Image Acquisition

- Energy
  - Illumination
- The Optical System
  - The Lens
- The Image Sensor
- The Digital Image

Energy

✓**To capture an image a camera requires some sort of measurable energy.**

✓**Light or *electromagnetic* waves (*Photon*). It is massless entity.**

✓**Electromagnetic wave:** electric and magnetic fields vary sinusoidally

1. **A photon can be described by its energy E, which is measured in [eV]**
2. **A photon can be described by its frequency f , which is measured in Hertz [Hz]. A frequency is the number of cycles or wave-tops in one second.**
3. **A photon can be described by its wavelength λ, which is measured in meters [m]. A wavelength is the distance between two wave-tops.**

$$\lambda = \frac{c}{f}, \qquad E = h \cdot f \quad \Rightarrow \quad E = \frac{h \cdot c}{\lambda}$$

c= 2.998 x 10^8 m/s

h=6.626176 x 10^{-34} joule-seconds (Planck'^s Constant)

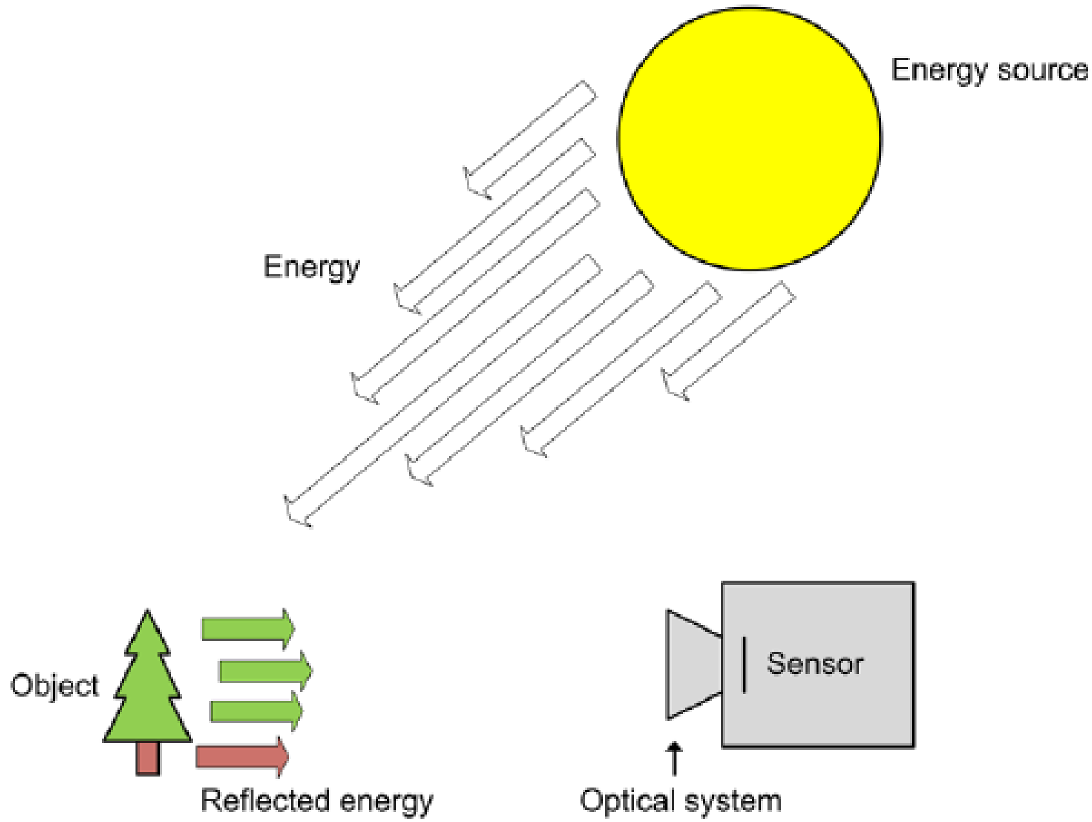


Fig. Overview of the typical image acquisition process.

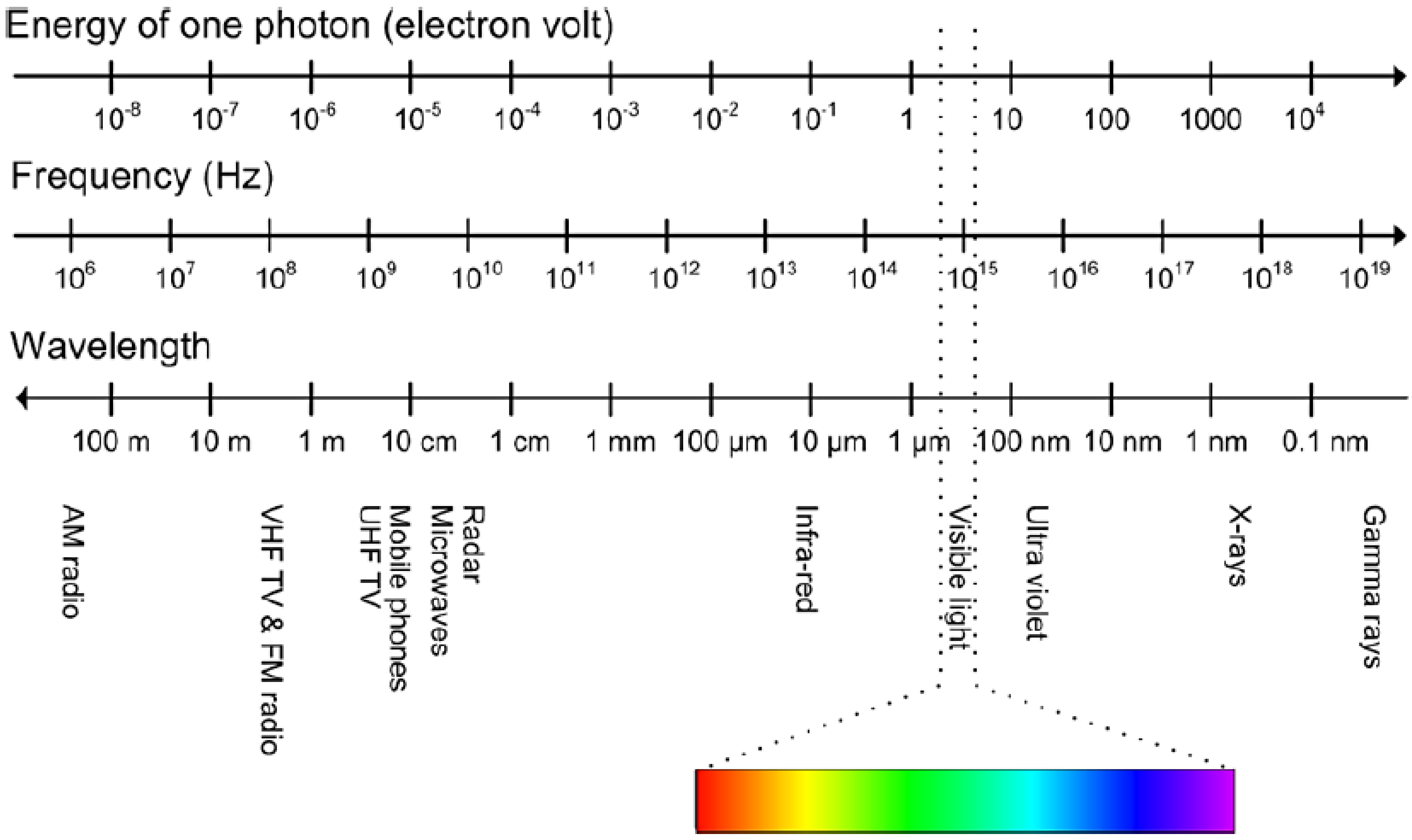


Fig. The electromagnetic spectrum

- ✓ **Energy is proportional to Frequency.**
- ✓ **Gamma Rays are more dangerous because of their energy.**
- ✓ **Radio waves energy is very less.**
- ✓ **Visible light range: 400 nm to 700 nm**

Illumination

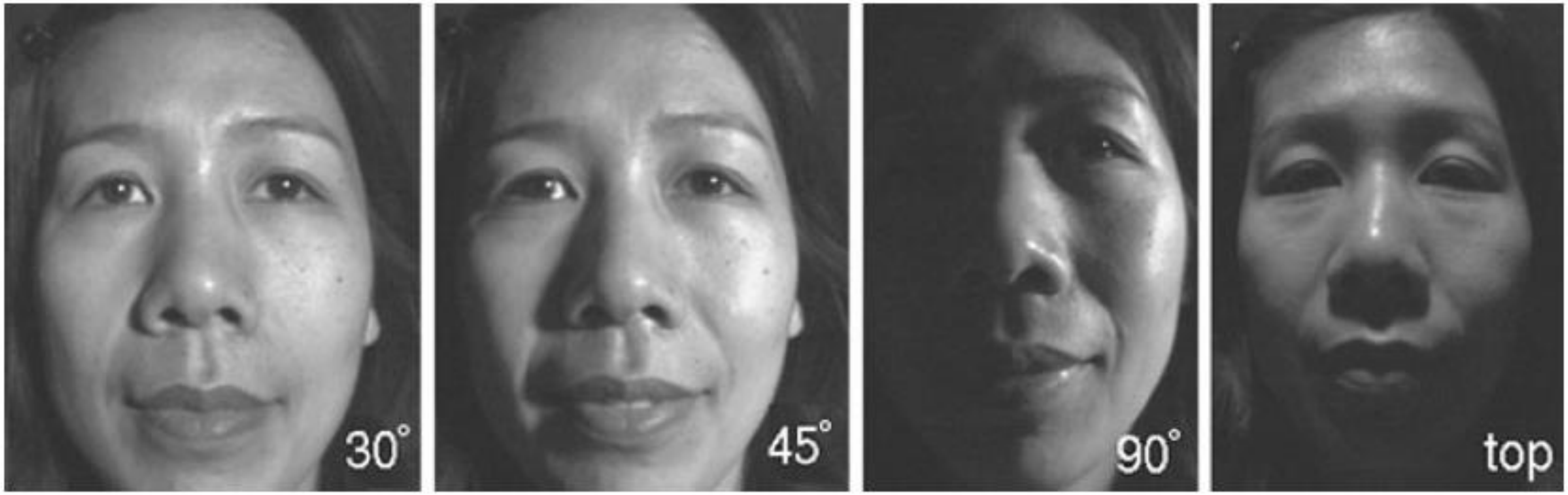
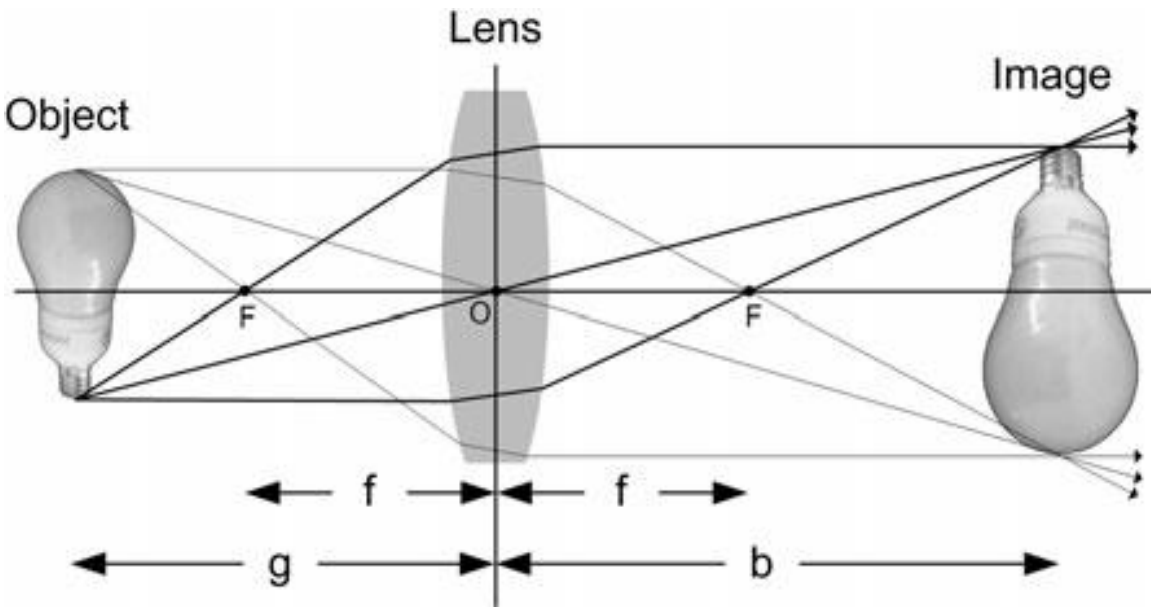


Fig. The effect of illuminating a face from four different directions

The Optical System

The Lens



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

- f and b are typically in the range [1 mm, 100 mm].
- If g is in meters, b=f.

The Optical System

The Lens

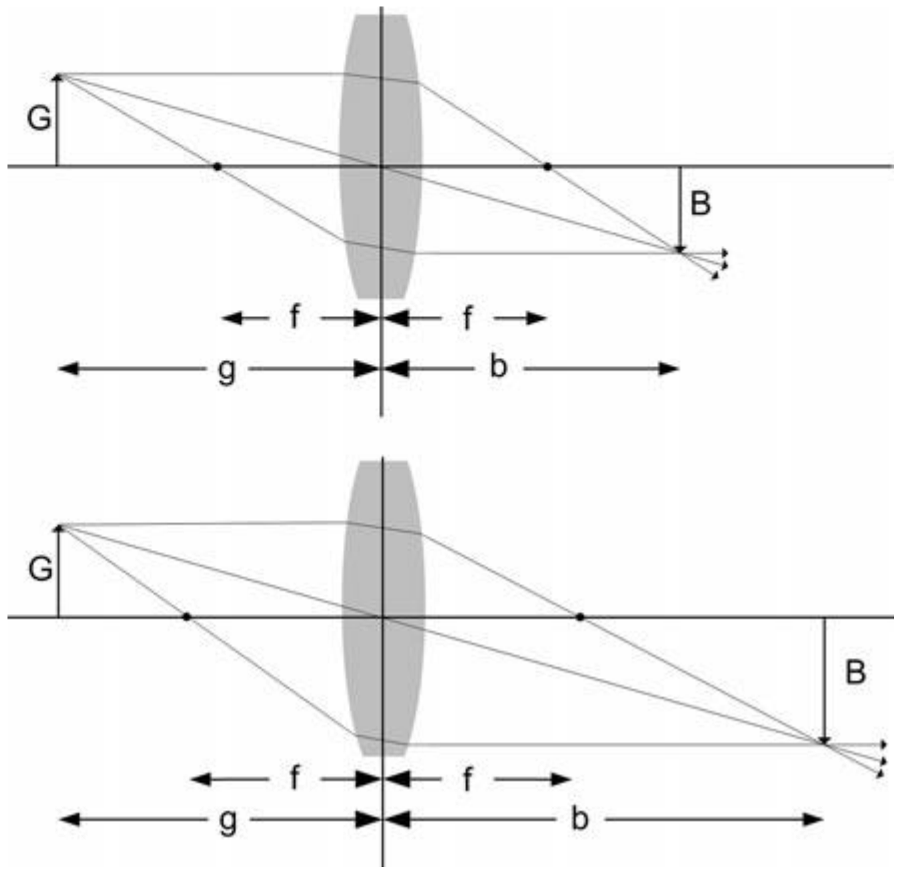


Fig. Different focal lengths results in optical zoom

- **Interesting aspect of the lens is that the size of the object in the image, *B*, increases as *f* increased. This is known as optical zoom.**

- **In practice *f* is changed by rearranging the optics, e.g., the distance between one or more lenses inside the optical system.**

- **Let us assume that we do not have a zoom-lens, i.e., *f is constant.***

- ***When we* change the distance from the object to the camera (lens), *g, then b* should also be changed, meaning that the sensor has to be moved slightly from the lens since the image will be formed there.**

- ***Such an image is said to be out of focus. So when you adjust* focus on your camera you are in fact changing *b until the sensor is located at the* position where the image is formed.**

Fig. A focused image (*left) and an unfocused image* (*right). The difference* between the two images is different values of *b.*

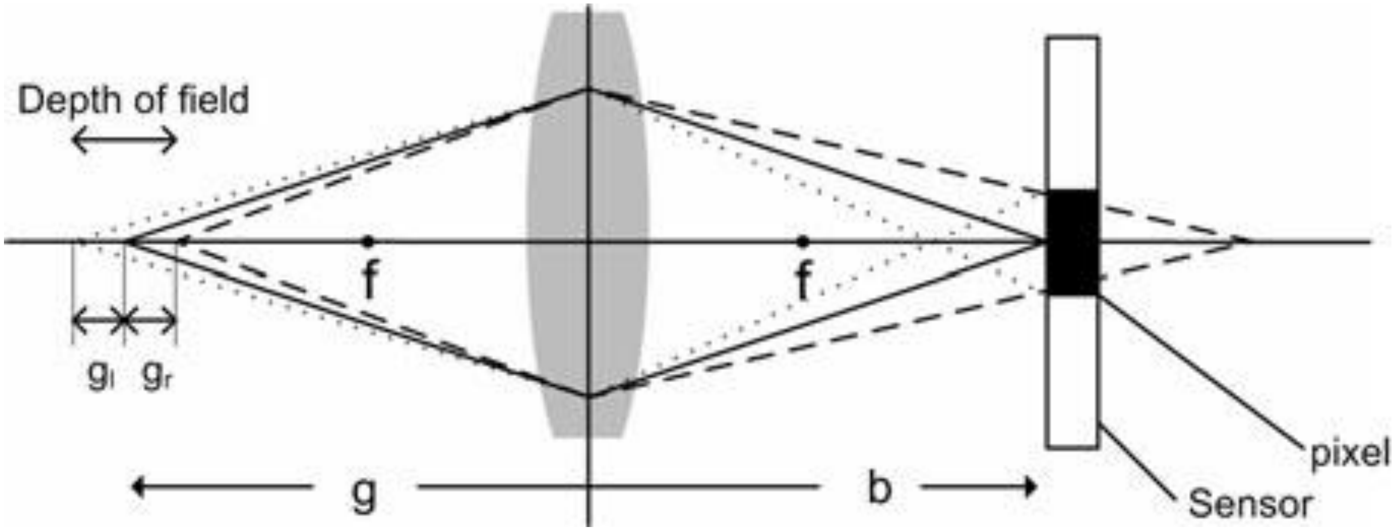


Fig. Depth-of-field

Fig.: Three different camera settings resulting in three different depth-of-fields

The Image Sensor

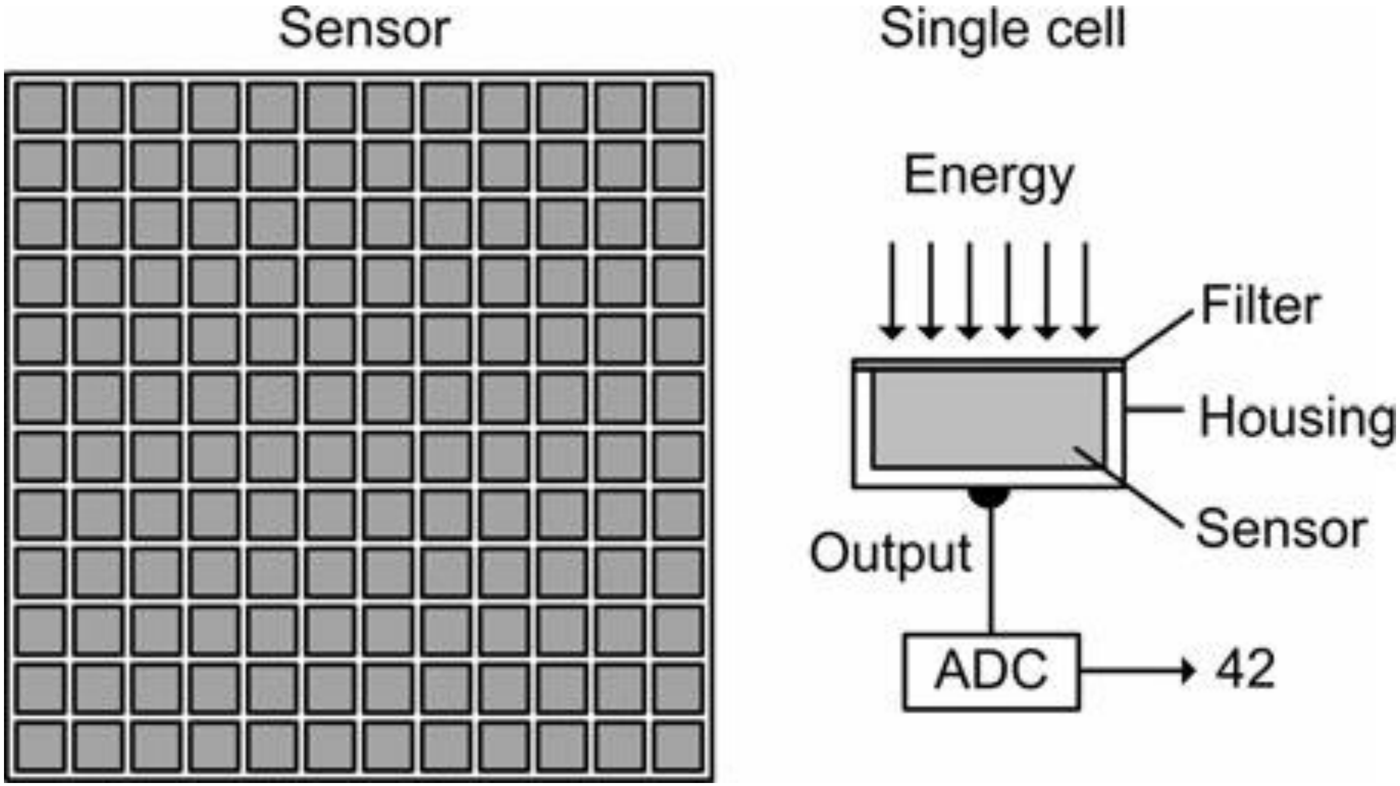


Fig. The Image Sensor

- **The sensor consists of an array of interconnected cells.**
- **Each cell consists of a housing which holds a filter, a sensor and an output.**
- **The filter controls which type of energy is allowed to enter the sensor.**
- **The sensor measures the amount of energy as a voltage, which is converted into a digital number through an analog-to-digital converter (ADC)**

- **Another parameter influencing the depth-of-field is the *aperture.***
- ***The aperture* corresponds to the human iris, which controls the amount of light entering the human eye.**
- **Similarly, the aperture is a flat circular object with a hole in the center with adjustable radius.**
- **The aperture is located in front of the lens and used to control the amount of incoming light.**
- **In the extreme case, the aperture only allows rays through the optical center, resulting in an infinite depth-of-field.**

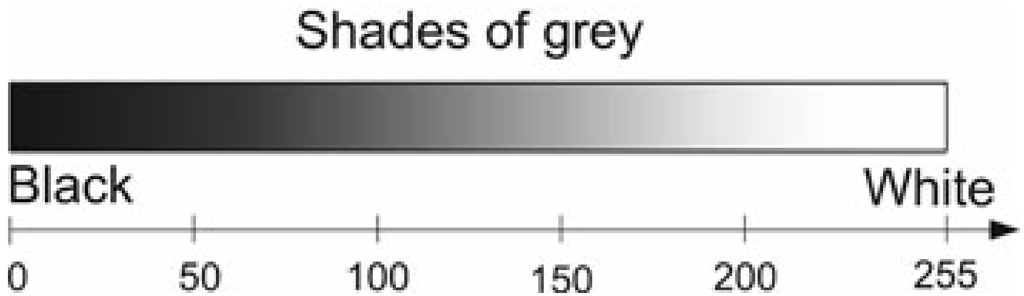
- ✓ **The more incident light the higher the voltage and the higher the digital number.**
- ✓ **Before a camera can capture an image, all cells are emptied, meaning that no charge is present.**
- ✓ **When the camera is to capture an image, light is allowed to enter and charges start accumulating in each cell.**
- ✓ **After a certain amount of time, known as the *exposure time, and controlled by the shutter, the incident light is shut out again.***

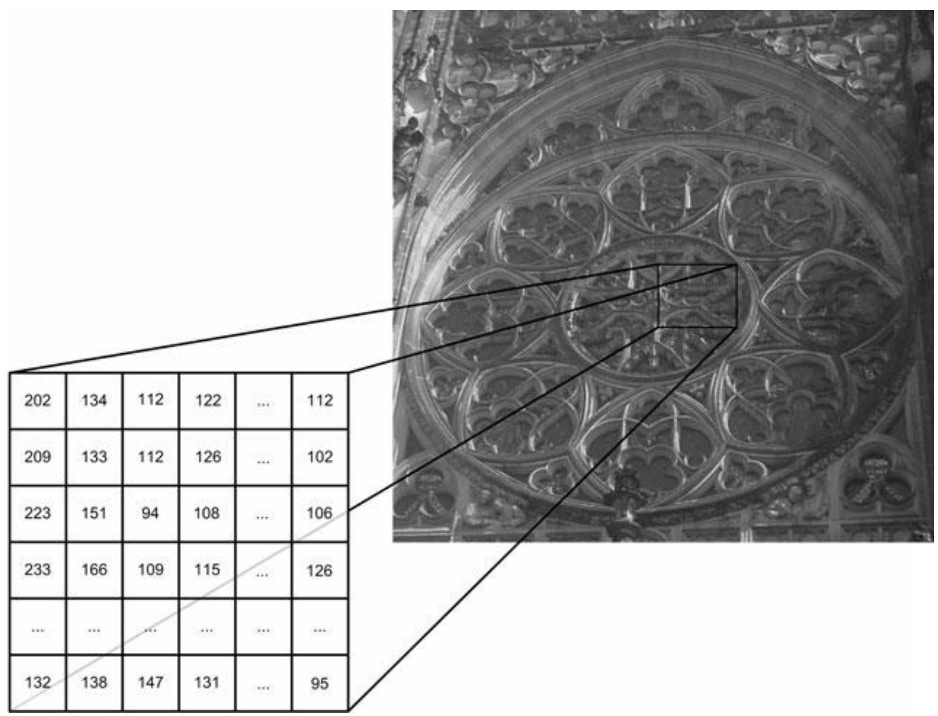
Fig: The input image taken with different amount of exposure.

Image Capture

- Distance to Object
- Motion of Object
- Zoom
- Focus
- Depth-of-field
- Focal Length
- Shutter
- Aperture
- Sensor

The Digital Image





202	134	112	122	...	112
209	133	112	126	...	102
223	151	94	108	...	106
233	166	109	115	...	126
...	...	...	...	...	...
132	138	147	131	...	95

Color Images

Photoreceptor cell	Wavelength in nanometers (nm)	Peak response in nanometer (nm)	Interpretation by the human brain
Cones (type L)	[400–680]	564	Red
Cones (type M)	[400–650]	534	Green
Cones (type S)	[370–530]	420	Blue
Rods	[400–600]	498	Shade of gray

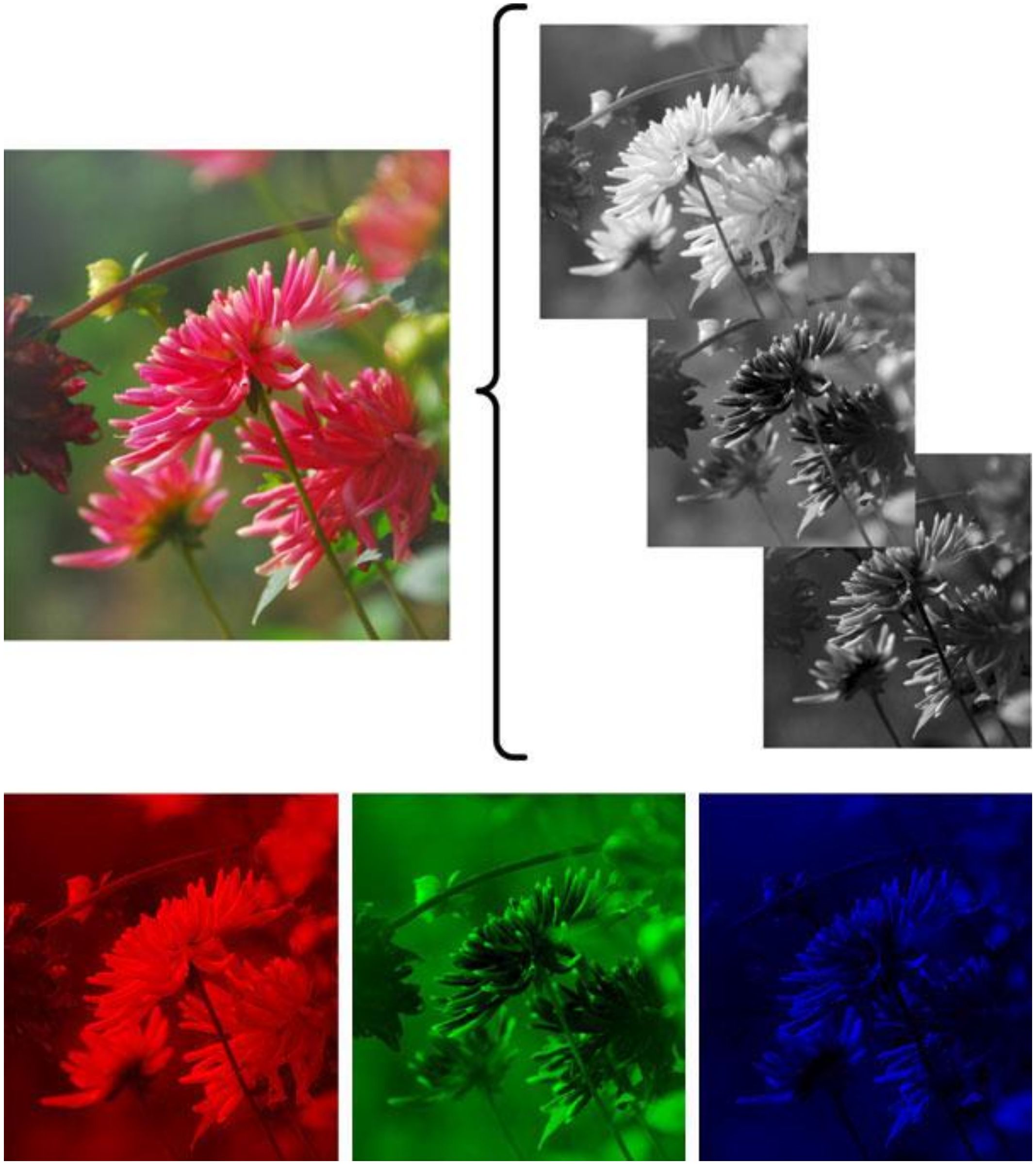
Color

- When the resulting color is created by illuminating an object by white light and then absorbing some of the wavelengths (colors) we use the notion of subtractive colors.
- Exactly as when you mix paint to create a color. Say you start with a white piece of paper, where no light is absorbed. The resulting color will be white.
- If you then want the paper to become green you add green paint, which absorbs everything but the green wavelengths.
- If you add yet another color of paint, then more wavelengths will be absorbed, and hence the resulting light will have a new color.
- Keep doing this and you will in theory end up with a mixture where all wavelengths are absorbed, that is, black.
- In practice, however, it will probably not be black, but rather dark gray/brown.

Color Image

- This notion applies when you create the wavelengths as opposed to manipulating white light.
- A good example is a color monitor like a computer screen or a TV screen. Here each pixel is a combination of emitted red, green and blue light.
- Meaning that a black pixel is generated by not emitting anything at all.
- White (or rather a shade of gray) is generated by emitting the same amount of red, green, and blue.
- Red will be created by only emitting red light etc.
- All other colors are created by a combination of red, green and blue.
- For example yellow is created by emitting the same amount of red and green, and no blue.

Fig.: A color image



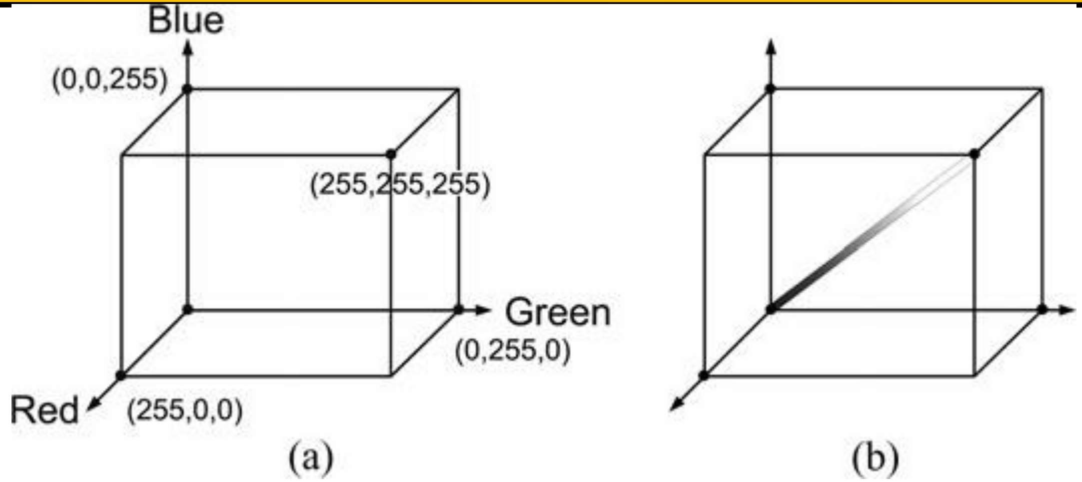


Fig. : (a) The RGB color cube. (b) The gray-vector in the RGB color cube

Corner	Color
(0, 0, 0)	Black
(255, 0, 0)	Red
(0, 255, 0)	Green
(0, 0, 255)	Blue
(255, 255, 0)	Yellow
(255, 0, 255)	Magenta
(0, 255, 255)	Cyan
(255, 255, 255)	White

RGB to GRAY

$$I = W_R \cdot \mathrm{R} + W_G \cdot \mathrm{G} + W_B \cdot \mathrm{B}$$

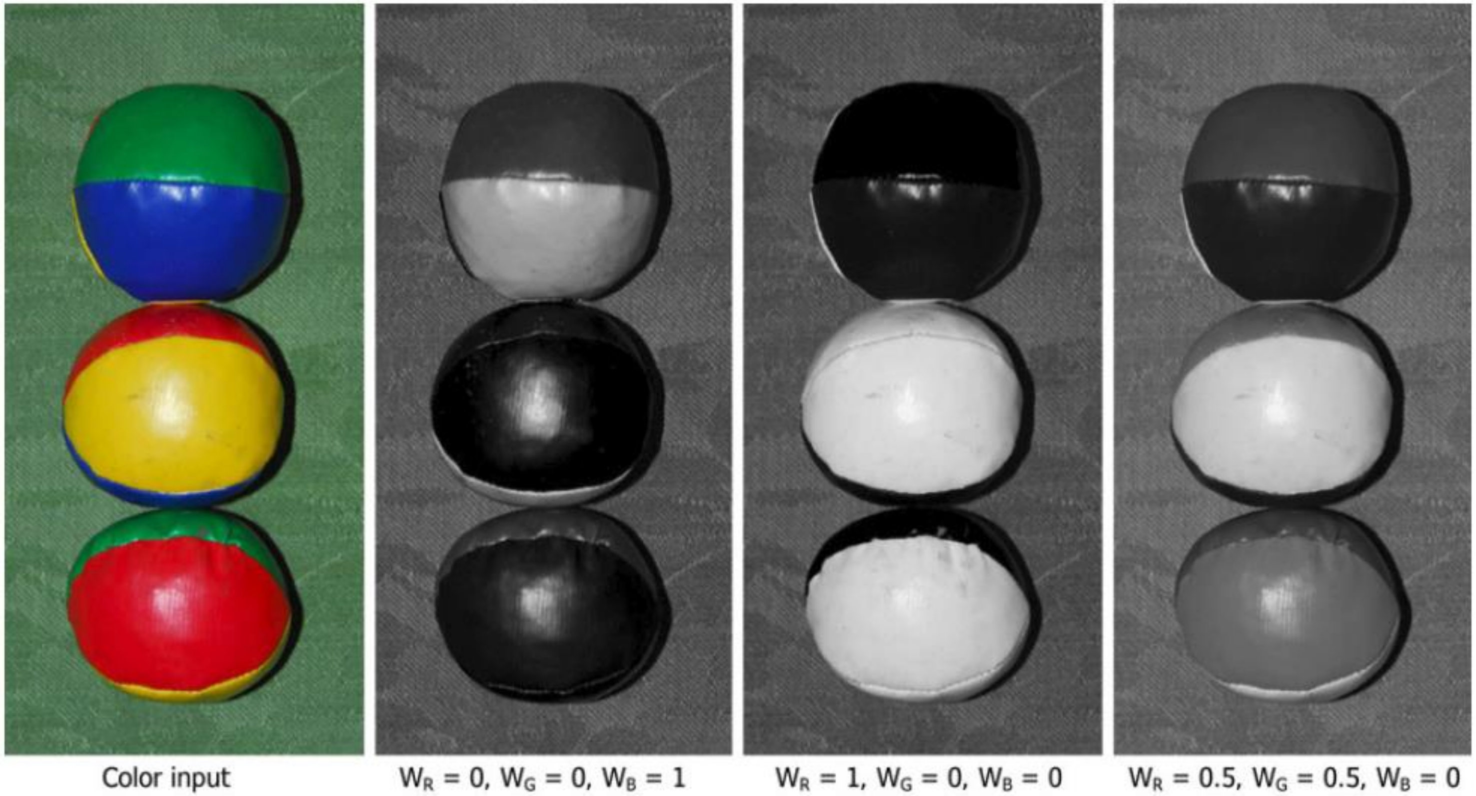


Fig.: A color image and how it can be mapped to different gray-scale images depending on the weights

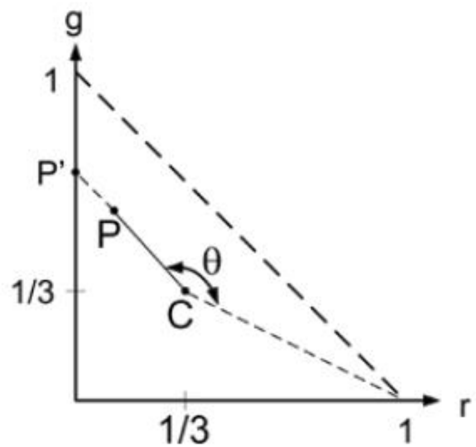
Normalized RGB

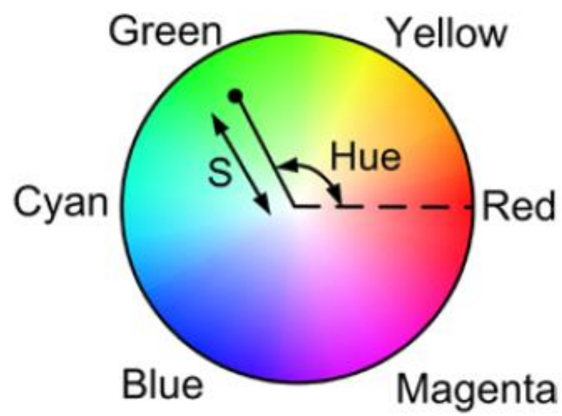
$$(r, g, b) = \left(\frac{R}{R+G+B}, \frac{G}{R+G+B}, \frac{B}{R+G+B} \right)$$

$$(R, G, B) \quad \Leftrightarrow \quad (r, g, I)$$

Hue and Saturation

- The **hue** is the dominant wavelength in the perceived light and represents the pure color, i.e., the colors located on the edges of the triangle in Fig.
- The **saturation** is the purity of the color and represents the amount of white light mixed with the pure color.





$$\text{Saturation} = \frac{\|\overrightarrow{CP}\|}{\|\overrightarrow{CP'}\|}, \qquad \text{Hue} = \theta$$

The HSI Color Representation

$$H = \begin{cases} \cos^{-1}\left(1/2 \cdot \frac{(R-G)+(R-B)}{\sqrt{(R-G)(R-G)+(R-B)(G-B)}}\right), & \text{if } G \geq B; \\ 360^\circ - \cos^{-1}\left(1/2 \cdot \frac{(R-G)+(R-B)}{\sqrt{(R-G)(R-G)+(R-B)(G-B)}}\right), & \text{Otherwise} \end{cases}$$

$$H \in [0, 360[$$

$$S = 1 - 3 \cdot \frac{\min\{R, G, B\}}{R + G + B} \quad S \in [0, 1]$$

$$I = \frac{R + G + B}{3} \quad I \in [0, 255]$$

The HSV Color Representation

$$H = \begin{cases} \frac{G-B}{V-\min\{R,G,B\}} \cdot 60^\circ, & \text{if } V = R \text{ and } G \geq B; \\ \left(\frac{B-R}{V-\min\{R,G,B\}} + 2\right) \cdot 60^\circ, & \text{if } G = V; \\ \left(\frac{R-G}{V-\min\{R,G,B\}} + 4\right) \cdot 60^\circ, & \text{if } B = V; \\ \left(\frac{R-B}{V-\min\{R,G,B\}} + 5\right) \cdot 60^\circ, & \text{if } V = R \text{ and } G < B \end{cases} \qquad H \in [0^\circ, 360^\circ$$

$$S = \frac{V - \min\{R, G, B\}}{V} \qquad S \in [0, 1]$$

$$V = \max\{R, G, B\} \qquad V \in [0, 255]$$