at that photosite to be a measure of that certain color
5) Knowing the intensities of red, green, and blue light, we can derive the actual color
Since each photosite must be designated some color, the Bayer pattern of blue, green, and red photosites is offset, with blue tending towards top-left and red tending towards bottom-right.

Loses 2/3 of light information.
At each photosite, 2 of 3 colors are filtered out, and light information discarded.

- Workarounds:
  - Expose pictures for 3x time
  - Not practical for photography
  - Demosaic algorithms to interpolate missing 2/3 data

Drawbacks

**Ideal**
Rate of incoming light is constant.

**Real life**
Rate of incoming light is fluctuating.

How much fluctuation?

Dictated by **Poisson Distribution**
For $n$ total photons in exposure,
\[
\text{standard deviation} = \sqrt{n}
\]
\[ \sqrt{n}, \text{ so what?} \]

Photons collected = \( n + \sqrt{n} \)

Variable brightness = noise!

Noise monster
One of the photographer’s worst enemies

Our camera:

- TRDB_D5M
- from Altera
Reference Design

LCD display

- TRDB_LCM
- From Altera

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<thead>
<tr>
<th>Item</th>
<th>Description</th>
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<td>Display Size (Diagonal)</td>
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<td>Number of Dots (HV/V)</td>
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<td>Dot Pitch (HV/V)</td>
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<td>Color Arrangement</td>
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<tr>
<td>Color Numbers</td>
<td>8-bit RGB (16M color)</td>
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This week in lab:

- Compile the demo project
- Get it running
- Study the code-- what does what
- Figure out the switches
- Answer some questions
- Write a test fixture