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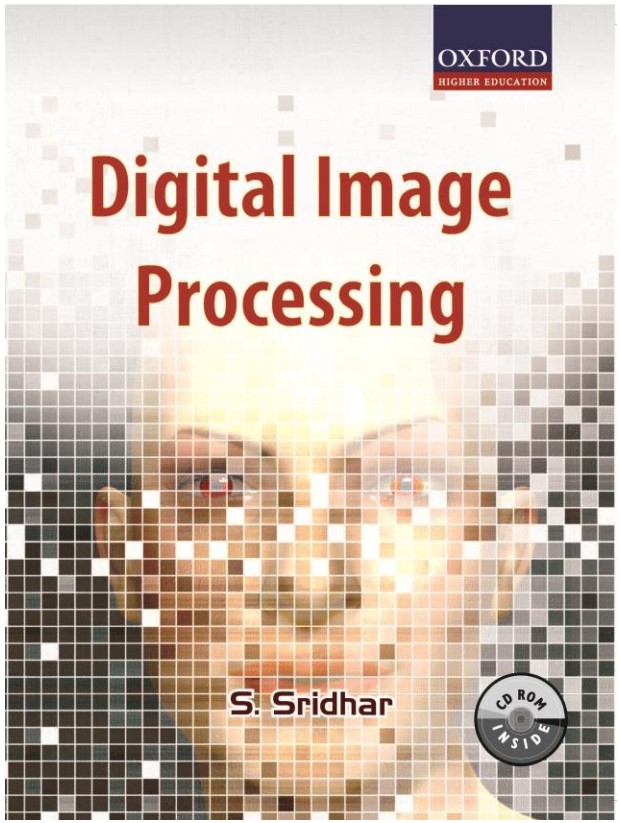


# Digital Image Processing

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# Chapter 2
# Digital Imaging System

- A digital imaging system is a set of devices for acquiring, storing, manipulating, and transmitting digital images.

# Nature of Light

- Human beings perceive objects because of light. Light sources are of two types— primary and secondary. The sun and lamps are examples of primary light sources. While primary sources generate light, secondary light sources simply reflect or diffuse light from primary sources. The moon and clouds are examples of secondary sources of light.

# Nature of Light

- ***Wavelength -*** Wavelength is the distance between two successive wave crests or wave troughs in the direction of travel.

- ***Amplitude -*** Amplitude is the maximum distance the oscillation travels, away from its horizontal axis.

- ***Frequency -*** The frequency of vibration is the number of waves crossing at a point

# *Simple image model*

- $I(x, y, l) = \sigma(x, y, l) \times L(l)$

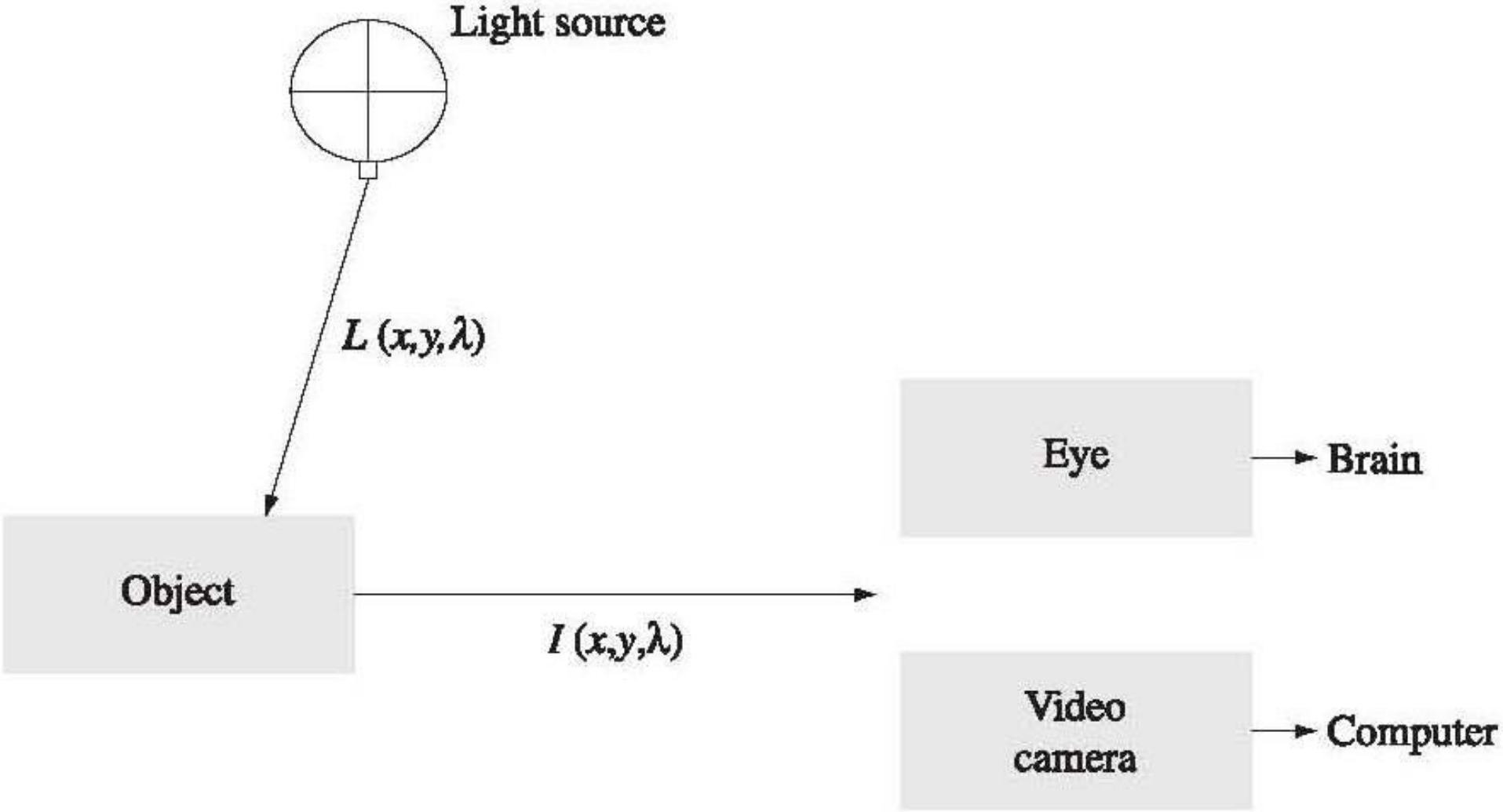



**Fig. 2.2** Similarity between the human eye and the camera

The different types of lighting are shown in Fig. 2.3.

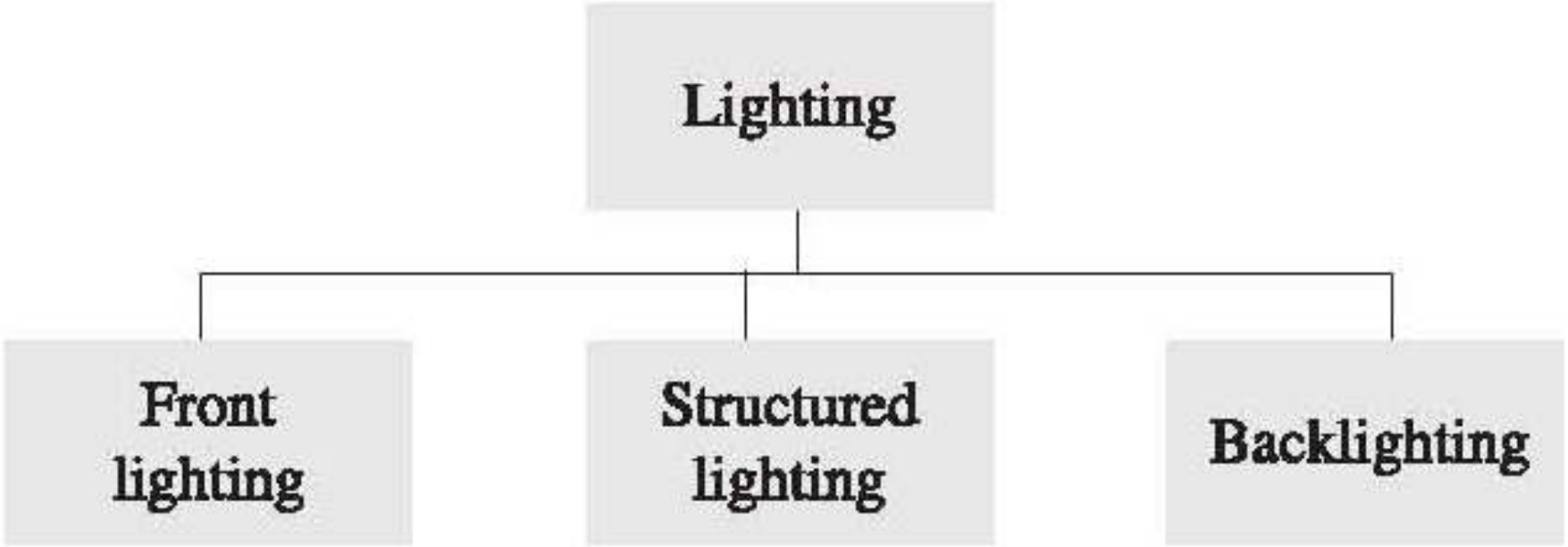



**Fig. 2.3** Types of lighting

# Simple Image Formation Process

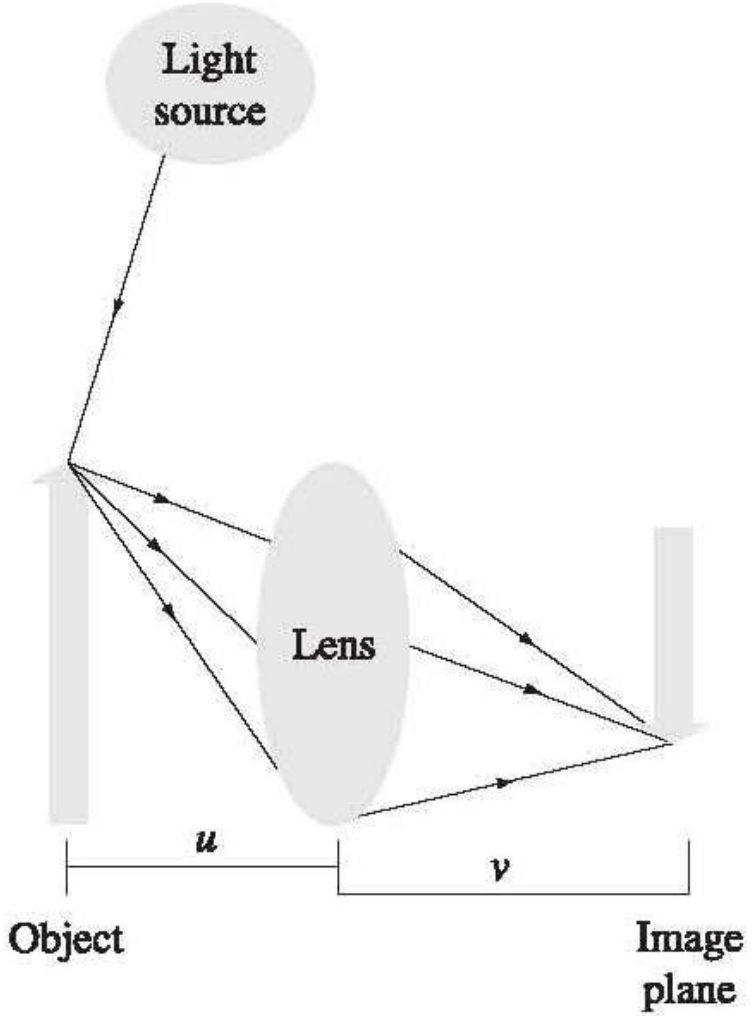



**Fig. 2.5** Image formation process

The basic lens equation is stated as

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

The *magnification factor* ($M$) can be defined as the ratio of the size of the image to the size of the object. Then the focal length is expressed in terms of $M$ as

Fig. 2.5

$$f=\frac{uM}{M+1}$$

## Important optical jargons

1. Optical transfer function: This is a measure the optical resolution of the lens.
2. Geometric distortions: These are caused by inaccuracies in the shape of the lens.
3. Depth of field/Depth of view: This is the difference between the acceptable nearest and furthest points in a scene.
4. Aperture: This is the size of the light opening.
5. Shutter speed: This is the time for which light is allowed to pass through the light opening.
6. F-measure: This is the amount of light allowed to pass through the light opening. F-measure = focal length/diameter of the aperture. Typical values of F-measure are 1.4, 2, 2.8, and 4.2.

# BIOLOGICAL ASPECTS OF IMAGE ACQUISITION

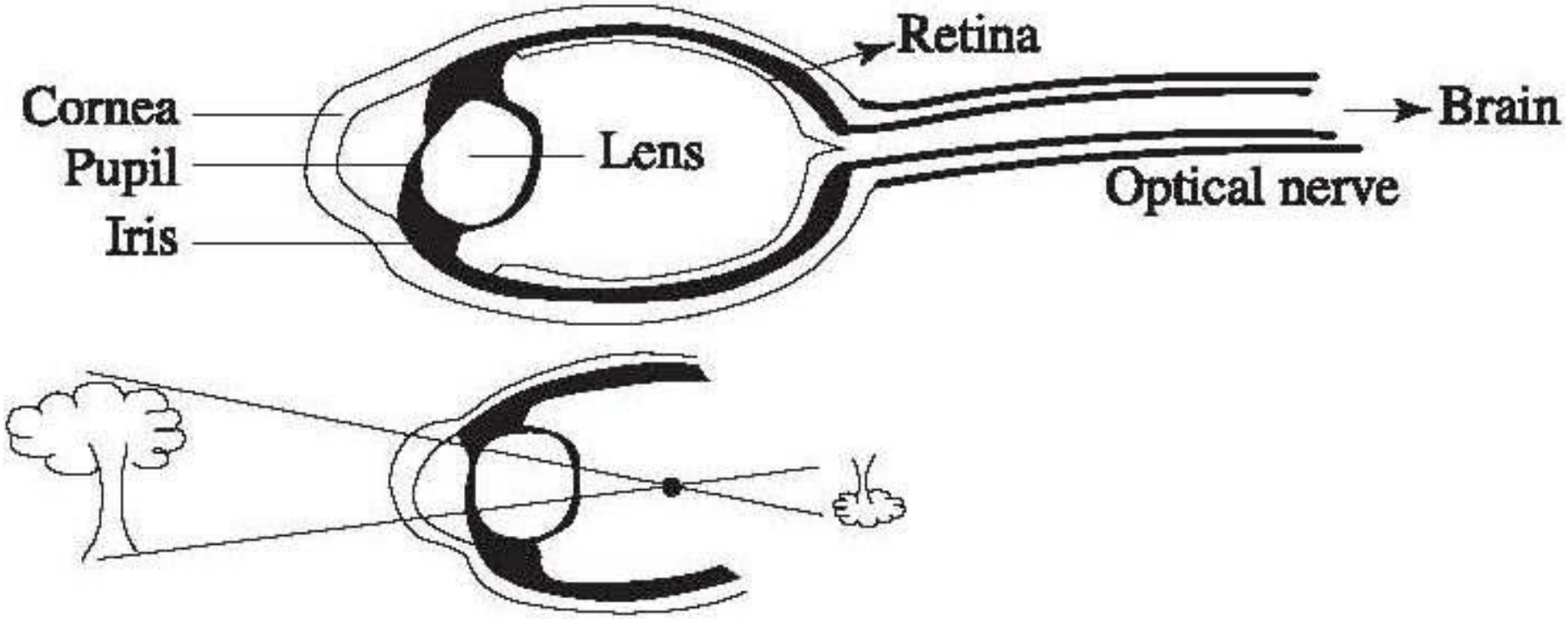



**Fig. 2.6** The human eye

The components of the human eye and their functions are as follows:

1. The cornea is the protective covering of the eye. This acts like a convex lens refracting the light rays. This is the first level of focussing that the light entering the eye undergoes. Light then travels through the aqueous and the vitreous humour, which are liquid media that facilitate the travel of light.
2. The iris acts as a variable aperture to control the amount of light that is allowed to pass through the lens. This is controlled by muscles, which open and close based on the average intensity of the scene being viewed.
3. The retina is the eye sensor system and is composed of photoreceptors. The distance between the lens and the retina varies from 14 mm to 17 mm.

**Table 2.1** Differences between rods and cones

| Rods | Cones |
|---|---|
| Number around 100 million | Number around 6–7 million |
| Respond to the broad spectrum of light but are colour blind | Perceive colour |
| Useful in low light vision | Useful in bright light vision |
| Absent in the region called fovea | Present more in the region around the fovea. Colour perception is best when the object is directly viewed |
| Best view in periphery | Minimal perception in periphery |

# Properties of Human Visual System

- ***Brightness adaptation***
- ***Intensity and brightness***
- ***Simultaneous contrast***

# *Simultaneous contrast*

$$dp = \frac{df}{f_0} = \frac{|f - f_b|}{f_0} = k$$

$$p = \ln \frac{f}{f_0}$$

Therefore, the relationship between the stimulus $f$ and perception is logarithmic.

# *Mach bands*

- Mach band effect is a phenomenon of lateral inhibition of rods and cones, where the sharp intensity changes are attenuated by the visual system.

# *Frequency response*

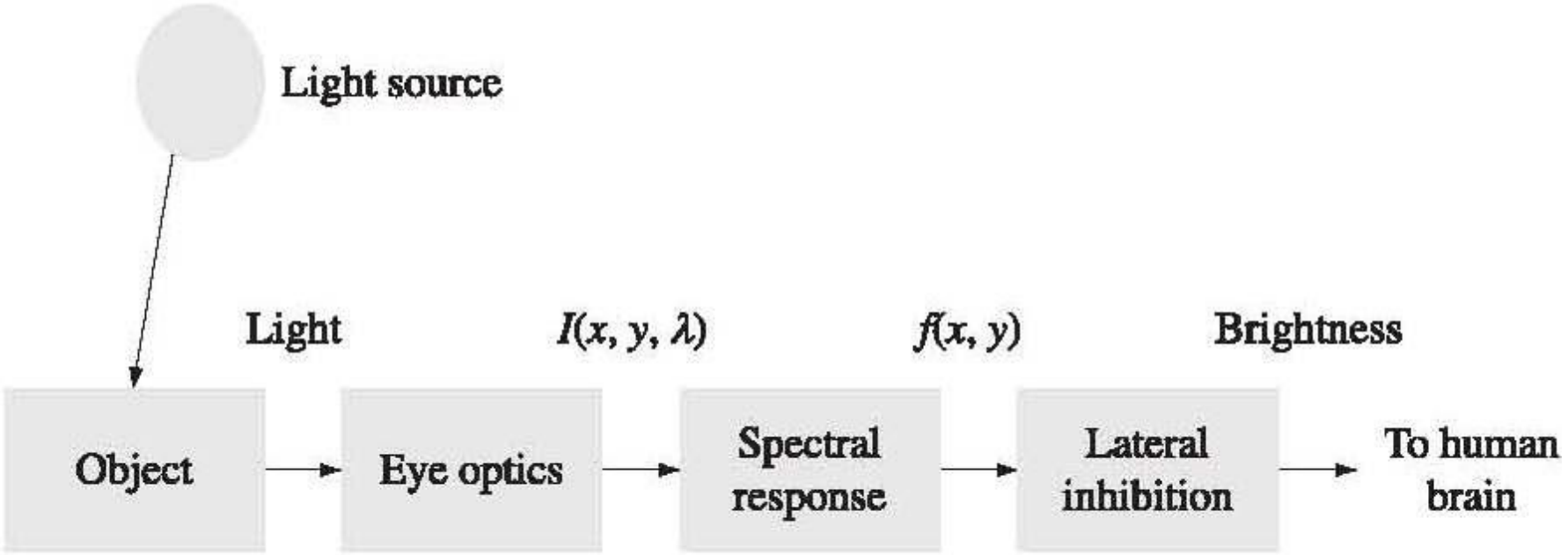



**Fig. 2.9** Mathematical model of the human visual system

# REVIEW OF DIGITAL CAMERA

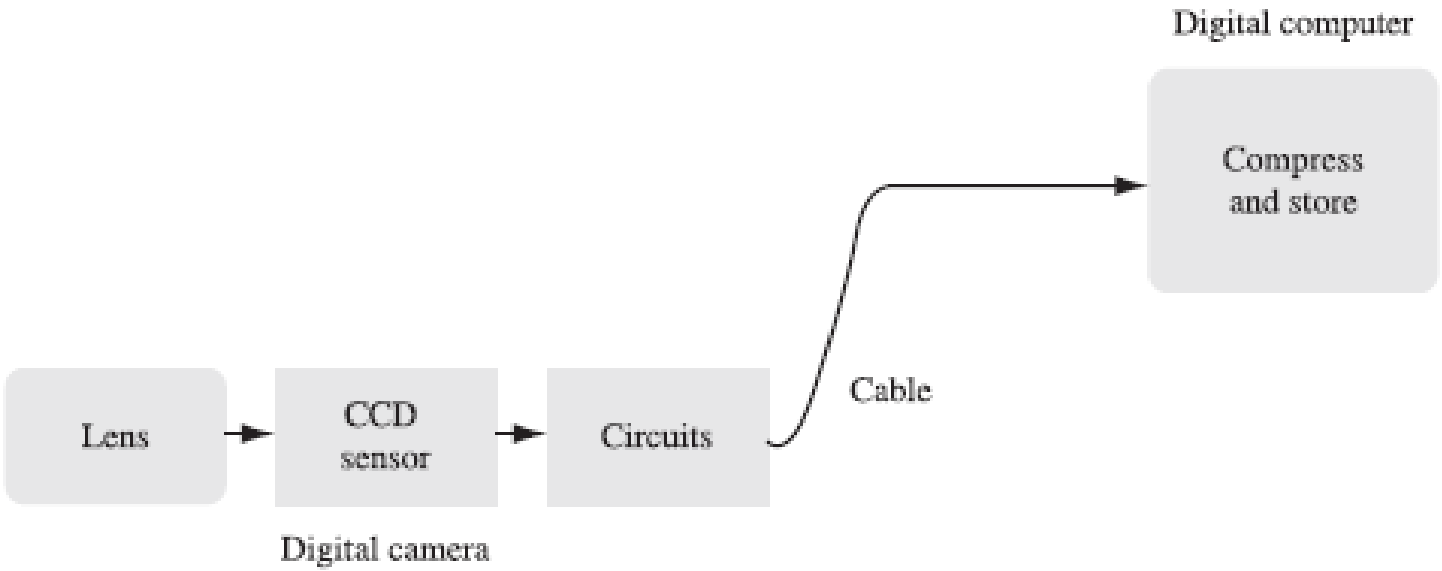



**Fig. 2.10** Components of a digital camera

# SAMPLING AND QUANTIZATION

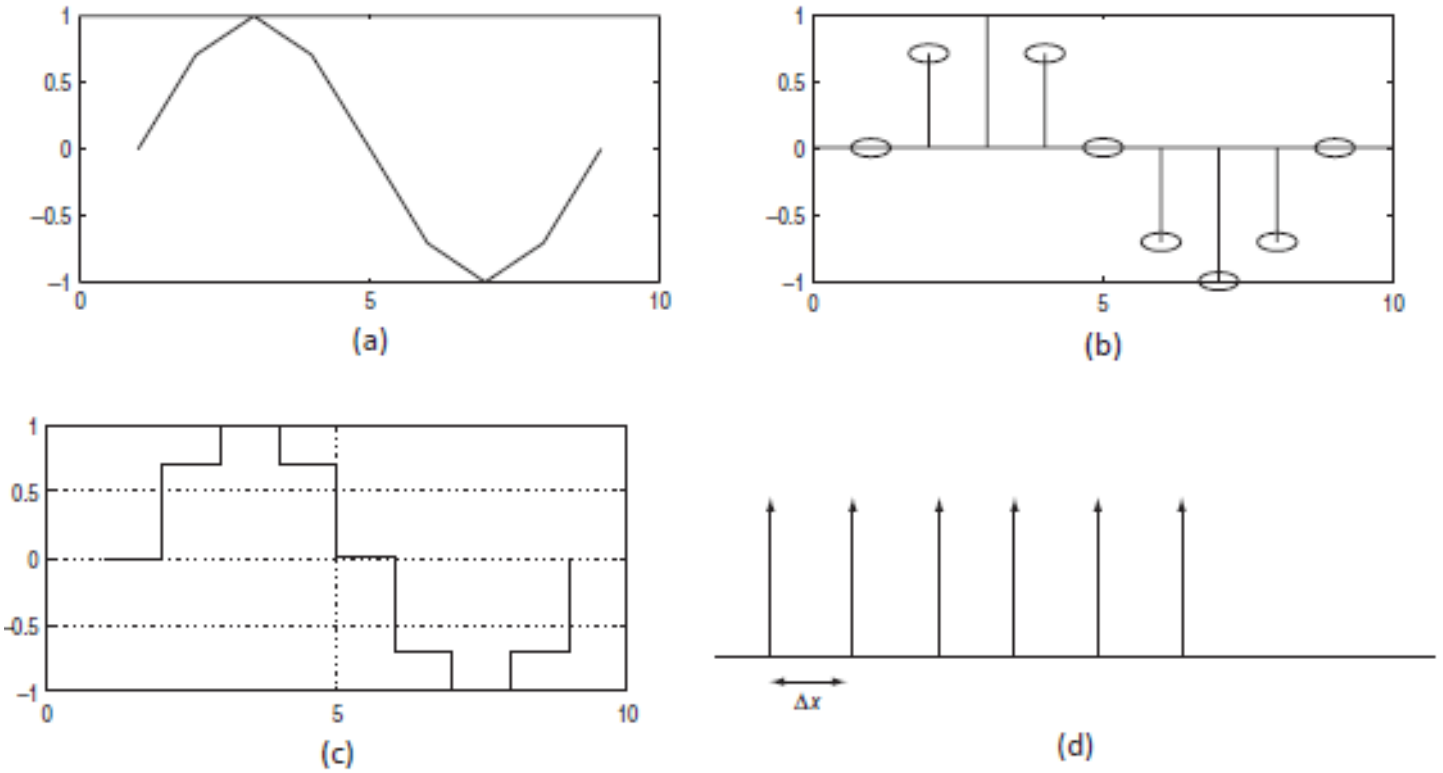



**Fig. 2.11** Sampling process (a) Original signal $f(t)$ (b) Sampled image $f(n) = f(t) \times r(t)$ (c) Reconstructed image (d) Train of the impulse function $r(t)$

# Shannon–Nyquist theorem

- What should be the ideal size of the pixel? Should it be big or small? The answer is given by the Shannon–Nyquist theorem. As per this theorem, the sampling frequency should be greater than or equal to 2 × *f*max, where *f*max is the highest frequency present in the image.

# *Image quantization*

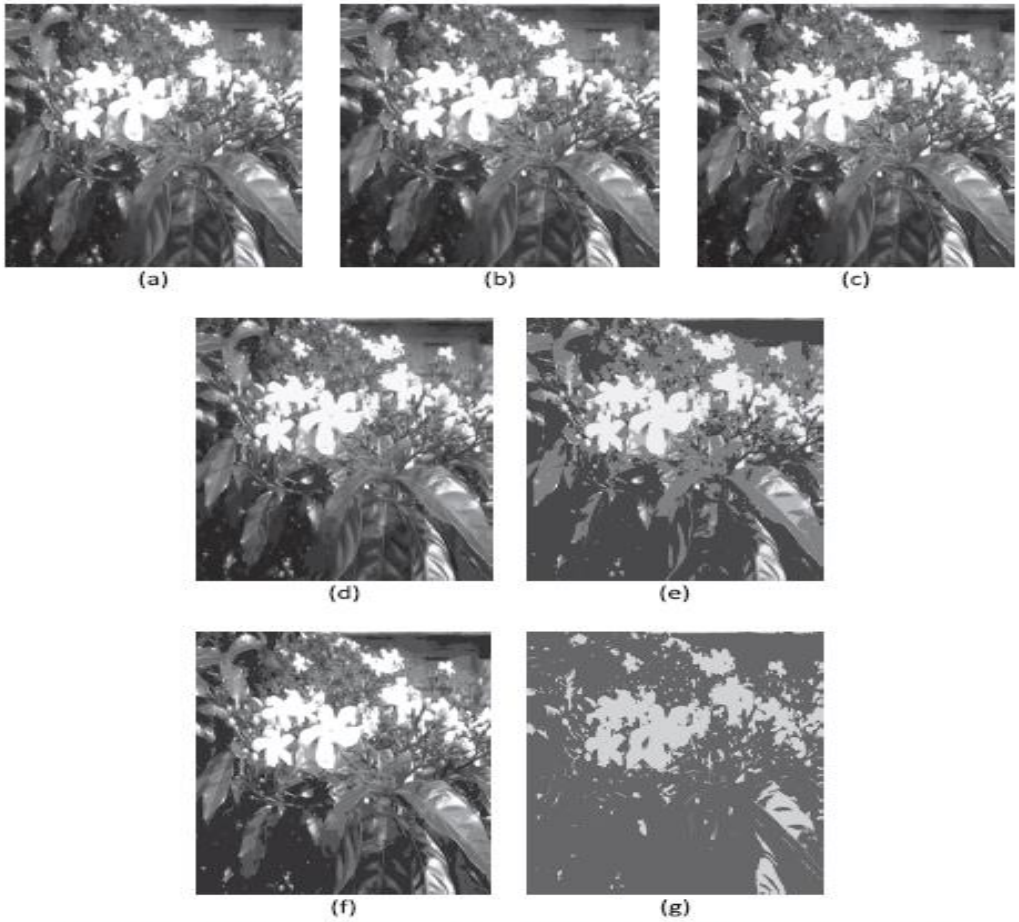



Fig. 2.13 Image quantization (a) Original image (b) Quantization at 64 bit (c) Quantization at 32 bit (d) Quantization at 16 bit (e) Quantization at 8 bit (f) Quantization at 4 bit (g) Quantization at 2 bit

# IMAGE QUALITY

- **Optical Resolution**

The modulation ($M$) is defined as

$$\text{Modulation (contrast)} = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

# Image Display Devices and Device Resolution

- *Frame rate* refers to the rate at which video images are acquired and processed or the rate at which the images are transferred from the system to the display. The international standard for frame rate is 25 frames per second and in the US it is 30 frames per second.

# Pixel Size

- *Pixel size* is the distance between the dots in the device monitor. It is also known as dot pitch. *Pixel* d*ensity* is the number of pixels per unit length in the device monitor.

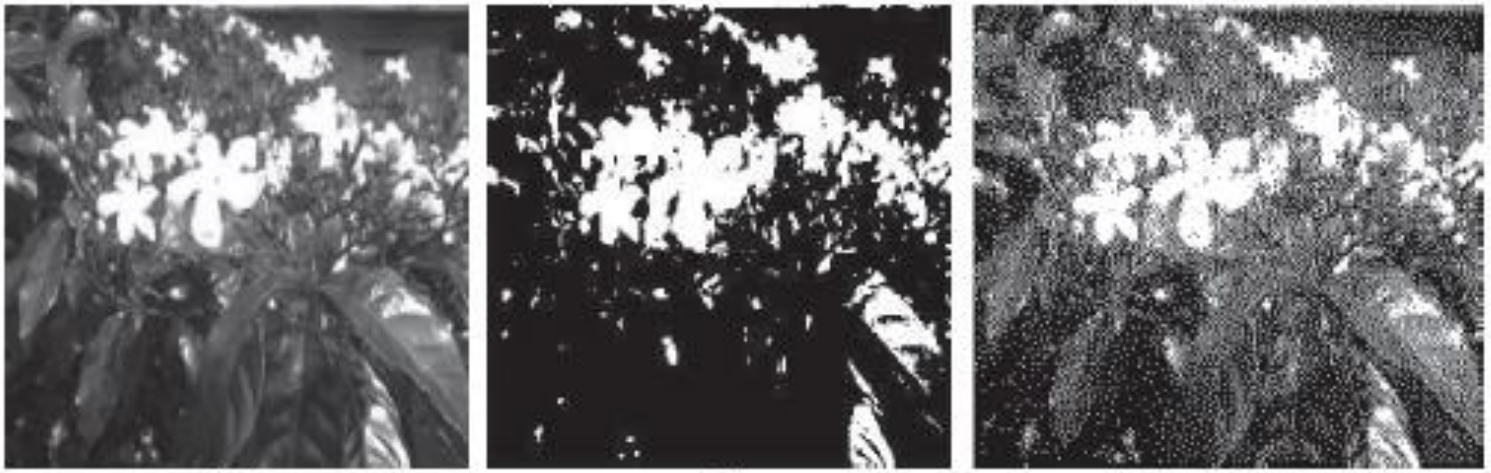
# Geometric Resolution

- *Geometric resolution* is the order of the display matrix. It is defined as the number of physical pixels of display compatible with the image. *Colour resolution* is the number of colours available for the display. *Colour depth* is the number of bits that is required to display all colours. *Gamut* or *palette* refers to the range of colours that are supported by the display system.

# Digital Halftone Process

- *Halftoning* is a technique used to produce the grey shades for bi-level devices such as printers.

# Halftoning Process



(a) (b) (c)

**Fig. 2.15** Halftoning process (a) Original image (b) Threshold image (c) Halftone image with more shades

# *Random dithering*

- Random dithering is a simple way of creating an illusion of continuous grey levels. The method generates a random number in the range 1–256 for a pixel. If the pixel value is greater than the random number generated, the pixel is plotted as white. Otherwise, it is plotted as a black pixel.

# *Ordered dithering*

- The patterns in ordered dithering are in a more compact form, based on the order of dots added. Some of the patterns are shown in Fig. 2.17. This pattern array is then used as a threshold mask for the given image. If the values of the pixel are less than the threshold value, it is plotted as white and otherwise as dark.

# Ordered Dithering

In general, any higher-order pattern array $M_{2n}$ matrix can be generated from the basic pattern array using the following pattern generation mask:

$$\begin{pmatrix} 4\times M_n & 4\times M_n + 2\times U_n \\ 4\times M_n + 3\times U_n & 4\times M_n + U_n \end{pmatrix}$$

Here, $U$ is a square matrix of size $(2^n \times 2^n)$, where all the elements are equal to 1. The following numerical example will help in understanding this process.

# Algorithm

- The algorithm for ordered dither can be written as follows:
  - » 1. Load the image.
  - » 2. Create a pattern of size $n \times n$.
  - » 3. Apply interpolation or replication technique to enlarge the image.
  - » 4. If the enlarged image ($x$, $y$) > threshold array, produce a dot at ($x$, $y$); otherwise insert zero.

# *Non-periodic dithering*

- The Floyd–Steinberg algorithm for non-periodic dithering is as follows:

1. Load the image.
2. Perform the quantization process.
3. Calculate the quantization error.
4. Spread the error over the neighbours to the right and below. The right pixel gets 7/16th of the error value. The bottom pixel gets 5/16th of the error, the south-west neighbour gets 3/16th of the error, and the south-east neighbour gets 1/16th of the error.

The error dispersion chart for the Floyd–Steinberg algorithm is shown in Fig. 2.19.

$$\begin{pmatrix} & X & 7 \\ 3 & 5 & 1 \end{pmatrix} \text{ where } X = 1/16$$

Fig. 2.19 Error dispersion chart for Floyd–Steinberg

The error dispersion chart for the Jarvis–Judice–Ninke algorithm is shown in Fig. 2.20

| | | | | |
|---|---|---|---|---|
| | | $X$ | 7 | 5 |
| 3 | 5 | 7 | 5 | 3 |
| 1 | 3 | 5 | 3 | 1 |

where $X = 1/48$

Fig. 2.20 Error dispersion chart for Jarvis–Judice–Ninke

The error dispersion chart for the Stucki algorithm is shown in Fig. 2.21.

| | | | | |
|---|---|---|---|---|
| | | $X$ | 8 | 4 |
| 2 | 4 | 8 | 4 | 2 |
| 1 | 2 | 4 | 2 | 1 |

where $X = 1/42$

Fig. 2.21 Error dispersion chart for Stucki

# IMAGE STORAGE AND FILE FORMATS

- Some of the raster file formats that are very popular are
    1. GIF (Graphics Interchange Format)
    2. JPEG (Joint Photographic Experts Group)
    3. PNG (Portable Network Graphics)
    4. DICOM (Digital Imaging and COMmunication)

# Structure of TIFF File Format

- Generally, file formats consist of two parts:

1. Image header
2. Image data

# Structure of TIFF File Format

- The tagged image file format (TIFF) is a standard format that is considered for the purpose of illustration. The TIFF image format is as follows:

1. Image file header (IFH)
2. Image file directory (IFD)
3. Directory entry (DE)
4. Image data

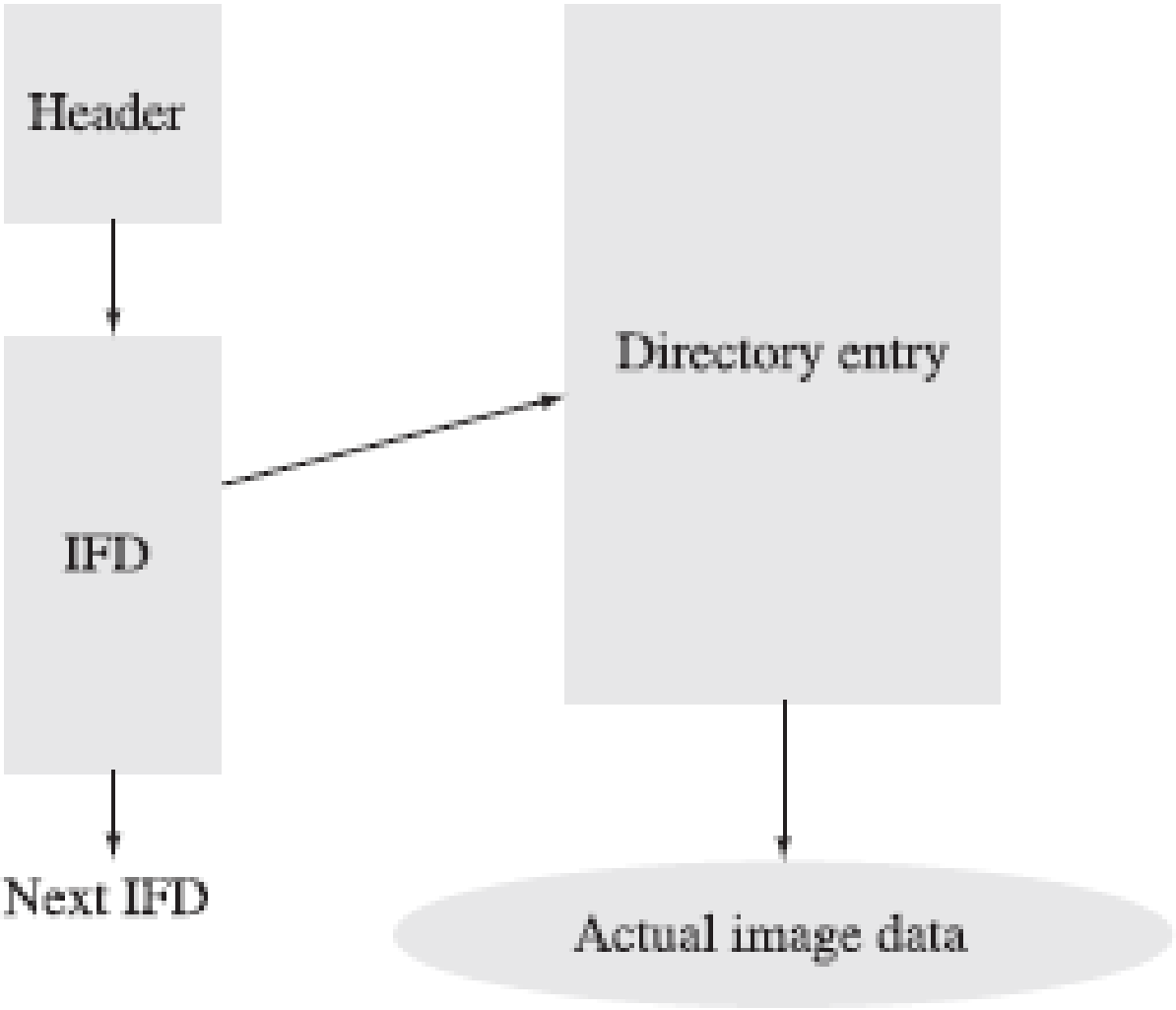



Fig. 2.23 TIFF structure

## SUMMARY

1. Objects are perceived by human beings because of light.
2. Any image processing application is intended to produce images that are to be viewed by human observers.
3. The human visual system and cameras help to observe images.
4. When light strikes the cones/rods, it creates electrochemical reactions. This generates neural impulses. These neural signals are sent to the visual cortex region through the optic nerves, where perception is created in the brain.
5. The lateral inhibition of the cones and rods creates the concept of simultaneous contrast.
6. Each cone responds to a distinct spectral band of light. This creates a perception of colour, as the cones respond by generating a unique set of responses for each colour of light. By getting these responses from the three cone types, the brain forms a distinct perception of colour.
7. Images contain both fine and coarse details.
8. Spatial density measures the number of pixels in a digital image.
9. Halftoning is a technique that is used to produce grey shades for bi-level devices. There are two types of halftoning algorithms—dithering and patterning algorithms.
10. File format is a way of maintaining interoperability. This also helps in easy editing, easy interchange, and fast transmission.