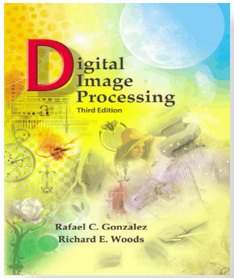
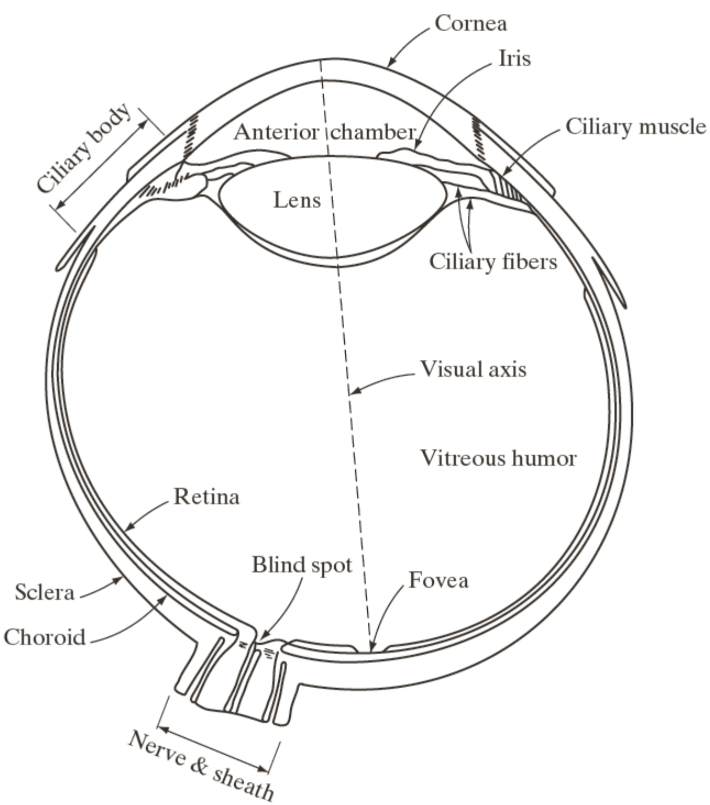


Digital Image Fundamentals

Structure of Human Eye

FIGURE 2.1 Simplified diagram of a cross section of the human eye.



Infrared and ultraviolet light are absorbed by proteins within the lens.

Iris contracts or expands – amount of light

Image on retina.

Two receptors in retina: *cones* & *rods*

Cons help to resolve fine details.
Cons are sensitive to color.
There are 6-7 million cones.

Rods serve to give a general overview.
Rods are not sensitive to color.
There are 75-150 million rods.

Image Formation in the Eye

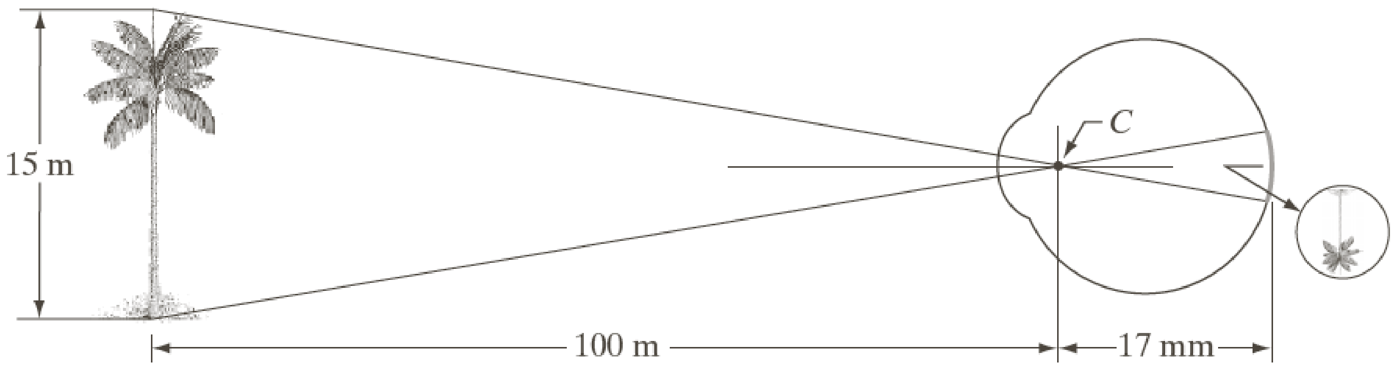


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

This distance is fixed
(lens to retina)

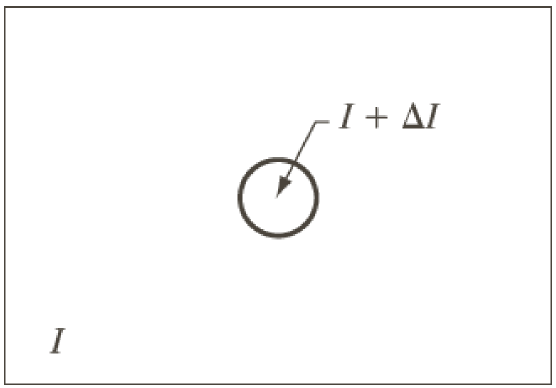
Focal length is adjusted by: (1) *flattening* (for distant objects) or (2) *thickening* (for near objects) the lens.

For photographic camera:

Focal length is fixed, but distance between lens and imaging plane is varied.

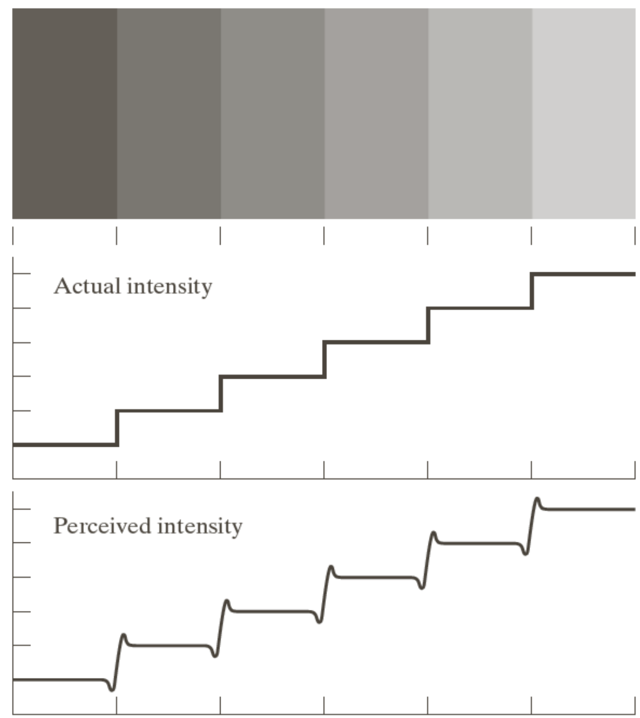
Image Formation in the Eye

Weber Ratio: $\Delta I_c/I$



The ratio of increment of illumination to background of illumination is called as weber ratio.

A small value of Weber ratio: a small change in intensity is discriminable; good brightness adaptation.



a
b
c

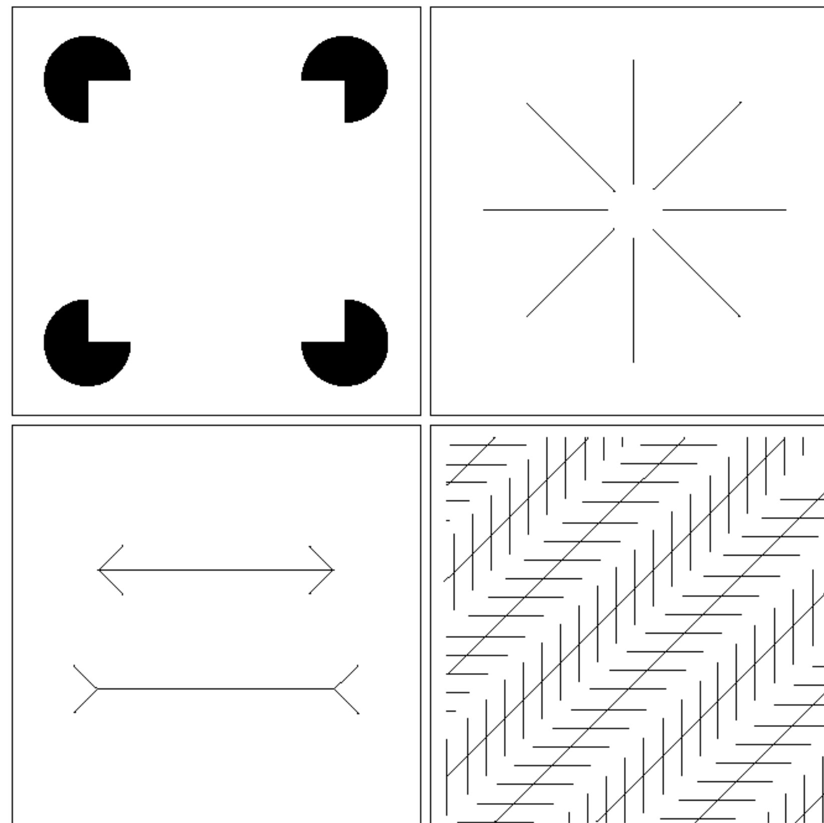
FIGURE 2.7 Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.

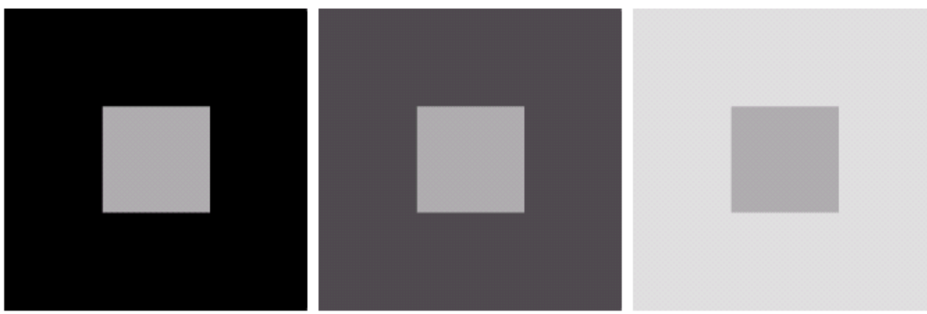
Machband effect means the intensity of the stripes is constant. Therefore, it preserves the brightness pattern near the boundaries, these bands are called as machband effect.

Simultaneous Contrast & Optical Illusions

a b
c d

FIGURE 2.9 Some well-known optical illusions.



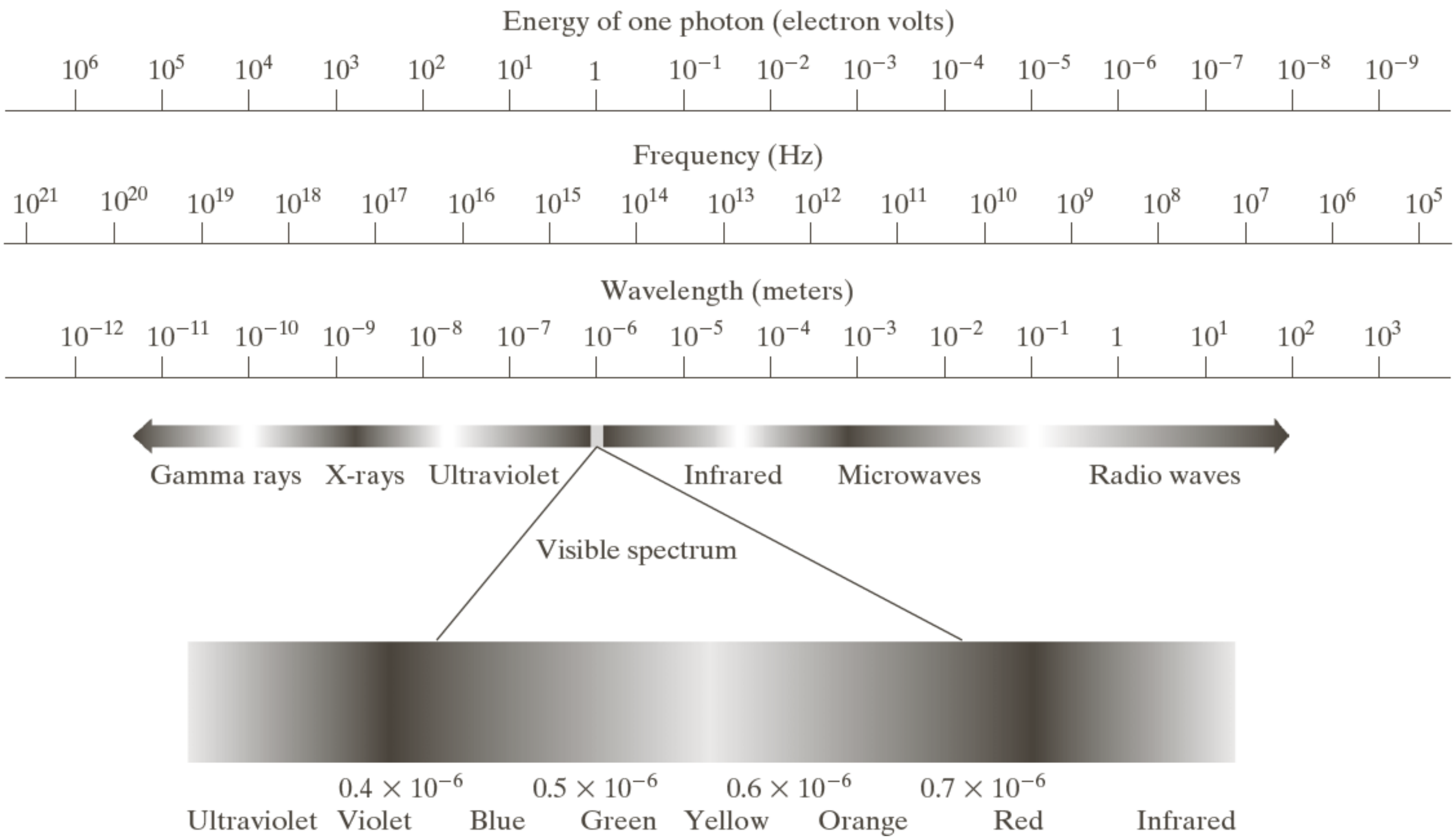


a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

A region's brightness does not only depend on its intensity but also on its background.

Electromagnetic Spectrum



Electromegnetic spectrum can be expressed in terms of energy, wavelength and frequency,

$$\lambda = c/v$$

Where λ is the wavelength

c is speed of light (2.998×10^8 m/s)

v is the frequecy of the electromagnetic wave

Light

Light is an electromagnetic radiation.

Monochromatic: gray scale image.

Chromatic: frequency, *radiance*, *luminance*, *brightness*.

Radiance: total energy that flows from the light source. Watt (W).

Luminance: amount of energy an observer perceives from the source. Lumens (lm).

Brightness: subjective descriptor of light perception. No measure.

Image Formation - I

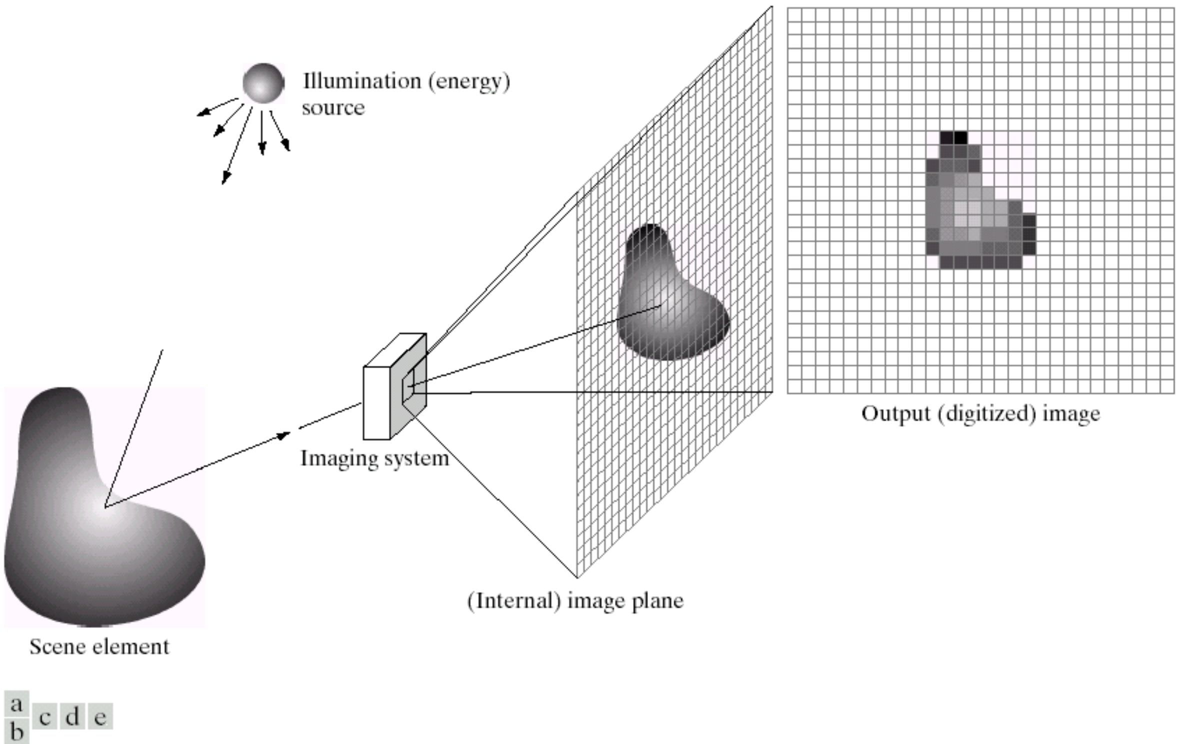


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image function: $f(x,y)$

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

illumination ($i(x,y)$)

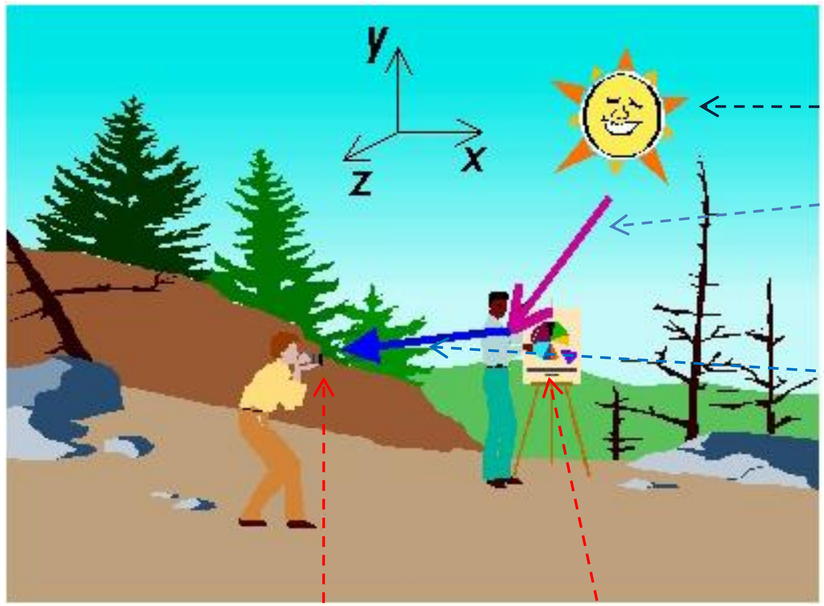
reflectance ($r(x,y)$)

$$0 < i(x,y) < \infty$$

$$0 < r(x,y) < 1$$

Image Formation - II

x, y, z: world coordinates of a point.



Light source

Illumination

Reflection

λ: wavelength.

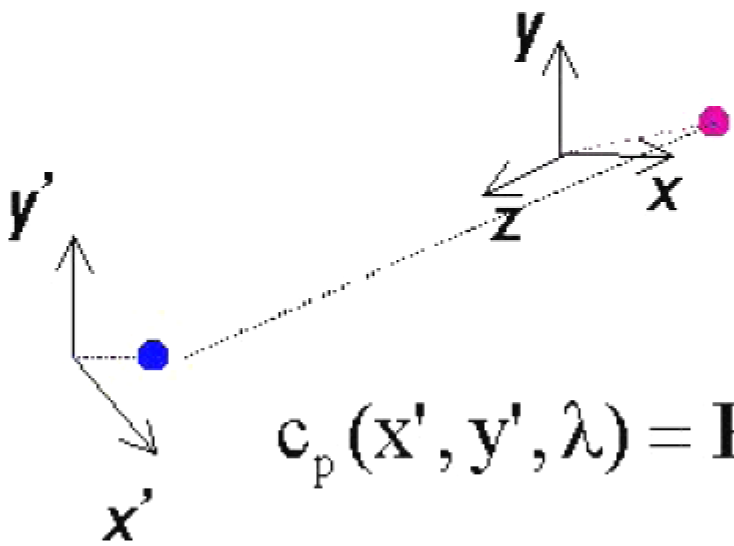
Scene

Imaging system (camera)

$$\textbf{Camera}(c(x, y, z, \lambda)) =$$

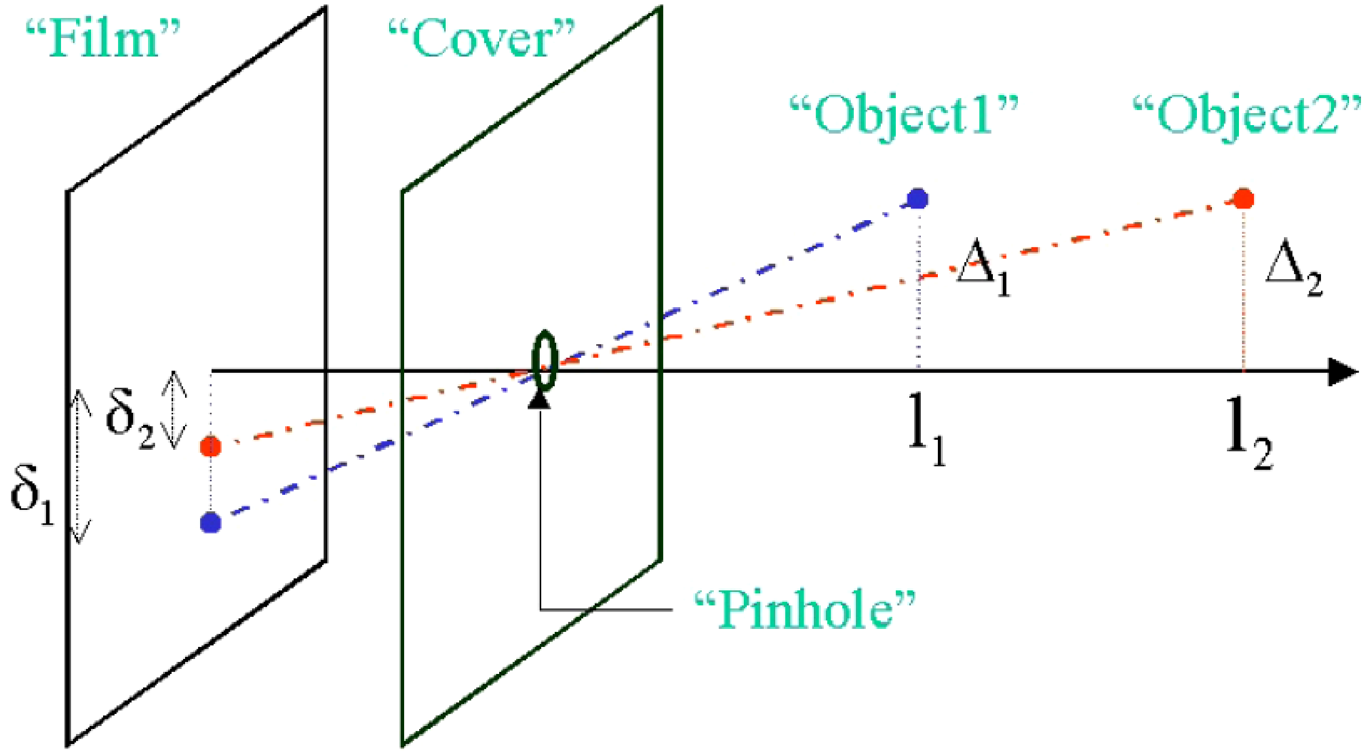
Inside the Camera: Projection

From world coordinate (3-dimensional) to image coordinate (1-dimensional).



$$c_p(x', y', \lambda) = \mathbf{P}(c(x, y, z, \lambda))$$

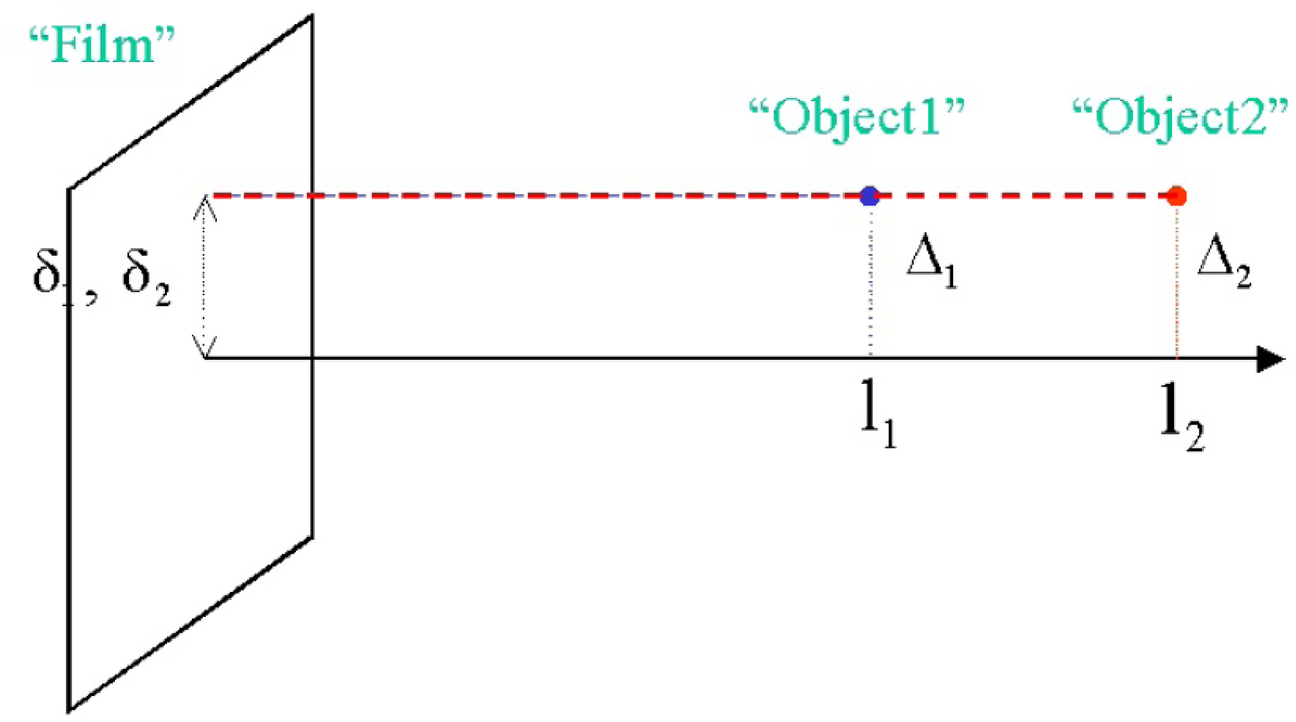
Projection: Perspective



- Perspective Projection: $\Delta_1 = \Delta_2,\ l_1 < l_2 \rightarrow \delta_2 < \delta_1$.

Objects closer to the capture device appear bigger. Human eye or camera.

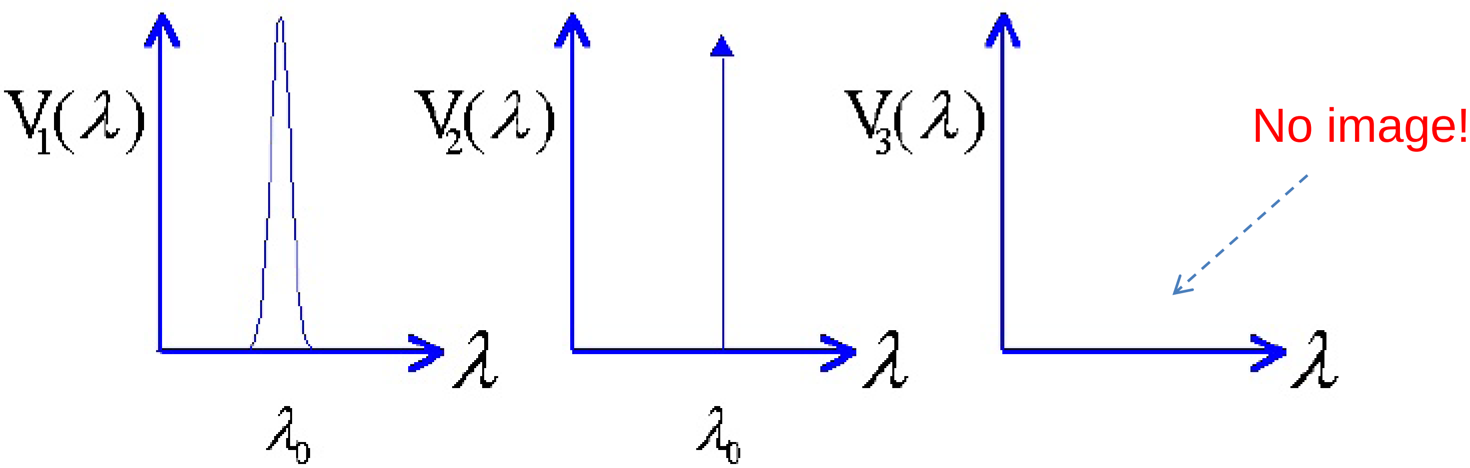
Projection: Orthographic



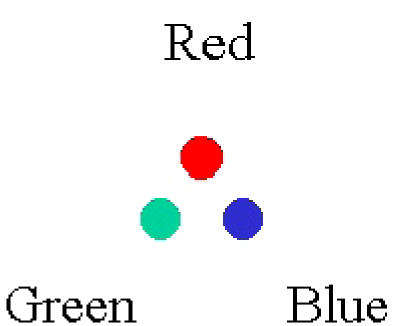
- Ortographic Projection: $\Delta_1 = \Delta_2,\ l_1 < l_2 \rightarrow \delta_2 = \delta_1.$

Objects appear to be of same size regardless to the distance from the capture device.

Sensitivity



$$f(x', y') = \int c_p(x', y', \lambda) V(\lambda) d\lambda$$



$$c_p(x', y', \lambda)$$

Three sensors

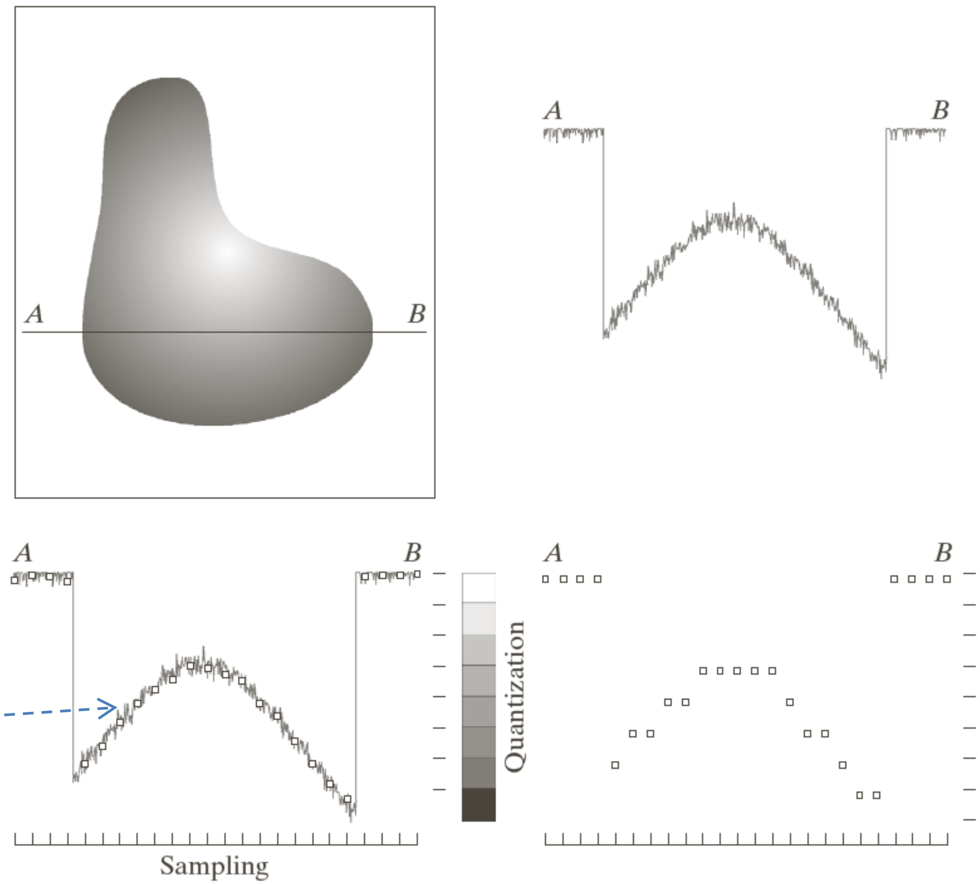
$$f_R(x', y') = \int c_p(x', y', \lambda) V_R(\lambda) d\lambda$$
$$f_G(x', y') = \int c_p(x', y', \lambda) V_G(\lambda) d\lambda$$
$$f_B(x', y') = \int c_p(x', y', \lambda) V_B(\lambda) d\lambda$$

Sampling & Quantization

Sampling: digitizing the coordinate values.

Quantization: digitizing the amplitude values.

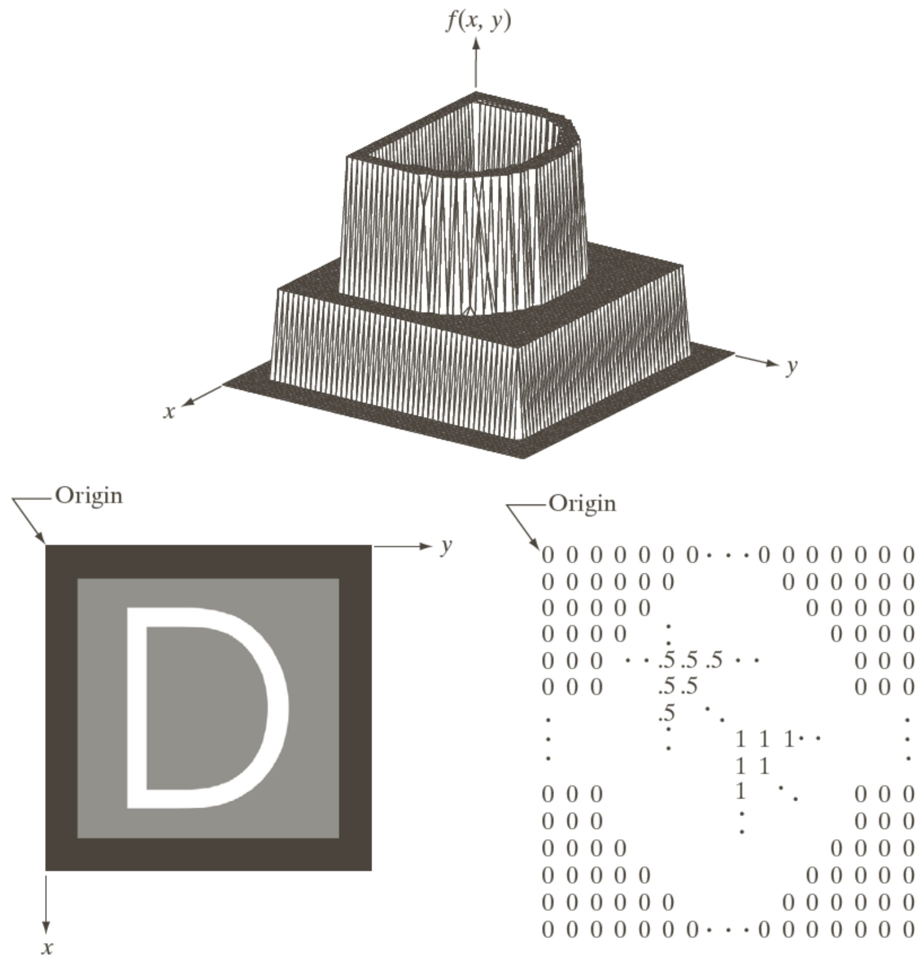
The random values are due to image noise.



$x',\ y' \Rightarrow x'_i,\ y'_j \quad (i = 0, \dots, N-1,\ j = 0, \dots, M-1)$: Sampling

$f_C(x'_i, y'_j) \Rightarrow \hat{f}_C(x'_i, y'_j)$: Quantization.

Representing Digital Images - I



Representing Digital Images - II

- An image matrix $(N \times M)$:

$$\mathbf{A} = \begin{bmatrix} A(0,0) & A(0,1) & A(0,2) & \dots & A(0,M-1) \\ A(1,0) & A(1,1) & A(1,2) & \dots & A(1,M-1) \\ \vdots & & & & \\ A(N-1,0) & A(N-1,1) & A(N-1,2) & \dots & A(N-1,M-1) \end{bmatrix}$$

L: discrete intensity level.

$$L = 2^k$$

The number, *b*, of bits required to store a digitized image:

$$b = M \times N \times k$$

Example: If each pixel is represented by 8 bits, there will be 256 discrete intensity levels [0 to 255] of the pixels.

Spatial Resolution

1250 dpi

300 dpi

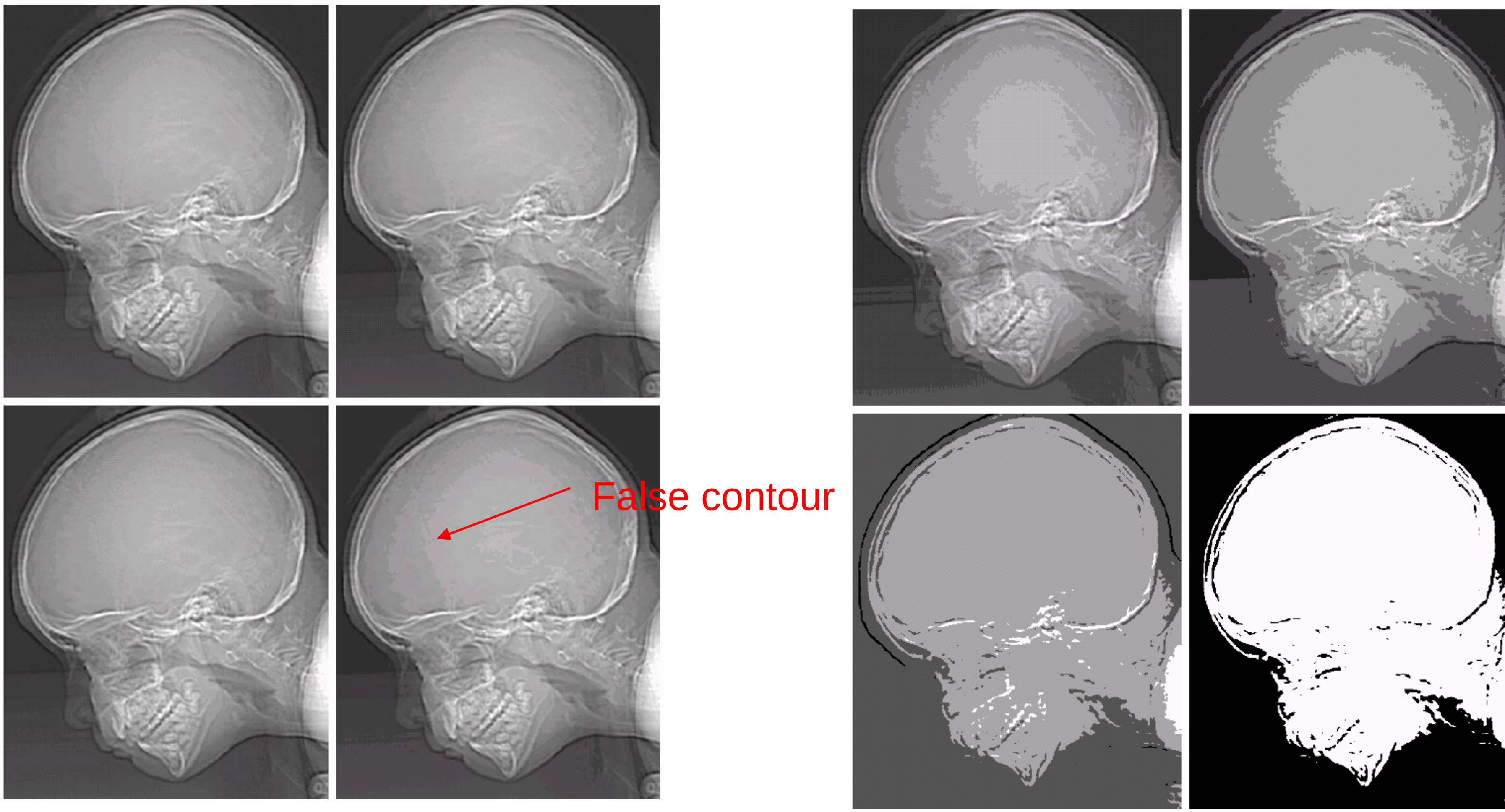
150 dpi

72 dpi

Intensity Resolution

Size: 452 X 374

256 level 128 level 16 level 8 level



64 level 32 level 4 level 2 level

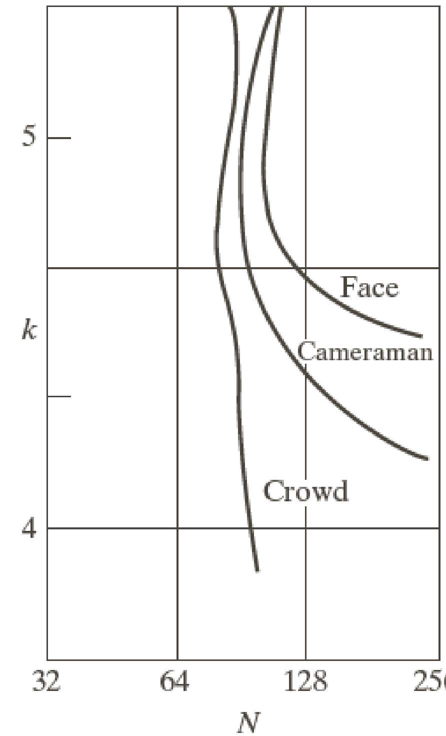
Intensity & Spatial

Low level of detail

Large amount of detail

a b c

FIGURE 2.22 (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)



Isopreference Curve

Image Interpolation

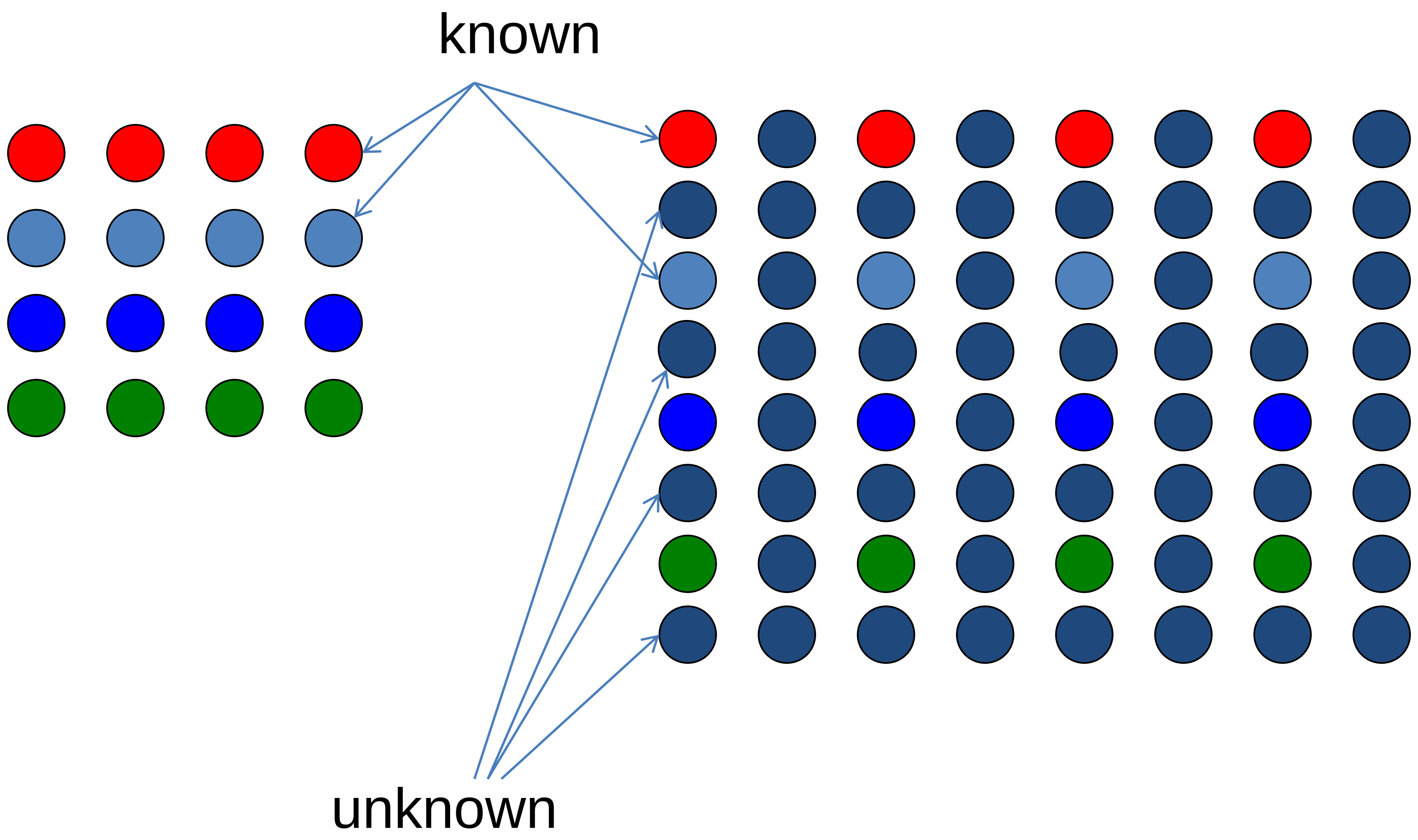
Interpolation: the process of using known data to estimate values at unknown locations.

- *Nearest neighborhood interpolation*.
- *Bilinear interpolation*: uses four nearest neighbors.
- *Bicubic interpolation*: uses sixteen nearest neighbors.

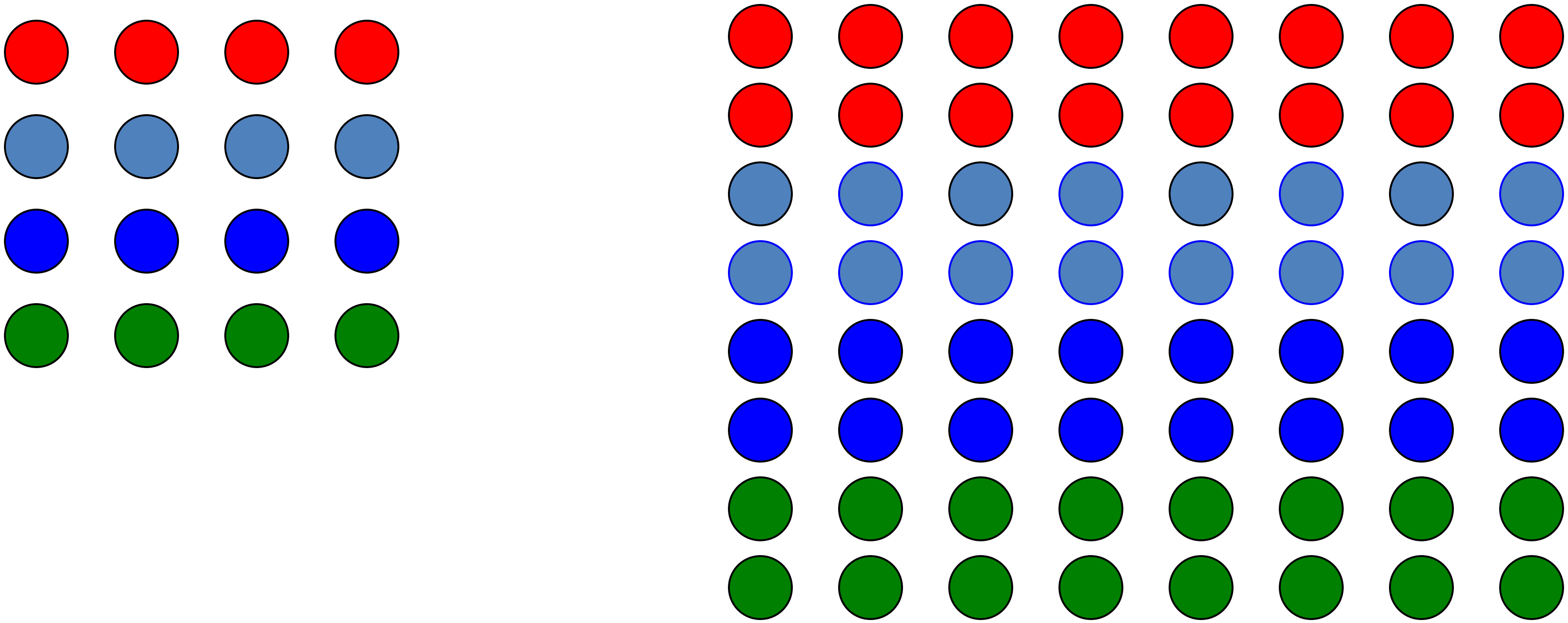
Used in Adobe Photoshop

Complexity, quality

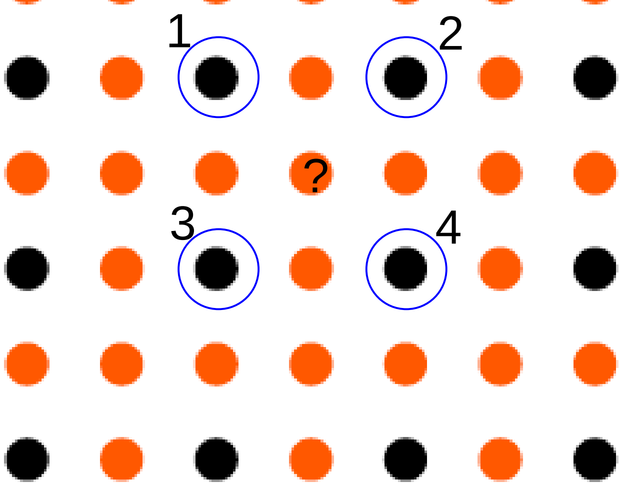
Nearest Neighbor Interpolation



Nearest Neighbor Interpolation



Bilinear Interpolation



$$f(x, y) = ax + by + cxy + d$$

coefficients that need to be estimated

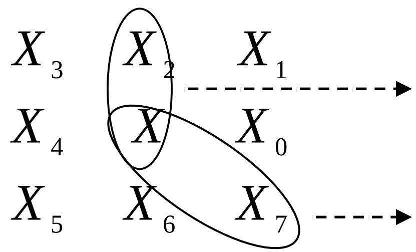
$$ax_1 + by_1 + cx_1y_1 + d = f(x_1, y_1)$$
$$ax_2 + by_2 + cx_2y_2 + d = f(x_2, y_2)$$
$$ax_3 + by_3 + cx_3y_3 + d = f(x_3, y_3)$$
$$ax_4 + by_4 + cx_4y_4 + d = f(x_4, y_4)$$

$$a, b, c, d$$

Known pixels

Unknown pixels

Binary Image Connectivity



Bond weight = 2

Bond weight = 1

Four connected: X is 1, and X_0, X_2, X_4, or X_6 are/is 1.

Eight connected: X is 1, and (X_0, X_1) and/or (X_0, X_7), etc. are 1.

1	1	1
0	*X*	0
1	1	0

Pixel bond = 7

Neighbors -1

4 - Neighbors

Vertical and horizontal neighbors of P (x,y) are called 4- neighbors of P. They are denoted by $N_4(P)$

	$N_4(P)$	
$N_4(P)$	P	$N_4(P)$
	$N_4(P)$	

The coordinates of 4- neighbors are:
(x-1, y), (x+1, y), (x, y-1), (x, y+1)

The distance between P and any of the $N_4(P)$ is 1.

$$d = \sqrt{(x-(x-1))^2 + (y-y)^2} = 1$$

Neighbors -2

D - Neighbors

Diagonal neighbors of P (x,y) are called D- neighbors of P. They are denoted by $N_D(P)$

$N_D(P)$		$N_D(P)$
	P	
$N_D(P)$		$N_D(P)$

The coordinates of D- neighbors are:
(x-1, y-1), (x+1, y+1), (x+1, y-1), (x-1, y+1)

The distance between P and any of the $N_D(P)$ is 1.414

$$d = \sqrt{(x-(x-1))^2 + (y-(y-1))^2} = 1.414$$

Neighbors -3

8 - Neighbors

$N_8(P) = N_4(P) \cup N_D(P)$

$N_D(P)$	$N_4(P)$	$N_D(P)$
$N_4(P)$	P	$N_4(P)$
$N_D(P)$	$N_4(P)$	$N_D(P)$

Adjacency -1

- *4-adjacency*. Two pixels *p* and *q* with values from *V* are 4-adjacent if q is in the set $N_4(p)$.
- *8-adjacency*. Two pixels p and q with values from *V* are 8-adjacent if q is in the set $N_8(p)$.
- *m-adjacency* (mixed adjacency). Two pixels p and q with values from *V* are m-adjacent if
  - *q* is in $N_4(p)$, *or*
  - *q* is in N_D(p) *and* the set $N_4(p) \cap N_4(q)$ has no pixels whose values are from *V.*

Adjacency -2

V={0,1}

0	0	3	2	1
1	2	0	0	3
0	1	2	1	3
0	3	1	0	2
1	2	0 q	0	3

4-adjacent pixels:

8-adjacent pixels:

4-adjacent pixels and

m-adjacent pixels:

4-adjacent pixels (1^{st} condition)

2^{nd} condition is not satisfied.

Consider q at (4,2), which is $N_D(P)$. Now the union of $N_4(q)$ and $N_4(P)$ is at (4,3) and value is 0, which is in V; so the union is not empty

Path

Let coordinates of pixel

p: (x, y), and of pixel q: (s, t)

A *path* from p to q is a sequence of distinct pixels with coordinates:

$(x_0, y_0), (x_1, y_1), \ldots\ldots, (x_n, y_n)$

where

$(x_0, y_0) = (x, y)$ & $(x_n, y_n) = (s, t)$,

and (x_i, y_i) is adjacent to (x_{i-1}, y_{i-1}) $1 \leq i \leq n$

length of path = n

If $(x_0, y_0) = (x_n, y_n)$ then closed path

Pixel Neighborhood Connectivity Definition

0	0	0
0	1	1
0	1	0

Four-connected

$B = 4$

0	0	0
0	1	1
0	0	1

Eight-connected

$B = 3$

0	0	0
0	1	0
0	0	0

Isolated

$B = 0$

0	0	0
0	1	0
0	0	1

Spur

$B = 1$

1	0	0
1	1	1
1	0	1

Bridge

$B = 7$

1	1	1
0	1	0
1	1	1

H-connected

$B = 8$

0	0	0
0	1	1
0	1	1

Corner

$B = 5$

0	1	1
1	1	1
1	1	1

Interior

$B = 1$

0	1	1
0	1	1
0	1	1

Exterior

$B = 8$

Acknowledgement

Gonzalez, R. C. and Woods, R. E., *Digital Image Processing*, 3rd Ed., 2008, Prentice Hall and Rafael C. Gonzalez, Richard E. Woods, *Digital Image Processing*, 2nd ed.