

# Computational Photography



**Dr. Irfan Essa**

Professor

School of Interactive Computing

Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

# Cameras, Optics, and Sensors



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Cameras: Aperture, Shutter speed Controls  
of a Camera.



# Lesson Objectives

★ Describe in your own words what is meant by Exposure Triangle by correctly using the terms Exposure, ISO, Aperture, and Shutter Speed.



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# Review: Focal Length vs. Viewpoint



# Review: Focal Length vs. Viewpoint



$f = 18\text{mm}$ , 35mm sensor

Distance to 1st Subject = 0.5m

Distance to 2nd Subject = 2.0m

# Review: Focal Length vs. Viewpoint



$f = 18\text{mm}$ , 35mm sensor  
Distance to 1st Subject = 0.5m  
Distance to 2nd Subject = 2.0m



$f = 180\text{mm}$ , 35mm sensor  
Distance to 1st Subject = 3.0m  
Distance to 2nd Subject = 4.5m

# Review: Focal Length vs. Viewpoint



$f = 18\text{mm}$ , 35mm sensor  
Distance to 1st Subject = 0.5m  
Distance to 2nd Subject = 2.0m



$f = 180\text{mm}$ , 35mm sensor  
Distance to 1st Subject = 3.0m  
Distance to 2nd Subject = 4.5m

- ★ Changing focal length allows us to move back, and still capture the scene

# Review: Focal Length vs. Viewpoint



$f = 18\text{mm}$ , 35mm sensor  
Distance to 1st Subject = 0.5m  
Distance to 2nd Subject = 2.0m



$f = 180\text{mm}$ , 35mm sensor  
Distance to 1st Subject = 3.0m  
Distance to 2nd Subject = 4.5m

- ★ Changing focal length allows us to move back, and still capture the scene
- ★ Changing viewpoint causes perspective changes

# Exposure



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# Exposure

★  $H = E \times T$

- Exposure = Irradiance x Time



[commons.wikimedia.org](https://commons.wikimedia.org)

# Exposure

★  $H = E \times T$

- Exposure = Irradiance x Time

★ Irradiance ( $E$ )

- Amount of Light falling on a unit area of sensor per second
- Controlled by Aperture on the Camera



[commons.wikimedia.org](https://commons.wikimedia.org)

# Exposure

★  $H = E \times T$

- Exposure = Irradiance x Time

★ Irradiance ( $E$ )

- Amount of Light falling on a unit area of sensor per second
- Controlled by Aperture on the Camera

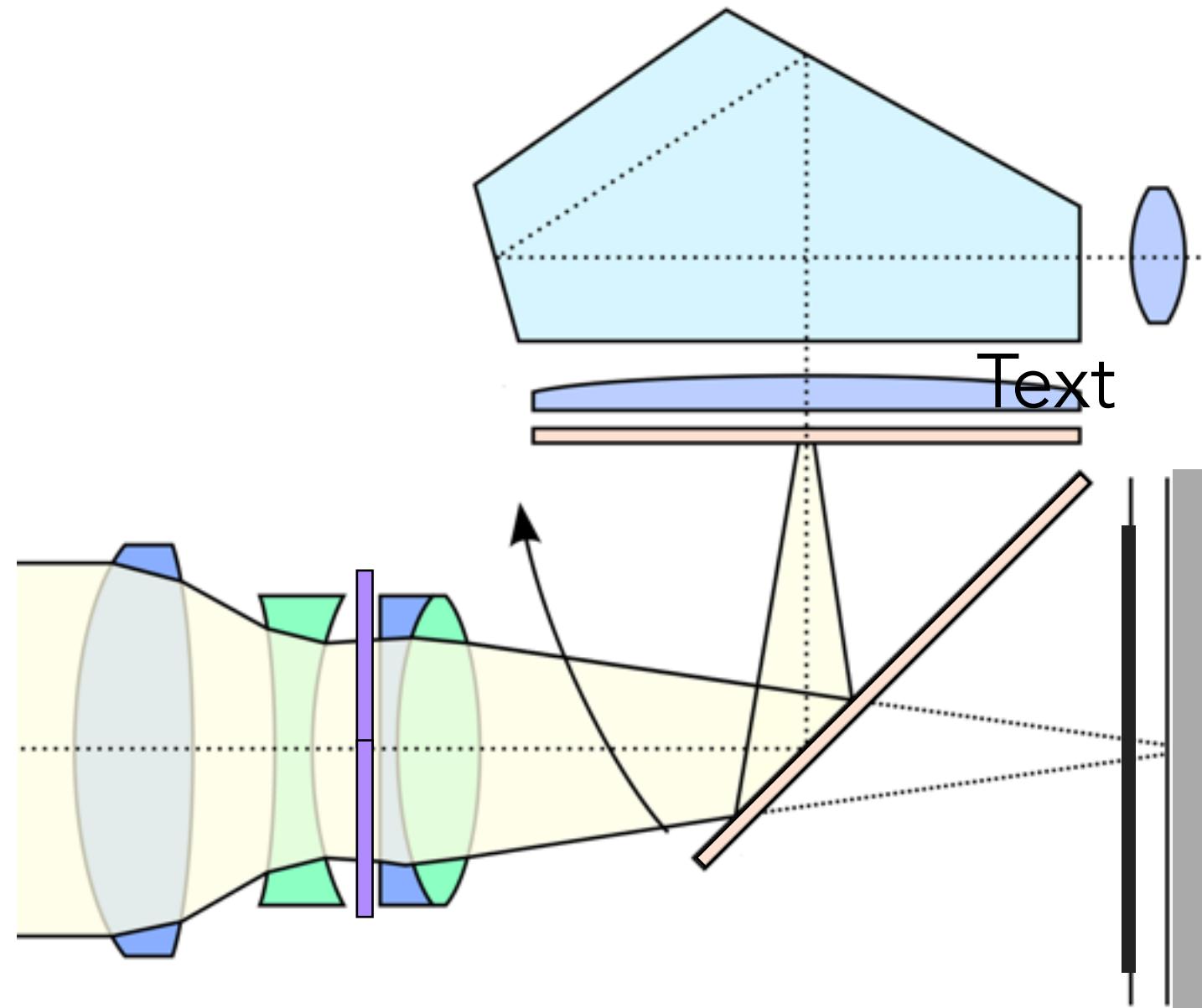
★ Exposure Time ( $T$ )

- Controlled by Shutter on the Camera



[commons.wikimedia.org](https://commons.wikimedia.org)

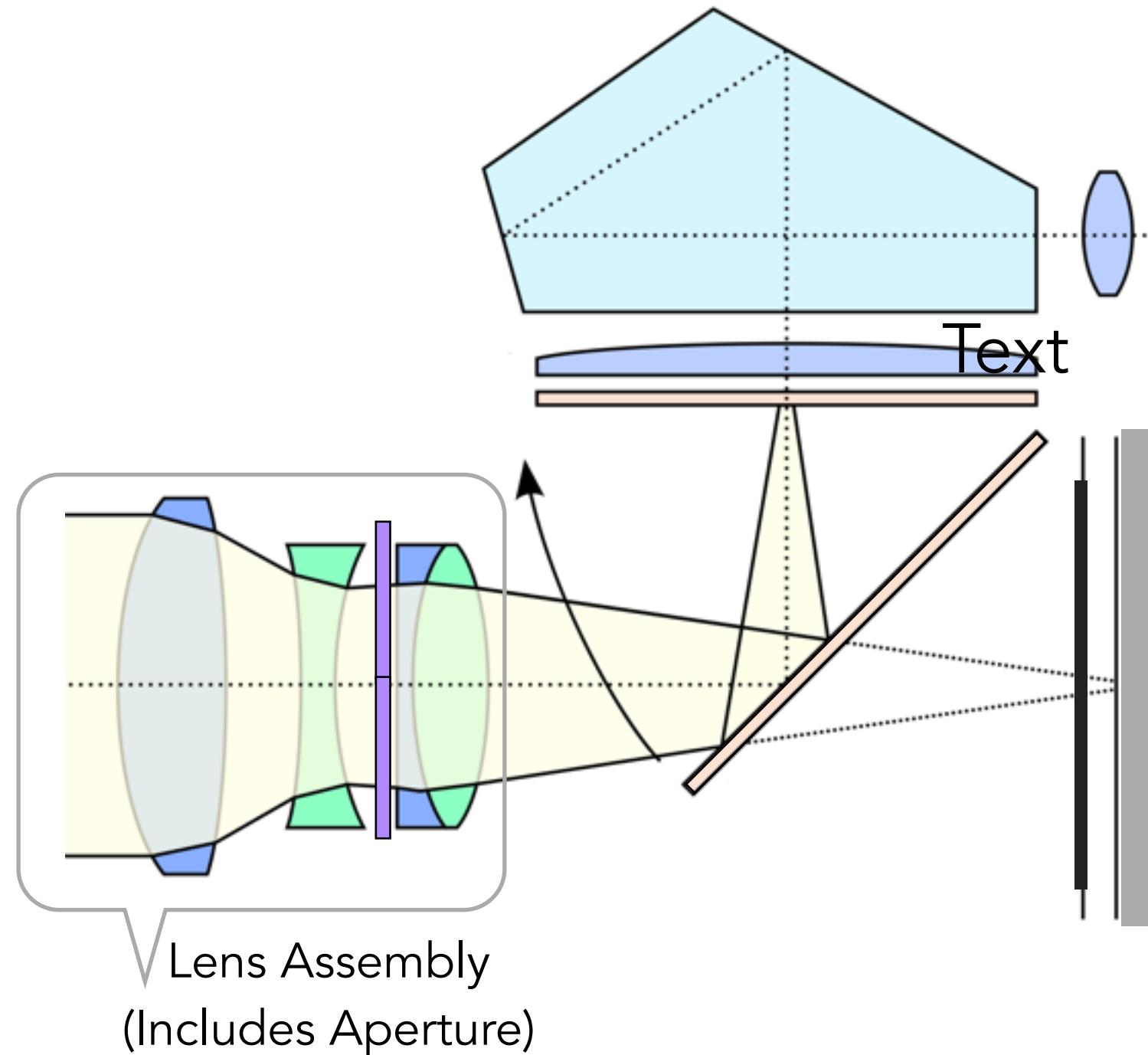
# Inside a Camera (an SLR)



Adapted from [commons.wikimedia.org/](https://commons.wikimedia.org/)

# Inside a Camera (an SLR)

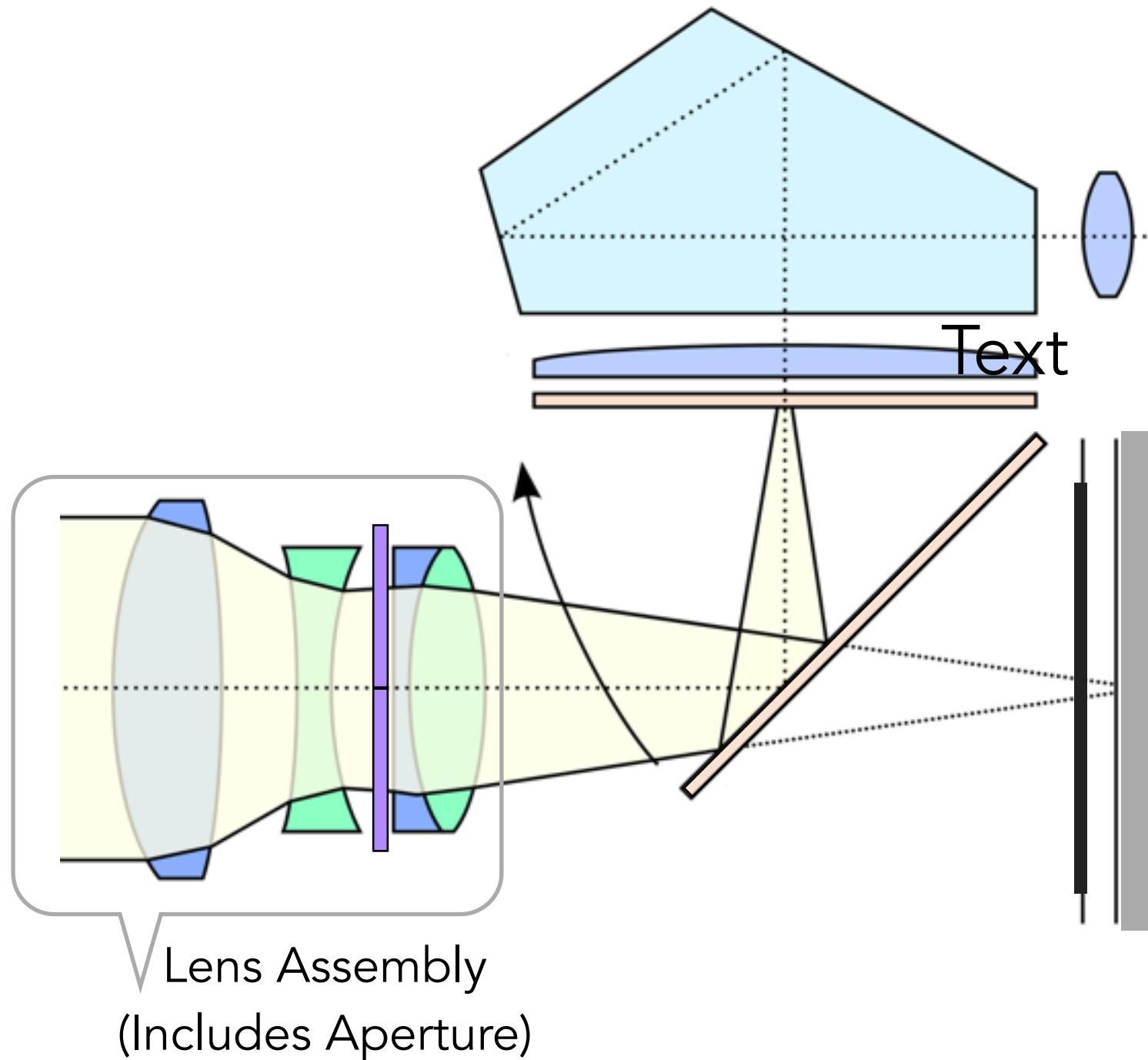
## 1. Lens assembly



Adapted from [commons.wikimedia.org/](https://commons.wikimedia.org/)

# Inside a Camera (an SLR)

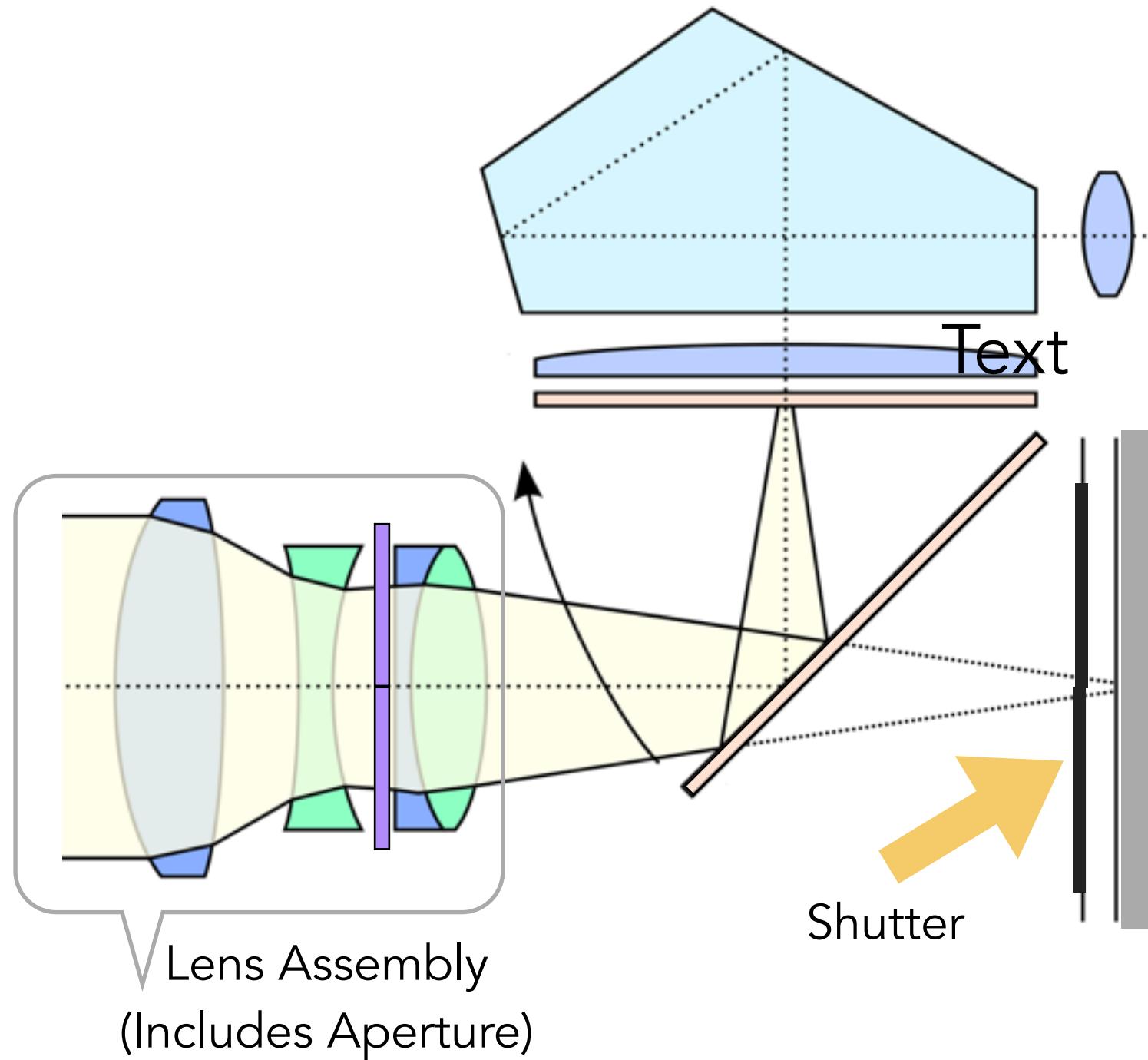
1. Lens assembly
  - a. Includes Aperture



Adapted from [commons.wikimedia.org/](https://commons.wikimedia.org/)

# Inside a Camera (an SLR)

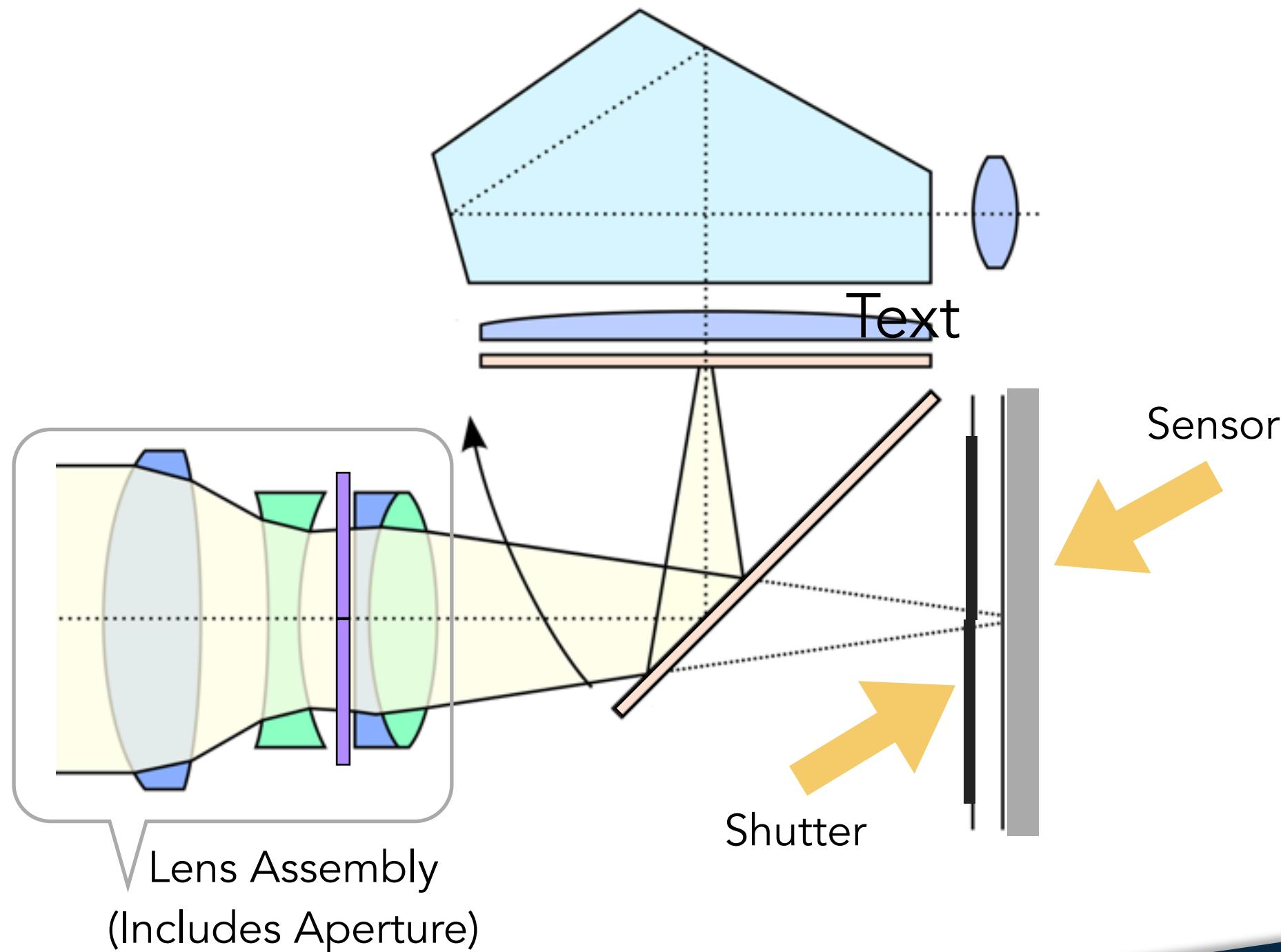
1. Lens assembly
  - a. Includes Aperture
2. Shutter



Adapted from [commons.wikimedia.org/](https://commons.wikimedia.org/)

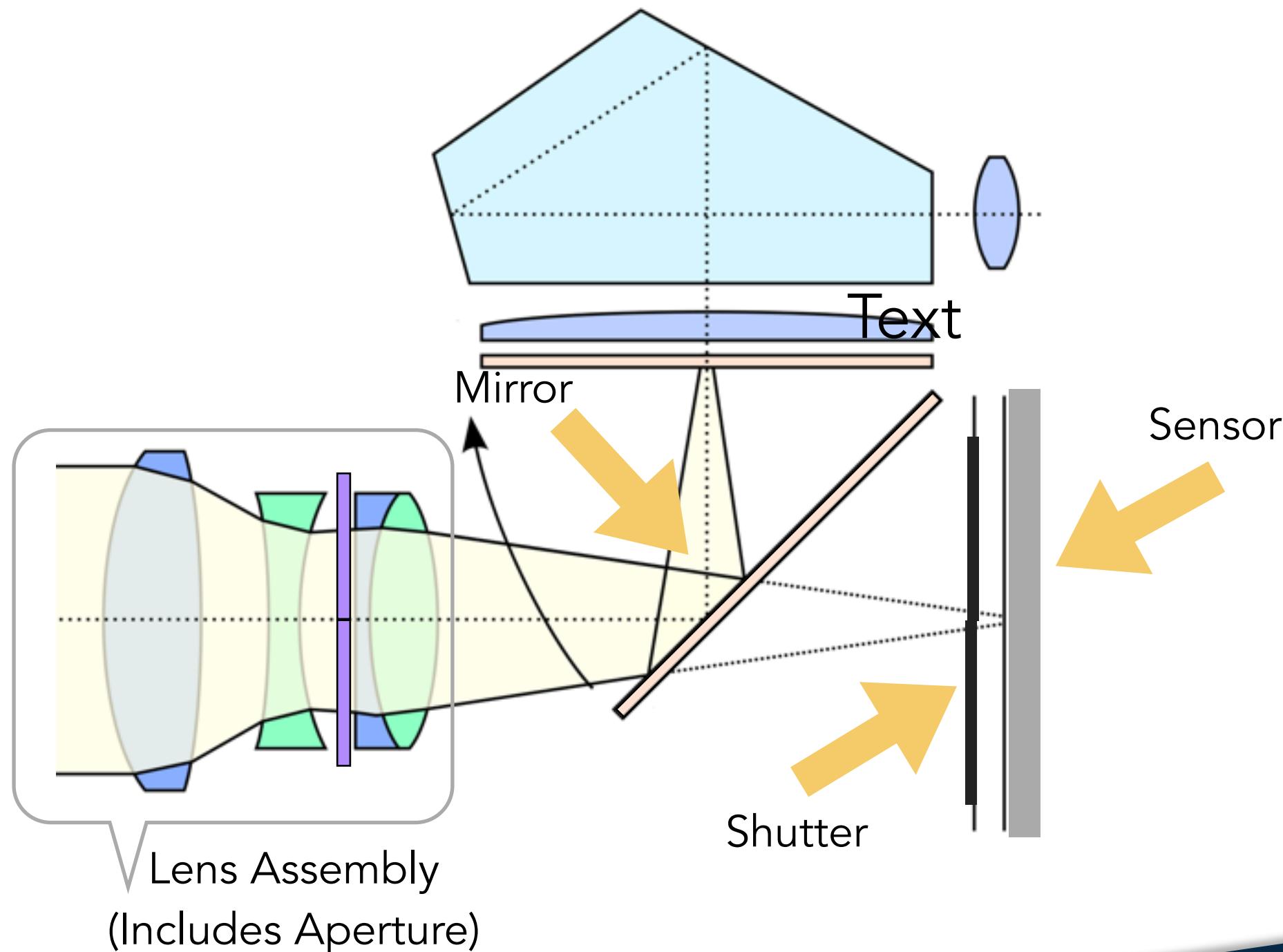
# Inside a Camera (an SLR)

1. Lens assembly
  - a. Includes Aperture
2. Shutter
3. Sensor/Film



Adapted from [commons.wikimedia.org/](https://commons.wikimedia.org/)

# Inside a Camera (an SLR)

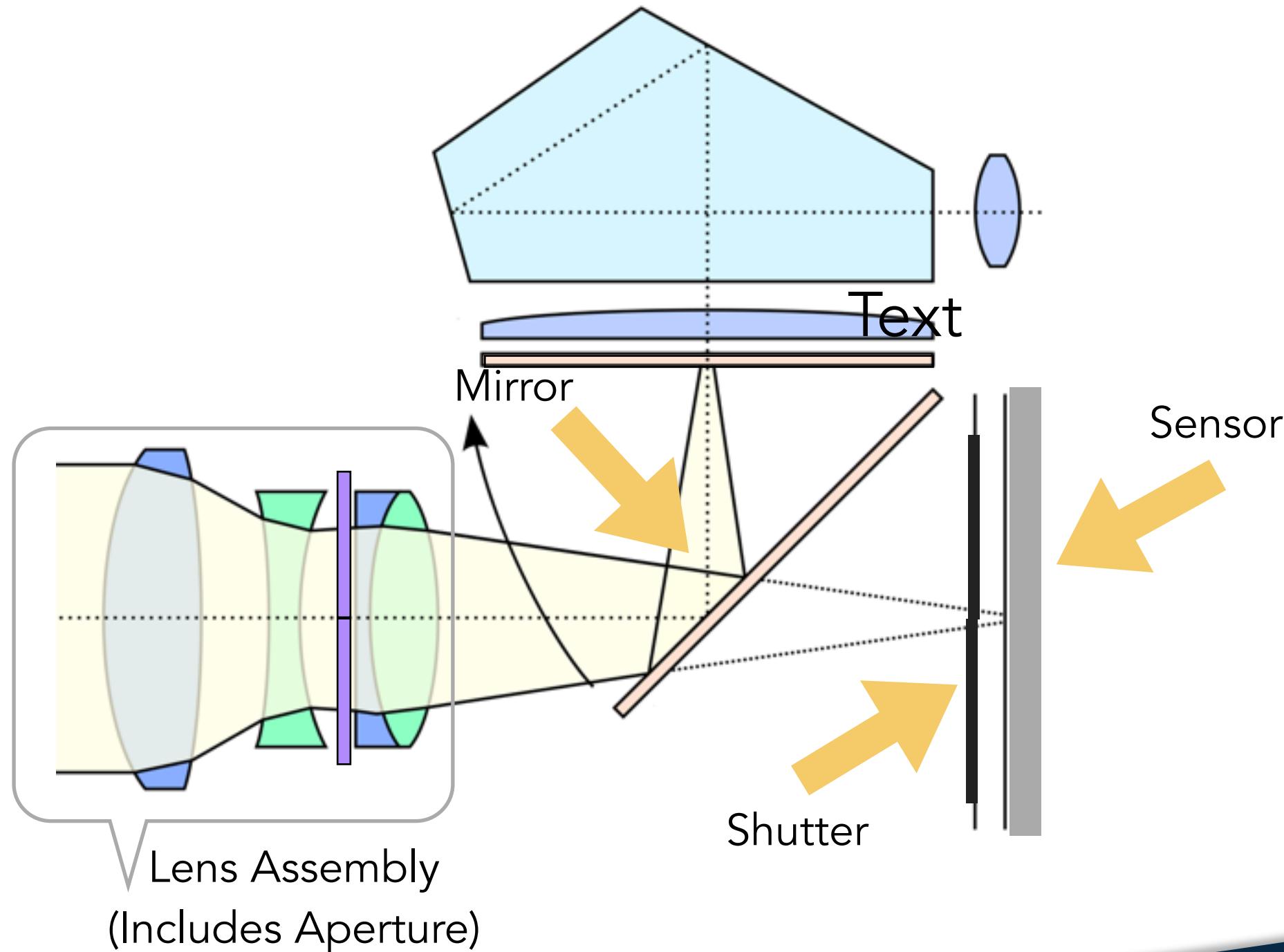


1. Lens assembly
  - a. Includes Aperture
2. Shutter
3. Sensor/Film
4. Mirror

Adapted from [commons.wikimedia.org/](https://commons.wikimedia.org/)

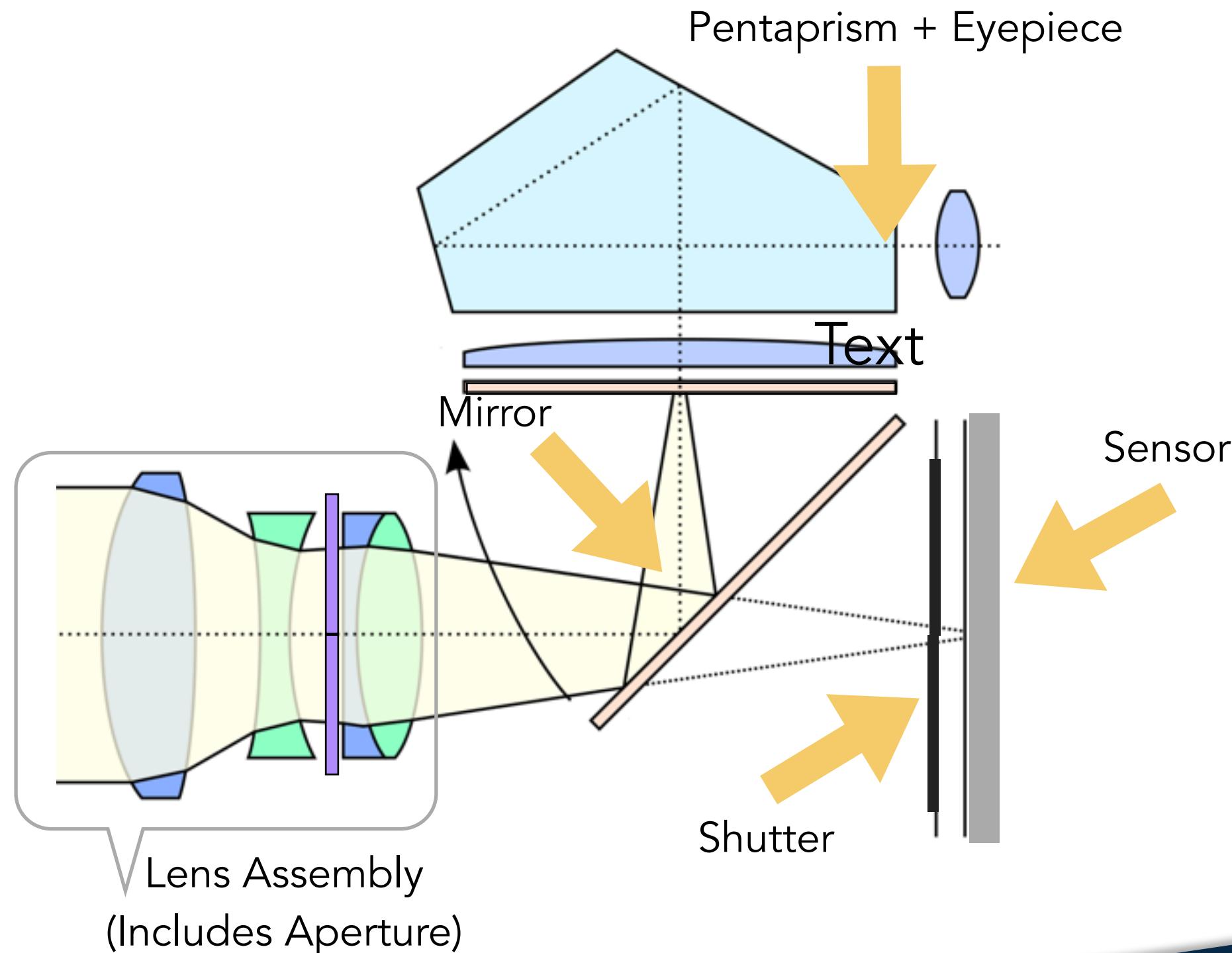
# Inside a Camera (an SLR)

1. Lens assembly
- a. Includes Aperture
2. Shutter
3. Sensor/Film
4. Mirror



Adapted from [commons.wikimedia.org/](https://commons.wikimedia.org/)

# Inside a Camera (an SLR)



1. Lens assembly
  - a. Includes Aperture
2. Shutter
3. Sensor/Film
4. Mirror
5. Pentaprism or Pentamirror and Eyepiece

Adapted from [commons.wikimedia.org/](https://commons.wikimedia.org/)



# Shutter Speed



[http://commons.wikimedia.org/wiki/File:Shutter\\_speed\\_waterfall.gif](http://commons.wikimedia.org/wiki/File:Shutter_speed_waterfall.gif)

- ★ Amount of time the sensor is exposed to light
- ★ Usually denoted in fractions of a second (1/2000, 1/1000, ..., 1/250, ..., 1/60, ..., 1/15, ..., 15, 30, Bulb)
- ★ Effects of Motion Blur to Streaks

# Shutter Speed



<http://commons.wikimedia.org/wiki/File:Windflower-05237-nevit.JPG>

- ★ Amount of time the sensor is exposed to light
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- ★ Effects of Motion Blur to Streaks

# Aperture

- ★ Irradiance on Sensor → The amount of light captured is proportional to the Area of the Aperture (opening):

$$Area = \pi \left( \frac{f}{2N} \right)^2$$

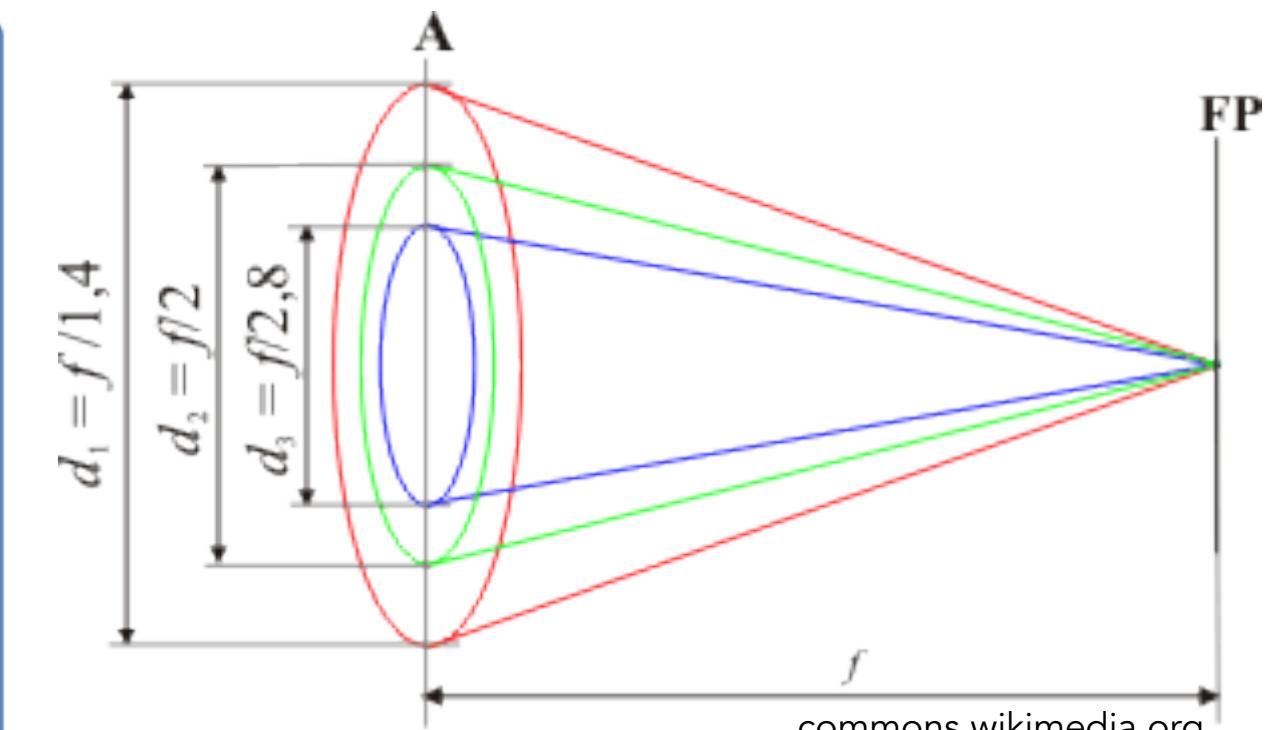
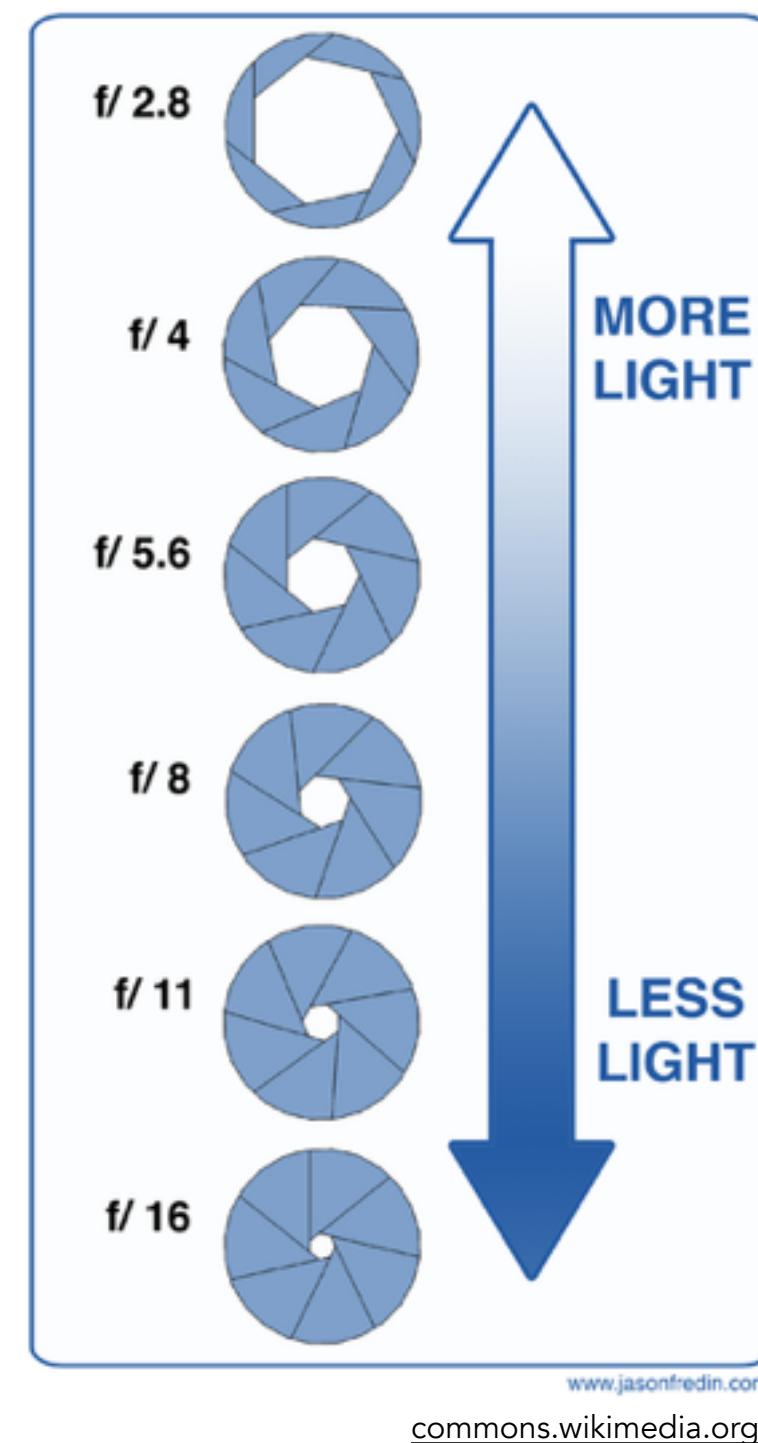
- ★  $f$  is the the focal length. What is the diameter of the Aperture?
- ★ Aperture Number N is usually written as f/N
  - Aperture Number gives irradiance irrespective to the lens in use
    - f/2.0 on a 50mm lens → aperture = 25mm
    - f/2.0 on a 200mm lens → aperture = 100mm
    - Low F-number (N) on telephoto lens means BIG lens

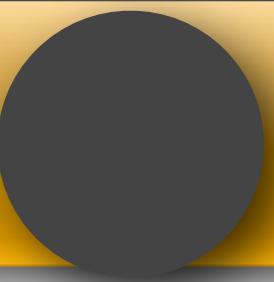


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# Aperture

- ★ Doubling  $N$  reduces  $A$  by  $2x$ , and therefore reduces light by  $4x$ 
  - from  $f/1.4$  to  $f/2.8$  cuts light by  $4x$
  - to cut light by  $2x$ , increase  $N$  by  $\sqrt{2}$





# Effects of Aperture



# Effects of Aperture

f/3.5





# Effects of Aperture

f/4.0  
f/3.5





# Effects of Aperture

f/5.6  
f/4.0  
f/3.5





# Effects of Aperture

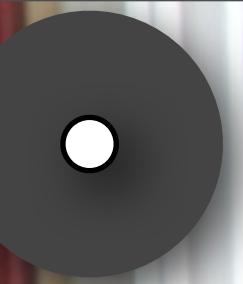
f/8

f/5.6

f/4.0

f/3.5





# Effects of Aperture

f/11

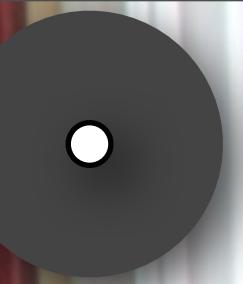
f/8

f/5.6

f/4.0

f/3.5





# Effects of Aperture



f/14

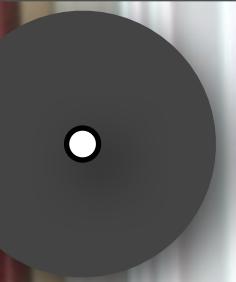
f/11

f/8

f/5.6

f/4.0

f/3.5



f/18  
f/14  
f/11  
f/8  
f/5.6  
f/4.0  
f/3.5

# Effects of Aperture





f/22

f/18

f/14

f/11

f/8

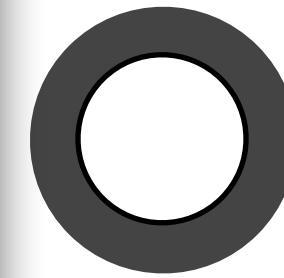
f/5.6

f/4.0

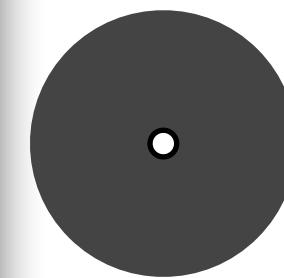
f/3.5

# Effects of Aperture





f/3.5



f/22

## Effects of Aperture

# Photographic Values of Aperture/Shutter



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[commons.wikimedia.org](https://commons.wikimedia.org)



[commons.wikimedia.org](https://commons.wikimedia.org)

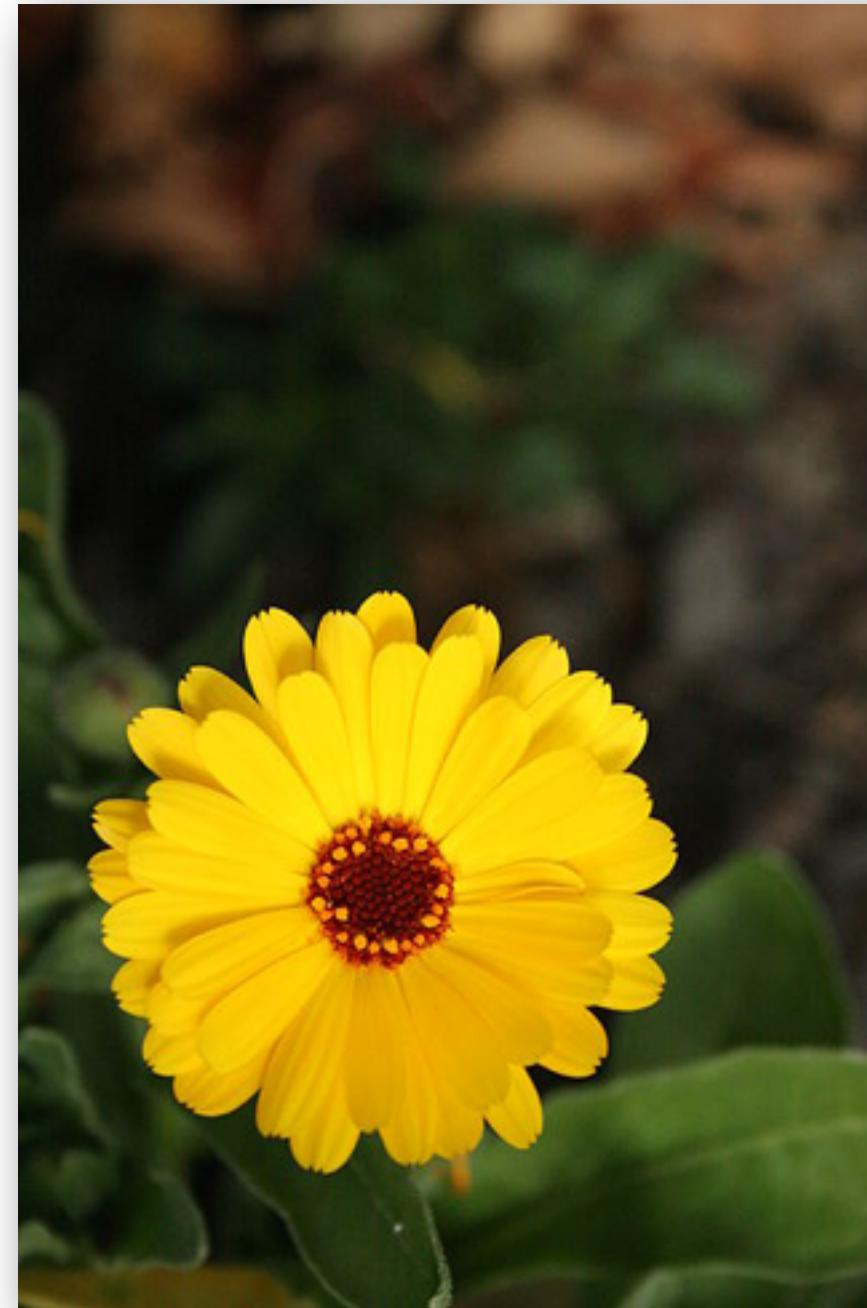
- ★ By symbiotic operation of controls of shutter speed and aperture opening, one can capture images with variations in
  - Motion Blur.
  - Depth of Field etc.

# ISO (Sensitivity)



[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 100



[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 1600

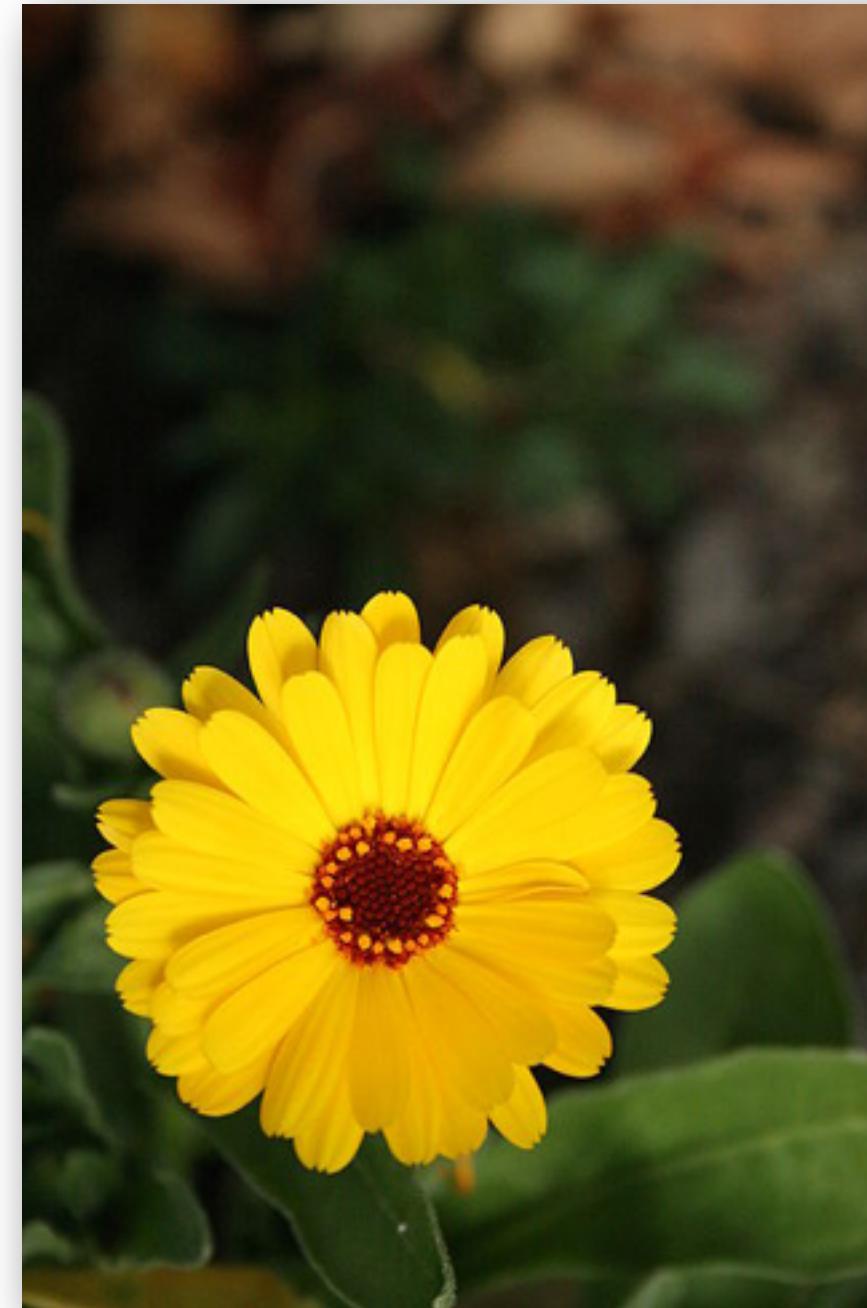
# ISO (Sensitivity)

- ★ Third Variable in getting the right Exposure



[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 100



[commons.wikimedia.org/](https://commons.wikimedia.org/)

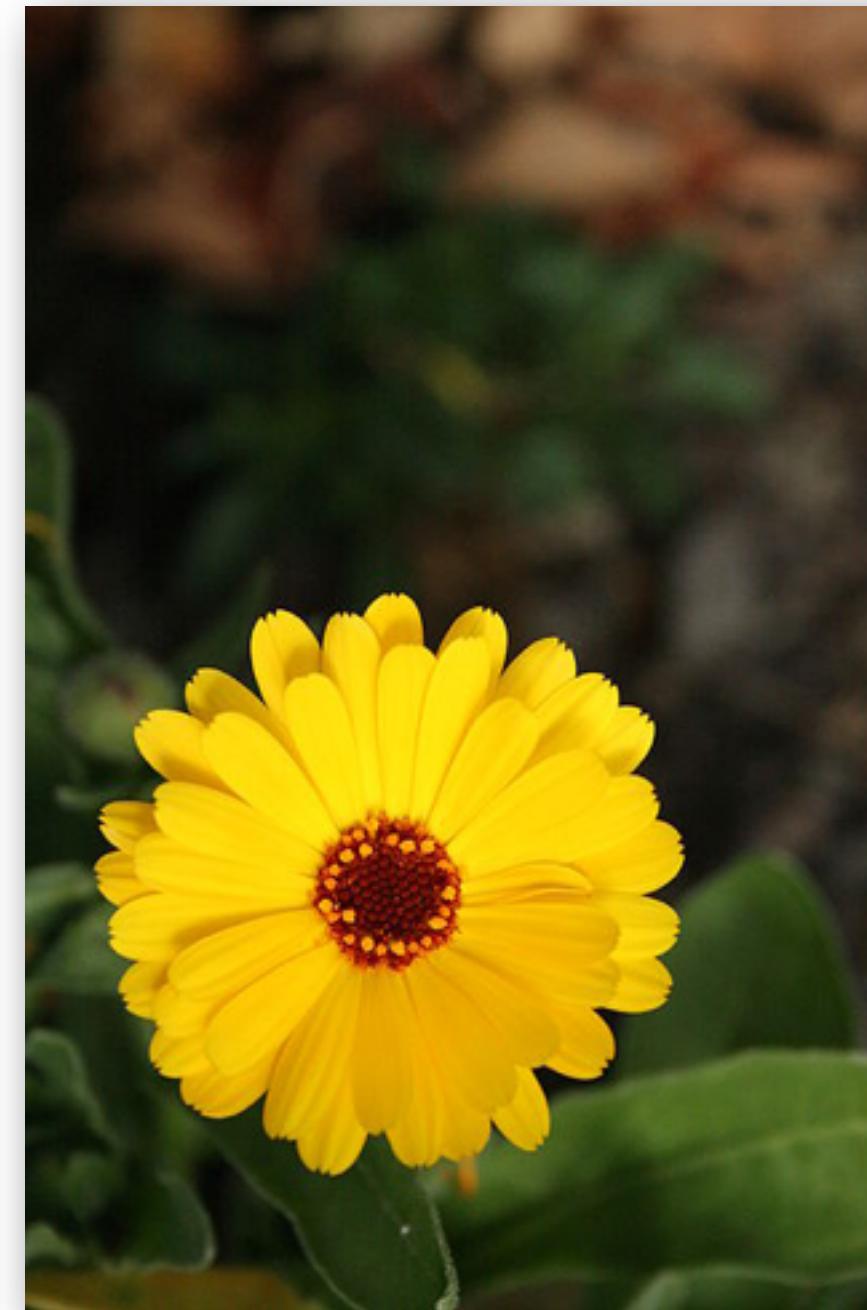
ISO 1600

# ISO (Sensitivity)



[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 100



[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 1600

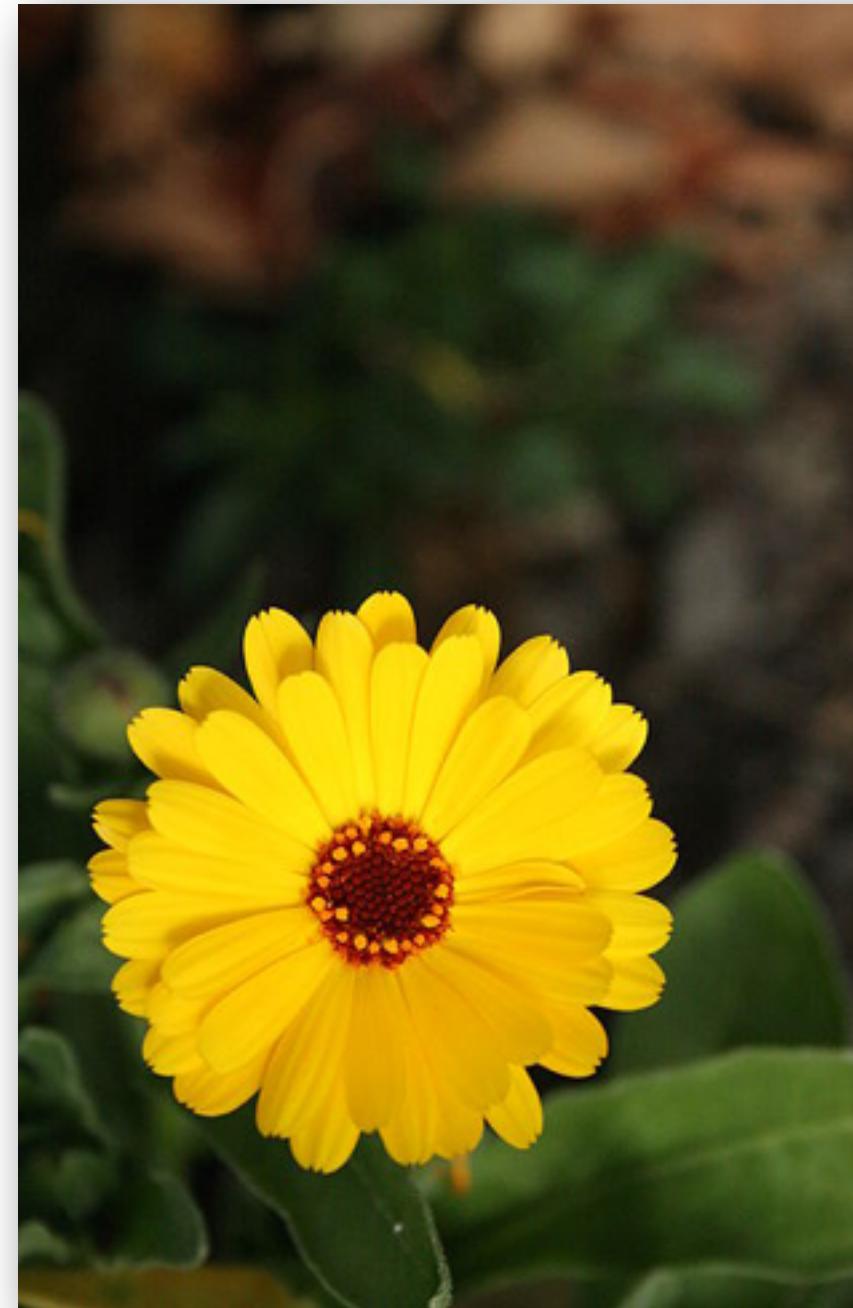
- ★ Third Variable in getting the right Exposure
- ★ Film: Sensitivity vs. Grain (of film)

# ISO (Sensitivity)



[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 100



[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 1600

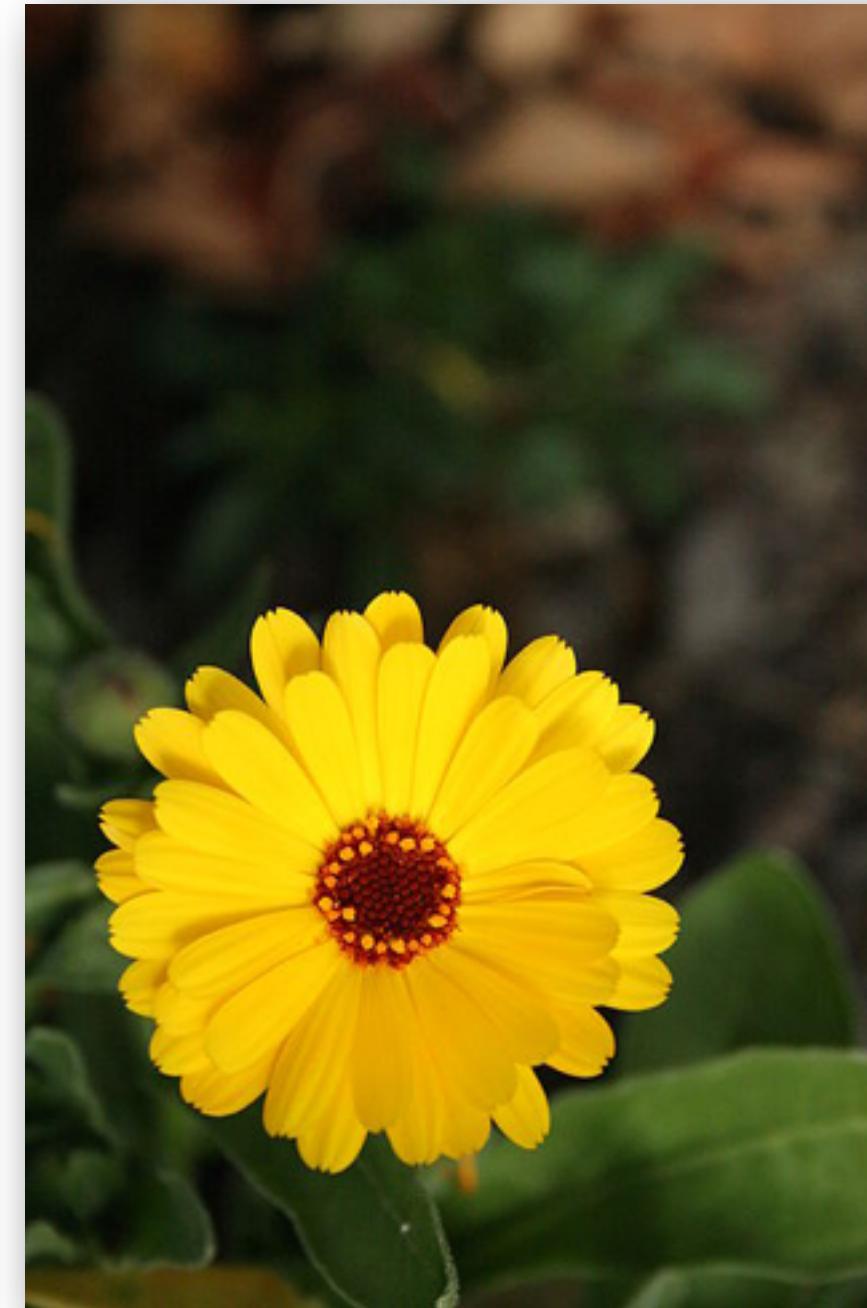
- ★ Third Variable in getting the right Exposure
- ★ Film: Sensitivity vs. Grain (of film)
- ★ Digital: Sensitivity vs. Noise (of sensor)

# ISO (Sensitivity)



[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 100

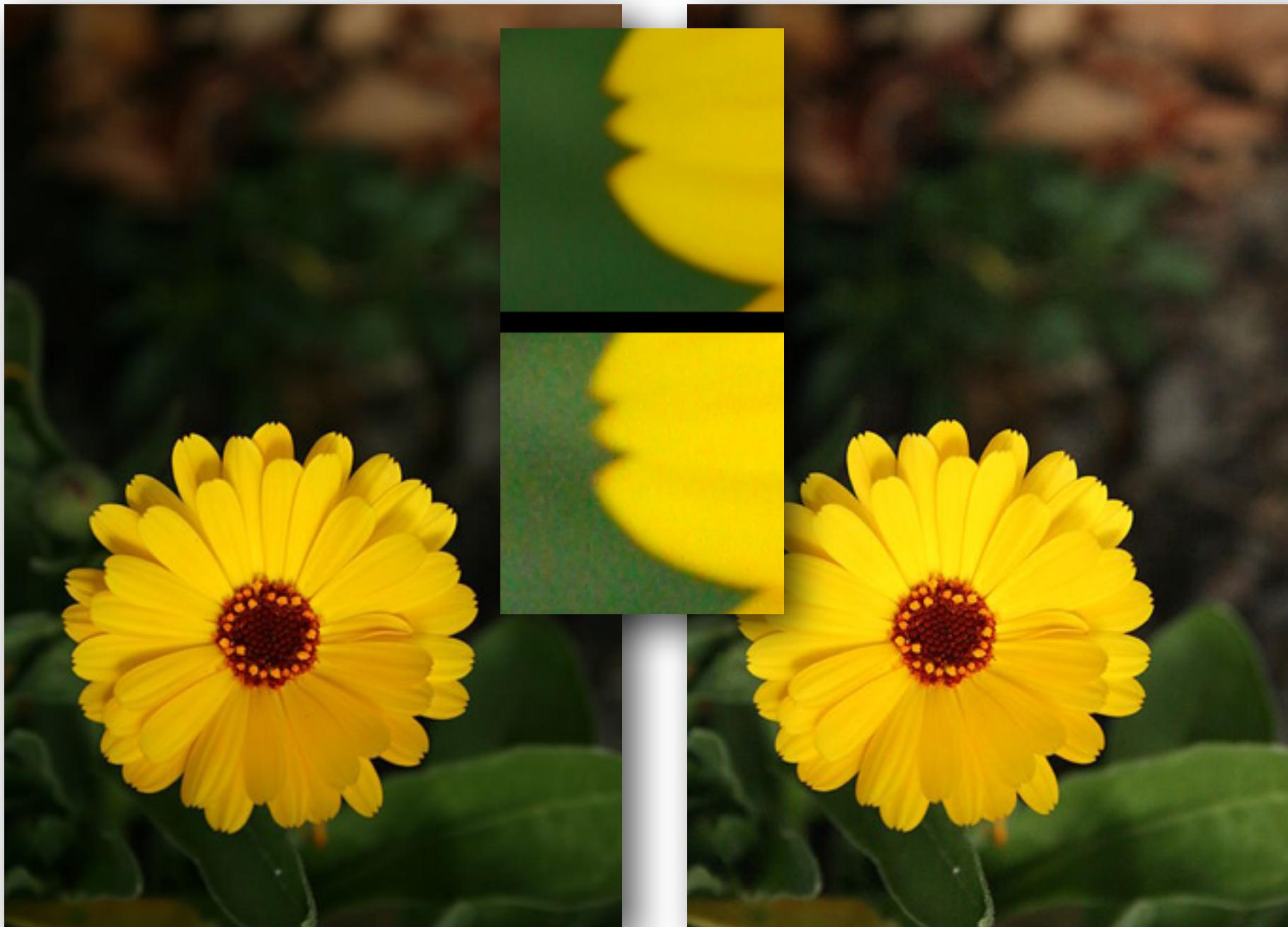


[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 1600

- ★ Third Variable in getting the right Exposure
- ★ Film: Sensitivity vs. Grain (of film)
- ★ Digital: Sensitivity vs. Noise (of sensor)
- ★ Linear: 200 ISO needs half the light of 100 ISO

# ISO (Sensitivity)



[commons.wikimedia.org/](https://commons.wikimedia.org/)

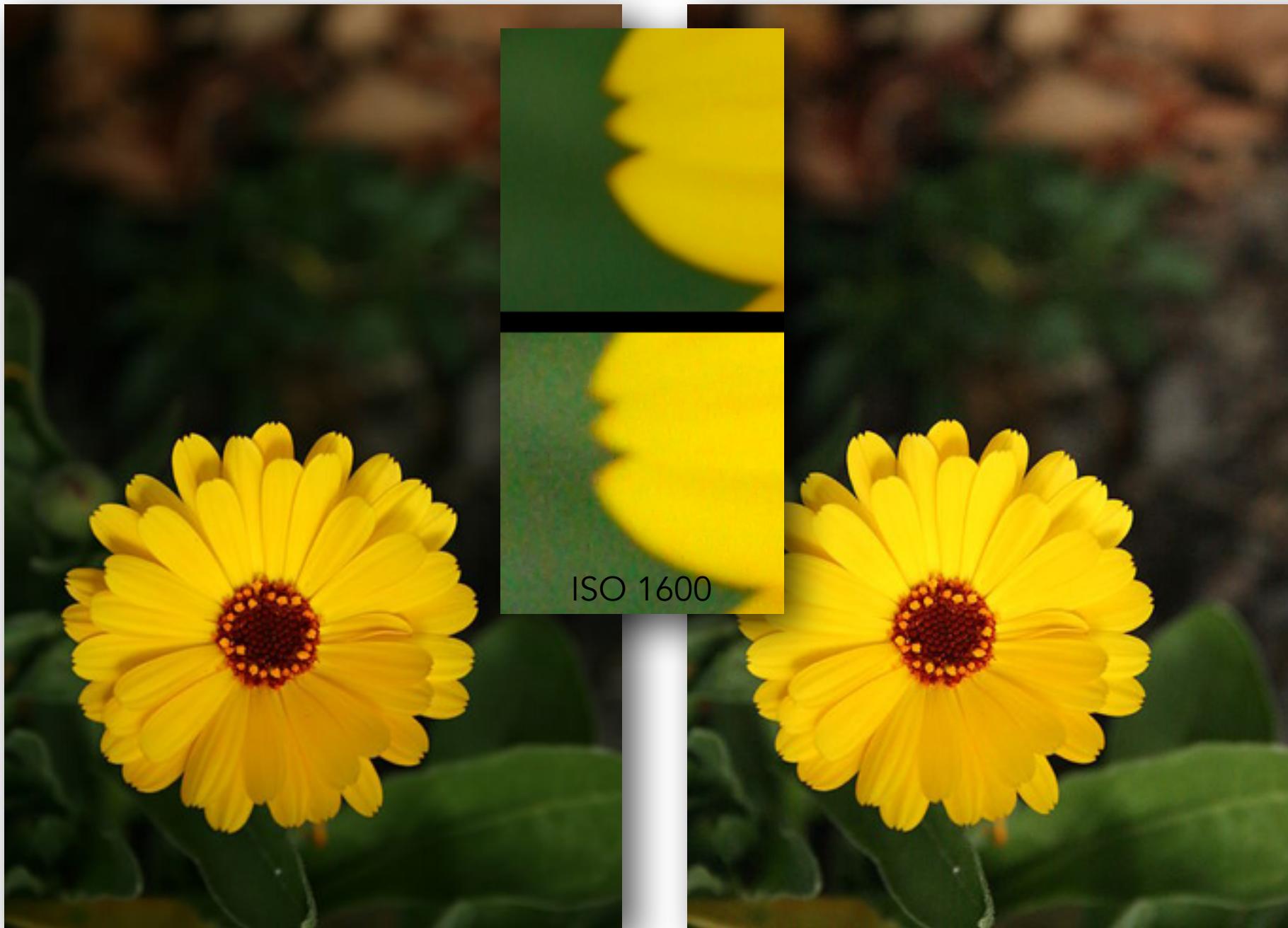
ISO 100

[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 1600

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# ISO (Sensitivity)

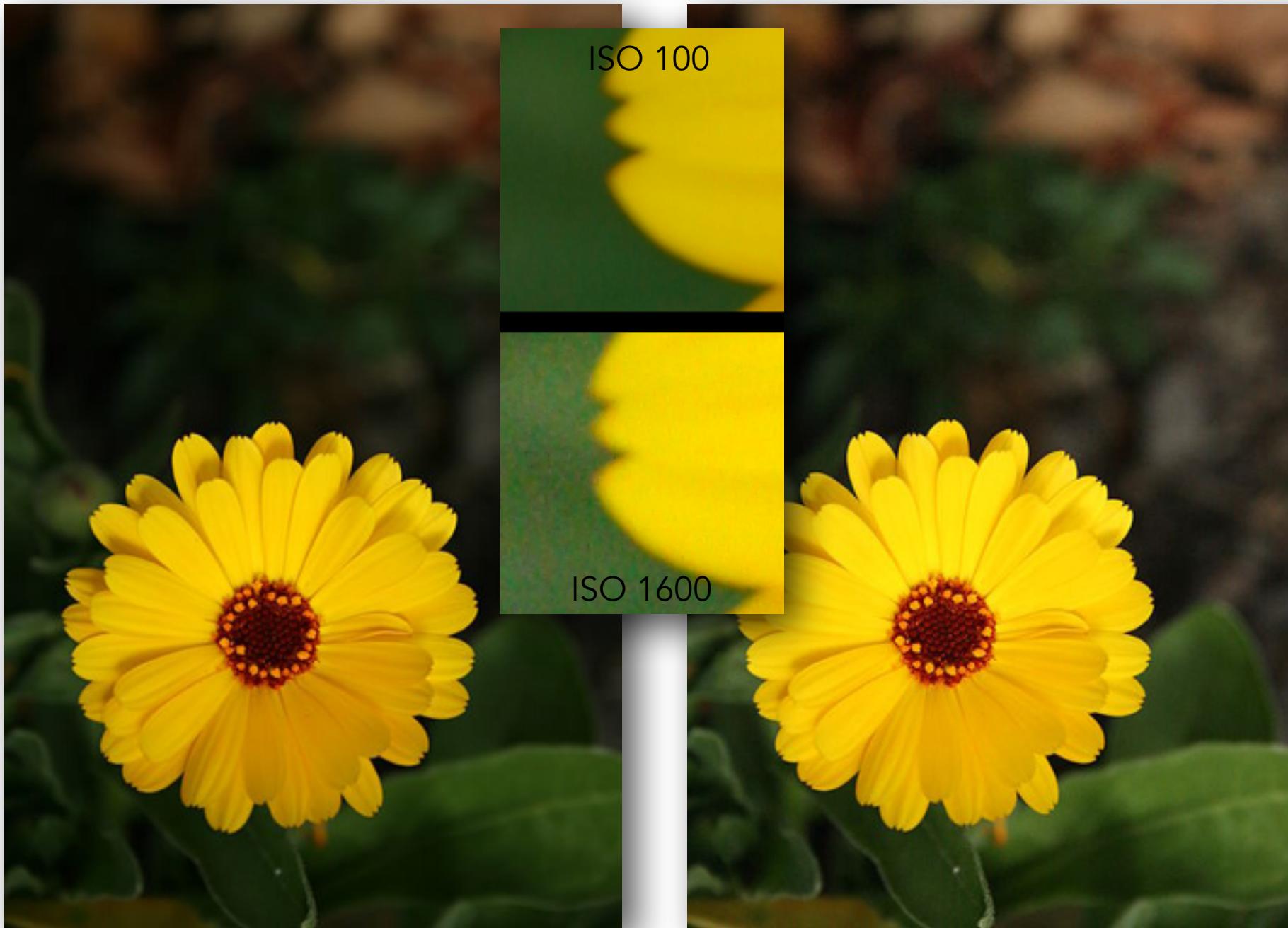


ISO 100

ISO 1600

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[commons.wikimedia.org/](https://commons.wikimedia.org/)

ISO 100

[commons.wikimedia.org/](https://commons.wikimedia.org/)

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- ★ Digital: Sensitivity vs. Noise (of sensor)
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# Aperture vs. Shutter

f/5.6



1/10

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/1250

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/1250

1/2500

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/1250

1/2500

1/100

f/4.0



# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/1250

1/2500

1/100

# Aperture vs. Shutter



1/100

# Aperture vs. Shutter

f/5.6



1/10



1/20



1/40

f/4.0



f/5.0



1/160

f/7.1



1/320

1/640



1/1250

1/2500



1/100

# Aperture vs. Shutter

f/5.6



1/10



1/20



1/40

f/4.0



f/5.0



1/160

f/7.1



1/320

f/9.0



1/640

1/1250

1/2500

1/100

# Aperture vs. Shutter

f/5.6



1/10



1/20



1/40

f/4.0



f/5.0



1/160

f/7.1



1/320

f/9.0



1/640

f/13.0



1/1250

1/2500

1/100

# Aperture vs. Shutter

f/5.6



1/10

1/20

1/40

f/4.0



f/5.0



1/160

1/320

1/640

1/1250

1/2500

f/7.1

f/9.0



f/13.0



f/20.0



1/100

# ISO vs. Shutter

f/5.6



1/10

1/100

# ISO vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/1250

1/2500

1/100

# ISO vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/1250

1/2500

1/100

100



## ISO vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/1250

1/2500

1/100

# ISO vs. Shutter

f/5.6



1/10

1/20

1/40

1/100

1/160

1/320

1/640

1/1250

1/2500

1/100

# ISO vs. Shutter

f/5.6



1/10

1/20

1/40

100

200

1/160

1/320

1/640

1/1250

1/2500

800



1/100

# ISO vs. Shutter

f/5.6



1/10

1/20

1/40

100

200

1/160

1/320

1/640

1/1250

1/2500

800

1600

1/100

# ISO vs. Shutter

f/5.6



1/10

1/20

1/40

100

200

1/160

1/320

1/640

1/1250

1/2500

800

1600

3200

1/100

# ISO vs. Shutter

f/5.6



1/10

1/20

1/40

100

200

1/160

1/320

1/640

1/1250

1/2500

800

1600

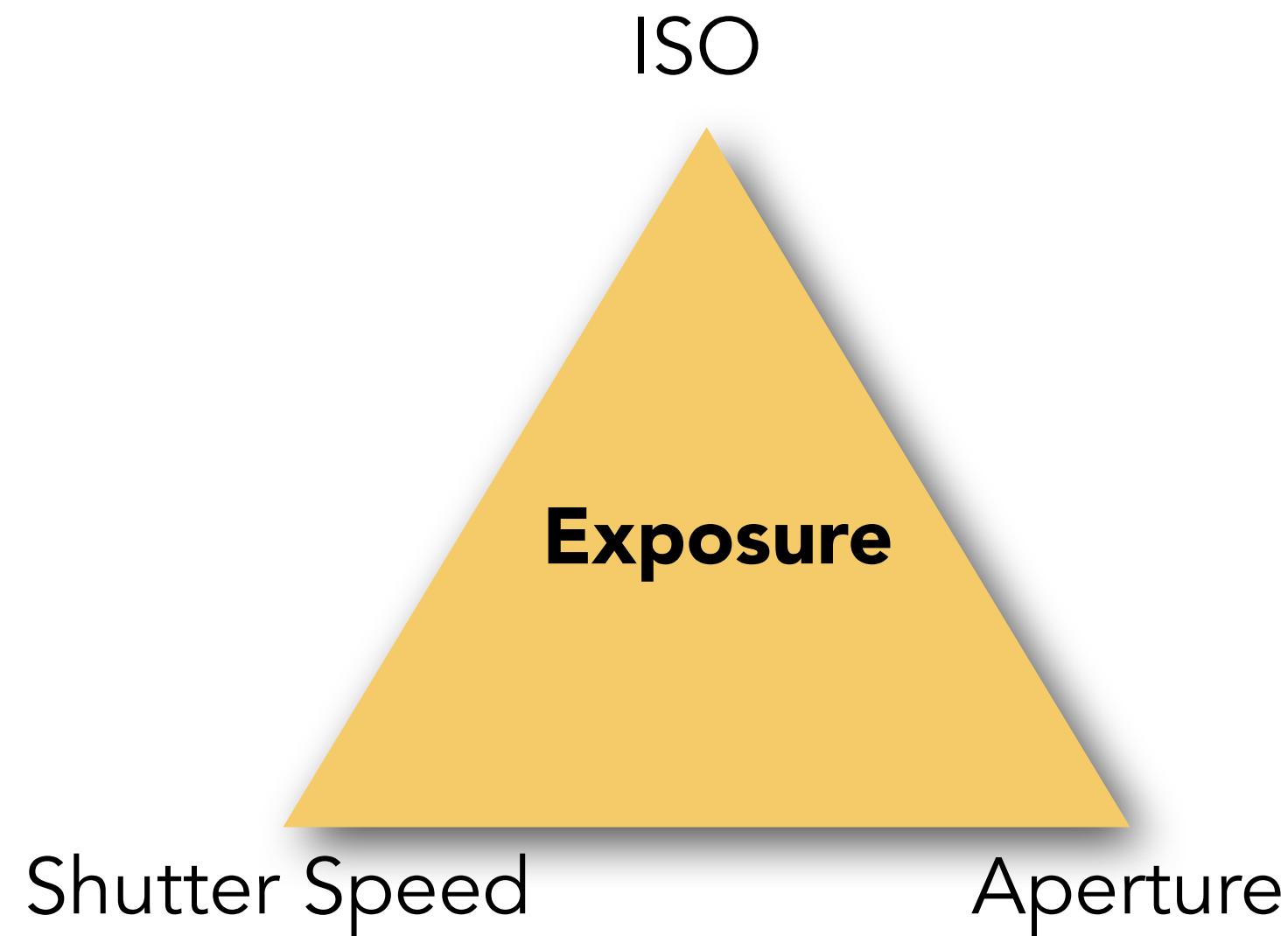
3200

6400

1/100



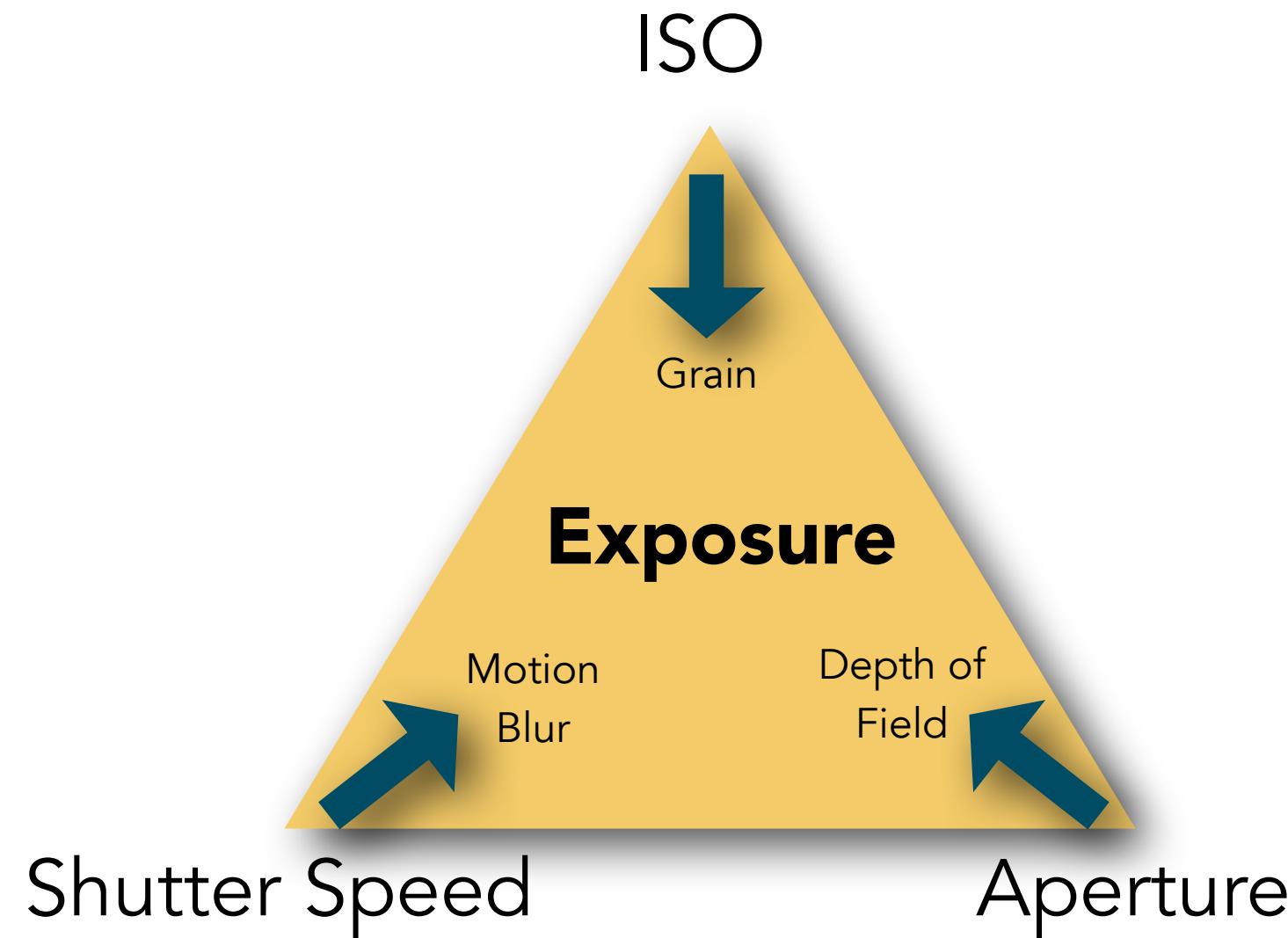
# Exposure Triangle



★ Exposure Triangle combines

- Aperture opening, Shutter Speed, Sensor/Film Sensitivity (ISO) is OPTIMIZED to get a “desired” exposure.

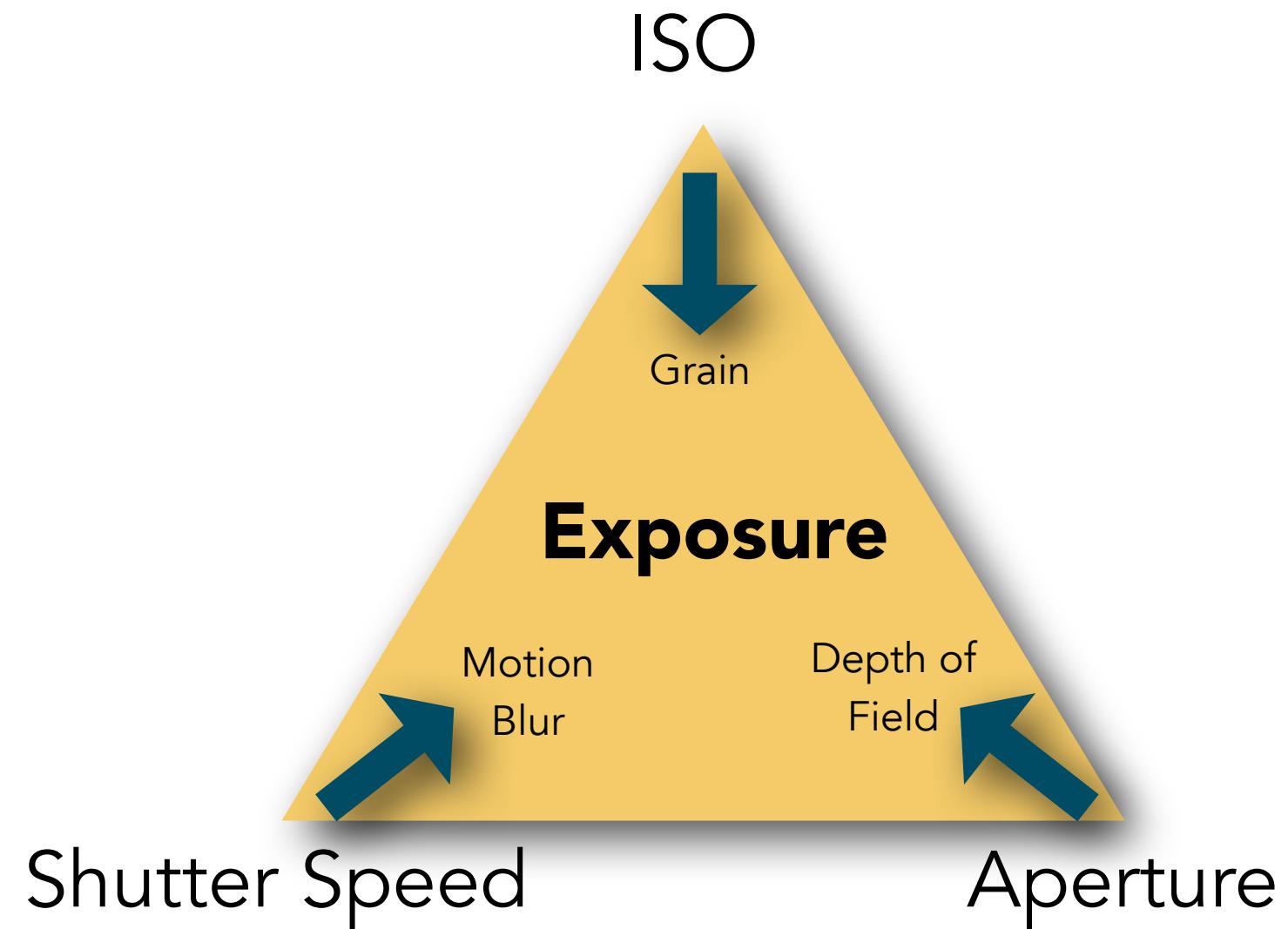
# Exposure Triangle



## ★ Exposure Triangle combines

- Aperture opening, Shutter Speed, Sensor/Film Sensitivity (ISO) is OPTIMIZED to get a “desired” exposure.

# Exposure Triangle



## ★ Exposure Triangle combines

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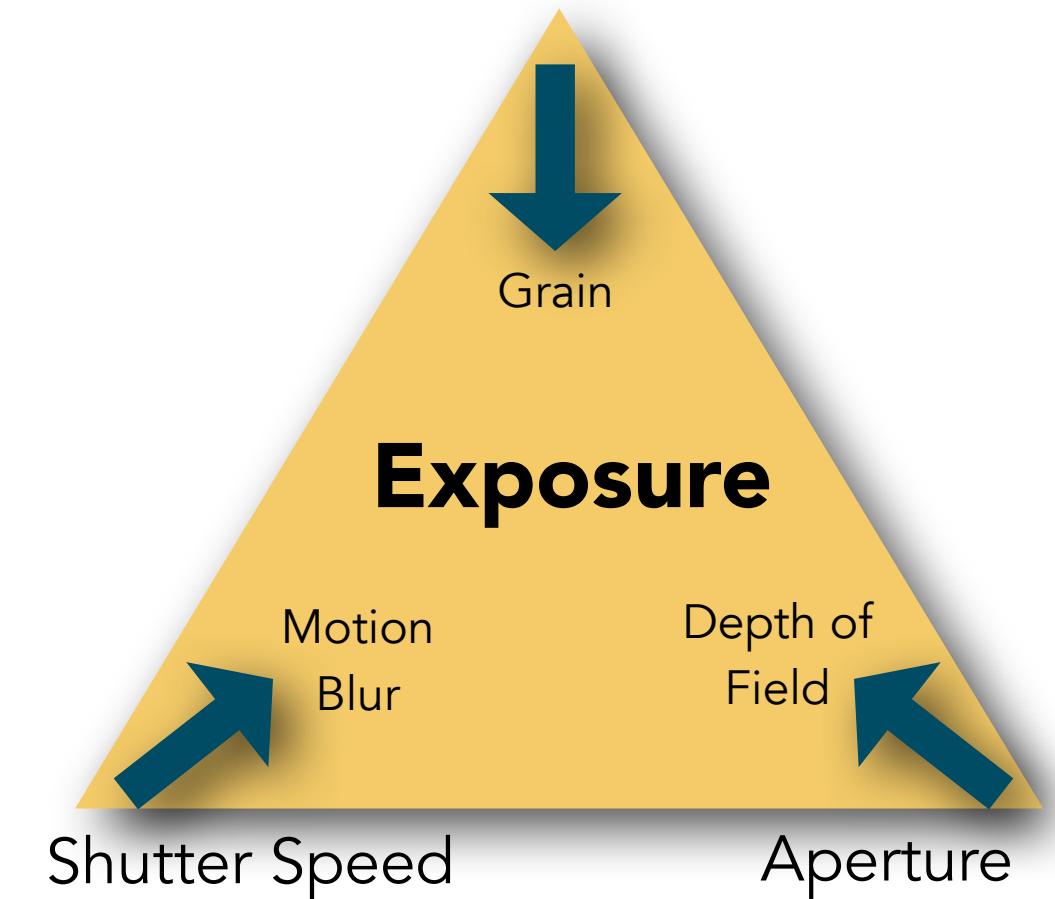
There are many resources on the web to learn more about Exposure Triangle.

Recommend this website for hands on experience with the Exposure Tiangle.

<http://graphics.stanford.edu/courses/cs178/applets/exposure.html>

# Recap: Exposure

- ★ Exposure ( $H$ ) = Irradiance ( $E$ )  $\times$  Time ( $T$ )
- ★ Irradiance ( $E$ ): Controlled by Aperture opening
  - Lowering by  $1/f$  stop doubles  $H$  (as Aperture opens more)
  - Lowering by  $2/f$  stops doubles depth of field (DoF).
- ★ Exposure Time ( $T$ ): Controlled by Shutter Speed
  - Doubling  $T$  doubles  $H$
  - Doubling  $T$  doubles Motion Blur
- ★ ISO: Doubling ISO needs half the light ...



# Summary

- ★ Presented how a camera operates.
- ★ Brought together the concepts Aperture Opening, Shutter Speed and Film Sensitivity (ISO) for optimizing Photographic Exposure.
- ★ Discussed the Exposure Triangle and how it combines various aspects of photography.



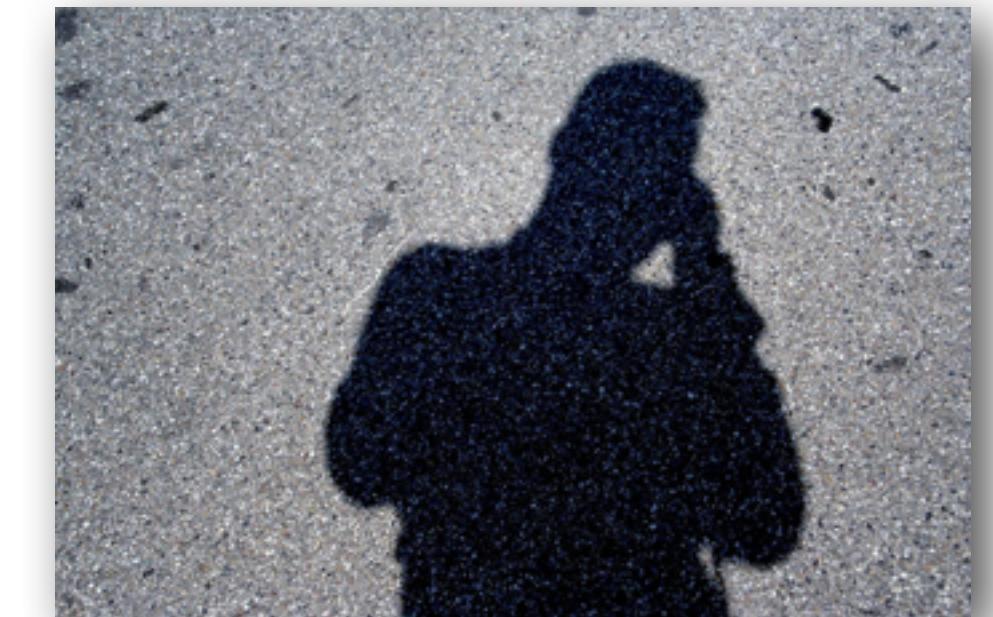
# Next Class

★ Cameras: Sensors ...



# Credits

- ★ For more information, see
  - Hecht, E. (2002), *Optics*, 4th ed. Reading, MA: Addison-Wesley and
  - London, B., Stone, J., & Upton, J. (2011), *Photography*, 10th ed. Upper Saddle River, NJ: Prentice Hall.
  
- ★ Some images retrieved from
  - <http://commons.wikimedia.org/>.
  - List will be available on website.
  
- ★ Some Slides adapted from Mark Levoy.



[www.flickr.com/photos/neneonline/231886965/](http://www.flickr.com/photos/neneonline/231886965/)



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Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.