Digital image processing

Course Outcome

CO 1.
Student will be able to describe the basic concepts and the scope of digital image processing, and the roles of image processing in a variety of applications.

CO **2.**
Student will be able to describe different techniques in image color image processing, image segmentation and object recognition in image.

CO 3.
Student will be able to illustrate relationship between pixels and arithmetic operations on images.

CO 4.
Student will be able to analyze the mathematical principles of digital image enhancement.

- Course Objectives:

1. To learn the fundamental concepts of Digital Image Processing

Click to add text

2. To study basic image processing operations.

3. To cover the basic analytical methods which are widely used in image processing

- Digital image processing deals with manipulation of digital images through a digital computer.

Introduction

- It is a subfield of signals and systems but focus particularly on images.
- DIP focuses on developing a computer system that is able to perform processing on an image. The input of that system is a digital image and the system process that image using efficient algorithms, and gives an image as an output.
- The most common example is Adobe Photoshop. It is one of the widely used application for processing digital images.

Introduction

- Signal processing is a discipline in electrical engineering and in mathematics that deals with analysis and processing of analog and digital signals , and deals with storing , filtering , and other operations on signals. These signals include transmission signals , sound or voice signals , image signals , and other signals e.t.c.

Introduction

- Out of all these signals , the field that deals with the type of signals for which the input is an image and the output is also an image is done in image processing. As it name suggests, it deals with the processing on images.
- It can be further divided into analog image processing and digital image processing.

Analog image processing

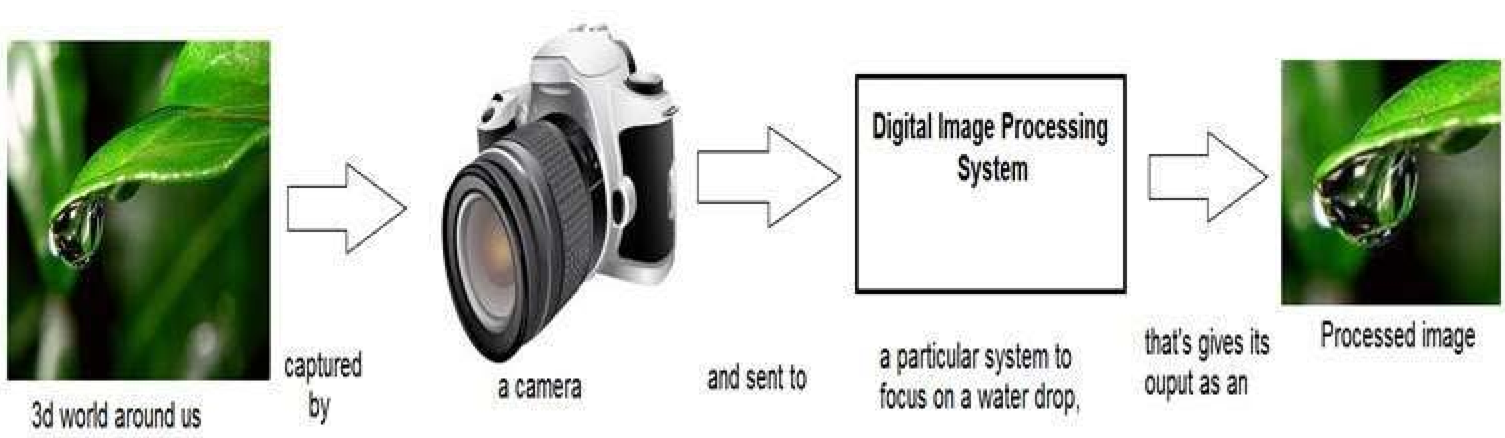
- Analog image processing is done on analog signals. It includes processing on two dimensional analog signals. In this type of processing, the images are manipulated by electrical means by varying the electrical signal. The common example include is the television image.
- Digital image processing has dominated over analog image processing with the passage of time due its wider range of applications.

Digital image processing

- The digital image processing deals with developing a digital system that performs operations on an digital image.

What is an Image

- An image is nothing more than a two dimensional signal. It is defined by the mathematical function f(x,y) where x and y are the two co-ordinates horizontally and vertically.
- The value of f(x,y) at any point is gives the pixel value at that point of an image.



3d world around us
captured
by
a camera
and sent to
Digital Image Processing
System
a particular system to
focus on a water drop,
that's gives its
ouput as an
Processed image

128	30	123
232	123	321
123	77	89
80	255	255

The above figure is an example of digital image that you are now viewing on your computer screen. But actually , this image is nothing but a two dimensional array of numbers ranging between 0 and 255.

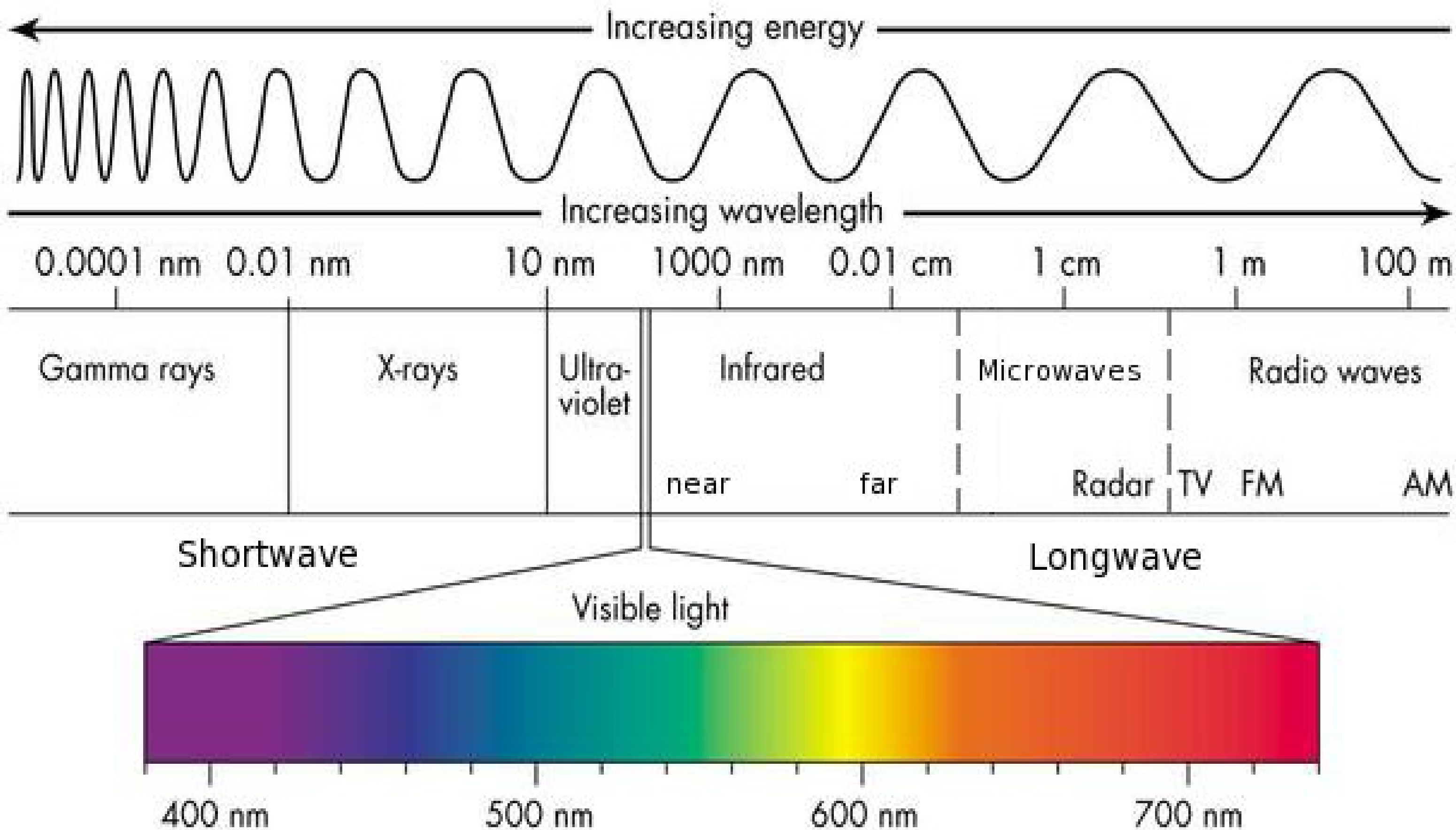
Each number represents the value of the function f(x,y) at any point. In this case the value 128 , 230 ,123 each represents an individual pixel value. The dimensions of the picture is actually the dimensions of this two dimensional array.

Electromagnetic spectrum

- Since digital image processing has very wide applications and almost all of the technical fields are impacted by DIP, we will just discuss some of the major applications of DIP.
- Digital Image processing is not just limited to adjust the spatial resolution of the everyday images captured by the camera. It is not just limited to increase the brightness of the photo, e.t.c. Rather it is far more than that.

Electromagnetic waves

- Electromagnetic waves can be thought of as stream of particles, where each particle is moving with the speed of light. Each particle contains a bundle of energy. This bundle of energy is called a photon.
- The electromagnetic spectrum according to the energy of photon is shown below.


Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-
violet
Infrared
near
far
Microwaves
Radar
Radio waves
TV
FM
AM
Shortwave
Longwave
Visible light
400 nm
500 nm
600 nm
700 nm

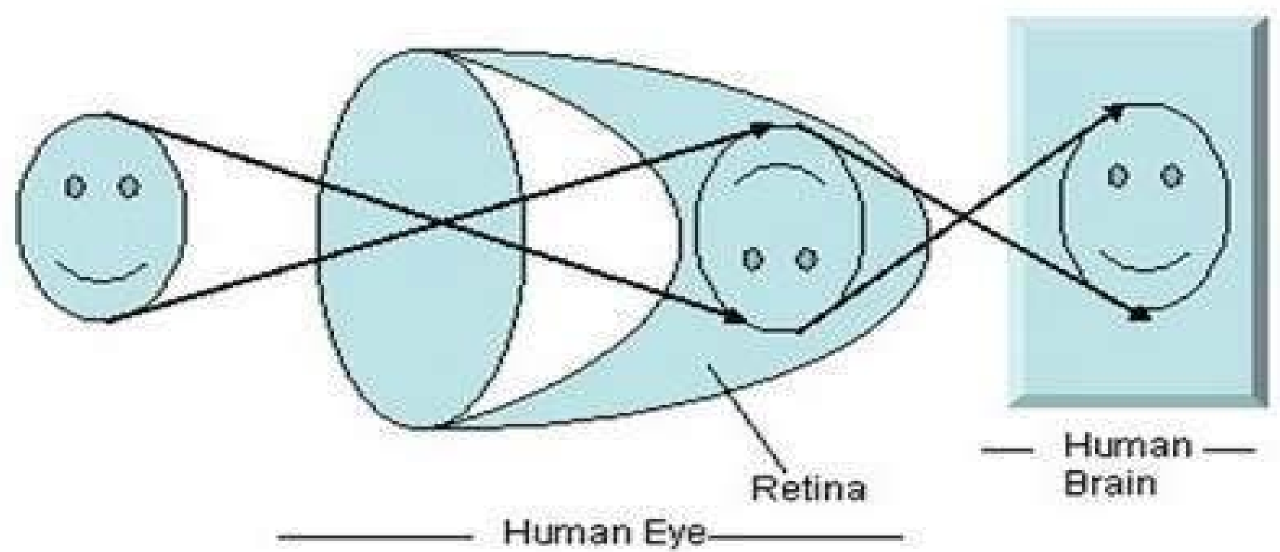
Electromagnetic spectrum

- In this electromagnetic spectrum, we are only able to see the visible spectrum.
- Visible spectrum mainly includes seven different colors that are commonly term as (VIBGOYR).
- VIBGOYR stands for violet , indigo , blue , green , orange , yellow and Red.
- But that does not nullify the existence of other stuff in the spectrum. Our human eye can only see the visible portion, in which we saw all the objects. But a camera can see the other things that a eye is unable to see.
- For example: x rays , gamma rays , e.t.c. Hence the analysis of all that stuff too is done in digital image processing.

Applications of Digital Image Processing

- Some of the major fields in which digital image processing is widely used are mentioned below
- Image sharpening and restoration
- Medical field
- Remote sensing
- Transmission and encoding
- Machine/Robot vision
- Color processing
- Pattern recognition
- Video processing
- Microscopic Imaging
- Others

How human eye works?



How human eye works?

- Before, the image formation on analog and digital cameras , consider the image formation on human eye. Because the basic principle that is followed by the cameras has been taken from the way , the human eye works.
- When light falls upon the particular object , it is reflected back after striking through the object.

- The rays of light when passed through the lens of eye , form a particular angle , and the image is formed on the retina which is the back side of the wall.
- The image that is formed is inverted. This image is then interpreted by the brain and that makes us able to understand things.
- Due to angle formation , we are able to perceive the height and depth of the object we are seeing. This has been more explained in the tutorial of perspective transformation

- As you can see in the above figure, that when sun light falls on the object (in this case the object is a face), it is reflected back and different rays form different angle when they are passed through the lens and an invert image of the object has been formed on the back wall. The last portion of the figure denotes that the object has been interpreted by the brain and re-inverted

- Image formation on digital cameras
- In the digital cameras , the image formation is not due to the chemical reaction that take place , rather it is a bit more complex then this.
- In the digital camera , a CCD array of sensors is used for the image formation.

What is an Image

- An image is nothing more than a two dimensional signal. It is defined by the mathematical function f(x,y) where x and y are the two co-ordinates horizontally and vertically.
- The value of f(x,y) at any point is gives the pixel value at that point of an image.

Terminology

- Pixel
- Pixel is the smallest element of an image.
- Each pixel correspond to any one value.
- In an 8-bit gray scale image, the value of the pixel between 0 and 255.
- The value of a pixel at any point correspond to the intensity of the light photons striking at that point.
- Each pixel store a value proportional to the light intensity at that particular location.

Terminology

- Gray level
- The value of the pixel at any point denotes the intensity of image at that location, and that is also known as gray level.

- Pixel value.(0)
- that each pixel can have only one value and each value denotes the intensity of light at that point of the image.
- The value 0 means absence of light. It means that 0 denotes dark, and it further means that when ever a pixel has a value of 0, it means at that point, black color would be formed.

Terminology

- Look at this image matrix
- 000
- 000
- 000
- Now this image matrix has all filled up with 0. All the pixels have a value of 0. If we were to calculate the total number of pixels form this matrix, this is how we are going to do it.
- Total no of pixels = total no. of rows X total no. of columns
- = 3 X 3
- = 9.

Terminology

- Bpp or bits per pixel denotes the number of bits per pixel.
- The number of different colors in an image is depends on the depth of color or bits per pixel.

Some terms

- its in mathematics:
- Its just like playing with binary bits.
- How many numbers can be represented by one bit.
- 0
- 1
- How many two bits combinations can be made.
- 00
- 01
- 10
- 11
- If we devise a formula for the calculation of total number of combinations that can be made from bit, it would be like this.
- Where bpp denotes bits per pixel. Put 1 in the formula you get 2, put 2 in the formula, you get 4. It grows exponentially.

Some terms

- Number of different colors:
- Now as we said it in the beginning, that the number of different colors depend on the number of bits per pixel.
- The table for some of the bits and their color is given below.
- Bits per pixel
- Number of colors 1 bpp2 colors
- 2 bpp 4 colors
- 3 bpp 8 colors
- 4 bpp 16 colors
- 5 bpp 32 colors
- 6 bpp 64 colors
- 7 bpp 128 colors
- 8 bpp 256 colors
- 10 bpp1024 colors16 bpp65536 colors24 bpp16777216 colors (16.7 million colors)32 bpp4294967296 colors (4294 million colors)

Some terms

- Shades
- You can easily notice the pattern of the exponentional growth. The famous gray scale image is of 8 bpp , means it has 256 different colors in it or 256 shades.

- Color images are usually of the 24 bpp format, or 16 bpp.
- We will see more about other color formats and image types in the tutorial of image types.
- 0 pixel value denotes black color.
- 0 pixel value always denotes black color. But there is no fixed value that denotes white color.
- White color:
- The value that denotes white color can be calculated as :

$$\text{White color} = (2)^{bpp} - 1$$

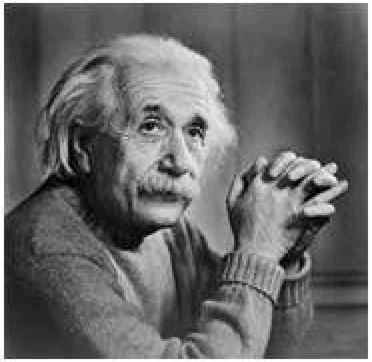
Image storage requirements

- After the discussion of bits per pixel, now we have every thing that we need to calculate a size of an image.
- Image size
- The size of an image depends upon three things.
- Number of rows
- Number of columns
- Number of bits per pixel
- The formula for calculating the size is given below.
- Size of an image = rows * cols * bpp

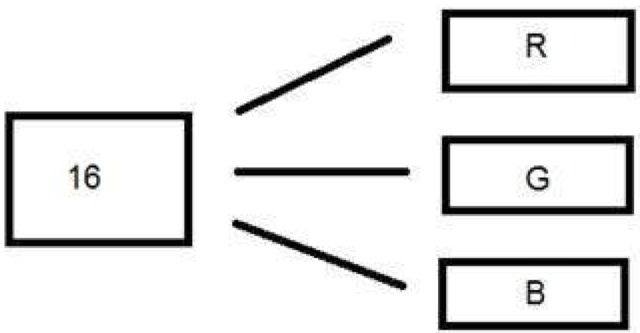
The binary image

- The binary image as it name states, contain only two pixel values.
- 0 and 1.
- Here 0 refers to black color and 1 refers to white color. It is also known as Monochrome.
- Black and white image:
- The resulting image that is formed hence consist of only black and white color and thus can also be called as Black and White image.
- No gray level
- One of the interesting this about this binary image that there is no gray level in it. Only two colors that are black and white are found in it.

- Format
- Binary images have a format of PBM (Portable bit map)
- 2, 3, 4,5, 6 bit color format
- The images with a color format of 2, 3, 4, 5 and 6 bit are not widely used today. They were used in old times for old TV displays, or monitor displays.
- But each of these colors have more then two gray levels, and hence has gray color unlike the binary image.
- In a 2 bit 4, in a 3 bit 8, in a 4 bit 16, in a 5 bit 32, in a 6 bit 64 different colors are present.
- 8 bit color format
- 8 bit color format is one of the most famous image format. It has 256 different shades of colors in it. It is commonly known as Grayscale image.
- The range of the colors in 8 bit vary from 0-255. Where 0 stands for black, and 255 stands for white, and 127 stands for gray color.
- This format was used initially by early models of the operating systems UNIX and the early color Macintoshes.
- A grayscale image of Einstein is shown below:
-



- 16 bit color format
- It is a color image format. It has 65,536 different colors in it. It is also known as High color format.
- It has been used by Microsoft in their systems that support more then 8 bit color format. Now in this 16 bit format and the next format we are going to discuss which is a 24 bit format are both color format.
- The distribution of color in a color image is not as simple as it was in grayscale image.
- A 16 bit format is actually divided into three further formats which are Red , Green and Blue. The famous (RGB) format.
- It is pictorially represented in the image below.


16
R
G
B

- 24 bit color format
- 24 bit color format also known as true color format. Like 16 bit color format, in a 24 bit color format, the 24 bits are again distributed in three different formats of Red, Green and Blue.

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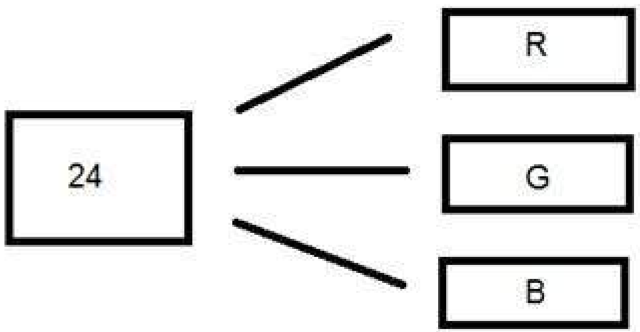
- 24 bit color format also known as true color format. Like 16 bit color format, in a 24 bit color format, the 24 bits are again distributed in three different formats of Red, Green and Blue.


24
R
G
B

- Since 24 is equally divided on 8, so it has been distributed equally between three different color channels.
- Their distribution is like this.
- 8 bits for R, 8 bits for G, 8 bits for B.

- Behind a 24 bit image.
- Unlike a 8 bit gray scale image, which has one matrix behind it, a 24 bit image has three different matrices of R, G, B.

- Different color codes
- All the colors here are of the 24 bit format, that means each color has 8 bits of red, 8 bits of green, 8 bits of blue, in it. Or we can say each color has three different portions. You just have to change the quantity of these three portions to make any color.

- Binary color format
- Color:Black
- Image:
- Decimal Code:
- (0,0,0)

- Color:White
- Image:
- Decimal Code:
- (255,255,255)

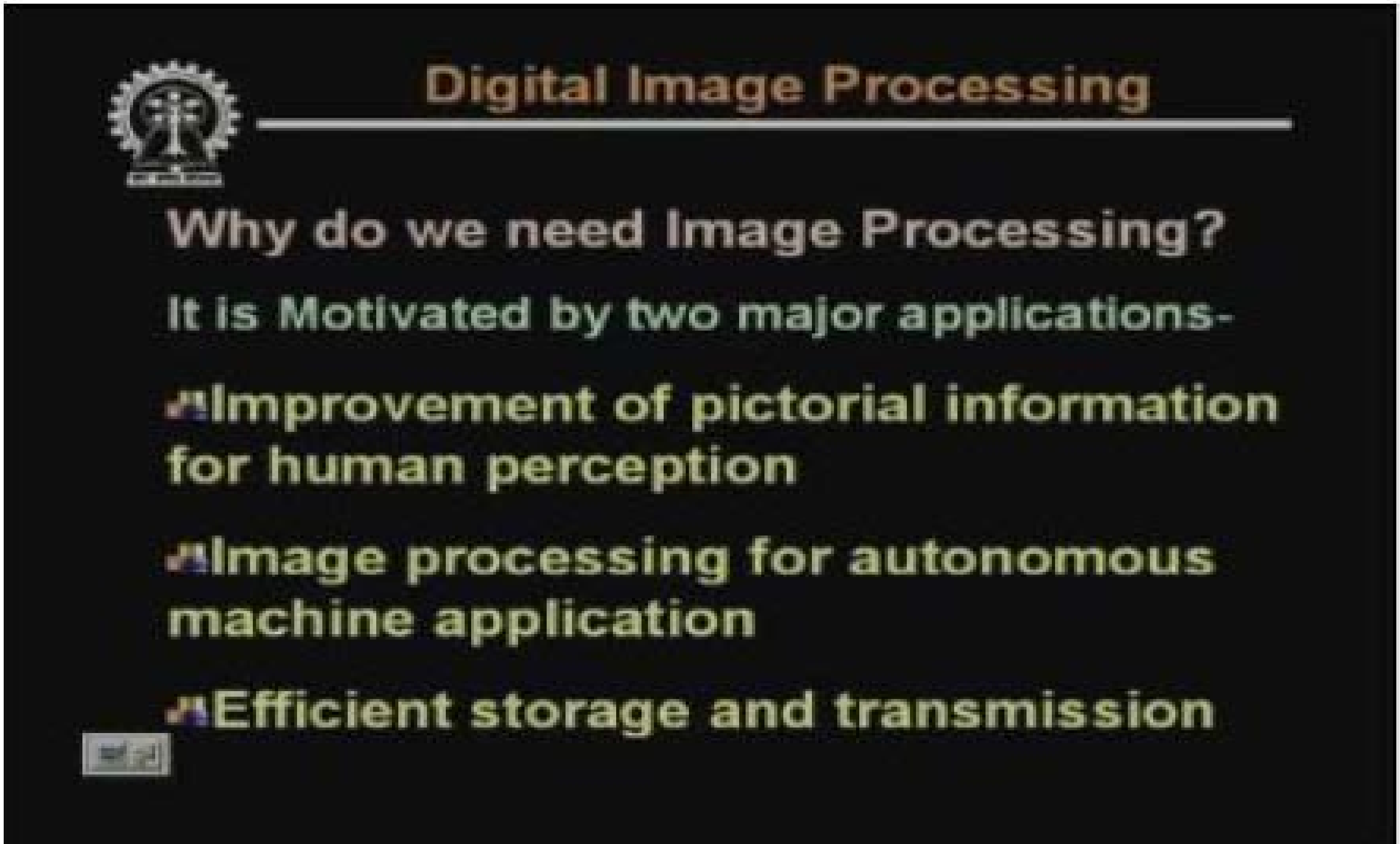
- RGB color model:
- Color:Red
- Image:
- Decimal Code:
- (255,0,0)

- Color:Green
- Image:
- green
- Decimal Code:
- (0,255,0)

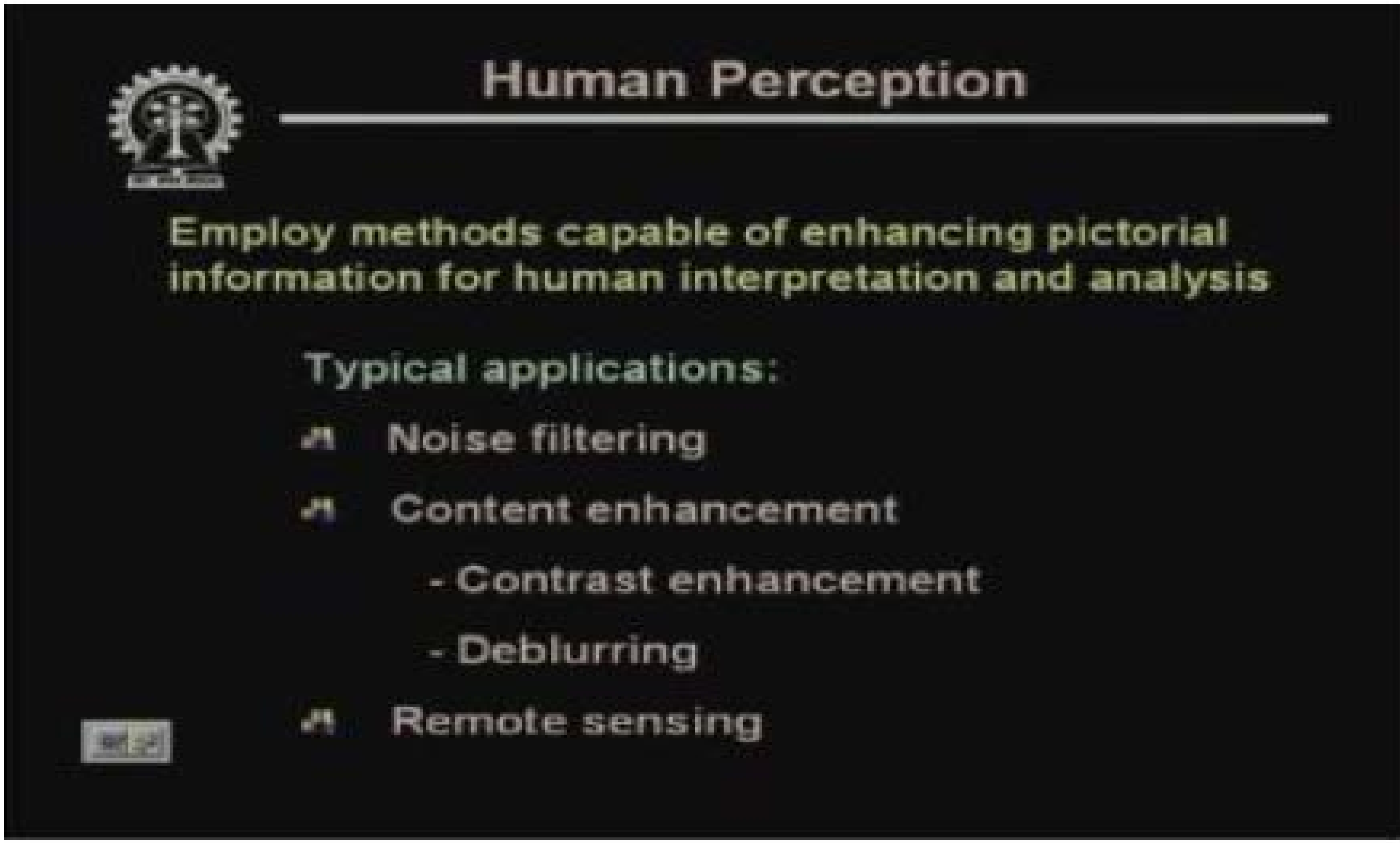
- Color: Blue
- Image:
- Decimal Code:
- (0,0,255)

Digital image processing

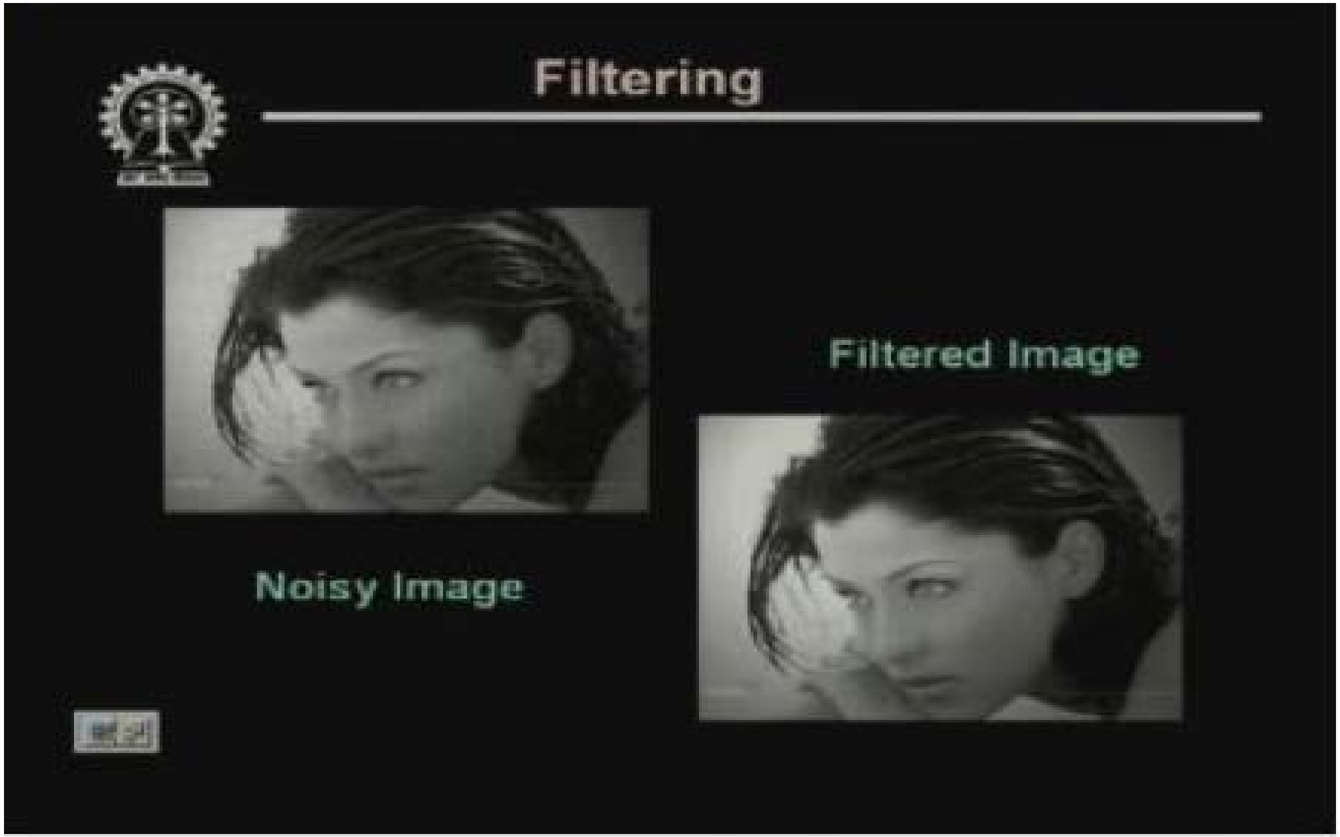
Applications of DIP



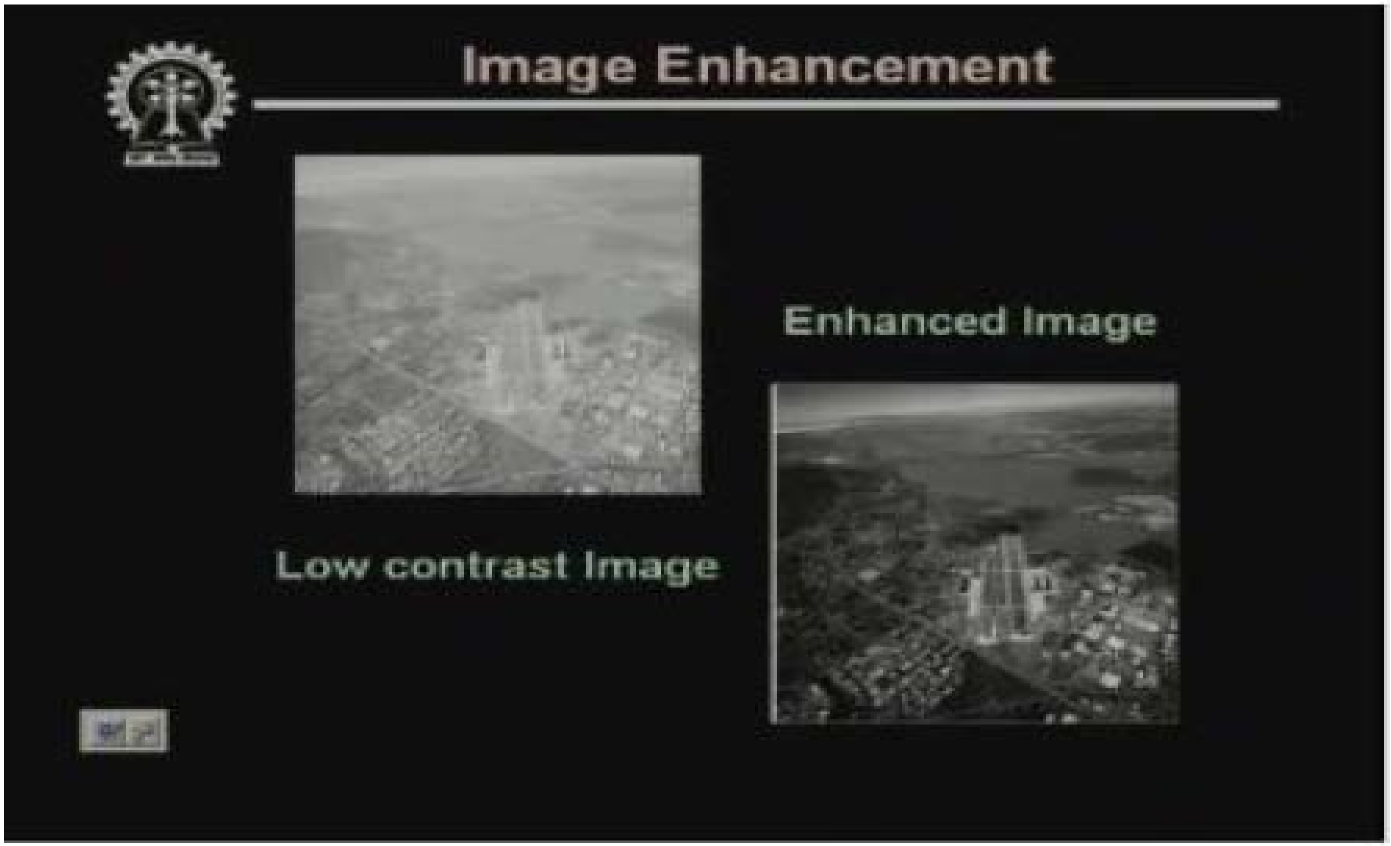
Applications of DIP



Applications of DIP



Applications of DIP



Applications of DIP

Applications of DIP

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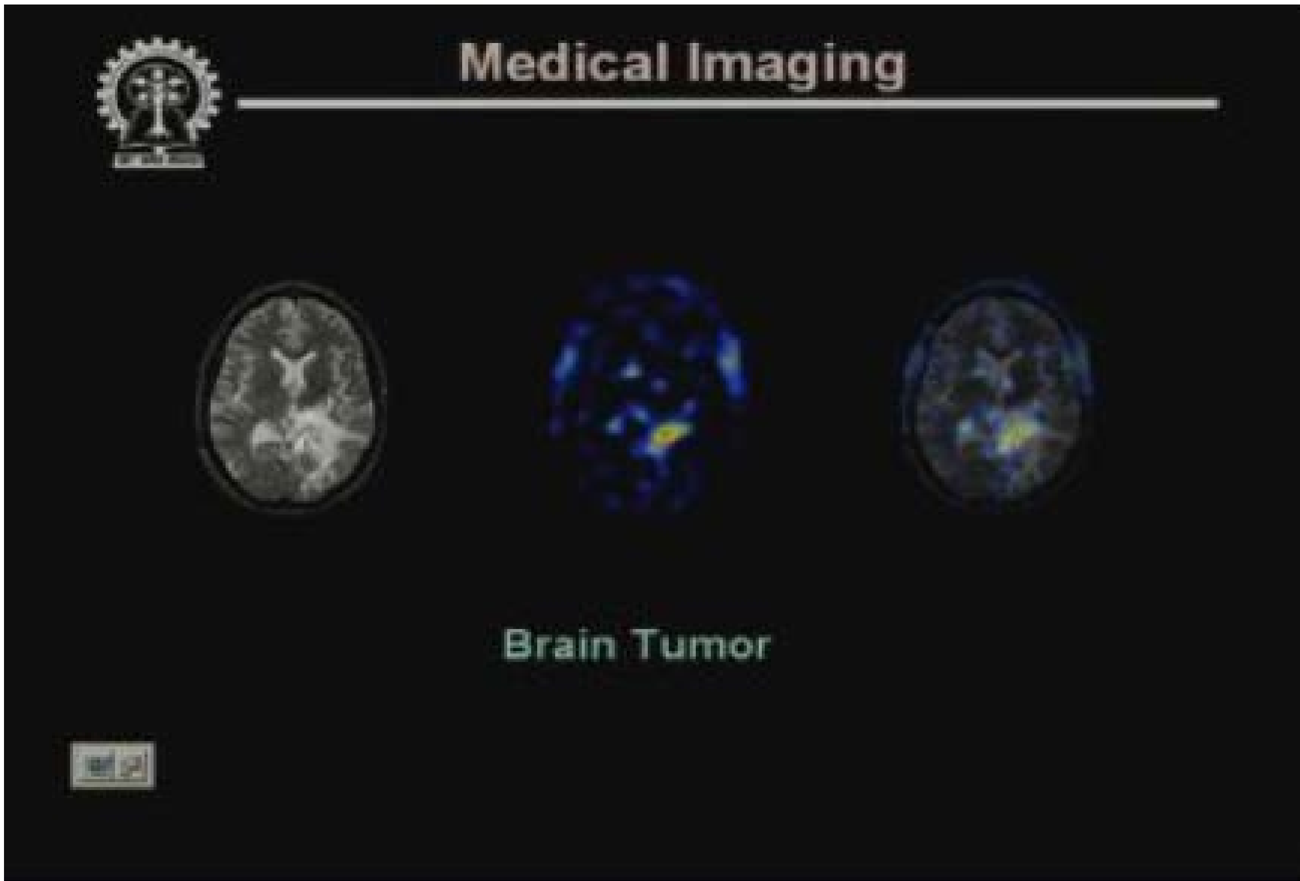
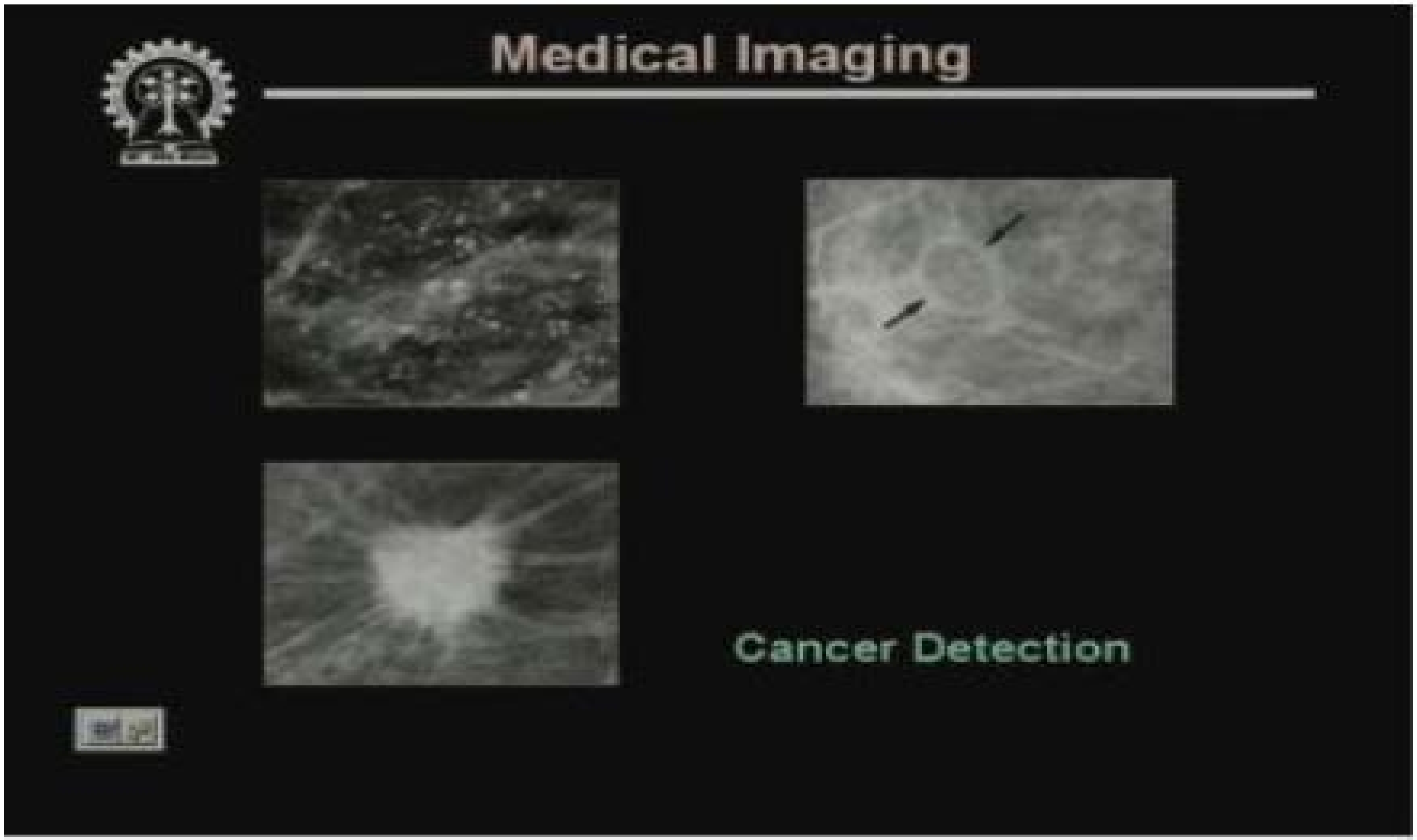
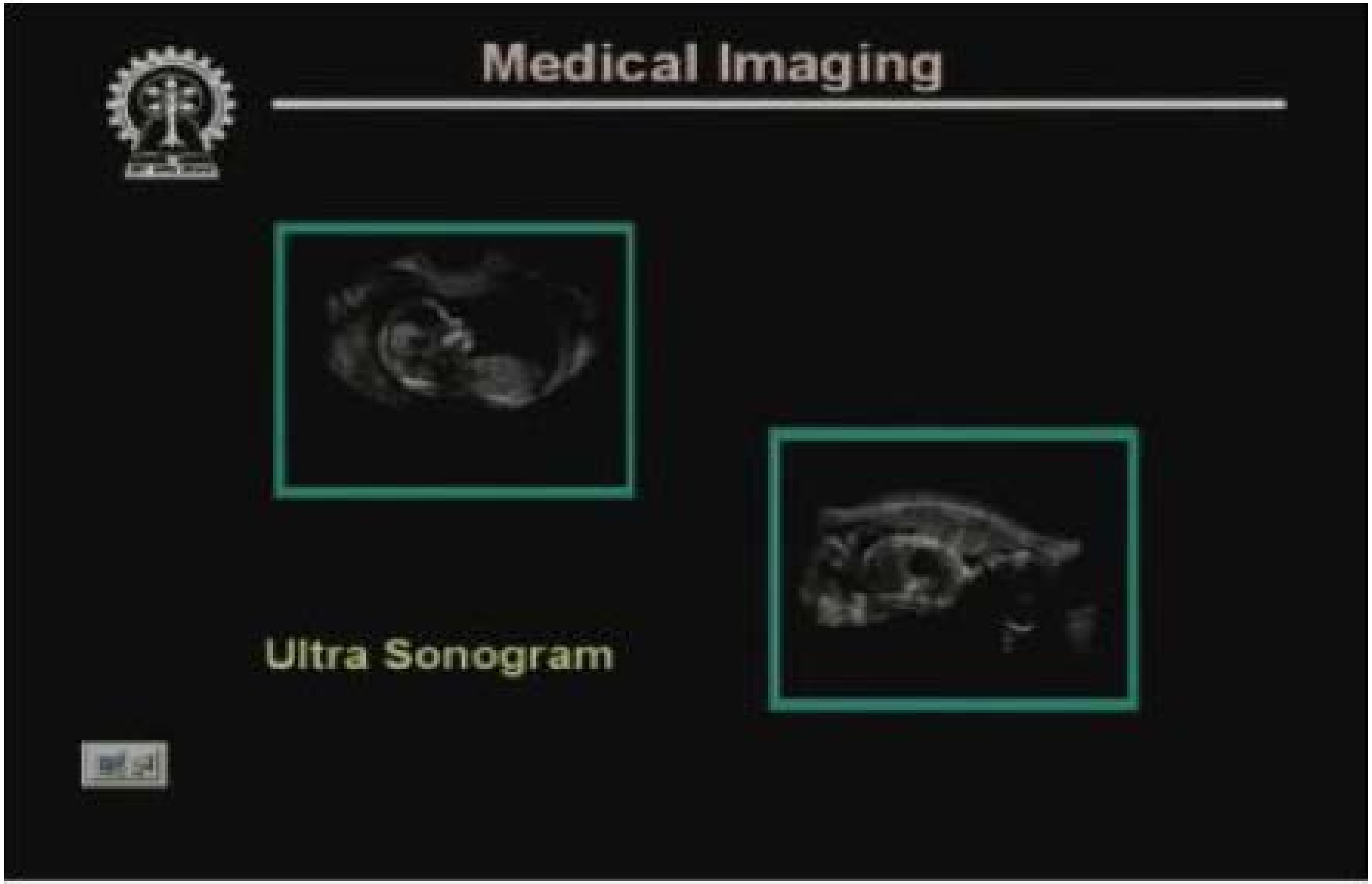


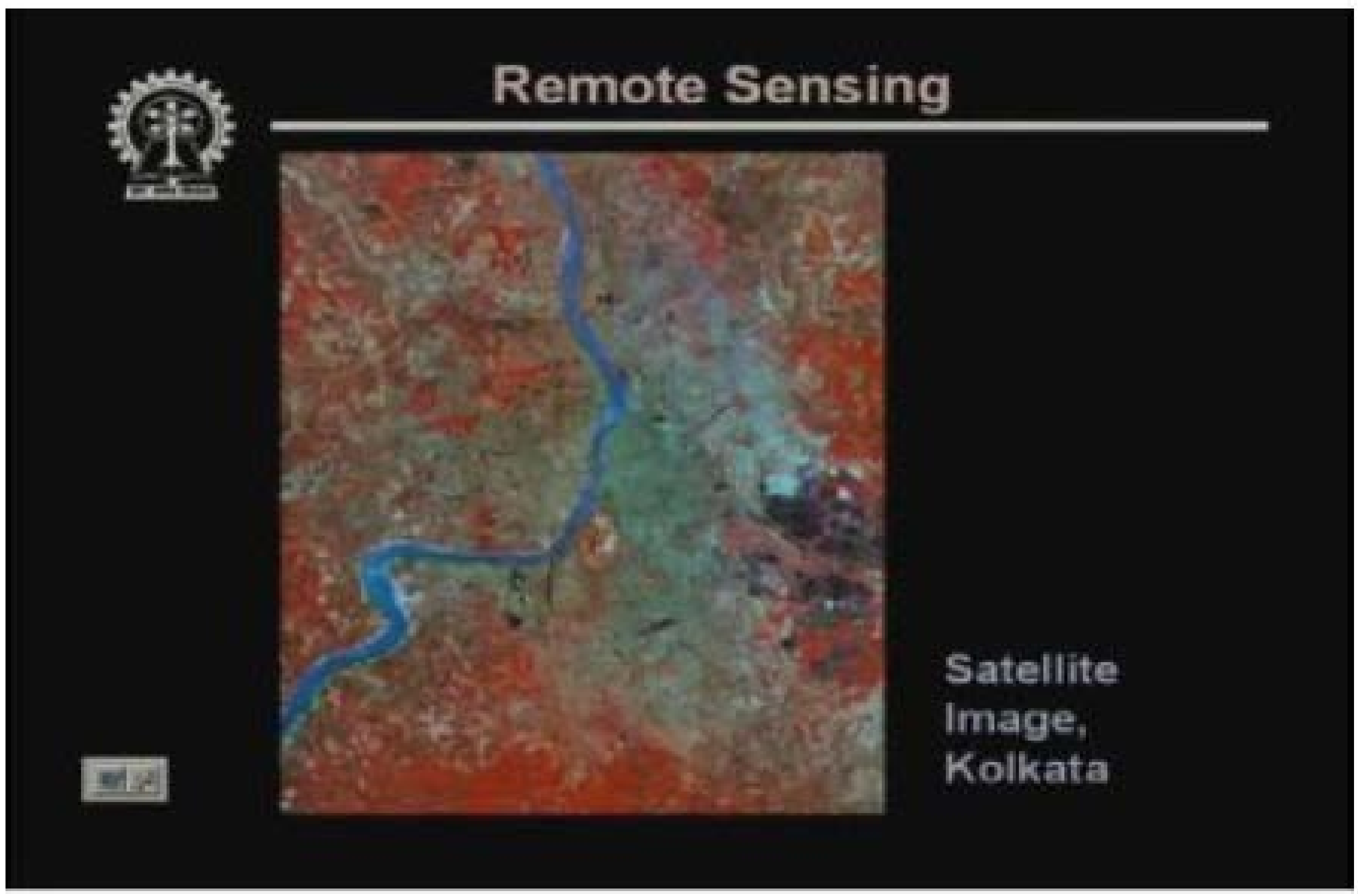
Applications of DIP



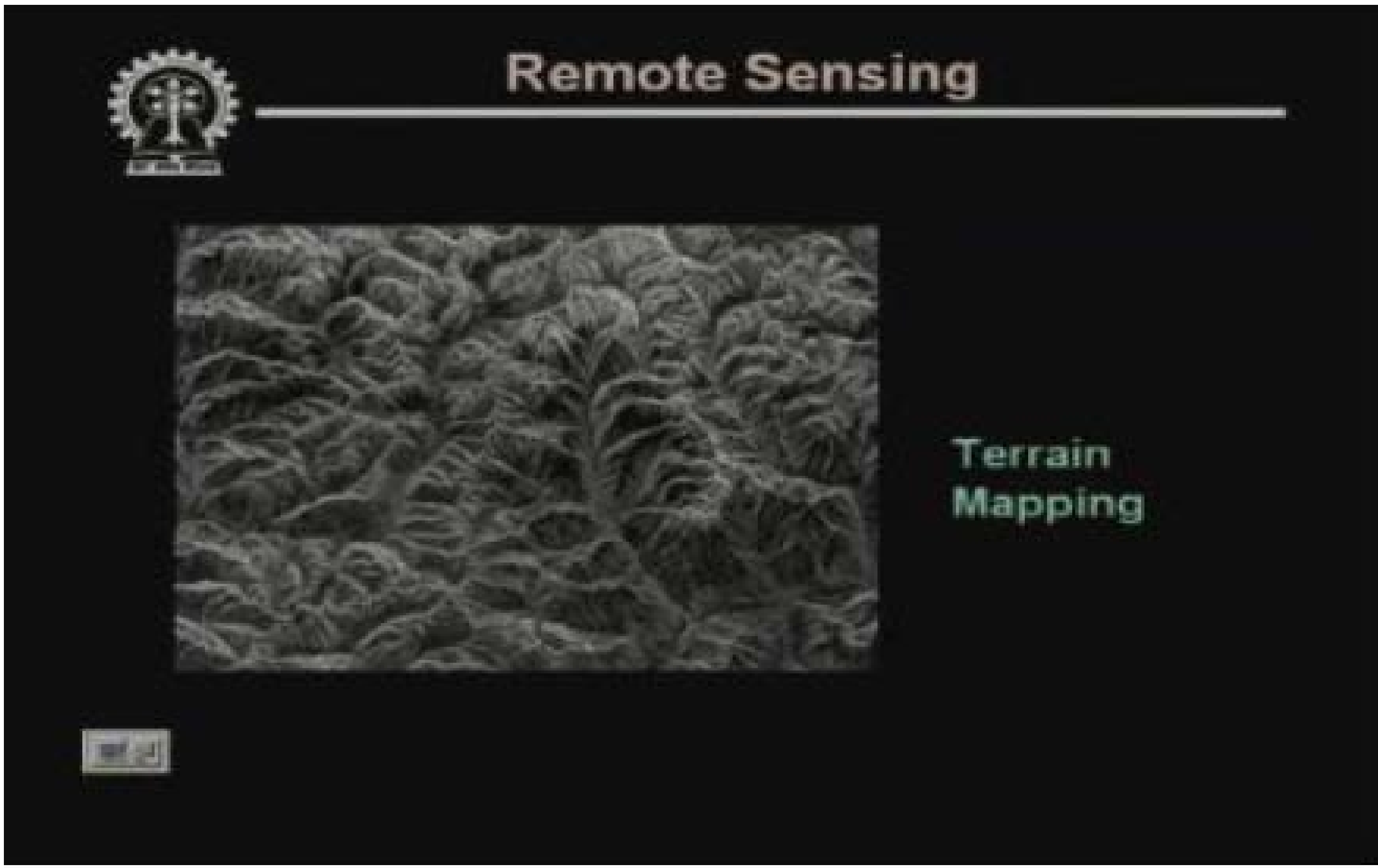
Applications of DIP



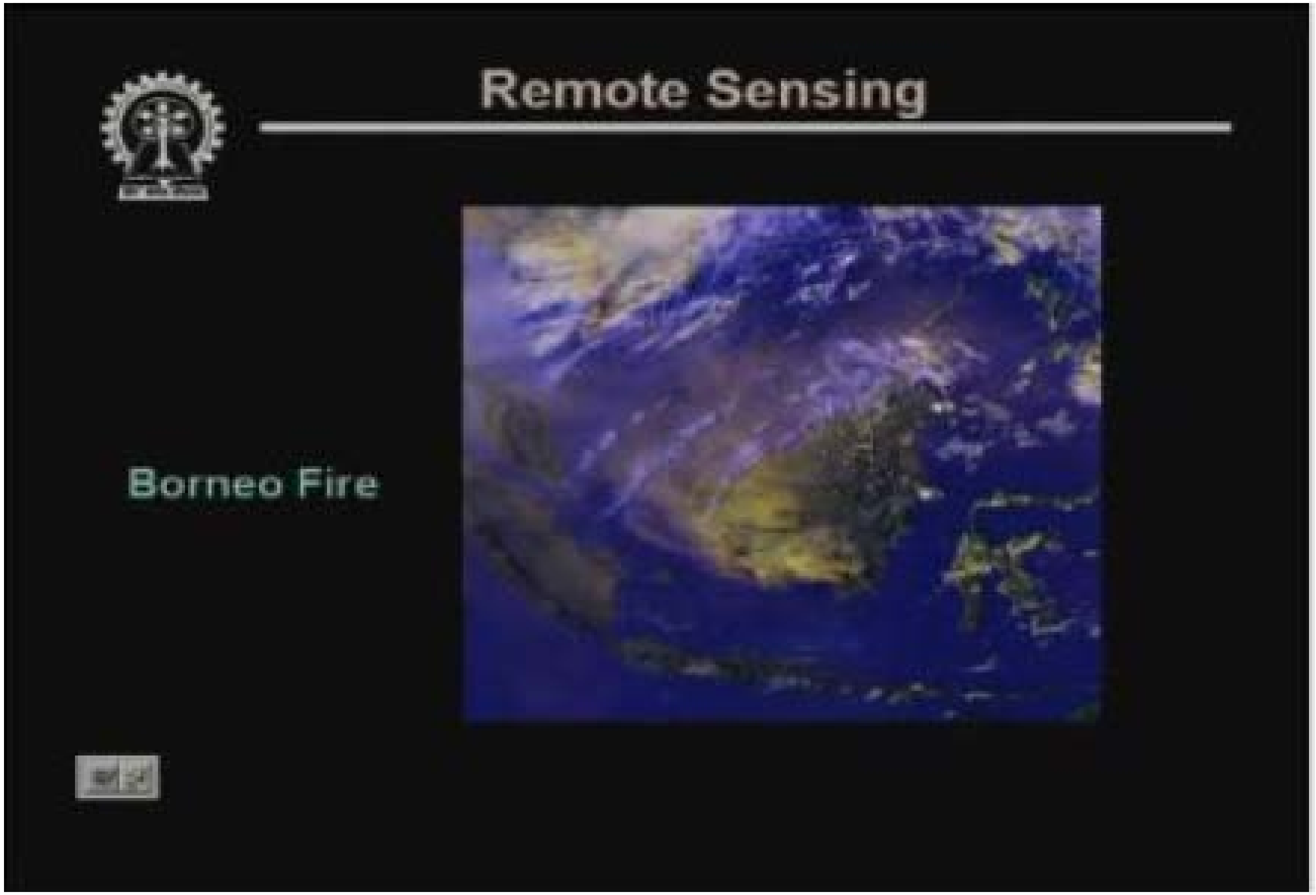
Applications of DIP



Applications of DIP

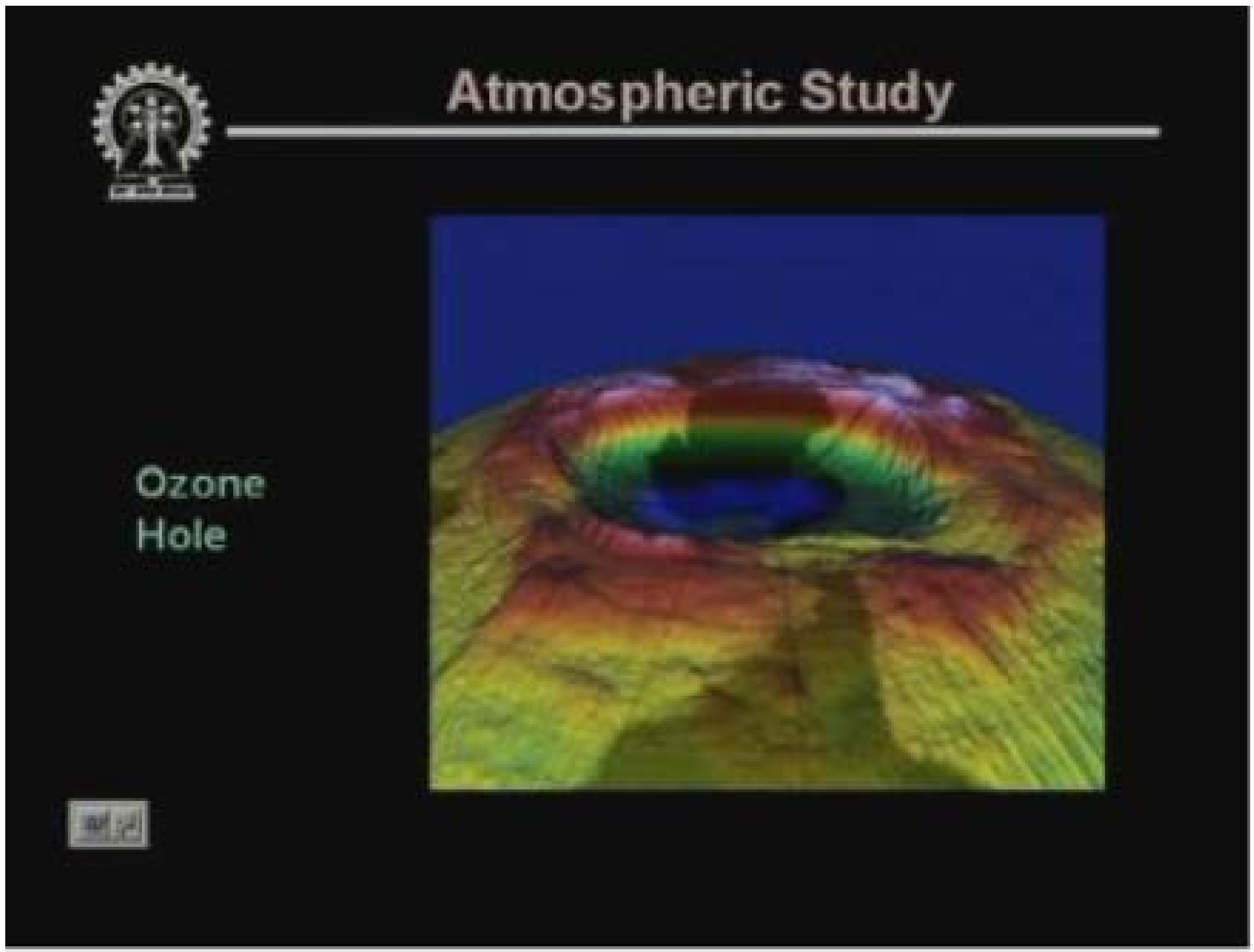


Applications of DIP

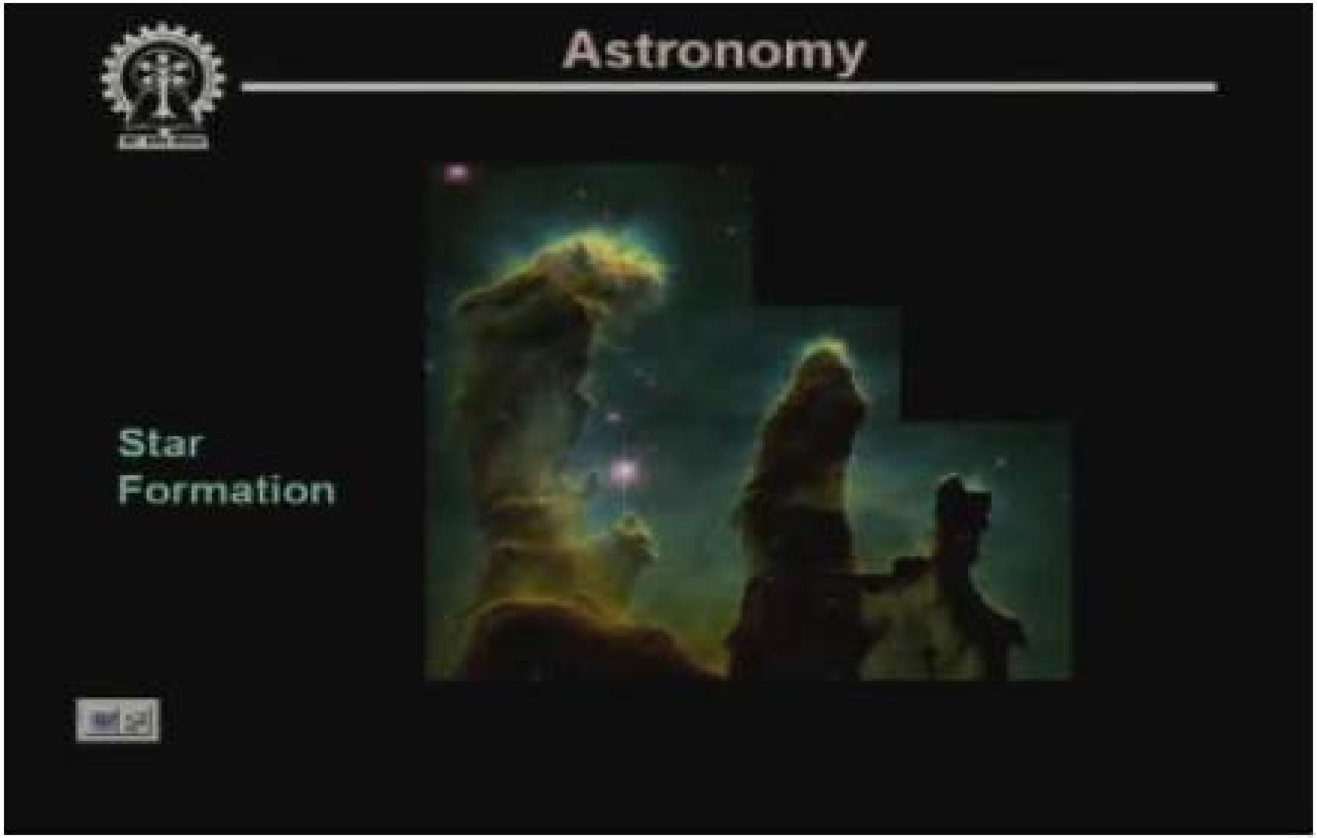


Applications of DIP

Applications of DIP



Applications of DIP



Applications of DIP

Applications of DIP

Machine Vision Applications

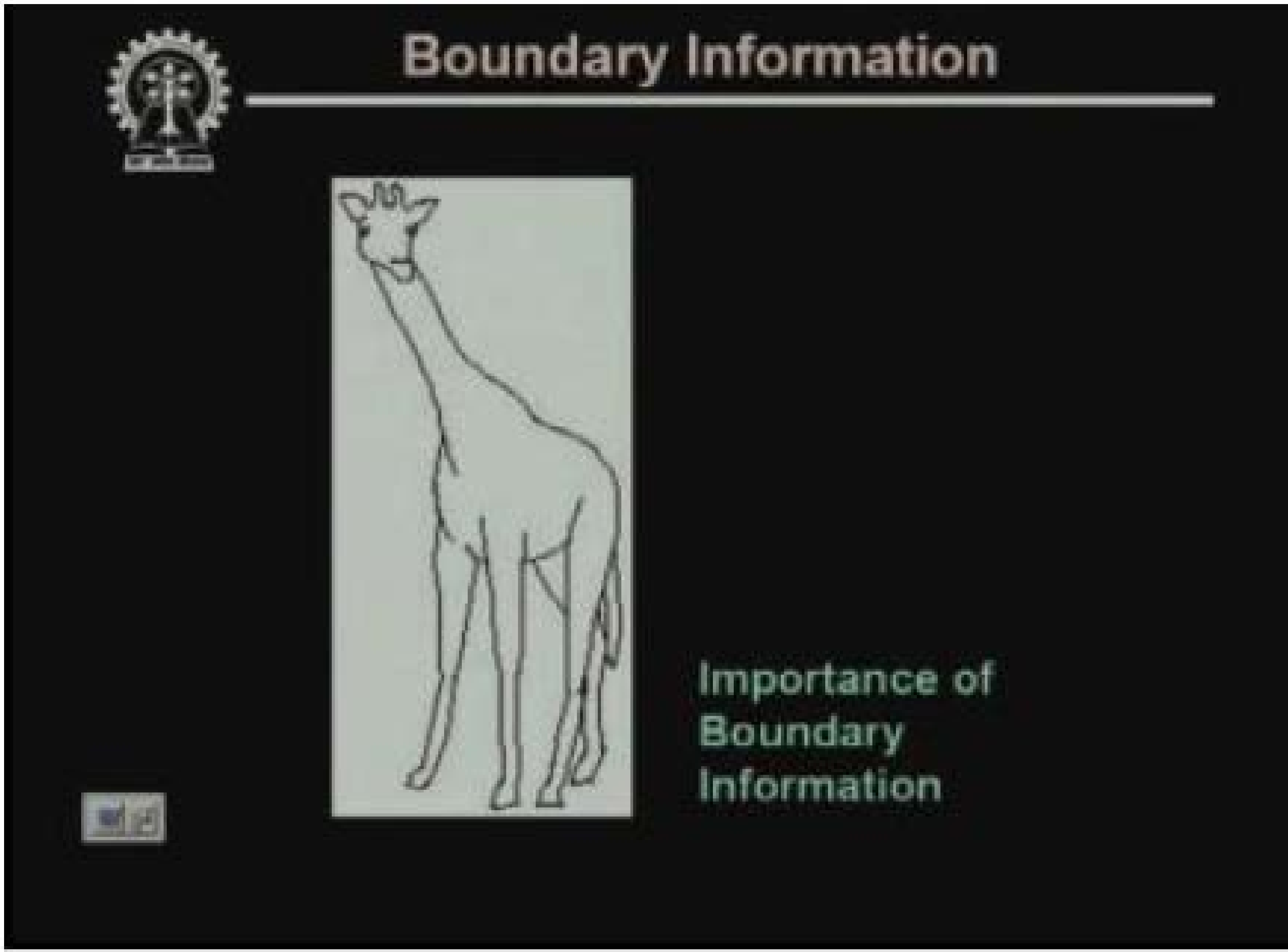
Here the interest is on procedures for extraction of image information suitable for computer processing

Typical Applications:

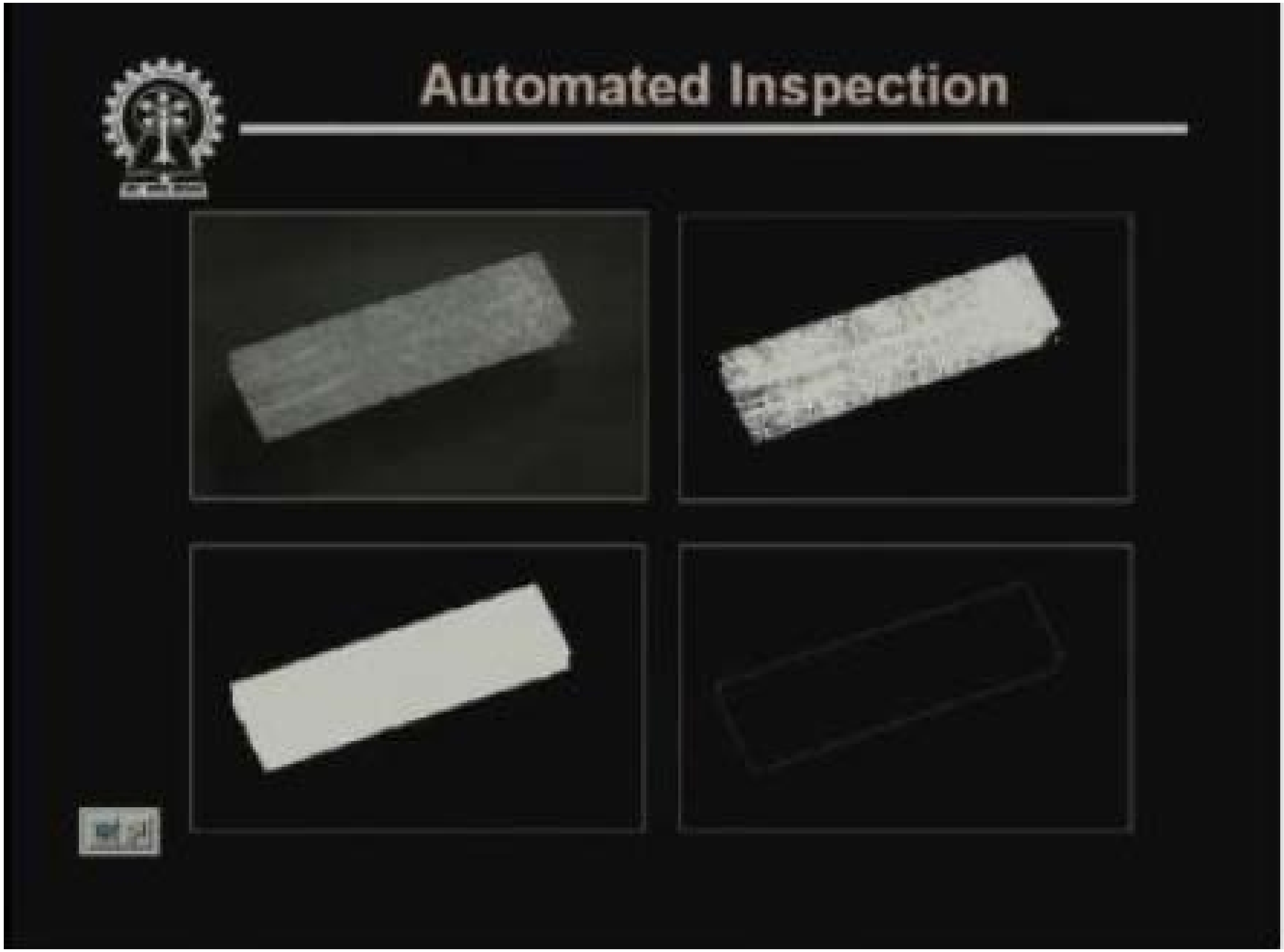
- Industrial Machine vision for product assembly and inspection
- Automated Target detection and tracking
- Finger print recognition
- Machine processing of aerial and satellite imagery for weather prediction and crop assessment etc

Applications of DIP

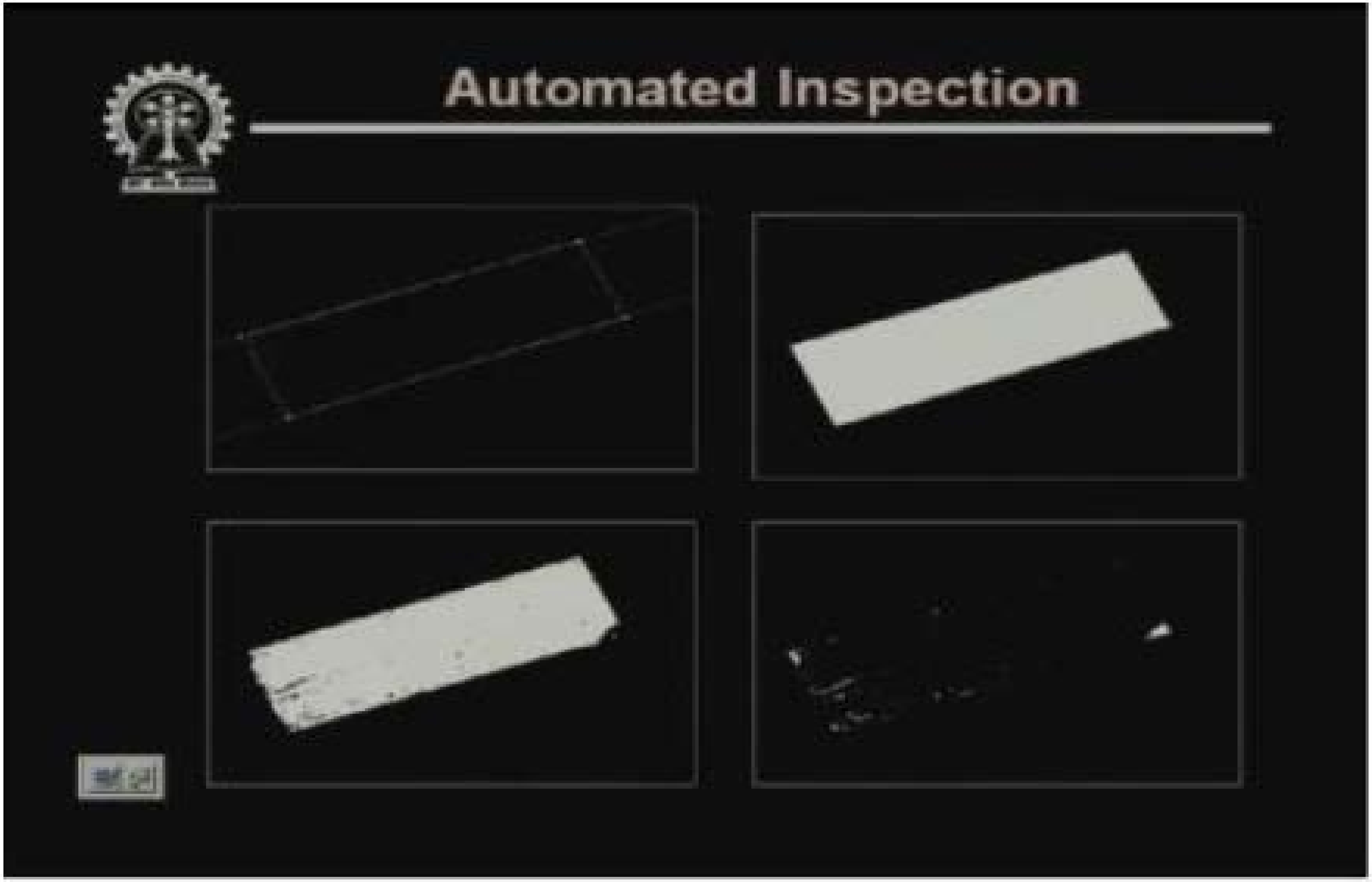
Applications of DIP



Applications of DIP



Applications of DIP



Applications of DIP

Automated Inspection

Inspection of IC Manufacturing

Video Sequence Processing

The major emphasis of image sequence processing is detection of moving parts

This has various applications

- Detection and tracking of moving targets for security surveillance purpose
- To find out the trajectory of a moving target
- Monitoring the movements of organ boundaries in medical applications etc.

Movement Detection

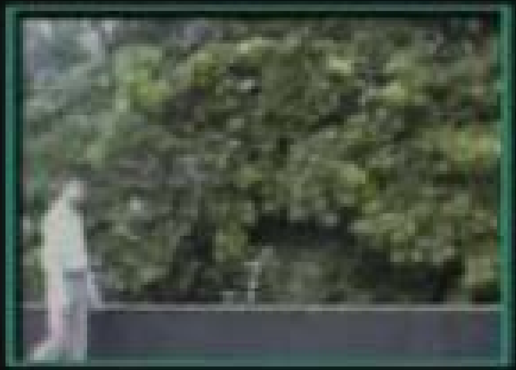



Image Compression
An image usually contains lot of redundancy that can be exploited to achieve compression
Pixel redundancy
Coding redundancy
Psychovisual redundancy
Applications:
Reduced storage
Reduction in bandwidth

Image Compression

Original Image

1:55

1:156

What Is Digital Image Processing?

- The field of digital image processing refers to processing digital images by means of a digital computer.

What is a Digital Image ?

- An image may be defined as a two- dimensional function, f(x,y) where x and y are *spatial (plane) coordinates, and the amplitude of f at any pair of* coordinates (x, y) is called the *intensity or gray level of the image at that point.*

- When x, y, and the amplitude values of f are all finite, discrete quantities, we call the image a *digital image*

Picture elements, Image elements, pels, and pixels

- A digital image is composed of a finite number of elements, each of which has a particular location and value.
- These elements are referred to as *picture elements, image elements, pels, and pixels.*

- Pixel is the term most widely used to denote the elements of a digital image.

The Origins of Digital Image Processing

- **One of the first applications of digital images was in the newspaper industry, when pictures were first sent by submarine cable between London and New York.**

- **Specialized printing equipment coded pictures for cable transmission and then reconstructed them at the receiving end.**

- Figure was transmitted in this way and reproduced on a telegraph printer fitted with typefaces simulating a halftone pattern.

- The initial problems in improving the visual quality of these early digital pictures were related to the selection of printing procedures and the distribution of intensity levels

- The printing technique based on photographic reproduction made from tapes perforated at the telegraph receiving terminal from 1921.

- Figure shows an image obtained using this method.

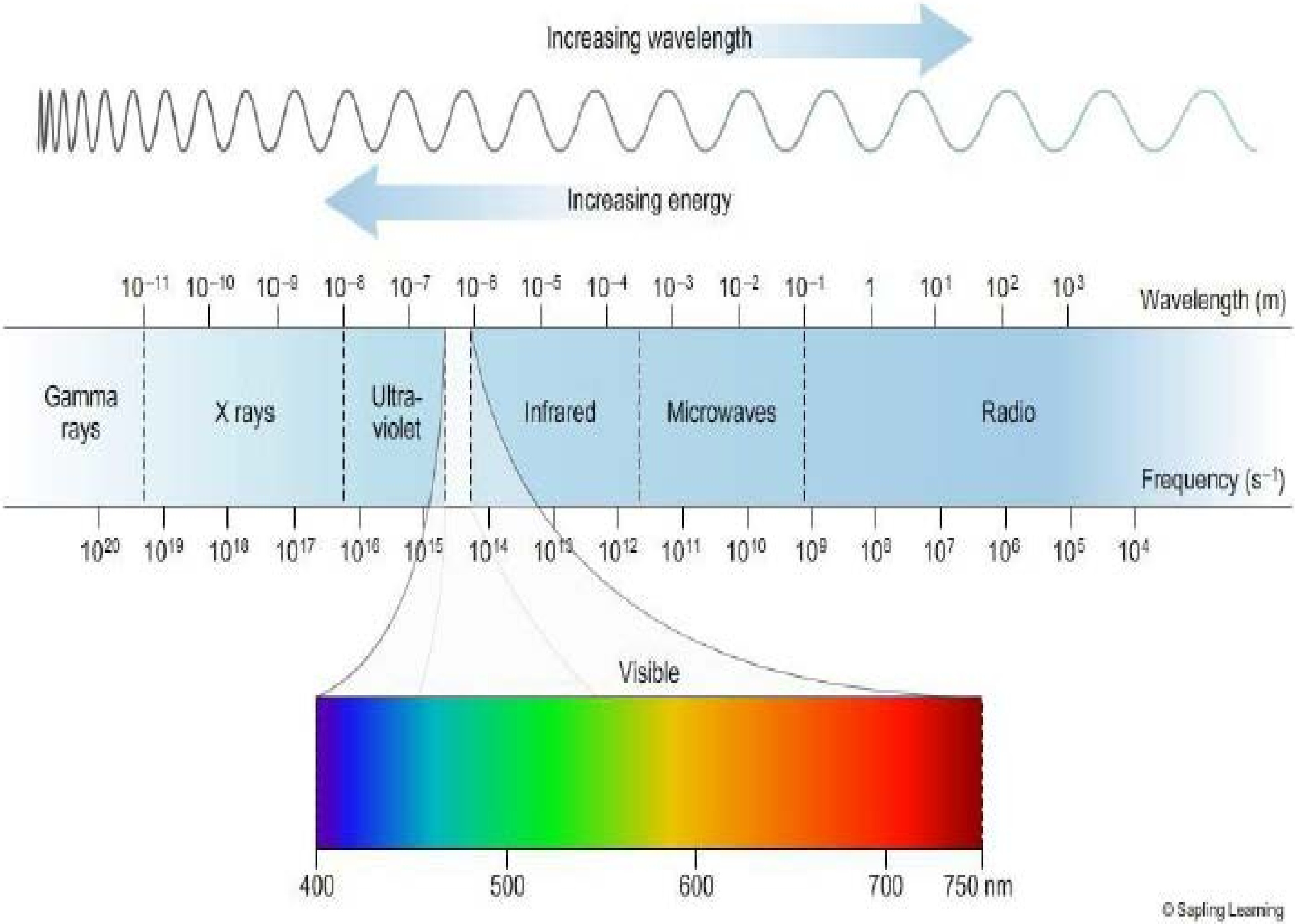
- The improvements are tonal quality and in resolution.

- The early Bartlane systems were capable of coding images in five distinct levels of gray.
- This capability was increased to 15 levels in 1929.

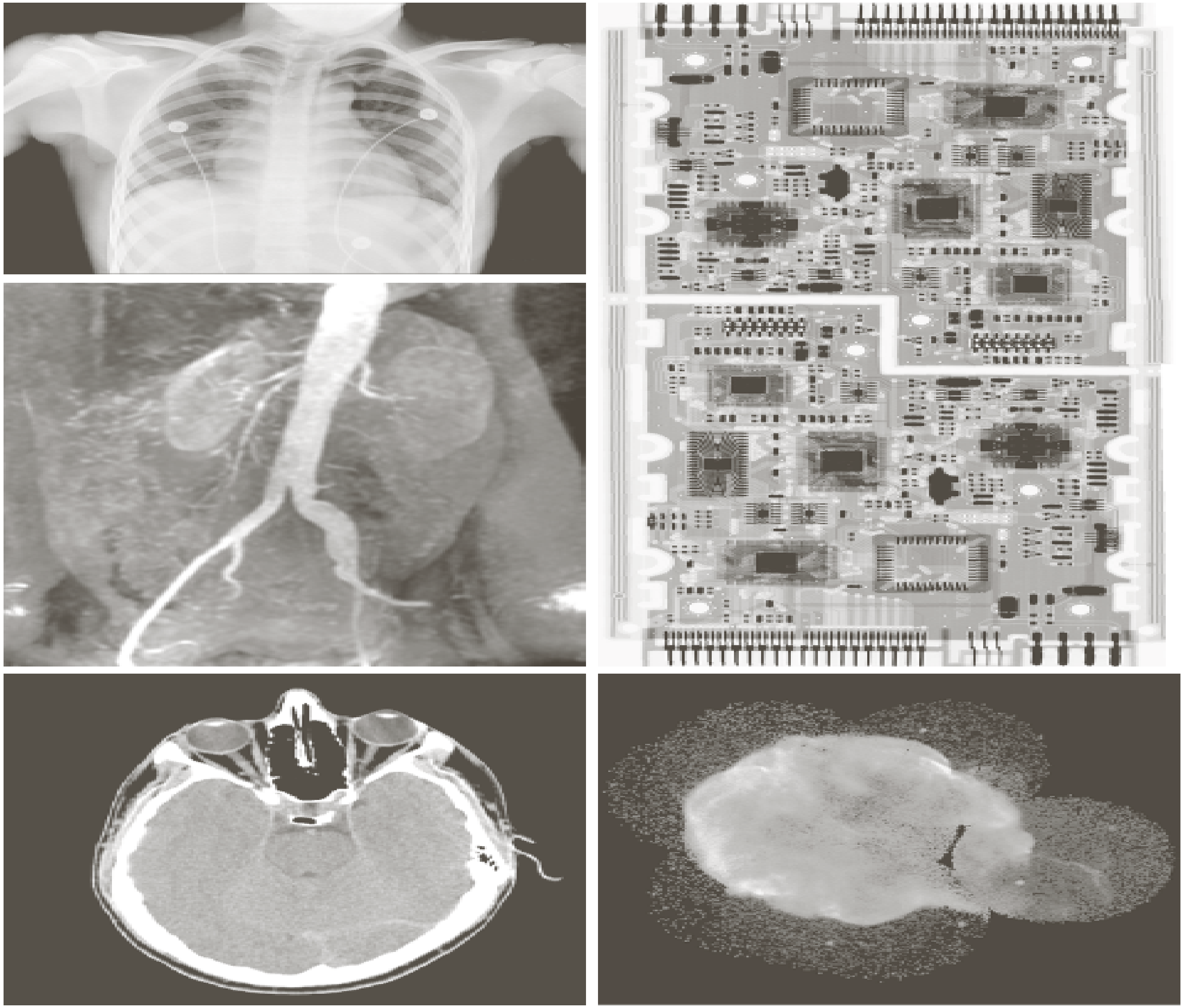
- Figure is typical of the type of images thatcould be obtained using the 15-tone equipment.

- Figure shows the first image of the moon taken by *Ranger*

Example of fields that use Digital image processing



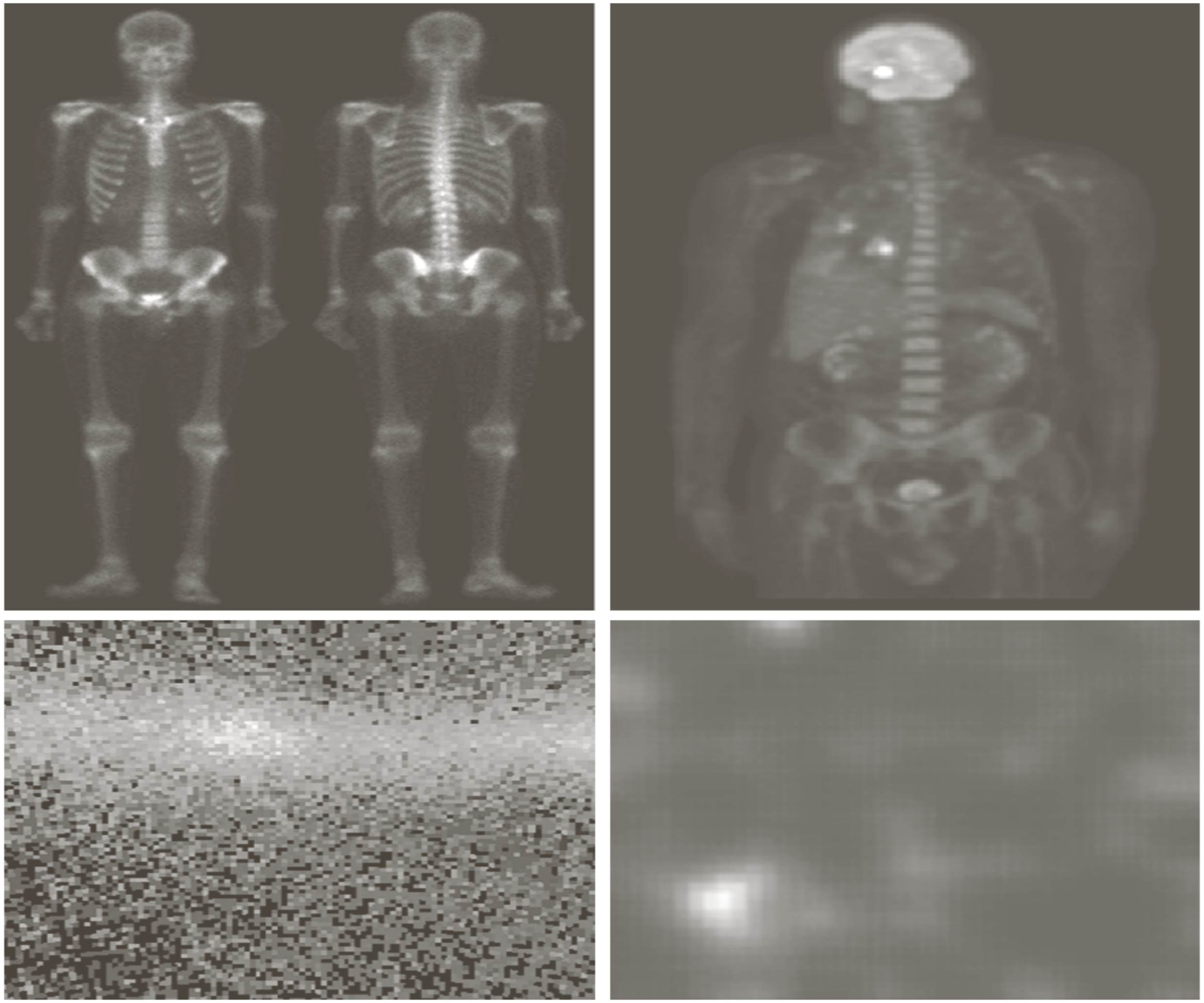
X RAYS



a	d
b	
c	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.)

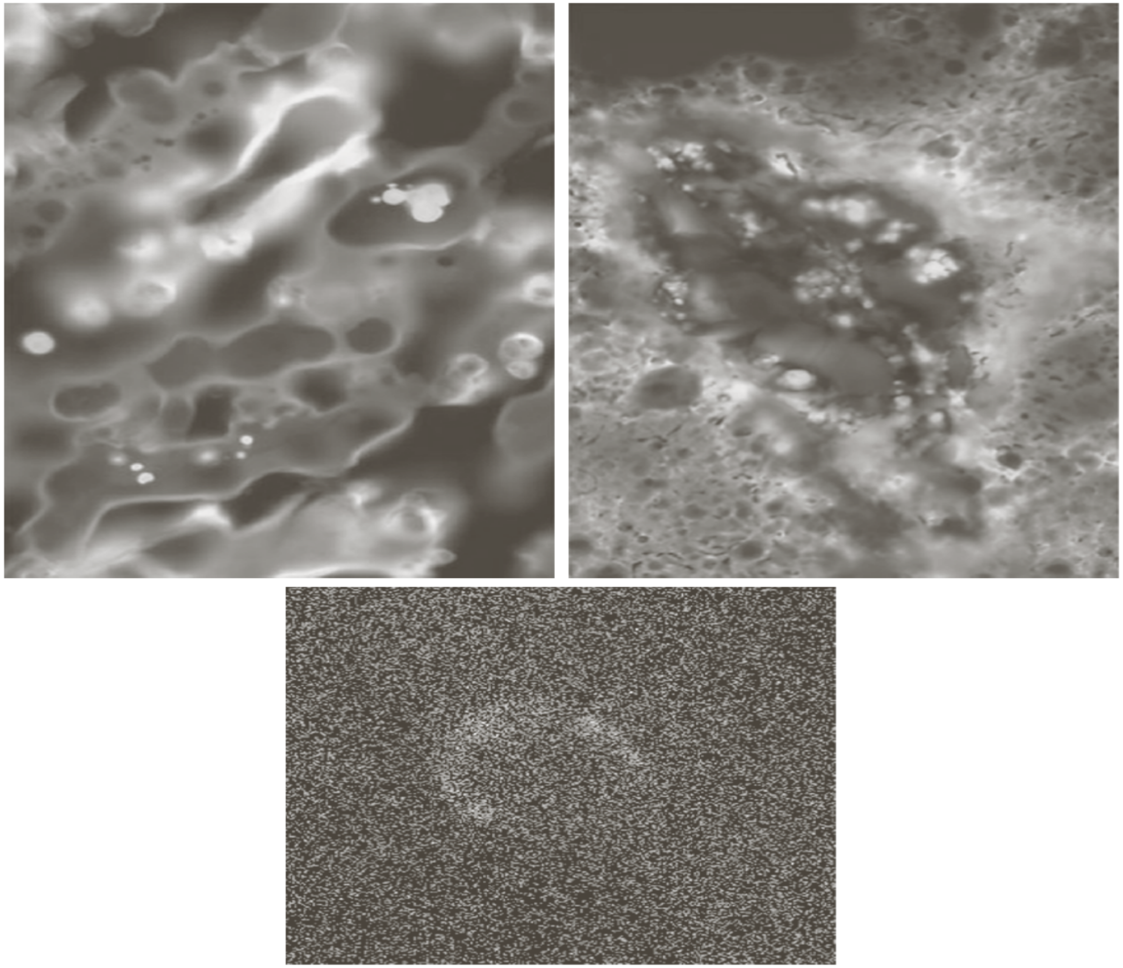
GAMMA RAYS



a b
c d

FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of Michigan.)

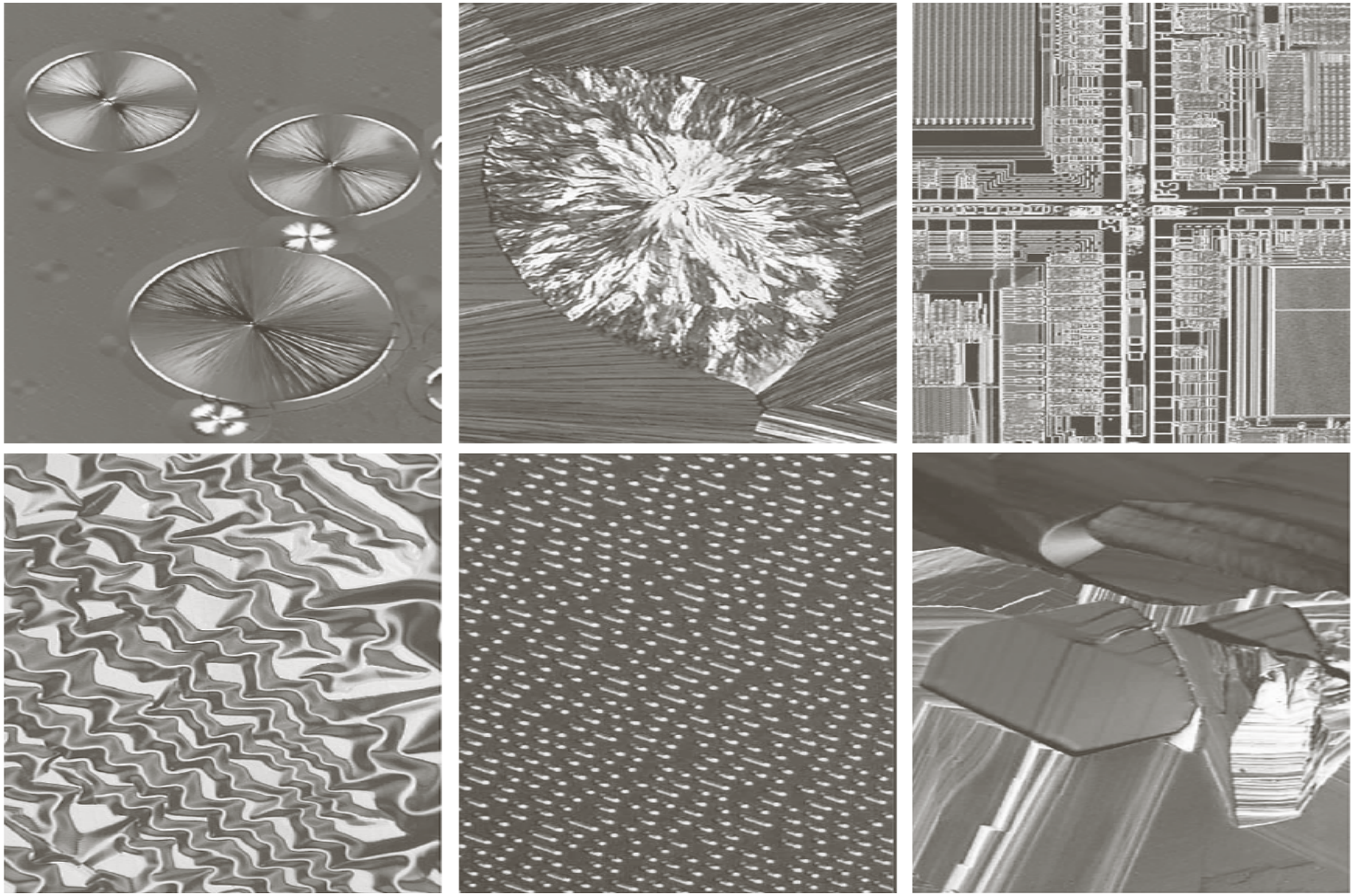
UV RAYS



a b
c

FIGURE 1.8 Examples of ultraviolet imaging. (a) Normal corn. (b) Smut corn. (c) Cygnus Loop. (Images courtesy of (a) and (b) Dr. Michael W. Davidson, Florida State University, (c) NASA.)

VISIBLE AND INFRARED BAND



a b c
d e f

FIGURE 1.9 Examples of light microscopy images. (a) Taxol (anticancer agent), magnified 250×. (b) Cholesterol—40×. (c) Microprocessor—60×. (d) Nickel oxide thin film—600×. (e) Surface of audio CD—1750×. (f) Organic superconductor—450×. (Images courtesy of Dr. Michael W. Davidson, Florida State University.)

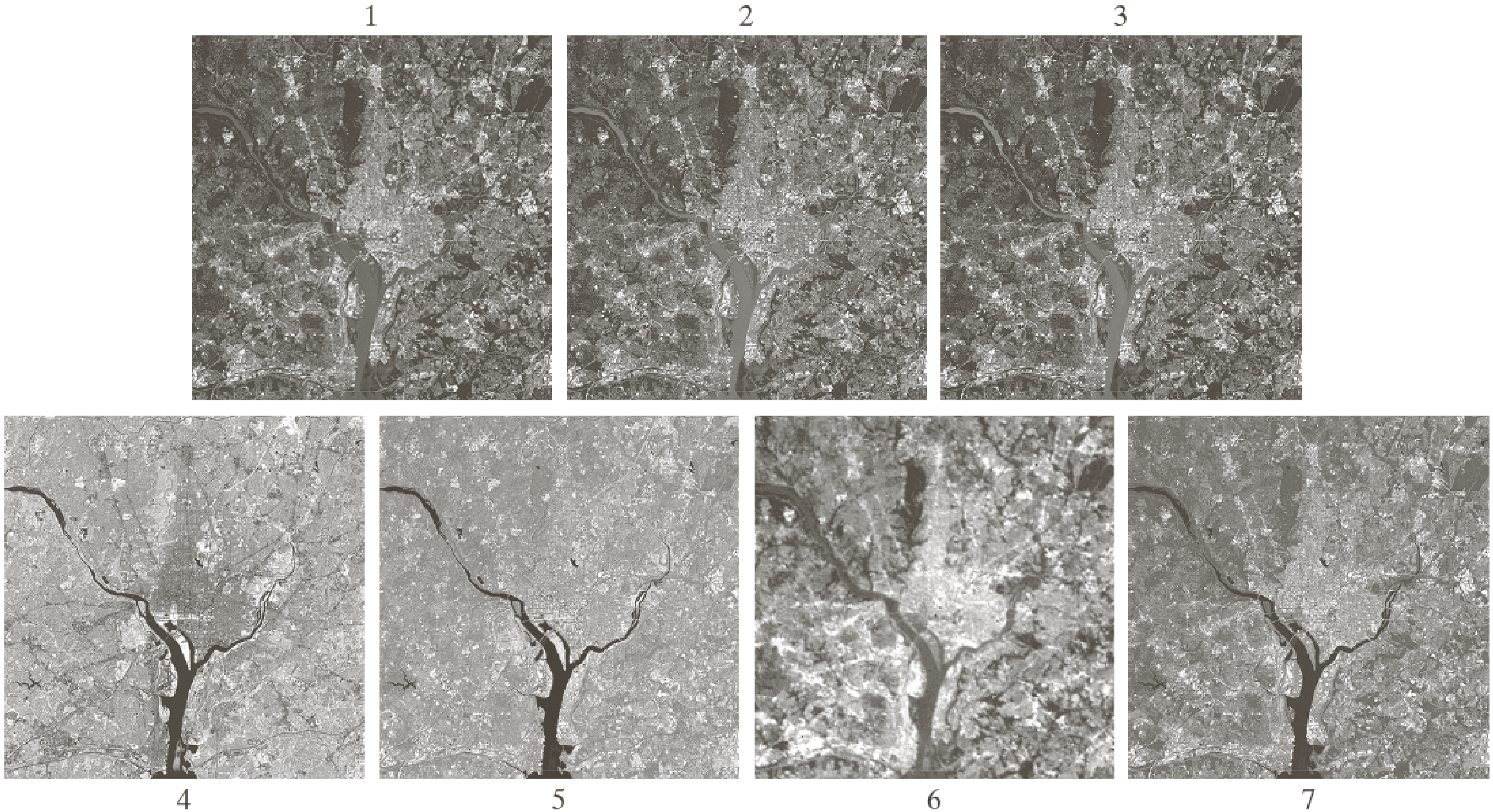


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

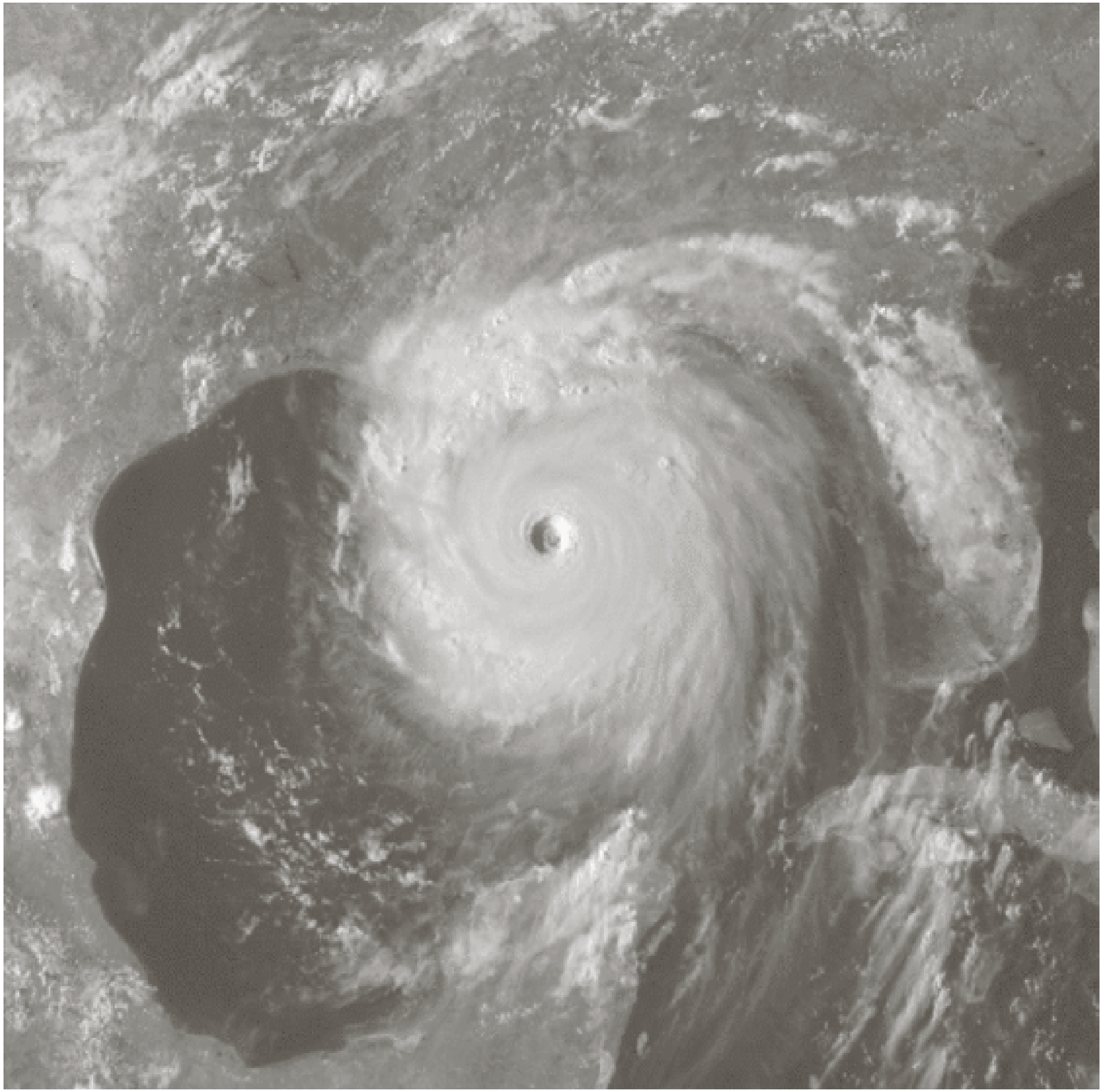


FIGURE 1.11 Satellite image of Hurricane Katrina taken on August 29, 2005. (Courtesy of NOAA.)

FIGURE 1.12 Infrared satellite images of the Americas. The small gray map is provided for reference. (Courtesy of NOAA.)

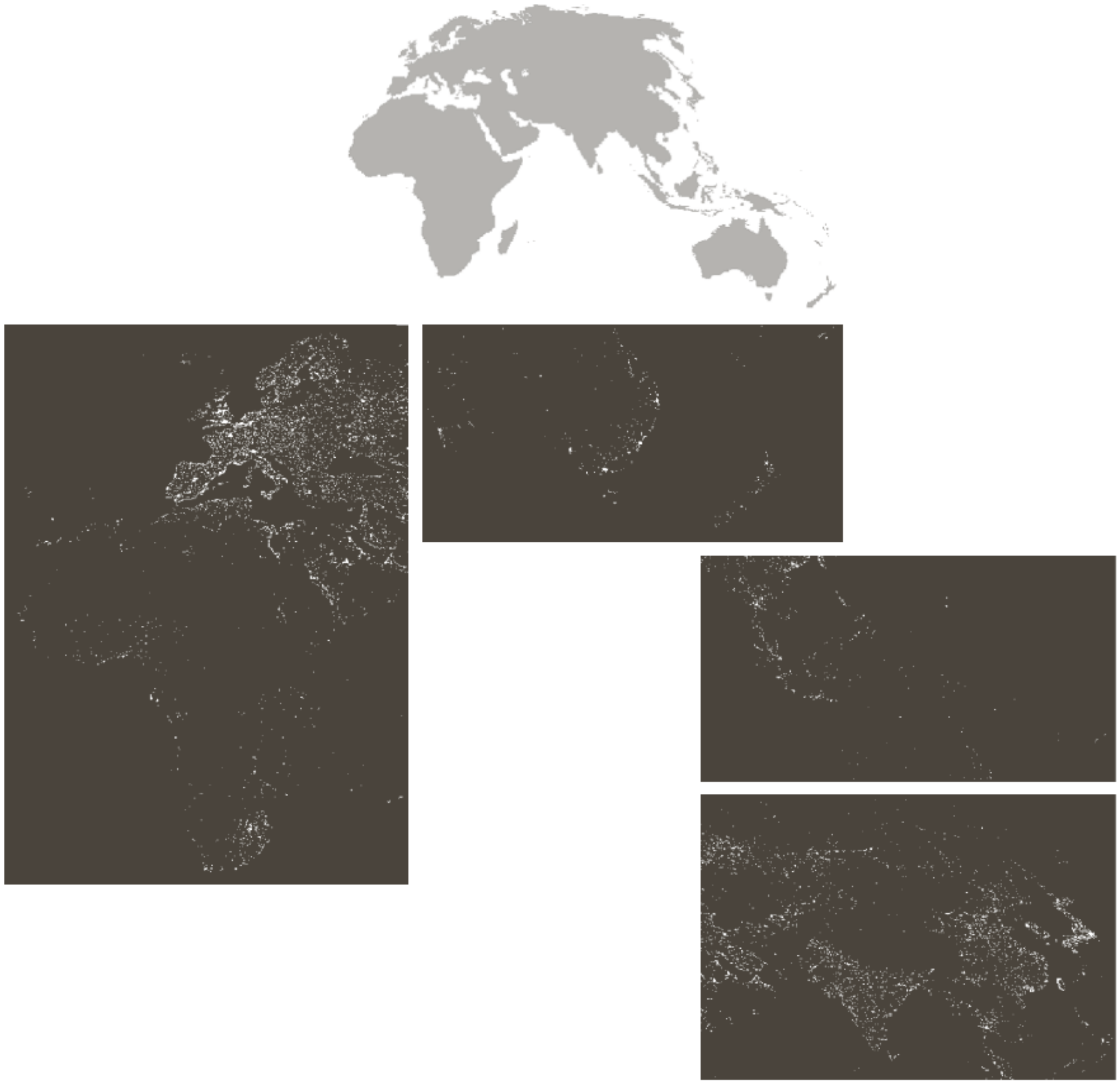
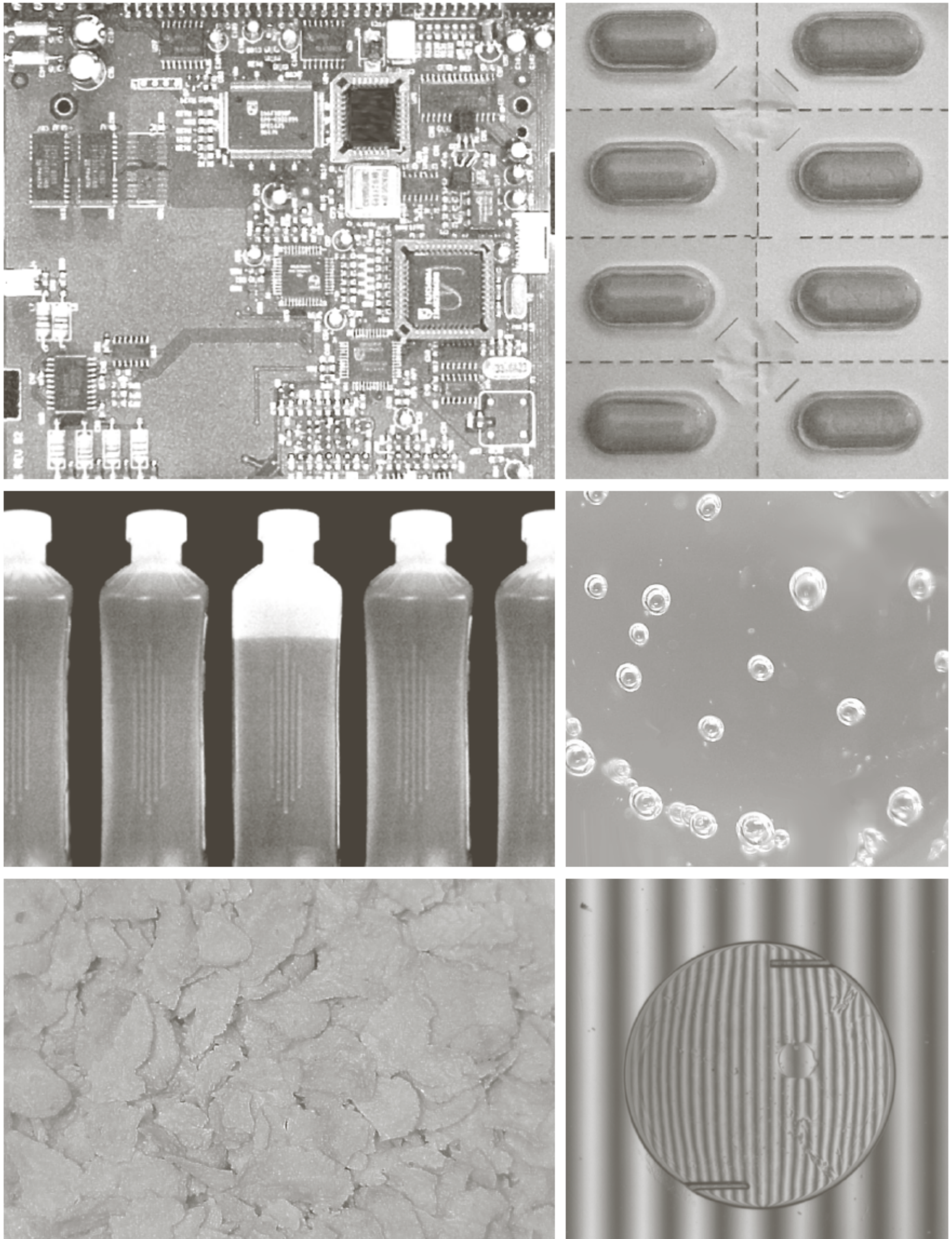


FIGURE 1.13 Infrared satellite images of the remaining populated part of the world. The small gray map is provided for reference. (Courtesy of NOAA.)



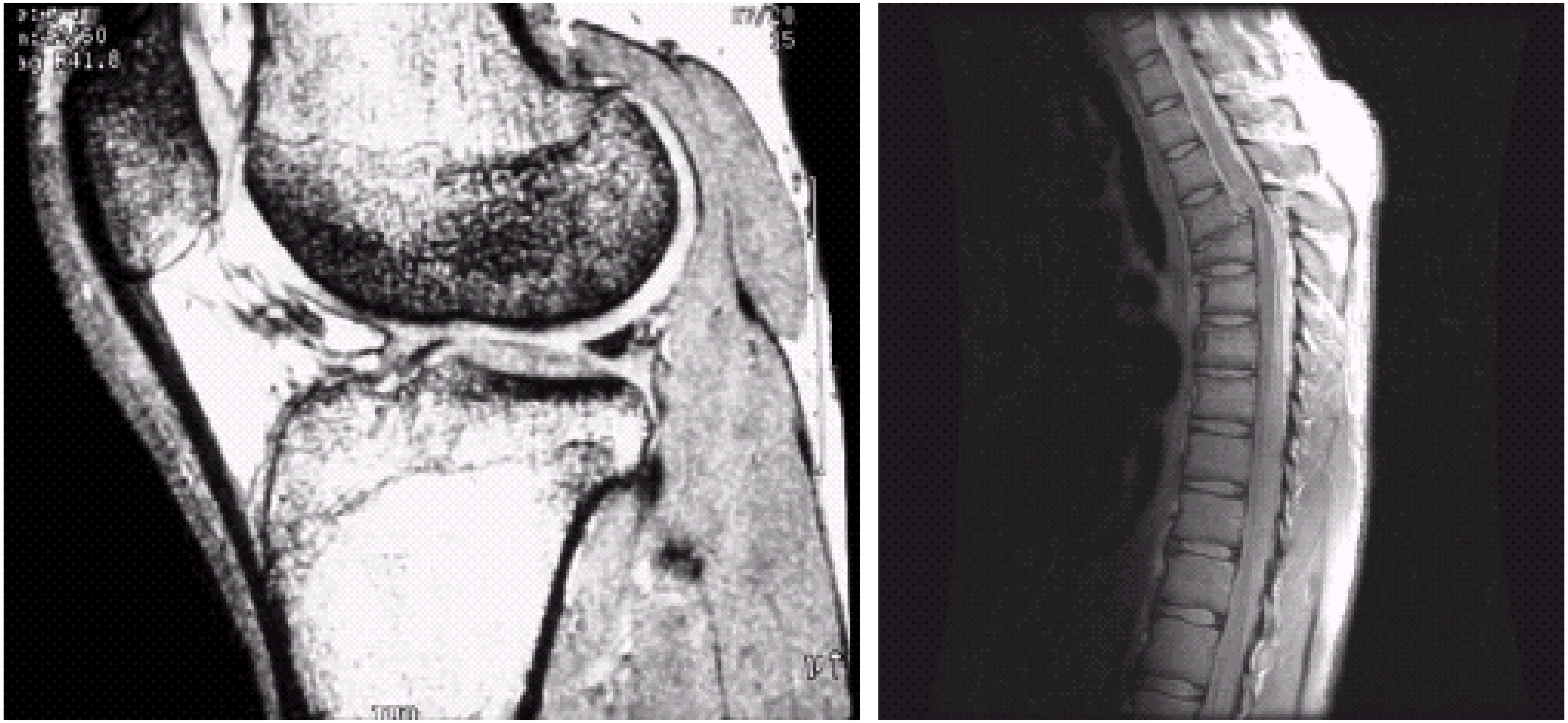
a b
c d
e f

FIGURE 1.14 Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Air bubbles in a clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)

a b
c
d

FIGURE 1.15 Some additional examples of imaging in the visual spectrum. (a) Thumb print. (b) Paper currency. (c) and (d) Automated license plate reading. (Figure (a) courtesy of the National Institute of Standards and Technology. Figures (c) and (d) courtesy of Dr. Juan Herrera, Perceptics Corporation.)

Example of fields that use Digital image processing



a b

FIGURE 1.17 MRI images of a human (a) knee, and (b) spine. (Image (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

Example of fields that use Digital image processing

Example of fields that use Digital image processing

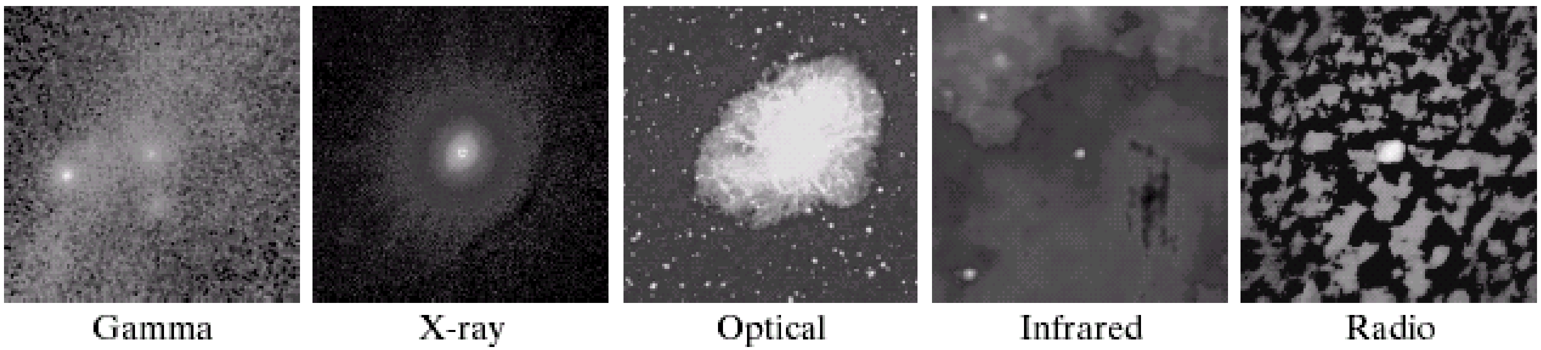


FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

Example of fields that use Digital image processing

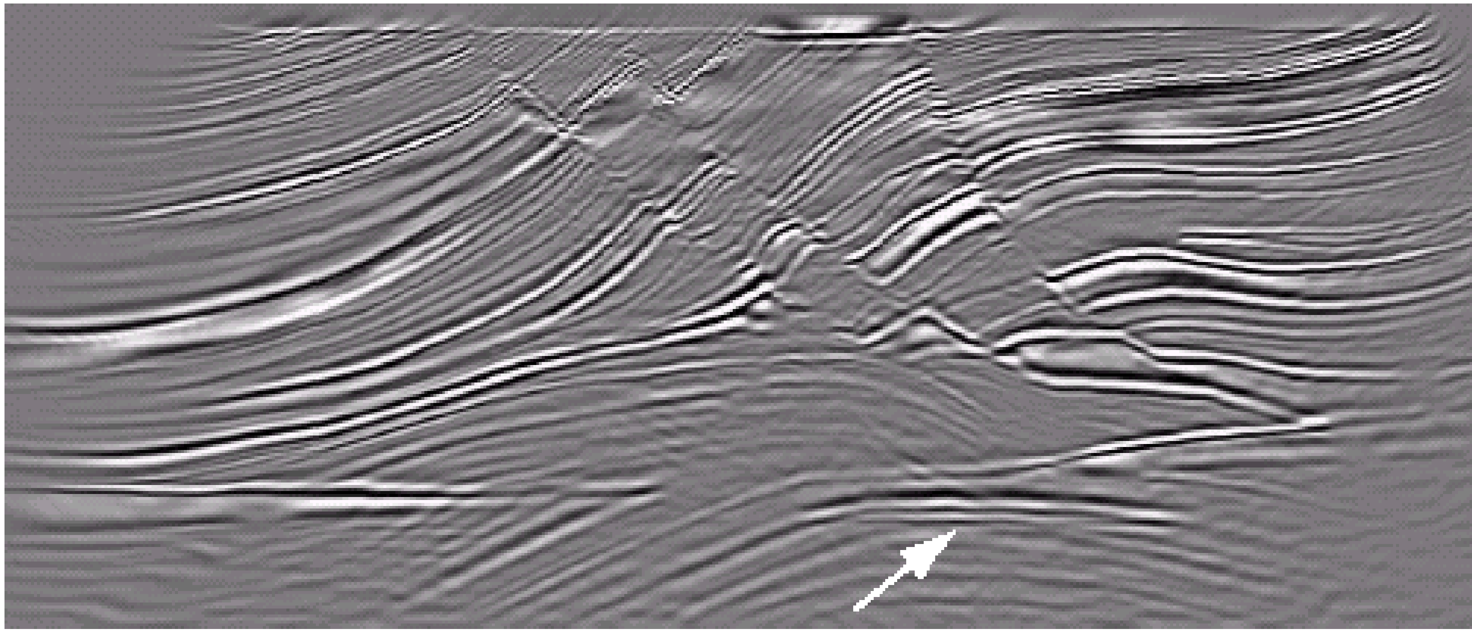
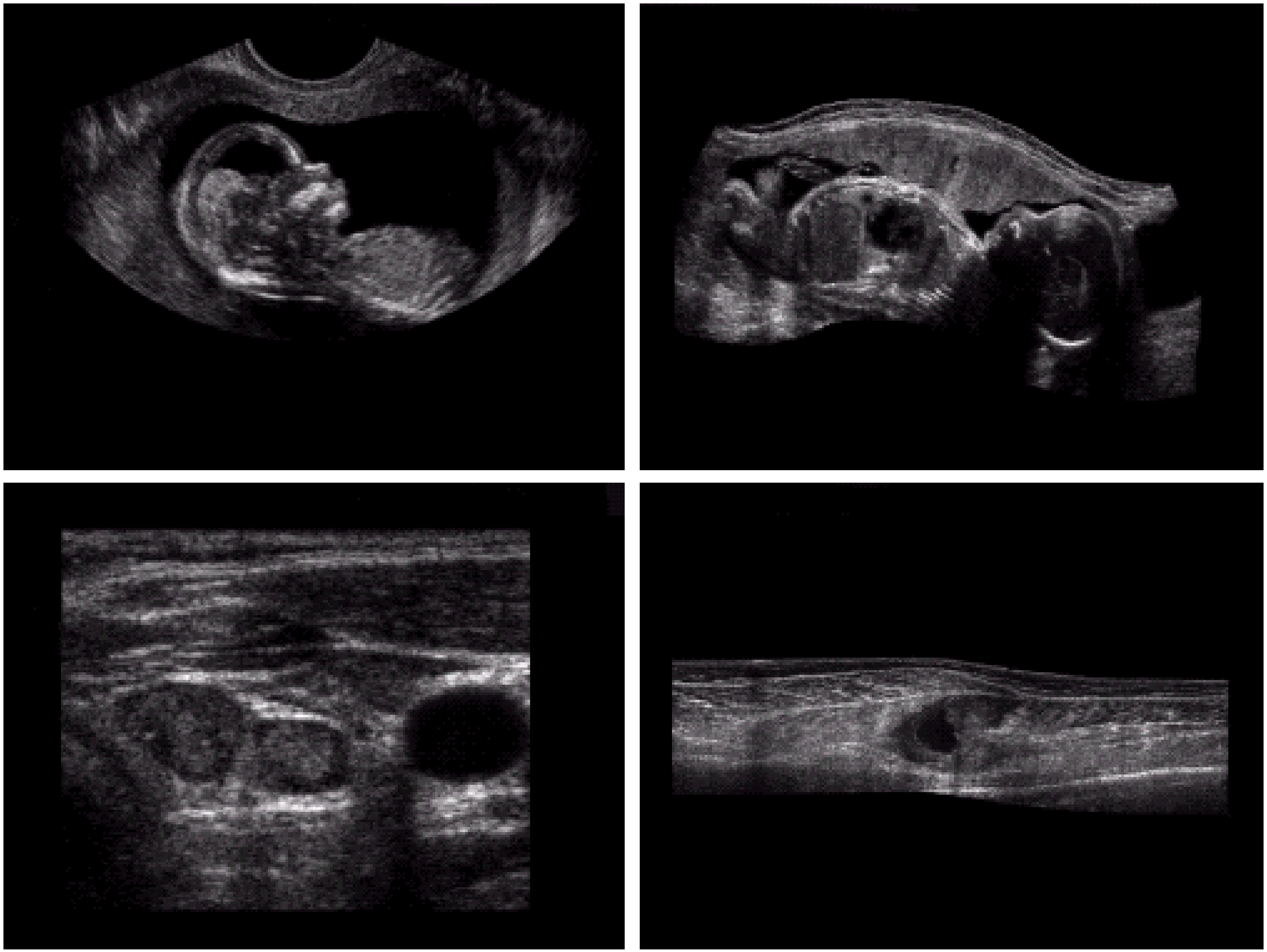


FIGURE 1.19 Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories.)

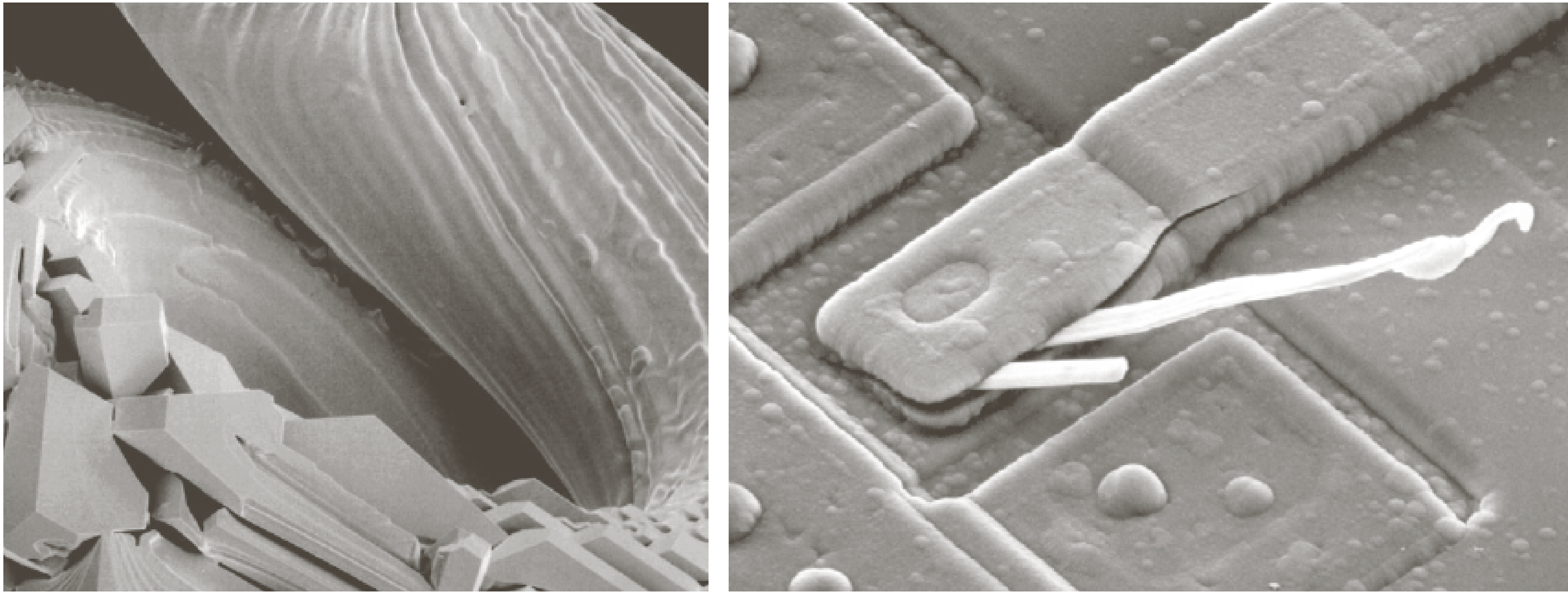
Example of fields that use Digital image processing



a b
c d

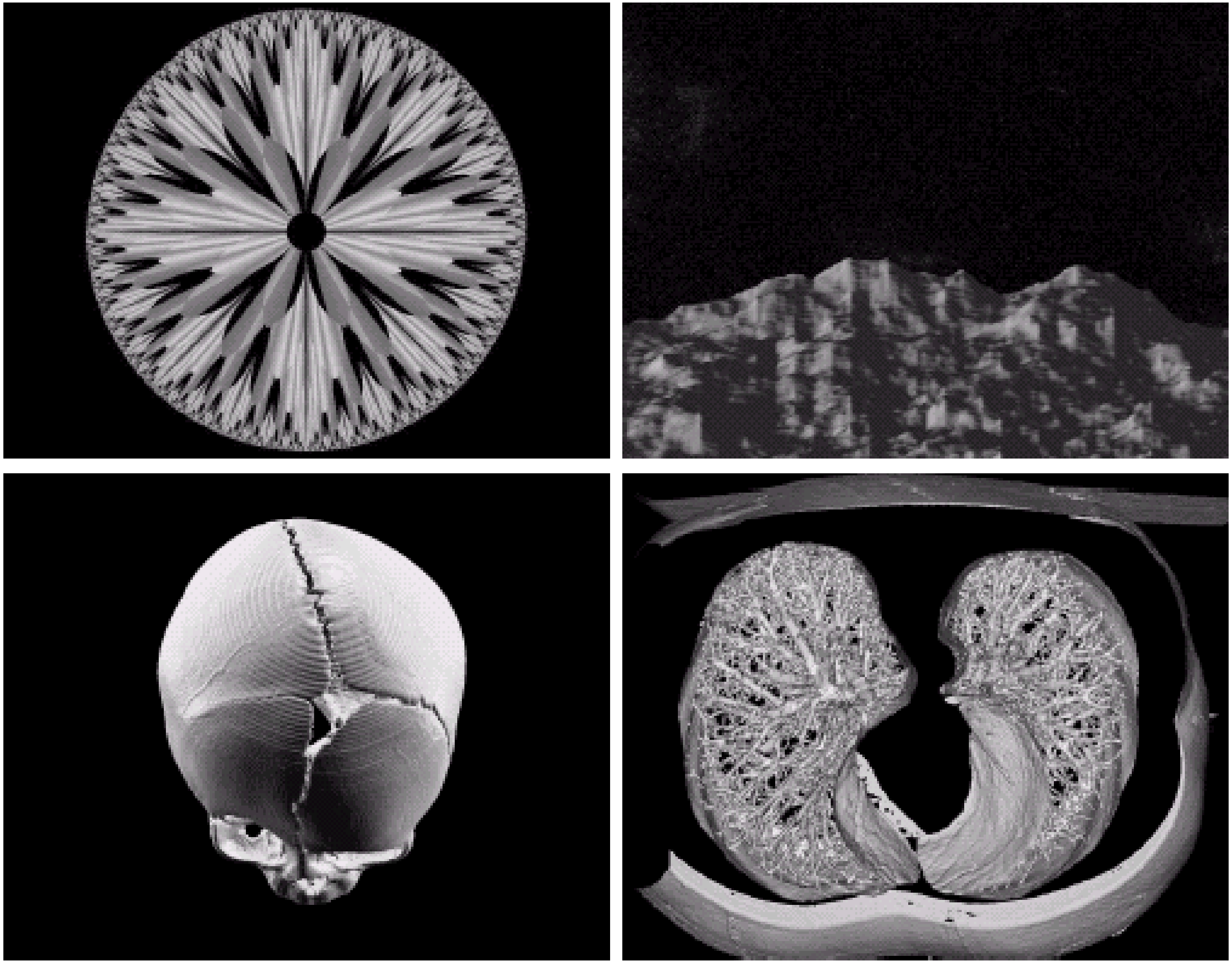
FIGURE 1.20 Examples of ultrasound imaging. (a) Baby. (2) Another view of baby. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

Example of fields that use Digital image processing



a b

FIGURE 1.21 (a) 250× SEM image of a tungsten filament following thermal failur (note the shattered pieces on the lower left). (b) 2500× SEM image of damage integrated circuit. The white fibers are oxides resulting from thermal destructio (Figure (a) courtesy of Mr. Michael Shaffer, Department of Geological Science University of Oregon, Eugene; (b) courtesy of Dr. J. M. Hudak, McMaster Universit Hamilton, Ontario, Canada.)



a b
c d

FIGURE 1.22 (a) and (b) Fractal images. (c) and (d) Images generated from 3-D computer models of the objects shown. (Figures (a) and (b) courtesy of Ms. Melissa D. Binde, Swarthmore College, (c) and (d) courtesy of NASA.)

Fundamental Steps in Digital Image Processing

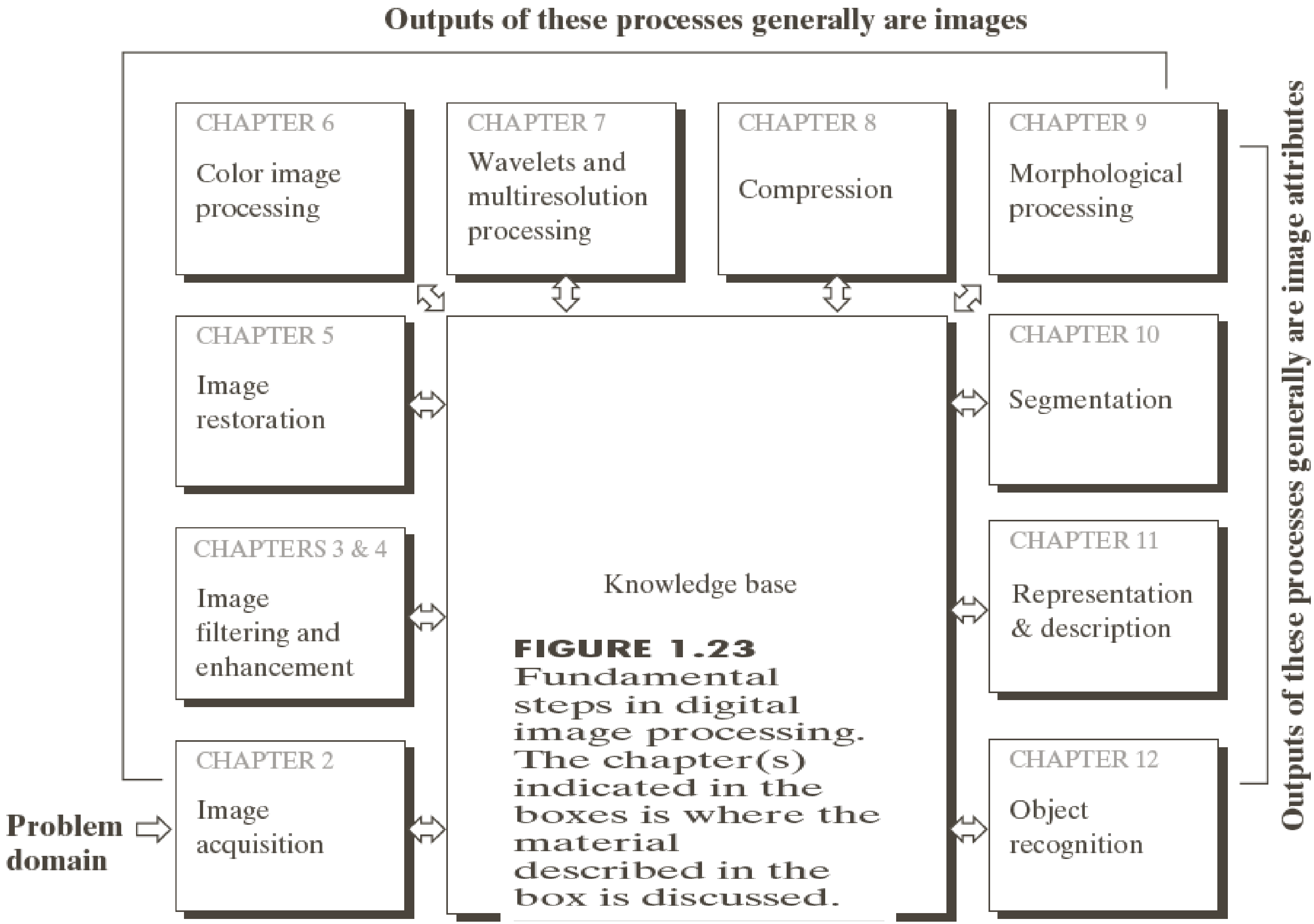


FIGURE 1.23 Fundamental steps in digital image processing. The chapter(s) indicated in the boxes is where the material described in the box is discussed.

Components of an Image Processing System

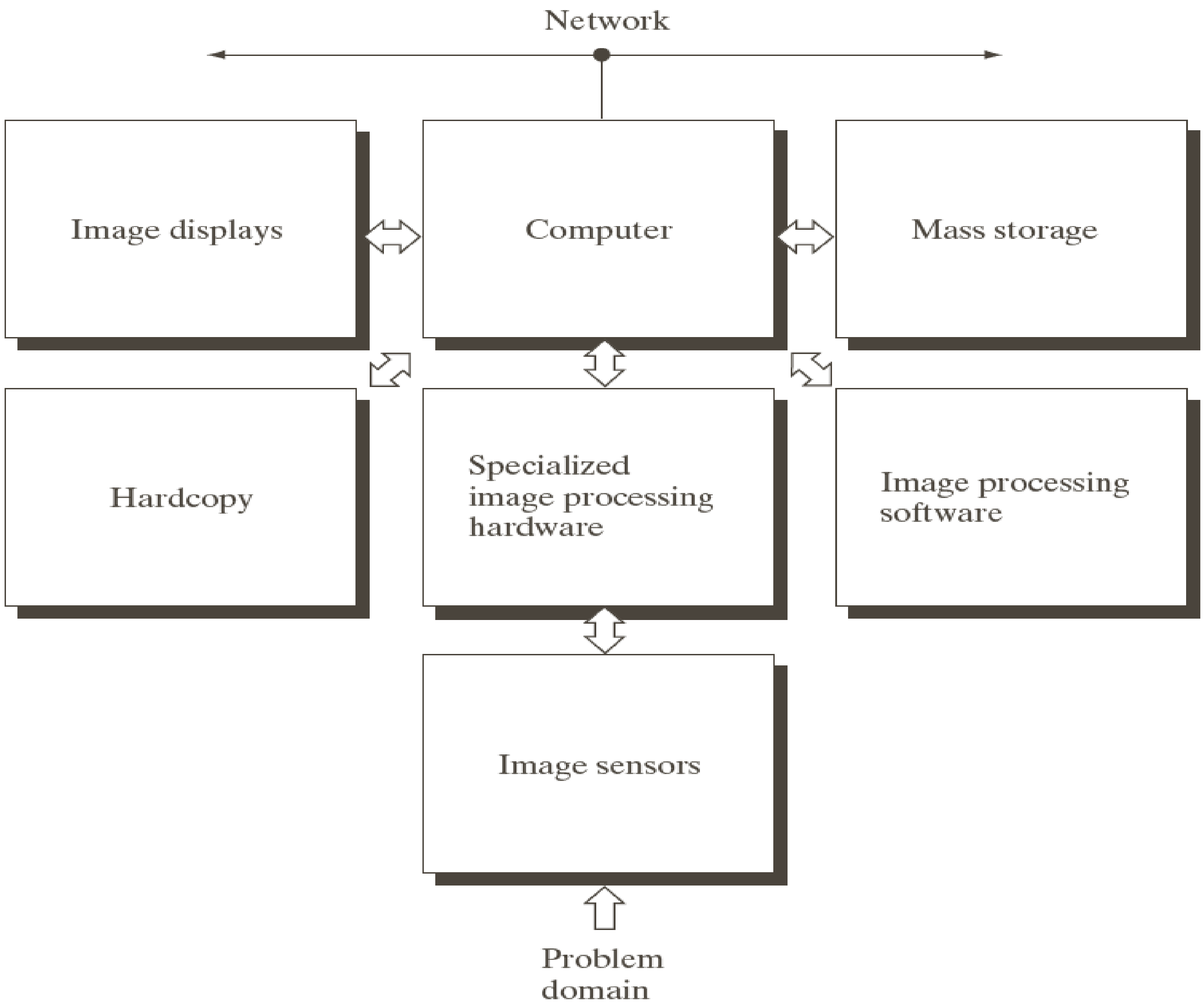


FIGURE 1.24 Components of a general-purpose image processing system.

A Simple Image Formation Model

- Images by two-dimensional functions of the form f(x, y).

- The value or amplitude of f at spatial coordinates (x, y) gives the intensity (brightness) of the image at that point.

- As light is a form of energy, f(x,y) must be non zero and finite.

- The function f(x, y) may be characterized by two components:

  (1)the amount of source illumination incident on the scene being viewed

  (2)the amount of illumination reflected by the objects in the scene.

- These are called the *illumination and reflectance components and are denoted by i(x, y) and r(x, y), respectively.*

- The two functions combine as a product to form f(x, y):

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

$r(x, y) = 0$ --- total absorption

1 --- total reflection

- The intensity of a monochrome image f at any coordinates (x, y) the *gray level (l) of the image at that point.*

That is, $l = f(x_0, y_0)$

L lies in the range $L_{\min} \le \ell \le L_{\max}$

In practice, $L_{\min} = i_{\min} r_{\min}$ and $L_{\max} = i_{\max} r_{\max}$.

GRAY SCALE

- The interval [L_{min} , L_{max}] is called the *gray scale.*

- *Common practice is to shift this interval numerically to the interval [0, L-1],*

- *where L = 0 is considered black and*

L = L-1 is considered white on the gray scale.

All intermediate values are shades of gray varying from black to white.

Image Representation

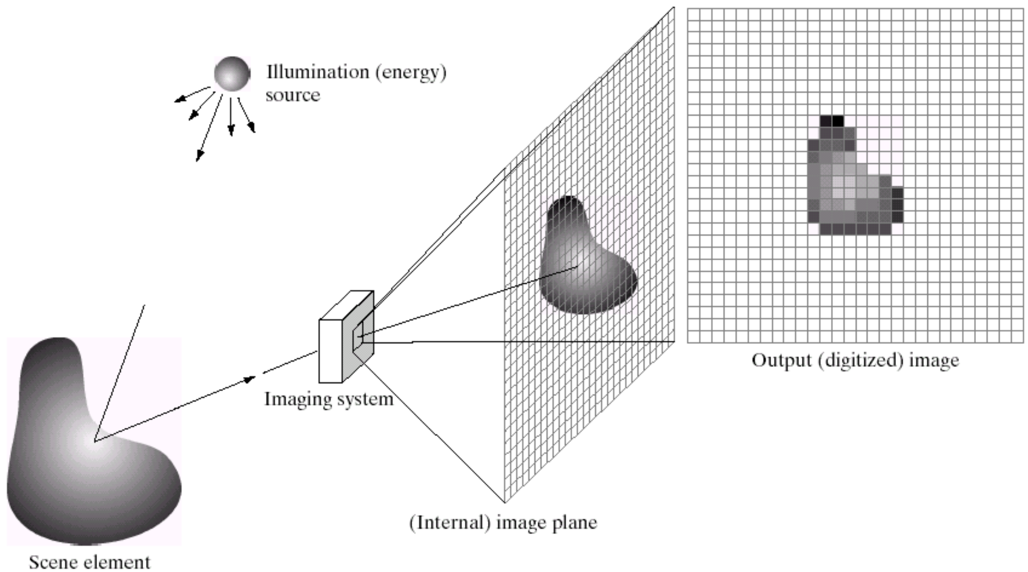
y

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

- An image is a 2-D light intensity function f(x,y)
- A digital image f(x,y) is discretized both in spatial coordinates and brightness
- It can be considered as a matrix whose row, column indices specify a point in the image and the element value identifies gray level value at that point
- These elements are referred to as pixels or pels

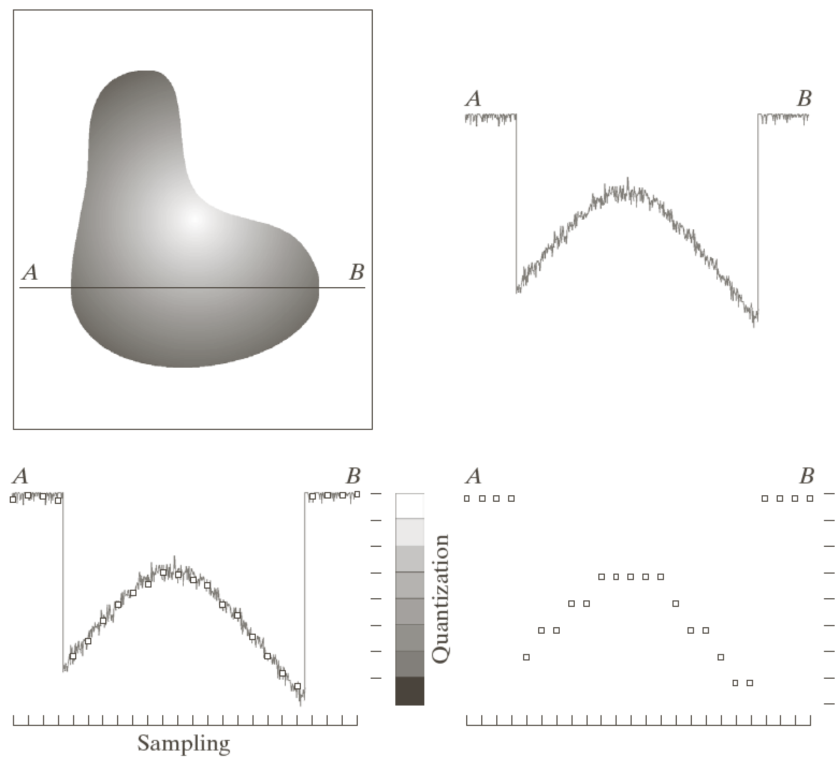
Image Representation

- Spatial discretization by grids
- Intensity discretization by quantization



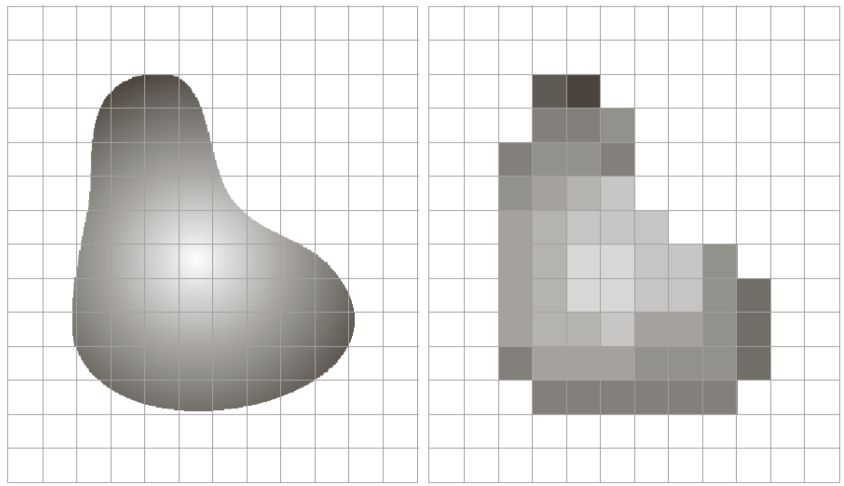
a b c d e

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.



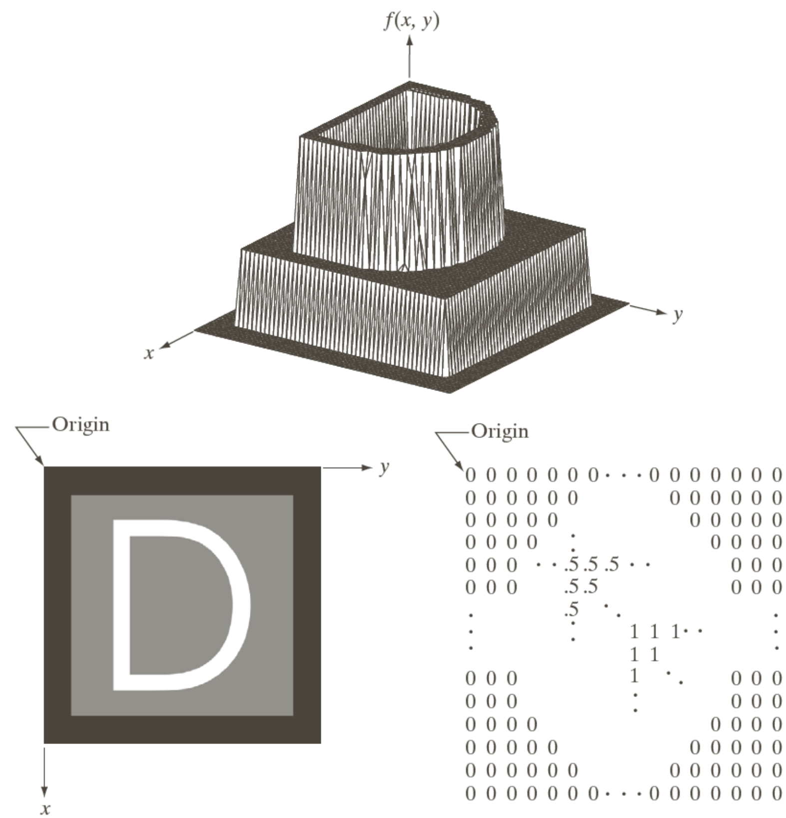
a b
c d

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.



a b

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



a
b c

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

Image Representation

$$
I = \begin{bmatrix}
f(0,0) & f(0,1) & f(0,2) \ldots\ldots\ldots & f(0,N-1) \\
f(1,0) & f(1,1) & f(1,2) \ldots\ldots\ldots & f(1,N-1) \\
f(2,0) & f(2,1) & f(2,2) \ldots\ldots\ldots & f(2,N-1) \\
\vdots & \vdots & \vdots & \vdots \\
f(M-1,0) & f(M,1) & f(M,2) .. & f(M-1,N-1)
\end{bmatrix}
$$

Image Size : 256x256, 512x512, 640x480, 1024x1024 etc

Quantization: 8 bits

Steps in Digital Image Processing

Digital Image Processing involves following basic tasks

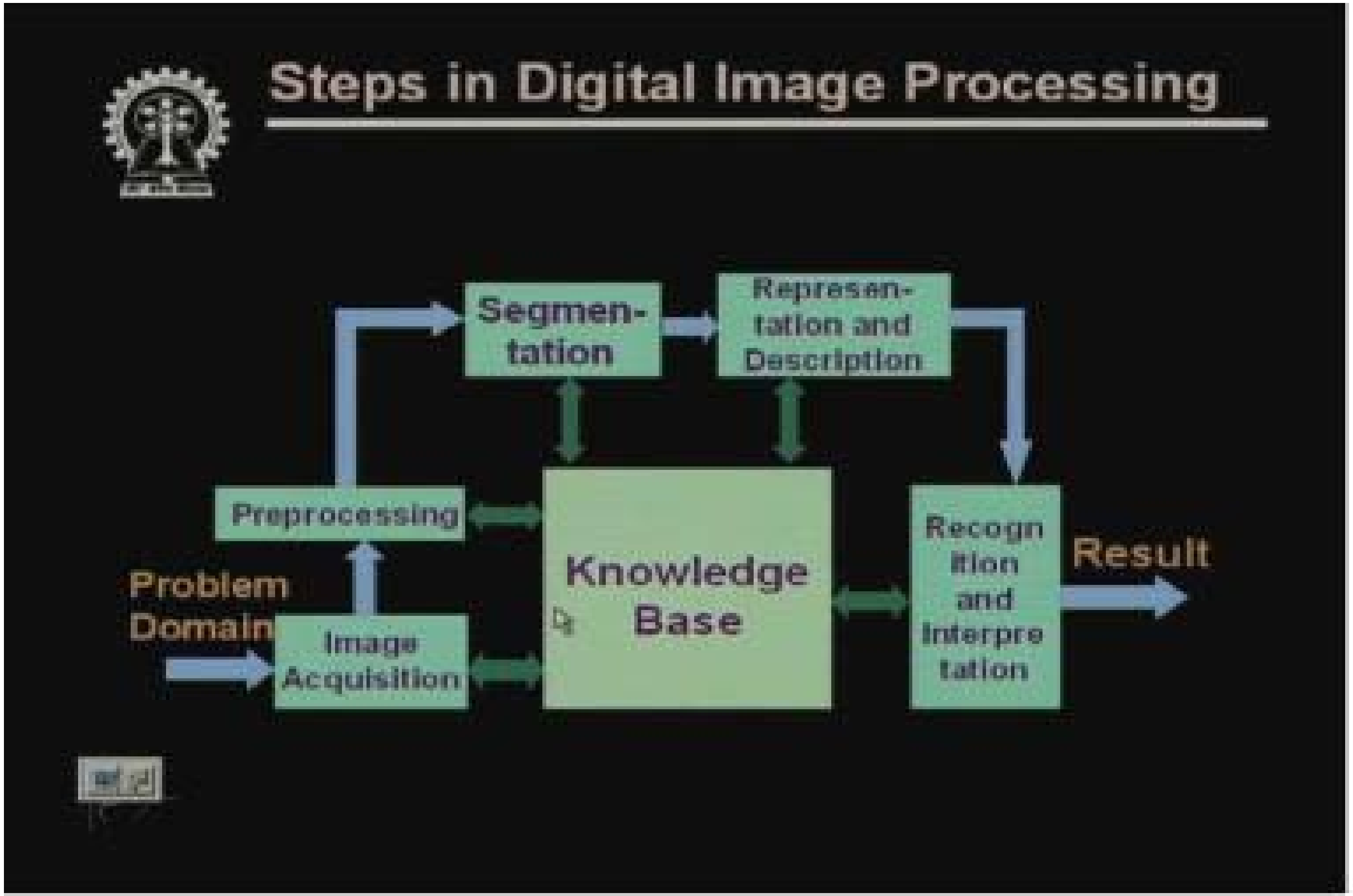
- Image Acquisition:- An imaging sensor and the capability to digitize the signal produced by the sensor
- Preprocessing:- Enhances the image quality, filtering, contrast enhancement etc.
- Segmentation:- Partitions an input image into constituent parts of objects

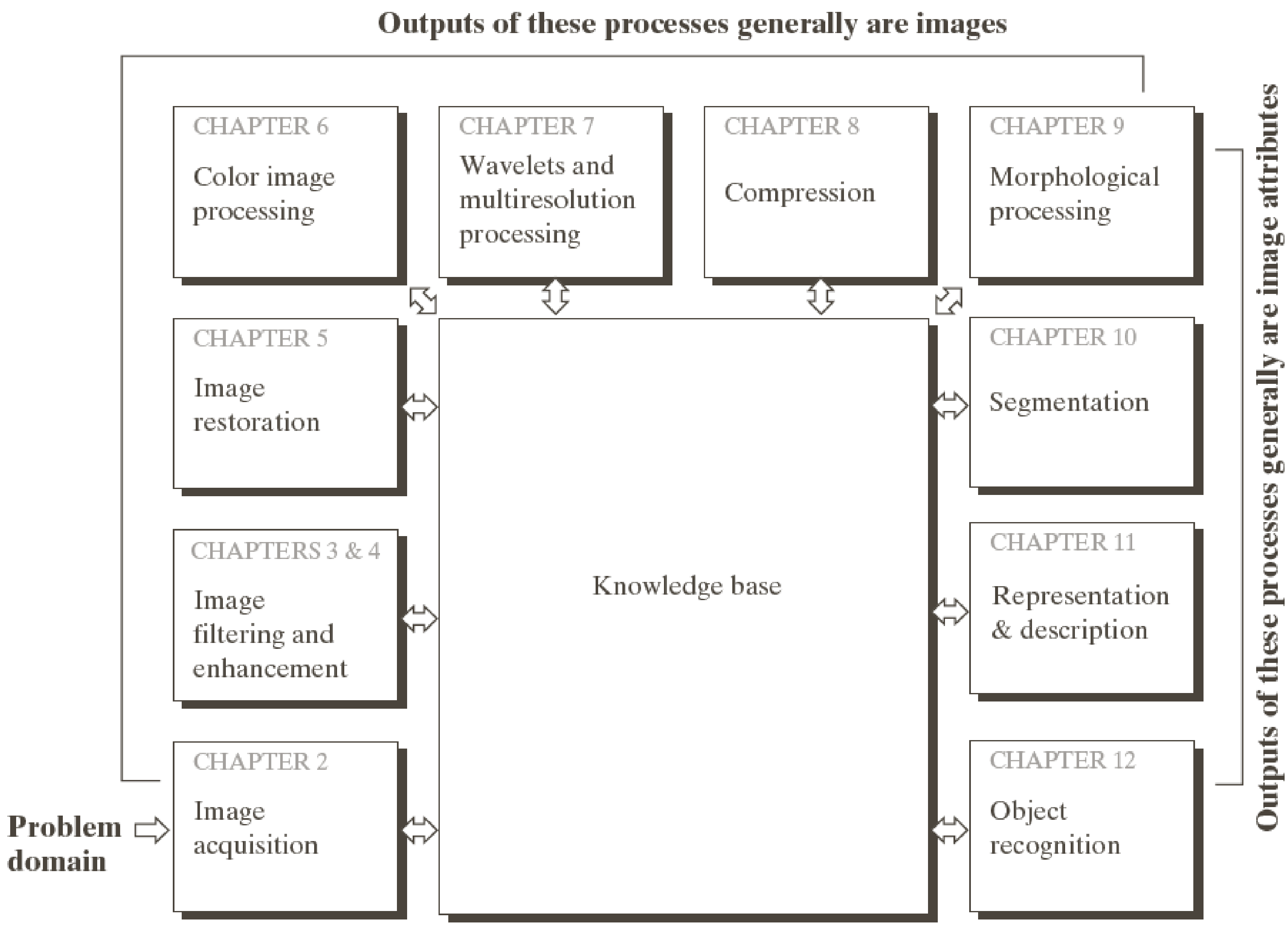
Steps in Digital Image Processing

- Description/ Feature Selection:- Extracts description of image objects suitable for further computer processing

- Recognition & Interpretation:- Assigning a label to the object based on the information provided by its descriptor. Interpretation assigns meaning to a set of labeled objects.

- Knowledge Base:- Knowledge Base helps for efficient processing as well as inter module cooperation


Steps in Digital Image Processing
Segmen-
tation
Represen-
tation and
Description
Preprocessing
Knowledge
Base
Recogn
ition
and
Interpre
tation
Result
Problem
Domain
Image
Acquisition



Outputs of these processes generally are images
CHAPTER 6
Color image processing
CHAPTER 7
Wavelets and multiresolution processing
CHAPTER 8
Compression
CHAPTER 9
Morphological processing
CHAPTER 5
Image restoration
CHAPTER 10
Segmentation
CHAPTERS 3 & 4
Image filtering and enhancement
Knowledge base
CHAPTER 11
Representation & description
CHAPTER 2
Image acquisition
CHAPTER 12
Object recognition
Problem domain
Outputs of these processes generally are image attributes

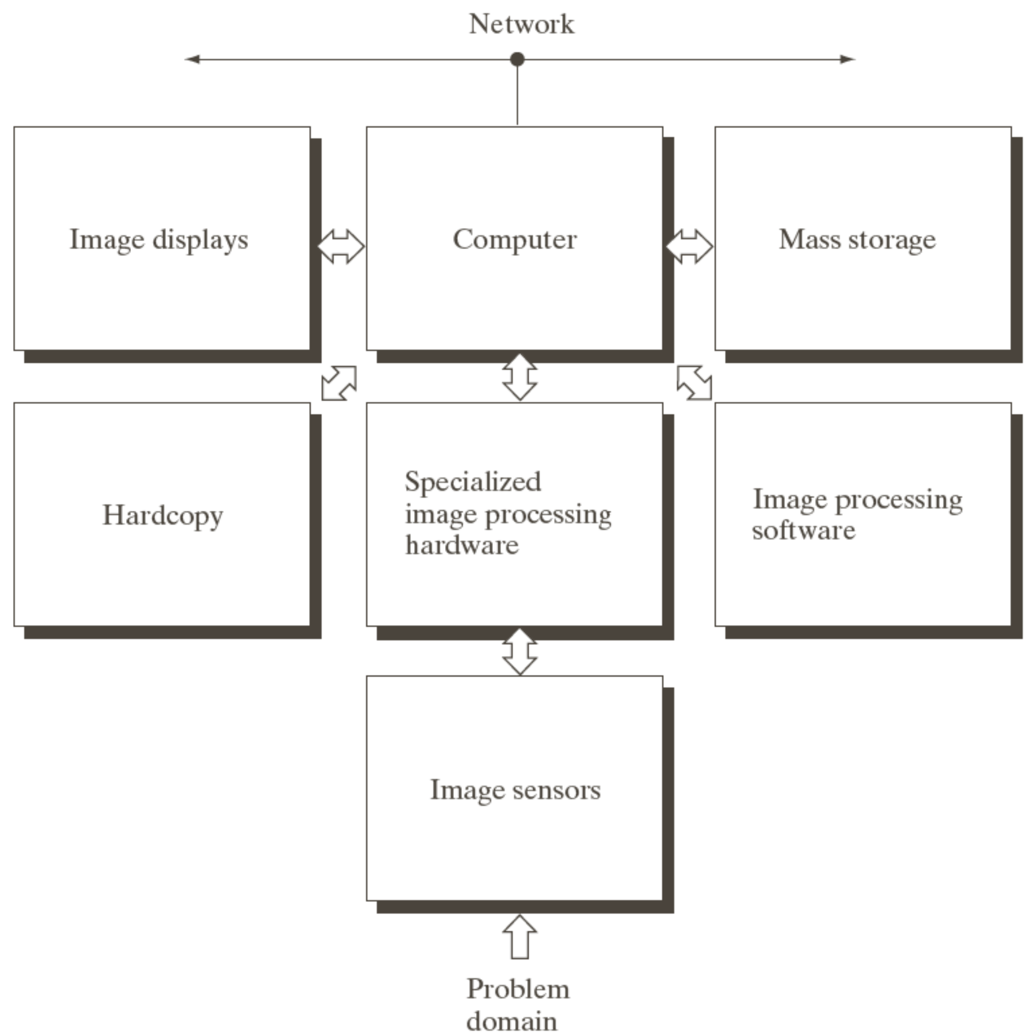

Network
Image displays
Computer
Mass storage
Hardcopy
Specialized image processing hardware
Image processing software
Image sensors
Problem domain

TABLE 2.1
Number of storage bits for various values of N and k.

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

GRAY SCALE

- The interval [L_{min} , L_{max}] is called the*gray scale.*

- *Common practice is to shift this interval numerically to the interval [0, L-1],*

- *where L = 0 is considered black and*

L = L-1 is considered white on the gray scale.

All intermediate values are shades of gray varying from black to white.

Basic Relationships Between Pixels

- 1. **Neighbors of a Pixel :-**

A pixel p at coordinates (x, y) has four *horizontal and vertical neighbors whose coordinates are given by* (x+1, y), (x-1, y), (x, y+1), (x, y-1)

- This set of pixels, called the 4-*neighbors of p, is denoted by* N_4(p).

- Each pixel is a unit distance from (x, y), and some of the neighbors of p lie outside the digital image if (x, y) is on the border of the image.

N_D(p) and N_8(p)

- The four *diagonal neighbors of p have coordinates*

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

  and are denoted by N_D(p).

- These points, together with the 4-neighbors, arecalled the 8-*neighbors of p, denoted by* N_8(p).

- If some of the points in N_D(p) and N_8(p) fall outside the image if (x, y) is on the border of theimage.

Adjacency, Connectivity, Regions, and Boundaries

- To establish whether two pixels are connected, it must be determined if they are neighbors and
- if their gray levels satisfy a specified criterion of similarity (say, if their gray levels are equal).

- For instance, in a binary image with values 0 and 1, two pixels may be 4-neighbors,

- but they are said to be connected only if they have the same value

- Let *V be the set of gray-level values used todefine connectivity. In a binary image, V={1} for the connectivity of pixels with value 1.*

- *In a grayscale image, for connectivity of pixels with a range of intensity values of say 32, 64 V typically contains more elements.*

- *For example,*

- *In the adjacency of pixels with a range of possible gray-level values 0 to 255,*
- *set V could be any subset of these 256 values.We consider three types of adjacency:*

- **We consider three types of adjacency:**

(a) 4-*adjacency.*

***Two pixels p and q with values from V are 4-adjacent if q is in the set N_4*(p).**

(b) 8-*adjacency.*

***Two pixels p and q with values from V are 8-adjacent if q is* in the set N_8(p).**

(c) m-adjacency (mixed adjacency).

$N_4(p) \cap N_4(q)$

(d) Two pixels p and q with values from V are m-adjacent if

- **(i) q is in N_4**(p), *or*
  - ***(ii) q is in N_D***(p) *and the set whose values are from V.*

- A *path from pixel p with coordinates (x, y) to pixel q with coordinates (s, t) is a sequence of distinct pixels with coordinates*

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

- where ($x_{\text{б’}}$ y_0) = (x, y) and ($x_{\text{Ŷ’}}$ y_n) = (s, t),

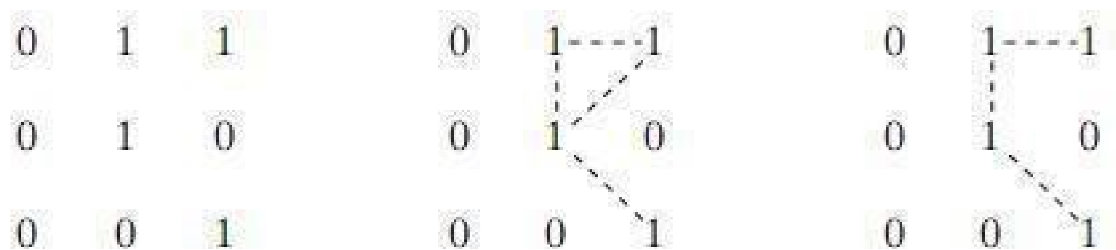
($x_{\text{i’}}$ y_i) and ($x_{\text{i-б’}}$ y_{i-1}) pixels and are adjacent for б ч i ч Ŷ. IŶ this Đase, Ŷ is the *length of the path.*

- *If* ($x_{\text{б’}}$ y_0) = ($x_{\text{Ŷ’}}$ y_n) the path is a *closed path*.

.

- Two pixels p and q are said to be *connected in S if there exists a path between them consisting entirely of pixels in S.*

- *For any pixel p in S, the set of pixels that are connected to it in S is called a connected component of S.*



a b c

FIGURE (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.

Relations, equivalence

- A binary relation R on a set A is a set of pairs of elements from A. If the pair (a, b) is in R, the notation used is aRb (ie a is related to b)

- Ex:- the set of points A = { p1,p2,p3,p4} arranged as

P1

p2

P3

p4

- In this case R is set of pairs of points from A that are 4-connected that is R = {(p1,p2), (p2,p1), (p1,p3), (p3,p1)} .

thus p1 is related to p2 and p1 is related to p3 and vice versa but p4 is not related to any other point under the relation .

Reflective - Symmetric - Transitive

- Reflective

if for each a in A, aRa

- Symmetric

if for each a and b in A, aRb implies bRa

- Transitive

if for a, b and c in A, aRb and bRc implies aRc

A relation satisfying the three properties is called an equivalence relation.

Distance Measures

- For pixels p, q,and z,with coordinates (x, y), (s, t),and (u, v) respectively, *D is a distance function or metric if*

  (a) D(p, q)D;p, if p = q),

  (b) D(p, q) = D(q, p)

The *Euclidean distance between p and q is defined as*

$$D_e(p, q) = \left[(x - s)^2 + (y - t)^2\right]^{\frac{1}{2}}.$$