Lecture 20: Cameras & Lenses I
Image Capture Overview
What’s Happening Inside the Camera?

Cross-section of Nikon D3, 14-24mm F2.8 lens
Pinholes & Lenses Form Image on Sensor

Photograph made with small pinhole

Photograph made with lens
Shutter Exposes Sensor For Precise Duration

The Slow Mo Guys, https://youtu.be/CmjeCchGRQo
Sensor Accumulates Irradiance During Exposure
Why Not Sensors Without Lenses?

Each sensor point would integrate light from all points on the object, so all pixel values would be similar*

*But there is computational imaging research…
Image Processing: From Sensor Values to Image
Pinhole Image Formation
Recall: Pinhole Camera (Camera Obscura)

Mo Tzu (c. 470–c. 390 BC)
Aristotle (384–322 BC)
Ibn al-Haytham (965–1040)
Shen Kuo (1031–1095)
Roger Bacon (c. 1214–1294)
Johannes Kepler (1571–1630)

A. H. Zewail, Phil. Trans. R. Soc. A 2010;368:1191-1204
Largest Pinhole Photograph

“The Great Picture”
Largest Pinhole Photograph
Largest Pinhole Photograph
Largest Pinhole Photograph
Largest Pinhole Photograph
Largest Pinhole Photograph
Field of View
Effect of Focal Length on FOV

For a fixed sensor size, decreasing the focal length increases the field of view.

\[
FOV = 2 \arctan \left( \frac{h}{2f} \right)
\]
Focal Length v. Field of View

- For historical reasons, it is common to refer to angular field of view by focal length of a lens used on a 35mm-format film (36 x 24mm).

- Examples of focal lengths on 35mm format:
  - 17mm is wide angle 104°
  - 50mm is a “normal” lens 47°
  - 200mm is telephoto lens 12°

- Careful! When we say current cell phones have approximately 28mm “equivalent” focal length, this uses the above convention. The physical focal length is often 5-6 times shorter, because the sensor is correspondingly smaller.
Focal Length v. Field of View

From London and Upton, and Canon EF Lens Work III

CS184/284A  Ren Ng
Focal Length v. Field of View

From London and Upton, and Canon EF Lens Work III
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CS184/284A Ren Ng
Focal Length v. Field of View

From London and Upton, and Canon EF Lens Work III
Telephoto: 200mm, 1/200, f/2.8
Effect of Sensor Size on FOV

35mm Full Frame

APS-C

Ren Ng
# Sensor Sizes

<table>
<thead>
<tr>
<th>Sensor Name</th>
<th>Medium Format</th>
<th>Full Frame</th>
<th>APS-H</th>
<th>APS-C</th>
<th>4/3</th>
<th>1&quot;</th>
<th>1/1.63&quot;</th>
<th>1/2.3&quot;</th>
<th>1/3.2&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Size</td>
<td>53.7 x 40.2mm</td>
<td>36 x 23.9mm</td>
<td>27.9x18.6mm</td>
<td>23.6x15.8mm</td>
<td>17.3x13mm</td>
<td>13.2x8.8mm</td>
<td>8.38x5.59mm</td>
<td>6.16x4.62mm</td>
<td>4.54x3.42mm</td>
</tr>
<tr>
<td>Sensor Area</td>
<td>21.59 cm²</td>
<td>8.6 cm²</td>
<td>5.19 cm²</td>
<td>3.73 cm²</td>
<td>2.25 cm²</td>
<td>1.16 cm²</td>
<td>0.47 cm²</td>
<td>0.28 cm²</td>
<td>0.15 cm²</td>
</tr>
<tr>
<td>Crop Factor</td>
<td>0.64</td>
<td>1.0</td>
<td>1.29</td>
<td>1.52</td>
<td>2.0</td>
<td>2.7</td>
<td>4.3</td>
<td>5.62</td>
<td>7.61</td>
</tr>
</tbody>
</table>

Credit: lensvid.com
Maintain FOV on Smaller Sensor?

To maintain FOV, decrease focal length of lens in proportion to width/height of sensor.
Perspective Composition
(Photographer’s Mindset)
In this sequence, distance from subject increases with focal length to maintain image size of human subject.

Notice the dramatic change in background perspective.

From Canon EF Lens Work III
Perspective Composition

Up close and zoomed wide with short focal length

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Perspective Composition

Walk back and zoom in with long focal length

200 mm (12°)
Dolly-Zoom Cinema Technique – “Vertigo Effect”

First used by Alfred Hitchcock in “Vertigo” 1958
Dolly-Zoom Cinema Technique – a.k.a. “Vertigo Effect”

By Steven Spielberg in “Jaws” 1975
A Photographer’s Mindset

“Choose your perspective before you choose your lens.”

— Ming Thein, mingthein.com
Exposure
Exposure

• $H = T \times E$

• Exposure = time $\times$ irradiance

• Exposure time ($T$)
  • Controlled by shutter

• Irradiance ($E$)
  • Power of light falling on a unit area of sensor
  • Controlled by lens aperture and focal length
Focal Plane Shutter (1/25 Sec Exposure)

The Slow Mo Guys, https://youtu.be/CmjeCchGRQo
Focal Plane Shutter (Fast Exposures)

Electronic Rolling Shutter

The Slow Mo Guys, https://youtu.be/CmjeCchGRQo
Other Shutter Systems

Also have leaf shutters
- Circular iris that closes

Global electronic shutter
- Different circuit design that exposes all pixels with the same time duration

Mixtures of physical and electronic shutter
- E.g. Electronic reset starts exposure, physical shutter closing ends exposure
Shutter Speed

Controls how long the sensor is exposed to light

- Linear effect on exposure until sensor saturates

Denoted in fractions of a second:

- $1/4000, 1/2000, 1/1000, 1/500, 1/125, 1/60, 1/30, 1/15, 1/8, 1/4, 1/2, 1, 2, 4, 8, 15, 30s$

Blur due to hand-shake is a concern for hand-held shots:

- Rule of thumb: longest hand-held exposure $= 1 / f$
  - e.g. $1/180$ second for a 180mm lens (35 mm equiv.)
Main Side Effect of Shutter Speed

Motion blur

Doubling shutter time doubles motion blur
Acknowledgments

Many thanks to Marc Levoy, who created many of these slides, and Pat Hanrahan.


• Peterson, Understanding Exposure, AMPHOTO 1990.

• The Slow Mo Guys

• bobatkins.com
Art Competition #2 Results
Art Competition #2 – 3rd Place

XOR Cloud Pattern Cow, Eli Lipsitz
Art Competition #2 – 2nd Place

Cottage, Isabel Zhang

Art Competition #2 – Winner

Shader Animation (see link for animation), Anders Lewis

http://imgur.com/xfZKzd7