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

1. Photograph made with small pinhole
2. 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
Field of View
Effect of Focal Length on FOV

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

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

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Focal Length v. Field of View

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Ren Ng
Telephoto: 420mm, 4.0s, f/4
Effect of Sensor Size on FOV

35mm Full Frame

APS-C

Object

Lens

Sensor(s)
# 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>
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</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>6.38x5.59mm</td>
<td>6.16x4.62mm</td>
<td>4.54x3.42mm</td>
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<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>
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<table>
<thead>
<tr>
<th>Image</th>
<th>Example</th>
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<td><img src="image9.png" alt="Image" /></td>
<td><img src="example9.png" alt="Example" /></td>
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</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.
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°)
A Photographer’s Mindset

“Choose your perspective before you choose your lens.”

— Ming Thein, mingthein.com
Improve Your Own Photography

Tip 1: Make sure you have a strong subject
  • Make it prominent, e.g. 1/3 of your image

Tip 2: choose a good perspective relationship (relative size) between your subject and background (or foreground)
  • Complement, don’t compete with the subject

Tip 3: change the zoom and camera distance to your subject
  • Implement: actively zoom, and move your camera in/out
  • Even works with your smartphone!
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
Fast and Slow Photography
High-Speed Photography

long exposure
bright strobe illumination
gun synced to camera

Slide courtesy L. Waller
High-Speed Photography

Harold Edgerton
High-Speed Photography

Harold Edgerton
Long-Exposure Photography

https://www.demilked.com/best-long-exposure-photos/
Long-Exposure Photography

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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
Exposure Controls in Photography

Aperture size

- Change the f-stop by opening / closing the aperture (if camera has iris control)

Shutter speed

- Change the duration the sensor pixels integrate light

ISO gain

- Change the amplification (analog and/or digital) between sensor values and digital image values
Exposure: Aperture, Shutter, Gain (ISO)
Exposure Levels (1 “Stop” = 2x Exposure)

Exposure bracketing with +/- 1 stop exposure

### Constant Exposure: F-Stop vs Shutter Speed

Example: these pairs of aperture and shutter speed give equivalent exposure

<table>
<thead>
<tr>
<th>F-Stop</th>
<th>1.4</th>
<th>2.0</th>
<th>2.8</th>
<th>4.0</th>
<th>5.6</th>
<th>8.0</th>
<th>11.0</th>
<th>16.0</th>
<th>22.0</th>
<th>32.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shutter</td>
<td>1/500</td>
<td>1/250</td>
<td>1/125</td>
<td>1/60</td>
<td>1/30</td>
<td>1/15</td>
<td>1/8</td>
<td>1/4</td>
<td>1/2</td>
<td>1</td>
</tr>
</tbody>
</table>

If the exposure is too bright/dark, may need to adjust f-stop and/or shutter up/down.
Physical, Electronic & Computational Shutters
Electronic Shutter

- Pixel is electronically reset to start exposure
- Fills with photoelectrons at rate proportional to irradiance
- Reading out pixel electronically “ends” exposure
- Problem: most sensors read out pixels sequentially, takes time (e.g. 1/30 sec) to read entire sensor
  - If reset all pixels at the same time, last pixel read out will have longer exposure
  - Can stagger reset of pixels to ensure uniform exposure time, but get rolling shutter artifact
Electronic Rolling Shutter

The Slow Mo Guys, https://youtu.be/CmjeCchGRQo
Electronic Rolling Shutter

Exposure duration (e.g. 1/1000 sec)

Delay from top to bottom of sensor (e.g. 1/30 sec)
Physical Shutter (1/25 Sec Exposure)

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

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
Main Side Effect of Shutter Speed

Motion blur: handshake, subject movement

Doubling shutter time doubles motion blur
Main Side Effect of Shutter Speed

Motion blur: handshake, subject movement

Doubling shutter time doubles motion blur
Acknowledgments

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- Peterson, Understanding Exposure, AMPHOTO 1990.
- The Slow Mo Guys
- bobatkins.com