CS559: Computer Graphics

Lecture 2: Image Formation in Eyes and Cameras

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Today

• Eyes
• Cameras
Why can we see?

Light
Visible Light and Beyond

Newton’s prism experiment, 1666.

Infrared, e.g. radio wave
longer wavelength

shorter wavelength

Ultraviolet, e.g. X ray

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Cones and Rods

Photomicrographs at increasing distances from the fovea. The large cells are cones; the small ones are rods.
Color Vision

**Rods**
- rod-shaped
- highly sensitive
- operate at night
- gray-scale vision

**Cones**
- cone-shaped
- less sensitive
- operate in high light
- color vision

Photomicrographs at increasing distances from the fovea. The large cells are cones; the small ones are rods.
Color Vision

Three kinds of cones:
Electromagnetic Spectrum

Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm
Lightness contrast

• Also know as
  – Simultaneous contrast
  – Color contrast (for colors)
Why is it important?

• This phenomenon helps us maintain a consistent mental image of the world, under dramatic changes in illumination.
But, It causes Illusion as well

• [http://www.michaelbach.de/ot/lum_white-illusion/index.html](http://www.michaelbach.de/ot/lum_white-illusion/index.html)
Noise

- Noise can be thought as randomness added to the signal.
- The eyes are relatively insensitive to noise.
Vision vs. Graphics

Computer Graphics

Modelling
Simulation & Rendering
Image

Computer Vision
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
Shrinking the aperture

Sharpest image is obtained when:

\[ d = 2 \sqrt{f \lambda} \]

d is diameter,
f is distance from hole to film
\( \lambda \) is the wavelength of light, all given in metres.

Example: If \( f = 50mm \),

\[ \lambda = 600nm \text{ (red)}, \]

\[ d = 0.36mm \]
Pinhole cameras are popular.

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

<table>
<thead>
<tr>
<th>KODAK Film or Paper</th>
<th>Bright Sun</th>
<th>Cloudy Bright</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRI-X Pan</td>
<td>1 or 2 seconds</td>
<td>4 to 8 seconds</td>
</tr>
<tr>
<td>T-MAX 100 Film</td>
<td>2 to 4 seconds</td>
<td>8 to 16 seconds</td>
</tr>
<tr>
<td>KODABROMIDE Paper, F2</td>
<td>2 minutes</td>
<td>8 minutes</td>
</tr>
</tbody>
</table>

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!

• Require long exposure time
What’s the solution?

- 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
Demo!

http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html (by Fu-Kwun Hwang)
Film camera

scene

aperture & shutter

lens & motor

film
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
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
Exposure

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

See http://www.photonhead.com/simcam/
Effects of shutter speeds

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

• Faster shutter speed freezes motion
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
• X3 sensor
Field sequential
Field sequential
Field sequential
Prokudin-Gorskii (early 1900’s)

Lantern projector

http://www.loc.gov/exhibits/empire/
Prokudin-Gorskii (early 1990’s)
Multi-chip

wavelength dependent
Embedded color filters

Color filters can be manufactured directly onto the photodetectors.
Color filter arrays (CFAs)/color filter mosaics
Color filter array

Color filter arrays (CFAs)/color filter mosaic

Kodak DCS620x
Why CMY CFA might be better

Kodak 13um Pixel CMY & RGB Response

Quantum Efficiency (%) vs Wavelength (nm)
Bayer’s pattern
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.

red  green  blue  output
Foveon X3 sensor

Bayer CFA  X3 sensor
Cameras with X3

Sigma SD10, SD9

Polaroid X530
Sigma SD9 vs Canon D30