Educational for Drone (eDrone)
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Educational for Drone
(eDrone)
Image Processing
Introduction and Applications

Francesco Lamonaca

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Università
degli Studi
del Sannio

Outline

➢ **Introduction to Image Processing, Application and Prospects**

➢ **Fourier Transform theory , Convolution and Correlation**

➢ **Color, Image enhancement Techniques**

➢ **Binary images: thresholding, moments, topology**
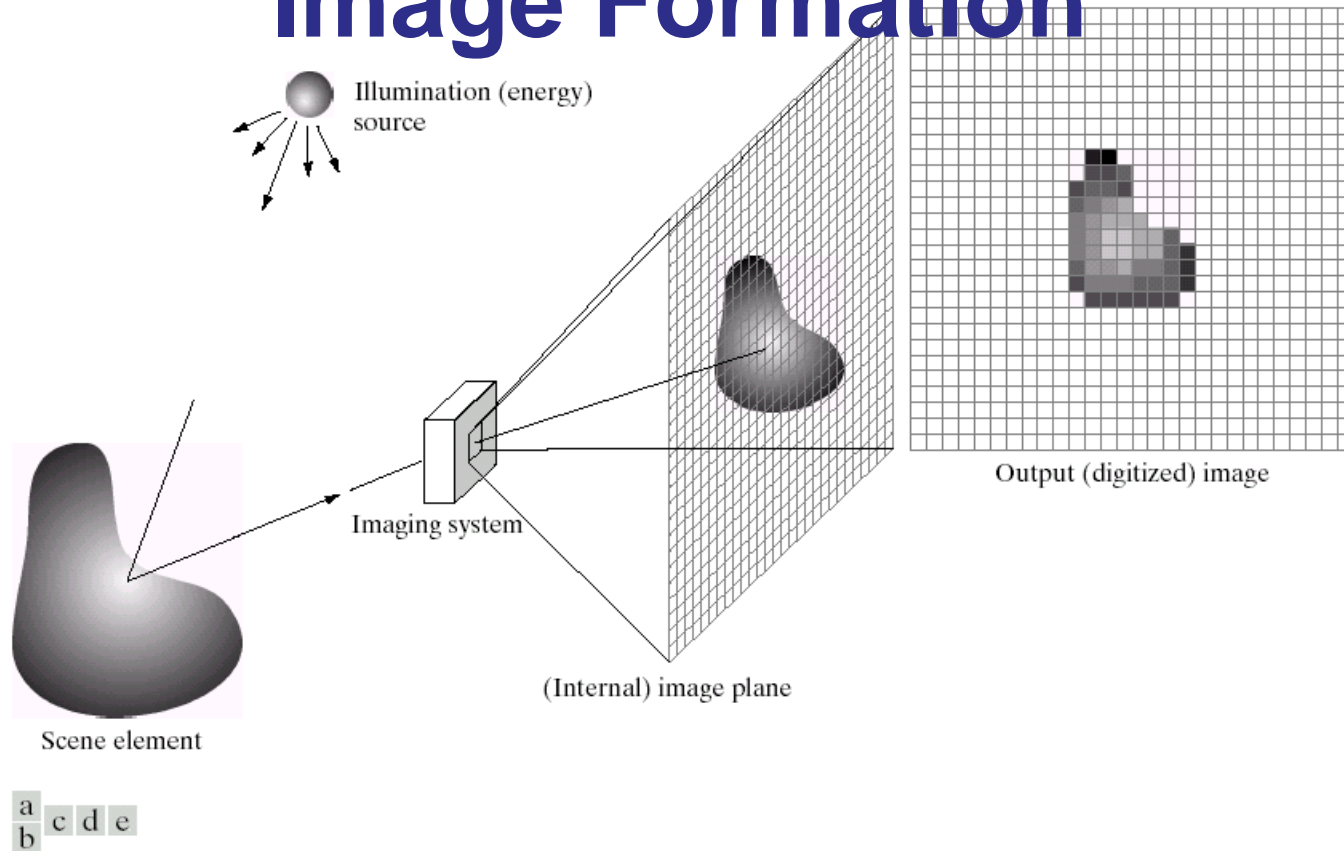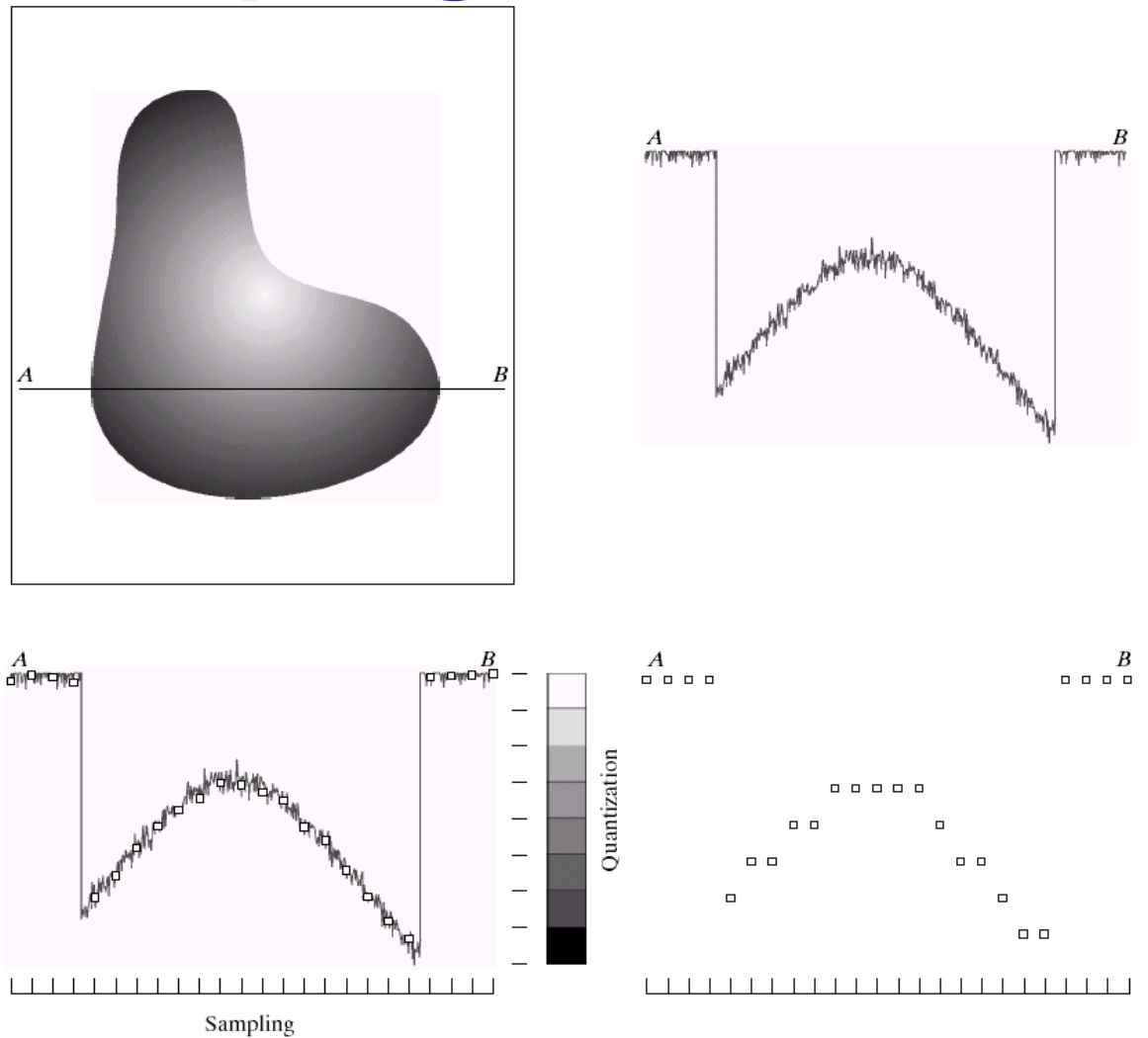
Image Formation

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.

*f(x,y) = reflectance(x,y) * illumination(x,y)*
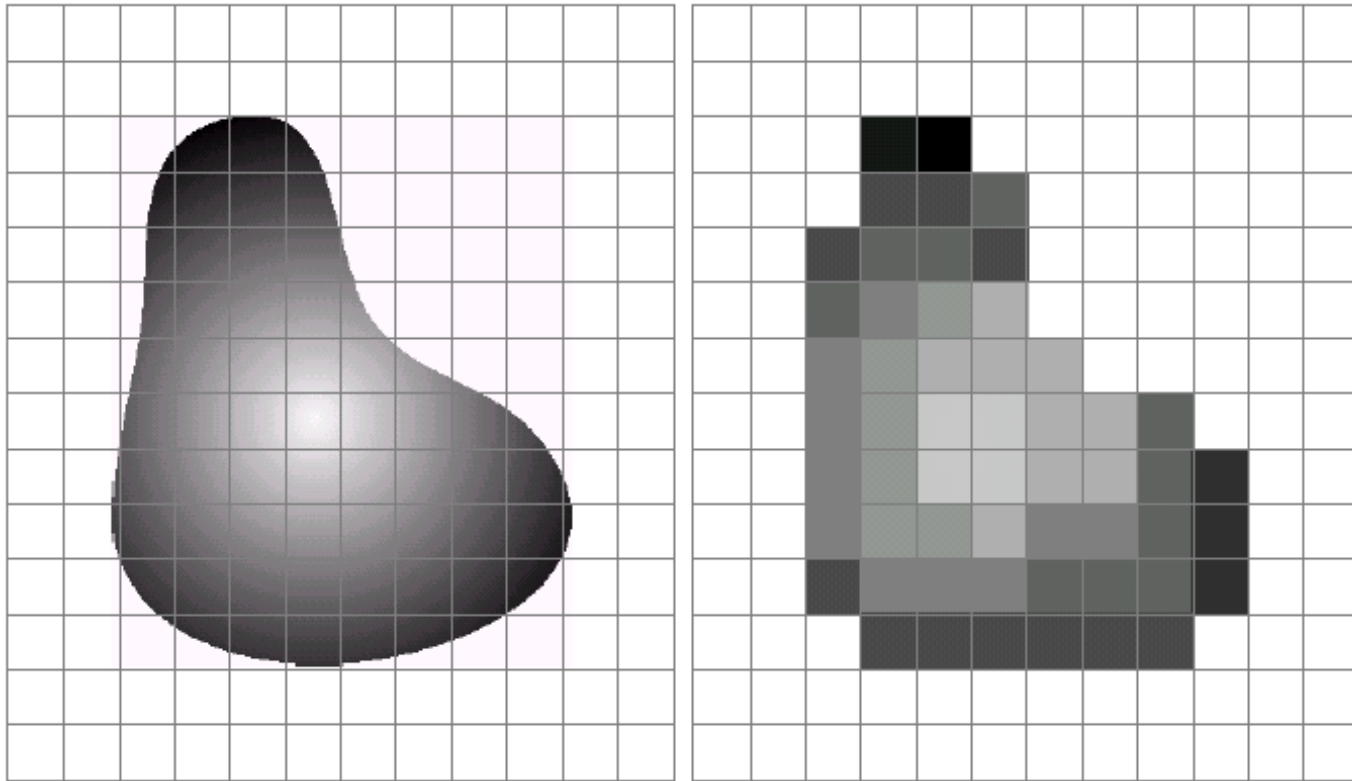*Reflectance in [0,1], illumination in [0,inf]*

Sampling and Quantization

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling and Quantization

a b

FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.
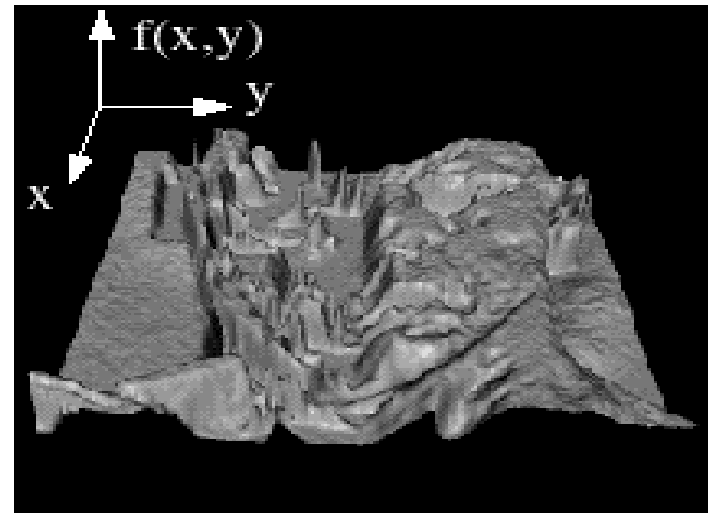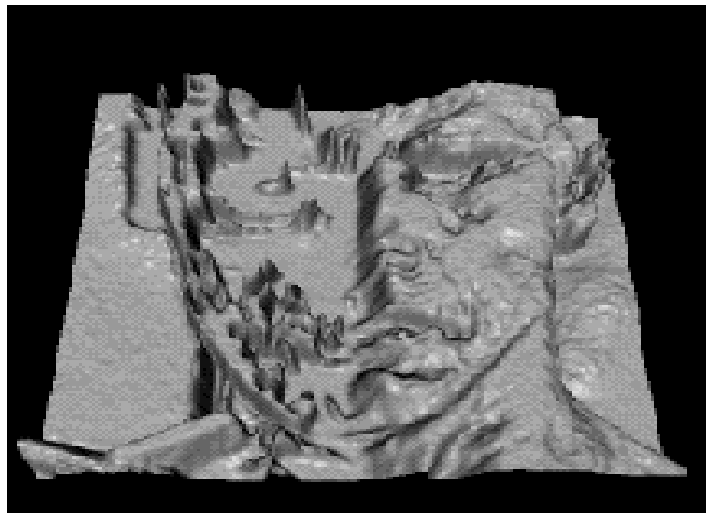
What is an image?

- We can think of an **image** as a function, f, from R^2 to R:

  – $f(x, y)$ gives the **intensity** at position (x, y)

  – Realistically, we expect the image only to be defined over a rectangle, with a finite range:

    - $f: [a,b] \times [c,d] \rightarrow [0,1]$

- A color image is just three functions pasted together. We can write this as a "vector-valued" function:

$$f(x, y) = \begin{bmatrix} r(x, y) \\ g(x, y) \\ b(x, y) \end{bmatrix}$$

Images as functions

What is a digital image?

- We usually operate on **digital** (**discrete**) images:
  - **Sample** the 2D space on a regular grid
  - **Quantize** each sample (round to nearest integer)
- If our samples are Δ apart, we can write this as:

  $f[i,j]$ = Quantize{ $f(i\,\Delta, j\,\Delta)$ }
- The image can now be represented as a matrix of integer values

$j \longrightarrow$

62	79	23	119	120	105	4	0
10	10	9	62	12	78	34	0
10	58	197	46	46	0	0	48
176	135	5	188	191	68	0	49
2	1	1	29	26	37	0	77
0	89	144	147	187	102	62	208
255	252	0	166	123	62	0	31
166	63	127	17	1	0	99	30

$i \downarrow$

Image processing

- An **image processing** operation typically defines a new image g in terms of an existing image f.
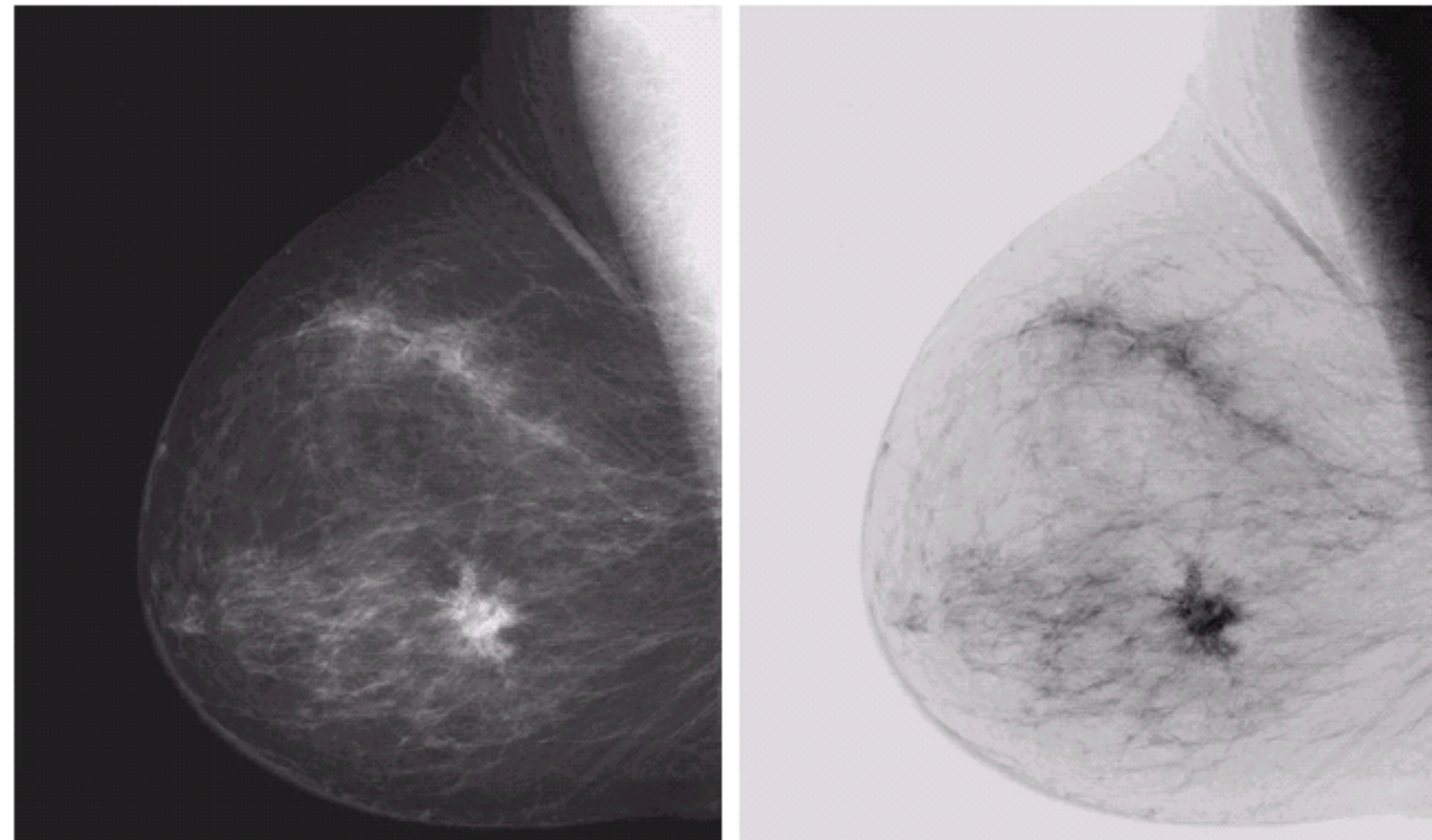- We can transform either the range of f.

$$g(x, y) = t(f(x, y))$$

- Or the domain of f:

$$g(x, y) = f(t_x(x, y), t_y(x, y))$$

- What kinds of operations can each perform?

Negative

a b

FIGURE 3.4
(a) Original digital mammogram.
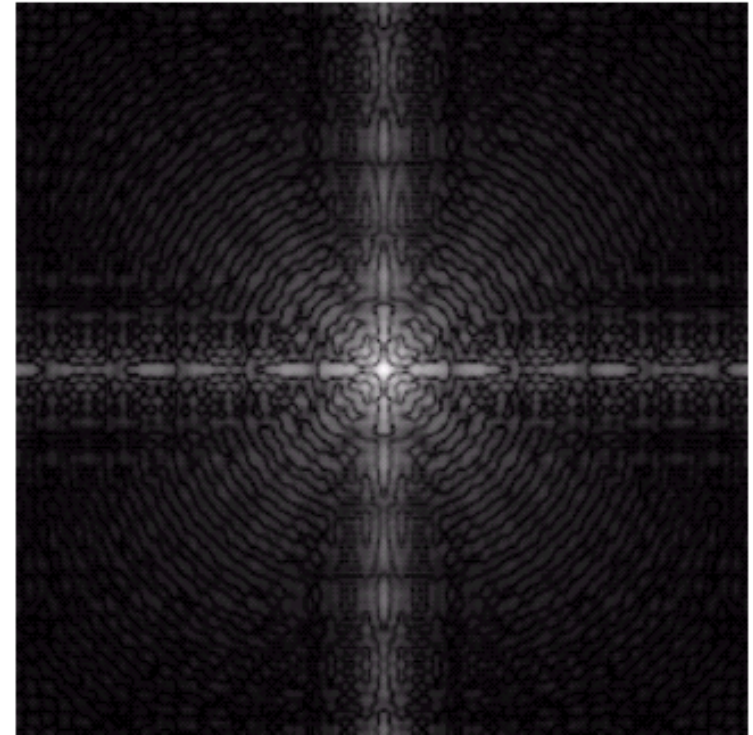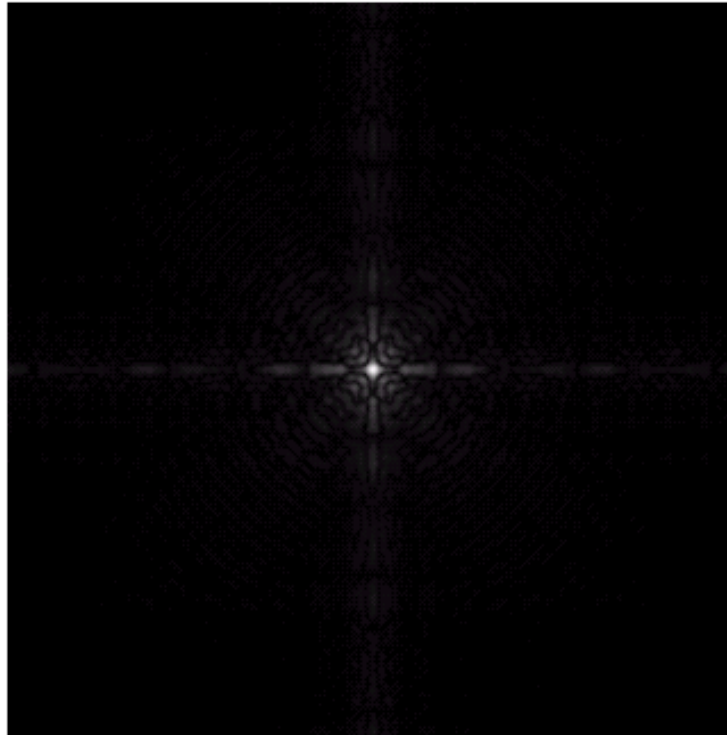(b) Negative image obtained using the negative transformation in Eq. (3.2-1). (Courtesy of G.E. Medical Systems.)

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Log

a b

FIGURE 3.5
(a) Fourier
spectrum.
(b) Result of
applying the log
transformation
given in
Eq. (3.2-2) with
$c = 1$.

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Image Enhancement
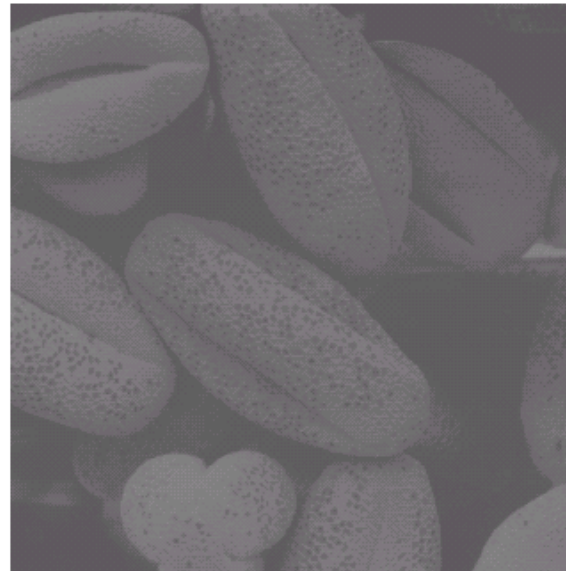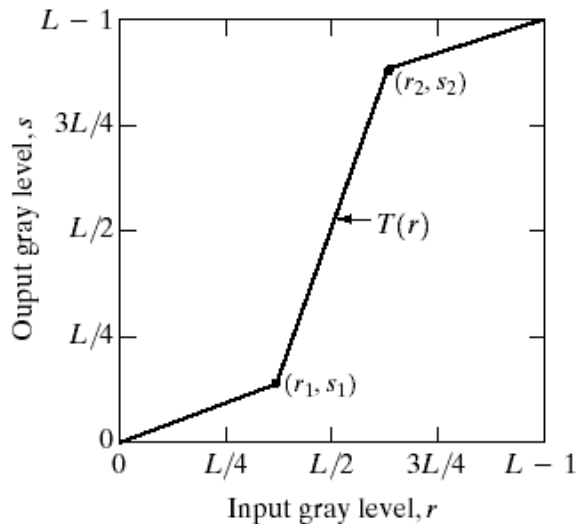

a b
c d

FIGURE 3.9
(a) Aerial image.
(b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0, 4.0,$ and $5.0,$ respectively. (Original image for this example courtesy of NASA.)

Contrast Streching

FIGURE 3.10
Contrast stretching.
(a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)
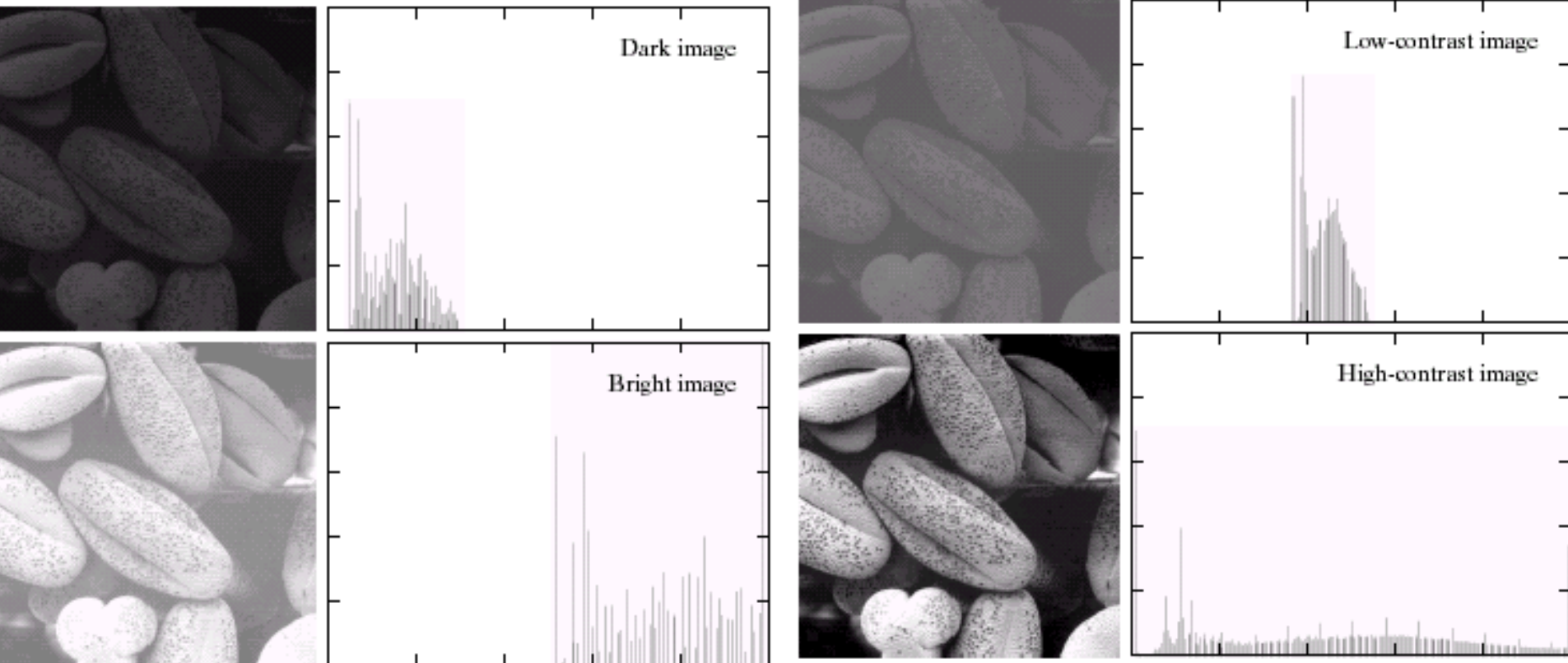
Image Histograms

Dark image

Low-contrast image

Bright image

High-contrast image

a b

FIGURE 3.15 Four basic image types: dark, light, low contrast, high contrast, and their corresponding histograms. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)
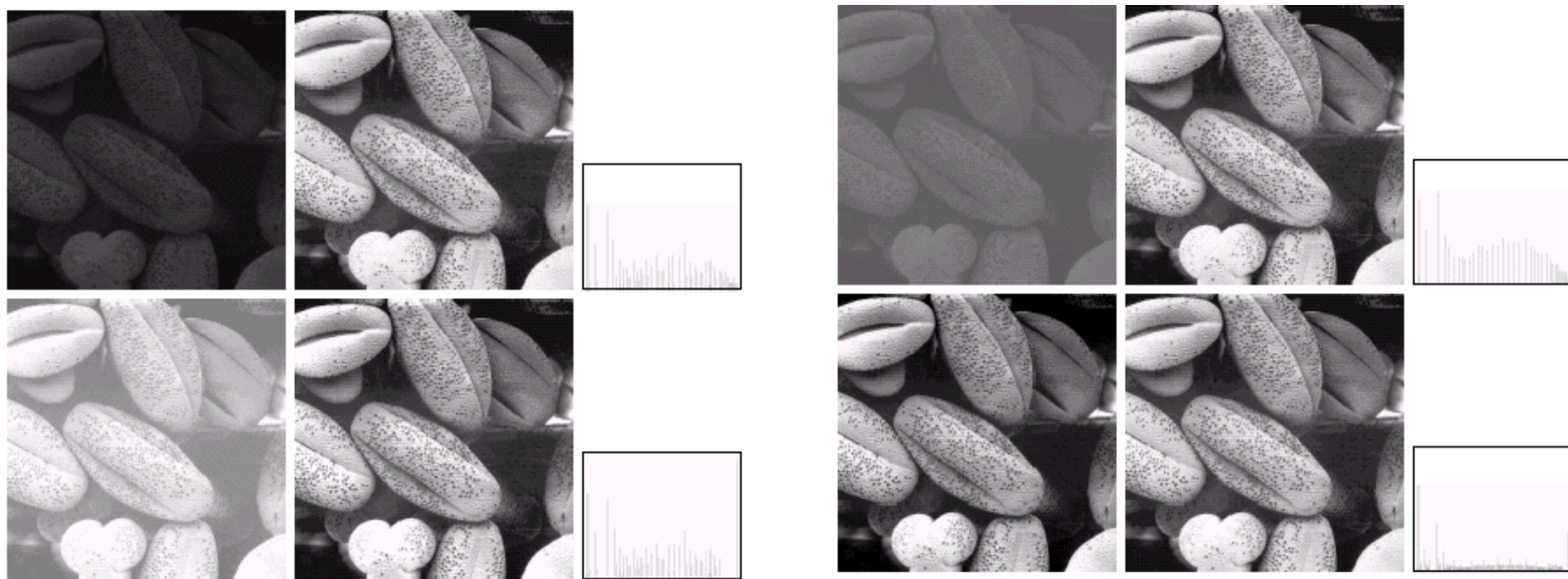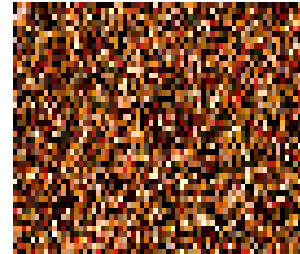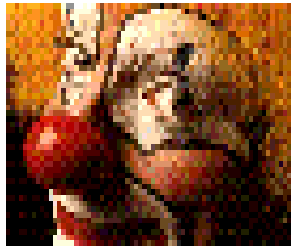
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Histogram Equalization

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FIGURE 3.17 (a) Images from Fig. 3.15. (b) Results of histogram equalization. (c) Corresponding histograms.
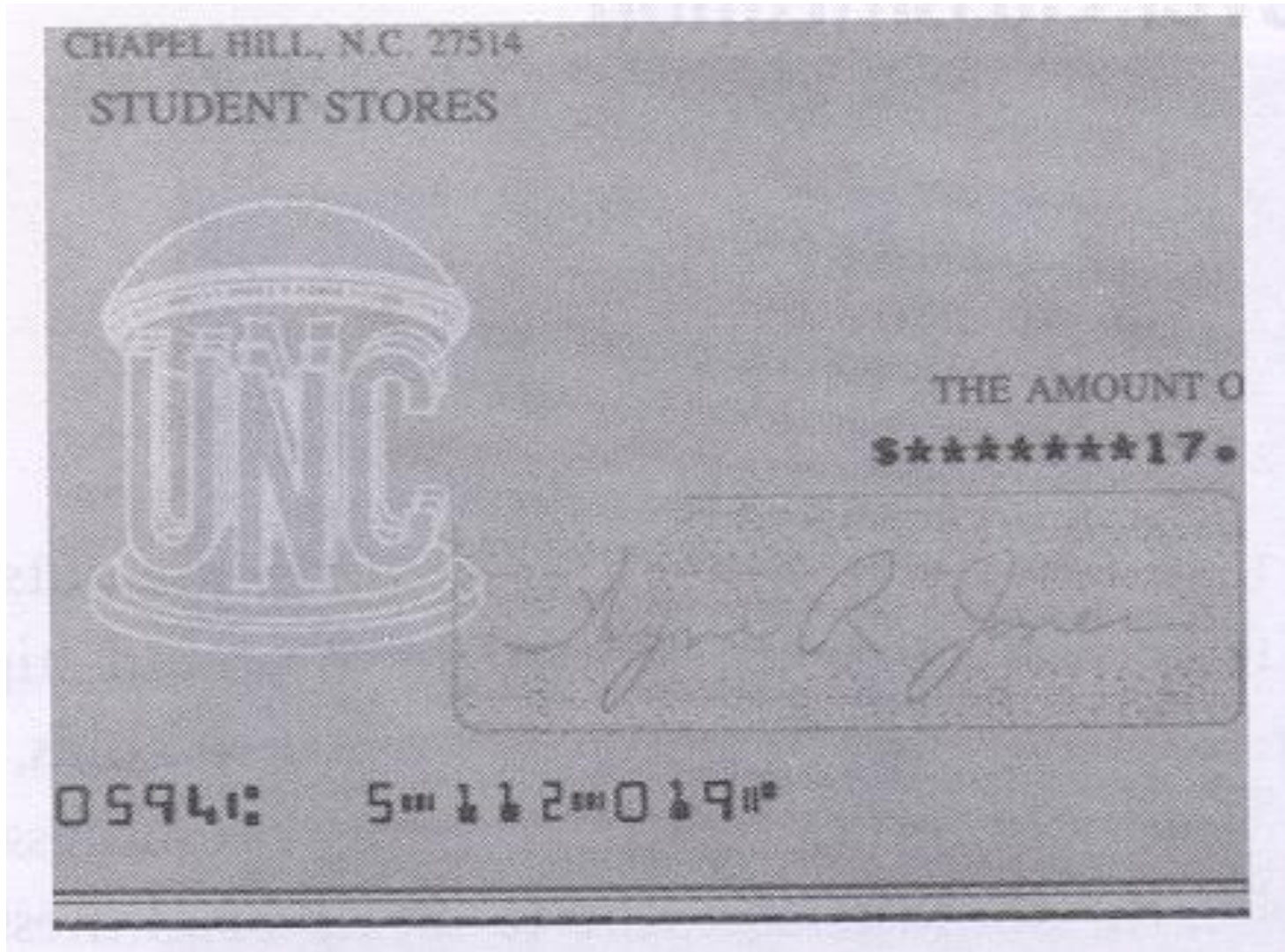
Neighborhood Processing (filtering)

- Q: What happens if I reshuffle all pixels within the image?

- A: It's histogram won't change. No point processing will be affected…
- Need spatial information to capture this.
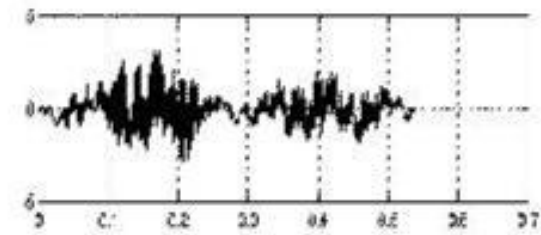
Applications & Research Topics

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Document Handling

Signature Verification

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Biometrics

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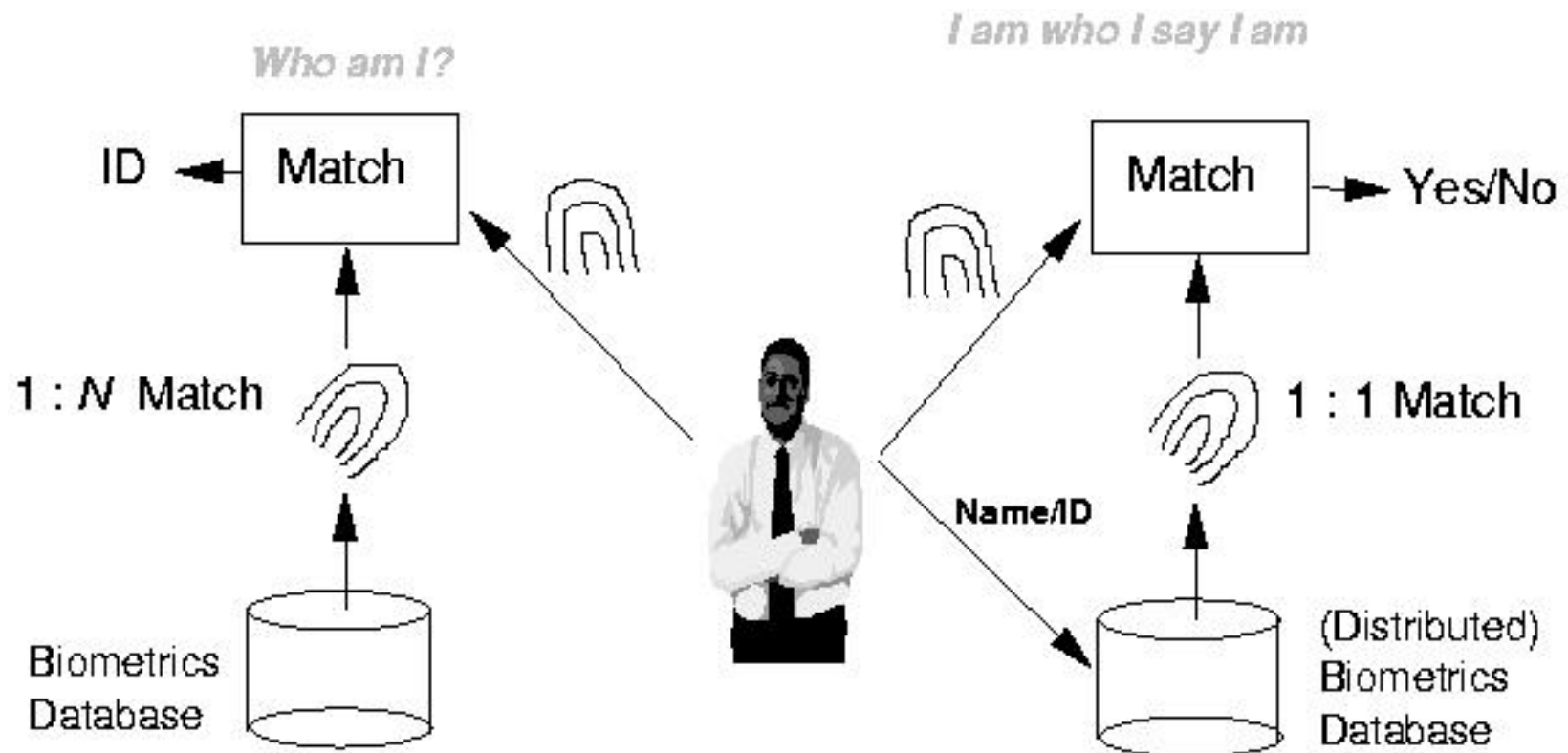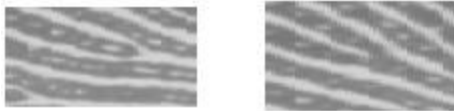
Fingerprint Verification / Identification

Fingerprint Identification Research at UNR

Minutiae

Matching

Delaunay Triangulation

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Object Recognition

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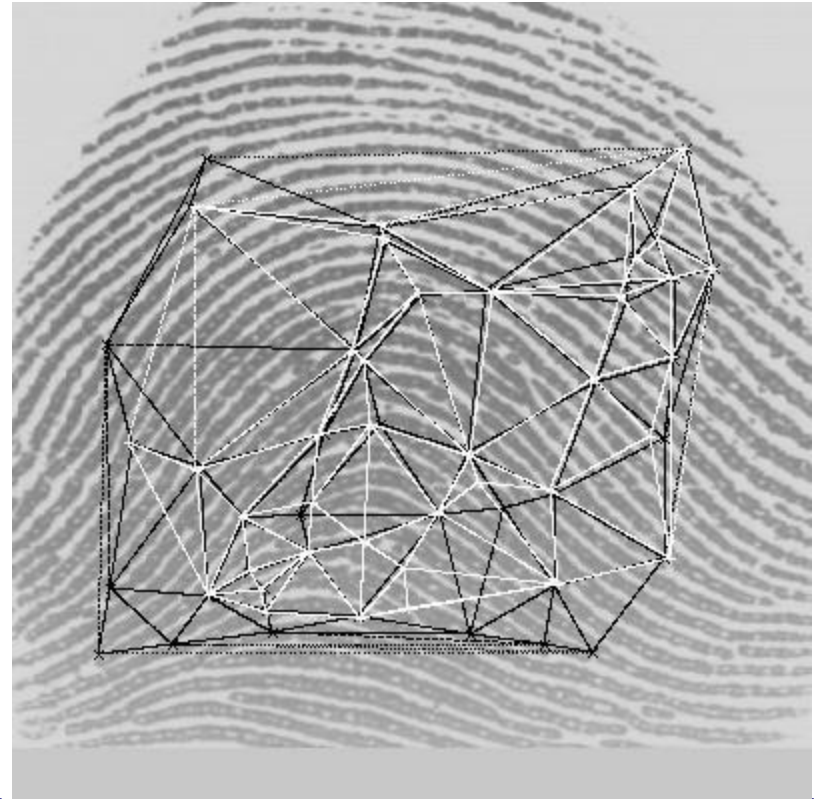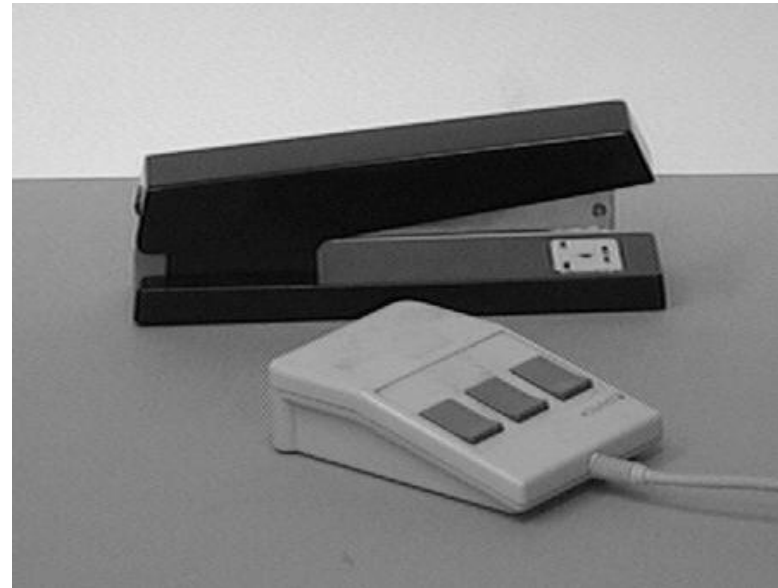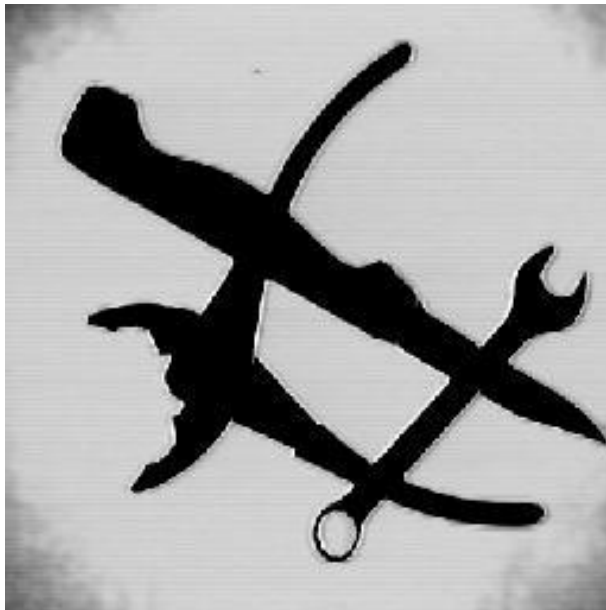
Object Recognition Research

reference view 1
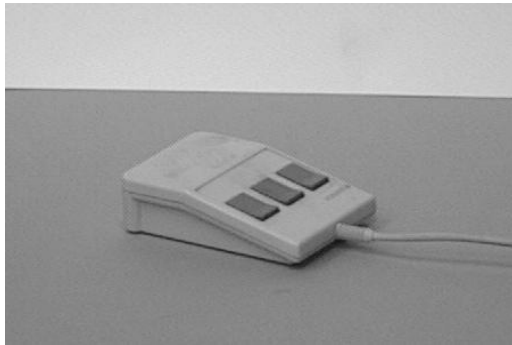
reference view 2
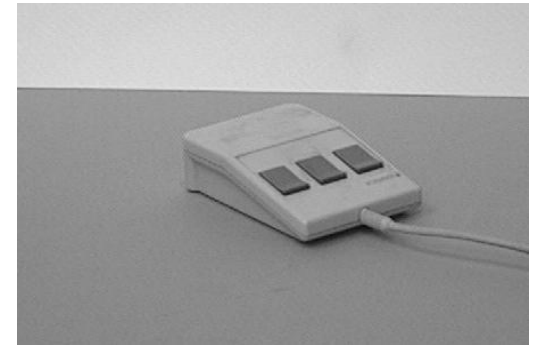
novel view recognized

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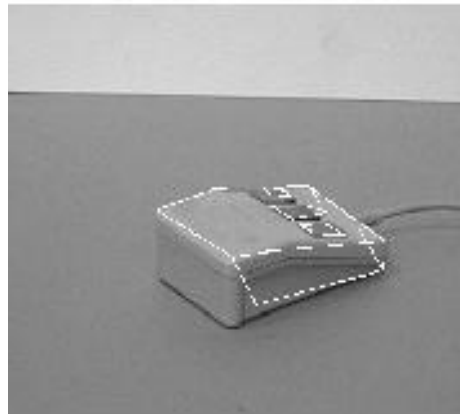
Indexing into Databases

- Shape content

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- Color, texture
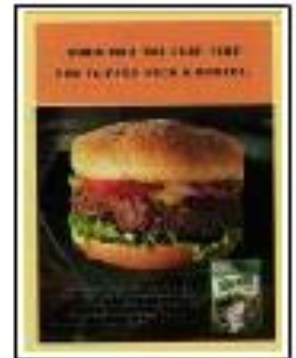
$T = 33.6s$, found 2 of 2

Target Recognition

- Department of Defense (Army, Airforce, Navy)
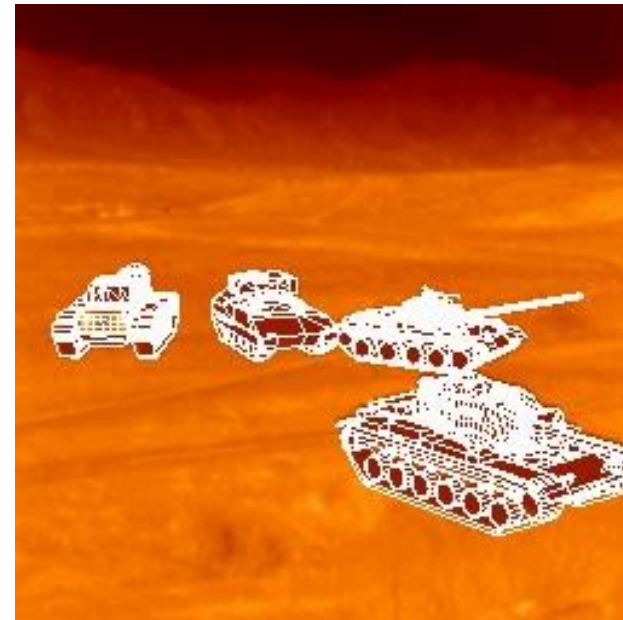
Interpretation of Aerial Photography

Interpretation of aerial photography is a problem domain in both computer vision and registration.

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Autonomous Vehicles

- Land, Underwater, Space
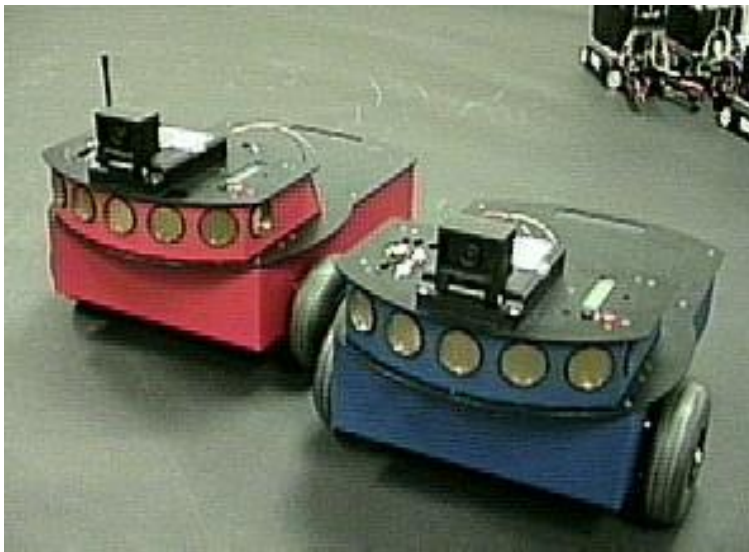
Traffic Monitoring
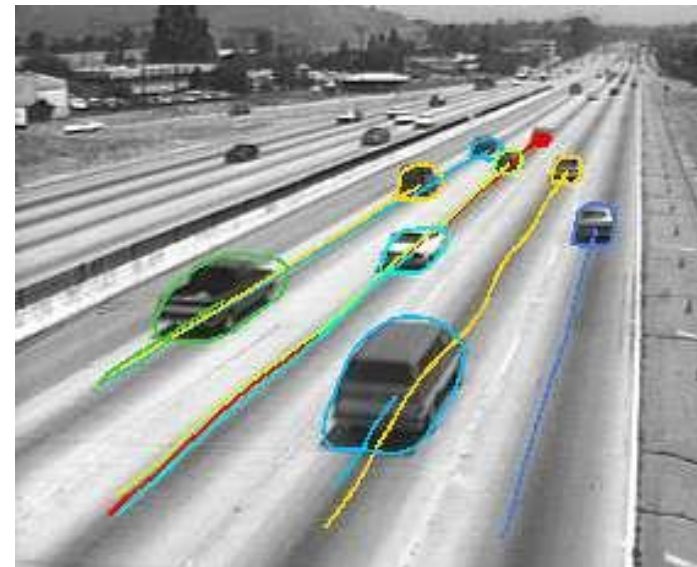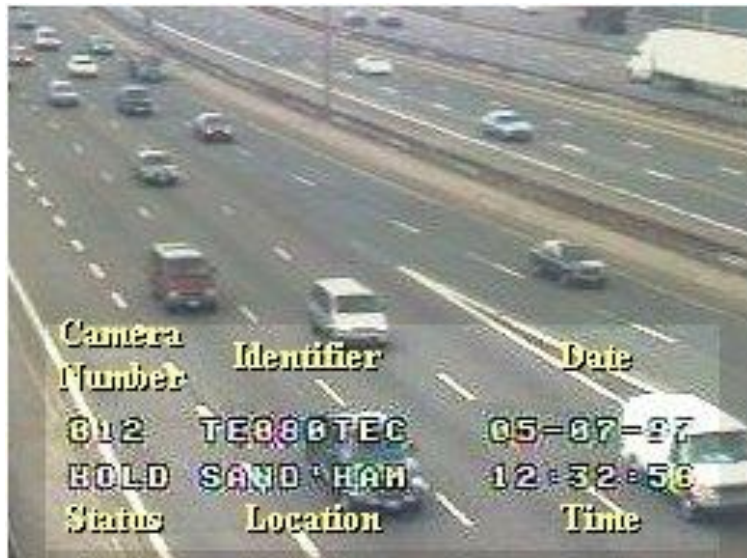
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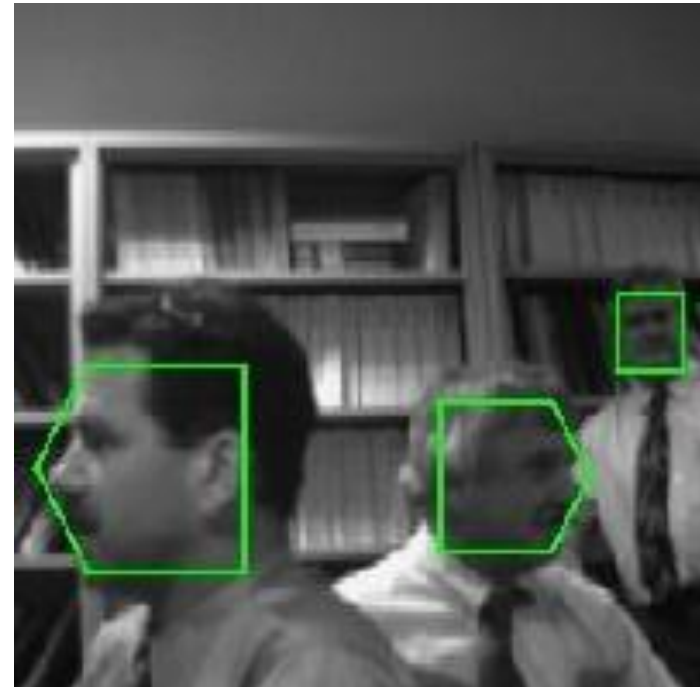
Face Detection

Face Recognition

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Face detection

Facial Expression Recognition

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Face Tracking

https://www.youtube.com/watch?v=jAwBjWC3vHw
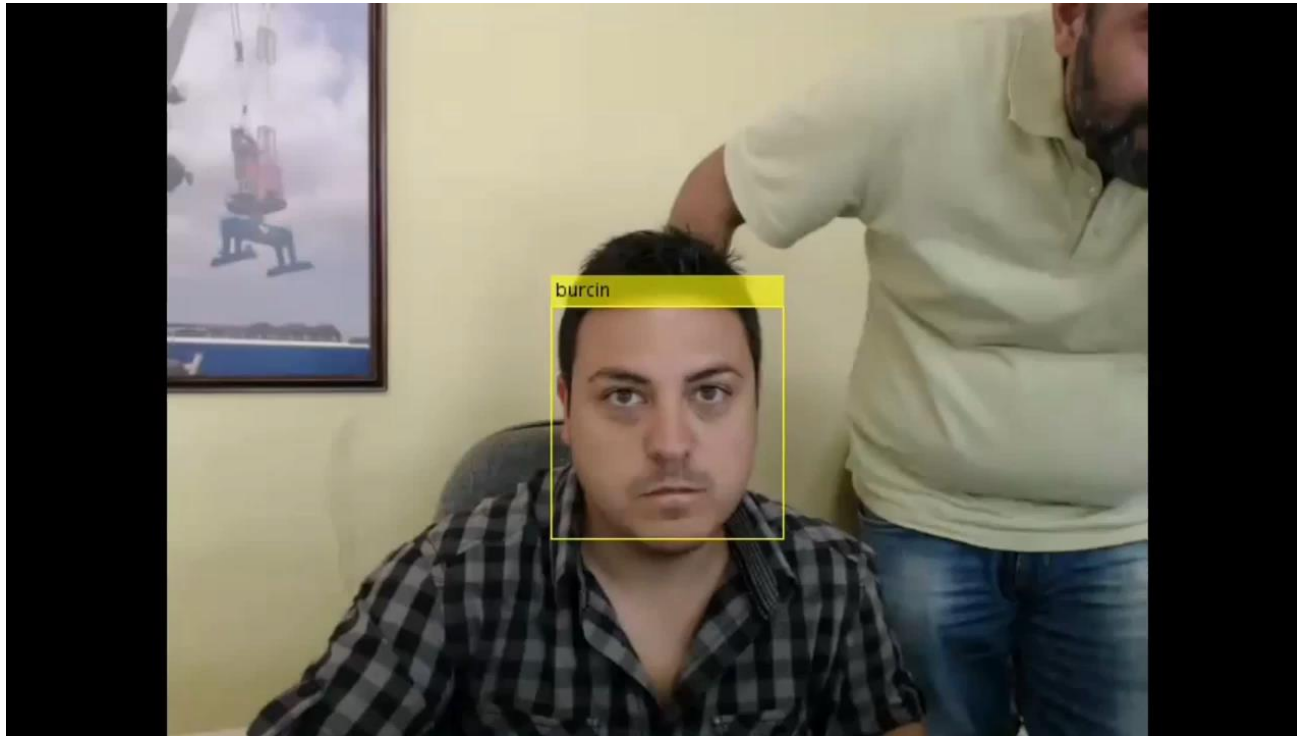
Hand Gesture Recognition

- Smart Human-Computer User Interfaces
- Sign Language Recognition

Human Activity Recognition

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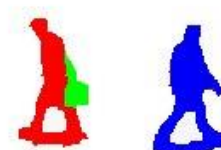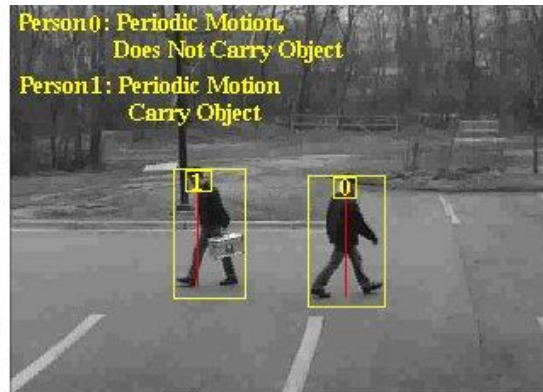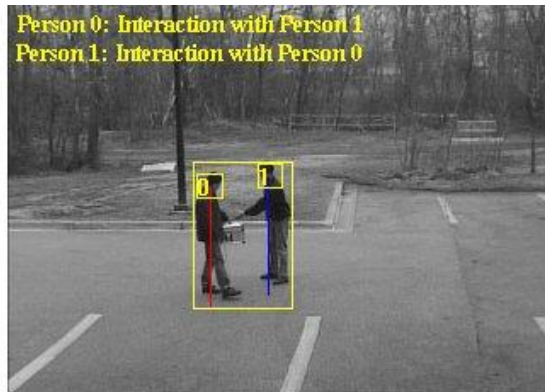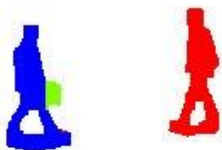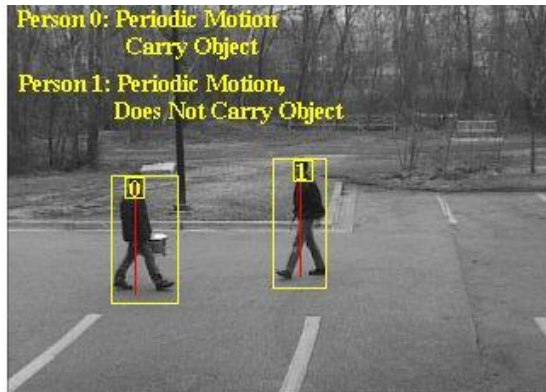
Medical Applications
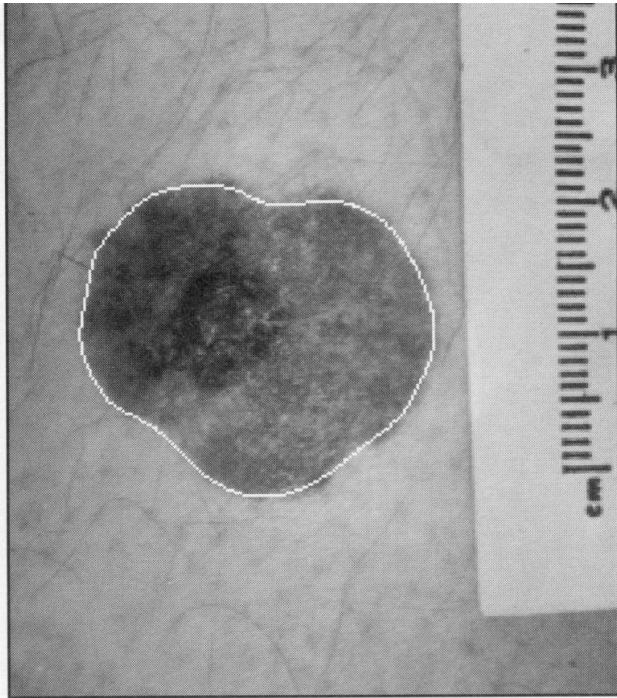
- skin cancer · · · · · · · · · · · · · · · · breast cancer
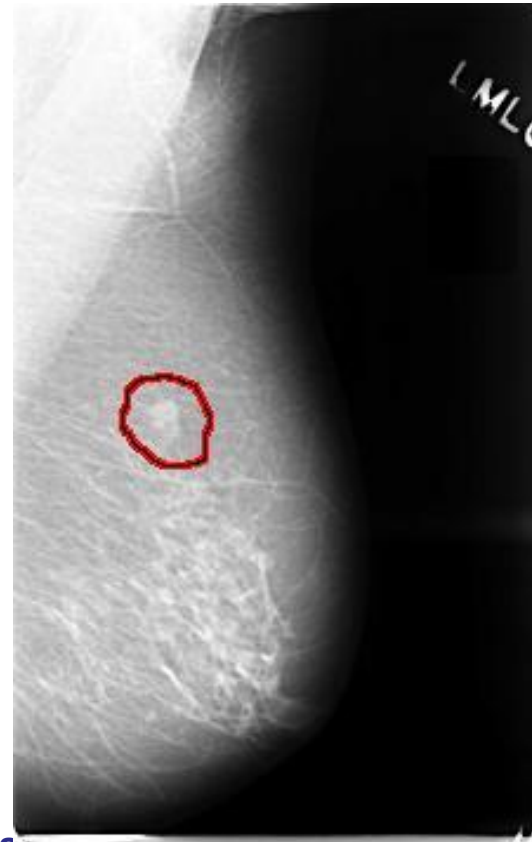
Morphing
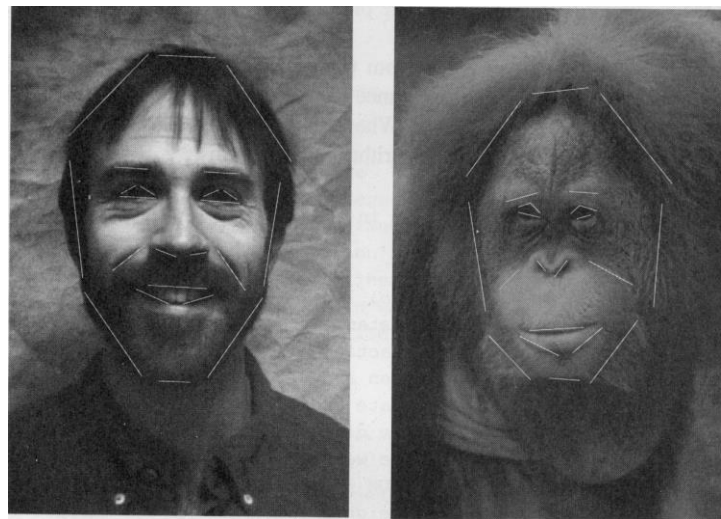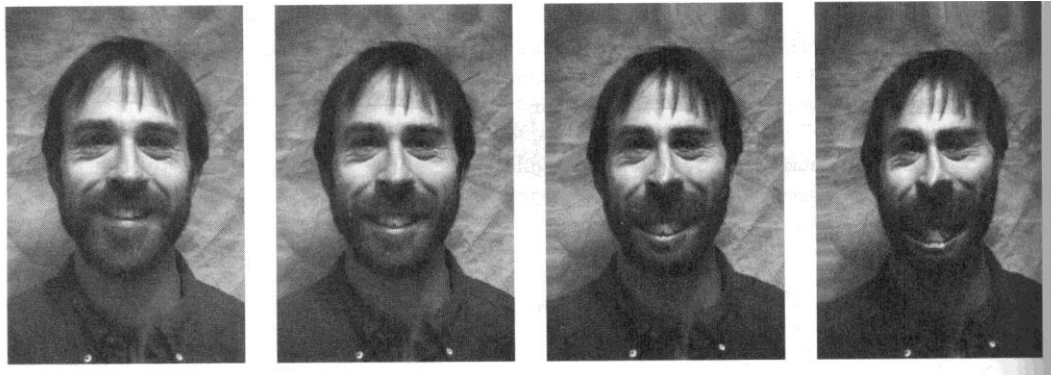
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Inserting Artificial Objects into a Scene

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Image Enhancement

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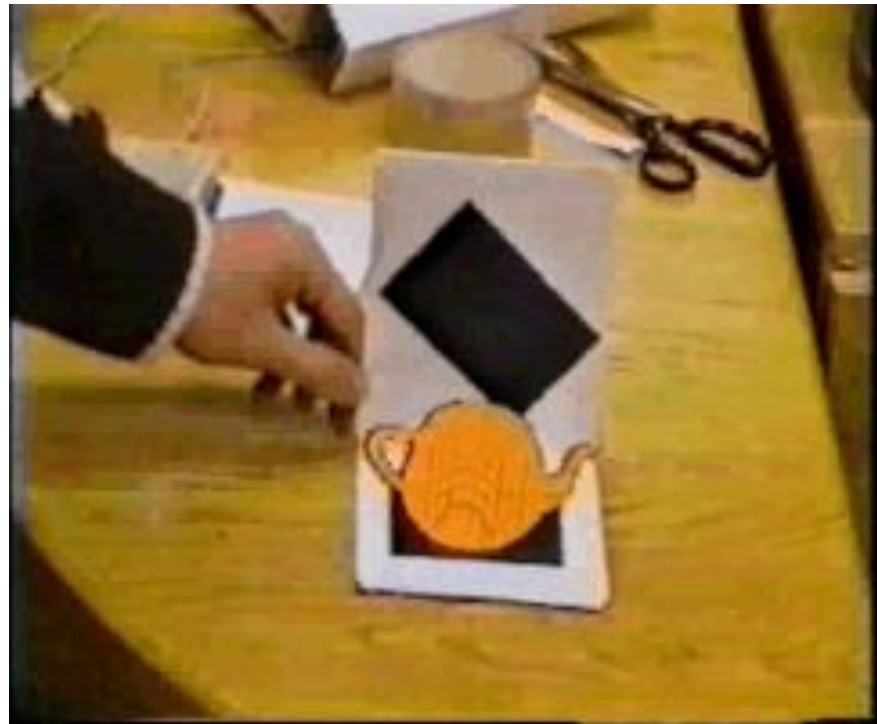
Convolution

- **Definition:**

$$(f * g)(u) = \int_{-\infty}^{\infty} f(x)g(u - x)\,dx$$

- **For discrete functions:**

$$(f * g)(m) = \sum_{n} f(n)g(m - n)$$

- **Properties**
- Commutativity
- Associativity
- Distributivity

$$f * g = g * f$$
$$f * (g * h) = (f * g) * h$$
$$f * (g + h) = (f * g) + (f * h)$$

Convolution

- The convolution is performed by sliding the mask over the image

- Convolution can be used to implement many different operators, particularly spatial filters and feature detectors.

- Examples include Gaussian smoothing and Sobel edge detector
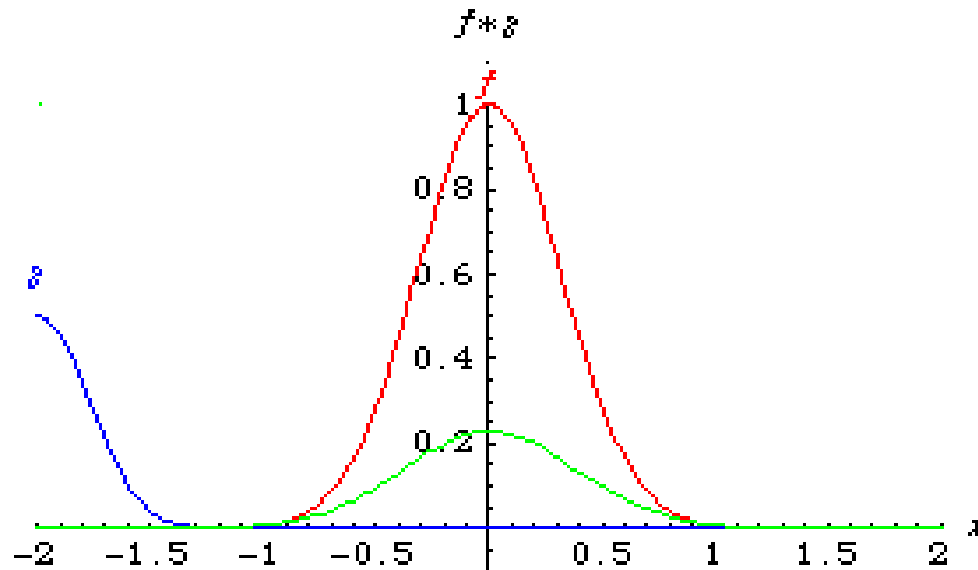
The animation graphically illustrate the convolution of two Gaussians functions.

The green curve shows the convolution of the blue and red curves and the position is indicated by the vertical green line. The gray region indicates the product *f(n)g(m-n)* as a function of *m*, so its area as a function of   is precisely the convolution.

2 D Convolution

$$f(x, y) \circ h(x, y) = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f^*(m, n) h(x - m, y - n)$$

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Masks - Convolution Kernels

- Convolution operation in spatial domain is also called masking

$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)$$

a=(m-1)/2 and *b=(n-1)/2,*

m x *n* (odd numbers)

For *x*=0,1,…,M-1 and *y*=0,1,…,N-1

Convolution Kernels for Image Enhancement
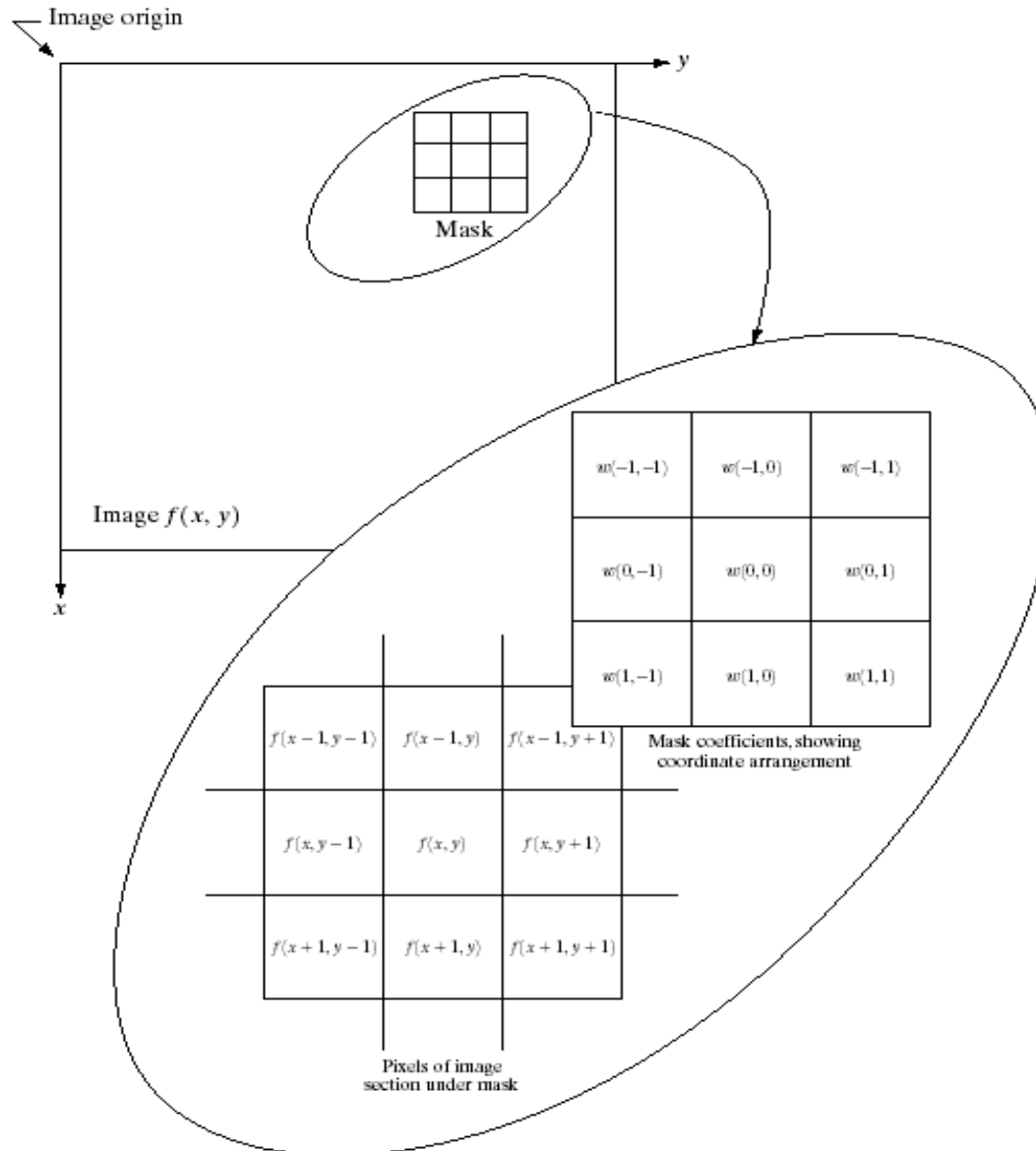
FIGURE 3.32 The mechanics of spatial filtering. The magnified drawing shows a 3×3 mask and the image section directly under it; the image section is shown displaced out from under the mask for ease of readability.

Image origin

y

Mask

Image $f(x, y)$

x

$w(-1,-1)$	$w(-1,0)$	$w(-1,1)$
$w(0,-1)$	$w(0,0)$	$w(0,1)$
$w(1,-1)$	$w(1,0)$	$w(1,1)$

Mask coefficients, showing coordinate arrangement

$f(x-1,y-1)$	$f(x-1,y)$	$f(x-1,y+1)$
$f(x,y-1)$	$f(x,y)$	$f(x,y+1)$
$f(x+1,y-1)$	$f(x+1,y)$	$f(x+1,y+1)$

Pixels of image section under mask

Correlation

- It is used to measure the similarity between images or parts of images.

- Definition:

$$f(x, y) \circ h(x, y) = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f*(m, n)h(x+m, y+n)$$

- The greater the similarity between the template and the image in a particular location, the greater the value resulting from the correlation.

Correlation

- If the two functions f and g contain similar features, but at a different position, the correlation function will have a large value at a vector corresponding to the shift in the position of the feature.
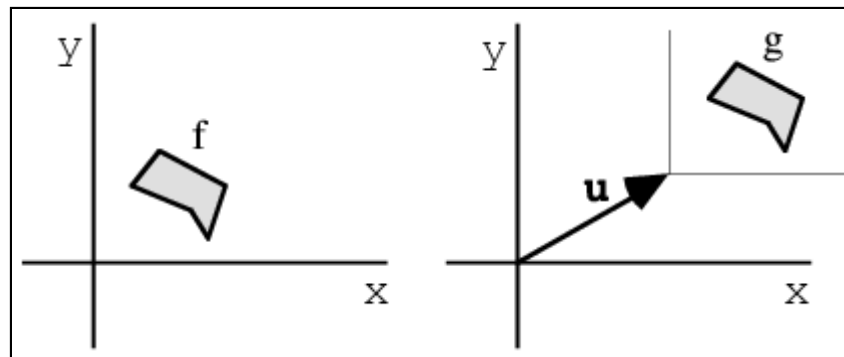
Possible Use

- Detection of an object in an image:
  - The image of the object is the mask,
  - Higher the correlation coefficient is, maximum is the probability that the object is in the image.
  - Problem: fix a threshold to accept the detection result.

Fourier Transforms and Applications

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Fourier Transform

- Processing images by looking at the grey level at each point in the image – Spatial Processing

- Alternative representations that are more amenable for certain types of analysis

- Most common image transform takes spatial data and transforms it into frequency data

What is frequency in Images ?

- FT expresses a function in terms of the sum of its projections onto a set of basis functions

- In images we are concerned with spatial frequency, that is, the rate at which brightness in the image varies across the image

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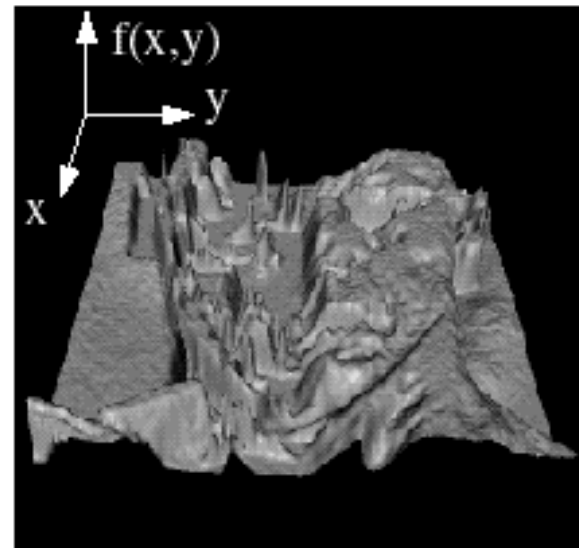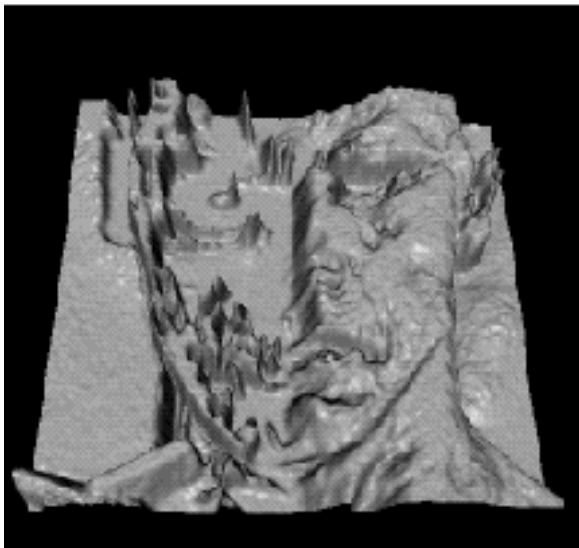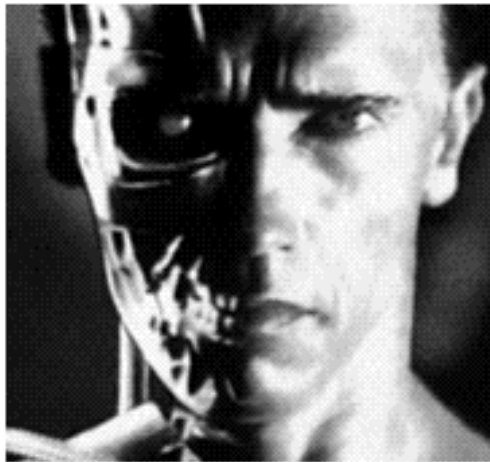
Fourier Transform

- ## Discrete Fourier Transform (DFT)
  - sampled Fourier Transform and therefore does not contain all frequencies forming an image

$$F(p,q) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m,n)e^{-j(2\pi/M)pm}e^{-j(2\pi/N)qn} \qquad \begin{aligned} p &= 0, 1, ..., M-1 \\ q &= 0, 1, ..., N-1 \end{aligned}$$

  - is complicated to work out as it involves many additions and multiplications involving complex numbers.

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Fourier Transform

- In many applications phase information is discarded

- In case of images, phase information must not be ignored – phase carries major information

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Why is phase important !
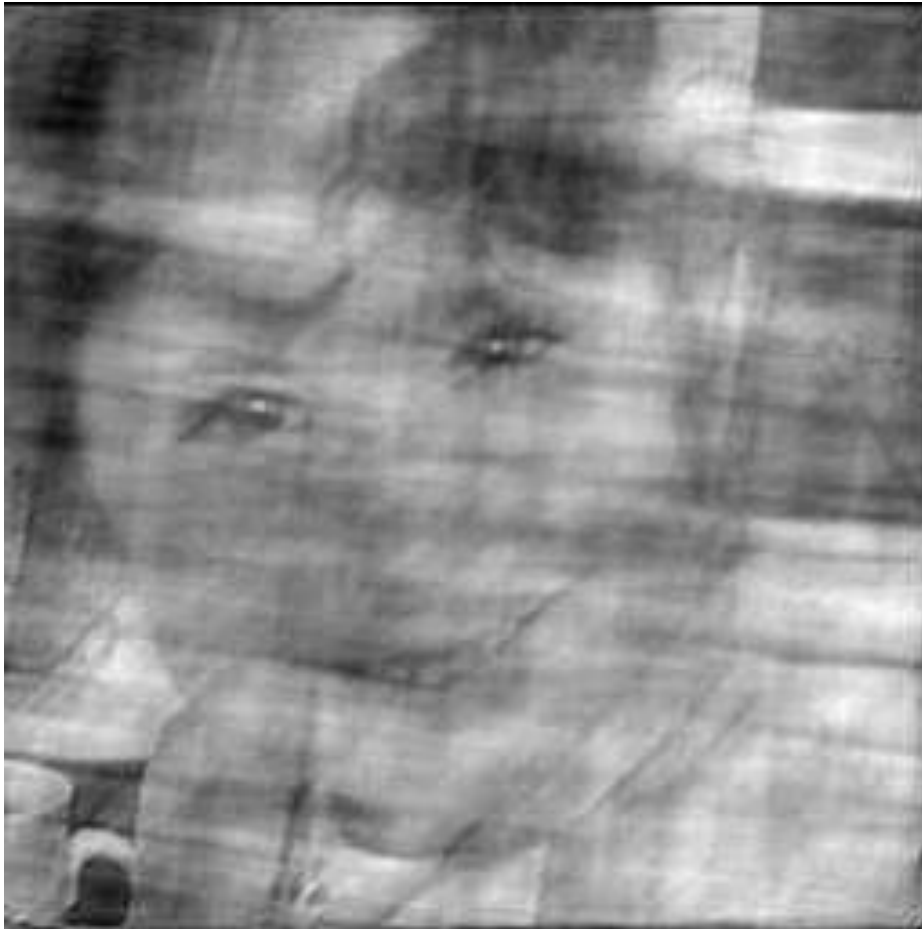
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Qualitative Filters

F G H

$\times$ $=$ Low-pass
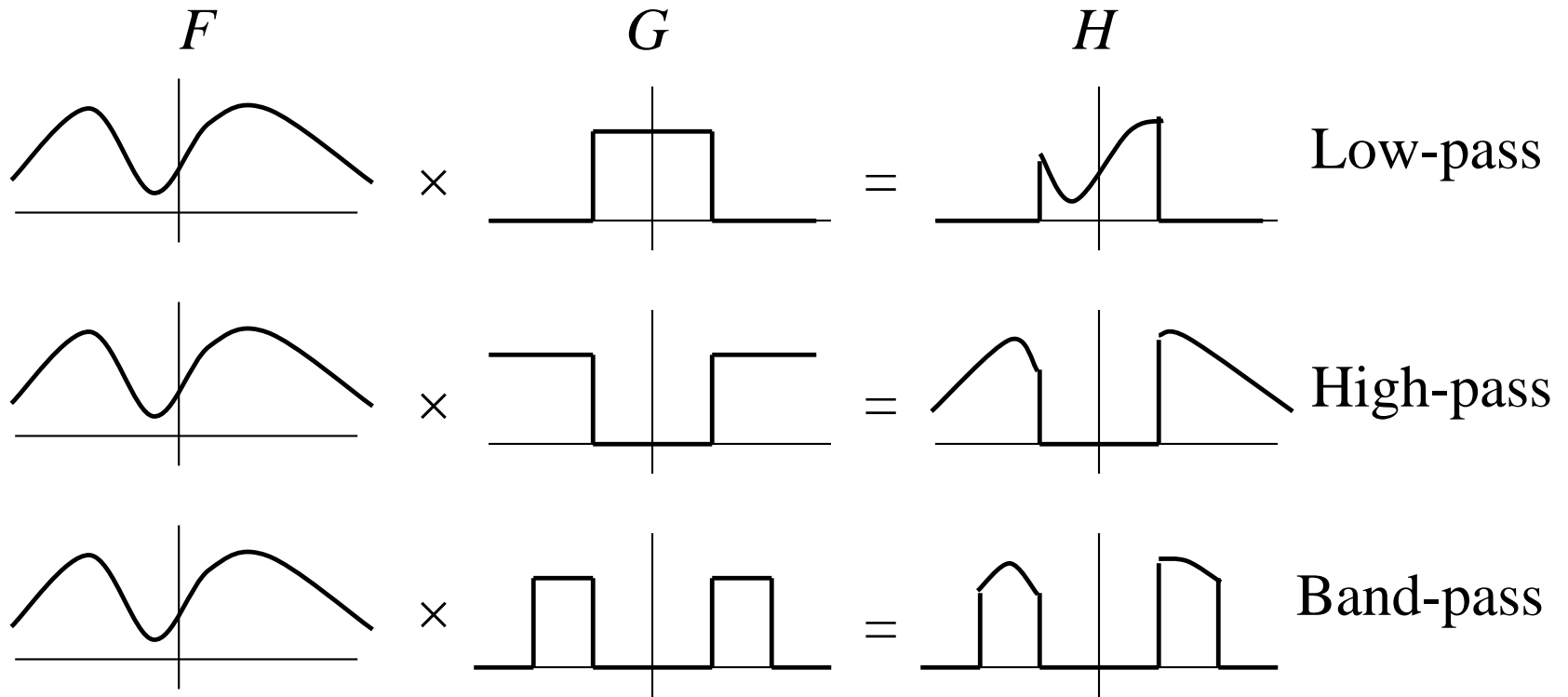
$\times$ $=$ High-pass

$\times$ $=$ Band-pass

Low-Pass Filtered Image

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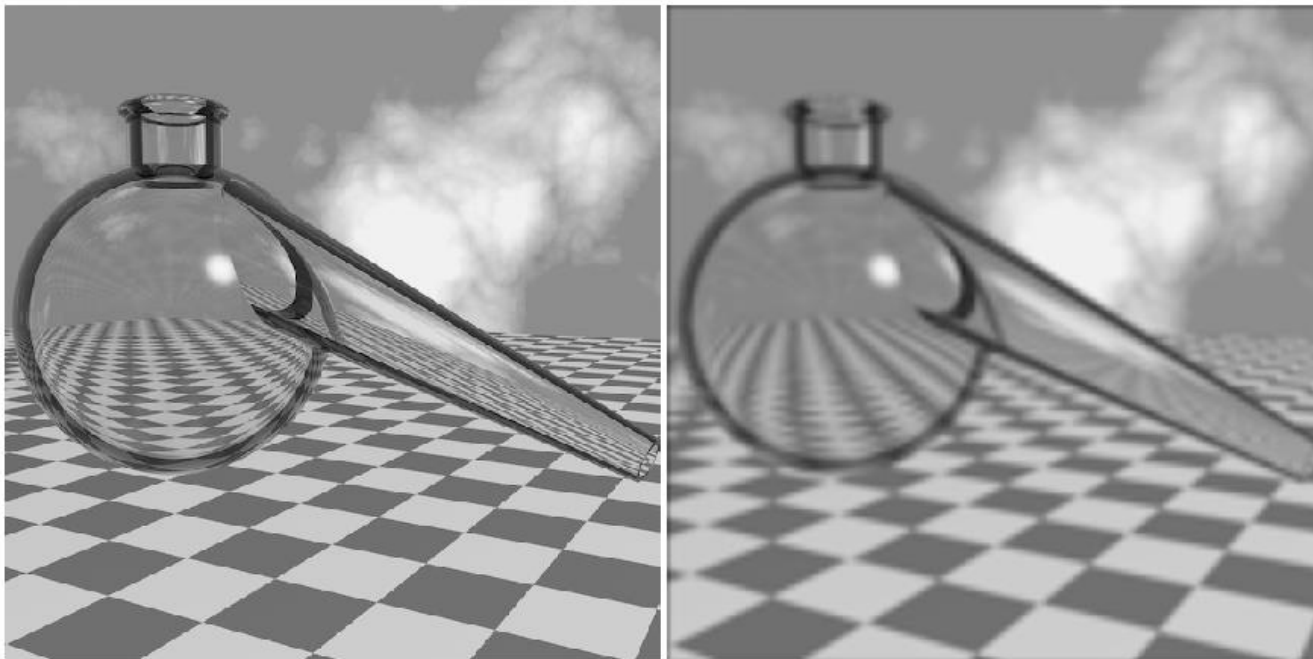
High-Pass Filtered Image
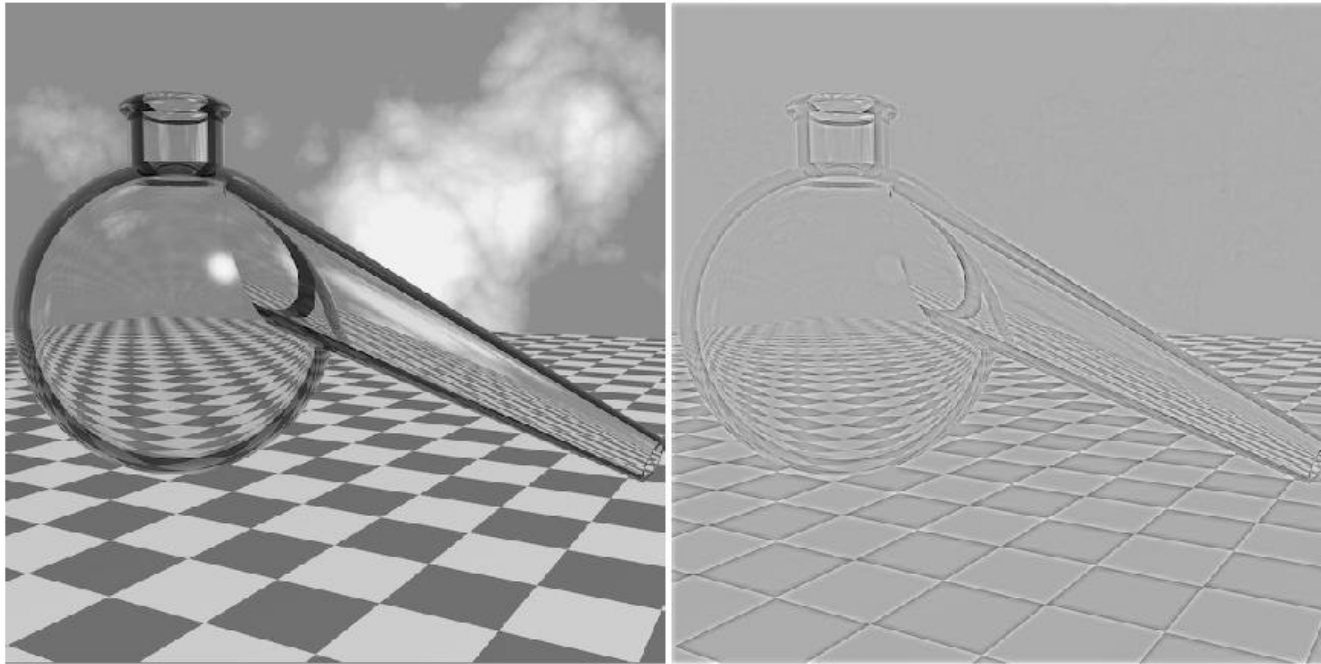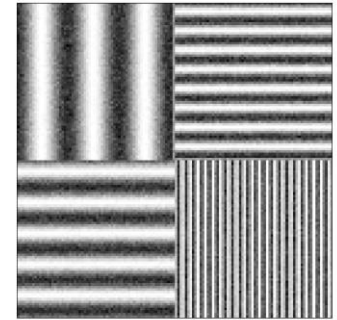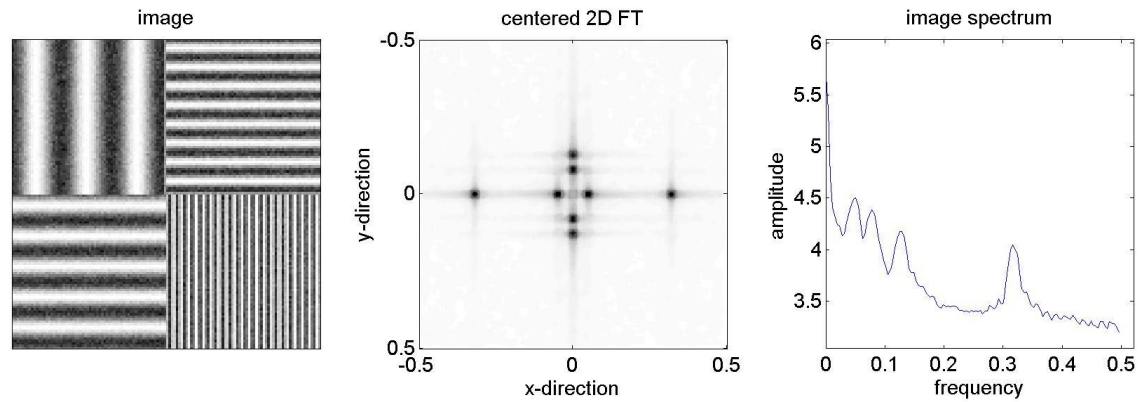
no filter
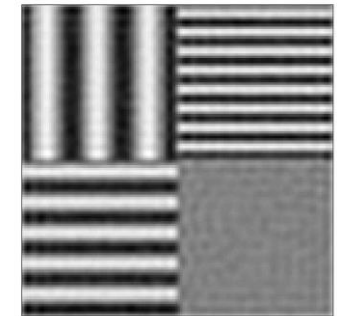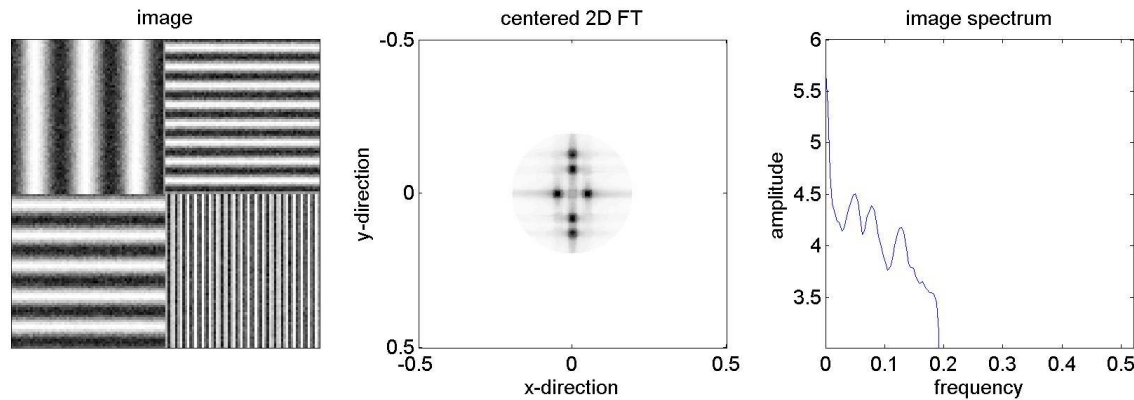
low-pass filter
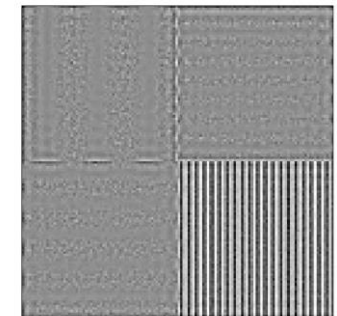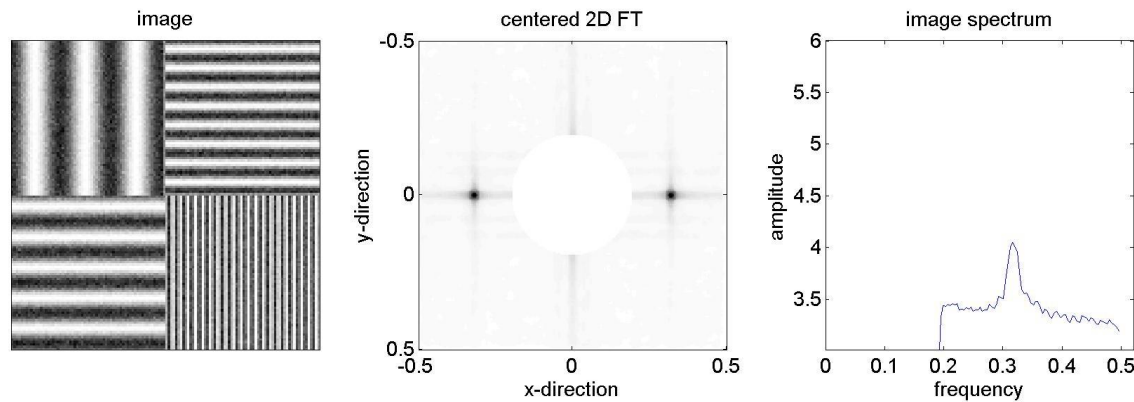
high-pass filter
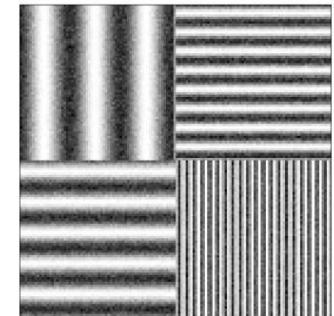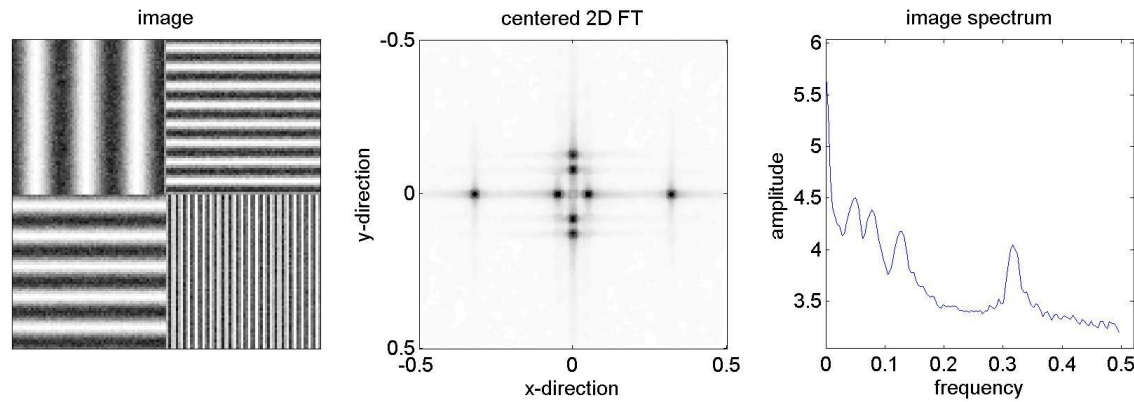
no filter
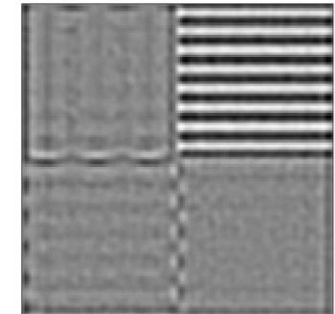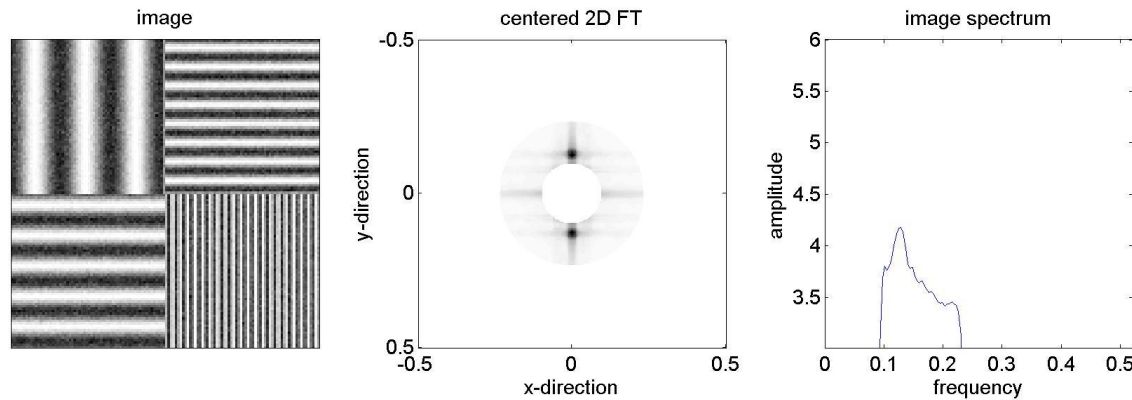
band-pass filter
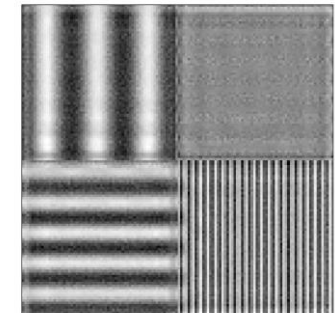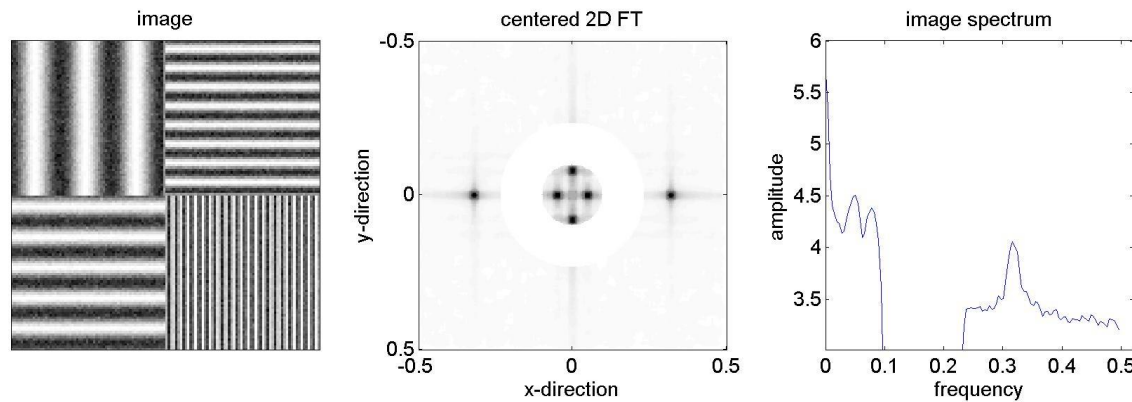
Summary:

Distance or size in spatial domain correlates inversely with frequency in frequency domain. Consequently, small structures in an image are said to have high spatial frequency, and the resolution capability of a camera is often expressed by means of the ***Nyquist frequency, that is, the highest frequency that the system can "see."***

Understanding that low frequencies correspond to large, uniform objects and that high frequencies correspond to small objects or sudden variations in count levels (e.g., at the edge of an object), one realizes the desirability of developing tools that enhance or deemphasize specific characteristics of an image. Filters are such tools.

Enhancement
Techniques

Spatial
Operates on pixels

Frequency Domain
Operates on FT of
Image

Spatial Domain Methods

- In these methods a operation (linear or non-linear) is performed on the pixels in the neighborhood of coordinate (x,y) in the input image F, giving enhanced image F'

- Neighborhood can be any shape but generally it is rectangular (3x3, 5x5, 9x9 etc)

$$g(x,y) = T[f(x,y)]$$

Grey Scale Manipulation

- Simplest form of window (1x1)

- Assume input gray scale values are in range [0, L-1] (in 8 bit images L = 256)

- Nth root Transformation

$$s = c \, (r)^n$$

contd...

FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.

- Linear: Negative, Identity
- Logarithmic: Log, Inverse Log
- Power-Law: nth power, nth root
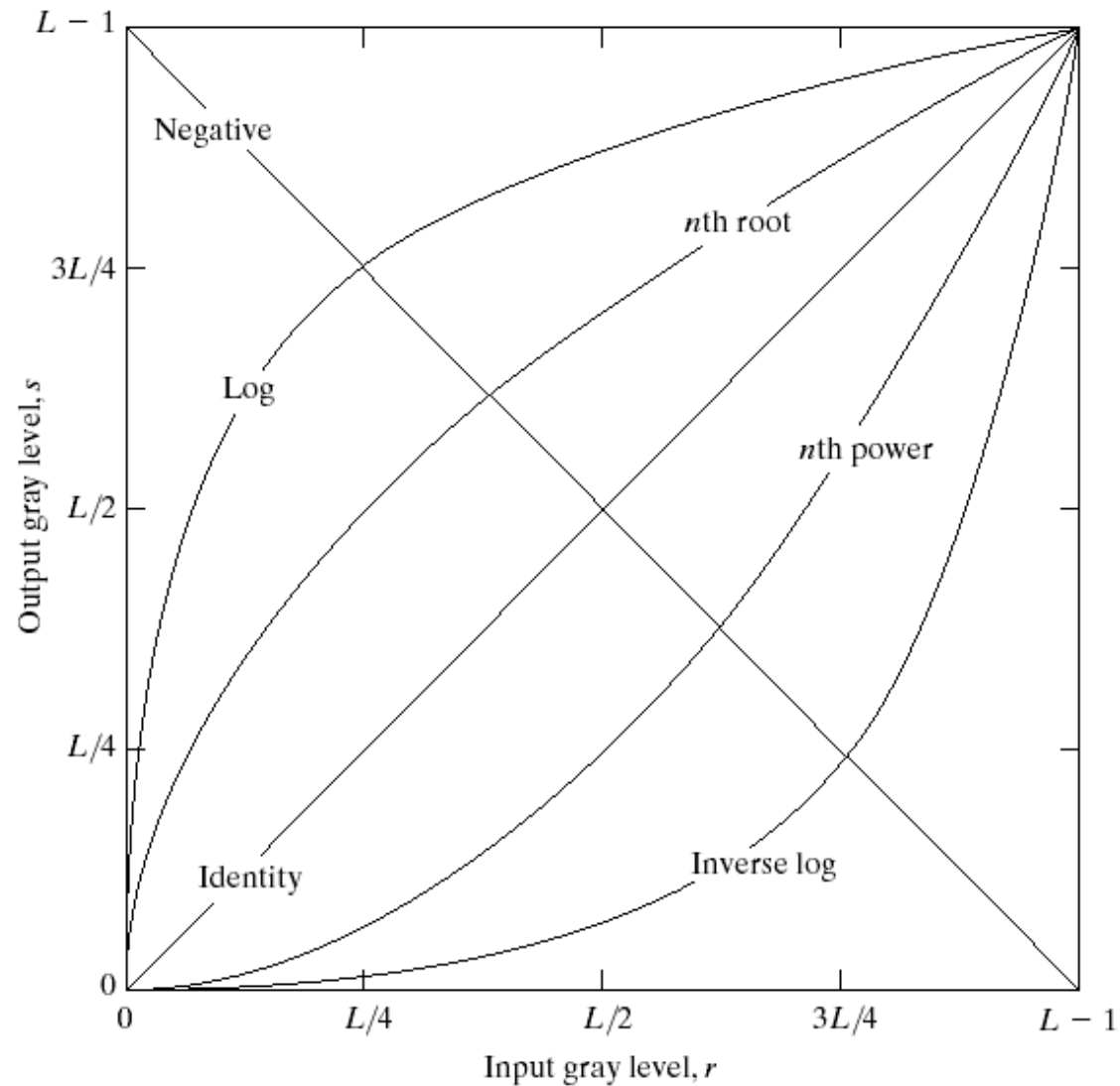
Image Negative
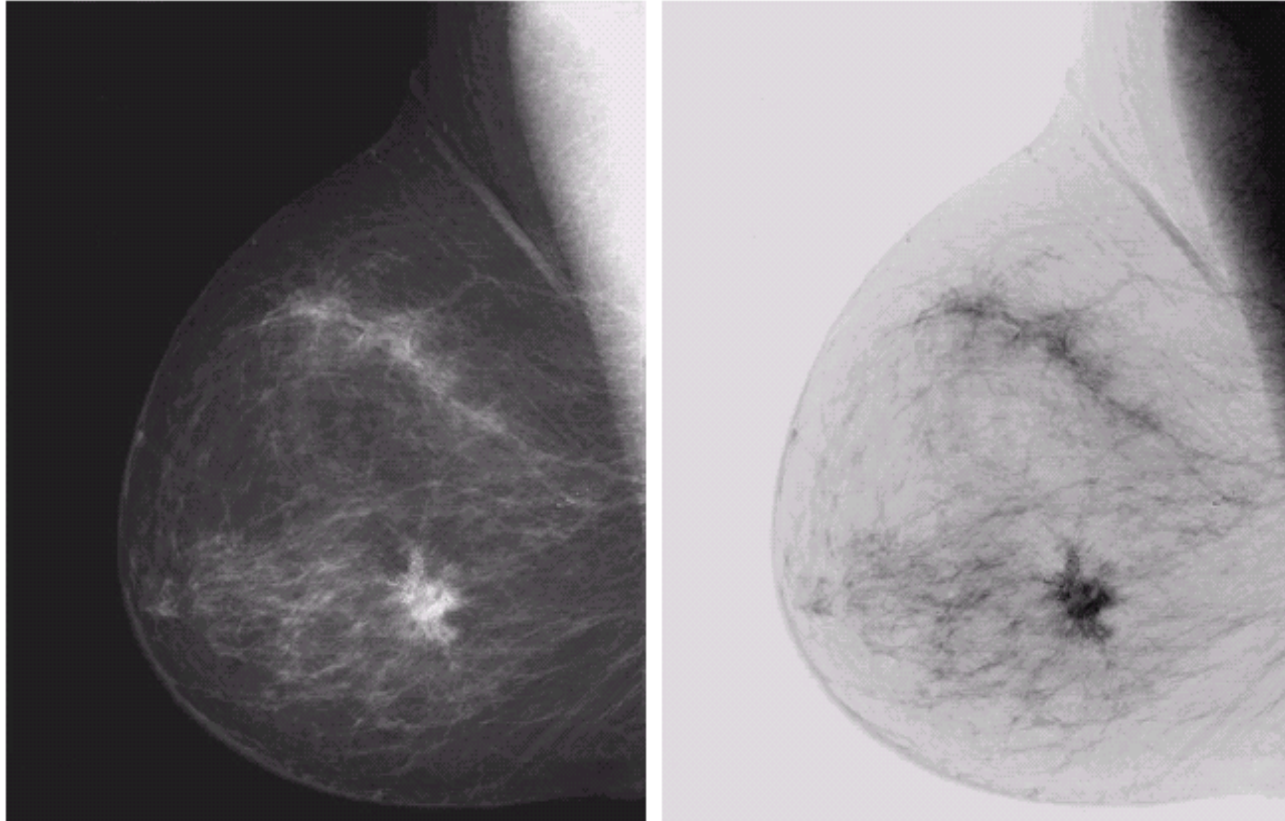
a b

FIGURE 3.4
(a) Original digital mammogram.
(b) Negative image obtained using the negative transformation in Eq. (3.2-1).
(Courtesy of G.E. Medical Systems.)

Image Negative: $s = L - 1 - r$

Log Transformation

$$s = c \log(1+r)$$

c: constant

- Compresses the dynamic range of images with large variations in pixel values

a b

FIGURE 3.5
(a) Fourier spectrum.
(b) Result of applying the log transformation given in Eq. (3.2-2) with $c = 1$.
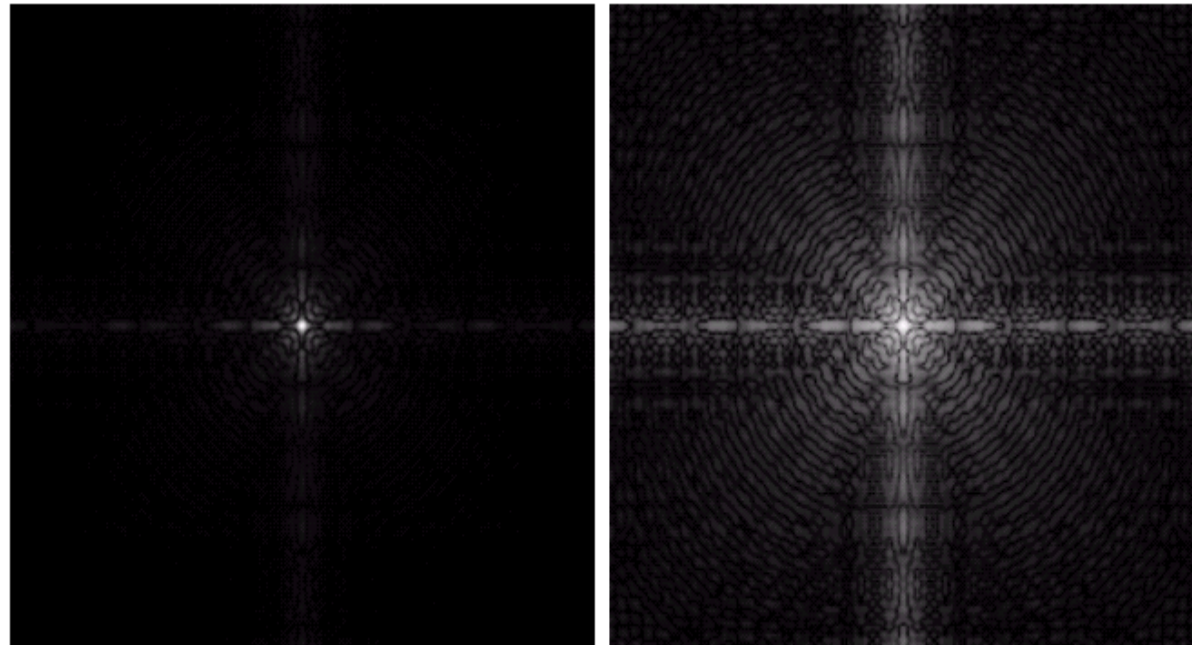
Power Law Transformation

- $s = cr^{\gamma}$

- C, γ : positive constants

- Gamma correction
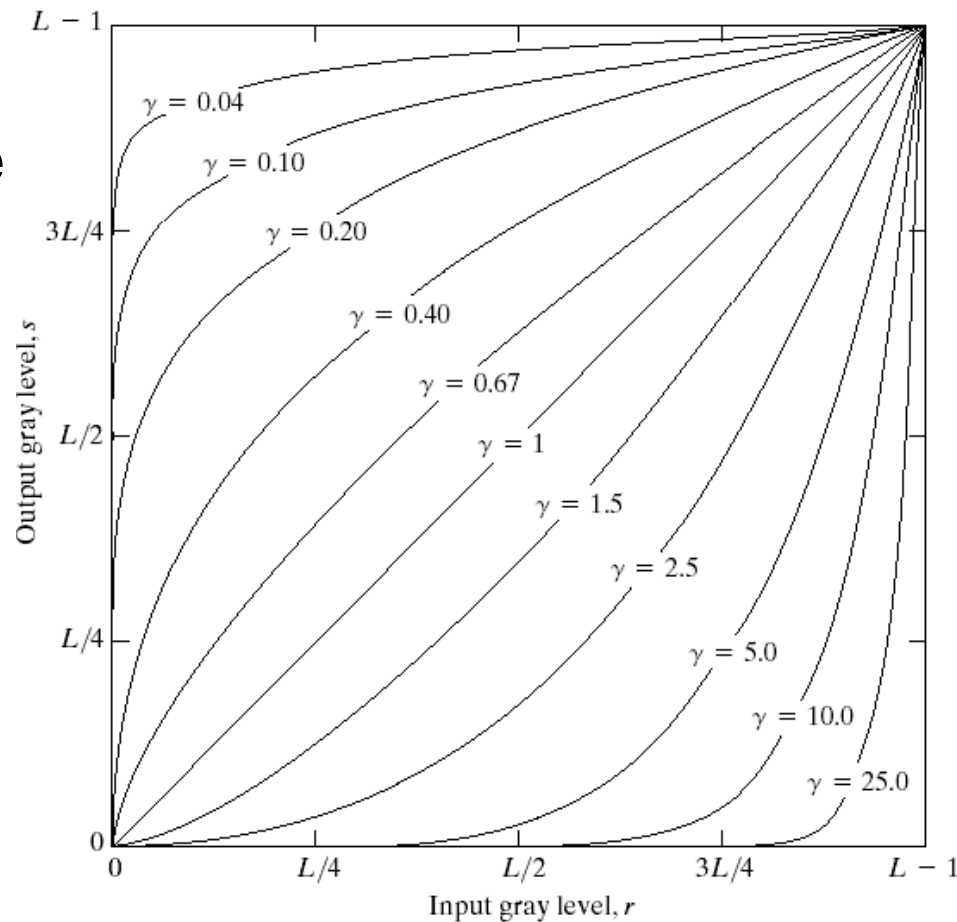
FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases).

Contrast Stretching

- To increase the dynamic range of the gray levels in the image being processed.
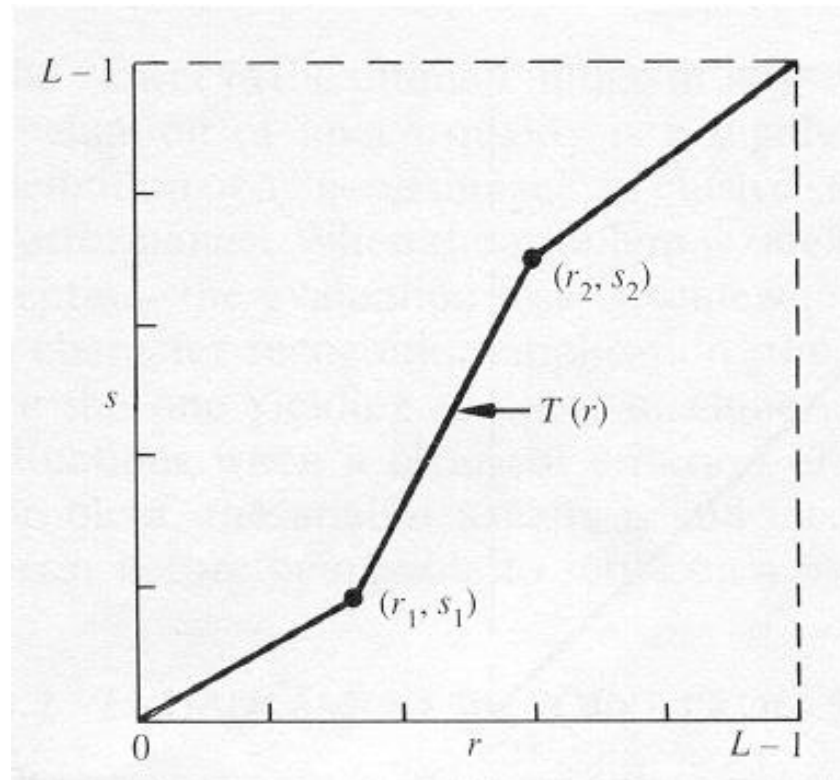
- The locations of (r_1,s_1) and (r_2,s_2) control the shape of the transformation function.

  - If $r_1= s_1$ and $r_2= s_2$ the transformation is a linear function and produces no changes.
  - If $r_1=r_2$, $s_1=0$ and $s_2=L-1$, the transformation becomes a thresholding function that creates a binary image.
  - Intermediate values of (r_1,s_1) and (r_2,s_2) produce various degrees of spread in the gray levels of the output image, thus affecting its contrast.
  - Generally, $r_1 \leq r_2$ and $s_1 \leq s_2$ is assumed.

Example
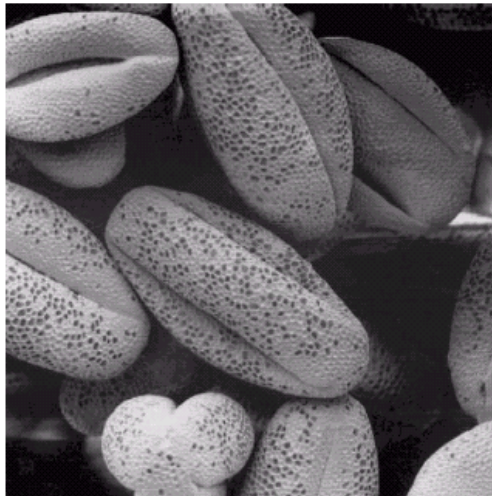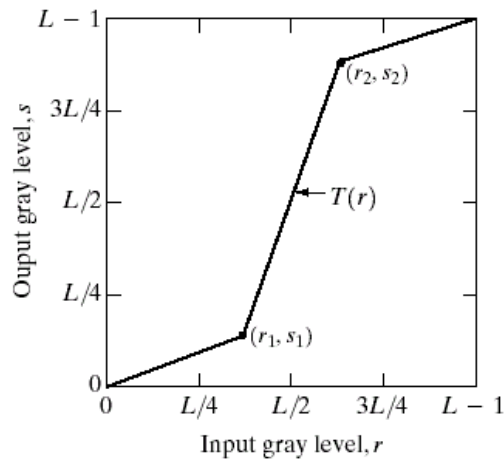
a b
c d

FIGURE 3.10
Contrast
stretching.
(a) Form of
transformation
function. (b) A
low-contrast
image. (c) Result
of contrast
stretching.
(d) Result of
thresholding.
(Original image
courtesy of
Dr. Roger Heady,
Research School
of Biological
Sciences,
Australian
National
University,
Canberra,
Australia.)

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Bit-Plane Slicing

- To highlight the contribution made to the total image appearance by specific bits.

  – i.e. Assuming that each pixel is represented by 8 bits, the image is composed of 8 1-bit planes.

  – Plane 0 contains the least significant bit and plane 7 contains the most significant bit.

  – Only the higher order bits (top four) contain visually significant data. The other bit planes contribute the more subtle details.
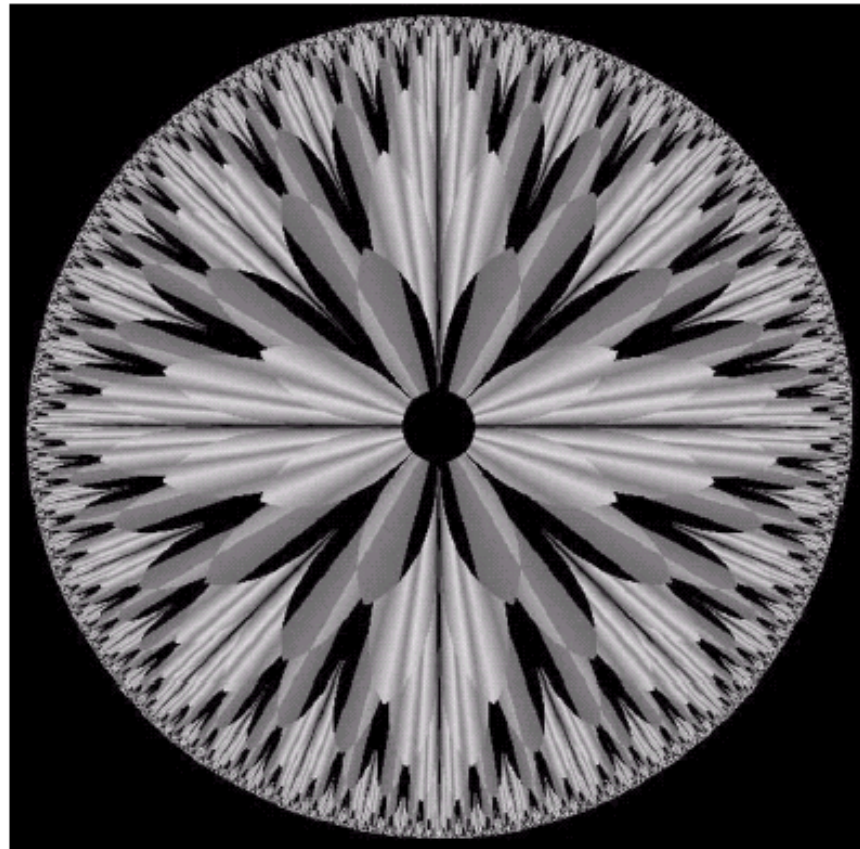
FIGURE 3.13 An 8-bit fractal image. (A fractal is an image generated from mathematical expressions). (Courtesy of Ms. Melissa D. Binde, Swarthmore College, Swarthmore, PA.)
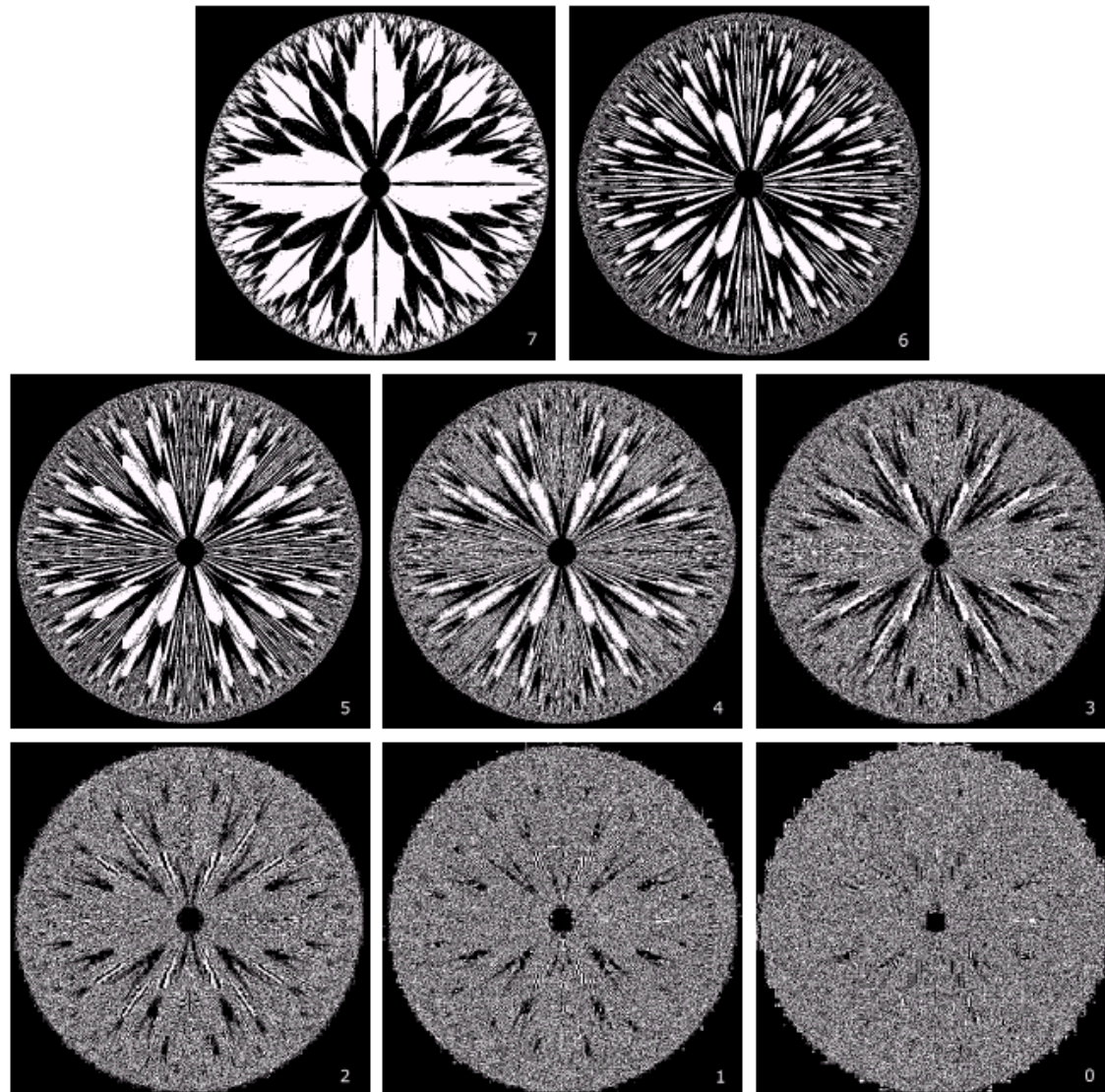
FIGURE 3.14 The eight bit planes of the image in Fig. 3.13. The number at the bottom, right of each image identifies the bit plane.

Histogram Processing

- The histogram of a digital image with gray levels from 0 to L-1 is a discrete function $h(r_k)=n_k$, where:

  - r_k is the kth gray level
  - n_k is the # pixels in the image with that gray level
  - n is the total number of pixels in the image
  - k = 0, 1, 2, …, L-1

- Normalized histogram: $p(r_k)=n_k/n$
  - sum of all components = 1

- Types of processing:

  – Histogram equalization

  – Histogram matching (specification)

  – Local enhancement

Histogram Equalization

$$s_k = T(r_k) = \sum_{j=0}^{k} \frac{n_j}{n} = \sum_{j=0}^{k} p_r(r_j)$$

- Histogram equalization (HE) results are similar to contrast stretching but offer the advantage of full automation, since HE automatically determines a transformation function to produce a new image with a uniform histogram.

Dark image

Bright image

Low-contrast image

High-contrast image
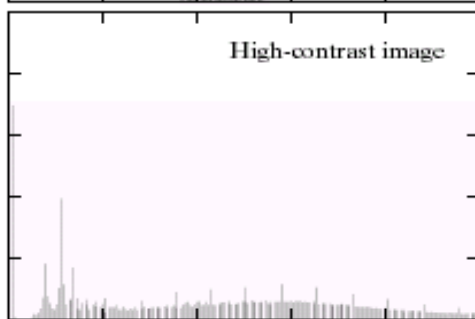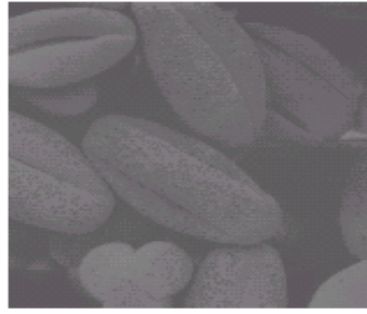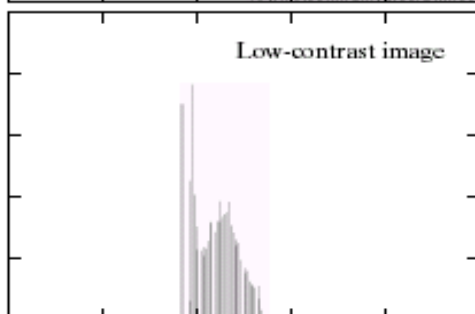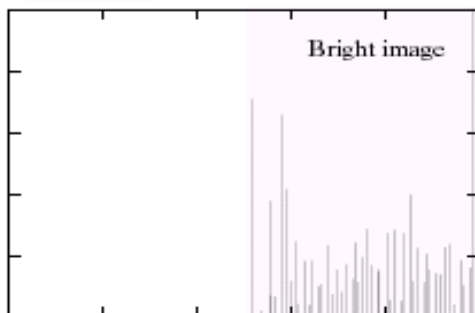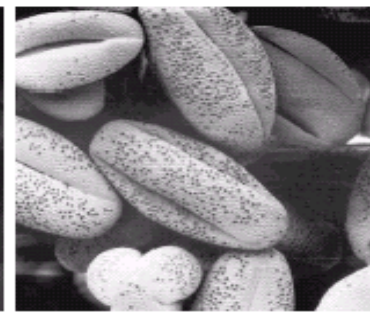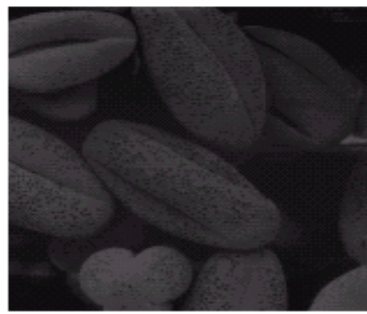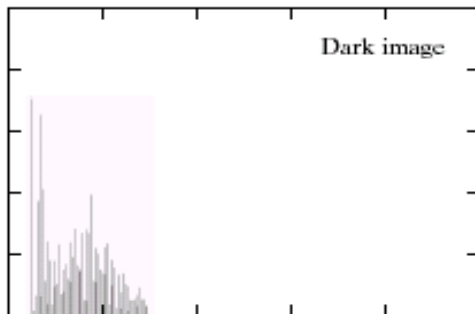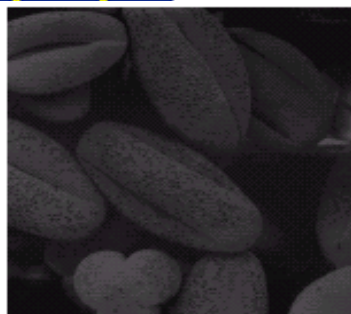
Histogram Matching (or Specification)

- Histogram equalization does not allow interactive image enhancement and generates only one result: an approximation to a uniform histogram.

- Sometimes though, we need to be able to specify particular histogram shapes capable of highlighting certain gray-level ranges.

Method

- Specify the desired density function and obtain the transformation function G(z):

$$v = G(z) = \sum_{0}^{z} p_z(w) \approx \sum_{i=0}^{z} \frac{n_i}{n}$$

p_z: specified desirable PDF for output

- Apply the inverse transformation function $z = G^{-1}(s)$ to the levels obtained in step 1.

Image Smoothing or Averaging

- A noisy image:

$$g(x, y) = f(x, y) + n(x, y)$$

- Averaging M different noisy images:

$$\overline{g}(x, y) = \frac{1}{M} \sum_{i=1}^{M} g_i(x, y)$$

- As M increases, the variability of the pixel values at each location decreases.

  – This means that g(x,y) approaches f(x,y) as the number of noisy images used in the averaging process increases.

Example

a b
c d
e f
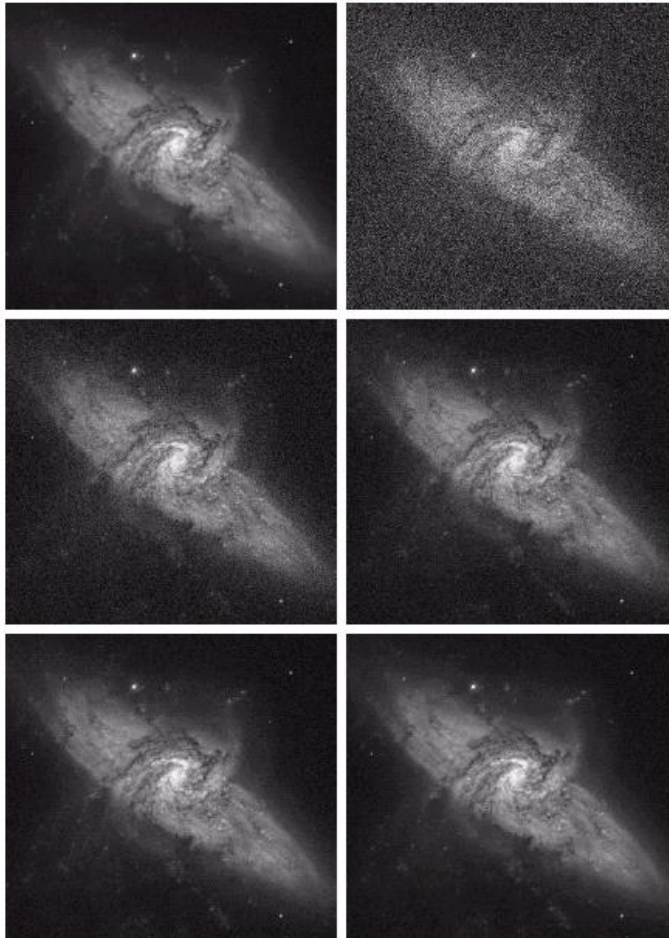
FIGURE 3.30 (a) Image of Galaxy Pair NGC 3314. (b) Image corrupted by additive Gaussian noise with zero mean and a standard deviation of 64 gray levels. (c)–(f) Results of averaging $K = 8, 16, 64$, and 128 noisy images. (Original image courtesy of NASA.)

Spatial Filtering

- Use of spatial masks for image processing (spatial filters)

- Linear and nonlinear filters

- Low-pass filters eliminate or attenuate high frequency components in the frequency domain (sharp image details), and result in image blurring.

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$a=(m-1)/2$ and $b=(n-1)/2$,
m x n (odd numbers)

For x=0,1,…,M-1 and y=0,1,…,N-1

$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)$$

The basic approach is to sum products between the mask coefficients and the intensities of the pixels under the mask at a specific location in the image:

$$R = w_1 z_1 + w_2 z_2 + \ldots + w_9 z_9$$

(for a 3 x 3 filter)

Neighborhood Averaging

Each point in the smoothed image, $\hat{F}(x, y)$ is obtained from the average pixel value in a neighbourhood of (x, y) in the input image.

For example, if we use a 3×3 neighbourhood around each pixel we would use the mask

$$
\begin{matrix}
1/9 & 1/9 & 1/9 \\
1/9 & 1/9 & 1/9 \\
1/9 & 1/9 & 1/9
\end{matrix}
$$

General Spatial Filter

FIGURE 3.33
Another representation of a general 3 × 3 spatial filter mask.

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

a b

FIGURE 3.34 Two 3 × 3 smoothing (averaging) filter masks. The constant multiplier in front of each mask is equal to the sum of the values of its coefficients, as is required to compute an average.

$$\frac{1}{9} \times \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array} \qquad \frac{1}{16} \times \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array}$$
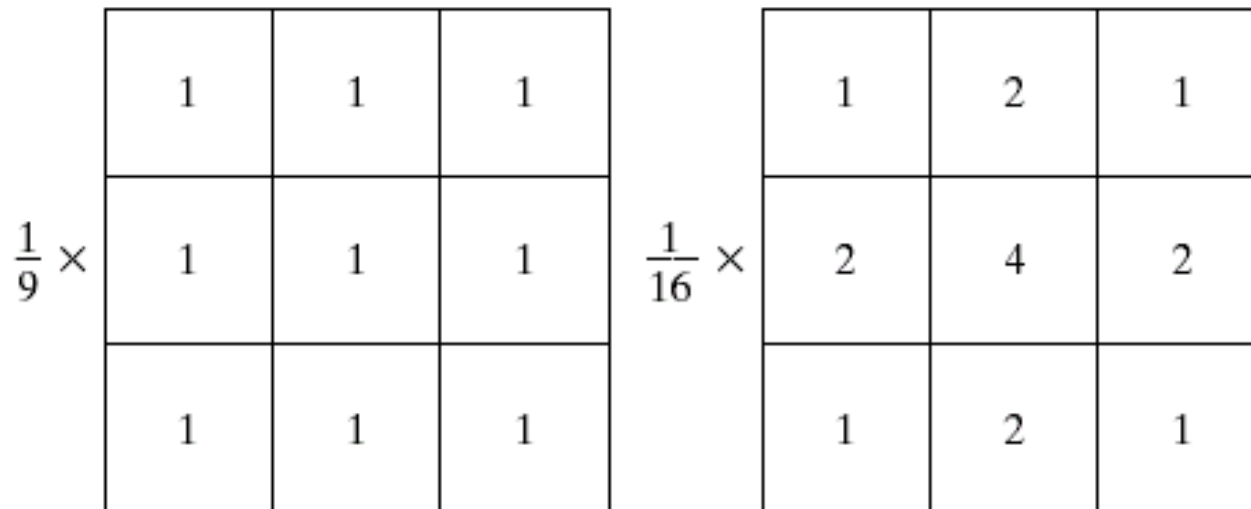
Non-linear Filter

- Median filtering (nonlinear)

  – Used primarily for noise reduction (eliminates isolated spikes)

  – The gray level of each pixel is replaced by the median of the gray levels in the neighborhood of that pixel (instead of by the average as before).

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original   added noise

average   median

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Sharpening Filters

- The main aim in image sharpening is to highlight fine detail in the image

- With image sharpening, we want to enhance the high-frequency components; this implies a spatial lter shape that has a high positive component at the centre
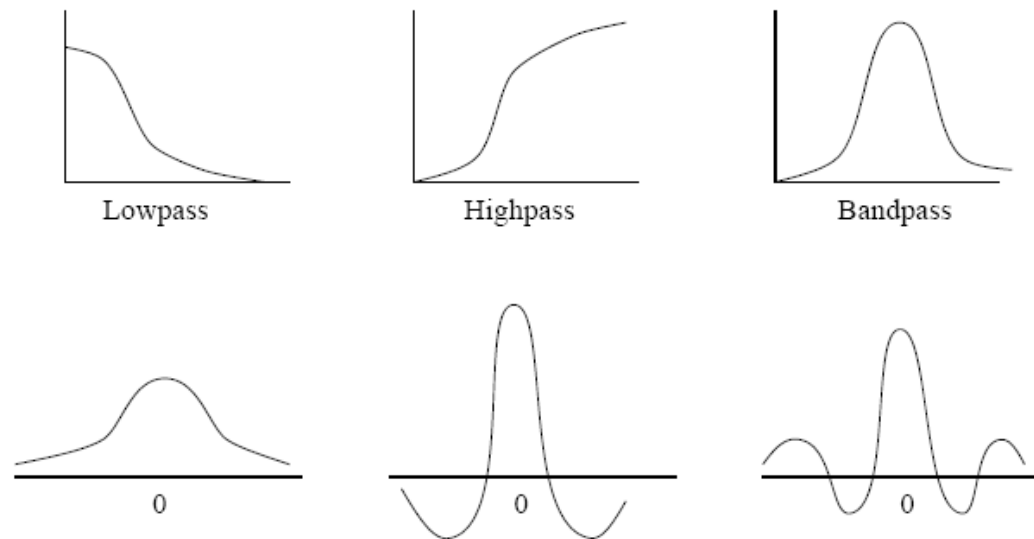
Figure 4: Frequency domain filters (top) and their corresponding spatial domain counterparts (bottom).

Derivatives

- First derivative

$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

- Second derivative

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x)$$

Observations

- 1st order derivatives produce thicker edges in an image

- 2nd order derivatives have stronger response to fine detail

- 1st order derivatives have stronger response to a gray lever step

- 2nd order derivatives produce a double response at step changes in gray level

A simple spatial filter that achieves image sharpening is given by

$$
\begin{array}{ccc}
-1/9 & -1/9 & -1/9 \\
-1/9 & 8/9 & -1/9 \\
-1/9 & -1/9 & -1/9
\end{array}
$$

- Since the sum of all the weights is zero, the resulting signal will have a zero DC value

Frequency Domain Methods

- We simply compute the Fourier transform of the image to be enhanced, multiply the result by a filter (rather than convolve in the spatial domain), and take the inverse transform to produce the enhanced image.

- Low pass filtering involves the elimination of the high frequency components in the image. It results in blurring of the image

Frequency Domain Methods

ideal frequency low pass filter

spatial domain counterpart
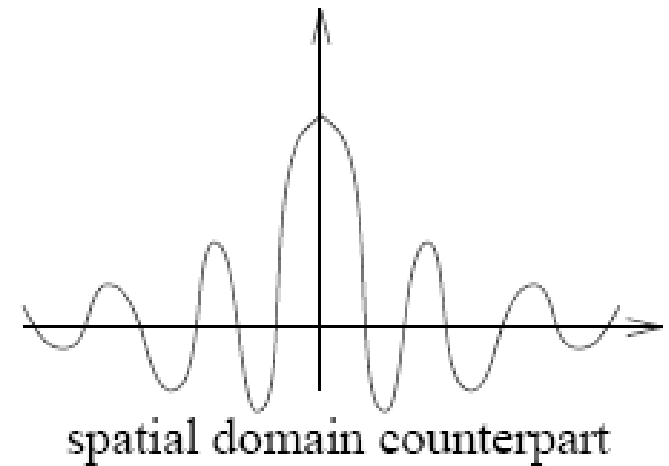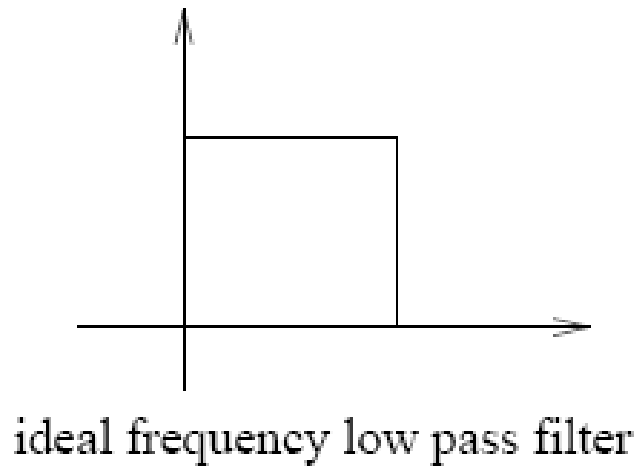
Figure 5: Transfer function for an ideal low pass filter.

Image Quality

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Image quality assessment categories

- **Full-reference (FR) methods** – FR metrics try to assess the quality of a test image by comparing it with a reference image that is assumed to have perfect quality, e.g. the original of an image versus a JPEG-compressed version of the image.

- **Reduced-reference (RR) methods** – RR metrics assess the quality of a test and reference image based on a comparison of features extracted from both images.

- **No-reference (NR) methods** – NR metrics try to assess the quality of a test image without any reference to the original one.

Full reference metrics

- Well-known and often-used metrics include:
  - Peak Signal to Noise Ratio (PSNR),
  - Structural Similarity (SSIM),
  - Visual Information Fidelity (VIF).

No Reference metrics

- based on Natural Scene Statistics (NSS), have also been developed at the LIVE group. They includes:
  - BRISQUE,
  - BLIINDS,
  - DIIVINE,
  - NIQE

Image Quality Factors

- **Sharpness** determines the amount of detail an image can convey. System sharpness is affected by the lens (design and manufacturing quality, focal length, aperture, and distance from the image center) and sensor (pixel count and anti-aliasing filter). In the field, sharpness is affected by camera shake (a good tripod can be helpful), focus accuracy, and atmospheric disturbances (thermal effects and aerosols). Lost sharpness can be restored by sharpening, but sharpening has limits. Oversharpening, can degrade image quality by causing "halos" to appear near contrast boundaries. Images from many compact digital cameras are sometimes oversharpened to compensate for lower image quality.

Image Quality Factors

- **Noise** is a random variation of image density, visible as grain in film and pixel level variations in digital images.

- It arises from the effects of basic physics— the photon nature of light and the thermal energy of heat— inside image sensors.

- Typical noise reduction (NR) software reduces the visibility of noise by smoothing the image, excluding areas near contrast boundaries.

- This technique works well, but it can obscure fine, low contrast detail.

Image Quality Factors

- **Dynamic range** (or exposure range) is the range of light levels a camera can capture, usually measured in f-stops, EV (exposure value), or zones (all factors of two in exposure). It is closely related to noise: high noise implies low dynamic range.

Image Quality Factors

- **Tone reproduction** is the relationship between scene luminance and the reproduced image brightness.

Image Quality Factors

- **Contrast**, also known as gamma, is the slope of the tone reproduction curve in a log-log space. High contrast usually involves loss of dynamic range — loss of detail, or clipping, in highlights or shadows.

Image Quality Factors

- **Color accuracy** is an important but ambiguous image quality factor. Many viewers prefer enhanced color saturation; the most accurate color isn't necessarily the most pleasing. Nevertheless it is important to measure a camera's color response: its color shifts, saturation, and the effectiveness of its white balance algorithms.

Image Quality Factors

- **Distortion** is an aberration that causes straight lines to curve. It can be troublesome for architectural photography and metrology (photographic applications involving measurement). Distortion tends to be noticeable in low cost cameras, including cell phones. It is usually very easy to see in wide angle photos. It can be now be corrected in software.

Image Quality Factors

- **Vignetting**, or light falloff, darkens images near the corners. It can be significant with wide angle lenses.

Image Quality Factors

- **Exposure accuracy** can be an issue with fully automatic cameras and with video cameras where there is little or no opportunity for post-exposure tonal adjustment. Some even have exposure memory: exposure may change after very bright or dark objects appear in a scene.

Image Quality Factors

- **Lateral chromatic aberration** (LCA), also called "color fringing", including purple fringing, is a lens aberration that causes colors to focus at different distances from the image center. It is most visible near corners of images. LCA is worst with asymmetrical lenses, including ultrawides, true telephotos and zooms. It is strongly affected by demosaicing.

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Image Quality Factors

- **Lens flare**, including "veiling glare" is stray light in lenses and optical systems caused by reflections between lens elements and the inside barrel of the lens. It can cause image fogging (loss of shadow detail and color) as well as "ghost" images that can occur in the presence of bright light sources in or near the field of view.

Image Quality Factors

- **Color moiré** is artificial color banding that can appear in images with repetitive patterns of high spatial frequencies, like fabrics or picket fences. It is affected by lens sharpness, the anti-aliasing (lowpass) filter (which softens the image), and demosaicing software. It tends to be worst with the sharpest lenses.

Image Quality Factors

- **Artifacts** – software (especially operations performed during RAW conversion) can cause significant visual artifacts, including data compression and transmission losses (e.g. Low quality JPEG), oversharpening "halos" and loss of fine, low-contrast detail.

Suggested Readings

- Book: Digital Image Processing, **2nd Edition** by Gonzalez and Woods, Prentice Hall.

- Book: The essential guide to Image Processing, AL BOVIK, Elsevier.