Optics and cameras

Advanced Graphics

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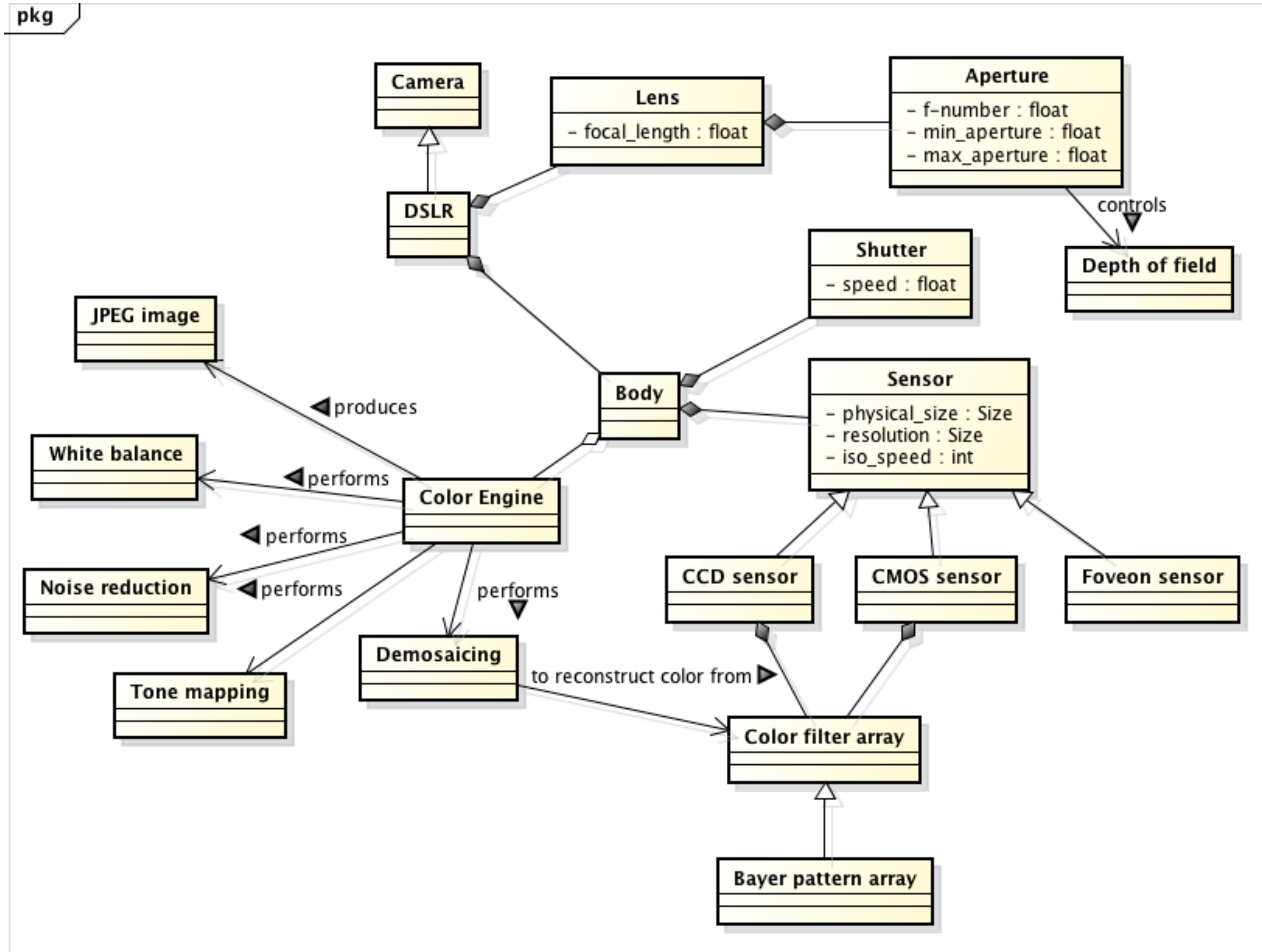
Why are cameras and optics relevant?

- Cameras in
  - Computer Vision
  - Computer Graphics
  - Because real-world cameras are not pin-hole cameras
- Human vision
  - To understand how the eye works
- To use a camera
  - How to control shutter and apperture

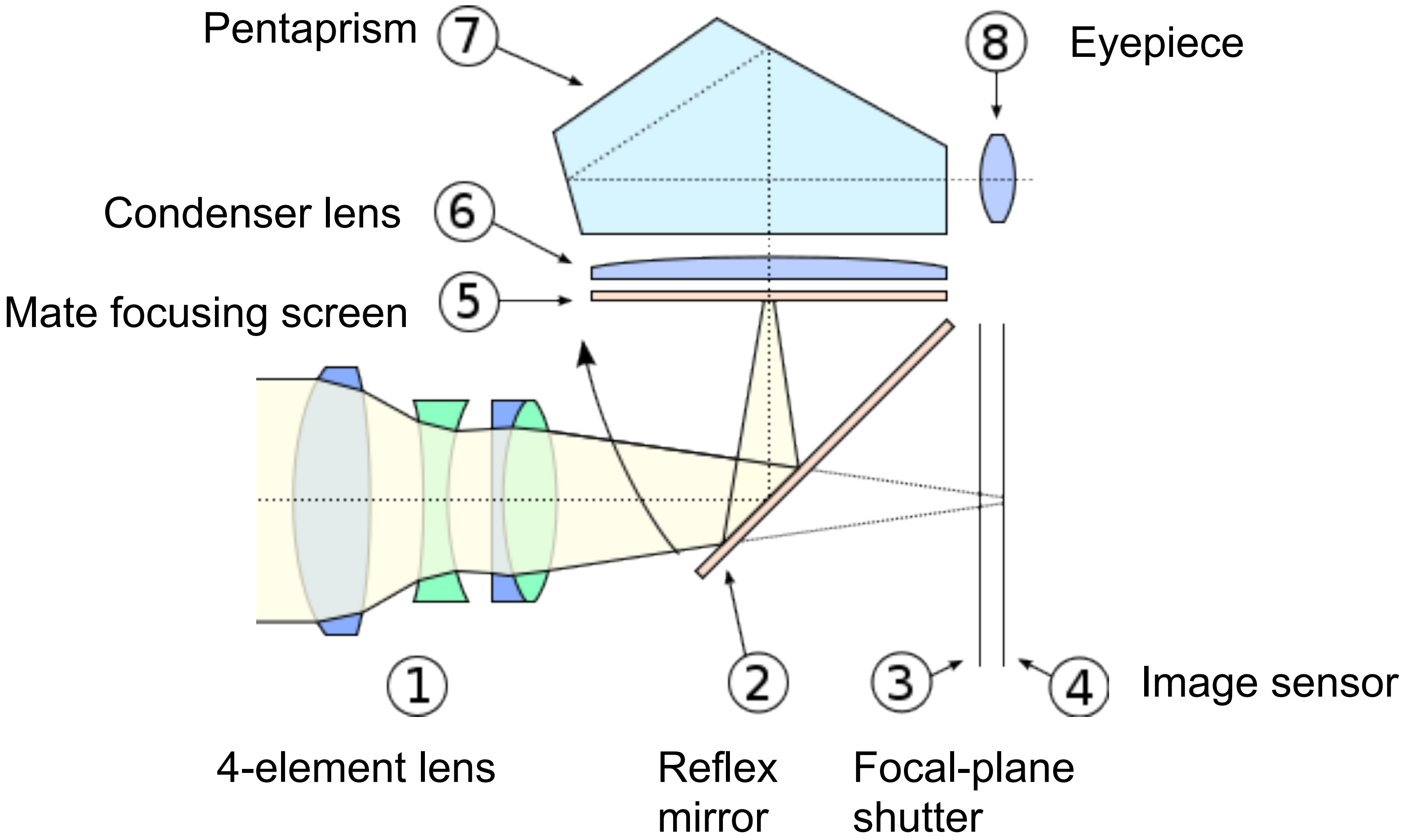
UML Overview



DSLR: Digital single-lens reflex camera

Twin-lens reflex camera

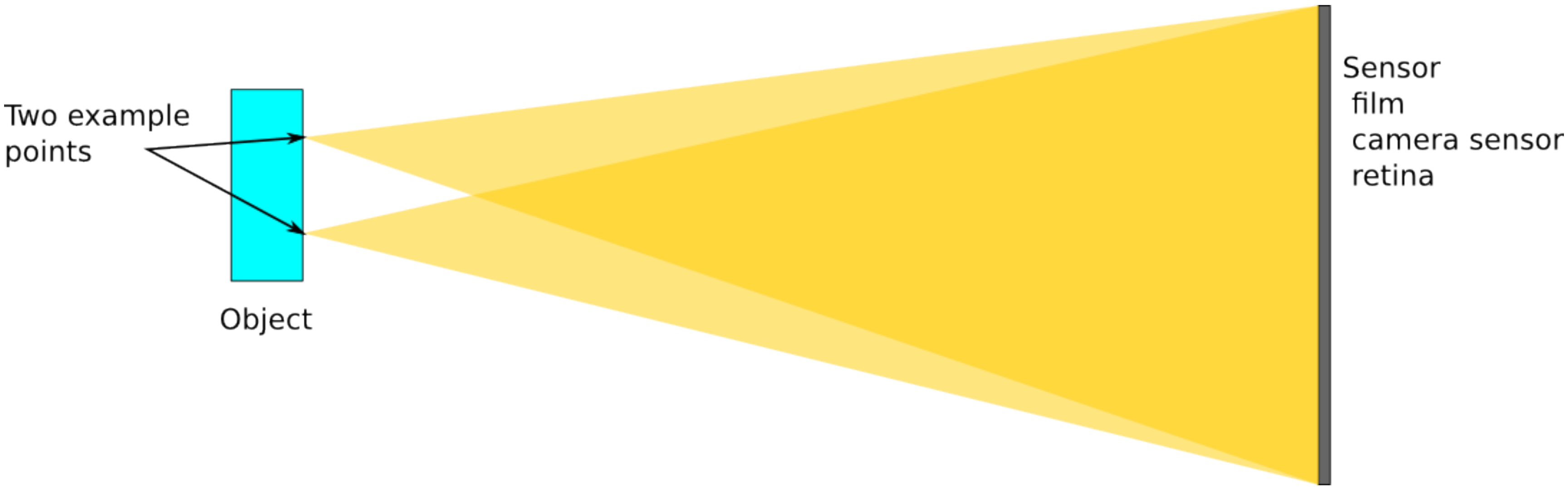
DSLR


Pentaprism
7
8
Eyepiece
Condenser lens
6
Mate focusing screen
5
1
2
3
4
Image sensor
4-element lens
Reflex
mirror
Focal-plane
shutter

Lens

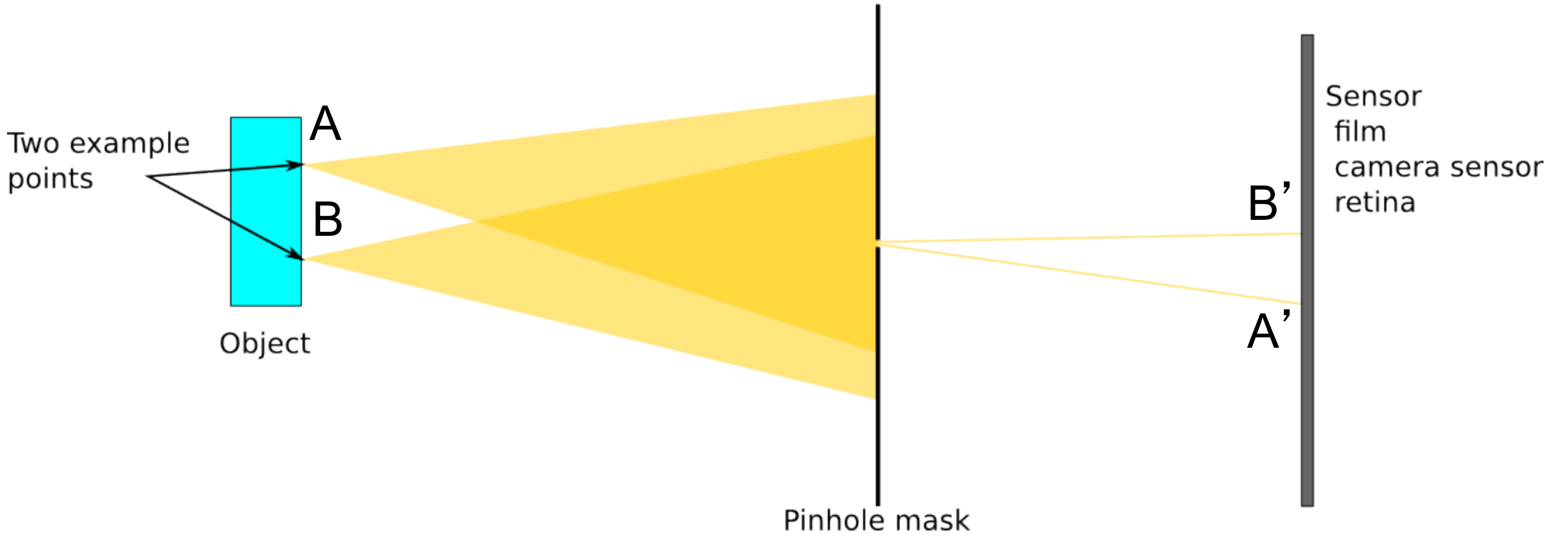

Photoshop PSD file download - Resolution 1280x1024 px - www.psdgraphics.com

Imaging – without lens



Every point in the scene illuminates every point (pixel) on a sensor. Everything overlaps - no useful image.

Imaging – pinhole camera

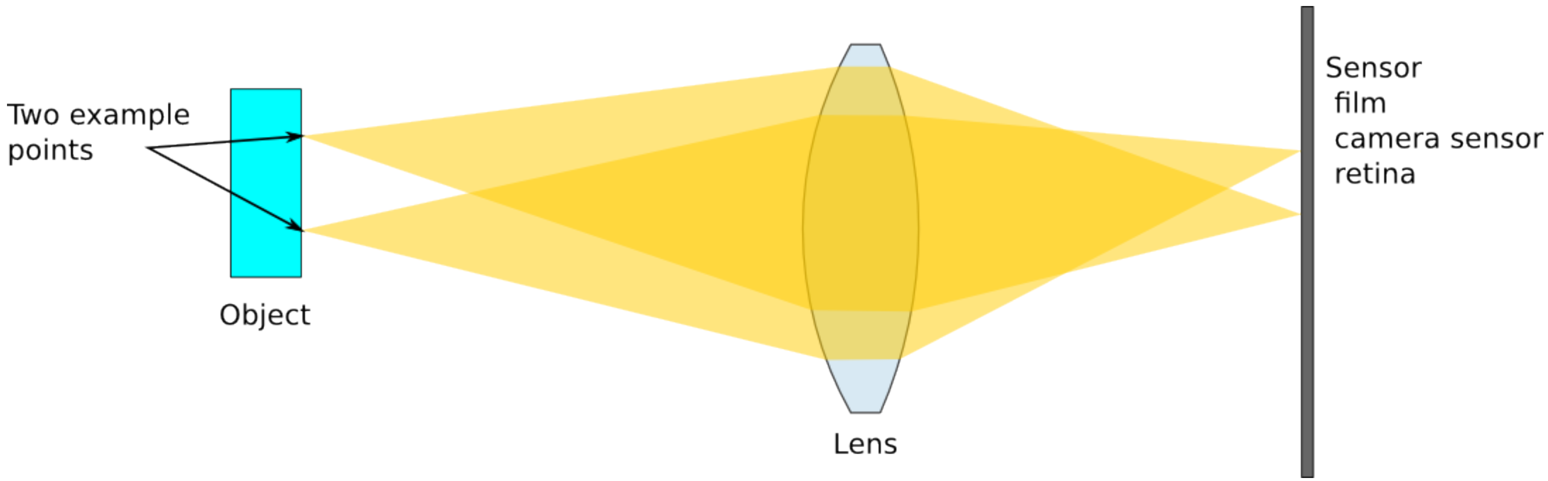


Pinhole masks all but only tiny beams of light. The light from different points is separated and the image is formed.

But very little light reaches the sensor.

Pinhole camera-body cap

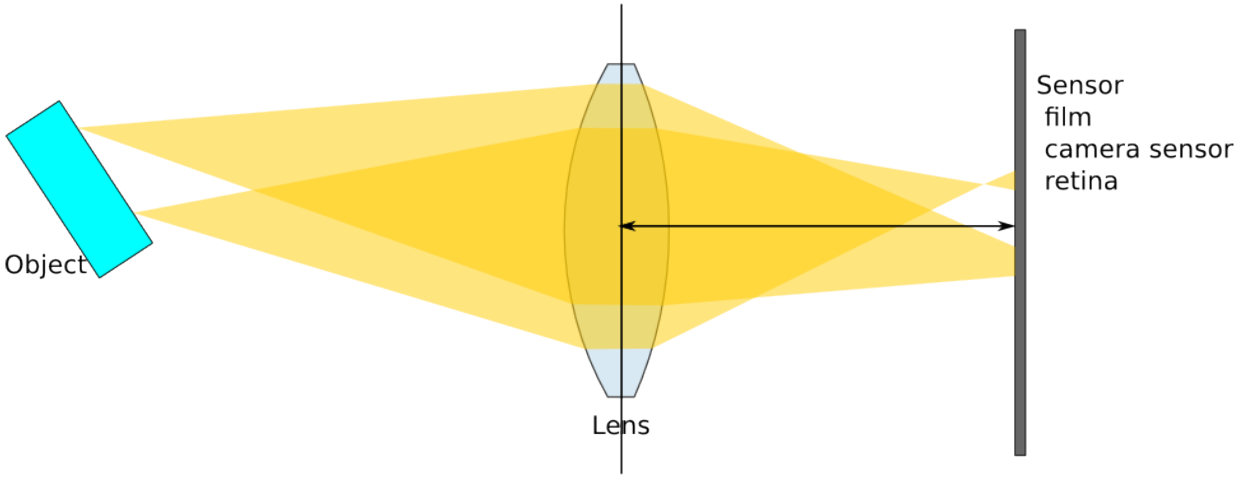
Imaging – lens



Lens can focus a beam of light on a sensor (focal plane).

Much more light-efficient than the pinhole.

Imaging – lens

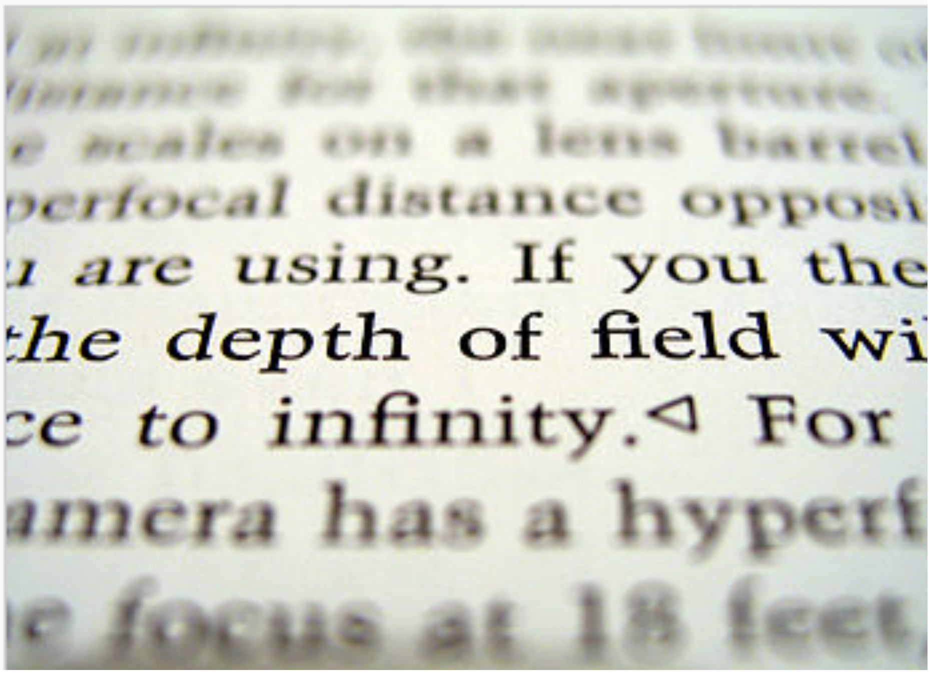


But it the light beams coming from different distances are not focused on the same plane.
These points will appear blurry in the resulting image.

Camera needs to move lens to focus an image on the sensor.

Depth of field

- Depth of field – range of depths that provides sufficient focus

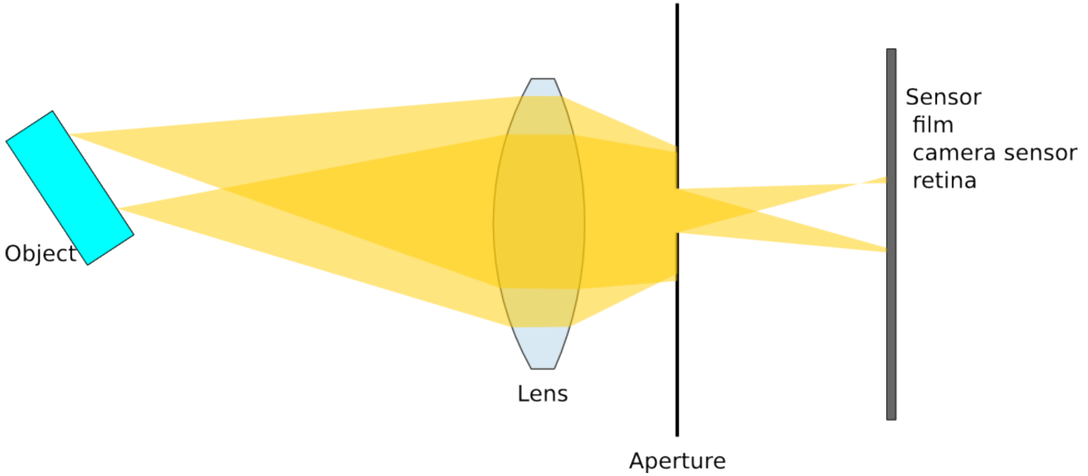


Defocus blur is often desirable

To separate the object of interest from background

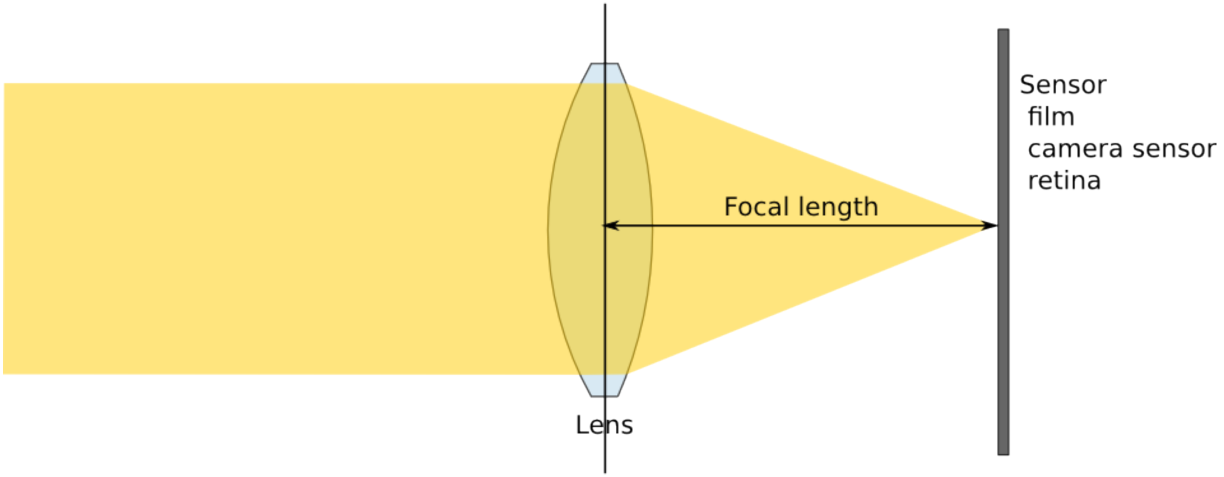
Defocus blur is a strong depth cue

Imaging – aperture



Aperture (introduced behind the lens) reduces the amount of light reaching sensor, but it also reduces blurriness from defocus (increases depth-of-field).

Imaging – lens

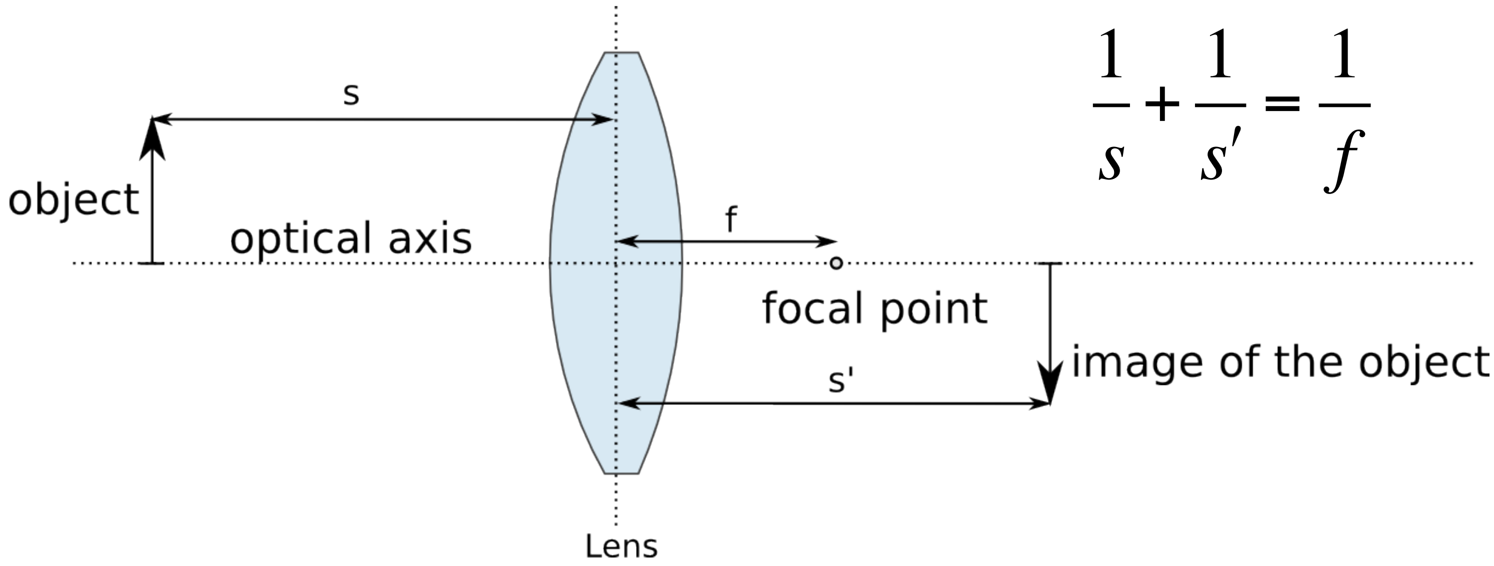


Focal length – length between the sensor and the lens that is needed to focus light coming from an infinite distance.

Larger focal length of a lens – more or less magnification?

Thin lens optics

- We assume a perfect lens of infinitively small thickness
  - Useful approximation that simplifies math and ray tracing

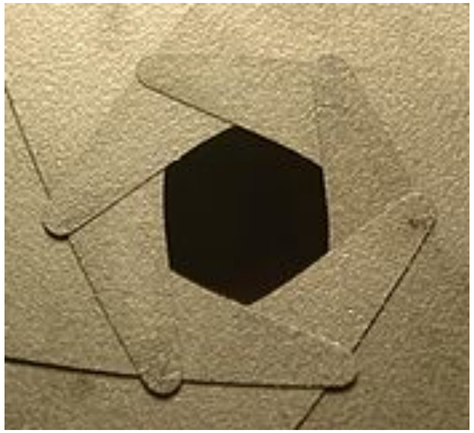


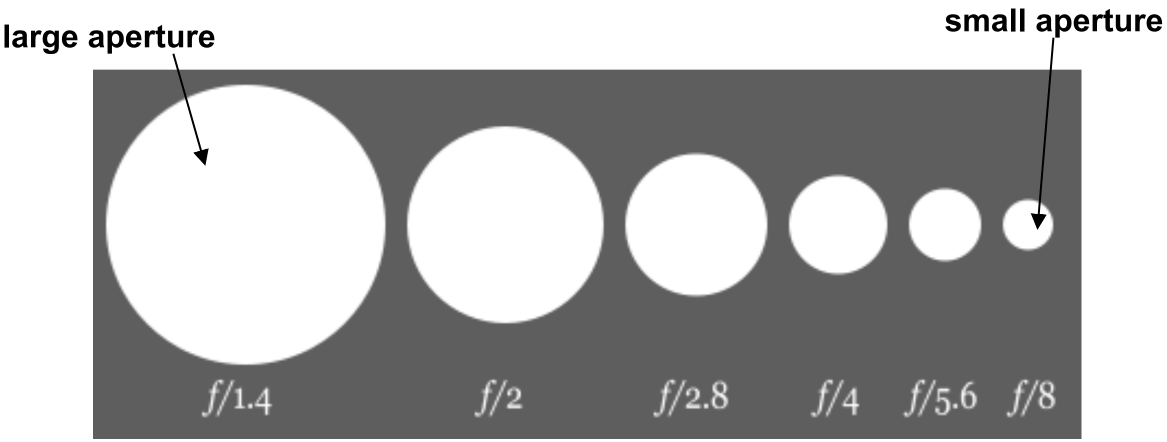
$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

  - Any ray parallel to the axis on one side, passes focal point on the other side
  - Any ray that passes though the centre of the lens do not change the direction

Aperture

Aperture – limits the amount of light reaching the sensor, controls effective focus range (depth of field).





lens speed – maximum aperture, minimum f-number

Aperture - f-number

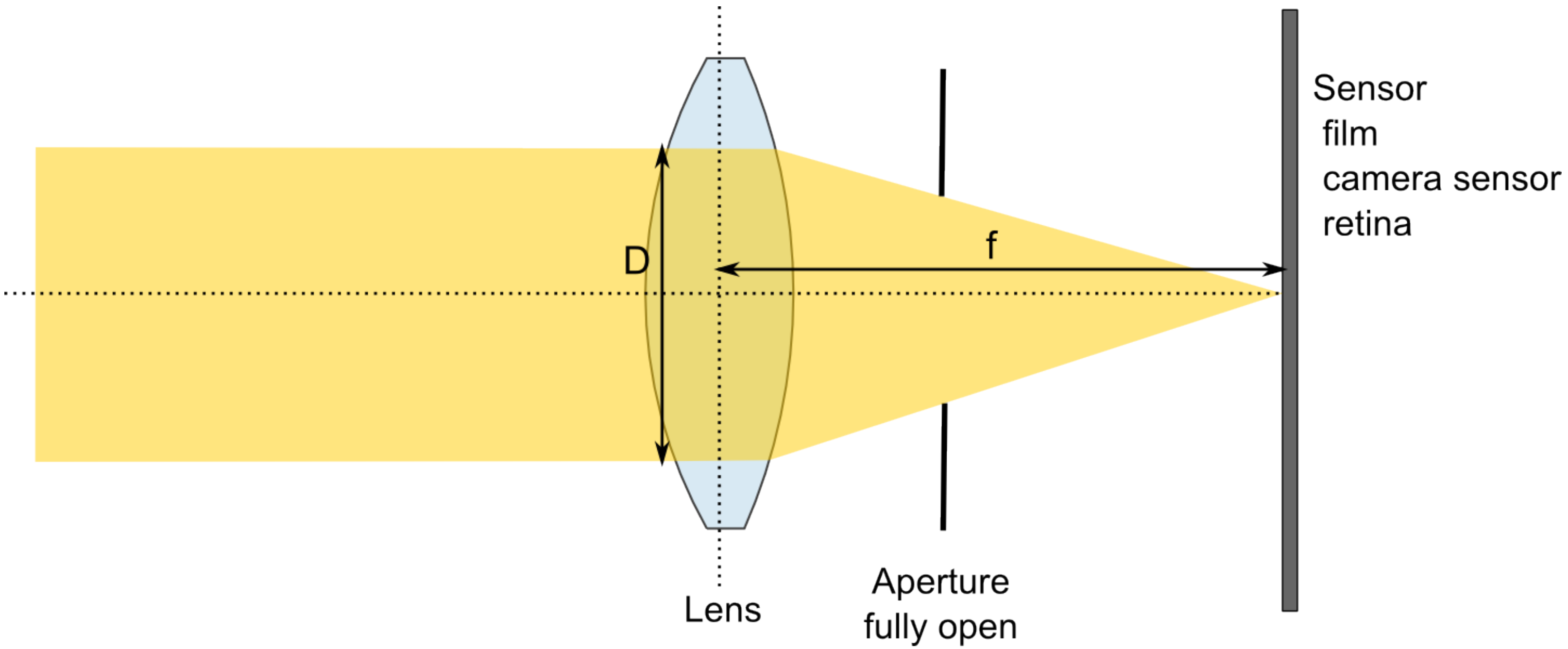
focal length

f-number

$$f/\# = N = \frac{f}{D}$$

Diameter of entrace pupil

The larger the f-number, the less light reaches the sensor



Aperture - f-number

f-number

focal length

$$f/\# = N = \frac{f}{D}$$

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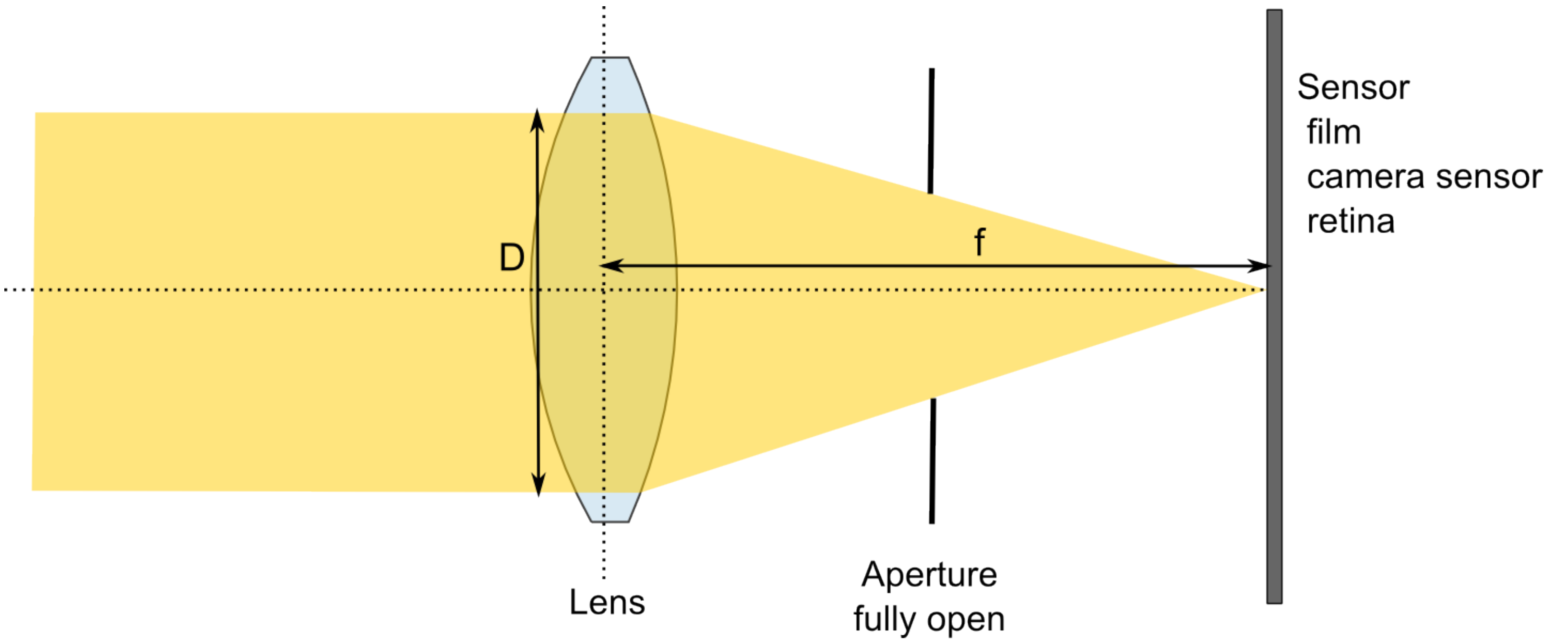


Aperture – Aperture Value

- f-numbers are not intuitive – increasing by one has a different effect on brightness depending on the f-number
- Thus some cameras use aperture values (AV)

$$AV = 2\log_2(N)$$

f-number

  - AV-1 doubles the amount of light
  - AV+1 reduces by half the amount of light
- Typical scale of f-stops and aperture values:

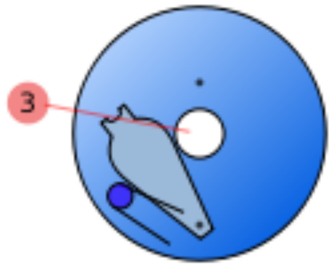
AV	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
f/#	0.5	0.7	1.0	1.4	2	2.8	4	5.6	8	11	16	22	32	45	64	90	128

Shutter

- Shutter – exposes sensor to light for a given amount of light
  - The time can vary from 1/8000 sec to 30 sec or more

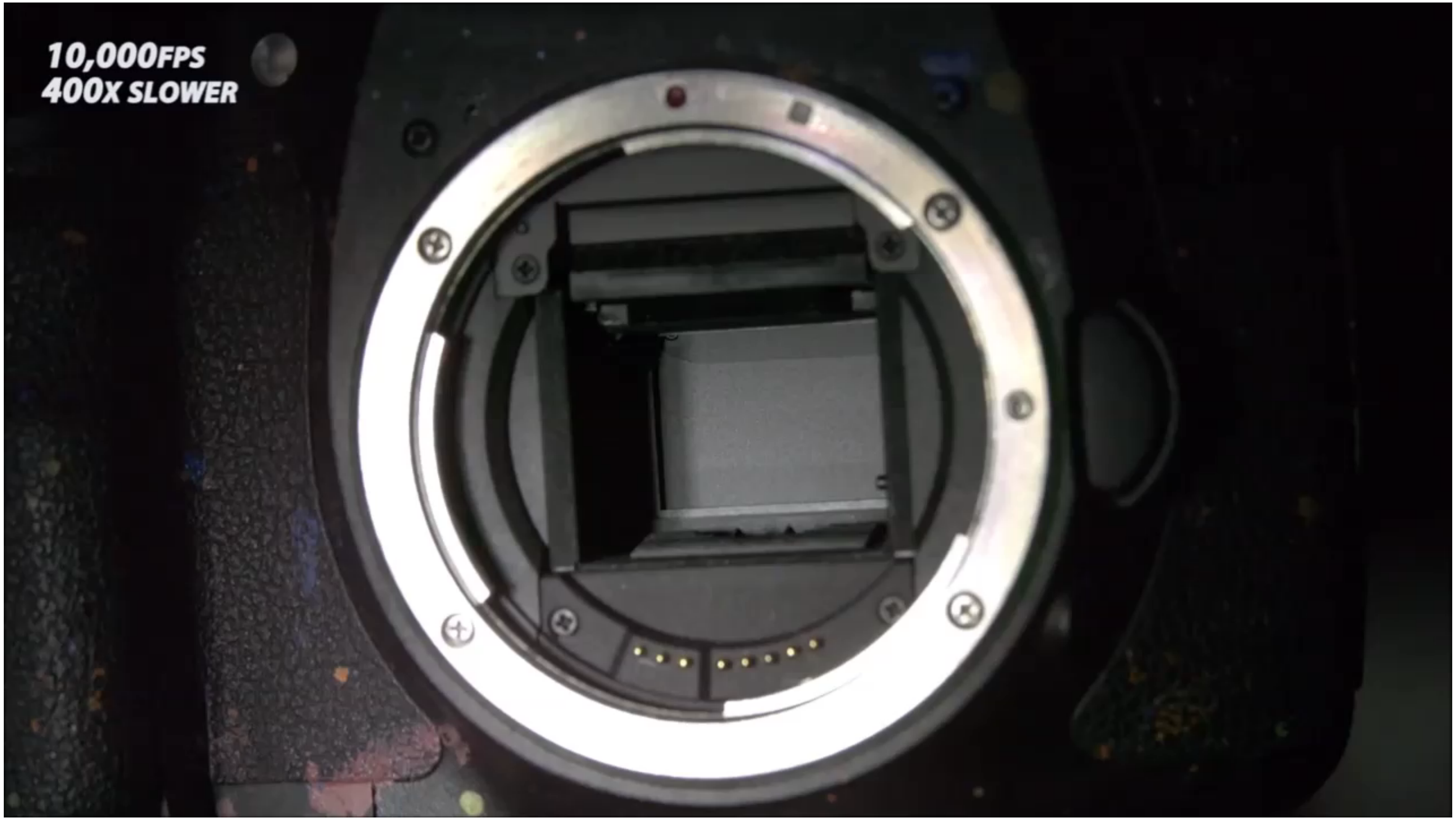
Focal plane shutter

Shutter integrated with aperture



Leaf shutter
(very fast)

Shutter captured with a high-speed camera



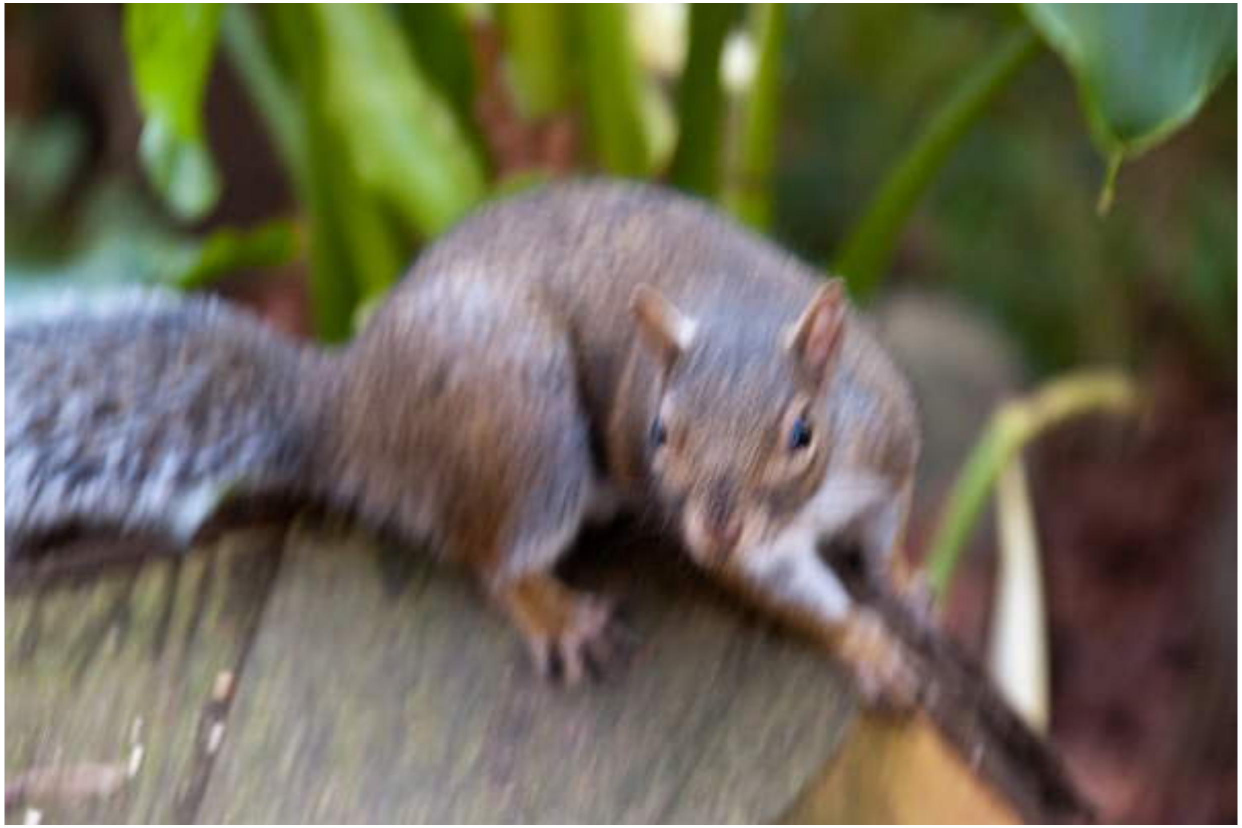
Watch full video at: http://youtu.be/CmjeCchGRQo

Exposure time

- Longer exposure times can result in motion-blur

Exposure time

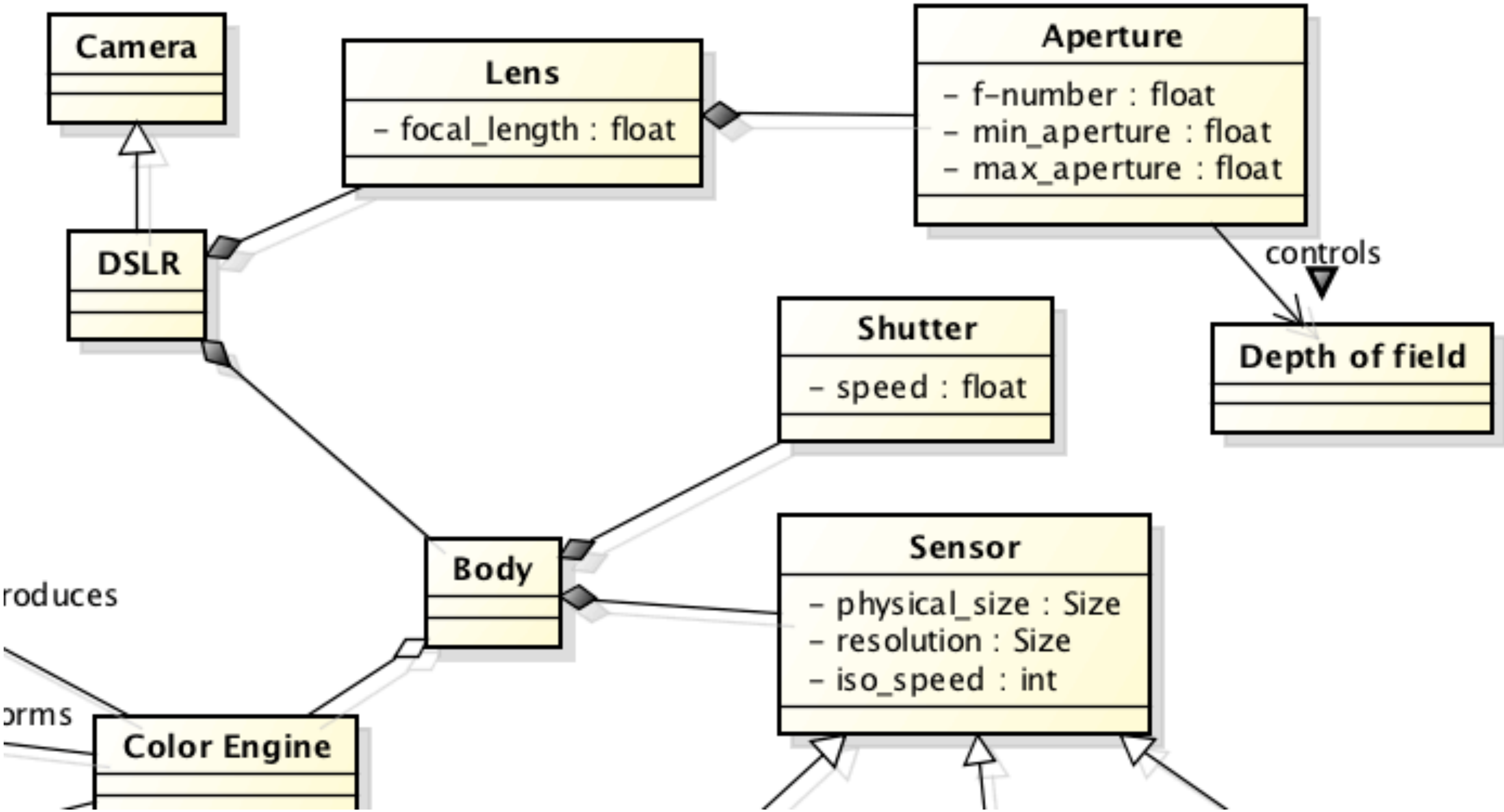
- or camera shake (if hand-held)



Example: long exposure time

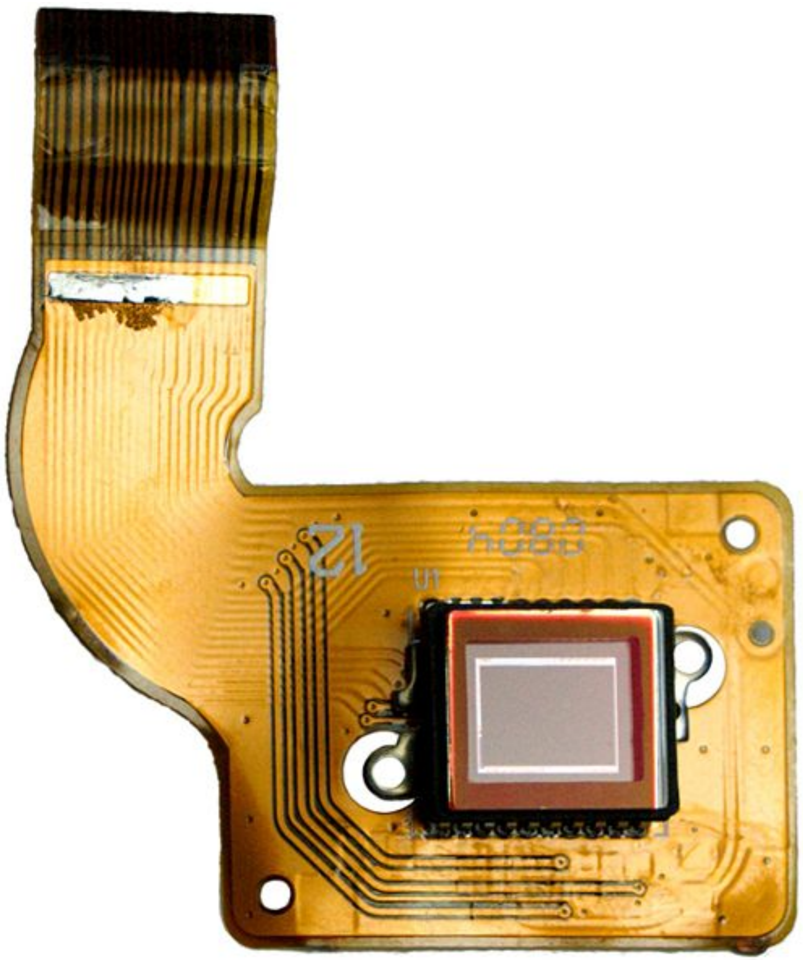
Example: short or long exposure time?

Review



Camera
Lens
- focal_length : float
Aperture
- f-number : float
- min_aperture : float
- max_aperture : float
DSLR
controls
Shutter
- speed : float
Depth of field
Sensor
- physical_size : Size
- resolution : Size
- iso_speed : int
Body
roduces
orms
Color Engine

Image sensors

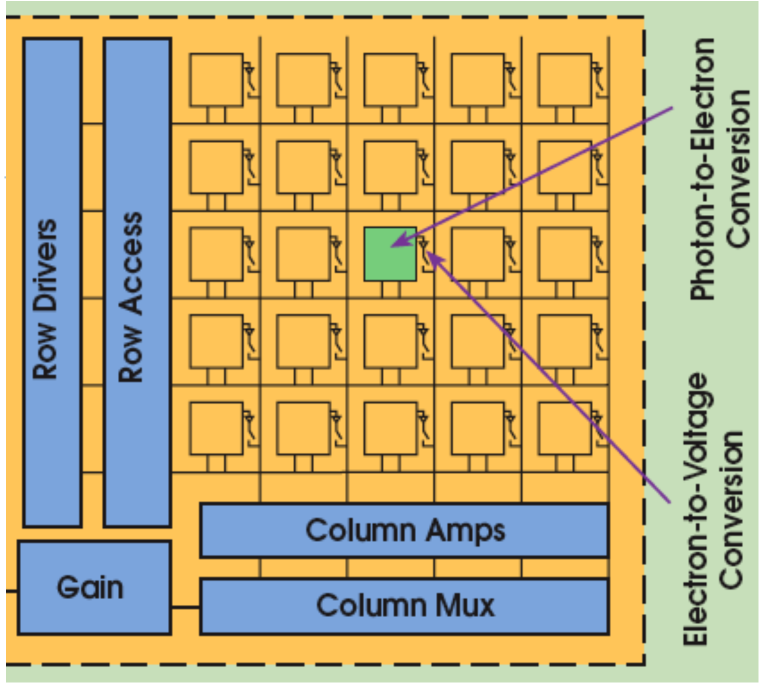


- Transform incoming light into electric current

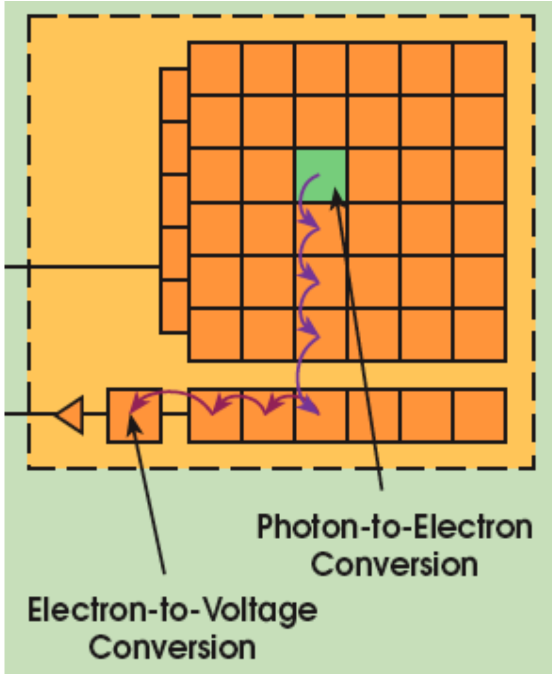
- The sensors vary from
  - tiny in mobile phones (2.3x1.7 mm)
  - large in professional camera (36x24 mm)
- Large sensors
  - can collect more light
  - produce less noise

CMOS vs CCD

- CMOS (Complementary Metal-Oxide-Semiconductors)
  - „easier" to fabricate
  - low power
  - higher noise

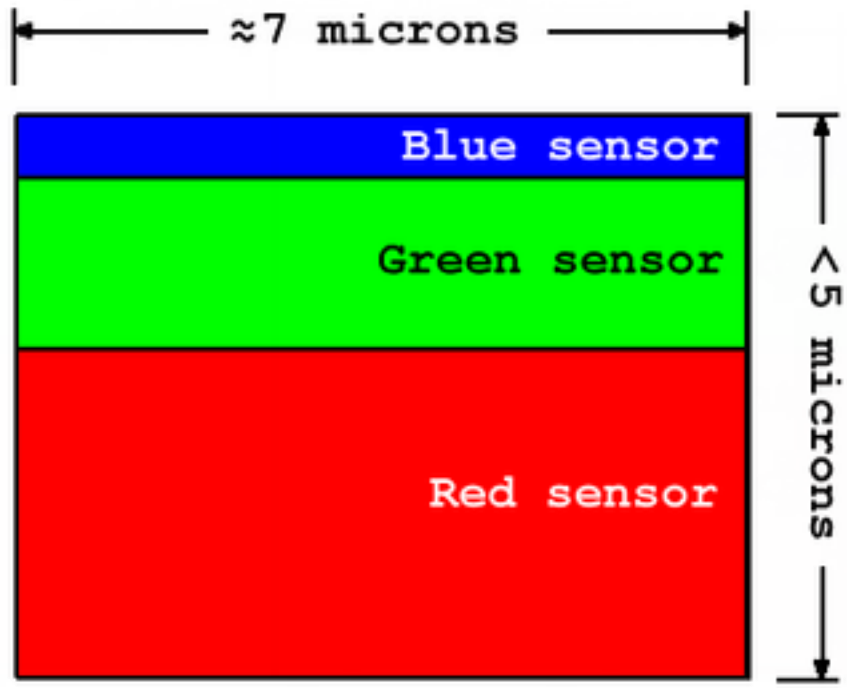


- CCD (Charge-Coupled Devices)
  - cells read line-by-line
  - more sensitive to light
  - slower read-out



Foveon CMOS sensors

- Three photodiodes one of top of the other
- Light of different wavelength enters into different depth of the silicone
  - No need for demosaicing
  - But lower sensitivity to light
    - Noisier images at low light



ISO speed

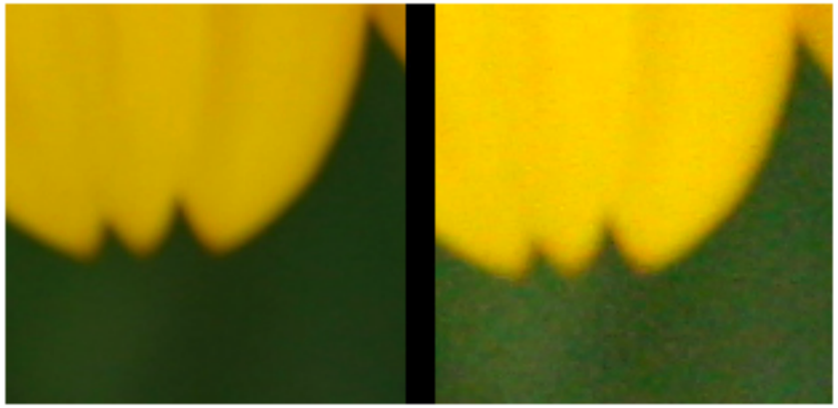
Sv – speed value [ISO]

Speed value (Sv)	Film speed (ISO)
0	3.125 [3]
1	6.25 [6]
2	12.5 [12]
3	25
4	50
5	100
6	200
7	400
8	800
9	1600
10	3200

$$S_v = \log_2 \frac{S}{3.125}$$

ISO speed – sensitivity of the film or digital sensor to light

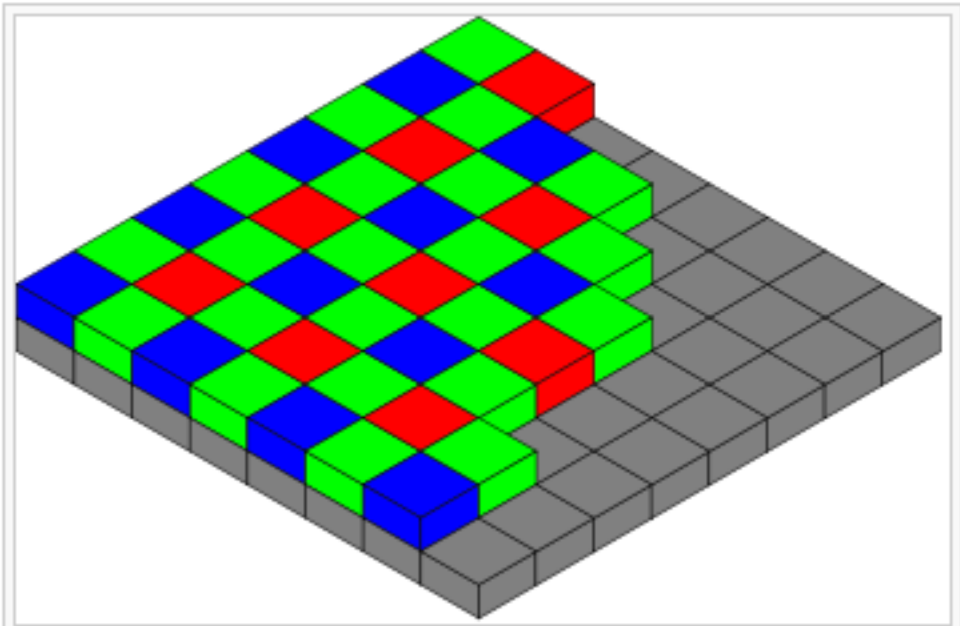
- Film cameras – films of different grain
- Digital cameras – digital amplifier



Higher speed makes the signal stronger, but introduces more noise

Color imaging

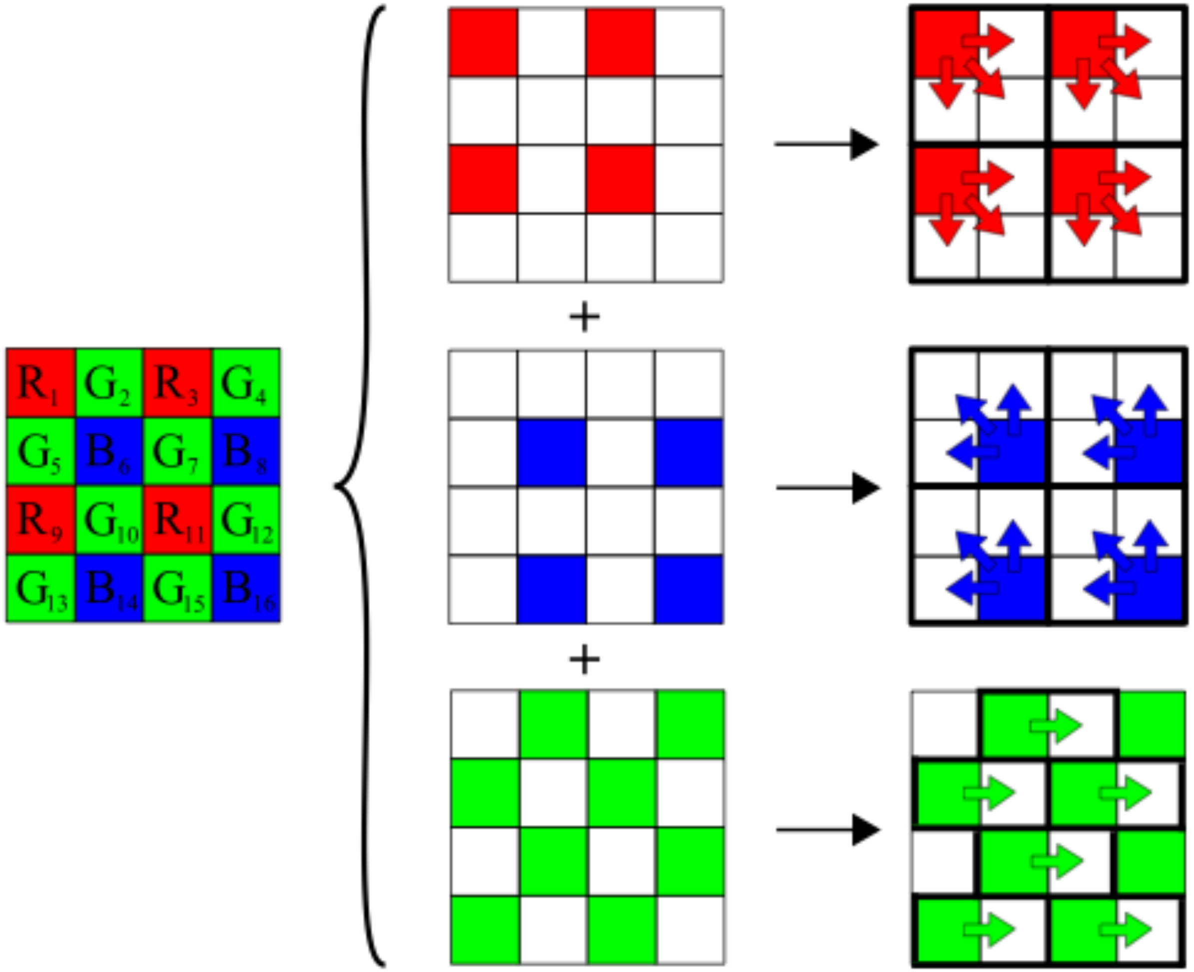
- Demosaicing – replace intensities registered by a sensor with red, green and blue pixel values.

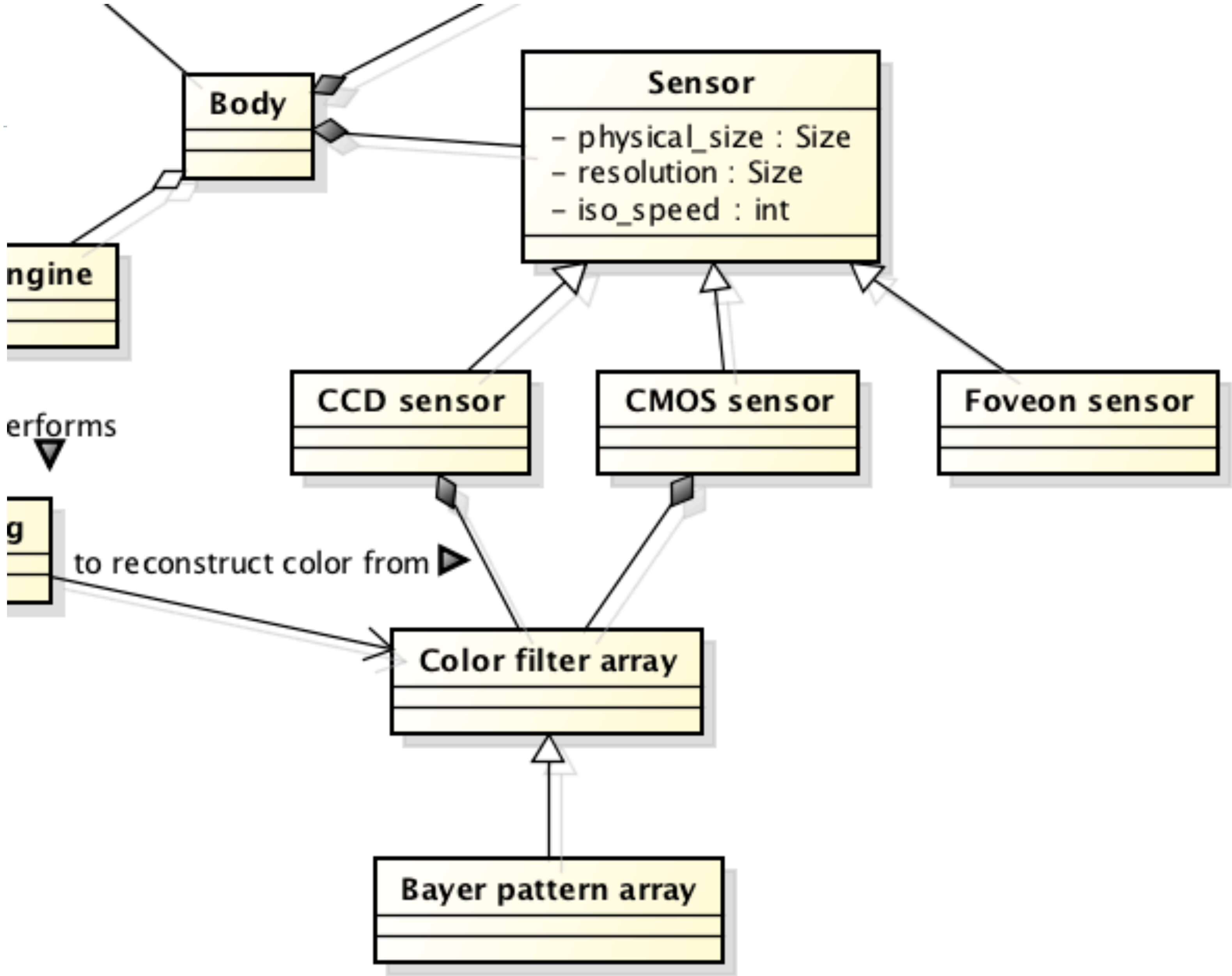


CFA (Color Filter Array) – Bayer pattern

Simple demosaicing – nearest neighbor

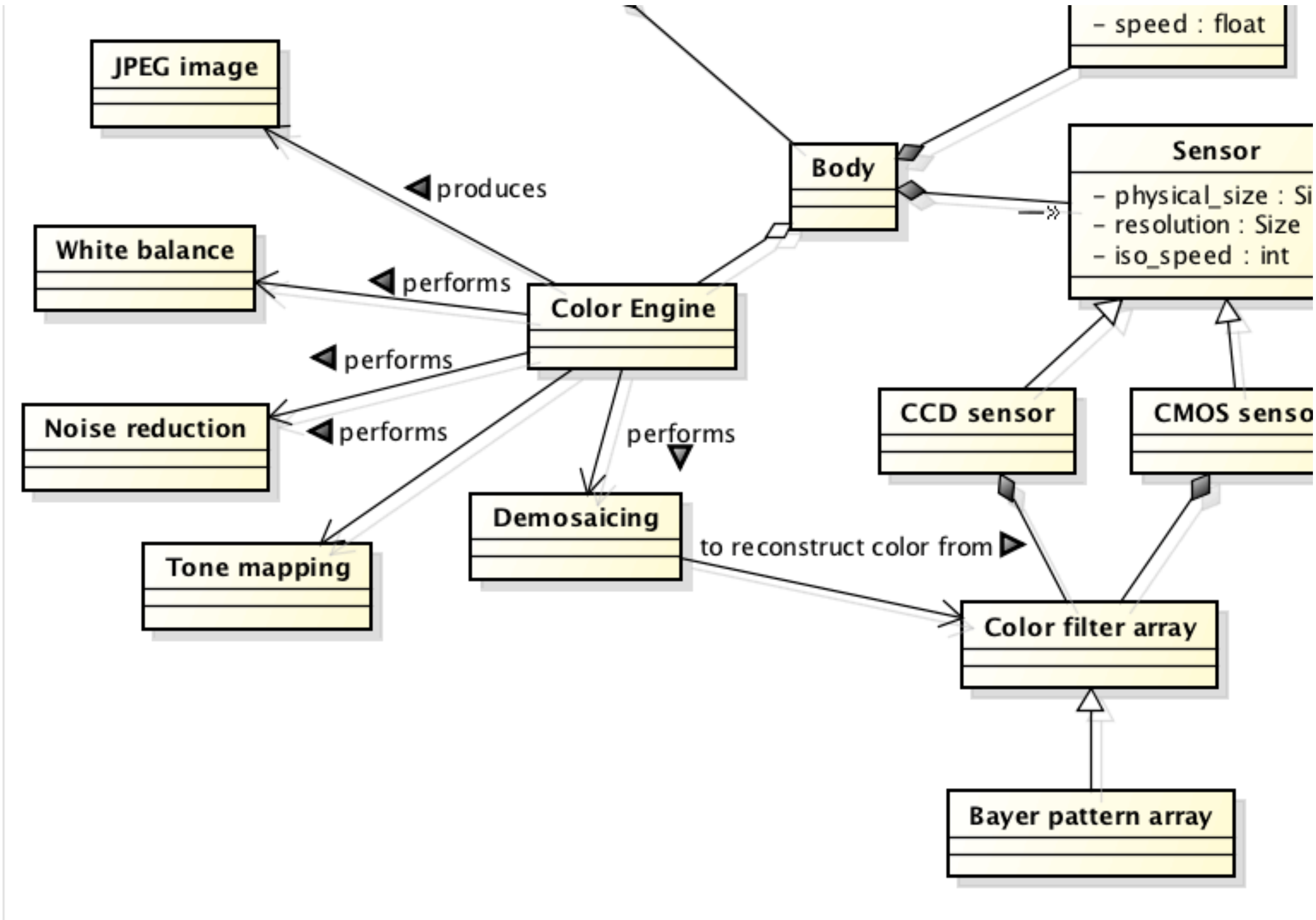
Replicate pixel values




Body
Sensor
- physical_size : Size
- resolution : Size
- iso_speed : int
ngine
erforms
CCD sensor
CMOS sensor
Foveon sensor
g
to reconstruct color from
Color filter array
Bayer pattern array

Color engine / JPEG engine

- Camera needs to map electrical charge collected by the sensor to color values in order to produce the best images
- This involves
  - Demosaicing
  - Noise reduction
  - White balance
  - Tone-mapping
  - Enhancement
  - Storing the result as a JPEG image


- speed : float
JPEG image
produces
Body
Sensor
- physical_size : Si
- resolution : Size
- iso_speed : int
White balance
performs
Color Engine
performs
Noise reduction
performs
performs
CCD sensor
CMOS senso
Demosaicing
Tone mapping
to reconstruct color from
Color filter array
Bayer pattern array

Camera buying guide

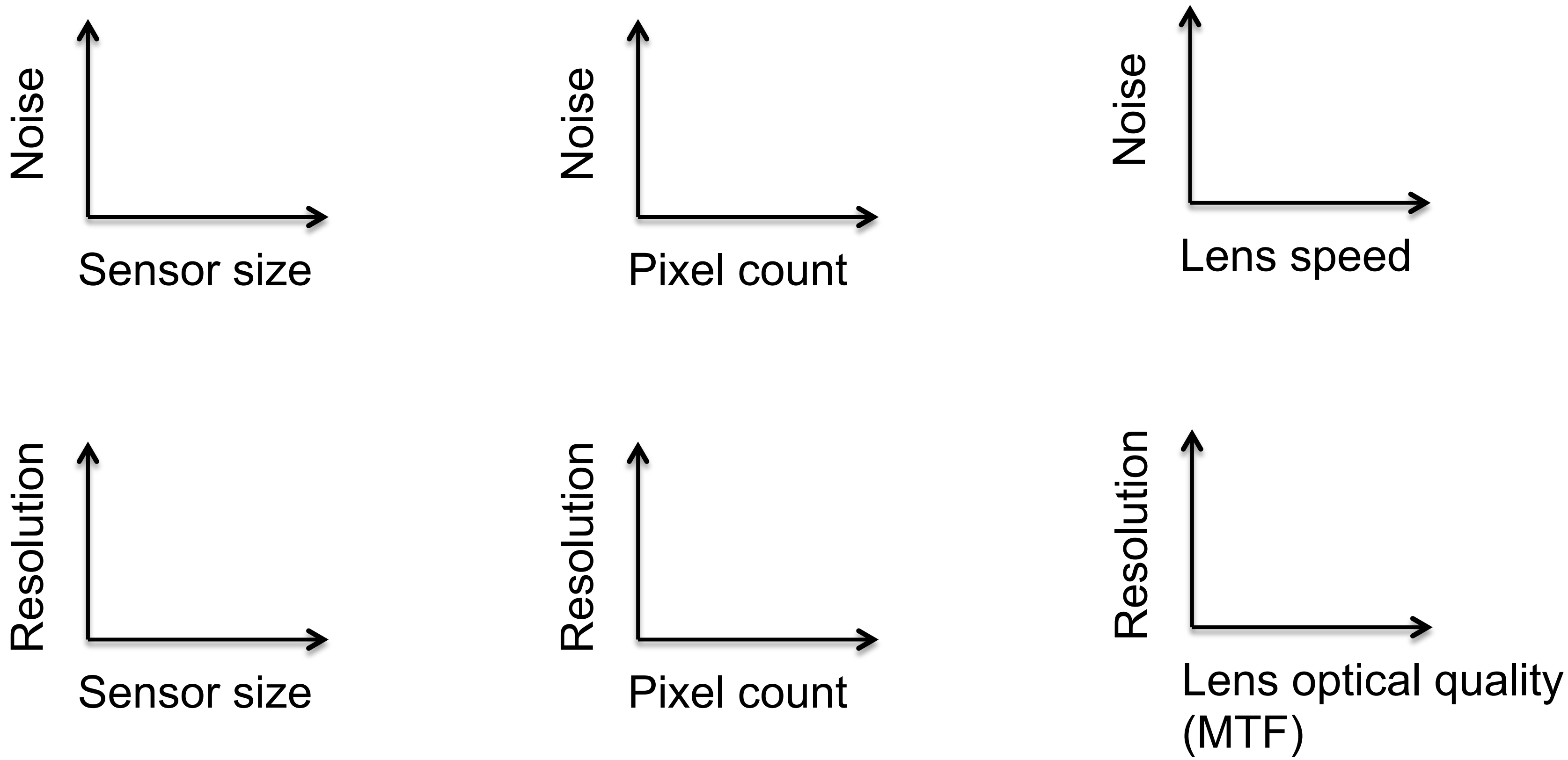
- What camera parameters are the most important?



Side by side 3 cameras compared ADD CAMERA ...	Canon EOS 5D Mark III move left move right	Nikon D3 move left move right	Sony Alpha DSLR-A900 move left move right
Basic Information			
Price			
Body type			
Sensor			
Max resolution	5760 x 3840	4256 x 2832	6048 x 4032
Other resolutions	3840 x 2560, 2880 x 1920, 1920 x 1280, 720 x 480	3184 x 2120, 2128 x 1416	4400 x 2936, 4400 x 2936, 3024 x 2016, 6048 x 3408, 4400 x 2472, 3024 x 1704, 3924 x 2656, 2896 x 1928, 1984 x 1320
Image ratio w:h	3:2	5:4, 3:2	3:2, 16:9
Effective pixels	22 megapixels	12 megapixels	25 megapixels
Sensor photo detectors	23 megapixels	13 megapixels	26 megapixels
Sensor size	Full frame (36 x 24 mm)	Full frame (36 x 23.9 mm)	Full frame (35.9 x 24 mm)
Sensor type	CMOS	CMOS	CMOS
Processor	Digic 5+	Expeed	Bionz
Color space	sRGB,Adobe RGB		
Color filter array	RGB Color Filter Array		
Image			
ISO	Auto, 100 - 25600 in 1/3 stops, plus 50, 51200, 102400 as option	200, 400, 800, 1600, 3200, 6400 (100 - 25600 with boost)	Auto, 100, 200, 400, 800, 1600, (up to 6400)
White balance presets	6	12	7
Custom white balance	Yes (1)	Yes	Yes (1)

from: http://www.dpreview.com/

What are the relations?



References

- Erik Reinhard, Erum Arif Khan, Ahmet Oguz Akyuz, G. J. (2008). *Color Imaging: Fundamentals and Applications*. CRC Press.
  - Chapter III
- Optics – advanced topics but with introduction to thin-lens optics
  - Modern Optical Engineering, by Warren Smith
- To learn more about sensors
  - Image Sensors, by Blake Jacquot
    - https://youtu.be/4Deyx3RighA?list=PL1x2LOKhjrBdwZhKThR6jBpSPkJczUcii