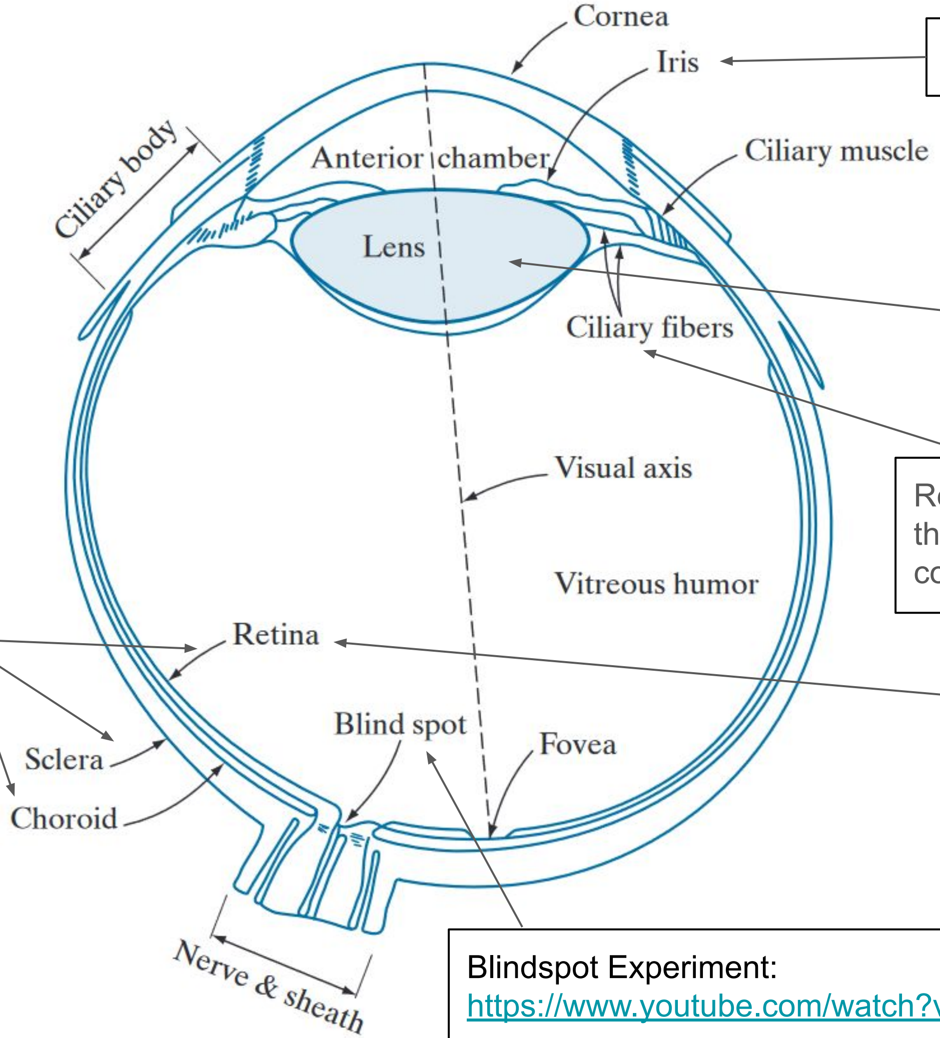
EE 604 Image Processing

Lec 02: Image Fundamentals

Outline

- Human Visual System
- Image Sensing & Acquisition
- Image Sampling & Quantization



Controls light entry

Biconvex and focuses light rays onto the retina

Responsible for flattening or thickening the lens, i.e. controlling the focal length

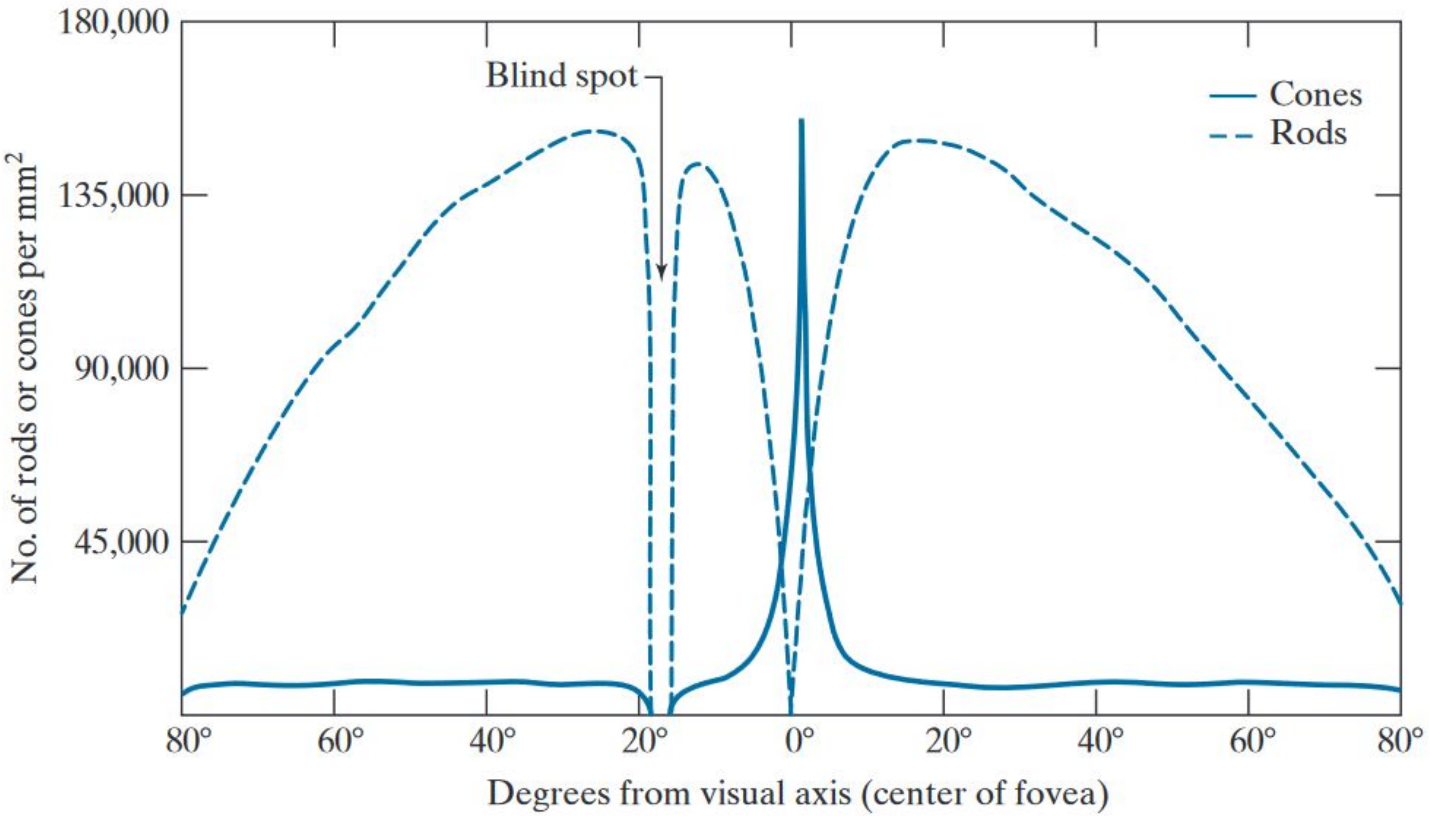
3-layer covering

Contains 2 types of receptors: cones & rods

Blindspot Experiment:
https://www.youtube.com/watch?v=QXzgokis33I

Credits: Primary Reference

FIGURE 2.2
Distribution of rods and cones in the retina.



Credits: Primary Reference

Cones

They are located primarily in the central portion of the retina, called the fovea, and are highly sensitive to color. Humans can resolve fine details because each cone is connected to its own nerve end.

Muscles rotate the eye until the image of a region of interest falls on the fovea. Cone vision is called photopic or bright-light vision.

Rods

The larger area of distribution, and the fact that several rods are connected to a single nerve ending, reduces the amount of detail discernible by these receptors.

Rods capture an overall image of the field of view. They are not involved in color vision, and are sensitive to low levels of illumination.

For example, objects that appear brightly colored in daylight appear as colorless forms in moonlight because only the rods are stimulated.

This phenomenon is known as scotopic or dim-light vision.

Scotopic (Low Light) Vision

Human

Cat

Google Images

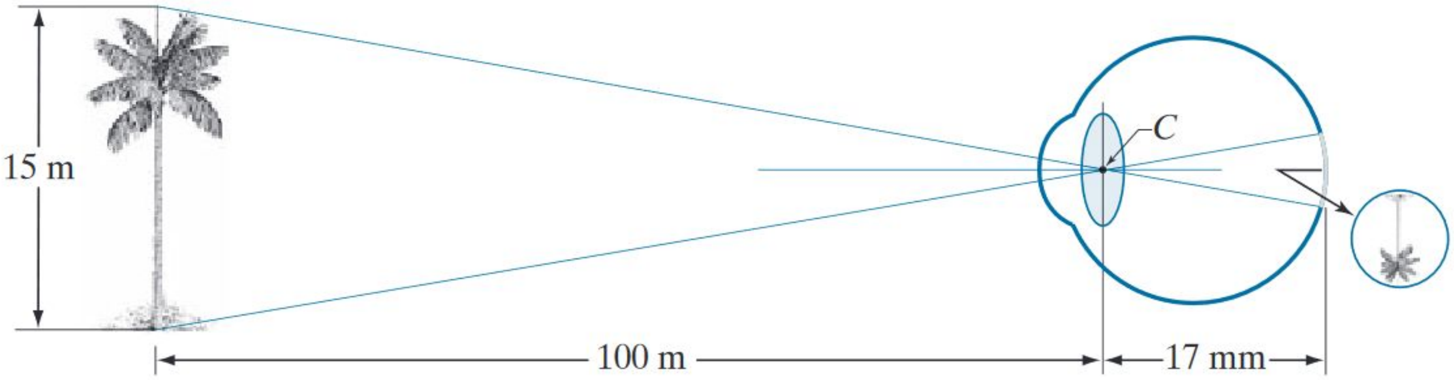


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the focal center of the lens.

Perception takes place by the relative excitation of the receptors, which transform radiant energy into electrical impulses that ultimately are decoded by the brain.

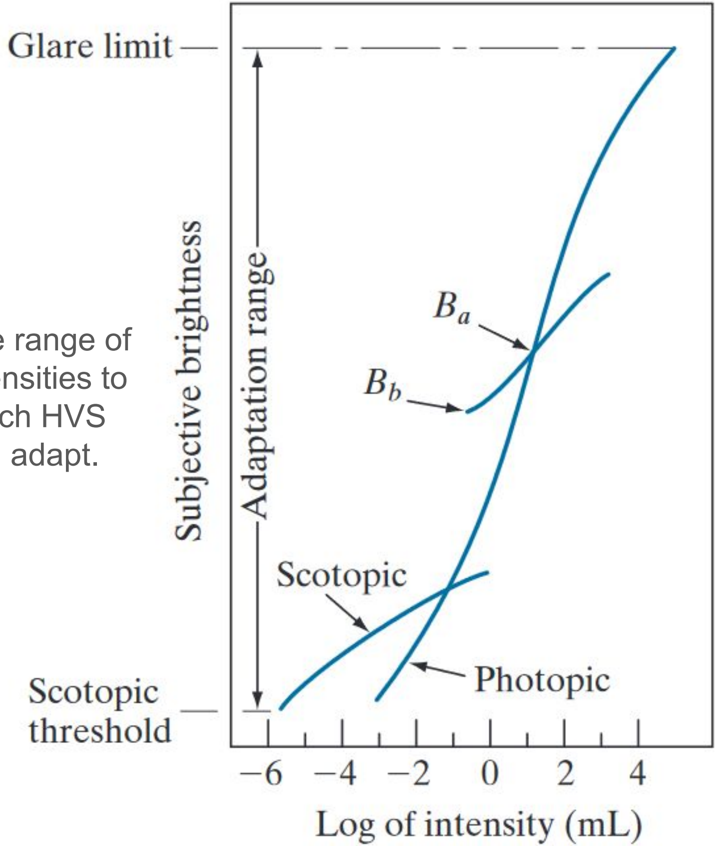
Focal-length range: 14 mm to 17 mm

BRIGHTNESS ADAPTATION

- Subjective brightness (intensity as perceived by HVS) is a logarithmic function of the light intensity incident on the eye.
- The total range of distinct intensity levels the eye can discriminate simultaneously is rather small when compared with the total adaptation range.
- The transition from scotopic to photopic vision is gradual.

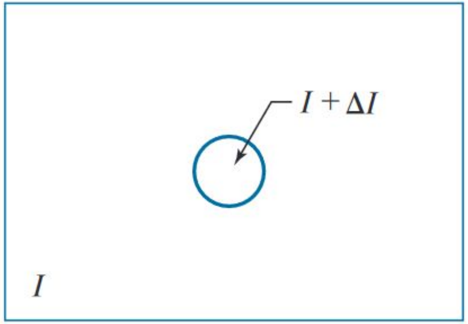
Brightness adaptation is your visual system's way of automatically adjusting to new lighting conditions so you can maintain good vision without being overwhelmed by glare or plunged into darkness.

The range of intensities to which HVS can adapt.

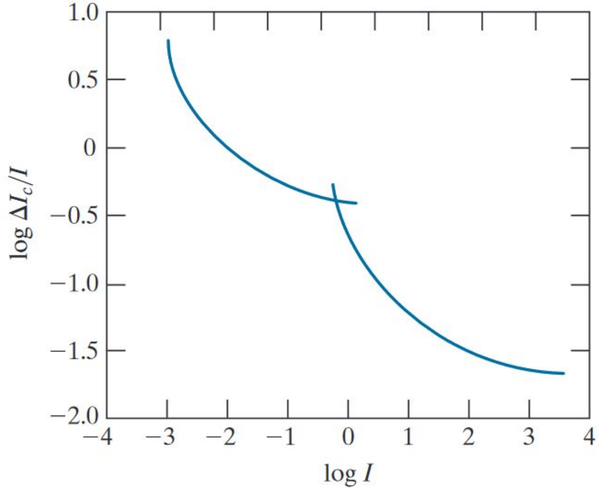


Brightness Discrimination

To measure the sensitivity of intensity change, the inner circular region is illuminated by a different intensity from the outer.



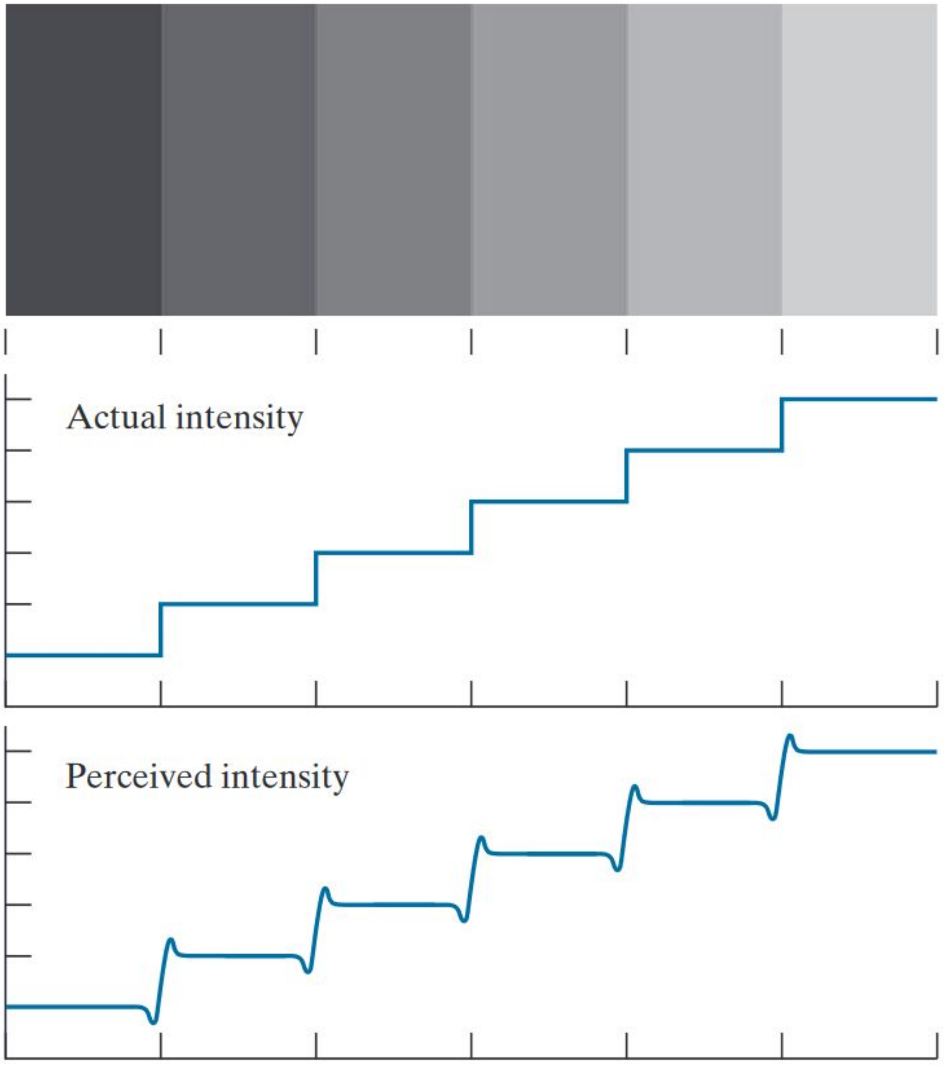
If ΔI is not bright enough, the subject says "no," indicating no perceivable change. As ΔI gets stronger, the subject may give a positive response of "yes," indicating a perceived change. Finally, when ΔI is strong enough, the subject will give a response of "yes" all the time. The quantity $\Delta I_c/I$, where ΔI_c is the increment of illumination discriminable 50% of the time with background illumination I, is called the *Weber ratio*. A small value of $\Delta I_c/I$ means that a small percentage change in intensity is discriminable. This represents "good" brightness discrimination. Conversely, a large value of $\Delta I_c/I$ means that a large percentage change in intensity is required for the eye to detect the change. This represents "poor" brightness discrimination.



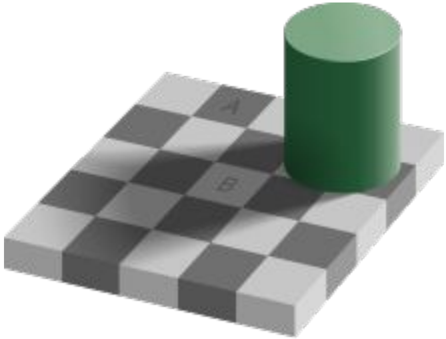
This curve shows that brightness discrimination is poor (the Weber ratio is large) at low levels of illumination, and it improves significantly (the Weber ratio decreases) as background illumination increases. The two branches in the curve reflect the fact that at low levels of illumination vision is carried out by the rods, whereas, at high levels, vision is a function of cones.

Mach band Effect

Perceived brightness is not a simple function of intensity alone.

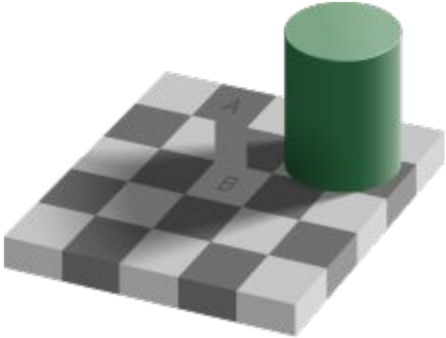


Checkerboxes A and B are different, right?



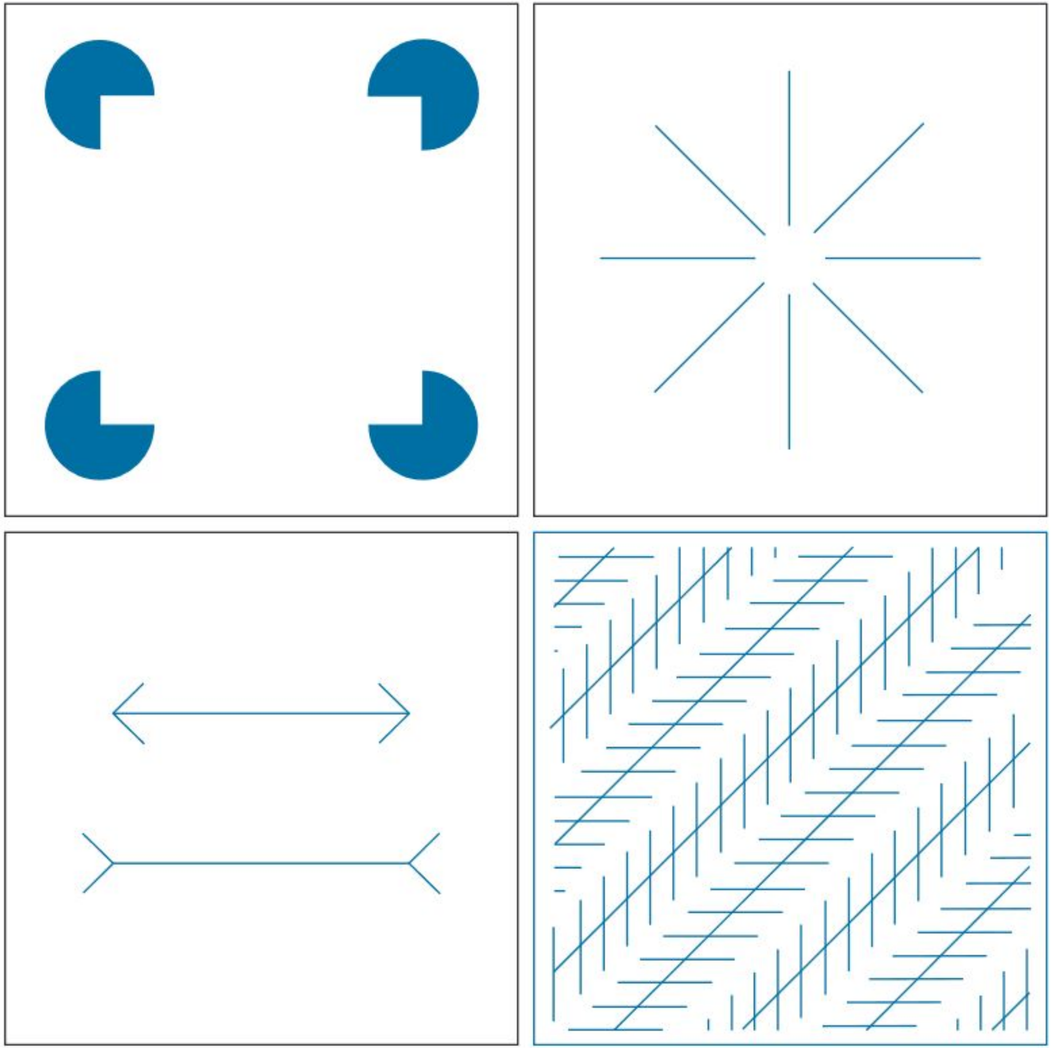
Now?

Perceived brightness also depends on surroundings and neighborhood

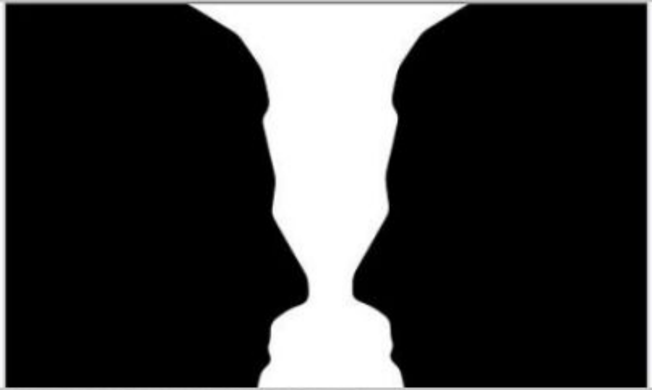


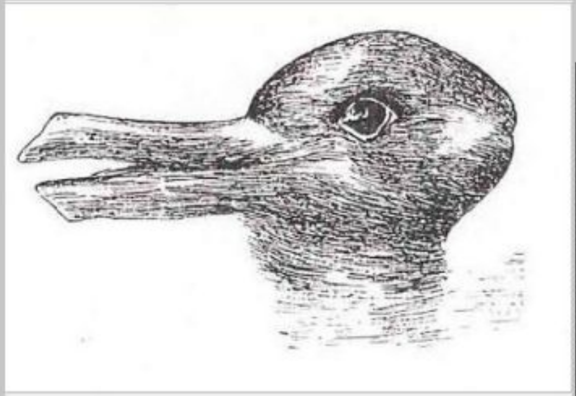
Optical Illusions

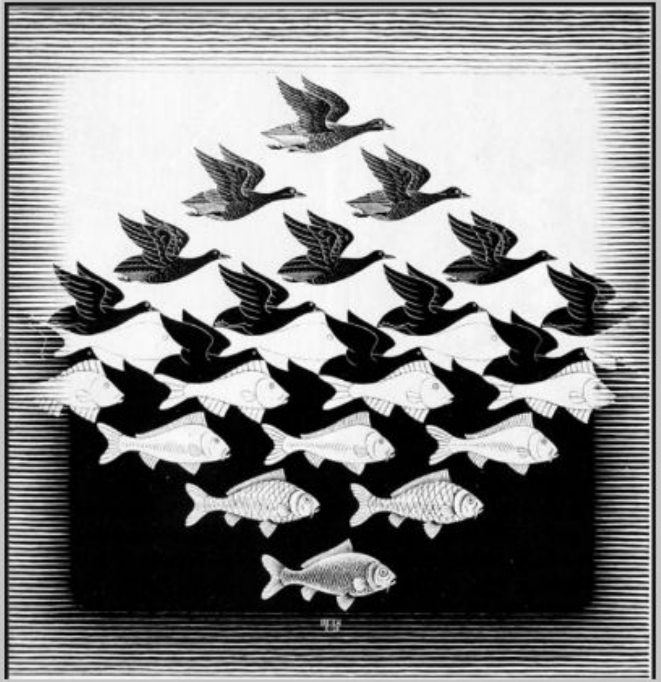
1) Gives an impression of square
2) Gives an impression of circle
3) It looks like the horizontal lines are of different size.
4) It looks like the long lines are not parallel.



Visual Gestalts: interpretational ambiguities







HVS Summary

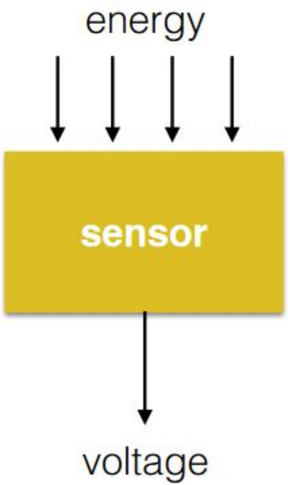
- Light rays enter our eyes through **cornea**, while **iris** controls the amount of light that can enter. The indecent light rays get focused by the **lens** on to the **retina**. The retina has **photoreceptors** (rods and cones) which encode the scene information, and pass it on to the **visual cortex** in the brain through a pair of **optic nerves**.

- Humans can perceive a large range of light intensity, but not simultaneously.

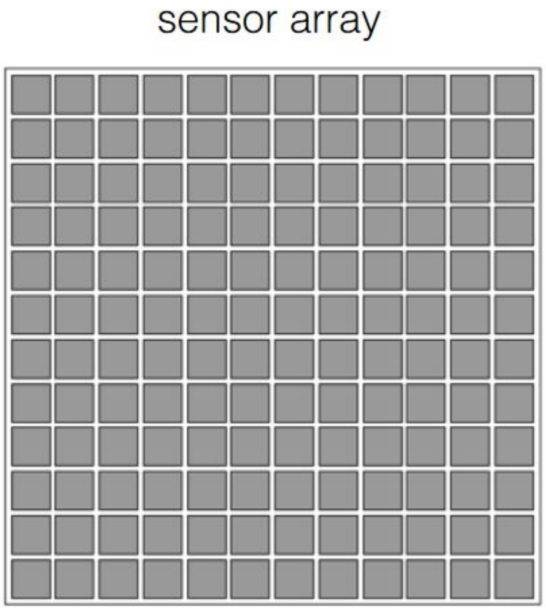
- How well can we distinguish between different levels of intensity will depend on the background illumination.

- Perceived brightness is a complicated function of true intensity.

Image sensor

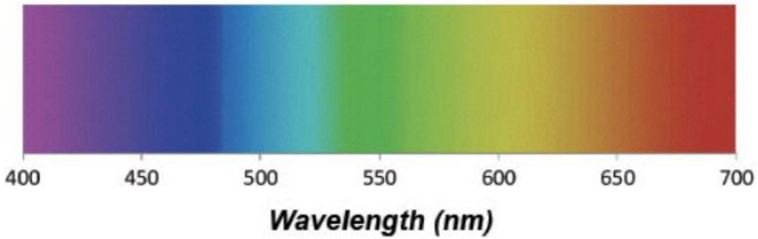


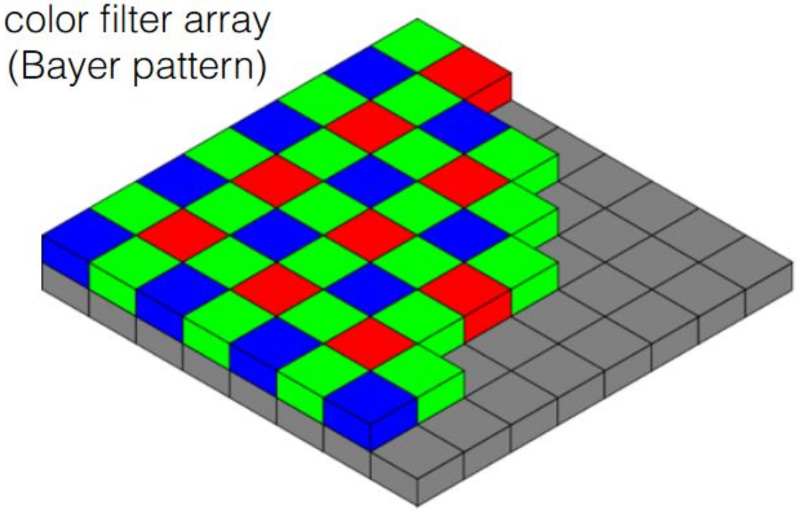
One of receptors like cones and rods in human eye



Needed for generating a 2D Image

Color filter array





Demosaicing is the process of recovering the complete RGB color channels from the Bayer pattern array. This is done my sophisticated interpolation algorithms (will be covered in later classes).

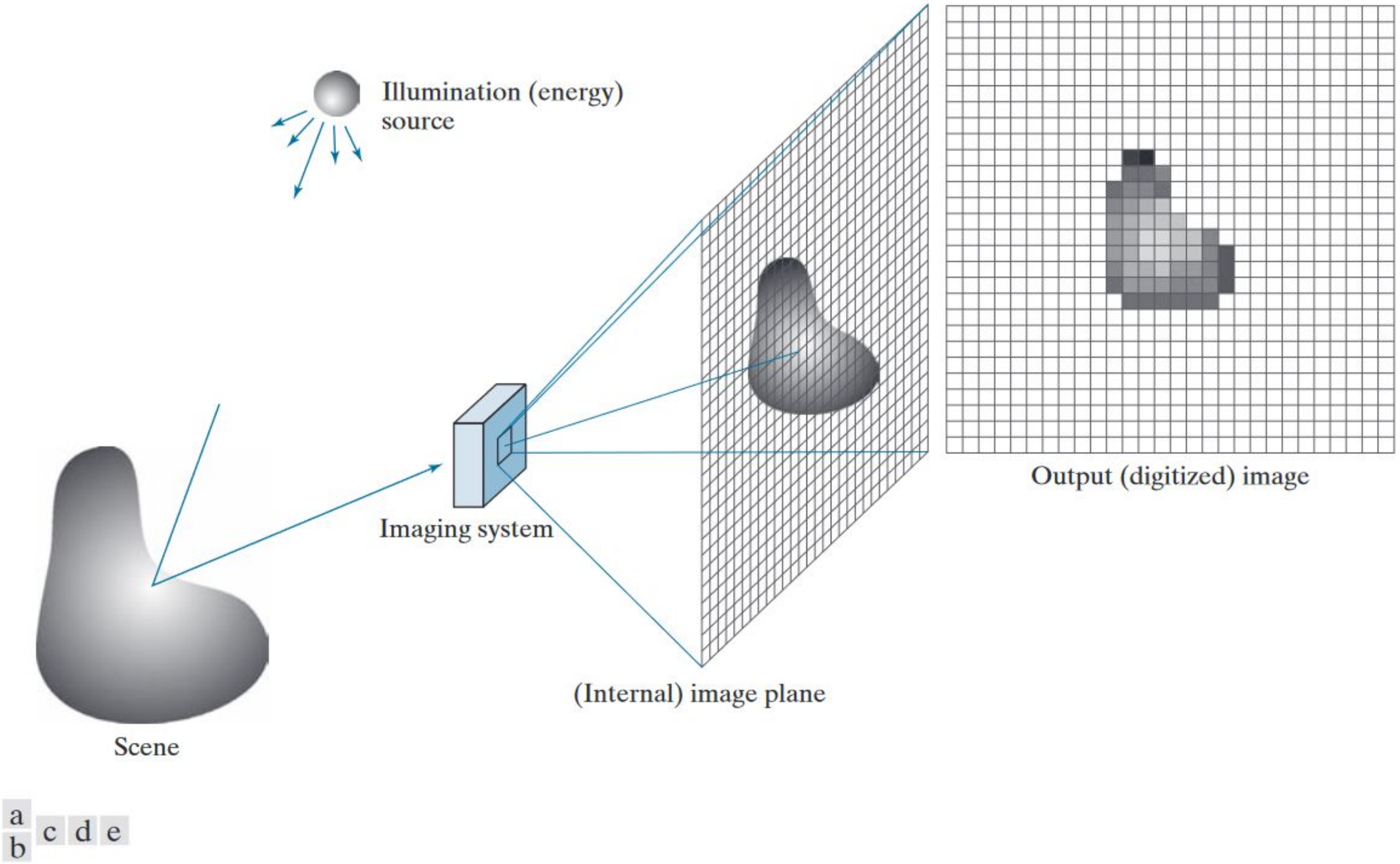


FIGURE 2.15 An example of digital image acquisition. (a) Illumination (energy) source. (b) A scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image formation model

- Let the intensity value at (x,y) of an image be $f(x,y)$.

- $f(x,y) = i(x,y)\ r(x,y)$
  where $i(x,y)$ is the amount of illumination the real-world scene received, and $r(x,y)$ is the reflectance.

- $i(x,y)$ is a positive, finite quantity.

- $r(x,y)$ varies from 0 to 1, where 0 means total absorption and 1 means total reflection.

- $f(x,y)$ thus is always a non-negative and finite quantity.

Monochrome (Grayscale Image)

$$\ell = f(x, y)$$

$$L_{\min} \le \ell \le L_{\max}$$

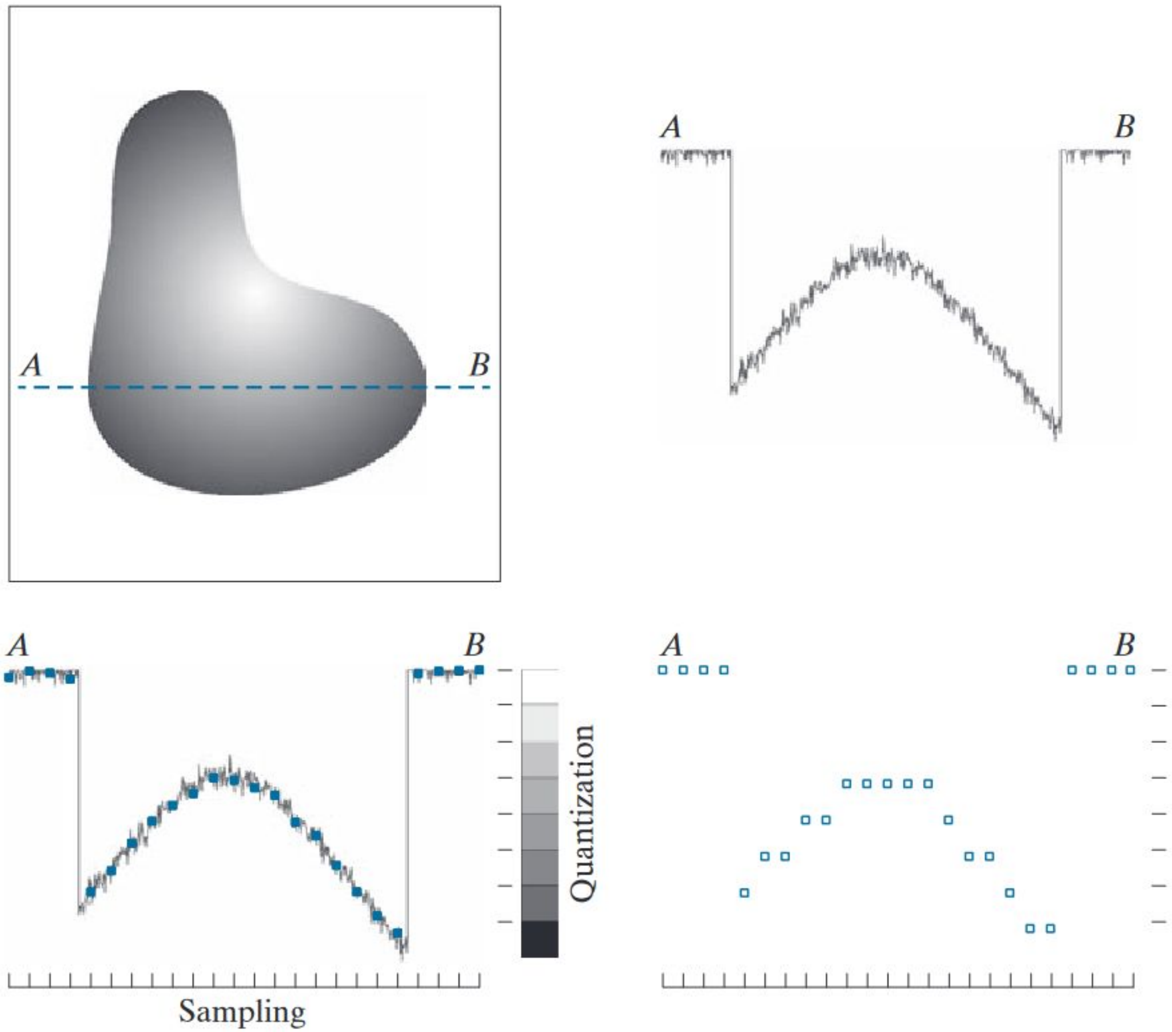
$$L_{\min} = i_{\min} r_{\min} \text{ and } L_{\max} = i_{\max} r_{\max}$$

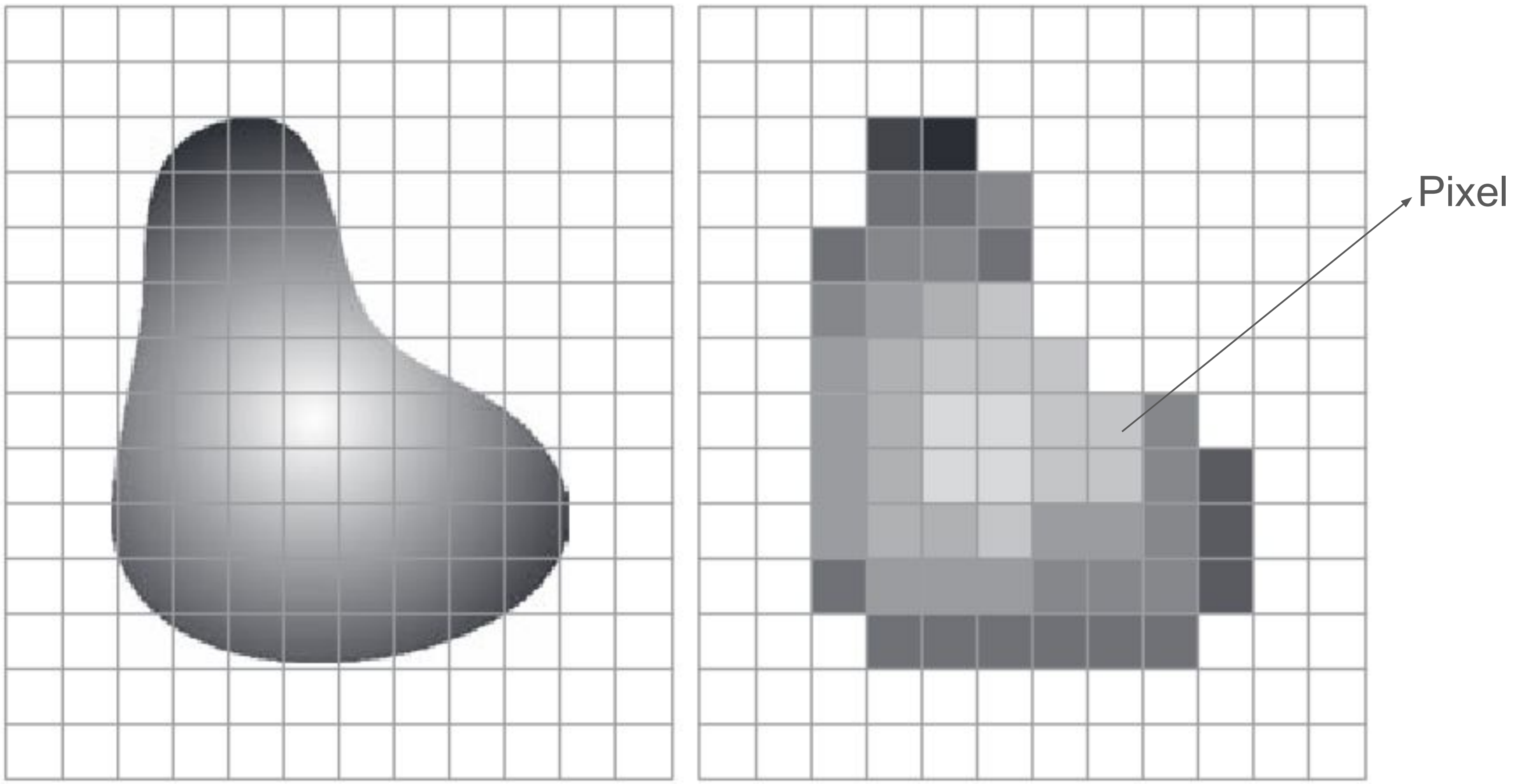
The interval $[L_{\min}, L_{\max}]$ is called the *intensity* (or *gray*) *scale*. Common practice is to shift this interval numerically to the interval $[0, 1]$, or $[0, C]$, where $\ell = 0$ is considered black and $\ell = 1$ (or C) is considered white on the scale. All intermediate values are shades of gray varying from black to white.

To have a digital image, we have to sample the function in both coordinates and also in amplitude.

Digitizing the coordinate values is called **sampling**.

Digitizing the amplitude values is called **quantization**.




Pixel

In general, the value of a digital image at any coordinates (x,y) is denoted by f(x,y), where x and y are integers.

$$\begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}$$

Image

$$\mathbf{A} = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \vdots & \vdots & & \vdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

Pixel value at (1,N-1)

Clearly, $a_{ij} = f(i,j)$

a
b c

FIGURE 2.18
(a) Image plotted as a surface. (b) Image displayed as a visual intensity array. (c) Image shown as a 2-D numerical array. (The numbers 0, .5, and 1 represent black, gray, and white, respectively.)

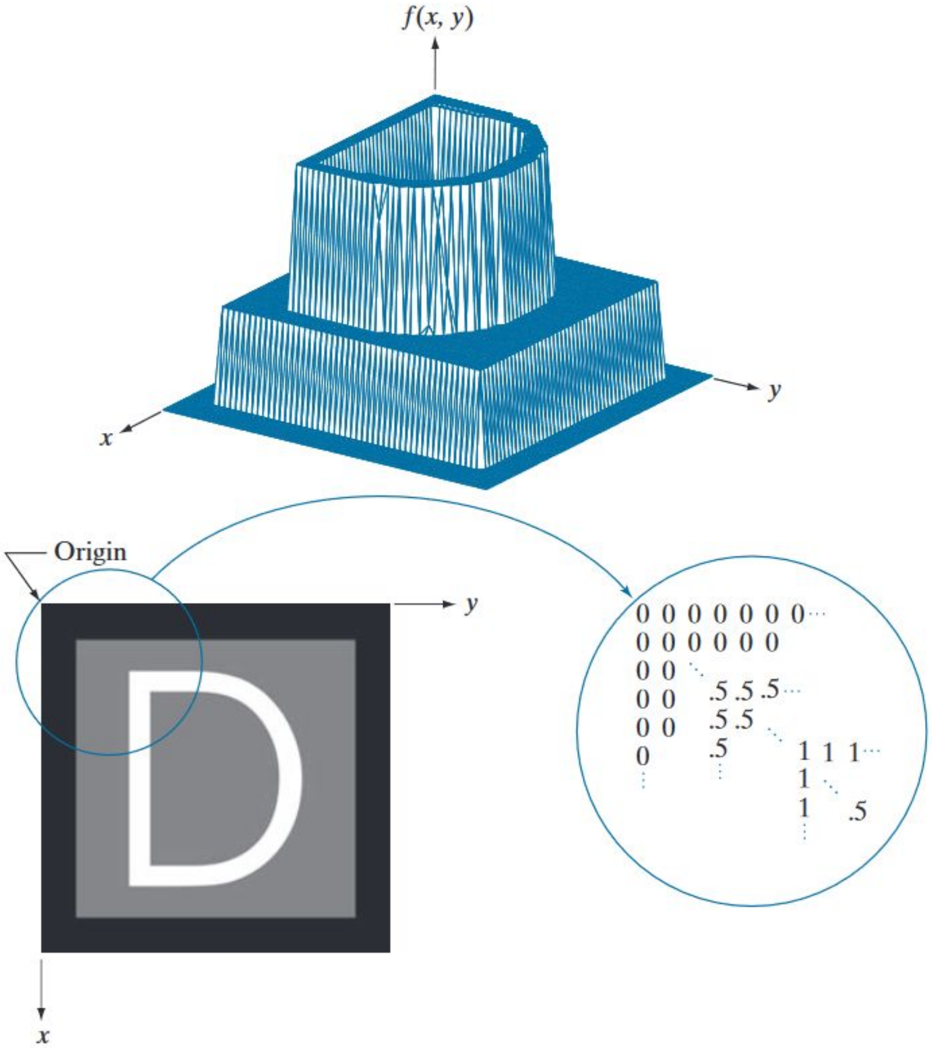
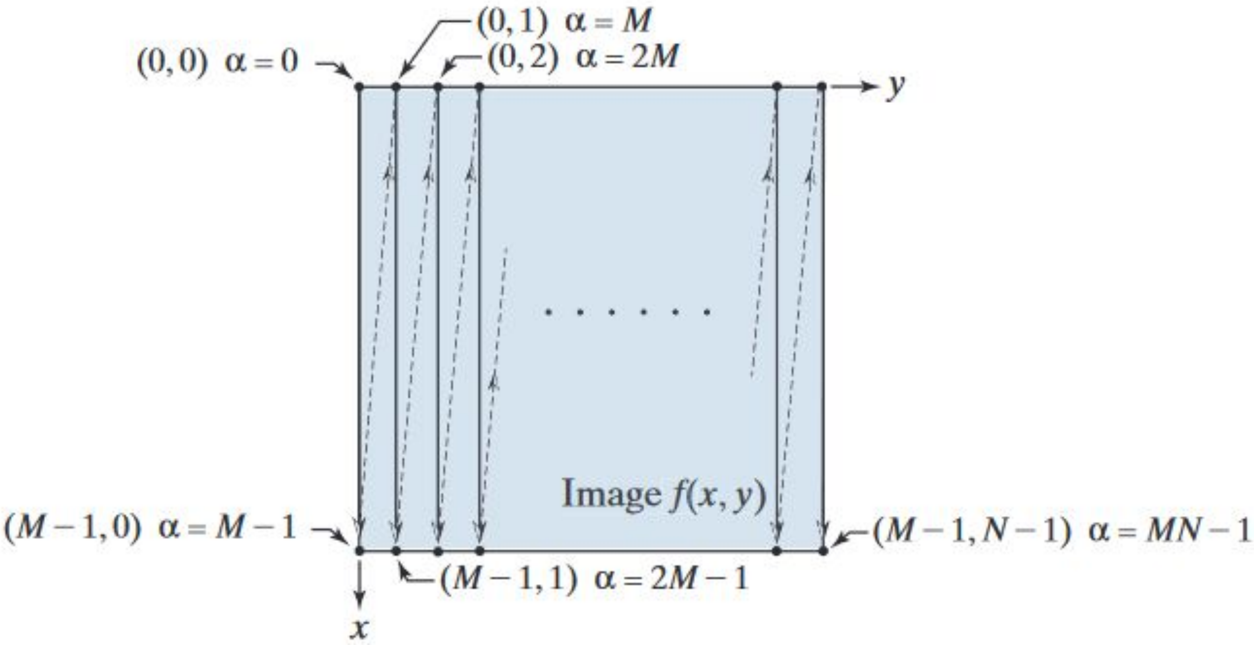


Image digitization requires that decisions be made regarding the values for M, N, and for the number, L, of discrete intensity levels. There are no restrictions placed on M and N, other than they have to be positive integers. However, digital storage and quantizing hardware considerations usually lead to the number of intensity levels, L, being an integer power of two; that is

$$L = 2^k$$

where k is an integer. We assume that the discrete levels are equally spaced and that they are integers in the range $[0, L-1]$.

FIGURE 2.22 Illustration of column scanning for generating linear indices. Shown are several 2-D coordinates (in parentheses) and their corresponding linear indices.



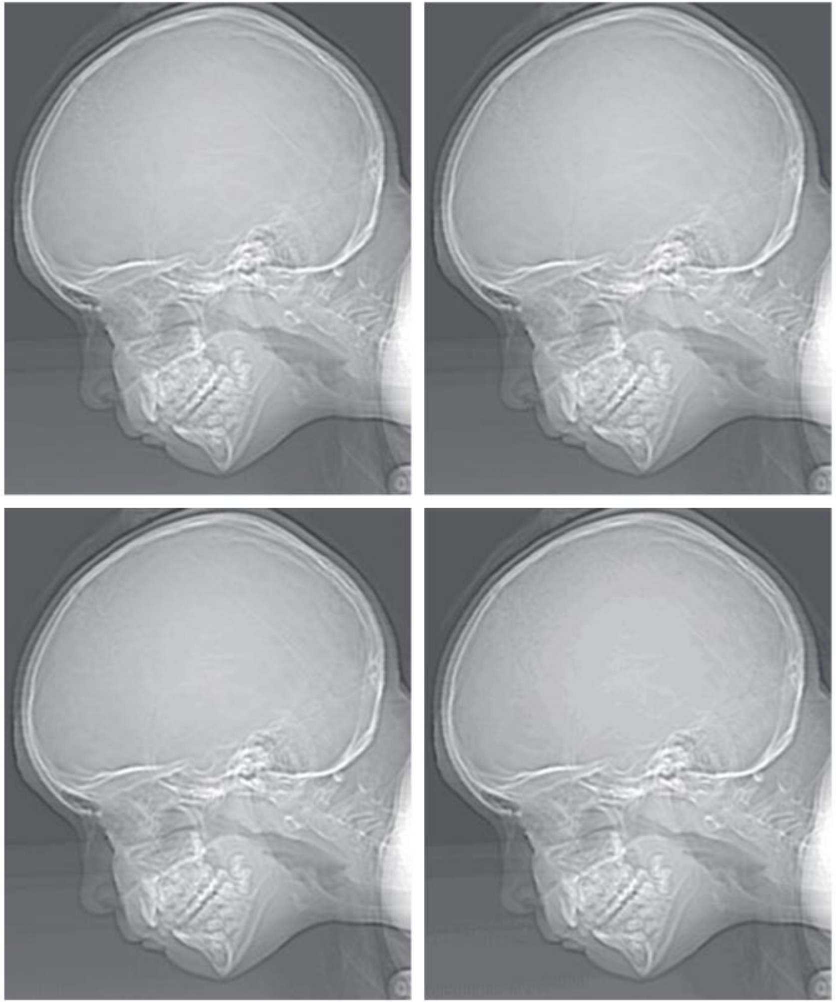
$$\alpha = My + x$$

$$x = \alpha \bmod M$$

$$y = (\alpha - x)/M$$

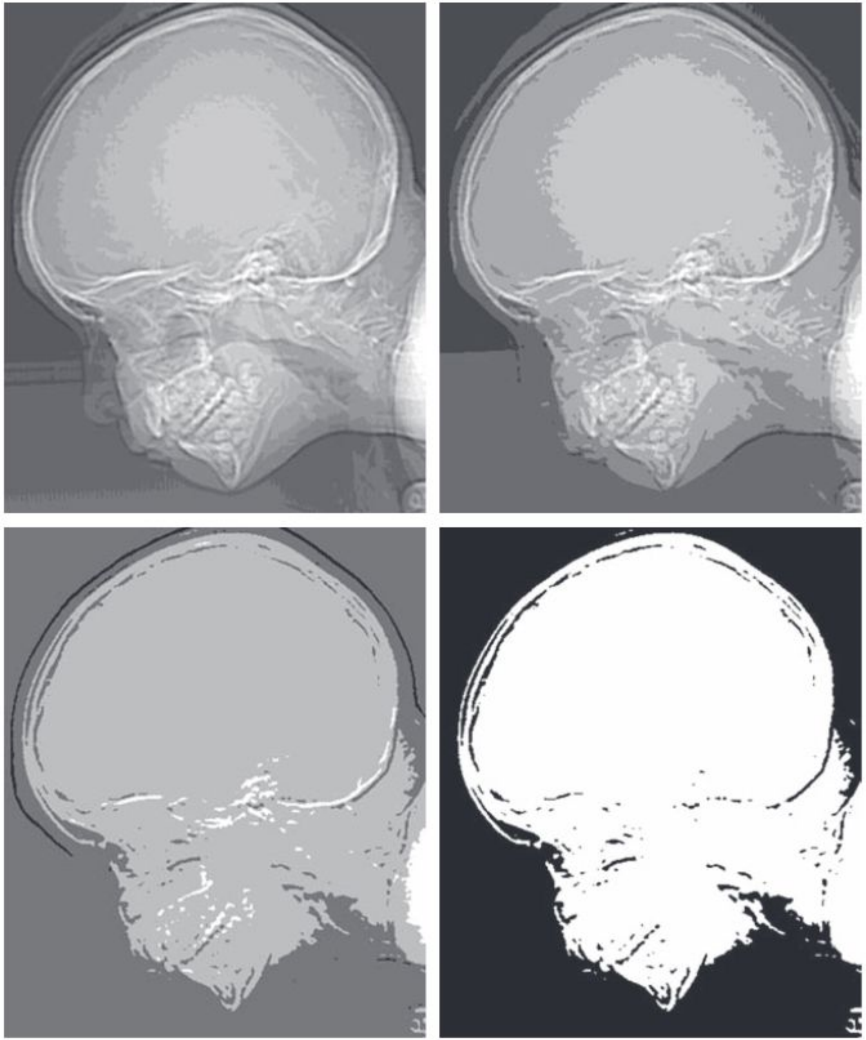
a	b
c	d

FIGURE 2.23 Effects of reducing spatial resolution. The images shown are at: (a) 930 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi.



a b
c d

FIGURE 2.24
(a) 774×640, 256-level image. (b)-(d) Image displayed in 128, 64, and 32 intensity levels, while keeping the spatial resolution constant. (Original image courtesy of the Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)



e f
g h

FIGURE 2.24 (*Continued*) (e)-(h) Image displayed in 16, 8, 4, and 2 intensity levels.