CSCI 1290: Comp Photo

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Many slides thanks to James Hays’ old CS 129 course, along with all of its acknowledgements.
Questions from Tuesday

• Ishaan: what is quantum efficiency?
  • https://en.wikipedia.org/wiki/Quantum_efficiency
  • Literally “the percentage of photons hitting the device's photoreactive surface that produce charge carriers. It is measured in electrons per photon or amps per watt.”

• Leslie: does the eye alias?
  • Spatially, apparently not. The retina (sensor) has high resolution, but the optics of the eye cannot meet that resolution, and so the image is blurred optically before being sampled (removes high-frequency content!)
Lenses
Let’s design a camera

Idea 1: Put a sensor in front of an object
Do we get a reasonable image?
Let’s design a camera

Idea 2: Add a barrier to block most rays
  – Pinhole in barrier
  – Only sense light from one direction.
    • Reduces blurring.
  – In most cameras, this **aperture** can vary in size.

Slide source: Seitz
Pinhole camera model

\[ f = \text{Focal length} \]
\[ c = \text{Optical center of the camera} \]

Figure from Forsyth
Projection: world coordinates $\rightarrow$ image coordinates

$\mathbf{p} = \begin{bmatrix} U \\ V \end{bmatrix}$

$\mathbf{p} = \text{distance from image center}$

$\mathbf{P} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$

$U = -X \frac{f}{Z}$

$V = -Y \frac{f}{Z}$

What is the effect if $f$ and $Z$ are equal?
The first camera

- Known to Aristotle
- Depth of the room is the effective focal length
Home-made pinhole camera

Why so blurry?

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

Less light gets through

Integrate over fewer angles
Shrinking the aperture

Why not make the aperture as small as possible?

- Less light gets through
- Diffraction effects…
Shrinking the aperture

![Image of text with different aperture sizes: 2 mm, 1 mm, 0.6 mm, 0.35 mm, 0.15 mm, 0.07 mm]
The reason for lenses
Focus and Defocus

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 lenses

Thin lens equation:
\[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad \text{and} \quad \frac{1}{f} - \frac{1}{d_o} = \frac{1}{d_i} \]

- 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: [https://sites.google.com/site/marclevoylectures/applets/operation-of-a-thin-lens](https://sites.google.com/site/marclevoylectures/applets/operation-of-a-thin-lens)
  (by Andrew Adams, Nora Willett, Marc Levoy)
Beyond Pinholes: Real apertures

Bokeh:

[Rushif – Wikipedia]
Depth Of Field
Depth of Field

http://www.cambridgeincolour.com/tutorials/depth-of-field.htm
Aperture controls 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
- But small aperture reduces amount of light – need to increase exposure
Varying the aperture

Large aperture = small DOF

Small aperture = large DOF
Depth of Field
Shutters

2500FPS
100X SLOWER

[The Slo-Mo Guys]
Shutters

[The Slo-Mo Guys]
Shutters

[The Slo-Mo Guys]
Sensor ISO

ISO = old film terminology
    = sensitivity to light

ISO 200 is twice as sensitive as ISO 100.

Digital Photography:
ISO = ‘gain’ or amplification of sensor signal
Sensors: Rolling shutter vs. global shutter

Some cameras have purely digital shutters.
EXPOSURE AND NOISE
Play with these settings in lab.

Come back at end to see the relationship.
https://sites.google.com/site/marclevoylectures/applets/variables-that-affect-exposure
Beyond Pinholes: Real apertures

Bokeh:

[Rushif – Wikipedia]
Accidental Cameras

Accidental Pinhole and Pinspeck Cameras
Revealing the scene outside the picture.
Antonio Torralba, William T. Freeman
Field of View (Zoom)
Field of View (Zoom)

From London and Upton
Field of View (Zoom) = Cropping

From London and Upton
FOV depends of Focal Length

Size of field of view governed by size of the camera retina:

\[ \varphi = \tan^{-1}\left(\frac{d}{2f}\right) \]

Smaller FOV = larger Focal Length
Field of View / Focal Length

Large FOV, small f
Camera close to car

Small FOV, large f
Camera far from the car
Fun with Focal Length (Jim Sherwood)

http://www.hash.com/users/jsherwood/tutes/focal/Zoomin.mov
Lens Flaws
Lens Flaws: Chromatic Aberration

Dispersion: wavelength-dependent refractive index
  • (enables prism to spread white light beam into rainbow)

Modifies ray-bending and lens focal length: $f(\lambda)$

Color fringes near edges of image

Corrections: add ‘doublet’ lens of flint glass, etc.
Chromatic Aberration

Near Lens Center

Near Lens Outer Edge
Radial Distortion (e.g. ‘barrel’ and ‘pin-cushion’)

Straight lines curve around the image center
Radial Distortion

Radial distortion of the image

- Caused by imperfect lenses
- Deviations are most noticeable for rays that pass through the edge of the lens

No distortion  Pin cushion  Barrel

Corrected Barrel Distortion

Image from Martin Habbecke