Human Visual System

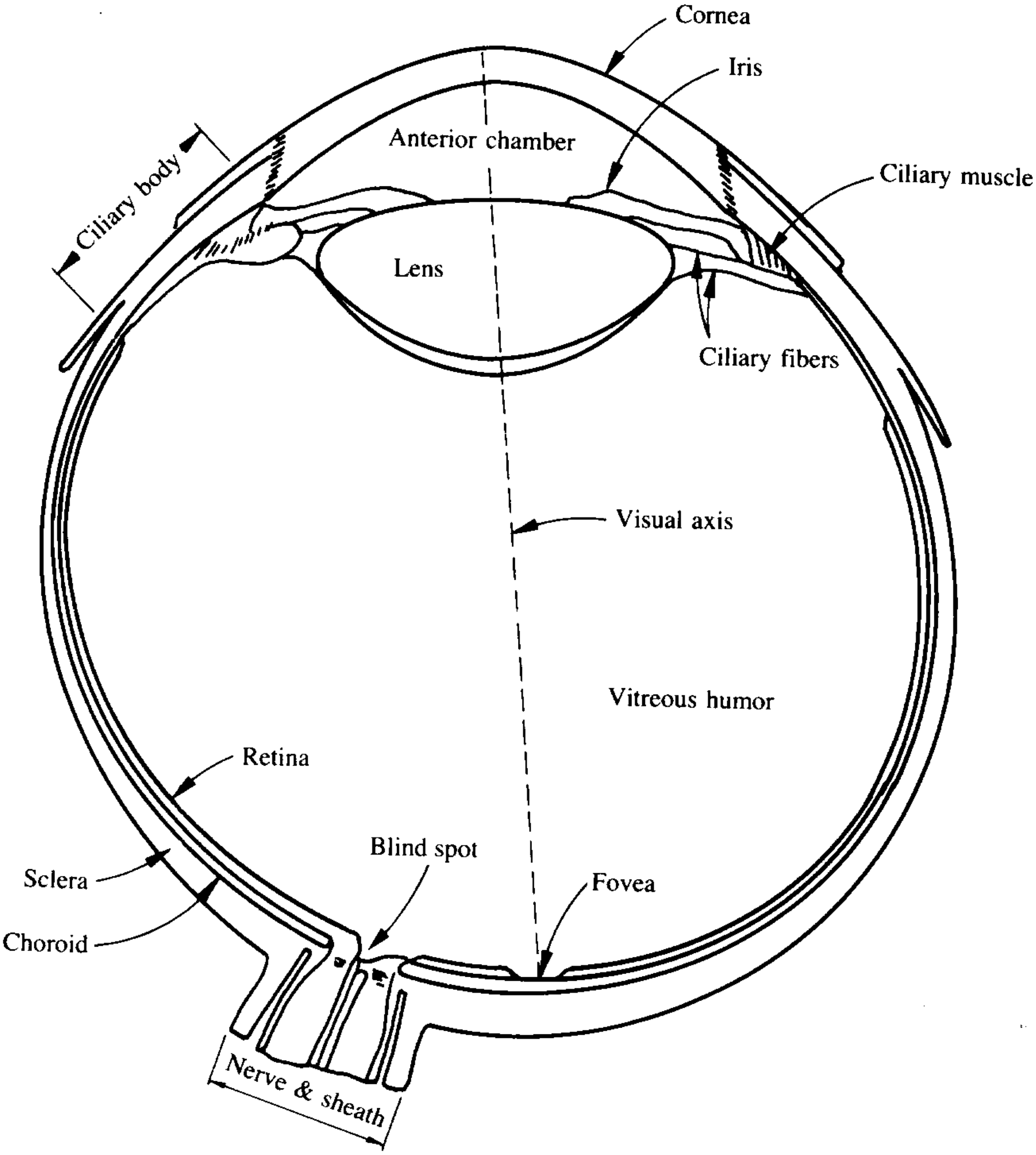
- In many image processing applications, the objective is to help a **human observer** perceive the visual information in an image. Therefore, it is important to understand the human visual system.

- The human visual system consists mainly of the eye (image sensor or camera), optic nerve (transmission path), and brain (image information processing unit or computer).

- It is one of the most sophisticated image processing and analysis systems.

- Its understanding would also help in the design of efficient, accurate and effective computer/machine vision systems.

Cross-section of the Human Eye



Cross-section of the Human Eye

- Nearly spherical with a diameter of 20 mm (approx.).
- **Cornea** --- Outer tough transparent membrane, covers anterior surface.
- **Sclera** --- Outer tough opaque membrane, covers rest of the optic globe.
- **Choroid** --- Contains blood vessels, provides nutrition.
- **Iris** --- Anterior portion of choroid, pigmented, gives color to the eye.
- **Pupil** --- Central opening of the Iris, controls the amount of light entering the eye (diameter varies from 2-8 mm).
- **Lens** --- Made of concentric layers of fibrous cells, contains 60-70% water.
- **Retina** --- Innermost layer, “screen” on which image is formed by the lens when properly focussed, contains photoreceptors (cells sensitive to light).

Retinal Photoreceptors

- Two types of photoreceptors: rods and cones (light sensors).
- **Cones** --- 6-7 million, located in central portion of retina (fovea), responsible for photopic vision (bright-light vision) and color perception, can resolve fine details.
- **Rods** --- 75-150 million, distributed over the entire retina, responsible for scotopic vision (dim-light vision), not color sensitive, gives general overall picture (not details).
- **Fovea** --- Circular indentation in center of retina, about 1.5mm diameter, dense with cones.
- Photoreceptors around fovea responsible for spatial vision (still images).
- Photoreceptors around the periphery responsible for detecting motion.
- **Blind spot** --- Point on retina where optic nerve emerges, devoid of photoreceptors.

Distribution of Rods and Cones on Retina

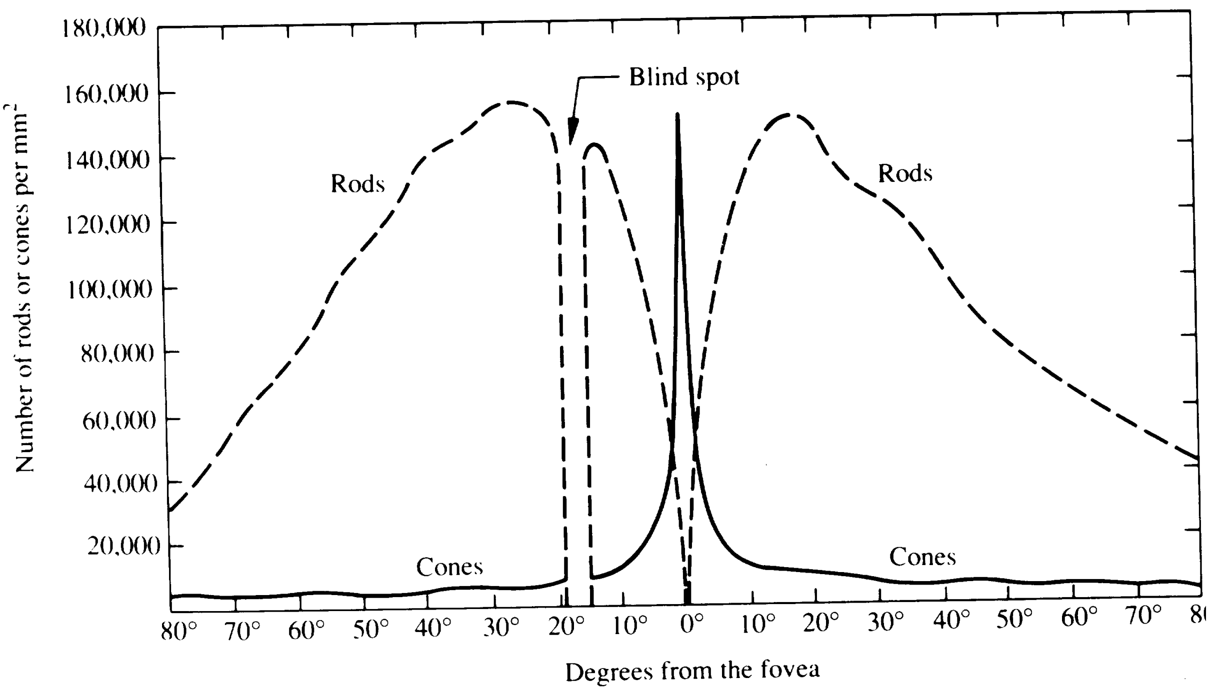


Figure 2.2 *Distribution of rods and cones in the retina. (Adapted from Graham [1965].)*

Simple model for image formation

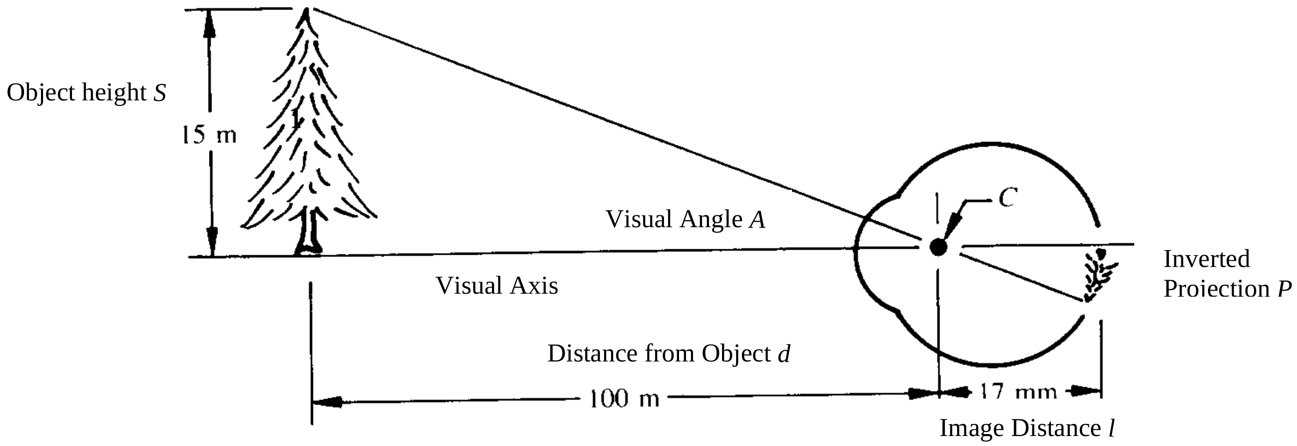


Figure 2.3 *Optical representation of the eye looking at a tree. Point C is the optical center of the lens.*

- Distance between center of lens and retina varies from 14-17mm.
- Farther the object, smaller the refractive power of lens, larger the focal length.
- From the geometry,

$$P = l\frac{S}{d} = 17\frac{15}{100} = 2.55\text{mm}$$

$$A = \tan^{-1}\left(\frac{S}{d}\right) = 8.53^{\circ}$$

Brightness Adaptation

- Human eye can adapt to an enormous range of light intensity levels, almost 10 orders of magnitude!
- Brightness **perceived** (**subjective brightness**) is a logarithmic function of light intensity.
- Eye cannot **simultaneously** operate over such a range of intensity levels.
- This is accomplished by changing the overall sensitivity --- **Brightness adaptation**.

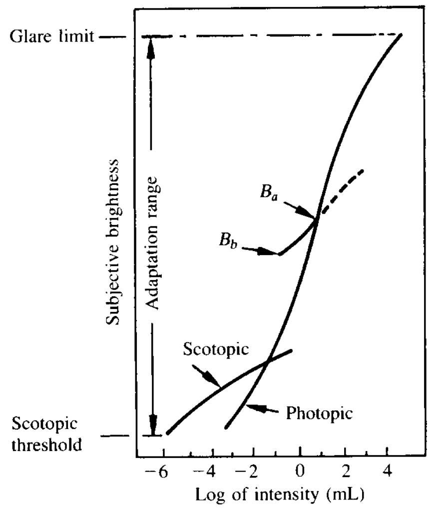


Figure 2.4 *Range of subjective brightness sensations showing a particular adaptation level.*

- At a given sensitivity, the eye can simultaneously discriminate only a small number of intensity levels.
- For a given condition, the sensitivity of the visual system is called the **brightness adaptation level** (ex. B_a).
- At this adaptation, the eye can perceive brightness in the range B_b (below which, everything is perceived as black) to B_a (above which, the eye adapts to a different sensitivity).

Brightness Discrimination

- The ability of the eye to discriminate between changes in brightness levels is called **brightness discrimination**.
- The increment of intensity ΔI_c that is discriminable over a background intensity of I is measured.
- **Weber ratio ---** it is the ratio $\Delta I_c / I$.
- Small value of Weber ratio --- good brightness discrimination, a small percentage change in intensity is discriminable.
- Large value of Weber ratio --- poor brightness discrimination, a large percentage change in intensity is required.

- At high intensities the brightness discrimination is good (small Weber ratio), than at low intensities.

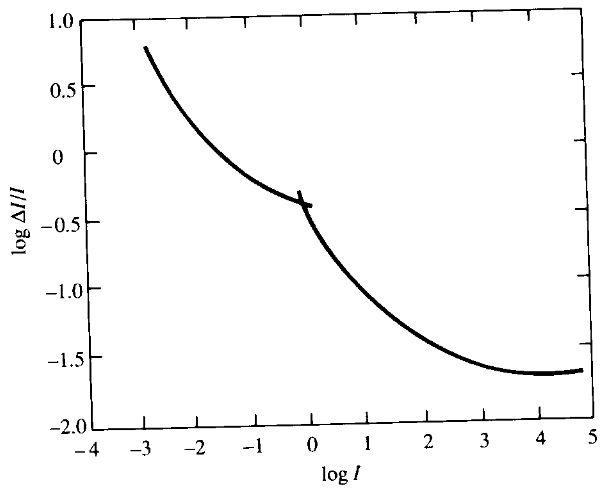


Figure 2.6 *Typical Weber ratio as a function of intensity. (Adapted from Graham [1965].)*

Perceived Brightness is not a Simple Function of Light Intensity

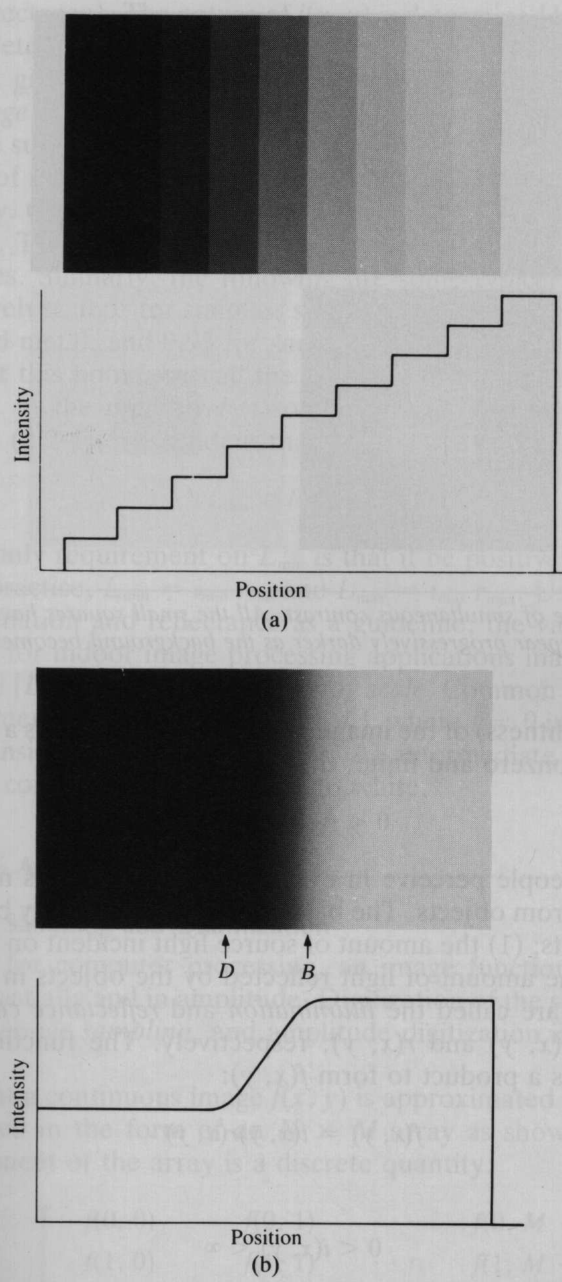
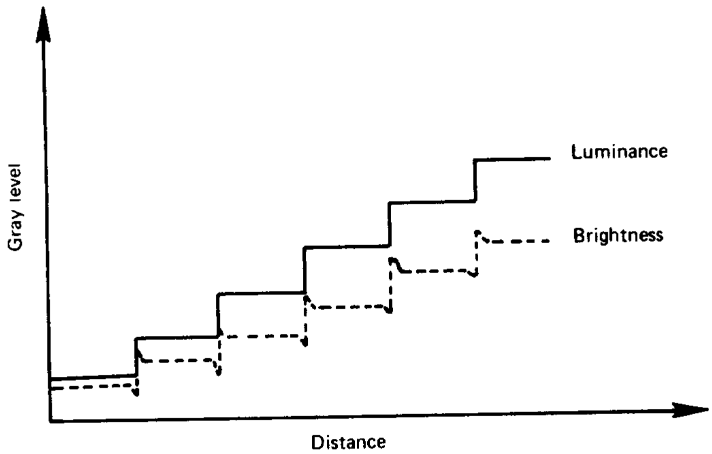
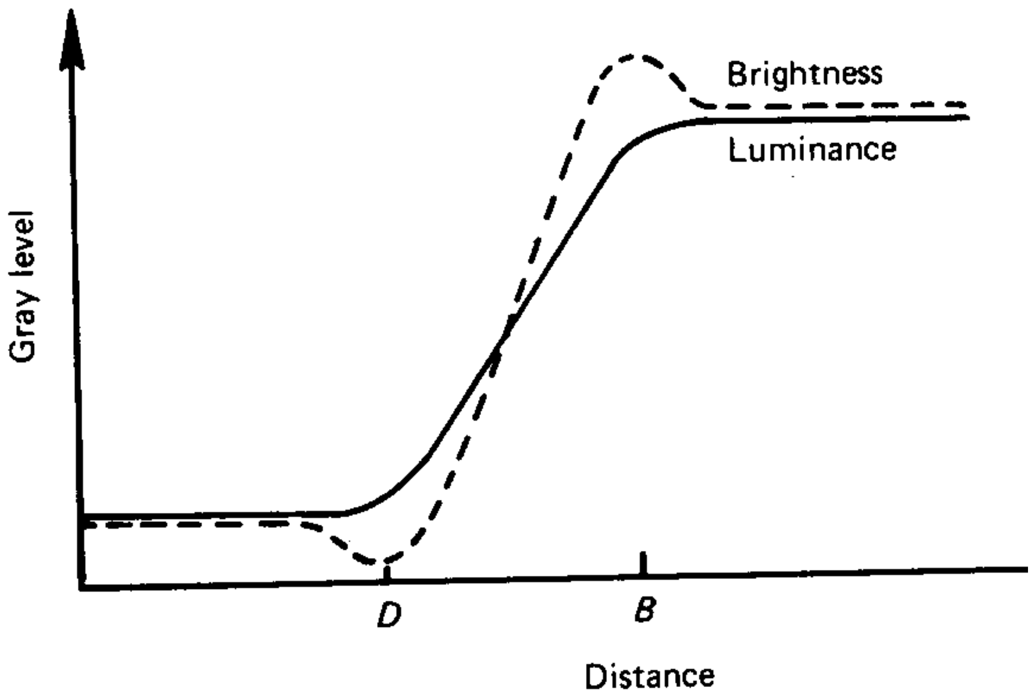


Figure 2.7 *Two examples showing that perceived brightness is not a simple function of intensity. (Adapted from Cornsweet [1970].)*



(b) Luminance versus brightness.

Figure 3.5 Mach band effect.



(b) Mach band effect.

Simultaneous Contrast

- A region's perceived brightness is not a function of only its intensity, but depends on the background intensity as well.
- All the center squares in the figure below have exactly the same intensity. However, they appear to the human eye to become darker as the background becomes brighter.

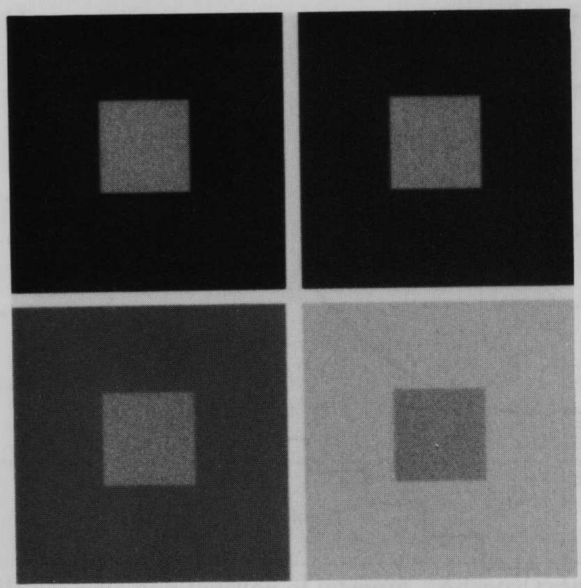


Figure 2.8 *Example of simultaneous contrast. All the small squares have exactly the same intensity, but they appear progressively darker as the background becomes lighter.*

Optical Illusion

- The fills in non-existent information or wrongly perceives geometrical properties of objects.
  See Figure 2.9 of text for some examples

Light and EM Spectrum

- Electromagnetic (EM) waves or radiation can be visualized as propogating sinusoidal waves with some wavelength λ or equivalently a frequency ν where $\lambda\nu = c$, c being the velocity of light.
- Equivalently, they can be considered as a stream of (massless) particles (or photons), each having an energy E proportional to its frequency ν; $E = h\nu$, where h is Planck's constant.
- EM spectrum ranges from high energy radiations like gamma-rays and X-rays to low energy radiations like radio waves.
- Light is a form of EM radiation that can be sensed or detected by the human eye. It has a wavelength between 0.43 to 0.79 micron.
- Different regions of the visible light spectrum corresponds to different colors.
- Light that is relatively balanced in all visible wavelengths appears white (i.e. is devoid of any color). This is usually referred to as **achromatic** or **monochromatic** light.
- The only attribute of such light is its **intensity** or amount. It is denoted by a grayvalue or gray level. White corresponds to the highest gray level and black to the lowest gray level.
- Three attributes are commonly used to describe a chromatic light source:
  - **Radiance** is the total amount of energy (in unit time) that flows from the source and it is measure in Watt (W).

    - **Luminance** is a measure of the amount of light energy that is received by an observer. It is measured in lumens (lm).
    - **Brightness** is a subjective descriptor of light measure (as perceived by a human).
- The wavelength of EM radiation used depends on the imaging application.
- In general, the wavelength of an EM wave required to “see” an object must be of the same size (or smaller) than that of the object.
- Besides EM waves, other sources of energy such as sound waves (ultra sound imaging) and electron beams (electron microscopy) are also used in imaging.

Image Sensing and Acquisition

- A typical image formation system consists of an “illumination” source, and a sensor.
- Energy from the illumination source is either reflected or absorbed by the object or scene, which is then detected by the sensor.
- Depending on the type of radiation used, a photo-converter (e.g., a phosphor screen) is typically used to convert the energy into visible light.
- Sensors that provide digital image as output, the incoming energy is transformed into a voltage waveform by a sensor material that is responsive to the particular energy radiation.
- The voltage waveform is then digitized to obtain a discrete output.
- Read Sections 2.3.1-2.3.3 for some more details about sensors.

Mathematical Representation of Images

- An image is a two-dimensional signal (light intensity) and can be represented as a function $f(x, y)$.

- The coordinates (x, y) represent the spatial location and the value of the function $f(x, y)$ is the light intensity at that point.

$$f(x, y) = i(x, y)r(x, y)$$

- $i(x, y)$ is the incident light intensity and $r(x, y)$ is the reflectance.

- We usually refer to the point (x, y) as a pixel (from **pic**ture **el**ement) and the value $f(x, y)$ as the **grayvalue** (or **graylevel**) of image f at (x, y).

- Images are of two types: continuous and discrete.

- A continuous image is a function of two independent variables, that take values in a continuum.
  Example: The intensity of a photographic image recorded on a film is two-dimensional function $f(x, y)$ of two real-valued variables x and y.

- A discrete image is a function of two independent variables, that take values over a discrete set (ex. an integer grid).
  Example: The intensity of a discretized 256 x 256 photographic image recorded on a CDROM is two-dimensional function $f(m, n)$ of two integer-valued variables m and n taking values $m, n = 0, 1, 2, \ldots, 255$.

- Similarly, grayvalues can be either real-valued or integer-valued. Smaller grayvalues denote darker shades of gray (smaller brightness levels).

Sampling

- For computer processing, a continuous-image must be spatially discretized. This process is called sampling.

- A continuous image *f* (*x*, *y*) is approximated by equally spaced samples arranged in a *M* x *N* array:

$$f(x,y) \approx \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & \ddots & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}_{M\times N}$$

- The right-hand side is normally referred to as a discrete image.

- The sampling process may be viewed as partitioning the real *xy* plane with a grid whose vertices are elements in the Cartesian product *Z* x *Z*, where *Z* is the set of integers.

- If Δx and Δy are separation of grid points in the *x* and *y* directions, respectively, we have

$$f(m,n) = f(m\Delta x, n\Delta y), \text{for } m = 0,1,\ldots, M-1, \text{and } n = 0,1,\ldots, N-1.$$

- The sampling process requires specification of Δx and Δy, or equivalently *M* and *N* (for a given image dimensions).

Effect of spatial resolution

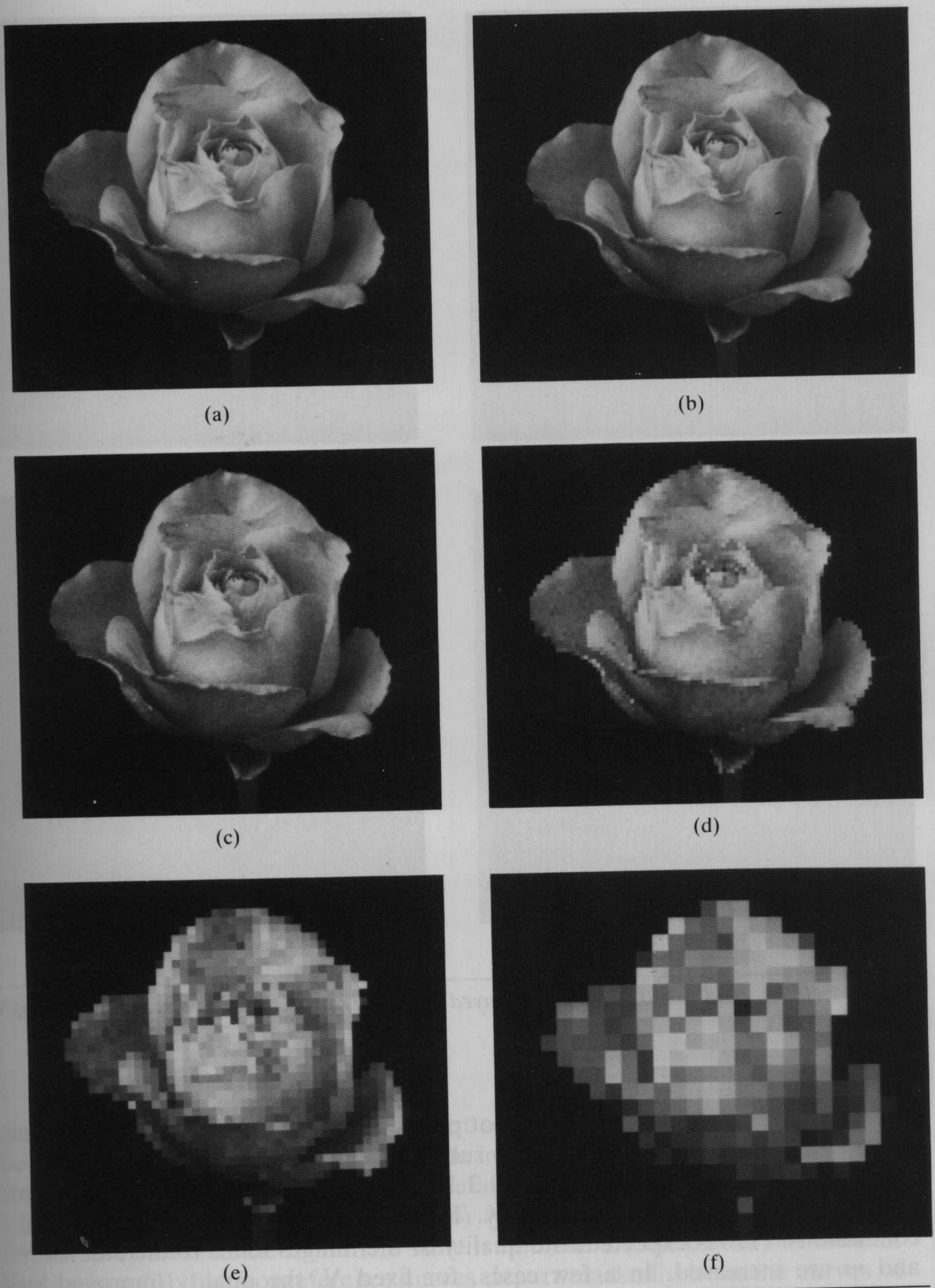
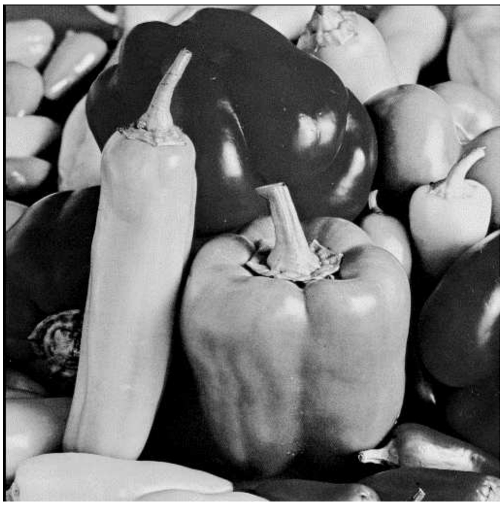
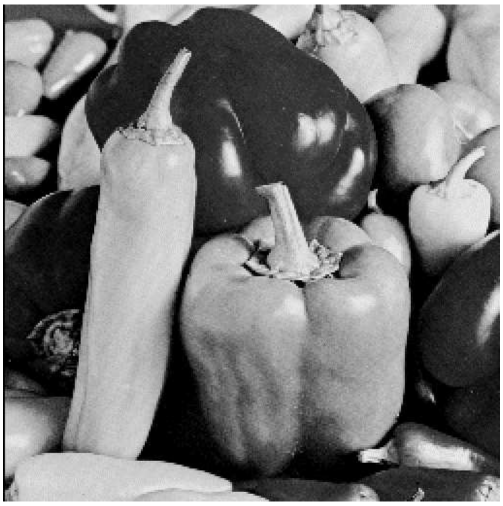


Figure 2.9 *Effects of reducing spatial resolution.*

Effect of spatial resolution

512 x
512



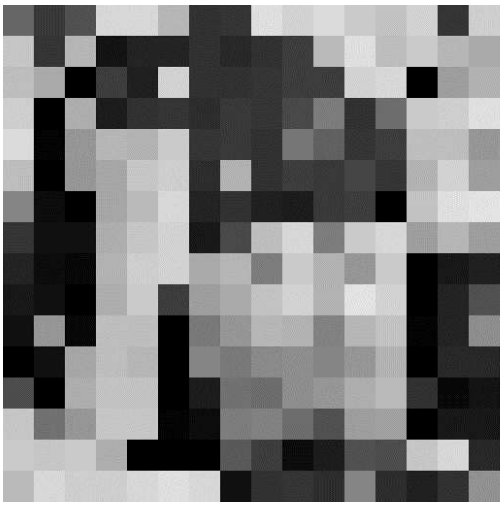


256 x
256

128 x
128

64 x
64

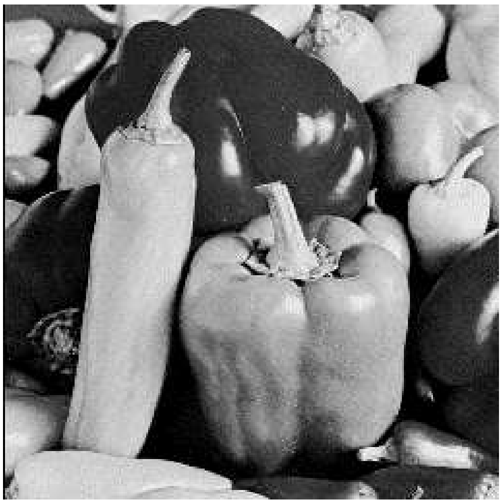
32 x
32



16 x
16

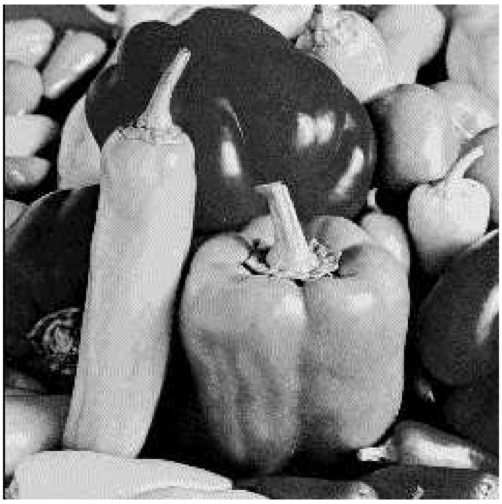
Effect of graylevel quantization

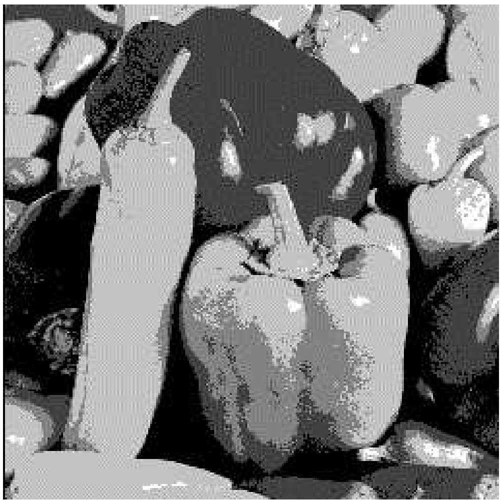
256



64

16





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