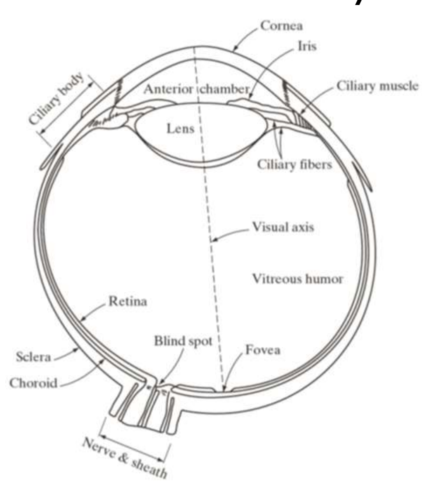
Digital Image Fundamentals

1

Elements of Visual Perception

- Structure of the Human Eye



2

Rods and Cones in the Retina

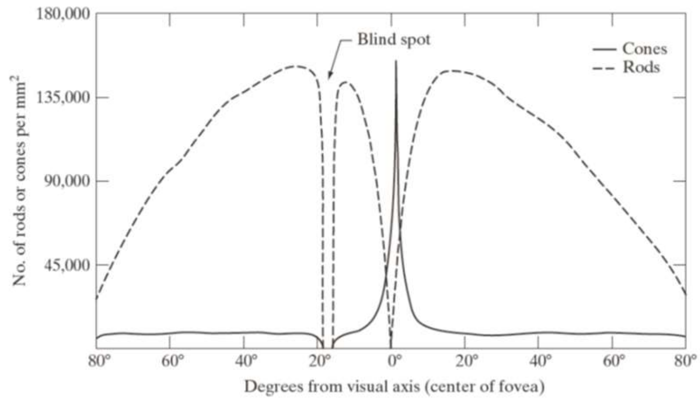


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Image Formation in the Eye

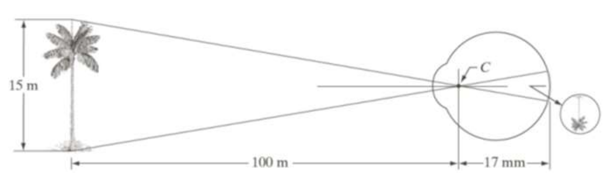

FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point C is the optical center of the lens.

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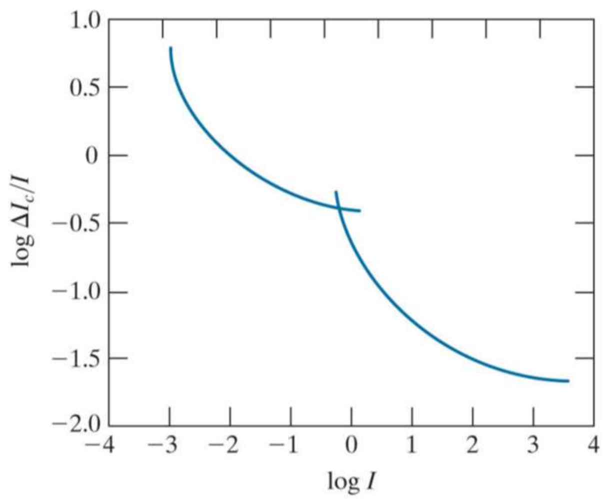
Weber ratio



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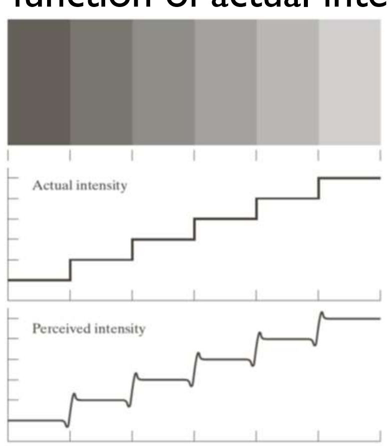
Mach band effect

- Perceived intensity is not a simple function of actual intensity



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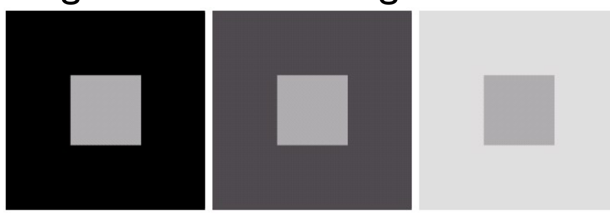
Simultaneous Contrast

- All the inner squares have the same intensity
- They appear progressively darker as the background becomes lighter



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.

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Example

- Piece of white paper
- Lying on a desk
- Looking directly at a bright sky by shielding the eyes with the paper

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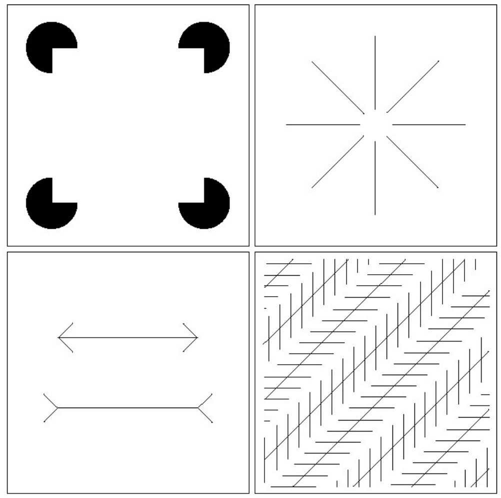
Optical Illusion



a b
c d
FIGURE 2.9 Some well-known optical illusions.

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Image Sensing and Acquisition

- Illumination source
- Reflection or absorption of energy from that source by the elements of the scene being imaged
- Sensor – responsive to particular type of energy

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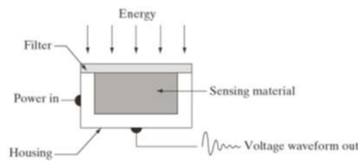
Sensor Arrangements



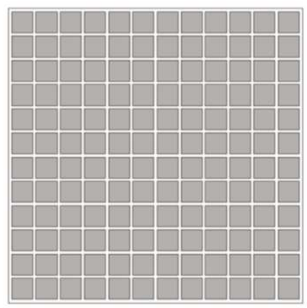


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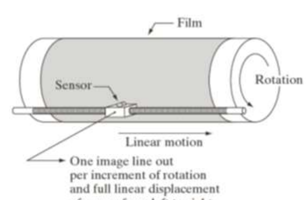
Image Acquisition using a Single Sensor

- Photodiode – silicon material
- Filter – improves selectivity
- Mechanical digitizers
  - Microdensitometers



- Laser source coincident with the sensor
  - Moving mirrors

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Image Acquisition using Sensor Strips

- In-line arrangement of sensors – strip
- Flat bed scanners
- Ring configuration – medical & industrial imaging (CT, MRI, PET)

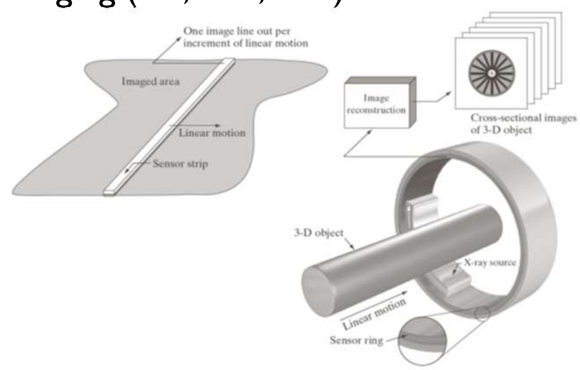

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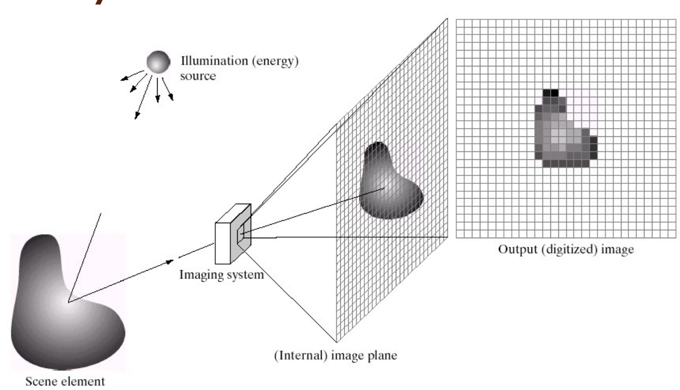
Image Acquisition using Sensor Arrays



a b c d e

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.

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Simple Image Formation Model

- $0 < f(x, y) < \infty$
  - Amount of source illumination incident on the scene being viewed – illumination component
  - Amount of illumination reflected by the objects in the scene – reflectance component
- $f(x, y) = i(x, y)r(x, y)$
- $0 < i(x, y) < \infty$, $0 < r(x, y) < 1$
- 0 – total absorption, 1 – total reflection
- i – illumination source, r – characteristics of imaged objects

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Illumination and Reflectance

- Illumination
  - Clear day – 90, 000lm/m^2
  - Cloudy day – 10, 000lm/m^2
  - Full moon on a clear evening – 0.1lm/m^2
  - Commercial office – 1000lm/m^2
- Reflectance
  - Black velvet – 0.01
  - Stainless steel – 0.65
  - Flat white wall paint – 0.80
  - Silver plated metal – 0.90
  - Snow – 0.93

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Intensity levels

- $l = f(x0, y0)$
- $L_{min} \leq l \leq L_{max}$
- $L_{min} = i_{min}\, r_{min}$
- $L_{max} = i_{max}\, r_{max}$
- $L_{min} \approx 10$, $L_{max} \approx 1000$
- Gray (intensity) scale [Lmin, Lmax]
- Common practice: [0, L-1],
- l = 0 – black, l = L-1 – white
- Shades of gray – intermediate values

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Image Sampling and Quantization

- Sensor output – continuous voltage
  - Amplitude and spatial behavior are related to the physical phenomenon being sensed
- Digital image
  - Sampling – digitizing the coordinate values
  - Quantization – digitizing the amplitude values

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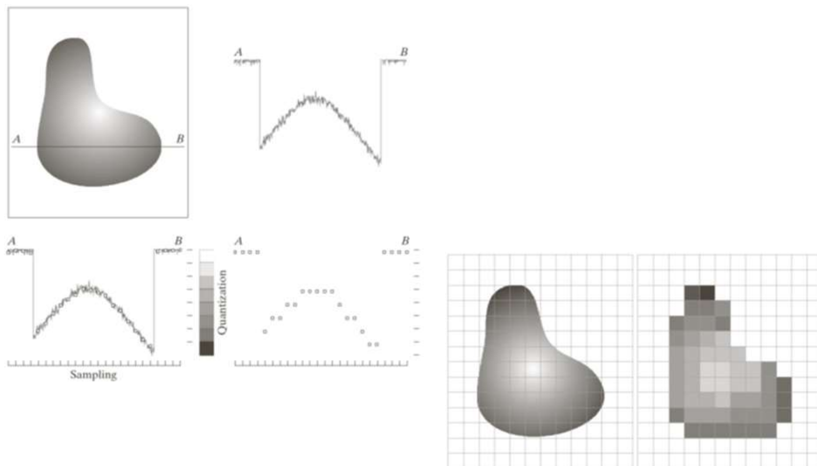
Sampling and Quantization



a b

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

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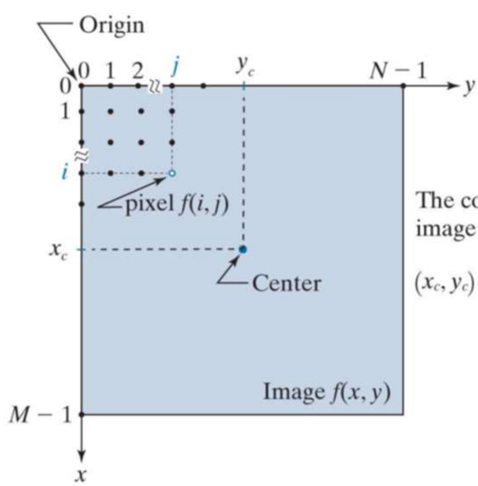
Coordinate convention



The coordinates of the image center are

$$(x_c, y_c) = \left(\text{floor}\left(\frac{M}{2}\right), \text{floor}\left(\frac{N}{2}\right)\right)$$

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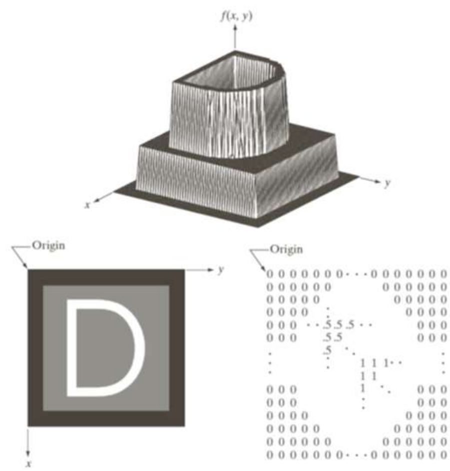
Representing Digital Images

- f(x, y), x = 0, 1, 2, …, M – 1, y = 0, 1, 2, …, N – 1



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Digital Image

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

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Definitions

- Dynamic range – range of values spanned by the gray scale
  - Ratio of the maximum measurable intensity to the minimum detectable intensity level
  - Upper limit – saturation
  - Lower limit – noise
- Image contrast – difference in intensity between the highest and lowest intensity levels
  - High dynamic range – high contrast
  - Low dynamic range – dull, washed-out gray look

Example

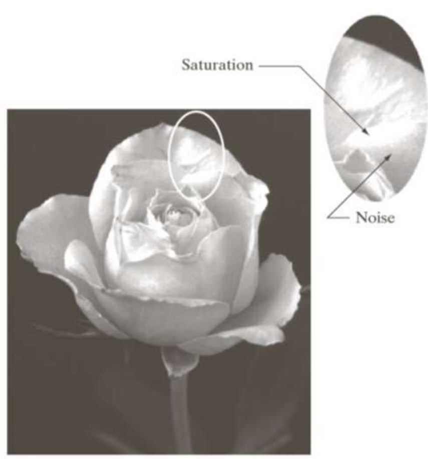
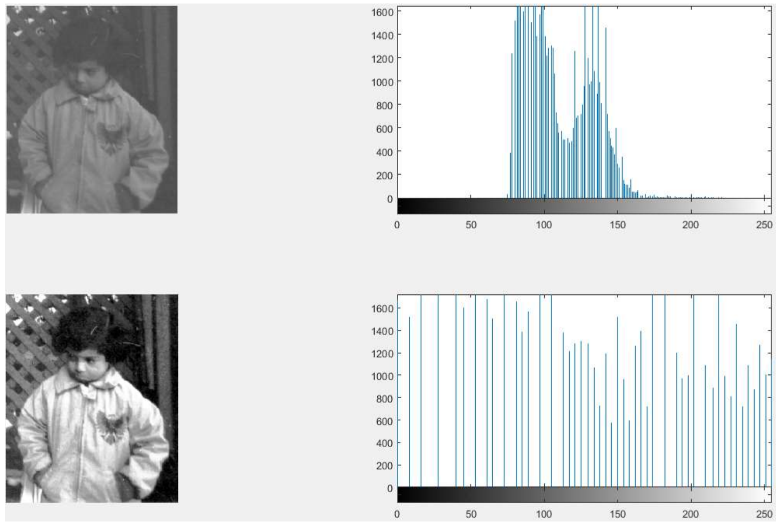


FIGURE 2.19 An image exhibiting saturation and noise. Saturation is the highest value beyond which all intensity levels are clipped (note how the entire saturated area has a high, *constant* intensity level). Noise in this case appears as a grainy texture pattern. Noise, especially in the darker regions of an image (e.g., the stem of the rose) masks the lowest detectable true intensity level.

Example



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Storing a digitized image

- Number of bits (b) required to store a digitized image b = M x N x k, L = 2^k
  - k-bit image

	1	2	3	4	5	6	7	8
32	1024	2048	3072	4096	5120	6144	7168	8192
64	4096	8192	12288	16384	20480	24576	28672	32768
128	16384	32768	49152	65536	81920	98304	114688	131072
256	65536	131072	196608	262144	327680	393216	458752	524288
512	262144	524288	786432	1048576	1310720	1572864	1835008	2097152
1024	1048576	2097152	3145728	4194304	5242880	6291456	7340032	8388608
2048	4194304	8388608	12582912	16777216	20971520	25165824	29360128	33554432
4096	16777216	33554432	50331648	67108864	83886080	100663296	117440512	134217728
8192	67108864	134217728	201326592	268435456	335544320	402653184	469762048	536870912

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Storage in MB

	1	2	3	4	5	6	7	8
32	0.000977	0.0019531	0.0029297	0.0039063	0.0048828	0.0058594	0.0068359	0.0078125
64	0.003906	0.0078125	0.0117188	0.015625	0.0195313	0.0234375	0.0273438	0.03125
128	0.015625	0.03125	0.046875	0.0625	0.078125	0.09375	0.109375	0.125
256	0.0625	0.125	0.1875	0.25	0.3125	0.375	0.4375	0.5
512	0.25	0.5	0.75	1	1.25	1.5	1.75	2
1024	1	2	3	4	5	6	7	8
2048	4	8	12	16	20	24	28	32
4096	16	32	48	64	80	96	112	128
8192	64	128	192	256	320	384	448	512

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Spatial Resolution

- Measure of the smallest discernible detail in an image
  - Dots (pixels) per unit distance (dpi)
  - Newspapers – 75dpi, magazines – 133dpi, glossy brochures – 175dpi, book page – 2400dpi
  - 20MP CCD imaging chip – higher capability to resolve detail than an 8MP camera

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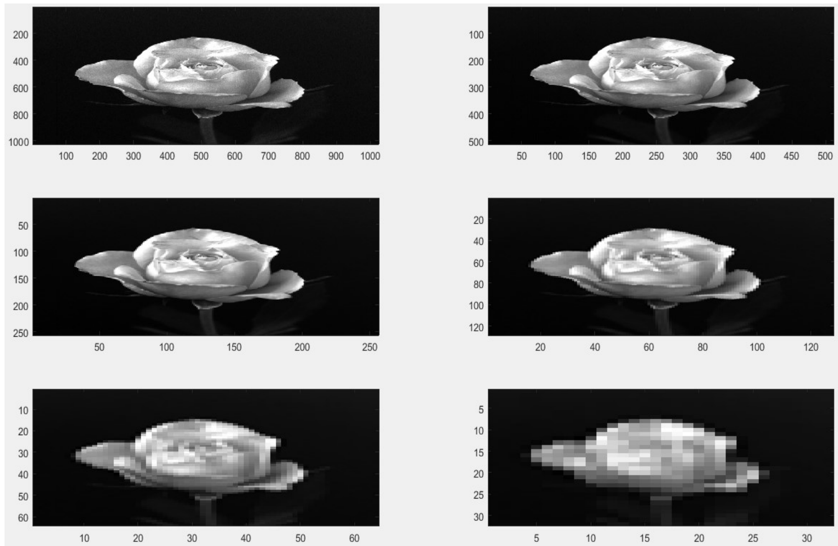
Example



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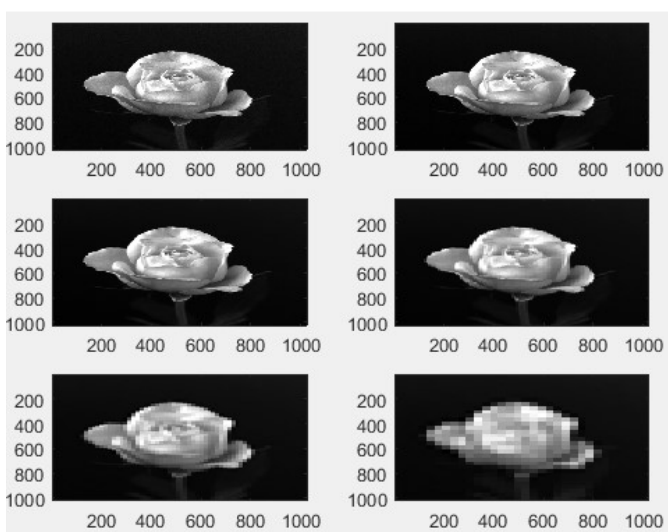
Example



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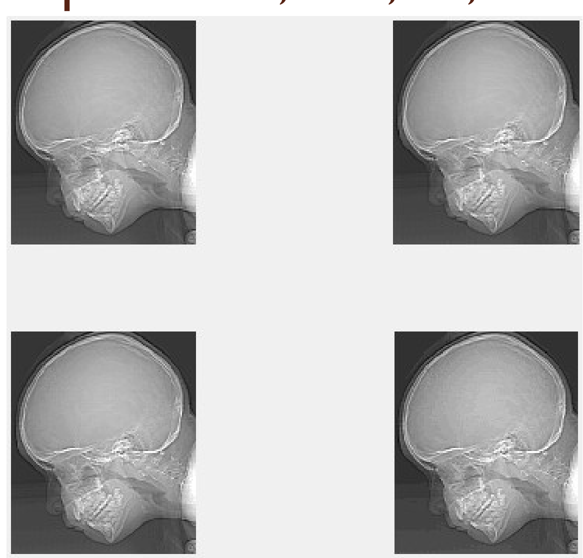
Intensity Resolution

- Smallest discernible change in intensity level
  - Number of bits used to quantize intensity
  - Influenced by noise and saturation values, capabilities of human perception

Example – 256, 128, 64, 32 levels



Example – 16, 8, 4, 2 levels

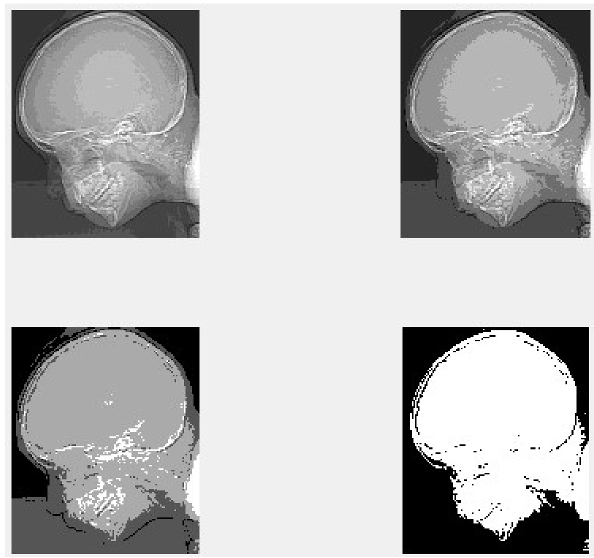


Image Details

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.)

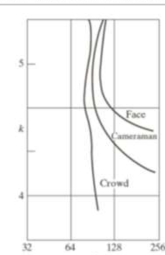


Image Interpolation

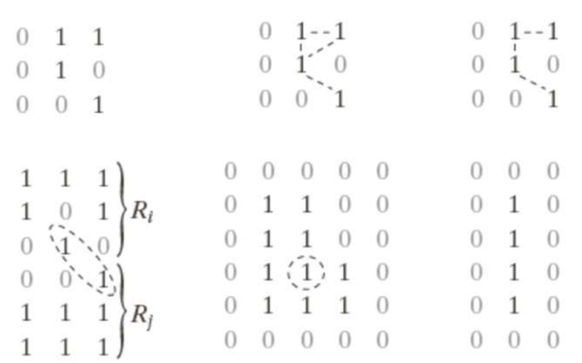
- Using known data to estimate values at unknown locations
- Nearest neighbor interpolation
  - Simple, undesirable artifacts (severe distortion of straight edges)
- Bilinear interpolation
  - Use 4 nearest neighbors
  - Modest increase in computational burden
- Bicubic interpolation
  - 16 nearest neighbors

Example

Relationship between pixels

- 4-neighbors
  - Horizontal & vertical neighbors
  - Unit distance
- 8-neighbors
  - Includes diagonal neighbors
- 4-adjacency
- 8-adjacency
- m-adjacency (mixed adjacency)
  - In N4(p)
  - In ND(p) and the set N4(p) ∩ N4(q) has no pixels whose values are from V

Example



a b c
d e f

FIGURE 2.25 (a) An arrangement of pixels. (b) Pixels that are 8-adjacent (adjacency is shown by dashed lines; note the ambiguity). (c) *m*-adjacency. (d) Two regions that are adjacent if 8-adjecency is used. (e) The circled point is part of the boundary of the 1-valued pixels only if 8-adjacency between the region and background is used. (f) The inner boundary of the 1-valued region does not form a closed path, but its outer boundary does.

Relationship between pixels

- Digital path or curve
  - Length of the path
  - Closed path
- Connected component
- One connected component – connected set
- Region – connected set
- Adjacent regions – union forms a connected set
- Disjoint regions – not adjacent

Relationship between pixels

- Union of K regions – foreground
- Complement – background
- Boundary or border or contour (inner border)
  - Atleast one background neighbor
- Outer border – border in the background
- Boundary – closed path – global concept
- Edges – local concept – intensity level discontinuity

Distance Measures

- $D(p, q) \geq 0$ ($D(p, q) = 0$ iff $p = q$)
- $D(p, q) = D(q, p)$
- $D(p, z) \leq D(p, q) + D(q, z)$
- Euclidean distance – disk of radius r
- City block distance – diamond
- Chess board distance – square

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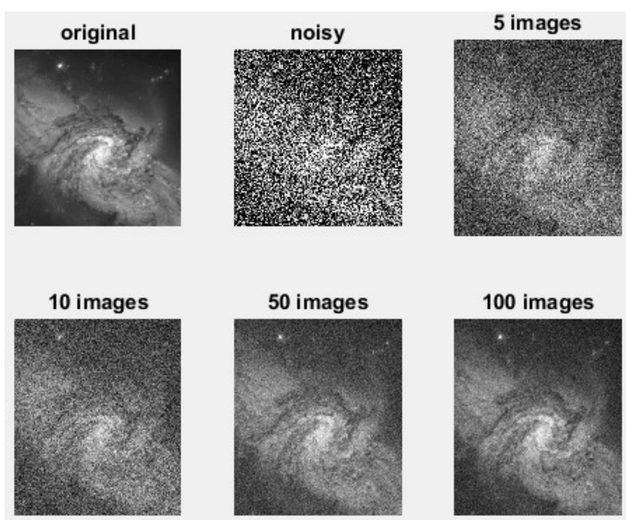
Image Averaging



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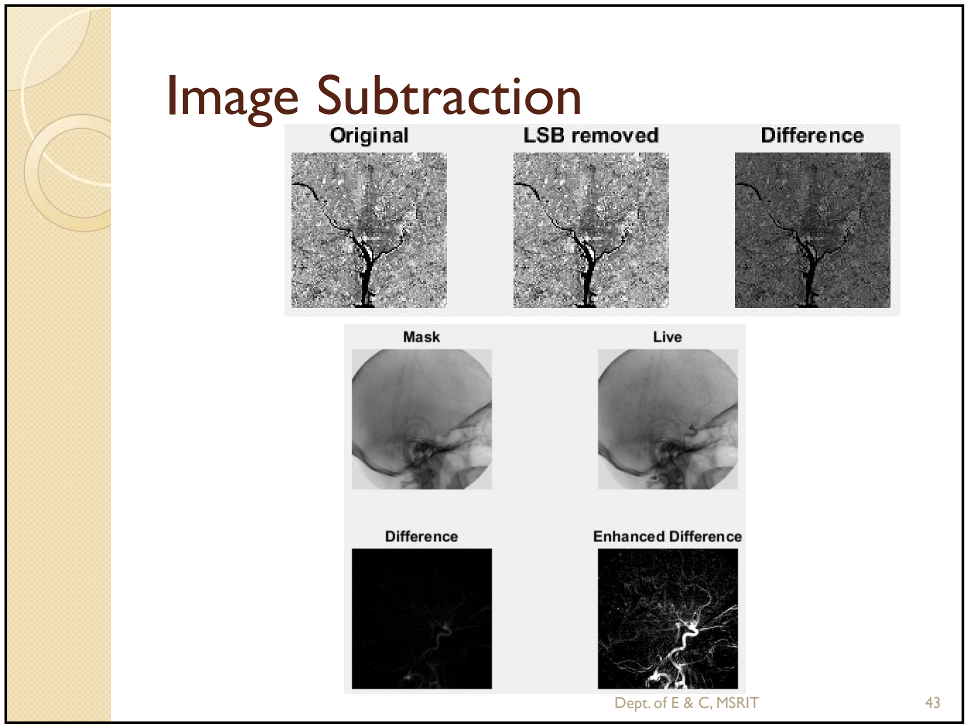
Image Subtraction
Original
LSB removed
Difference
Mask
Live
Difference
Enhanced Difference
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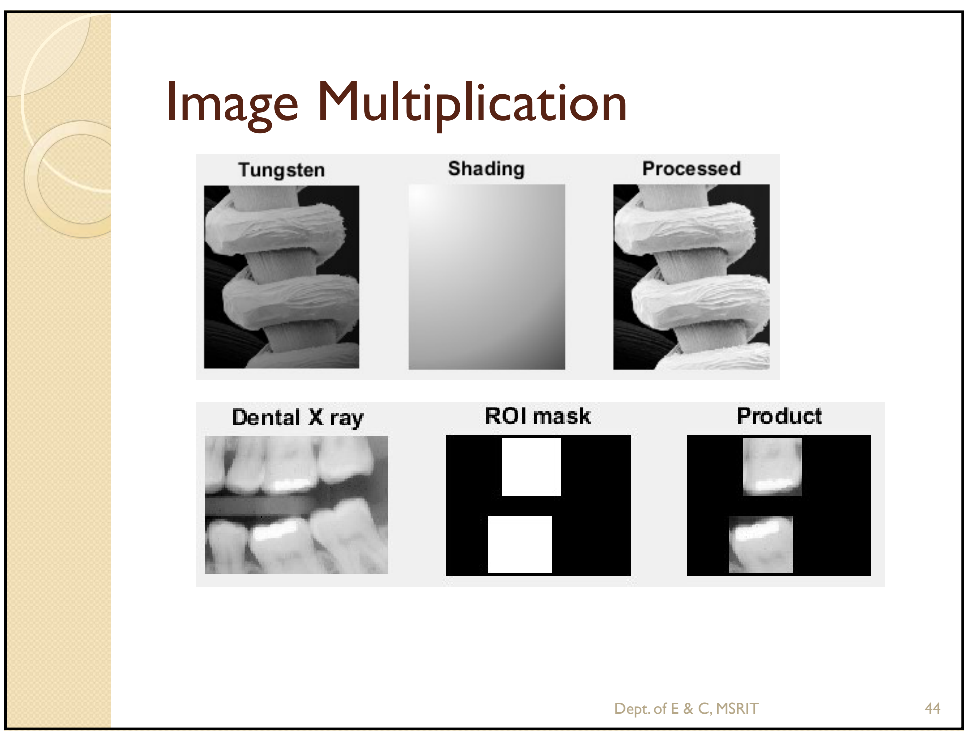
Image Multiplication
Tungsten
Shading
Processed
Dental X ray
ROI mask
Product
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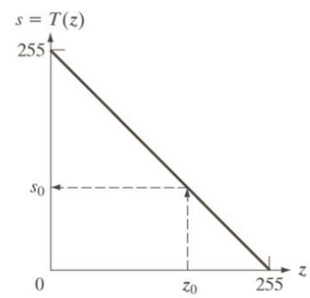
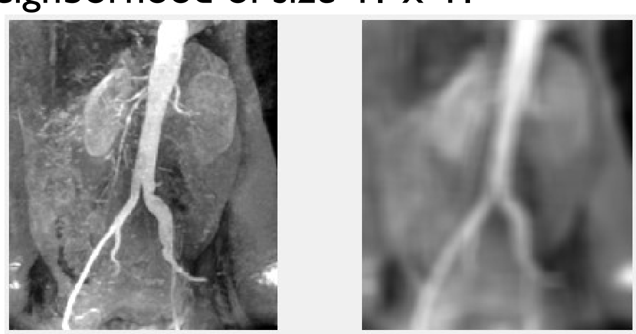
Spatial Operations

- Single pixel operation
  - Alter values based on their intensity s = T(z)
  - Negative of an 8-bit image



Spatial Operations

- Neighborhood operations
- Average value of pixels in a rectangular neighborhood of size 41 x 41

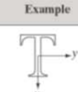


Geometric Spatial Transformations

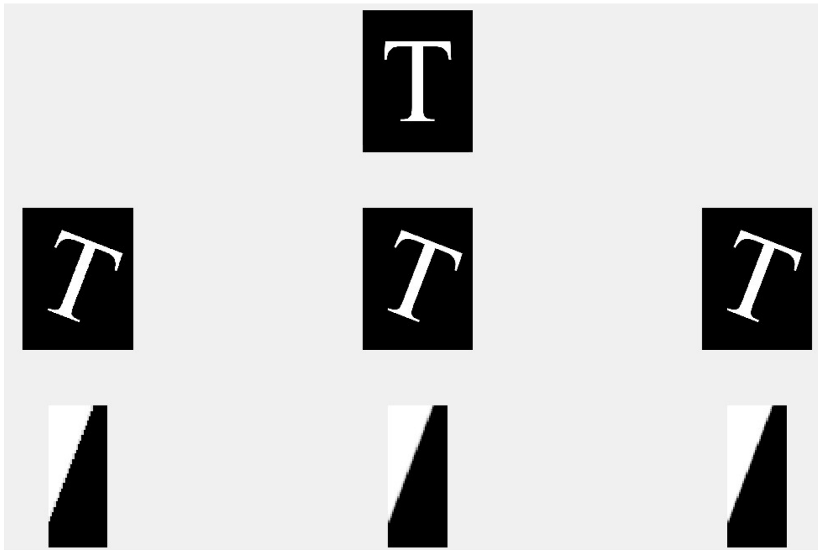
- Rubber sheet transformations
  - Spatial transformation of coordinates
  - Intensity interpolation that assigns intensity values to the spatially transformed pixels

Affine Transformations

TABLE 2.2
Affine transformations based on Eq. (2.6.–23).

Transformation Name	Affine Matrix, T	Coordinate Equations	Example
Identity	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v$ $y = w$	
Scaling	$\begin{bmatrix} c_x & 0 & 0 \\ 0 & c_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = c_x v$ $y = c_y w$	
Rotation	$\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v\cos\theta - w\sin\theta$ $y = v\cos\theta + w\sin\theta$	
Translation	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ t_x & t_y & 1 \end{bmatrix}$	$x = v + t_x$ $y = w + t_y$	
Shear (vertical)	$\begin{bmatrix} 1 & 0 & 0 \\ s_v & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v + s_v w$ $y = w$	
Shear (horizontal)	$\begin{bmatrix} 1 & s_h & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v$ $y = s_h v + w$	

Example



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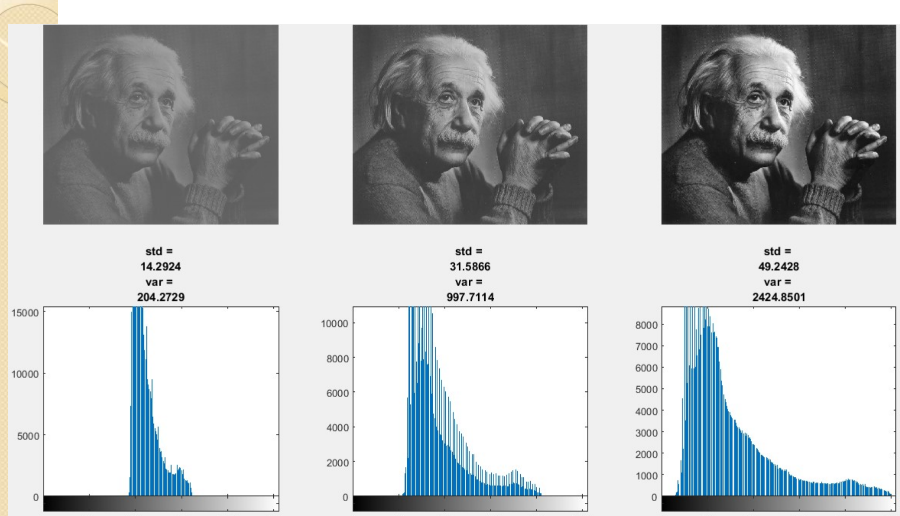
Probabilistic Methods



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