CS6670: Computer Vision
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Lecture 4a: Cameras

Source: S. Lazebnik
Reading

• Szeliski chapter 2.2.3, 2.3
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

- Basic principle known to Mozi (470-390 BC), Aristotle (384-322 BC)
- Drawing aid for artists: described by Leonardo da Vinci (1452-1519)

Source: A. Efros
Camera Obscura
Home-made pinhole camera

Why so blurry?

http://www.debevec.org/Pinhole/
Shrinking the aperture

- Why not make the aperture as small as possible?
  - Less light gets through
  - Diffraction effects...
Shrinking the aperture
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
  - Changing the shape of the lens changes this distance
• A lens focuses parallel rays onto a single focal point
  – focal point at a distance $f$ beyond the plane of the lens (the *focal length*)
    • $f$ is a function of the shape and index of refraction of the lens
  – Aperture restricts the range of rays
    • aperture may be on either side of the lens
    – Lenses are typically spherical (easier to produce)
Thin lenses

- Thin lens equation: \( \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \)
  - Any object point satisfying this equation is in focus
  - What is the shape of the focus region?
  - How can we change the focus region?
  - 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) (by Fu-Kwun Hwang)
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

Large aperture opening

Small aperture opening
The eye

- **The human eye is a camera**
  - **Iris** - colored annulus with radial muscles
  - **Pupil** - the hole (aperture) whose size is controlled by the iris
  - What’s the “film”?
    - photoreceptor cells (rods and cones) in the **retina**
Eyes in nature:
eyespots to pinhole camera
Eyes in nature

(polychaete fan worm)

Source: Animal Eyes, Land & Nilsson
Before Film was invented

Lens Based Camera Obscura, 1568
Film camera

*Still Life*, Louis Jaques Mande Daguerre, 1837
Silicon Image Detector, 1970
Digital camera

• A digital camera replaces film with a sensor array
  – Each cell in the array is a Charge Coupled Device
  • light-sensitive diode that converts photons to electrons
  • other variants exist: CMOS is becoming more popular
Color

• So far, we’ve talked about grayscale images.
• What about color?
• Most digital images are comprised of three color channels – red, green, and, blue – which combine to create most of the colors we can see.

  • Why are there three?
**Color perception**

- **Three types of cones**
  - Each is sensitive in a different region of the spectrum
    - but regions overlap
    - Short (S) corresponds to blue
    - Medium (M) corresponds to green
    - Long (L) corresponds to red
  - Different sensitivities: we are more sensitive to green than red
    - varies from person to person (and with age)
  - Colorblindness—deficiency in at least one type of cone
Field sequential
Field sequential
Field sequential

YungYu Chuang's slide
Prokudin-Gorskii (early 1900’s)

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

YungYu Chuang’s slide
Prokudin-Gorskii (early 1990’s)
Color sensing in camera: Prism

- Requires three chips and precise alignment
- More expensive
Color filter array

Estimate missing components from neighboring values (demosaicing)

Why more green?

Human Luminance Sensitivity Function

Source: Steve Seitz
Bayer’s pattern
Foveon X3 sensor

• Light penetrates to different depths for different wavelengths
• Multilayer CMOS sensor gets 3 different spectral sensitivities

YungYu Chuang’s slide
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

YungYu Chuang's slide
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.

red  green  blue  output

YungYu Chuang's slide
Foveon X3 sensor

Bayer CFA  X3 sensor

YungYu Chuang's slide
Historical context

- **Pinhole model:** Mozi (470-390 BC), Aristotle (384-322 BC)
- **Principles of optics (including lenses):** Alhacen (965-1039)
- **Camera obscura:** Leonardo da Vinci (1452-1519), Johann Zahn (1631-1707)
- **First photo:** Joseph Nicephore Niepce (1822)
- **Daguerréotypes** (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)