Digital Image Processing

Chapter 1: Introduction

Text book

- Textbook:
  - Rafael C. Gonzalez and Richard E. Woods, "Digital Image Processing, 3rd edition", Prentice Hall.

Course Content

Chapter 1: Introduction
Chapter 2: Digital Image Fundamentals
Chapter 3: Image Enhancement in the Spatial Domain
Chapter 4: Image Enhancement in the Frequency Domain
Chapter 6: Color image processing
Chapter 8: Image Compression (introduction)
Chapter 9: Morphological Image Processing
Chapter 11: Representation and Description
Chapter 12: Object Recognition (introduction)

Grading System

- First Exam 20%
- Second Exam 20%
- Assignment/Quiz/Report 20%
- Final Exam 40%

Overview

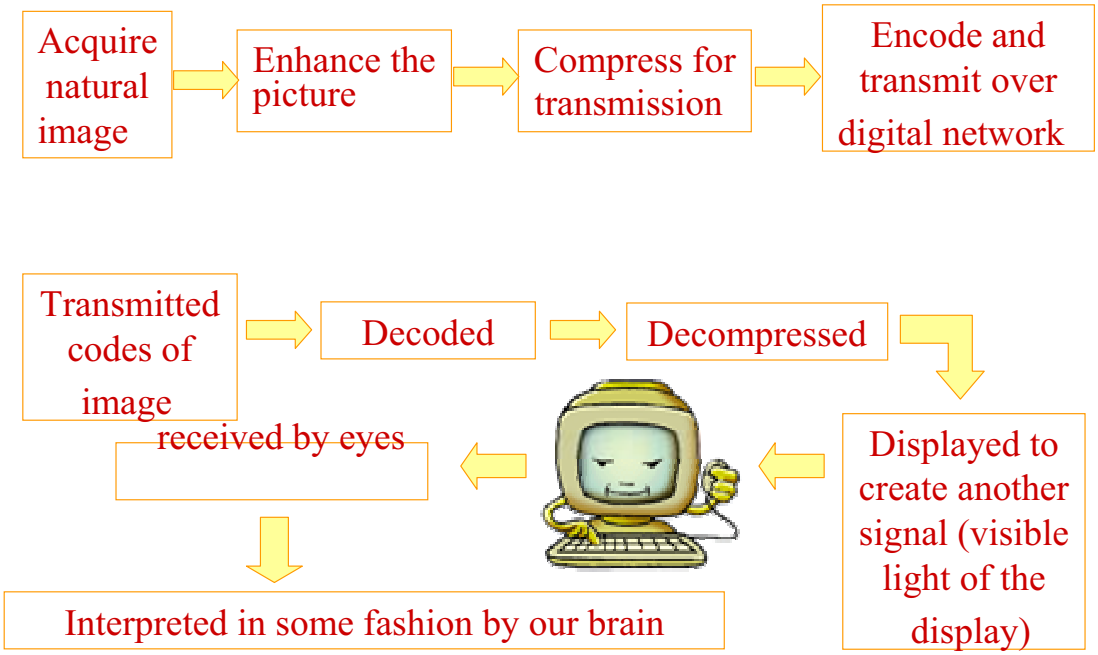
- Early days of computing, data was numerical and textual.
- Today, many other forms of data: voice, music, speech, images, computer graphics, etc.
- Each of these types of data are signals.
- Loosely defined, a signal is a function that conveys information.

Relationship of Signal Processing to other fields

- As long as people have tried to send or receive through electronic media : telegraphs, telephones, television, radar, etc. there has been the realization that these signals may be affected by the system used to acquire, transmit, or process them.
- Sometimes, these systems are imperfect and introduce noise, distortion, or other artifacts.

- Understanding the effects of these systems and finding ways to correct them is the fundamental of signal processing.
- Sometimes, these signals are specific messages that we create and send to someone else (e.g., telegraph, telephone, television, digital networking, etc.).
- That is, we specifically introduce the information content into the signal and hope to extract it out later.

- Sometimes, these man-made signals are encoding of natural phenomena (audio signal, acquired image, etc.),
- but sometimes we can create them from scratch (speech generation, computer generated music, computer graphics).
- Finally, we can sometimes merge these technologies together by acquiring a natural signal, processing it, and then transmitting it in some fashion.



Concerned fields:

- Digital Communication
- Compression
- Speech Synthesis and Recognition
- Computer Graphics
- Image Processing
- Computer Vision

What is Image Processing?

- Image processing is a subclass of signal processing concerned specifically with pictures.
- Improve image quality for human perception and/or computer interpretation.

Several fields deal with images

- Computer Graphics : the creation of images.
- Image Processing : the enhancement or other manipulation of the image – the result of which is usually another images.
- Computer Vision: the analysis of image content.

Several fields deal with images

Input/Output	Image	Description
Image	Image Processing	Computer Vision
Description	Computer Graphics	AI

.

2 Principal application areas

- Improvement of pictorial information for human interpretation
- Processing of image data for storage, transmission, and representation for autonomous machine perception

Ex. of fields that use DIP

- Categorize by image sources
  - Radiation from the Electromagnetic spectrum
  - Acoustic
  - Ultrasonic
  - Electronic (in the form of electron beams used in electron microscopy)
  - Computer (synthetic images used for modeling and visualization)

Radiation from EM spectrum

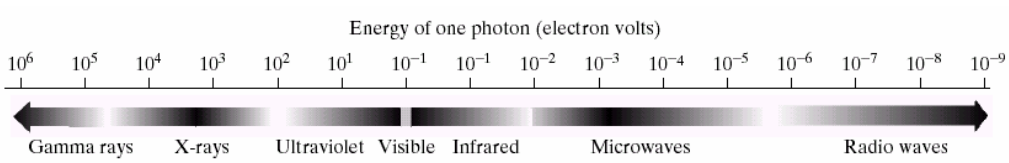
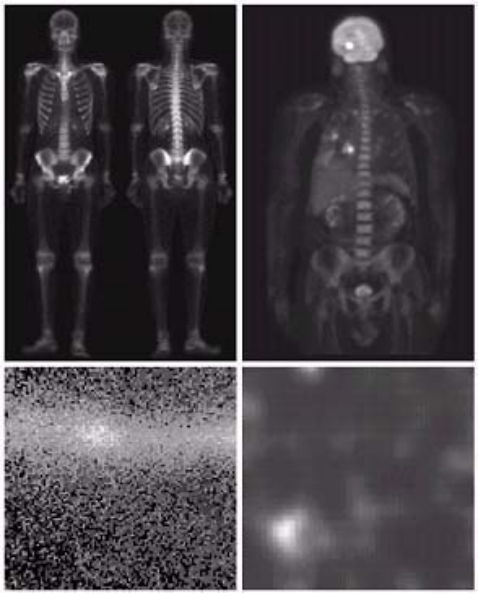


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

- Spectral bands are grouped by energy per photon
  - Gamma rays, X-rays, Ultraviolet, Visible, Infrared, Microwaves, Radio waves

Gamma-Ray Imaging

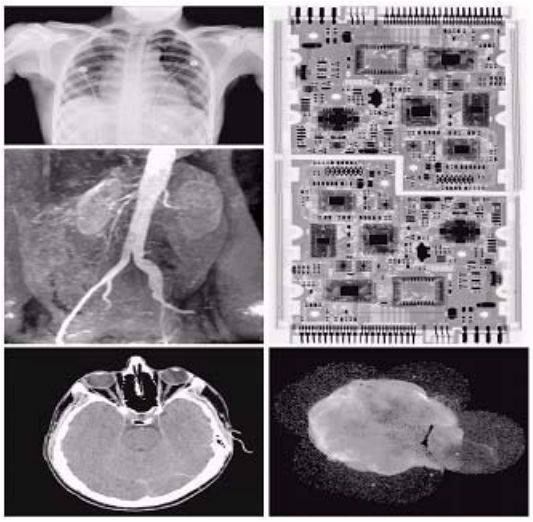
a	b
c	d



- Nuclear Image
  - (a) Bone scan
  - (b) PET (Positron emission tomography) image
- (c) Astronomical Observations.
- Nuclear Reaction
  - (d) Gamma radiation from a reactor valve

X-ray Imaging

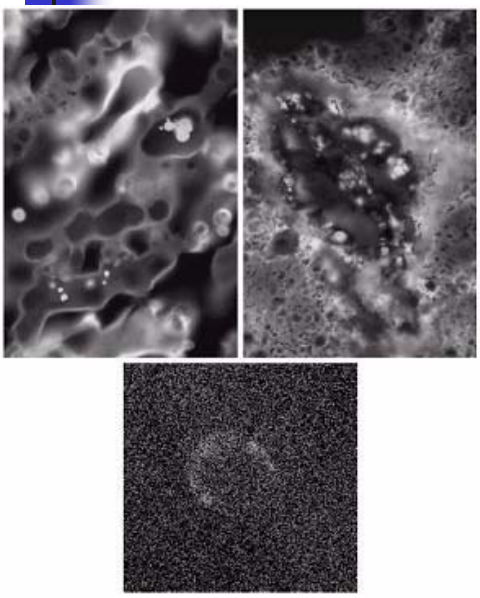
a	d
b	
c	e



- Medical diagnostics
  - (a) chest X-ray (familiar)
  - (b) aortic angiogram
  - (c) head CT
- Industrial imaging
  - (d) Circuit board
- (e) Astronomy

a	b
c	

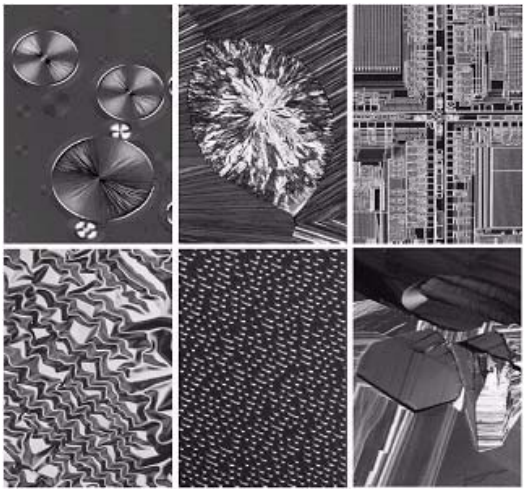
Imaging in Ultraviolet Band



- Industrial inspection
- Microscopy (fluorescence)
  - (a) Normal corn
  - (b) Smut corn
- Lasers
- Biological imaging
- (c) Astronomical observations

Imaging in Visible and Infrared Bands

a	b	c
d	e	f



- Astronomy
- Light microscopy
  - pharmaceuticals
    - (a). taxol (anticancer agent)
    - (b). cholesterol
  - Microinspection to materials characterization
    - (c). Microprocessor
    - (d). Nickel oxide thin film
    - (e). Surface of audio CD
    - (f). Organic superconductor

- Remote sensing

To monitor the environmental conditions on the planet

Thematic bands in visual and infrared regions

TABLE 1.1 Thematic bands in NASA's LANDSAT satellite.

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

NASA's LANDSAT: Washington DC

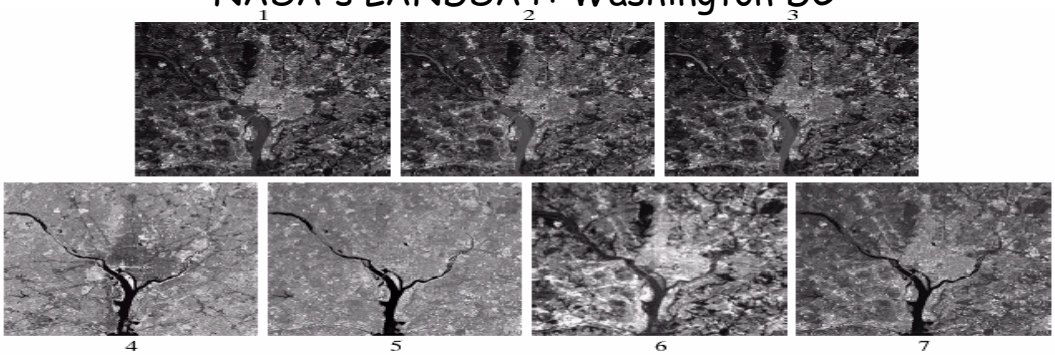
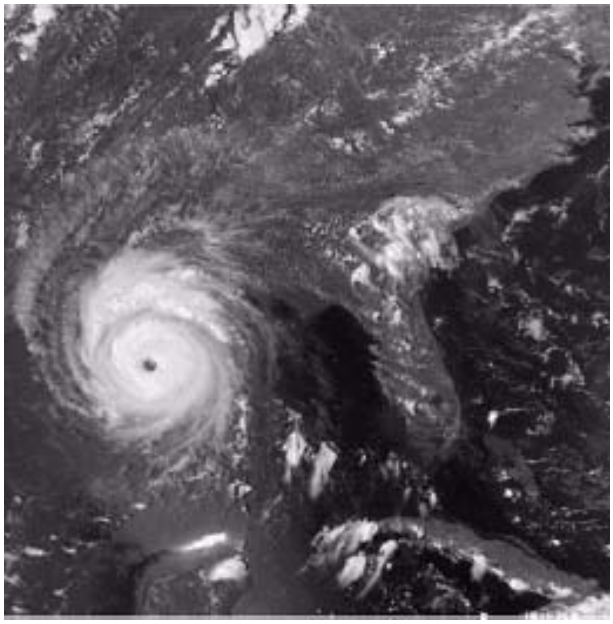


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

- Remote sensing : Weather observation and prediction



Multispectral image from satellites using sensors in the visible and infrared bands

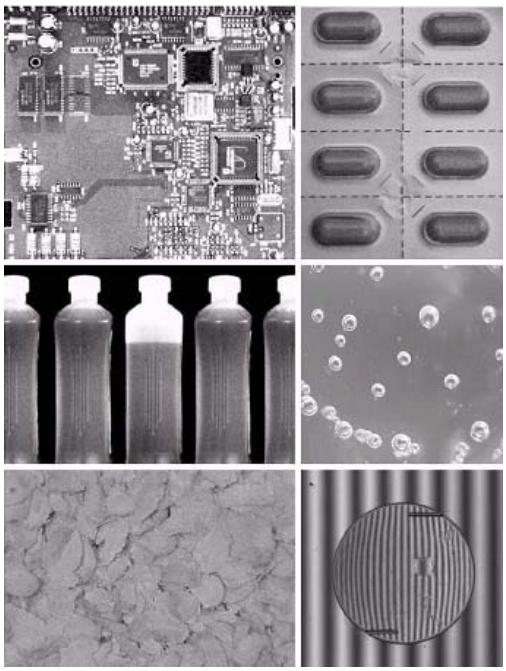
- Remote sensing : Nighttime Lights of the World
  (provides a global inventory of human settlements)

Infrared satellite images of the Americas.

Infrared satellite images of the remaining populated part of the world

- Industry : visual spectrum
  (automated visual inspection of manufactured goods)

a	d
b	e
c	f



(a). A circuit board: inspect them for missing parts
(b). Pill container: look for missing pills
(c). Bottles : look for bottles that are not filled up to an acceptable level
(d). Bubbles in clear-plastic product : detect unacceptable number of air pockets
(e). Cereal : inspection for color and the presence of anomalies such as burned flake.
(f). Inspection of damaged or incorrectly manufactured implants

- Law enforcement : visual spectrum

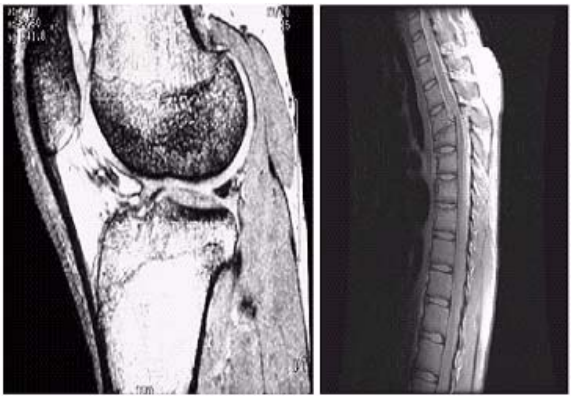
a
b
c

(a). Thumb print: automated search of a database for a potential matches
(b). Paper currency : automated counting / reading of the serial number for tracking and identifying bills
(c) and (d) Automated license plate reading

Imaging in Microwave Band

- Imaging radar : the only way to explore inaccessible regions of the Earth's surface
- Radar image of mountains in southeast Tibet
- Note the clarity and detail of the image, unencumbered by clouds or other atmospheric conditions that normally interfere with images in the visual band.

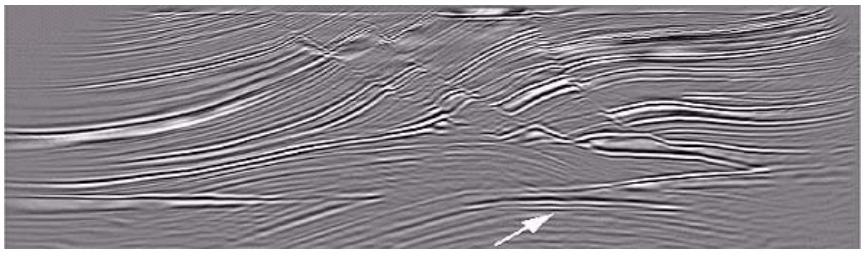
Imaging in Radio Band



- Medicine
  - Magnetic resonance image (MRI) : 2D picture of a section of the patient (any plane)
    - (a) knee
    - (b) spine
- Astronomy

Acoustic Imaging

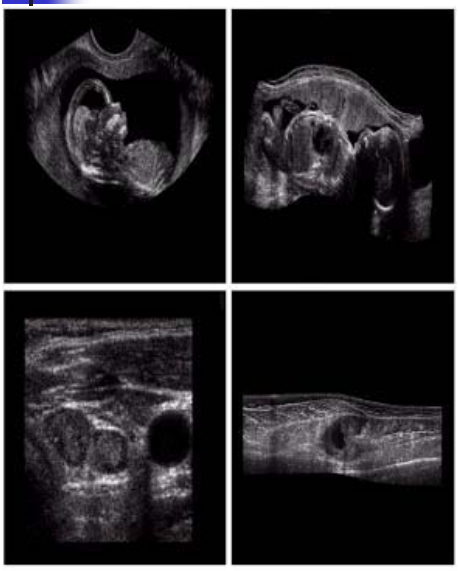
- Geological applications : use sound in the low end of the sound spectrum (hundred of Hz)
  - Mineral and oil exploration



Cross-sectional image of a seismic model.
The arrow points to a hydrocarbon (oil and/or gas) trap (bright spots)

Ultrasound Imaging

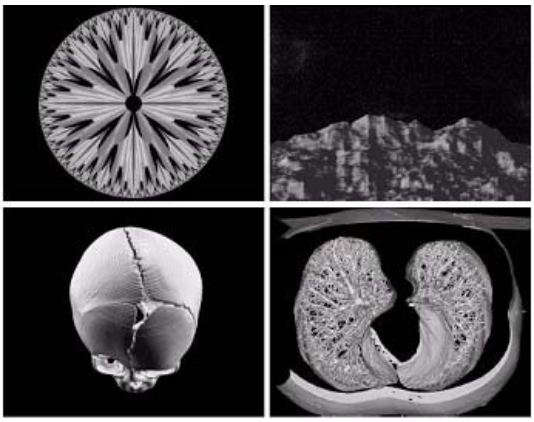
a	b
c	d



- Manufacturing
- Medicine
  - (a) Baby
  - (b) Another view of baby
  - (c) Thyroids
  - (d) Muscle layers showing lesion

Generated images by computer

a	b
c	d



- Fractals : an iterative reproduction of a basic pattern according to some mathematical rules
  - (a) and (b)
- 3-D computer modeling
  - (c) and (d)

3 types of computerized process

- Low-level : input, output are images
  - Primitive operations such as image preprocessing to reduce noise, contrast enhancement, and image sharpening
- Mid-level : inputs may be images, outputs are attributes extracted from those images
  - Segmentation
  - Description of objects
  - Classification of individual objects
- High-level :
  - Image analysis

Fundamental steps

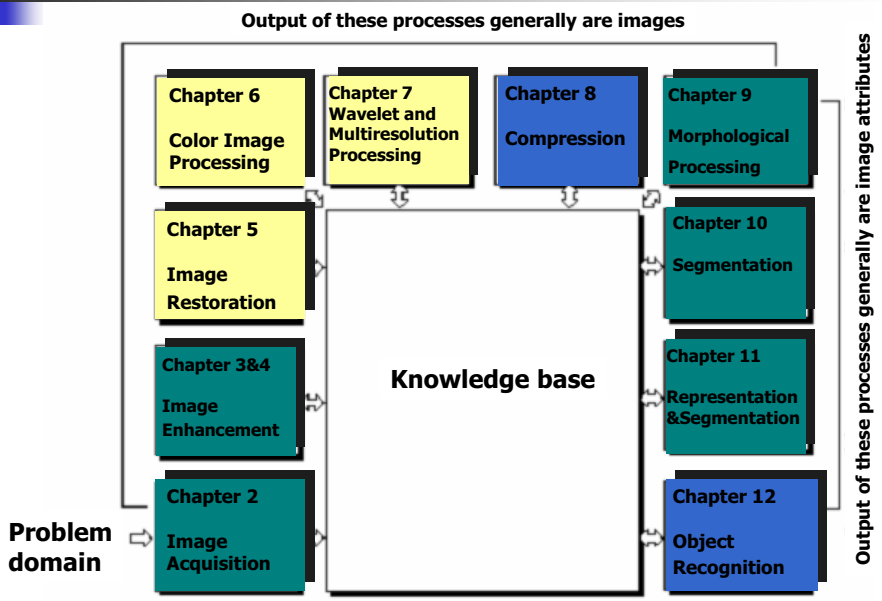


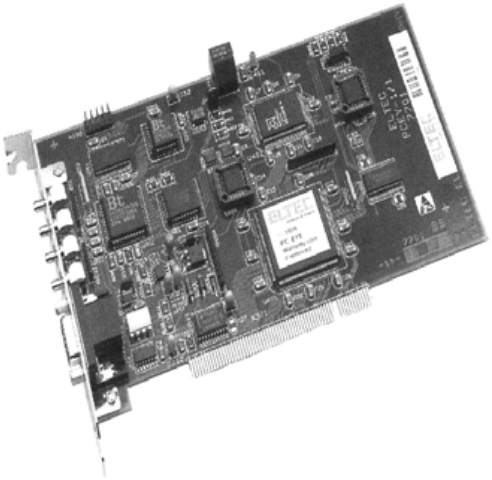
Image Acquisition:

- An image is captured by a sensor (such as a monochrome or color TV camera) and digitized.
- If the output of the camera or sensor is not already in digital form, an analog-to-digital converter digitizes it.

Camera

- Camera consists of 2 parts
  - A lens that collects the appropriate type of radiation emitted from the object of interest and that forms an image of the real object
  - a semiconductor device – so called charged coupled device or CCD which converts the image into an electrical signal.

Frame Grabber



- Frame grabber only needs circuits to digitize the electrical signal from the imaging sensor to store the image in the memory (RAM) of the computer.

Image Enhancement

- To highlight certain features of interest in an image.

Example:

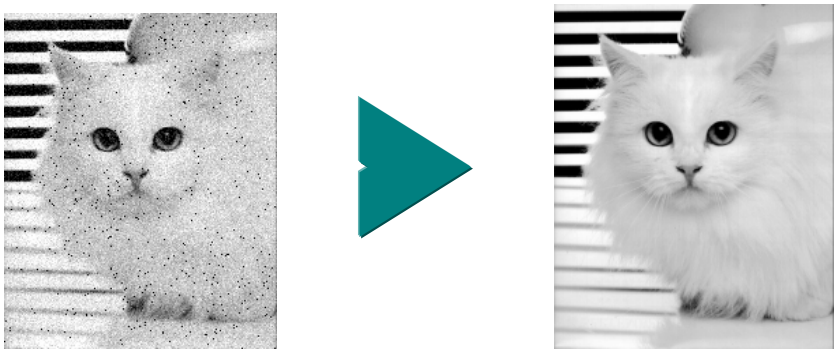


Image Restoration

- Improving the appearance of an image
- Tend to be based on mathematical or probabilistic models of image degradation

Example:

Distorted image

Restored image

Color Image Processing

- Gaining in importance because of the significant increase in the use of digital images over the Internet

Wavelets

- Foundation for representing images in various degrees of resolution.
- Used in image data compression and pyramidal representation.

Compression

- Reducing the storage required to save an image or the bandwidth required to transmit it.
- Ex. JPEG (Joint Photographic Experts Group) image compression standard.

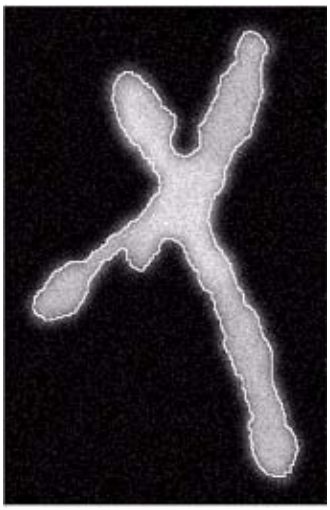
Morphological processing

- Tools for extracting image components that are useful in the representation and description of shape.

a b c

FIGURE 9.7 (a) Image of squares of size 1, 3, 5, 7, 9, and 15 pixels on the side. (b) Erosion of (a) with a square structuring element of 1's, 13 pixels on the side. (c) Dilation of (b) with the same structuring element.

Image Segmentation



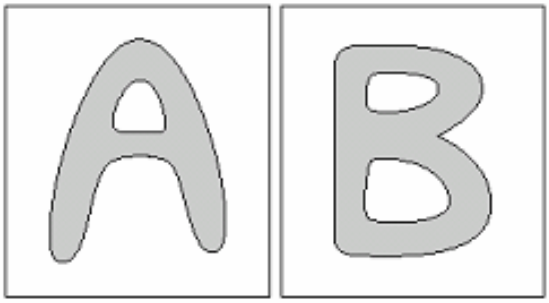
- computer tries to separate objects from the image background.
- It is one of the most difficult tasks in DIP.
- Output of the segmentation stage is raw pixel data, constituting either the boundary of a region or all the points in the region itself.

Representation & Description

- Representation ⇨ make a decision whether the data should be represented as a boundary or as a complete region.
  - Boundary representation ⇨ focus on external shape characteristics, such as corners and inflections.
  - Region representation ⇨ focus on internal properties, such as texture or skeleton shape.

Representation & Description

1 connected component, 1 hole



1 connected component, 2 holes

Representation + Description

transform raw data

a form suitable for the Recognition processing

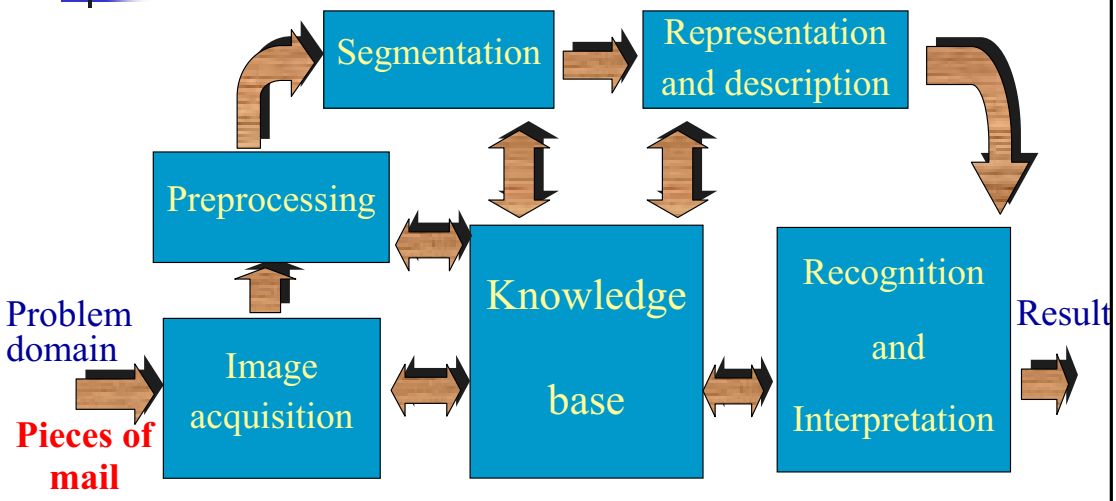
Recognition & Interpretation

- Recognition ⇨ the process that assigns a label to an object based on the information provided by its descriptors.
- Interpretation ⇨ assigning meaning to an ensemble of recognized objects.

Knowledge base

- a problem domain ⇨ detailing regions of an image where the information of interest is known to be located.
- Help to limit the search

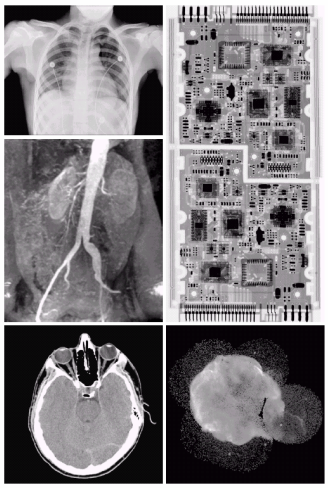
Not all the processes are needed. Ex. Postal Code Problem



Desired output = alphanumeric characters

Digital Image Processing (DIP)

"A picture is worth a thousand words".

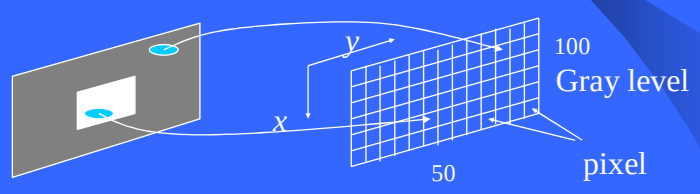


a b c d e

FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, (d) Mr. Joseph E. Pascente, Lixi, Inc., and (e) NASA.)

What Is A Digital Image?

- **Is composed of a finite number of elements each of which has a particular location and value (pixels, pels, picture elements).**



Original picture
$f(x, y)$

Digital image
$I[r, c]$ or $I[x, y]$

Image Processing: What Is It?

- Processing images by means of a digital computer.
  - Image acquisition.
  - Representing, storing and displaying images.
  - Image transformations.
  - Image filtering, enhancement and restoration.
  - Image compression.

Related Computations

- Image/Video processing: Improving or changing images/video.
- Image/Video analysis (computer vision).
- Image/Video indexing: Finding images and video (databases).
- Acting based on visual information (image understanding).
- Graphics and animation: Generating images and video.

Image Processing vs. Computer Vision

- Low-level processing: Involves primitive operations.
  Input: Image
  Output: Image

- Mid-level processing: Involves tasks such as partitioning an image into regions or objects, object description, and classification.
  Input: Image
  Output: Attributes

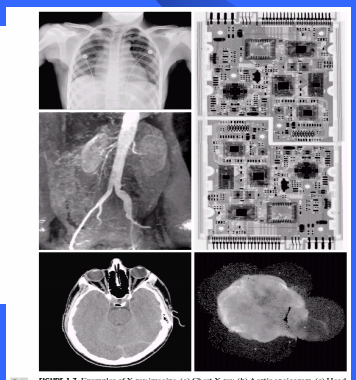
- High-level processing: Involves "making sense" of an ensembele of recognized objects (image analysis to computer vision).
  Input: …
  Output: …

History

- Newspaper industry: 1921

- Space imaging: 1960

- Computer axial tomography (CAT): 1970



a b c

FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, (d) Mr. Joseph E. Pascente, Lixi, Inc., and (e) NASA.)

DIP: Fundamentals

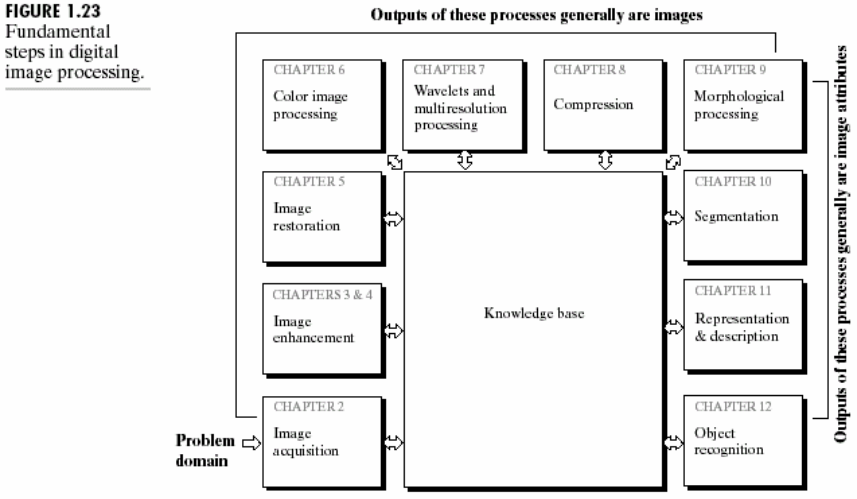


FIGURE 1.23 Fundamental steps in digital image processing.

DIP: Components

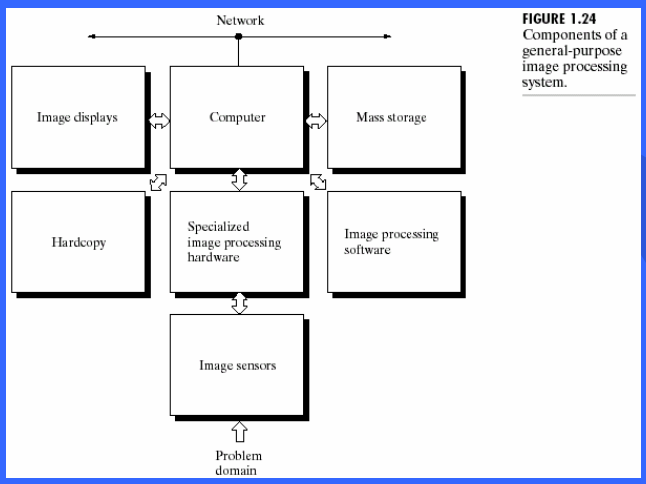


FIGURE 1.24 Components of a general-purpose image processing system.