

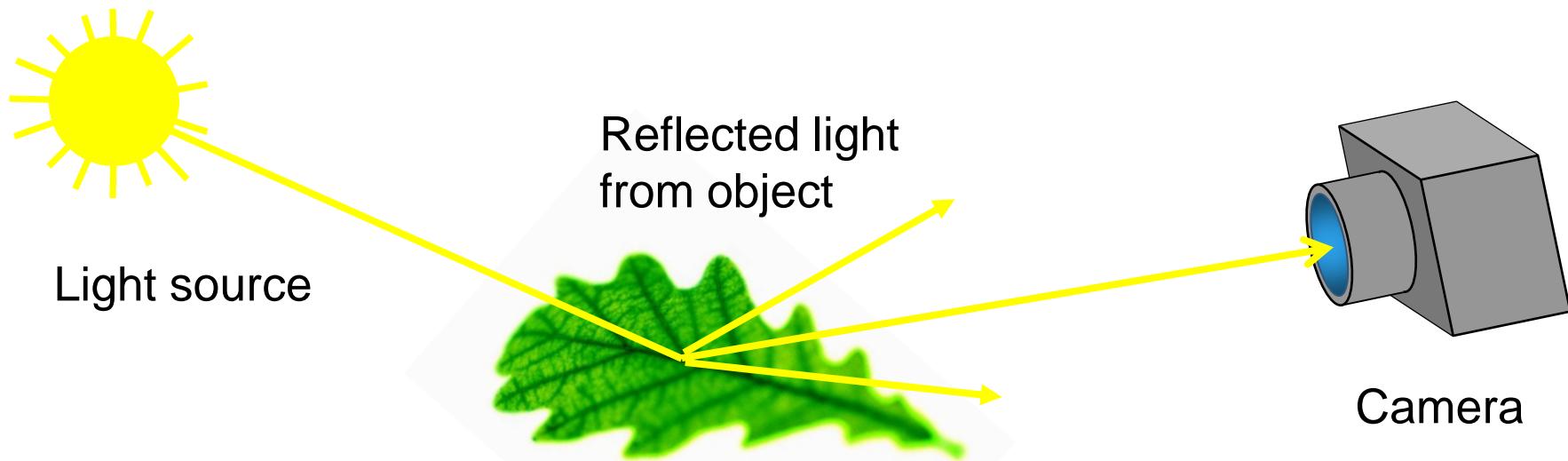
Light, camera, optics and colour

Idar Dyrdal



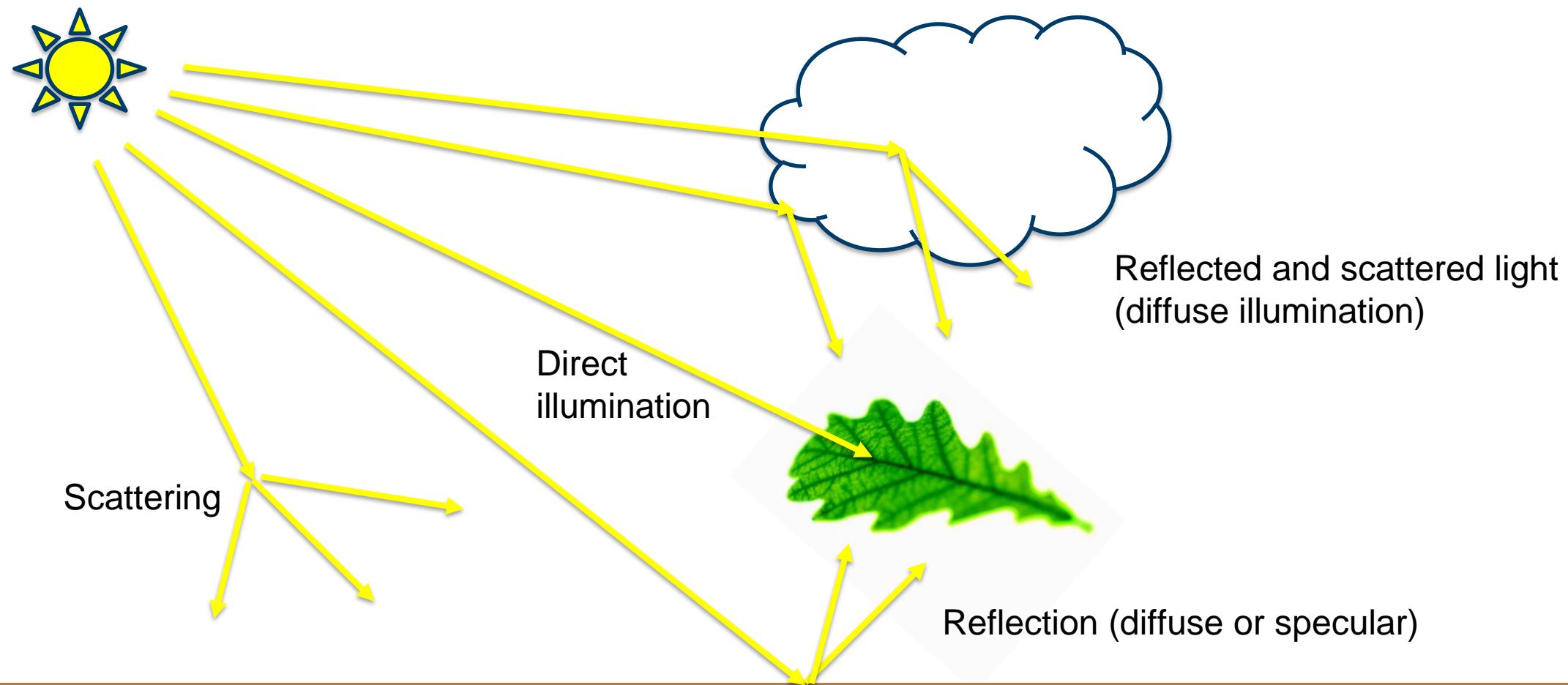
TEK5030

Imaging with visible light

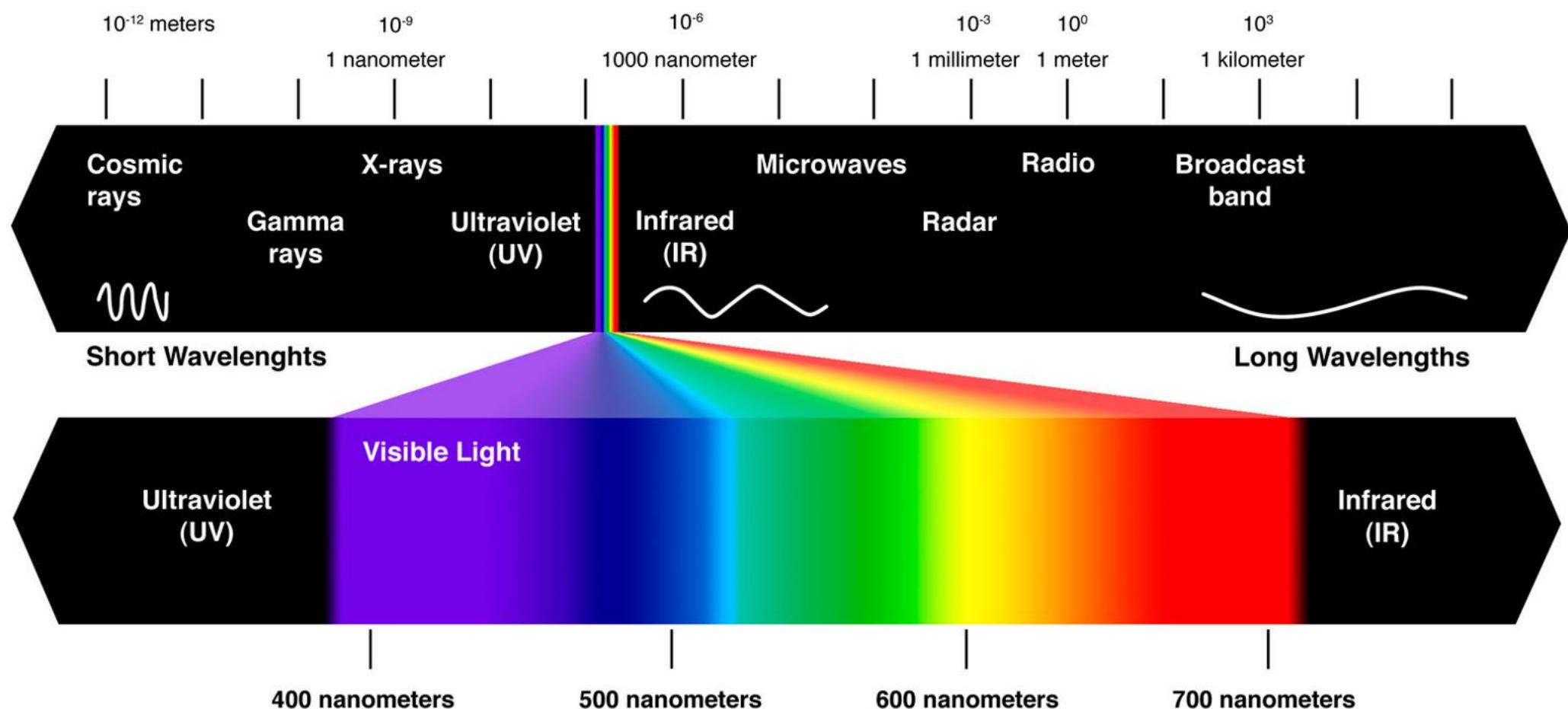


- Natural / artificial illumination
- Point sources / area sources

Direct and indirect illumination

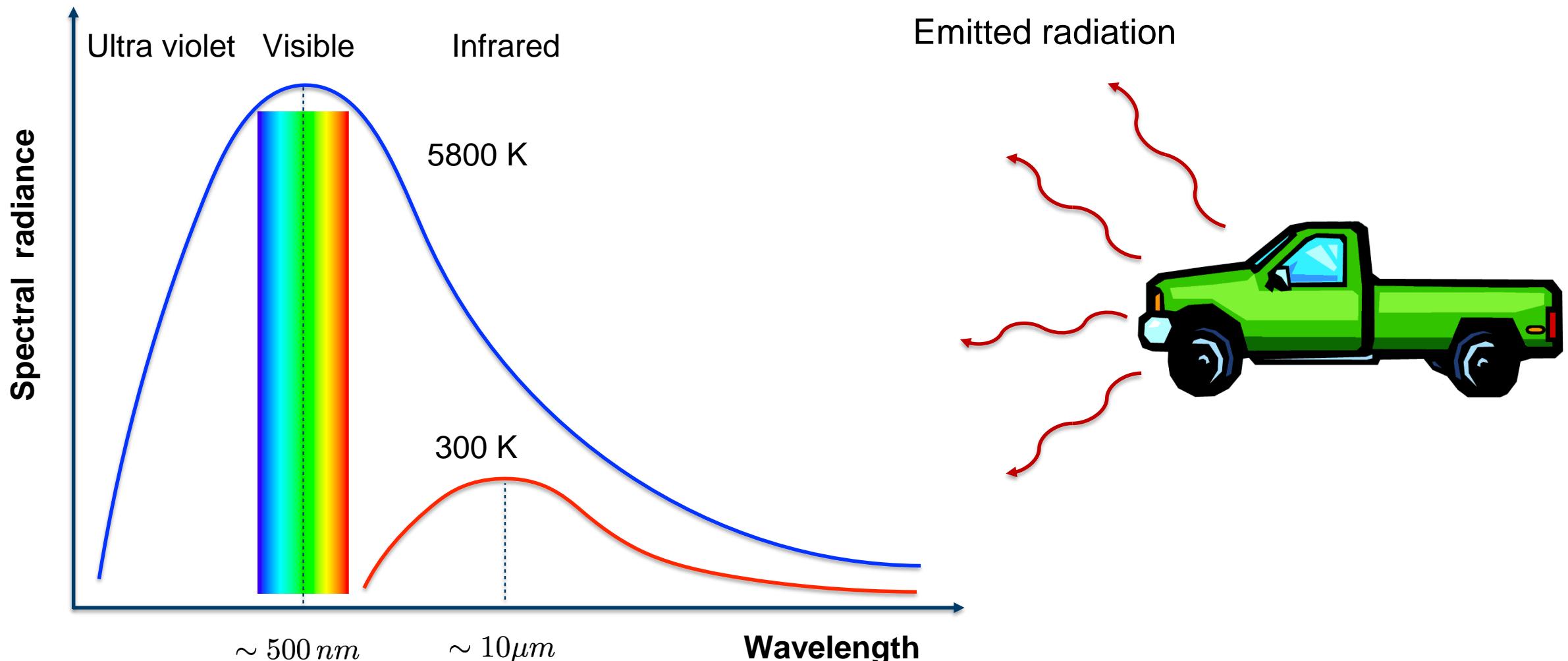


Electromagnetic spectrum



<http://www.infohow.org/wp-content/uploads/2012/11/Electromagnetic-Spectrum.jpg>

Thermal radiation - Planck distribution



Reflected and emitted radiation



Image in visible light:

- Imaging with **reflected** (and scattered) radiation from the sun or other natural or artificial sources.

Other frequency domains and wave types used for imaging:

- Millimeter waves, x-rays, ... (electromagnetic waves)
- Acoustic (sonar), seismic, ... (mechanical waves)

Infrared (thermal) image:

- Imaging with (mainly) the **emitted** thermal radiation from the scene.

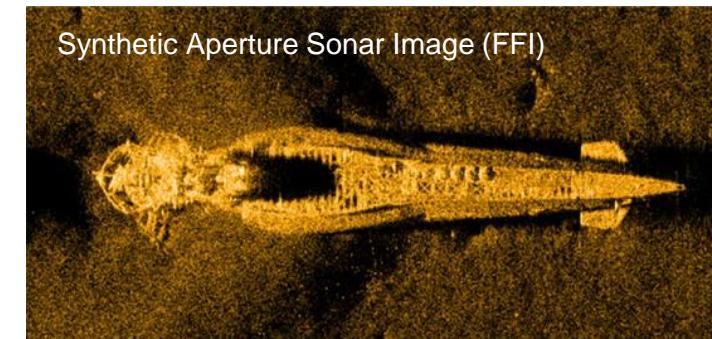
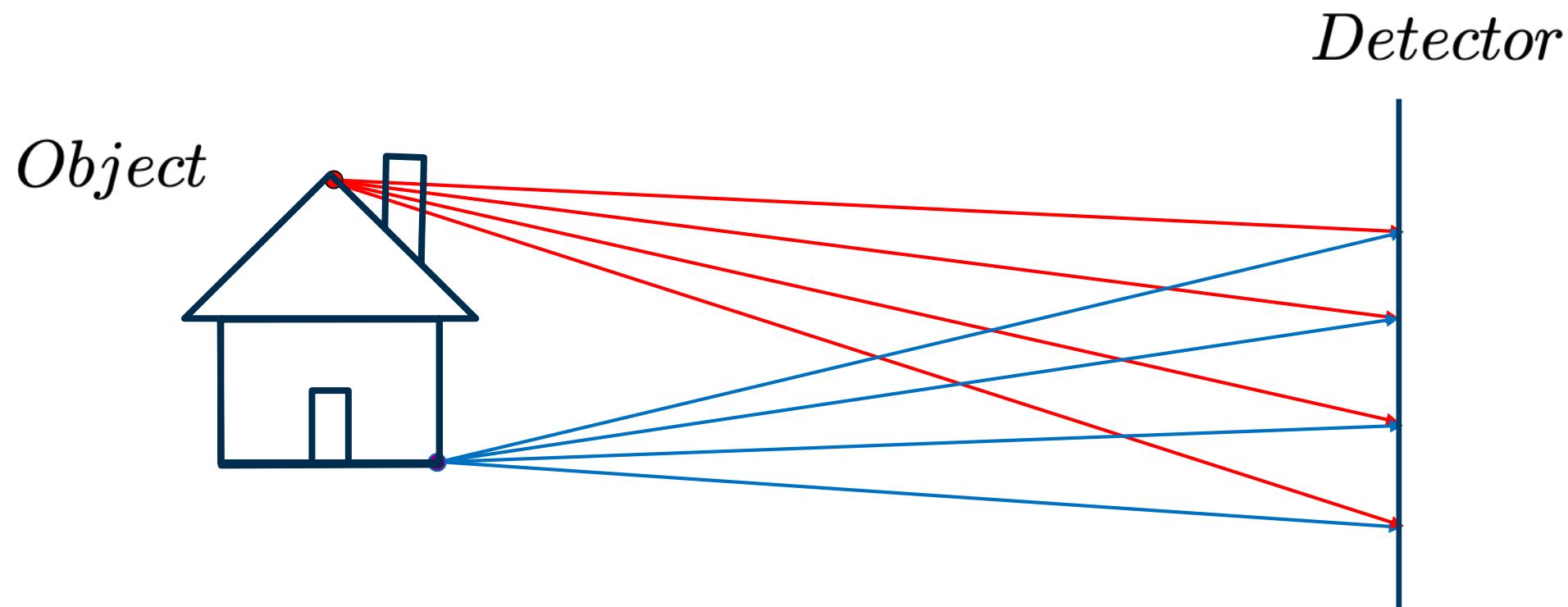
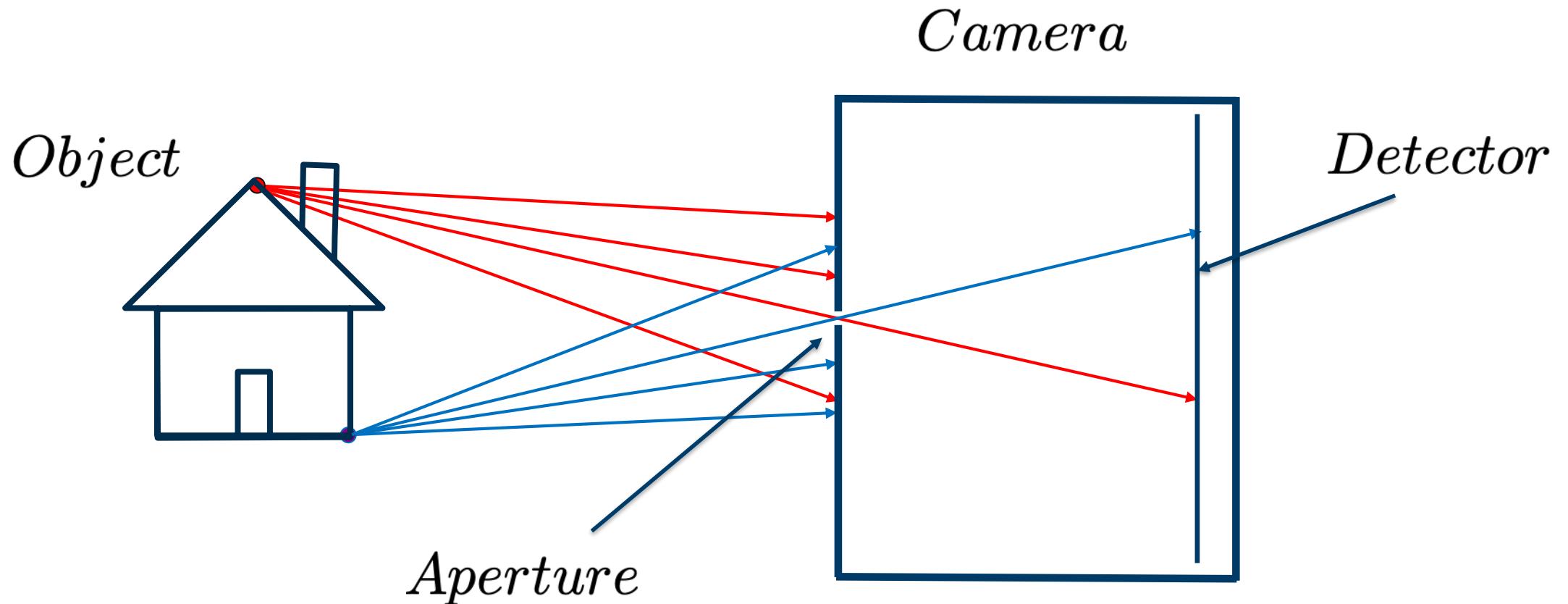


Image formation (with visible light)

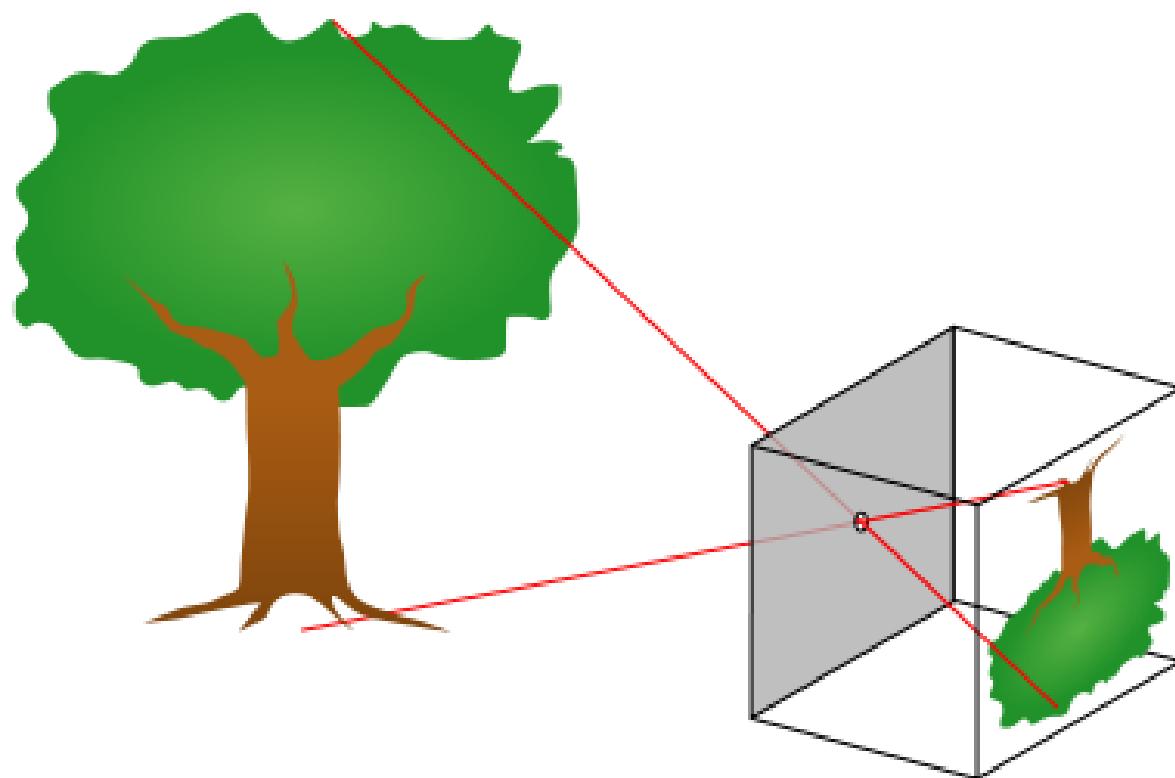


No image is formed! (Wide open aperture)

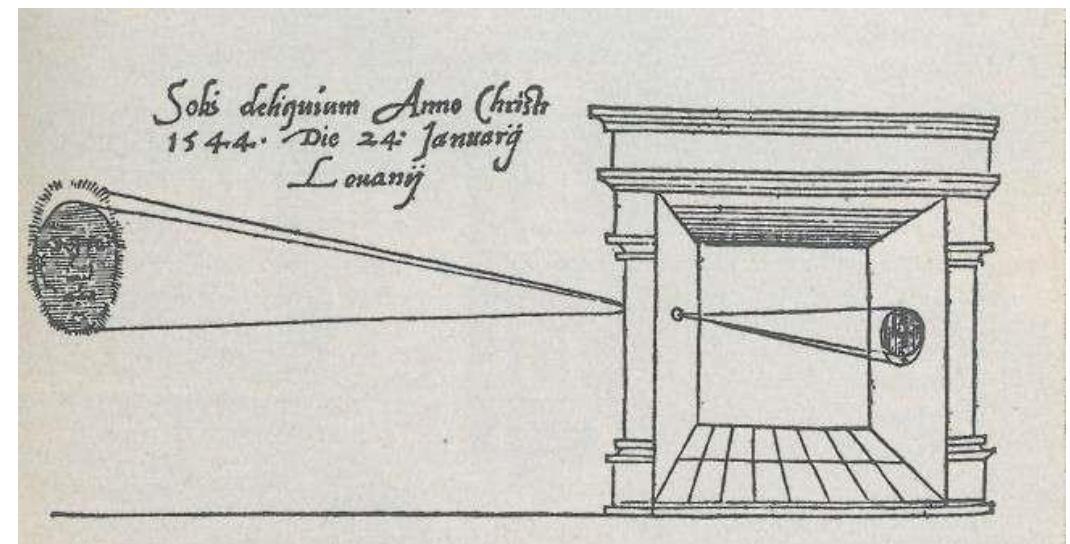
Simple camera - Pinhole camera



Pinhole camera



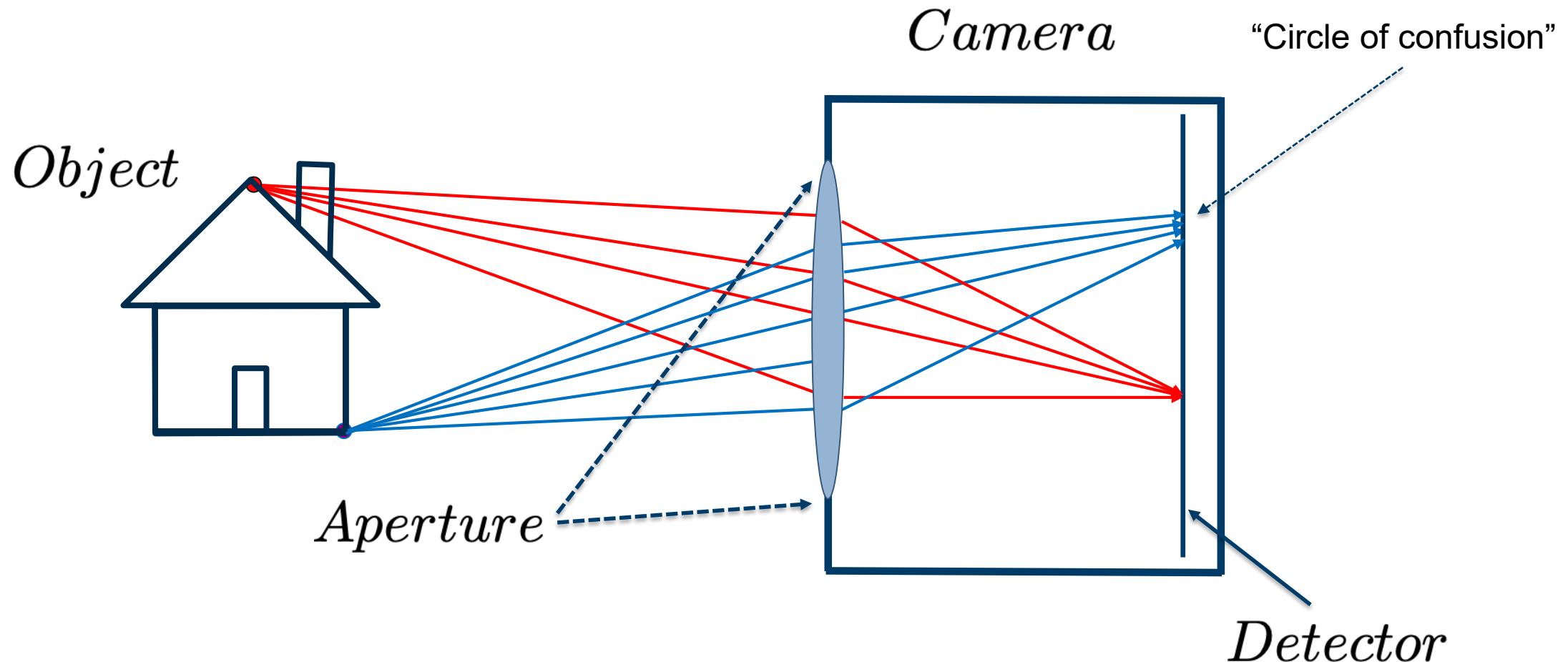
Camera obscura



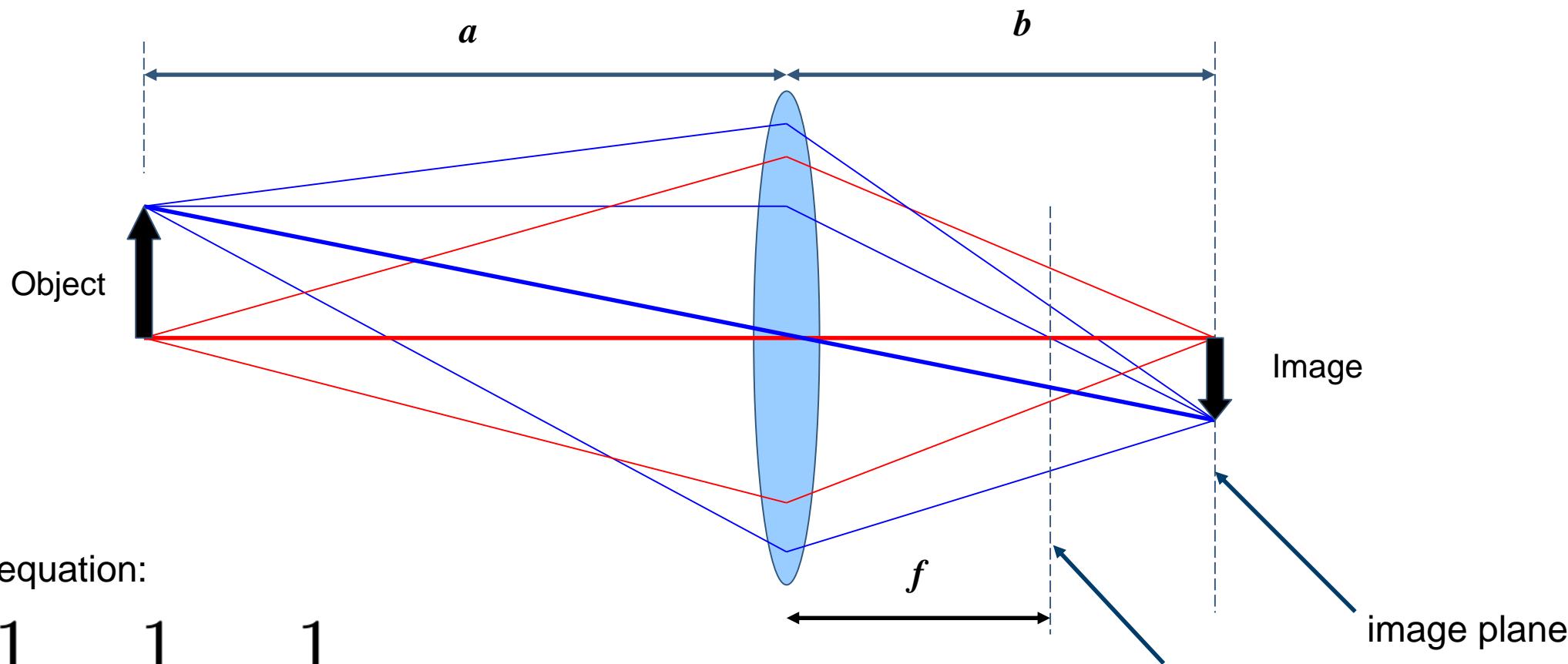
Small aperture Dark image

Large aperture Image out of focus

Camera with a lens



Imaging with a lens



Lens equation:

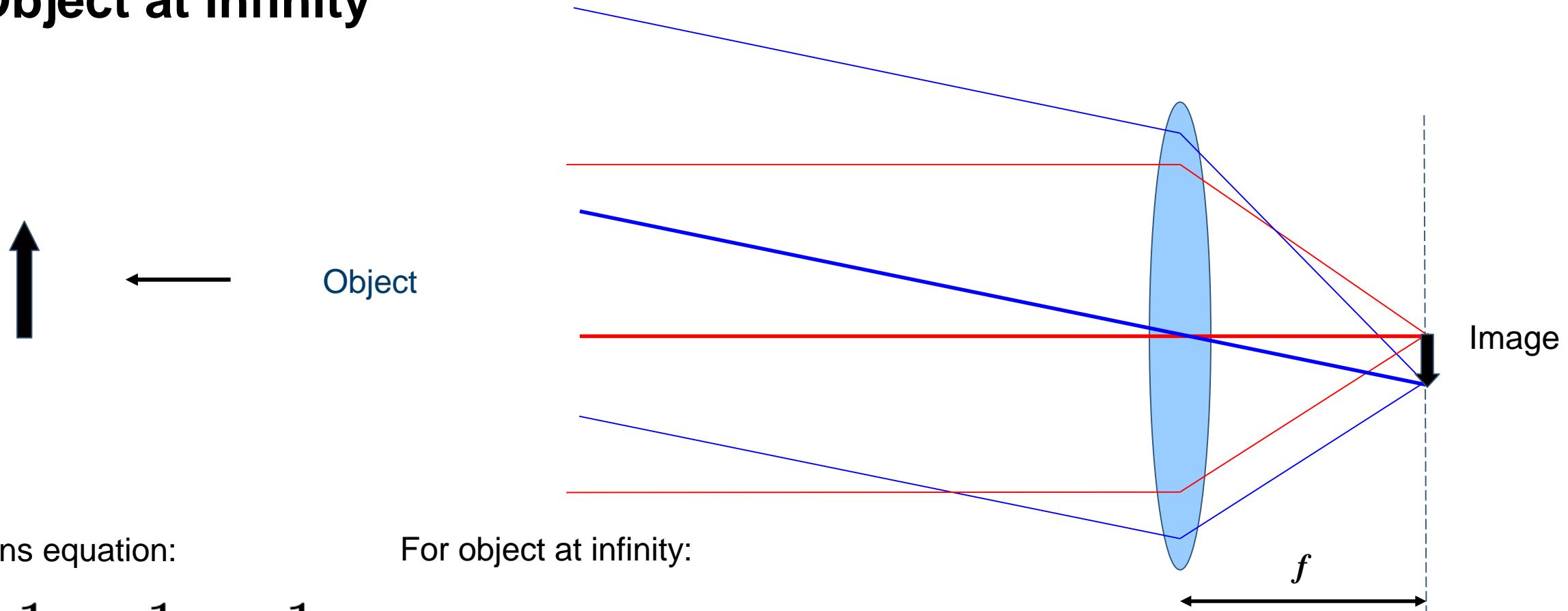
$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

f = focal length

focal plane

image plane

Object at infinity



Lens equation:

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

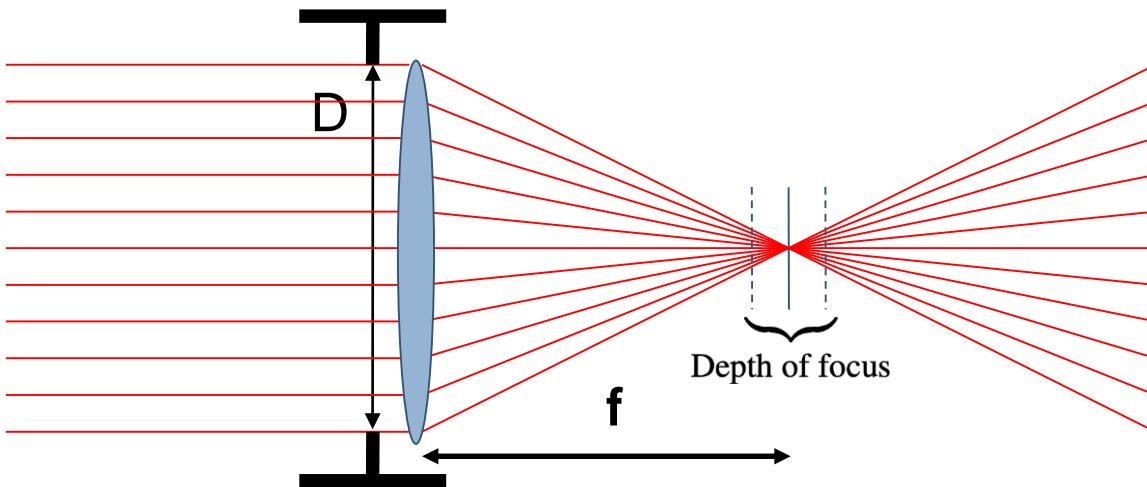
For object at infinity:

$$a = \infty \quad \Rightarrow \quad b = f$$

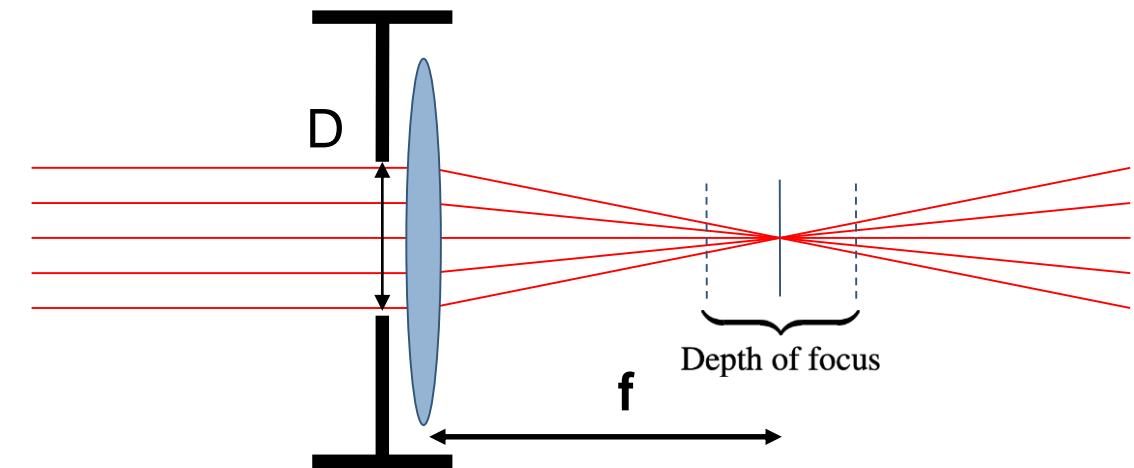
i.e. image plane = focal plane.

Depth of focus

Large aperture



Small aperture

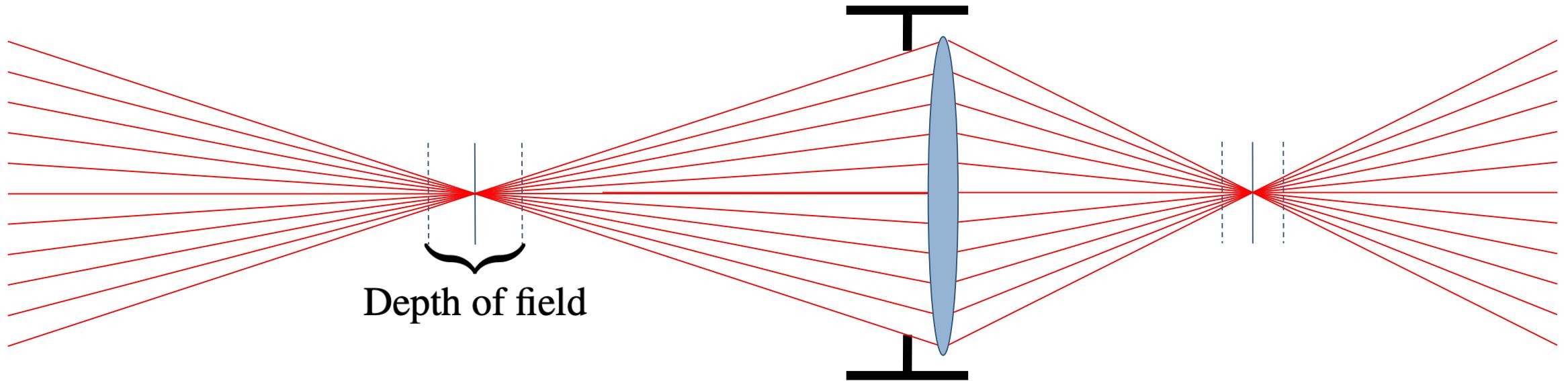


F-number: f/D (typical values: f/1.4, f/2, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22)

Small f-number → Narrow depth of focus

Large f-number → Large depth of focus

Depth of field – large aperture



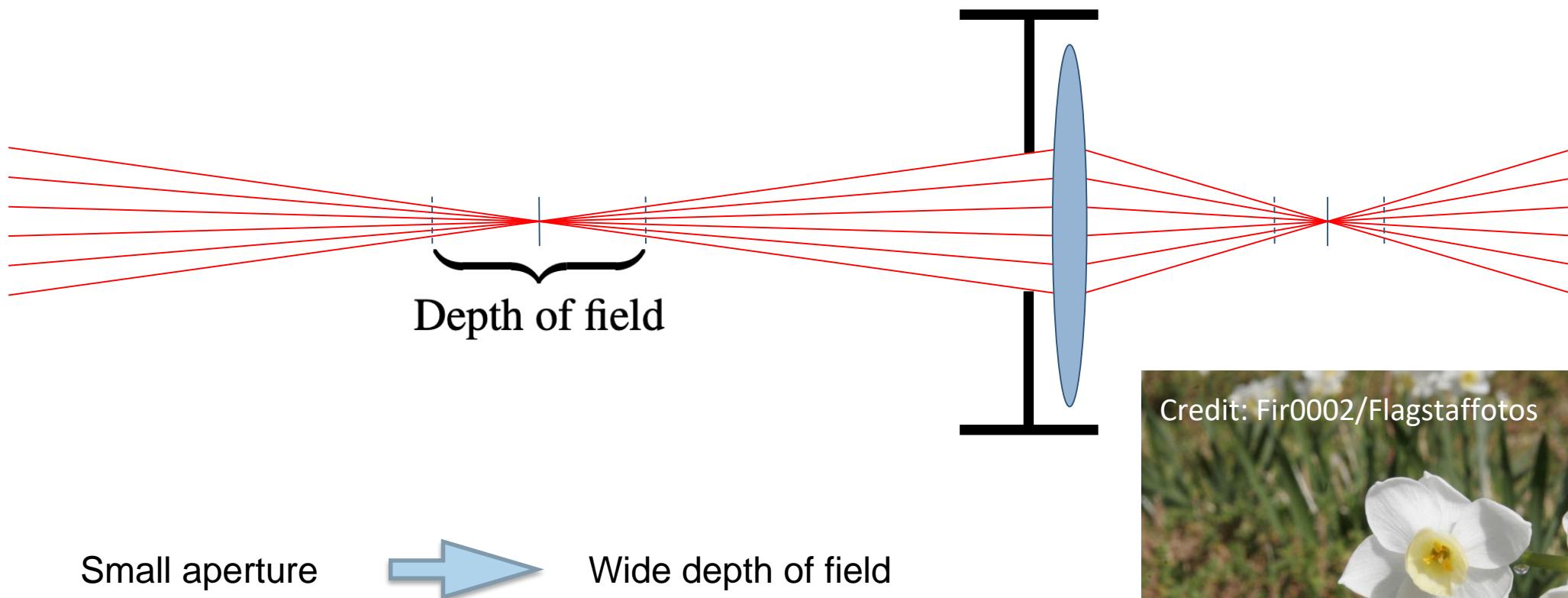
Large aperture



Narrow depth of field



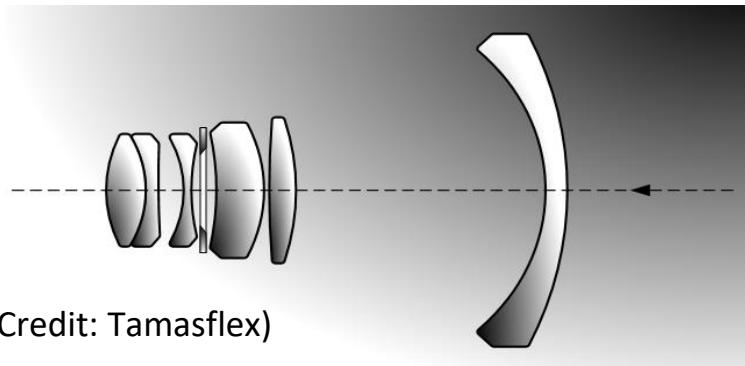
Depth of field – small aperture



Too small aperture will lead to *diffraction* and loss of sharpness



Practical (compound) lenses



(Credit: Tamasflex)



Fixed focal length lens

Correcting for:

- Geometric aberrations (e.g. image distortion)
- Chromatic aberrations
- Vignetting



Zoom lens (variable focal length)

Three pillars of image capture

- Detector Gain (or film sensitivity in film-based cameras)
- Aperture
- Shutter speed

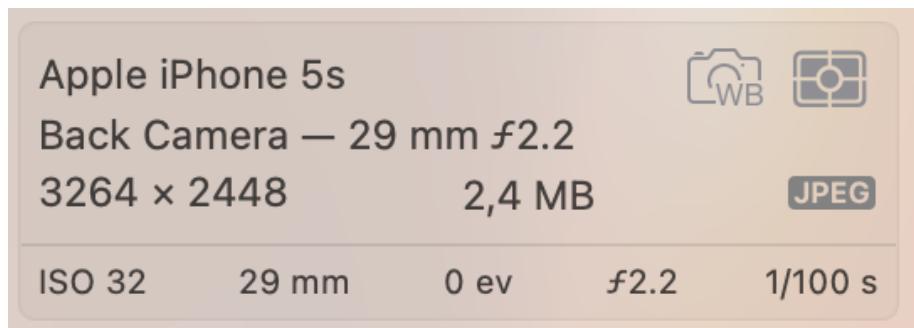
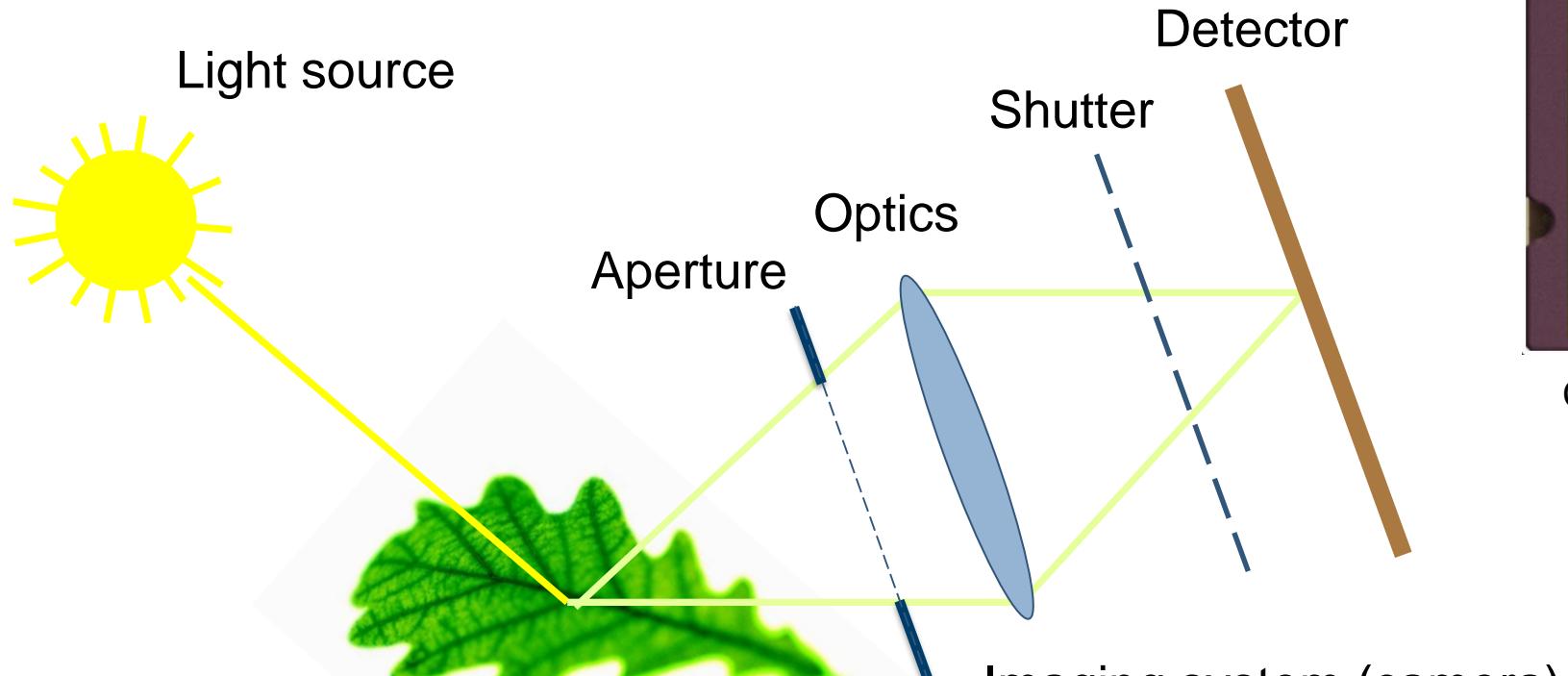


Image capture

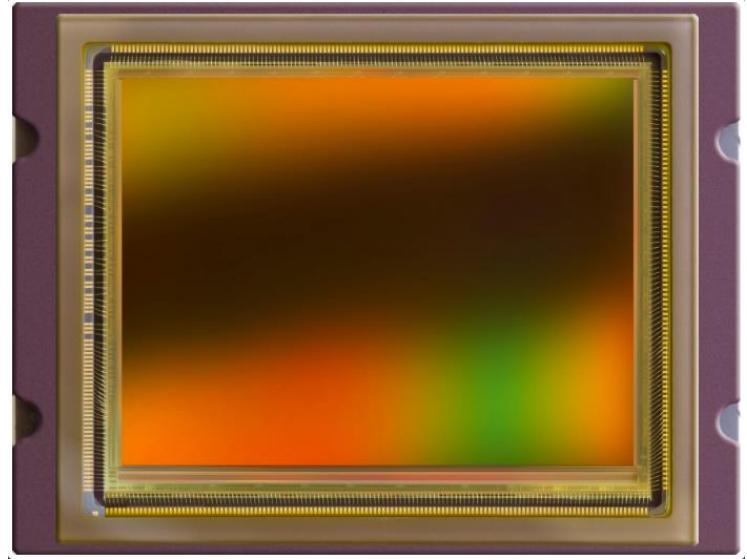


Detector:

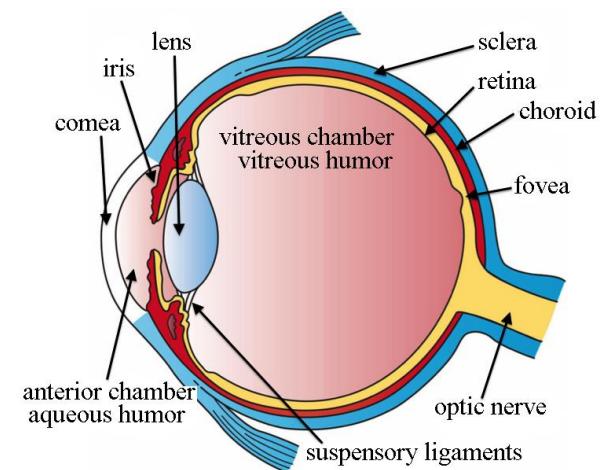
- Anti-alias filtering
- Gamma correction
- Compression
- Gain control

Shutter:

- Mechanical / electronic
- Global / rolling

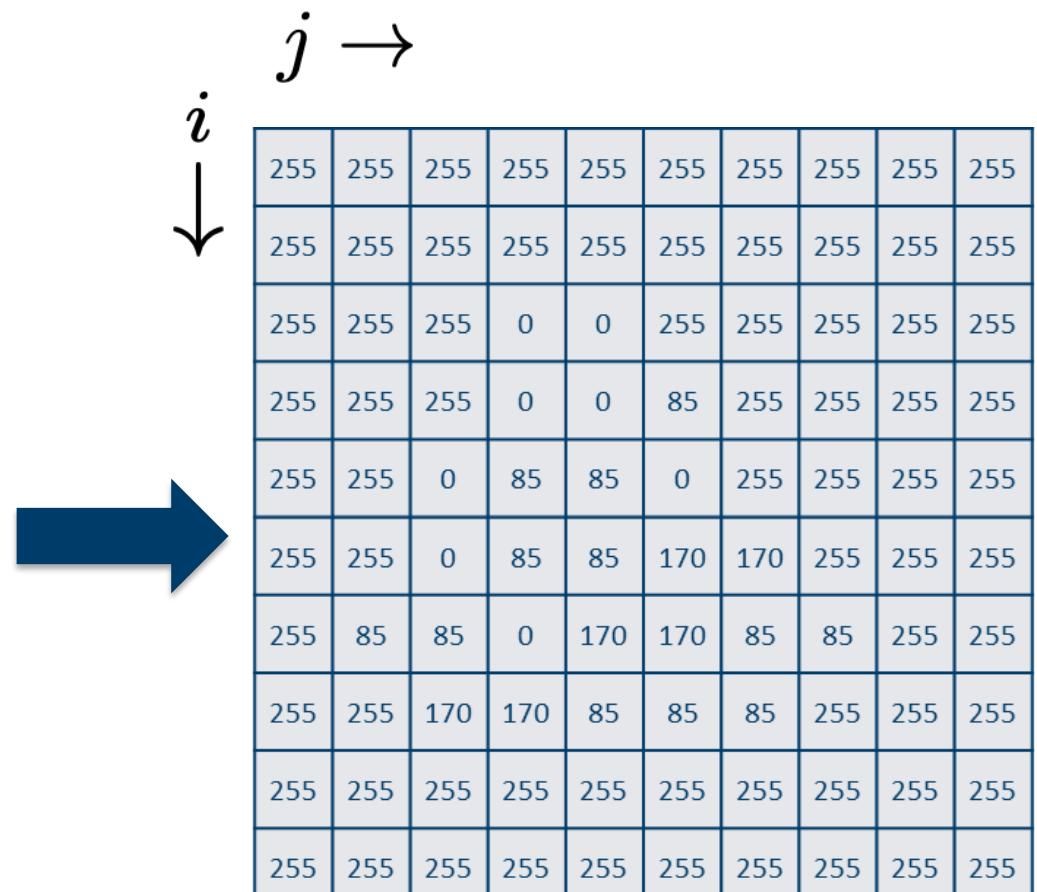


CMOS image sensor (CMOSIS 48Mp)



(Artwork by Holly Fischer)

Digital image



$image(i, j)$

Colour images



RGB colour image

Red



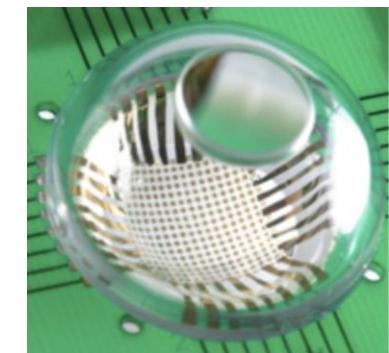
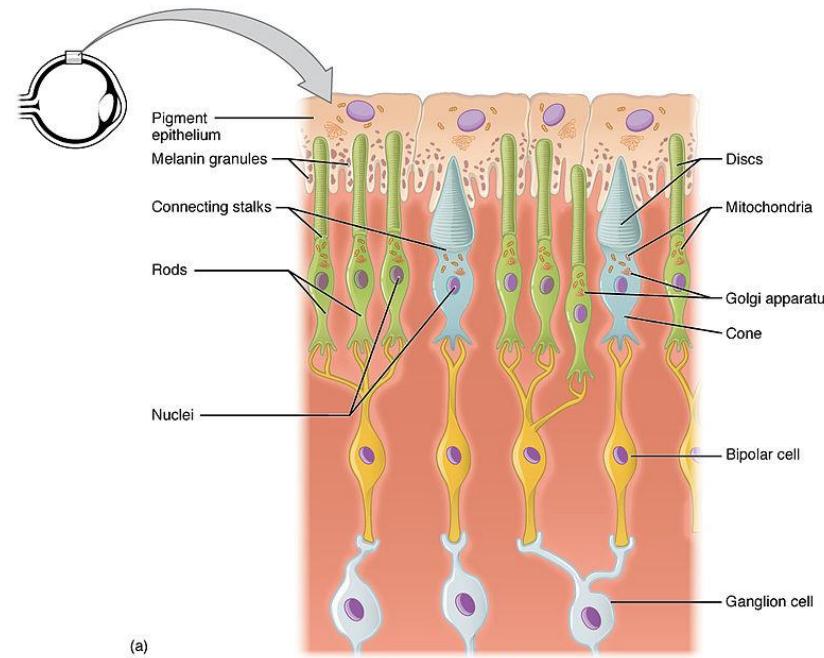
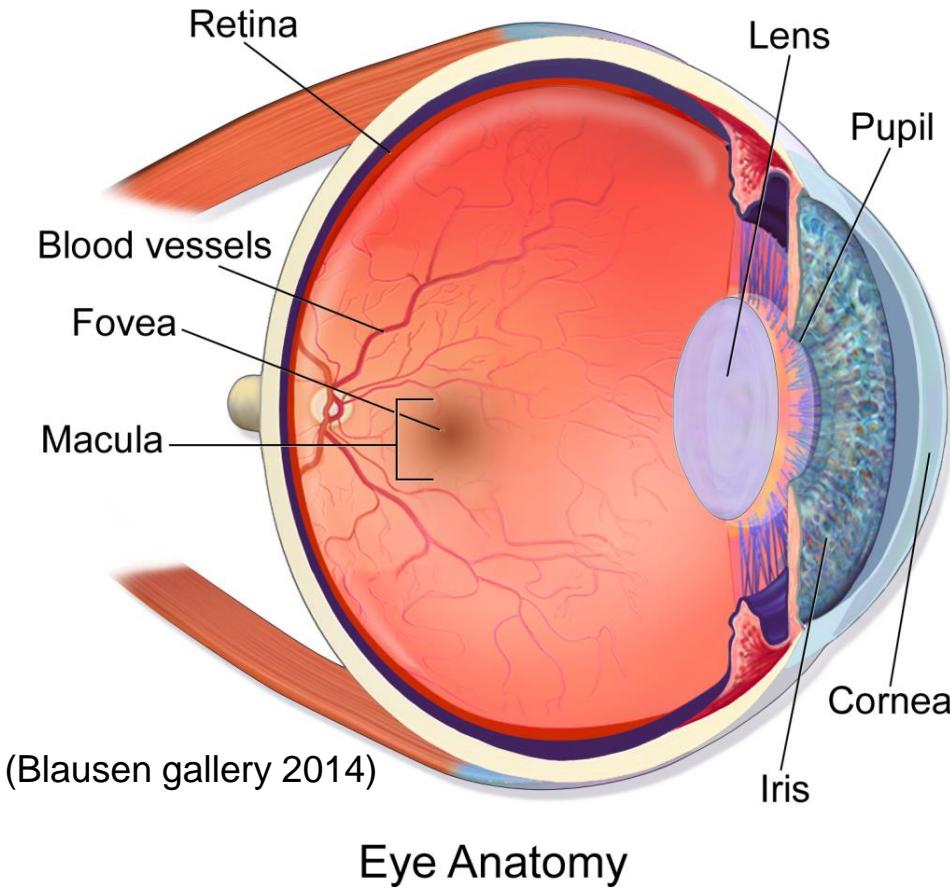
Green



Blue

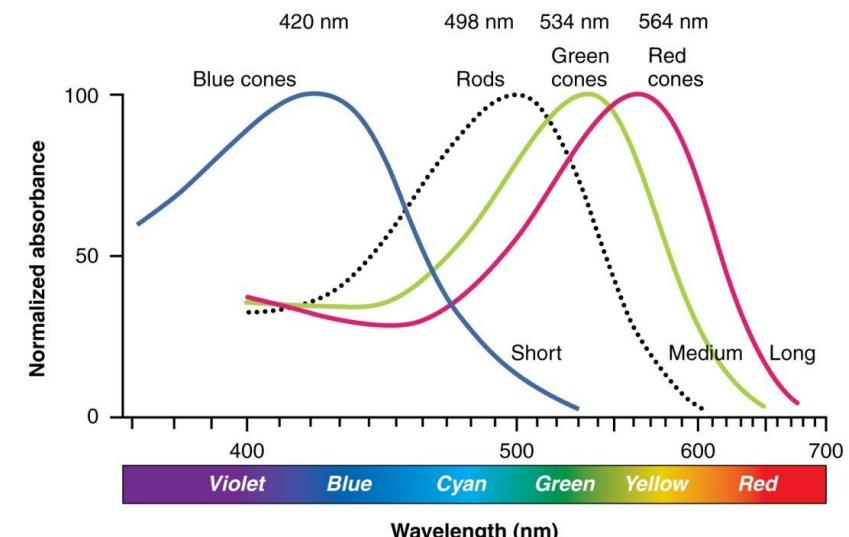


Human Vision

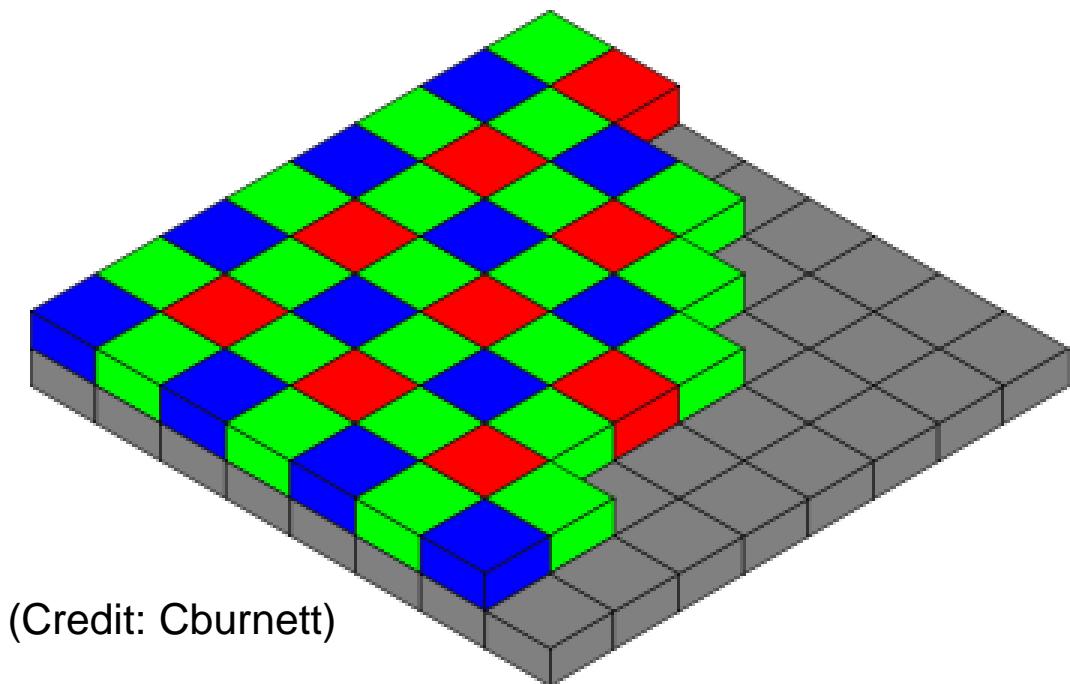


(MIT Technology Review 2008)

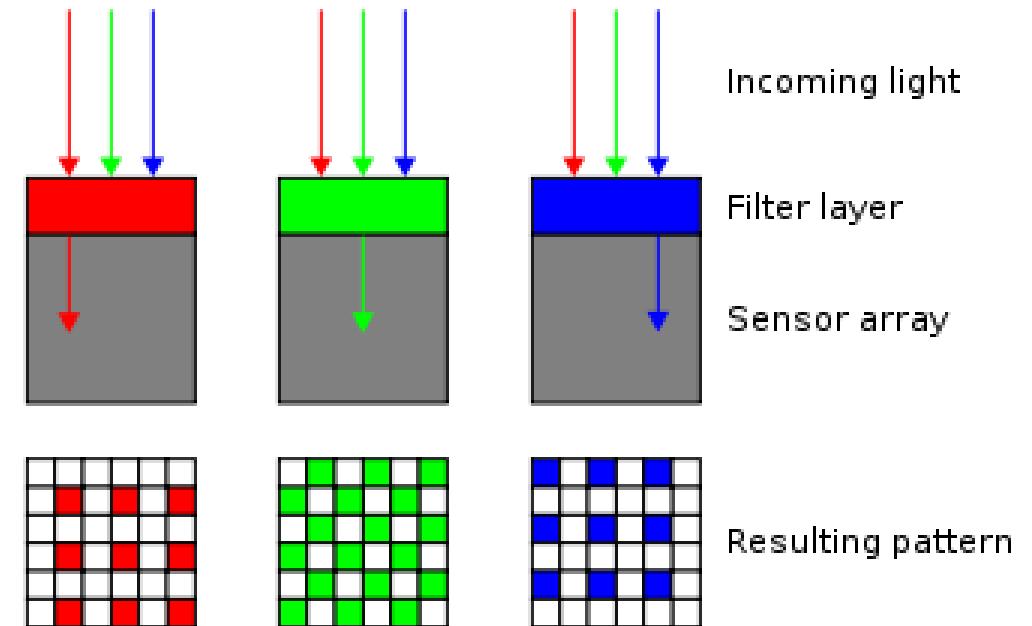
(OpenStax College - Anatomy & Physiology)



Colour Sensing in digital cameras - Bayer filter

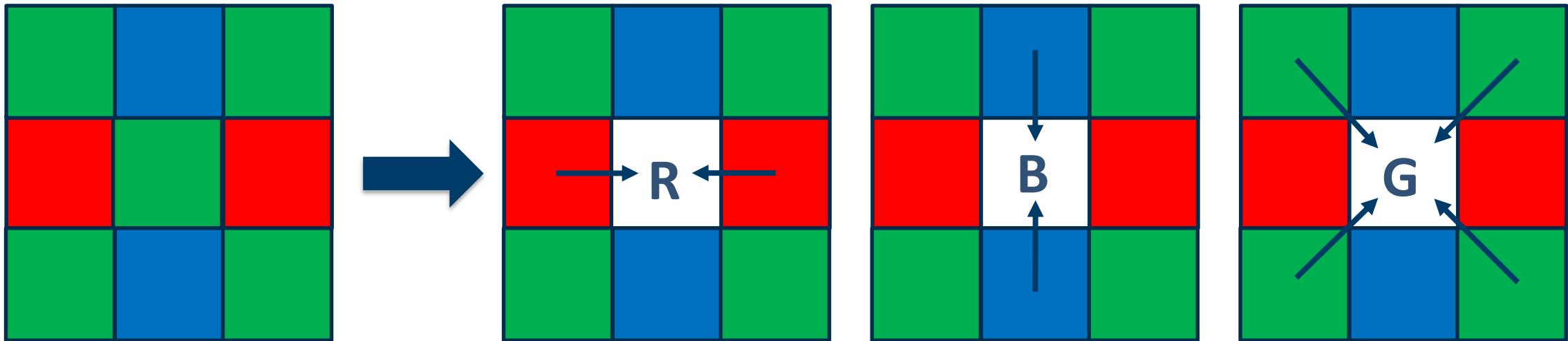


(Credit: Cburnett)



Demosaicing (debayering)

Reconstruction of full colour image from incomplete colour information from the image sensor.



Algorithms:

- Nearest-neighbor interpolation
- Bilinear interpolation
- Bicubic interpolation

Other methods:

- Splines
- Lanczos resampling
- Methods utilizing pixel values

Digital representation of colour images

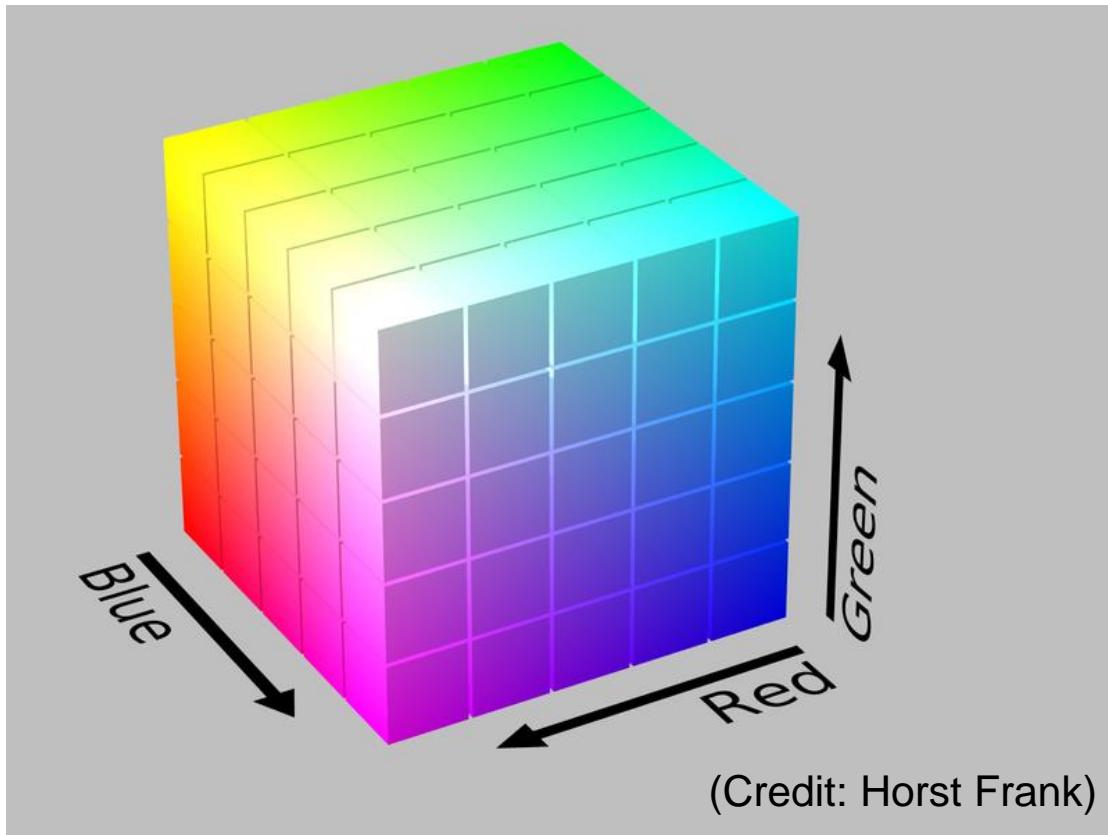
B

G

R

		31	32	33	29	32	32	34	29	28	31	27	27	27	32	30	33	32	32	29	30		
6	84	85	88	84	84	84	84	84	84	32	32	85	26	88	32	86	30	86	29	84	31	85	29
	84	86	84	86	88	86	29	86	30	85	27	88	30	84	29	86	32	88	32	85	32	33	30
	86	88	85	86	86	85	31	85	32	86	32	85	32	88	30	88	30	86	33	84	30	32	30
	85	86	85	85	84	85	35	86	36	86	35	84	34	88	33	85	33	86	29	86	29	32	30
	84	86	82	84	88	85	35	86	33	85	33	86	35	86	34	88	34	83	32	85	30	32	32
	82	85	85	88	85	84	36	86	35	88	36	85	35	86	32	86	31	85	32	92	34	31	34
	86	84	86	88	86	88	40	82	40	84	38	86	32	86	33	84	33	84	35	85	35	34	31
	85	86	84	85	85	88	39	86	36	82	38	85	34	85	35	84	38	88	38	85	33	31	34
	84	82	86	85	84	85	40	85	38	84	38	84	38	85	37	86	36	87	35	86	33	32	30
	84	85	82	84	85	84	43	86	44	85	40	81	41	82	37	85	32	86	33	86	37	34	34
	89	86	86	85	85	84	41	88	43	86	39	85	36	85	38	85	35	84	37	84	40	39	37
	89	89	88	86	86	84	41	85	41	88	40	85	35	86	38	86	42	85	42	84	38	40	37
	85	88	85	88	85	84	41	85	41	86	40	86	40	88	41	86	43	85	39	84	35	40	38
	83	88	86	81	84	90	41	88	43	84	41	84	40	85	41	85	43	85	41	88	40	36	42
	85	84	89	85	84	82	42	85	45	86	45	82	43	86	43	86	41	82	41	86	43	41	38
	88	87	85	87	84	86	43	82	42	85	45	86	46	88	41	86	43	84	44	84	45	44	43
	91	89	88	87	87	84	45	85	47	85	44	89	45	85	45	88	43	88	42	85	41	45	41
	87	91	87	91	88	89	48	88	47	85	47	87	48	85	48	82	45	85	43	88	42	43	43
	85	86	85	85	89	91	49	88	53	87	53	85	46	84	47	88	48	86	47	87	46	49	46
	89	90	88	85	85	88	88	87	85	87	88	87	87	87	87	87	87	87	87	87	89	90	88

RGB colour space



Normalized RGB values:

$$r = \frac{R}{R + G + B}$$

$$g = \frac{G}{R + G + B}$$

$$b = \frac{B}{R + G + B}$$

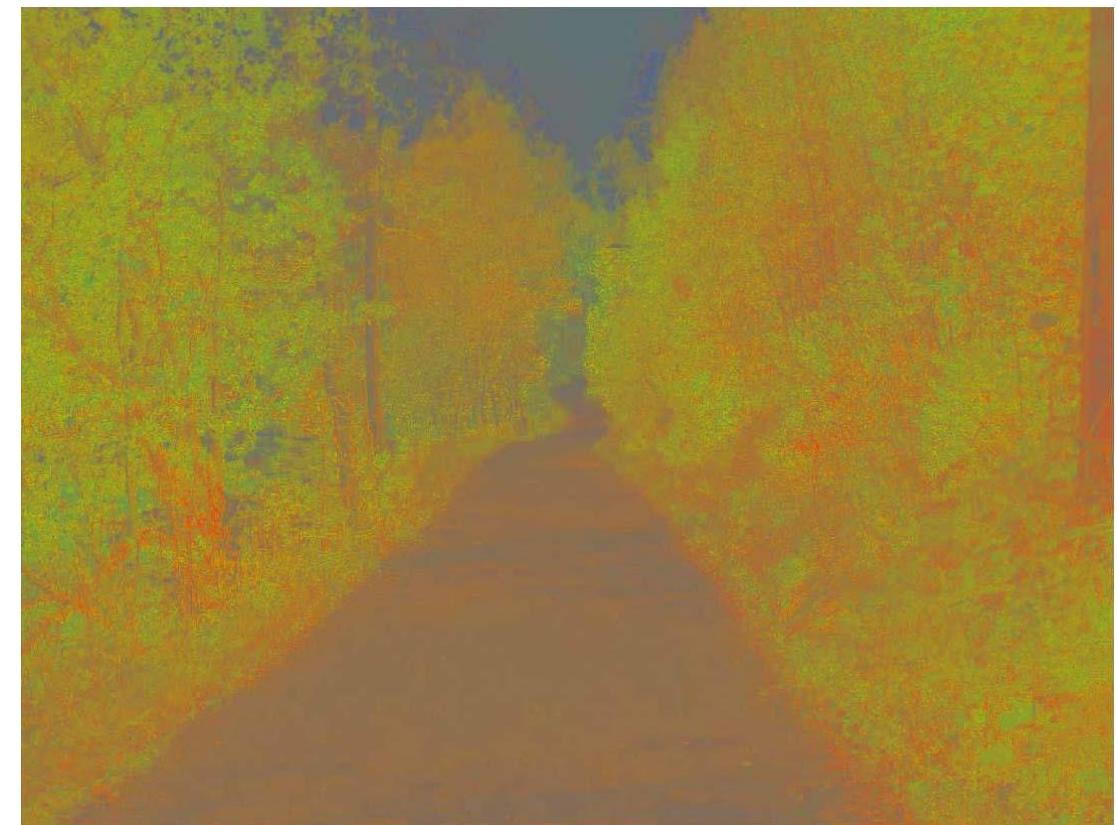
(Illumination invariance)

Other colour coordinate systems: XYZ, LAB, HSV, ...

RGB normalization (example)

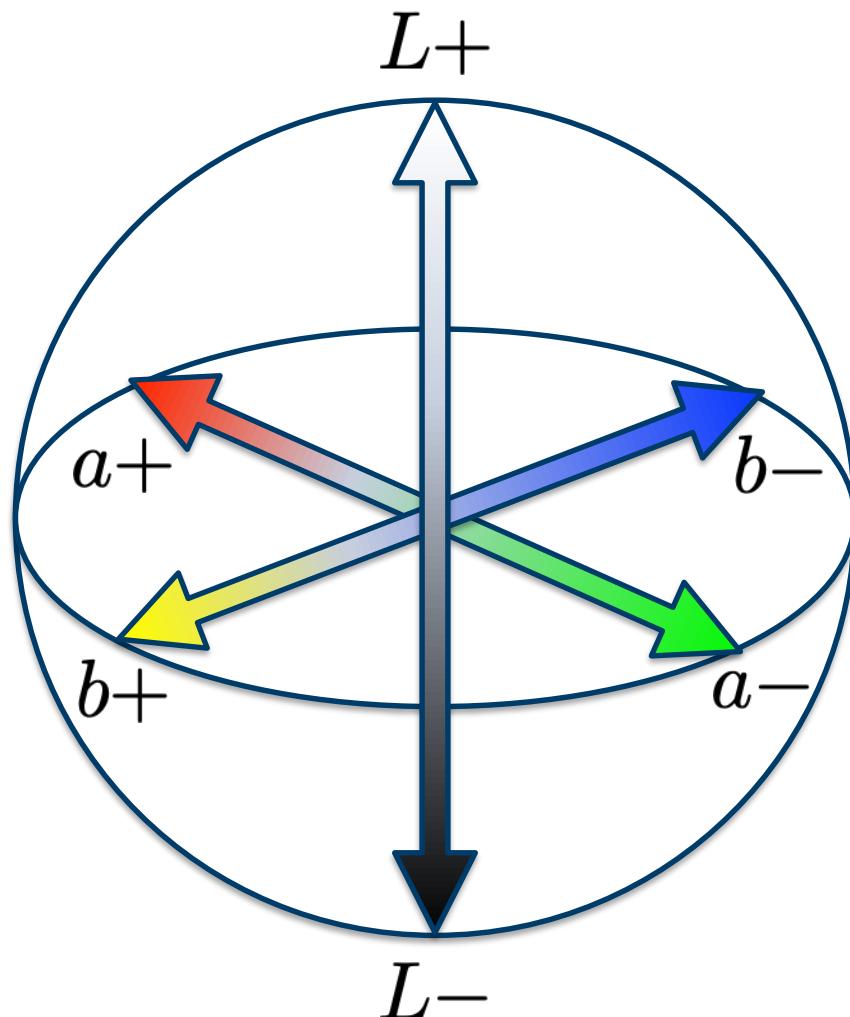


RGB original



Normalized RGB

Lab colour space (CIE 1976 L* a* b*)



“Perceptually uniform” colour space:

- Approximation to human vision
- L^* = Lightness
- a^* , b^* = Colour opponent dimensions
- L^* = darkest black to brightest white (0 - 100)
- a^* = green to red (-100 to +100)
- b^* = blue to yellow (-100 to +100)

Lab - example



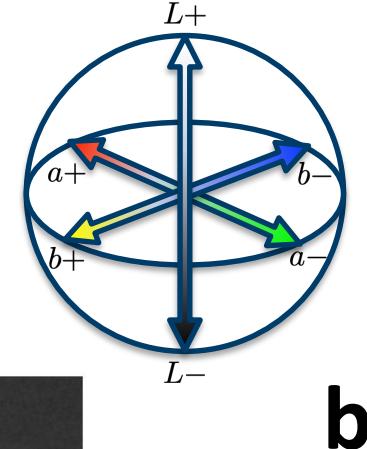
L



a



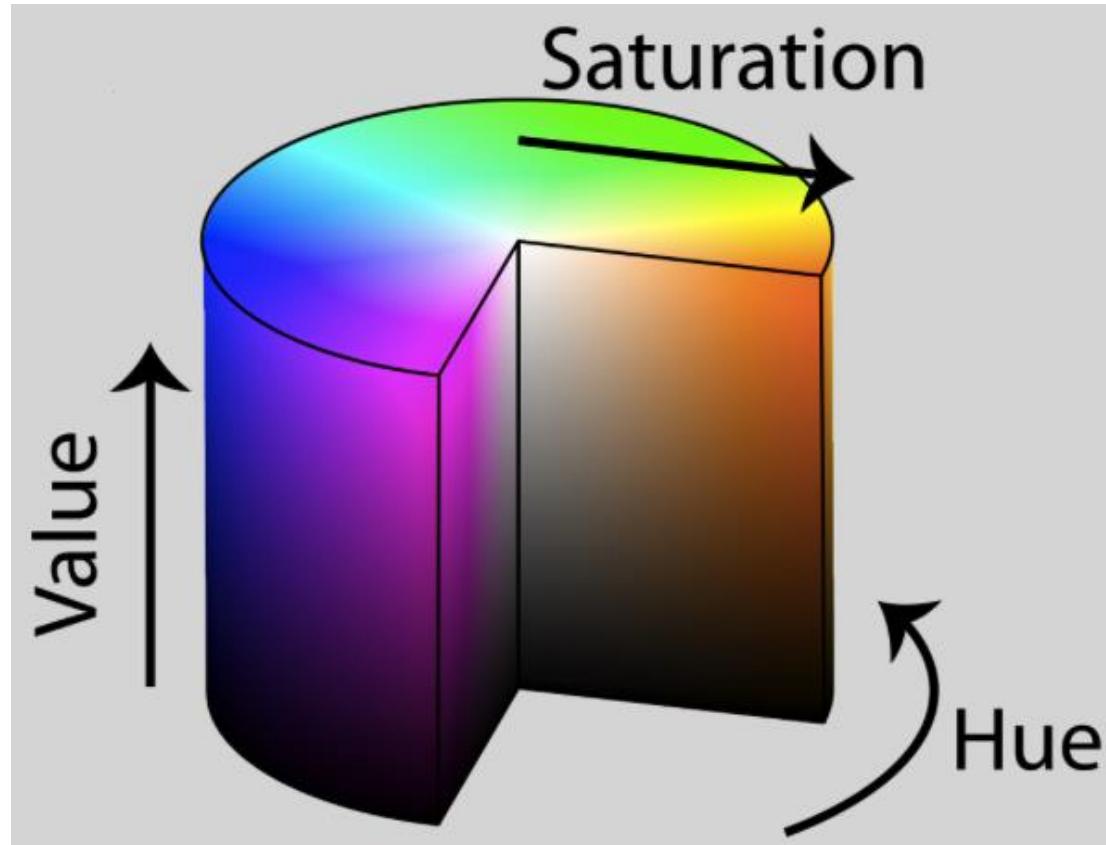
a



b



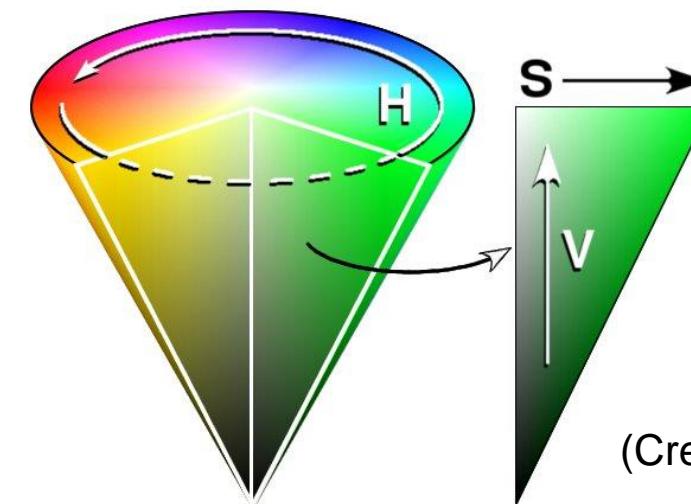
HSV colour space (Hue, Saturation, Value)



(Credit: Jacob Rus, 2010)

Intuitive colour space:

- Cylindrical representation of RGB values
- Hue = angle from 0° to 360°
- Saturation = 0 - 100% (gray to primary colour)
- Value = 0 - 100% (totally black to bright colours)

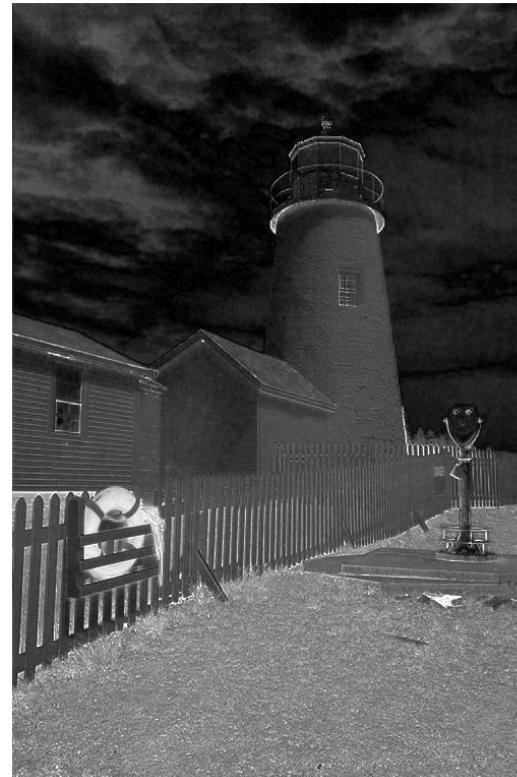


(Credit: Wapcaplet)

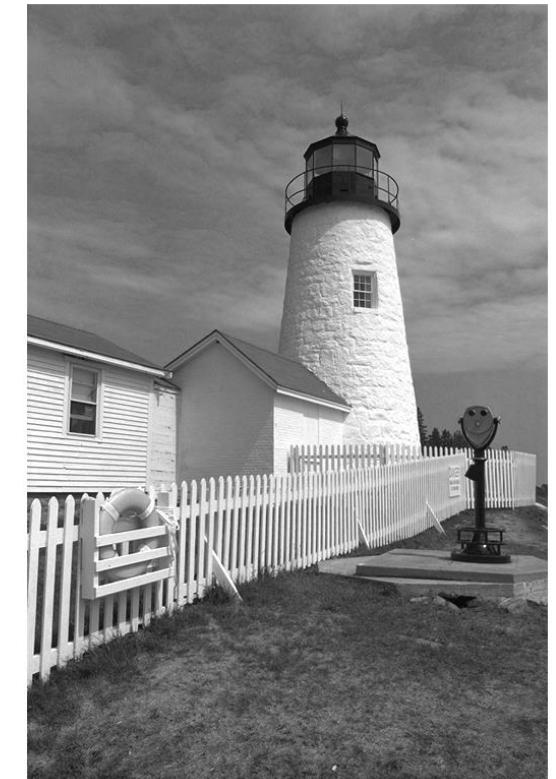
HSV - example



Hue



Saturation

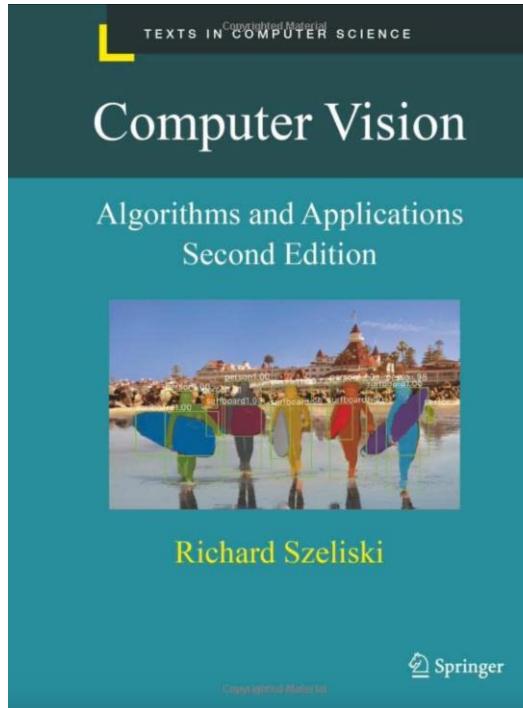


Value

Summary

Image formation:

- Illumination
- Cameras
- Optics
- Image Capture
- Colour Sensing



Recommended reading:

- Szeliski 2.2 and 2.3

Free download: <https://szeliski.org/Book>



Direct (specular) and indirect illumination