DIGITAL IMAGE PROCESSING

Dr. Usha B S
RNS Institute of Technology

- Textbook

Digital Image Processing- Rafel C Gonzalez and Richard E. Woods, PHI 3rd Edition 2010.

Reference

1. Digital Image Processing- S.Jayaraman, S.Esakkirajan, T.Veerakumar, Tata McGraw Hill 2014.

2. Fundamentals of Digital Image Processing-A. K. Jain, Pearson 2004.

* *Digital Image Processing with Matlab and Labview – Dr. Vipula Singh*

Module-1 Digital Image Fundamentals

- **Digital Image Fundamentals:**
- What is Digital Image Processing?, Origins of Digital Image Processing, Examples of fields that use DIP, Fundamental Steps in Digital Image Processing, Components of an Image Processing System [Text: Chapter 1]
- Elements of Visual Perception, Image Sensing and Acquisition, Image Sampling and Quantization, Some Basic Relationships Between Pixels, Linear and Nonlinear Operations.
- [Text: Chapter 2: Sections 2.1 to 2.5, 2.6.2]

Module-2 Spatial Domain 10 hours

- **Spatial Domain:** Some Basic Intensity Transformation Functions, Histogram Processing, Fundamentals of Spatial Filtering, Smoothing Spatial Filters, Sharpening Spatial Filters (Chapter 3: Sections 3.2 to 3.6)

- **Frequency Domain:** Preliminary Concepts, The Discrete Fourier Transform (DFT) of Two Variables, Properties of the 2-D DFT, Filtering in the Frequency Domain, Image Smoothing and Image Sharpening Using Frequency Domain Filters, Selective Filtering. (Chapter 4: Sections 4.2, 4.5 to 4.10)

Module-3 Restoration 10 hours

- **Restoration:** Noise models, Restoration in the Presence of Noise Only using Spatial Filtering and Frequency Domain Filtering, Linear, Position-Invariant Degradations, Estimating the Degradation Function, Inverse Filtering, Minimum Mean Square Error (Wiener) Filtering, Constrained Least Squares Filtering.

  [Text: Chapter 5: Sections 5.2, to 5.9]

Module-4 Color Image Processing 10 hours

- **Color Image Processing:** Color Fundamentals, Color Models, Pseudocolor Image Processing.() Chapter 6: Sections 6.1 to 6.3
- **Wavelets:** Background, Multiresolution Expansions. (Chapter 7: Sections 7.1 and 7.2)
- Morphological Image Processing: Preliminaries, Erosion and Dilation, Opening and Closing, The Hit-or-Miss Transforms, Some Basic Morphological Algorithms. (Chapter 9: Sections 9.1 to 9.5)

Module-5 Segmentation 10 hours

- **Segmentation:** Point, Line, and Edge Detection, Thresholding, Region-Based Segmentation, Segmentation Using Morphological Watersheds. (Chapter 10: Sections 10.2, to 10.5)
- **Representation and Description:** Representation, Boundary descriptors. (Chapter 11: Sections 11.1 and 11.2)

Origins of Digital Image Processing

FIGURE 1.1 A digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces. (McFarlane.†)

Sent by submarine cable between London and New York, the transportation time was reduced to less than three hours from more than a week

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Origins of Digital Image Processing

FIGURE 1.4 The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9 : 09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

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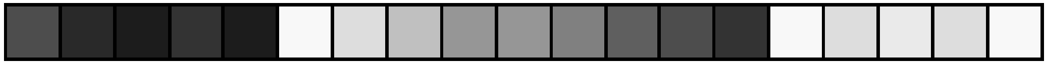
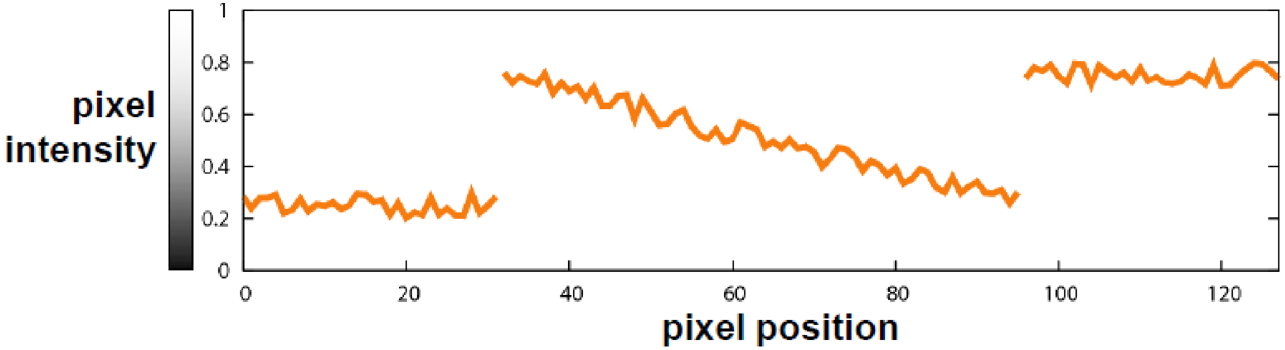
Illustration a 1D Image

- 1D image = line of pixels



- Better visualized as a plot



Digital Image

An image can be defined as a two-dimensional function *f(x, y)*

x and y are spatial (plane) coordinates

f, the amplitude at any pair of coordinates is called the intensity or grey level of the image at that point

- X→Rows   Y→Columns

What is an image?

An image is an array, or a matrix, of square pixels (picture elements) arranged in columns and rows.

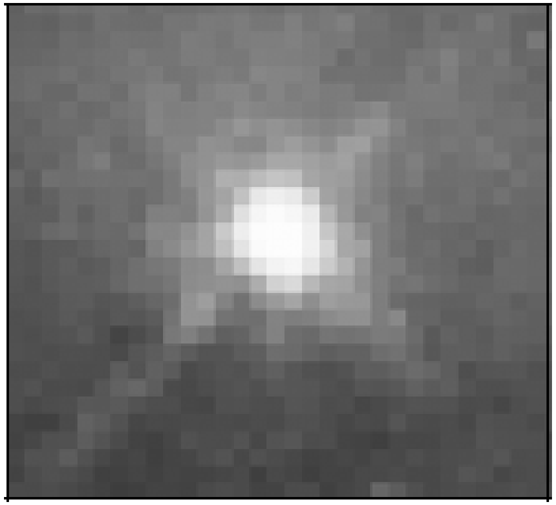
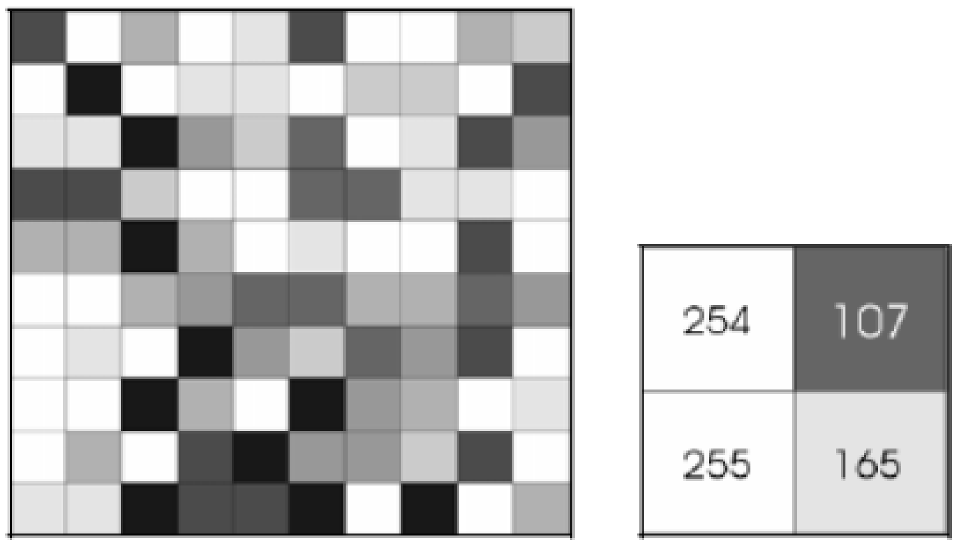


Figure 1: An image — an array or a matrix of pixels arranged in columns and rows.

Gray Scale Value

In a (8-bit) greyscale image each picture element has an assigned intensity that ranges from 0 to 255. A grey scale image is what people normally call a black and white image, but the name emphasizes that such an image will also include many shades of grey.



Digital Image-Sampled, Quantized

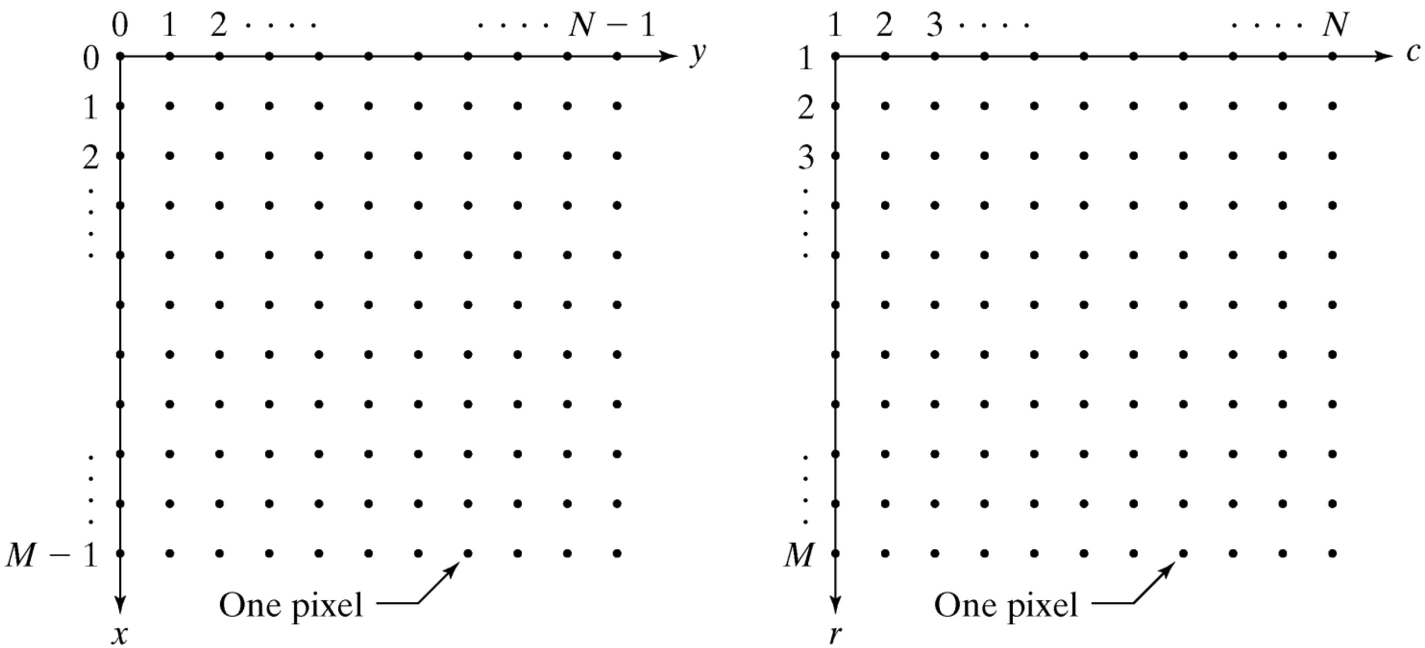
The image can now be represented as a matrix of integer values

$j \rightarrow$

$i \downarrow$

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

What is an image?



Pixel — the element of a digital image

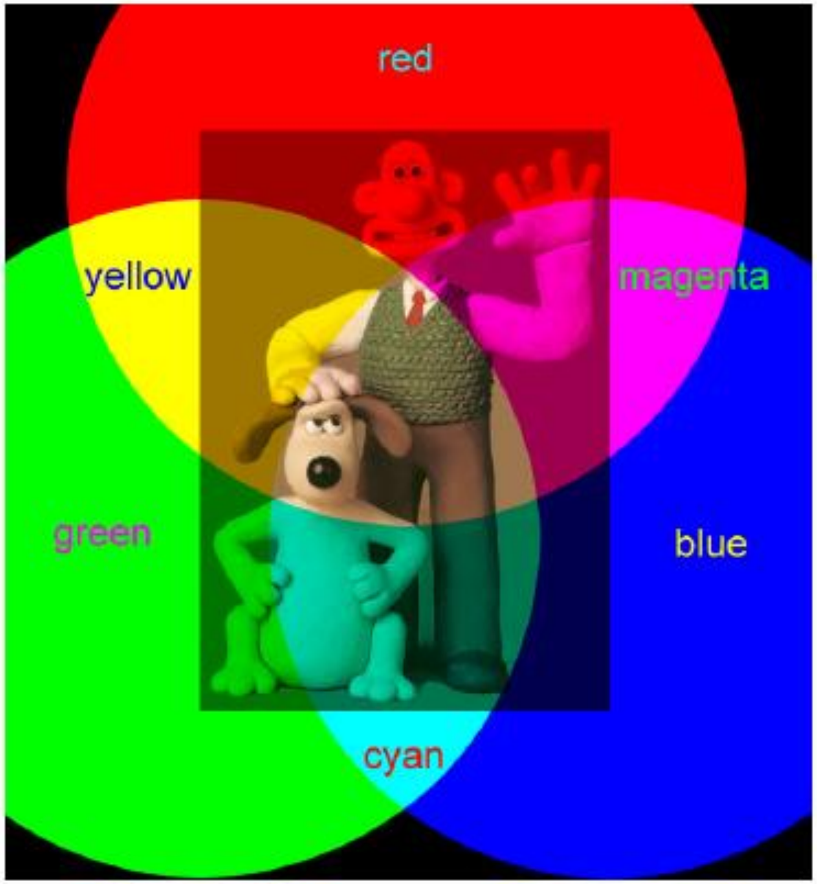
Representing Digital Images

- The Digital Image f(x,y) is represented as M rows and N columns numerical array as

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

Color Images

- Are constructed from three intensity maps.
- Each intensity map is projected through a color filter (*e.g.*, red, green, or blue, or cyan, magenta, or yellow) to create a monochrome image.
- The intensity maps are overlaid to create a color image.
- Each pixel in a color image is a three element vector.

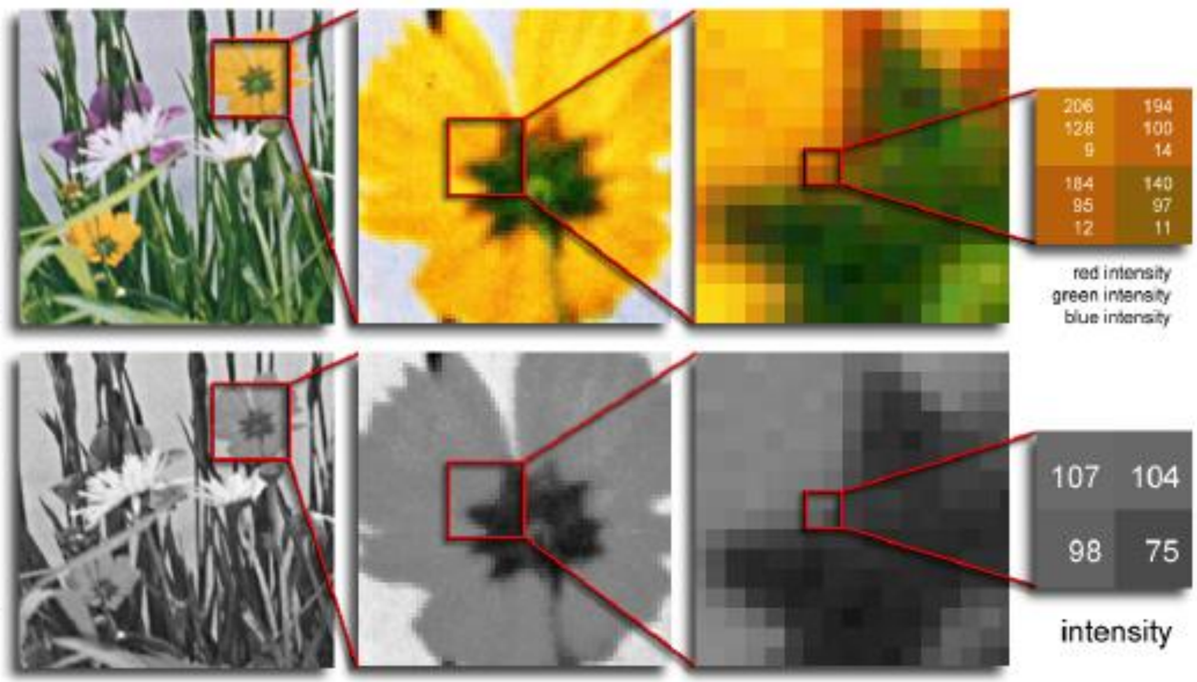


Digital Image

Color images have 3 values per pixel; monochrome images have 1 value per pixel.

a grid of squares, each of which contains a single color

each square is called a pixel (for *picture element*)



Introduction to Image Processing

Pixels: Grey Scale

0 (black)  1.0 (white)

255 – 8 bits

16383 – 14 bits

65535 – 16 bits

24 Columns

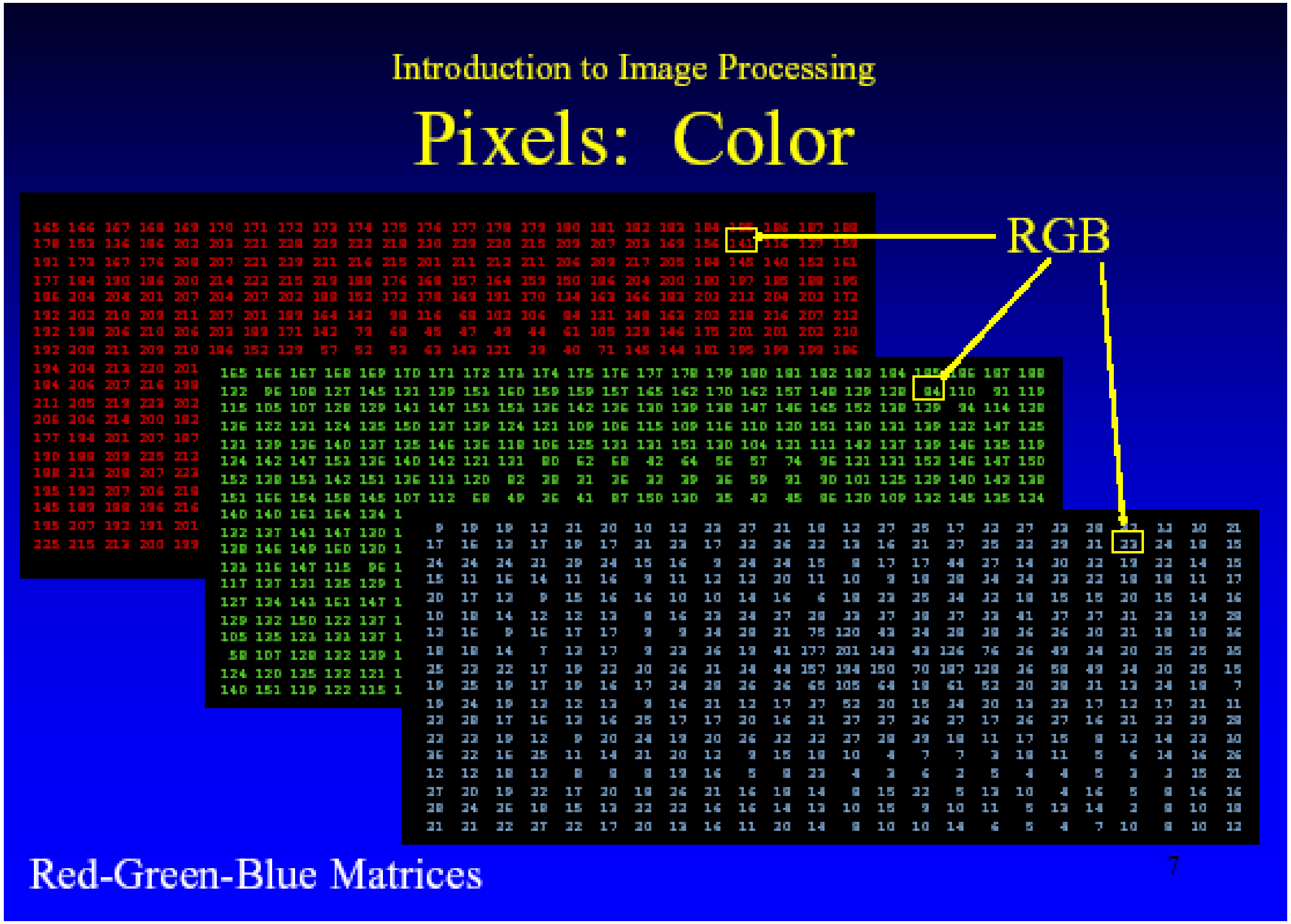
106	89	87	108	122	118	123	131	137	136	132	135	135	136	136	129	132	126	110	104	89	86	82	99
107	98	95	107	118	121	129	138	133	128	127	119	118	122	123	126	126	134	128	117	99	86	94	101
112	110	115	110	121	129	124	123	117	111	103	96	93	96	97	101	111	123	120	114	118	109	116	111
110	118	118	118	118	118	120	116	106	90	105	106	103	117	106	88	106	100	119	120	123	122	116	102
115	120	123	123	120	121	119	106	101	78	58	63	42	63	62	58	75	87	99	116	130	125	122	126
118	118	124	121	123	117	103	102	82	47	42	36	37	41	39	52	76	86	94	112	120	121	121	125
118	130	124	127	124	103	91	68	46	38	38	75	137	98	32	37	51	89	96	106	116	120	117	115
117	120	129	130	116	108	86	53	46	30	40	185	213	194	84	121	68	87	88	116	116	114	121	119
113	122	123	126	115	110	100	68	44	45	51	175	210	195	90	199	129	84	99	123	123	127	129	114
122	125	129	133	117	108	101	65	42	39	43	95	141	98	32	59	44	66	92	96	116	124	121	115
119	115	126	109	96	107	101	66	28	20	28	56	117	40	35	38	46	86	86	96	115	124	126	118
105	119	116	119	109	101	100	78	36	25	24	34	35	42	37	46	89	85	108	117	126	127	129	119
113	115	123	132	122	125	117	96	85	55	49	52	43	47	64	86	95	113	121	127	131	127	125	122
117	122	124	118	123	121	107	108	104	103	92	82	100	99	90	95	119	121	125	129	120	117	117	112
104	113	116	117	121	120	117	119	118	109	112	115	115	116	108	116	123	126	126	$\boxed{121}$	127	125	125	118
76	105	111	116	124	131	128	127	131	120	126	124	130	130	126	129	136	131	125	125	122	117	121	118
115	117	117	113	112	117	123	128	125	135	130	123	127	129	118	130	134	133	127	126	125	123	117	123
128	129	118	116	112	108	117	118	121	130	132	126	128	125	116	129	126	130	128	123	122	116	121	117

18 Rows

Each number is a picture element or "pixel"

Matrix: 24 Columns x 18 Rows = 432 numbers

3


Introduction to Image Processing
Pixels: Color
RGB
Red-Green-Blue Matrices
7

Sources for Images

Best way to categorize images is based on their sources

- Electromagnetic (EM) energy spectrum
- Acoustic
- Ultrasonic
- Electronic
- Synthetic images produced by computer

Electromagnetic (EM) energy spectrum

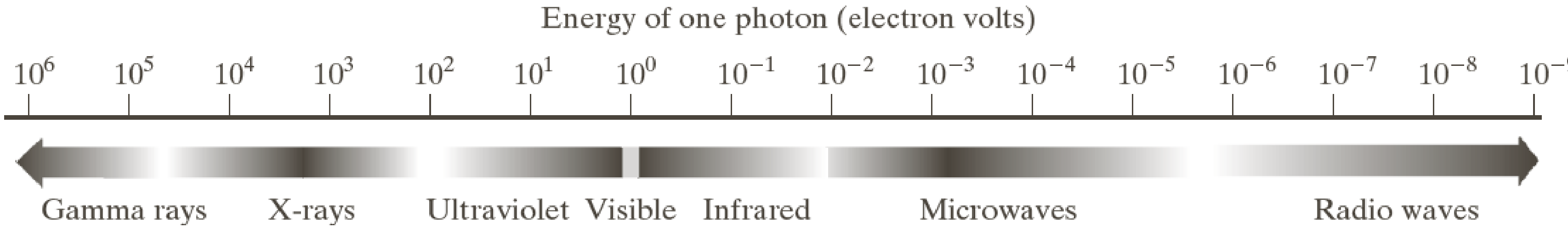
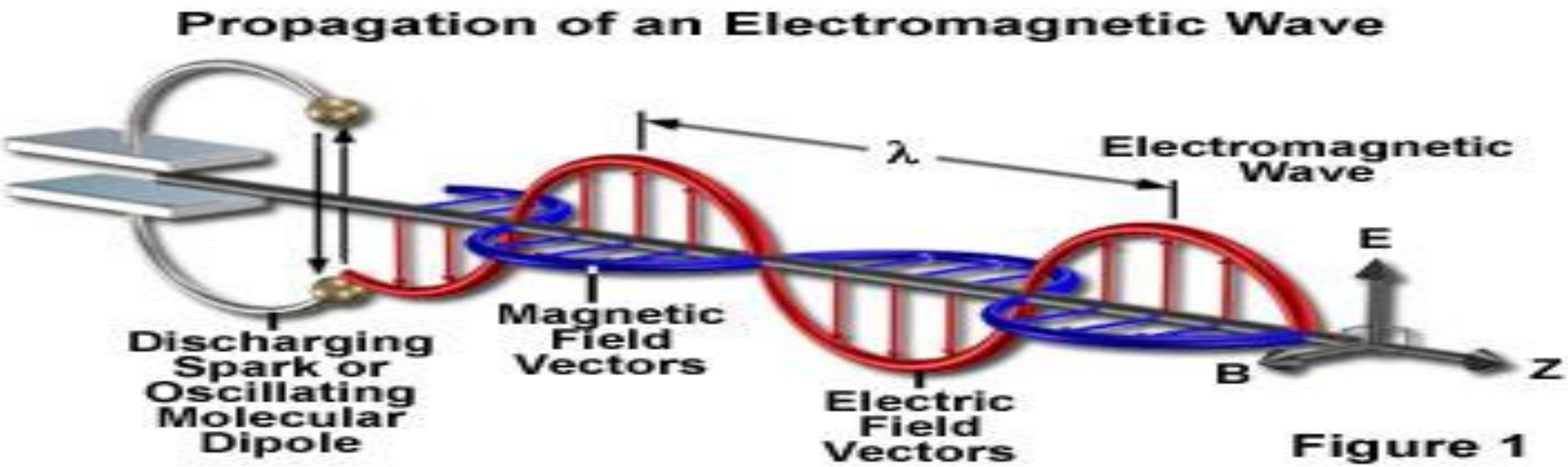


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

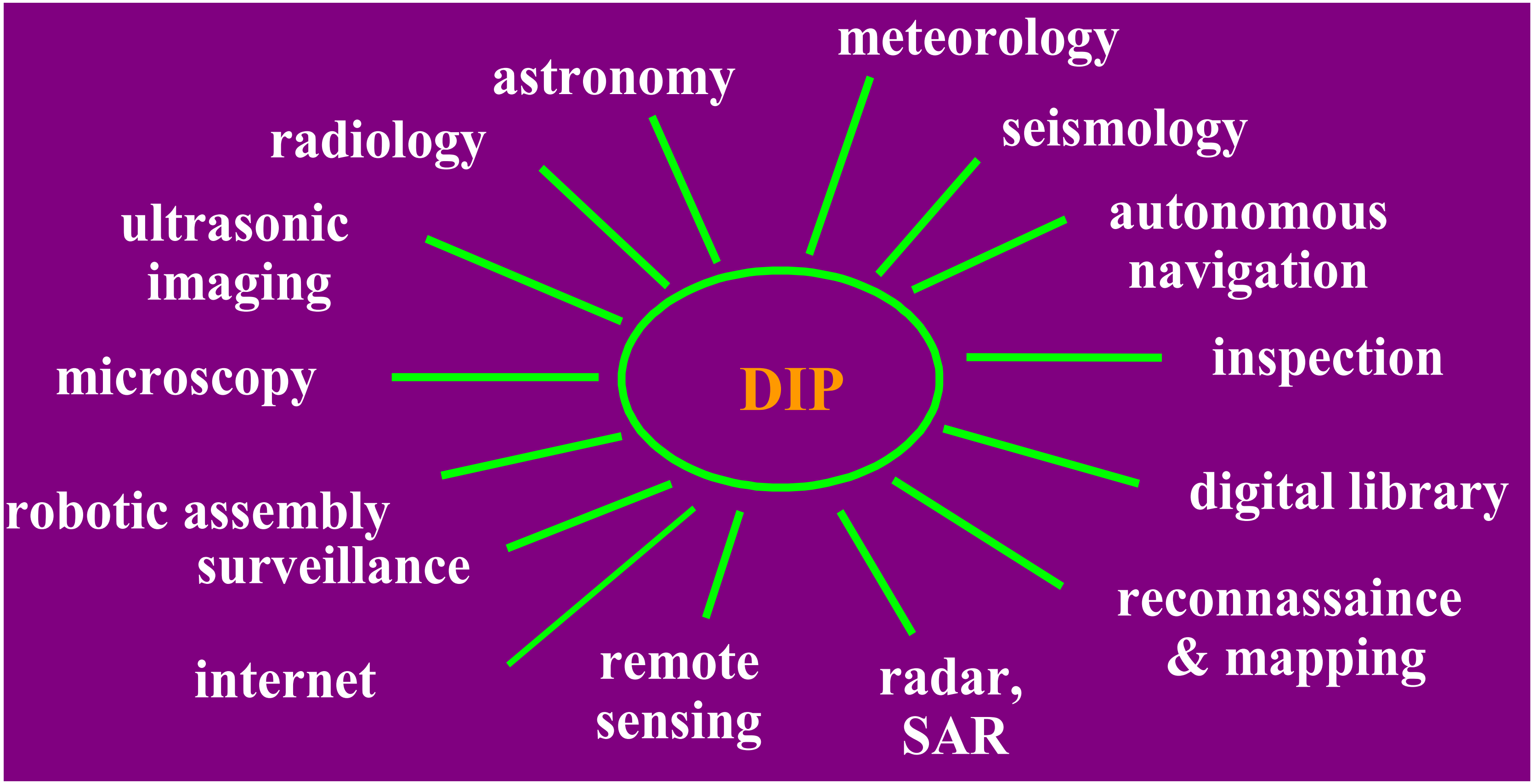


Stream of mass less particles travelling wavelike pattern @speed of light containing a certain amount of energy (photon)

Major uses

- Gamma-ray imaging: nuclear medicine and astronomical observations
- X-rays: medical diagnostics, industry, and astronomy, etc.
- Ultraviolet: lithography, industrial inspection, microscopy, lasers, biological imaging and astronomical observations
- Visible and infrared bands: light microscopy, astronomy, remote sensing, industry and law enforcement
- Microwave band: radar
- Radio band: medicine (such as MRI) and astronomy

Applications



From Prof. Alan C. Bovik

APPLICATIONS OF IMAGE PROCESSING

- **MEDICAL IMAGING**
  - CT SCAN, X-RAY IMAGING, ULTRASOUND SCANNING

- **MACHINE VISION**
  - INDUSTRIAL AUTOMATION & QUALITY ASSURANCE.

- **ASTRONOMY**
  - RESTORATION TECHNIQUES ON IMAGES RETURNED FROM MARS AND MOON.

APPLICATIONS OF IMAGE PROCESSING

- **PICTURE COMMUNICATION USING DATA COMPRESSION**

  - TRANSFORM CODING IN HDTV,
  - TELECONFERENCING
  - INTERACTIVE EDUCATION

- **REMOTE SENSING**

- NATURAL RESOURCE MAPPING LIKE FOREST, GROUND WATER, MINERALS ETC.
- POLLUTION PATTERN STUDY.
- NATURAL DISASTER PREDICTION / DAMAGE ASSESSMENT.
- APPLICATIONS USING GIS.

A visual example of the different filters available onboard Hubble is seen in the following figure.

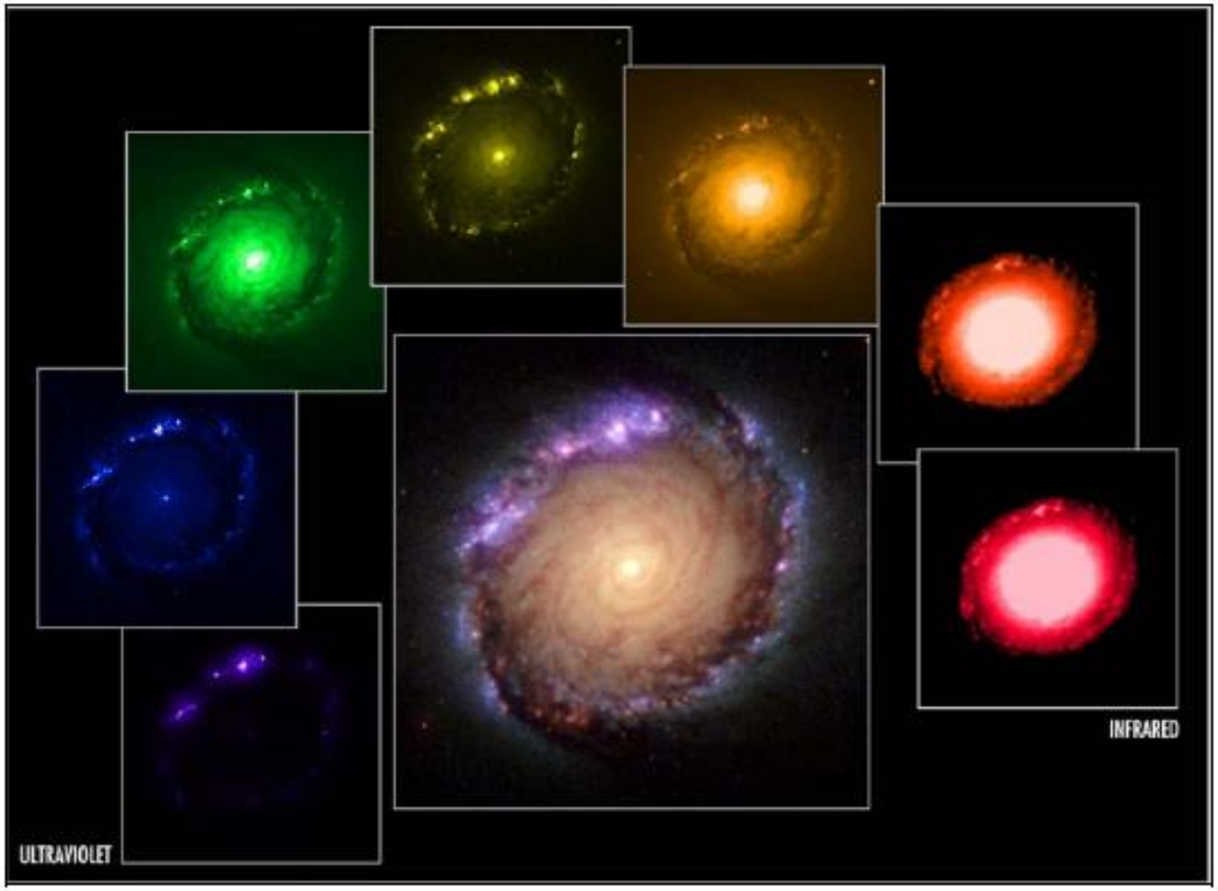


Figure 9: An example of an image constructed from 7 broad-band filters all the way from ultraviolet (left) to infrared (right).

Examples: Gama-Ray Imaging

Nuclear Medicine, Astronomical observations

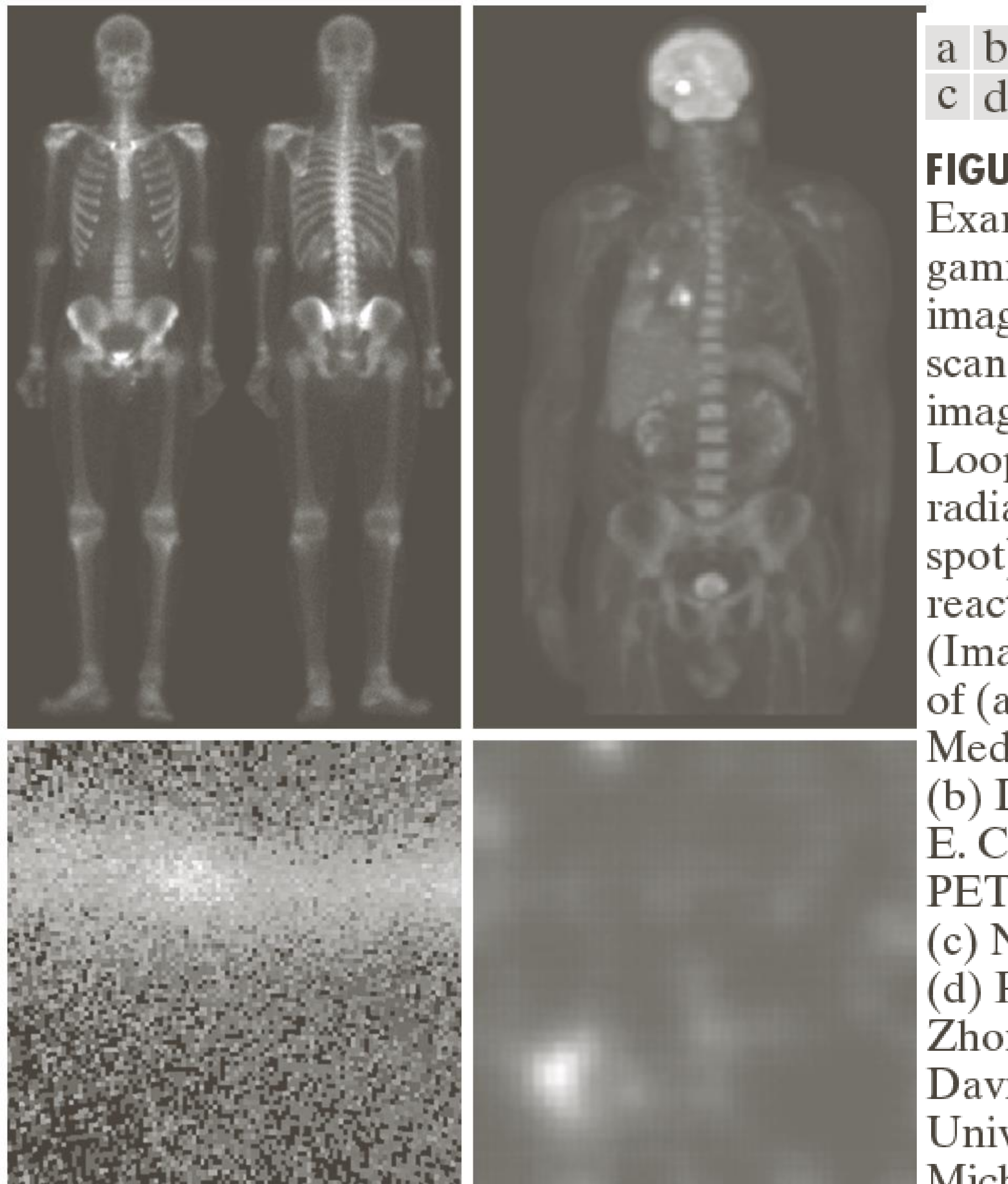
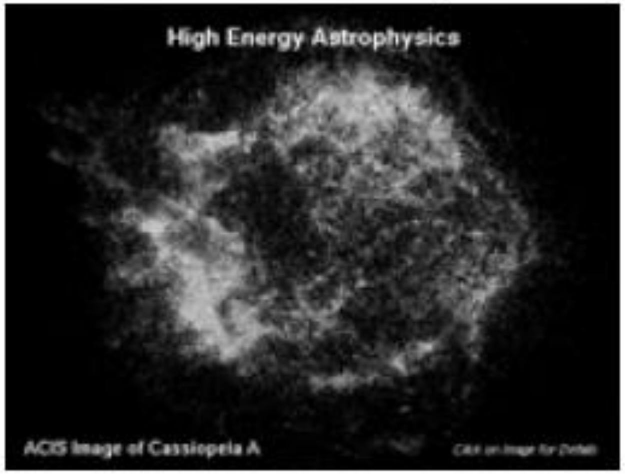


FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of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

X-ray

Astronomy



Security

Medical

X - Ray Images

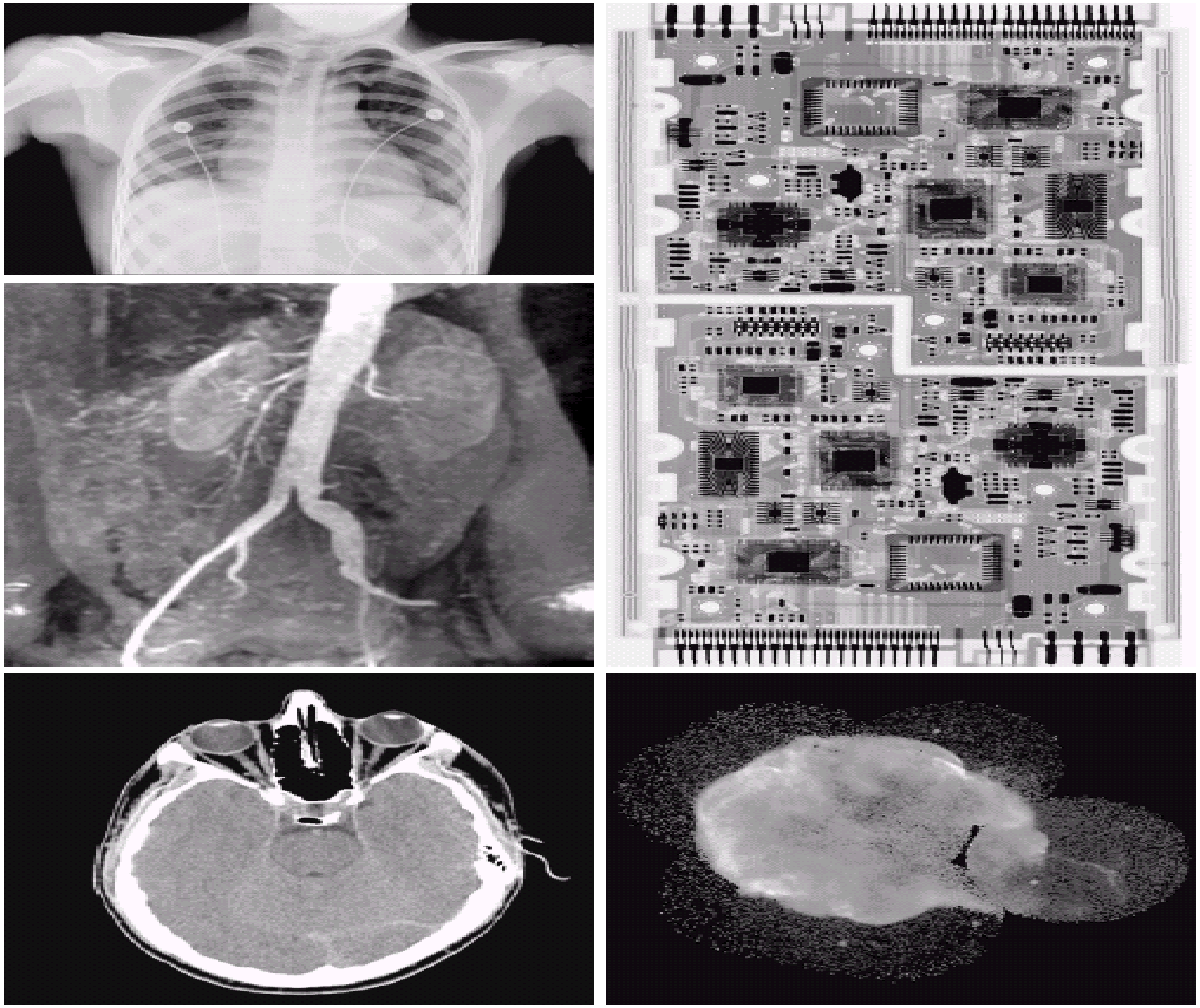
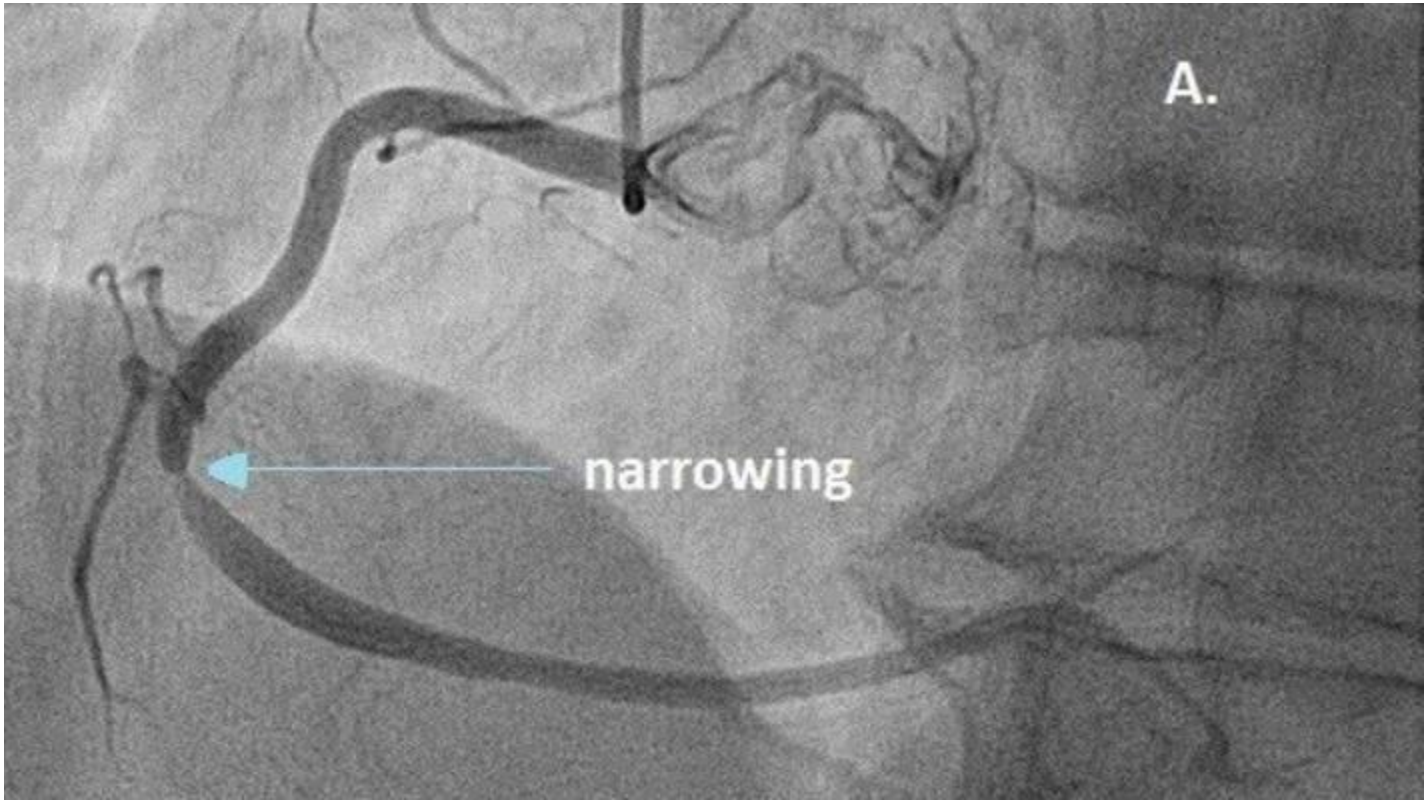
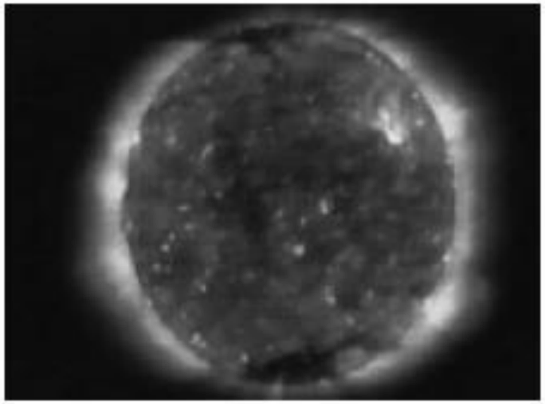


FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical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

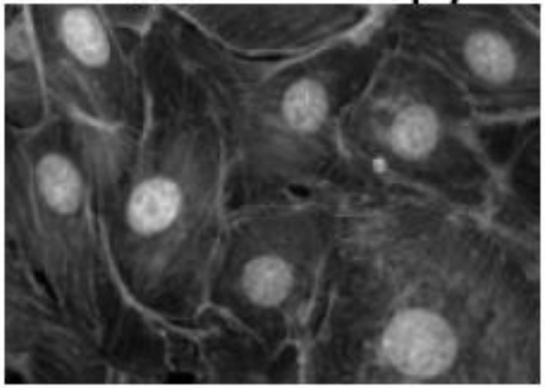

A.
narrowing

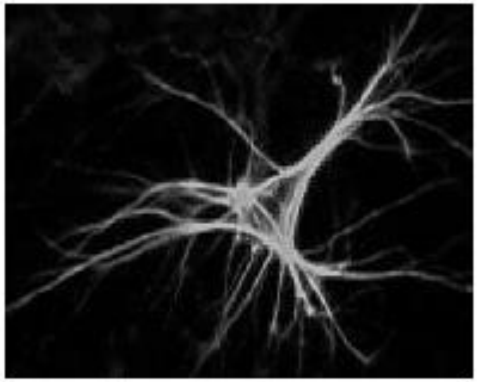
Ultraviolet

Astronomy



Microscopy





Fluorescence Microscopy: Endothelial Cells, Astrocyte

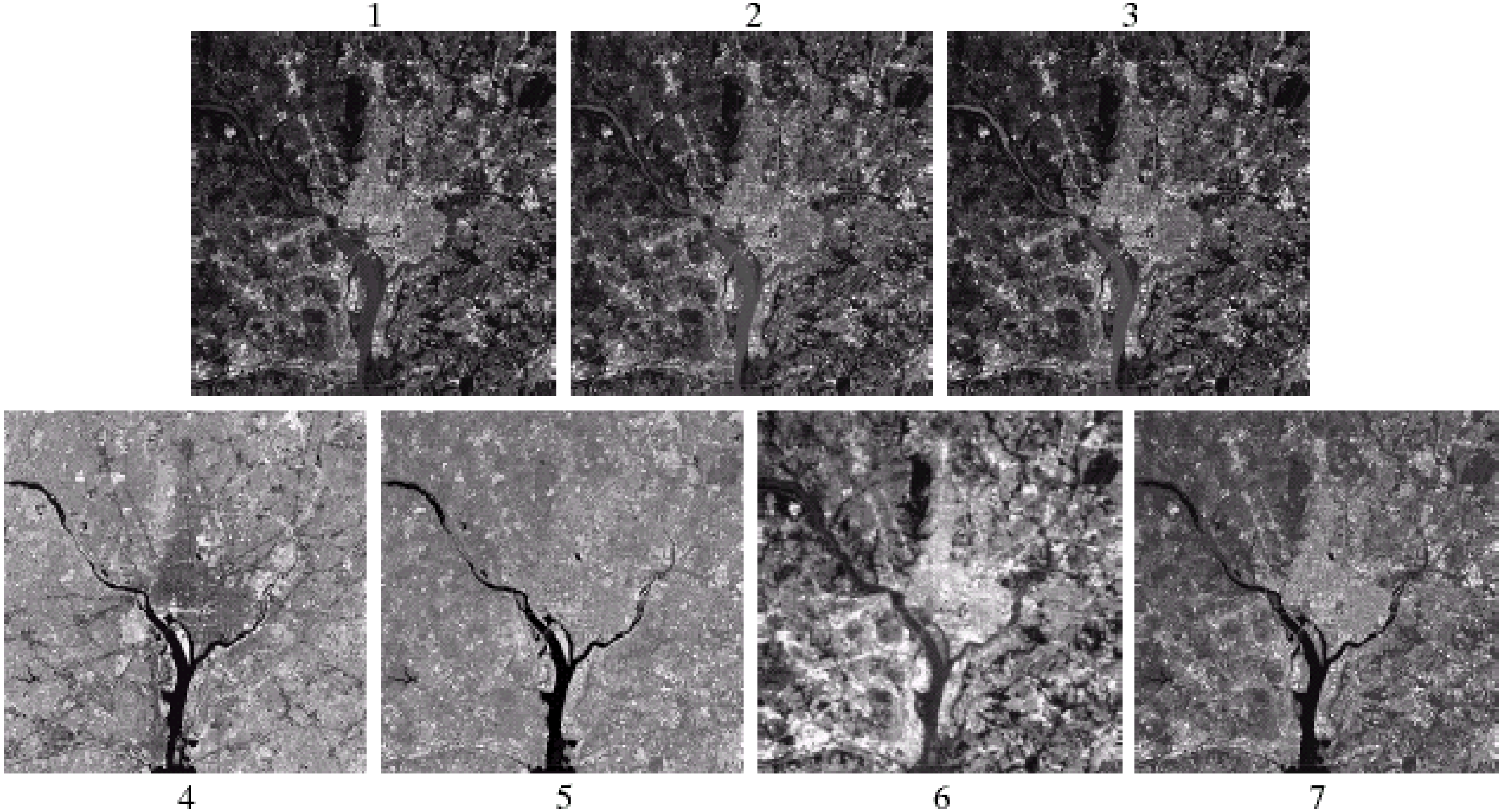
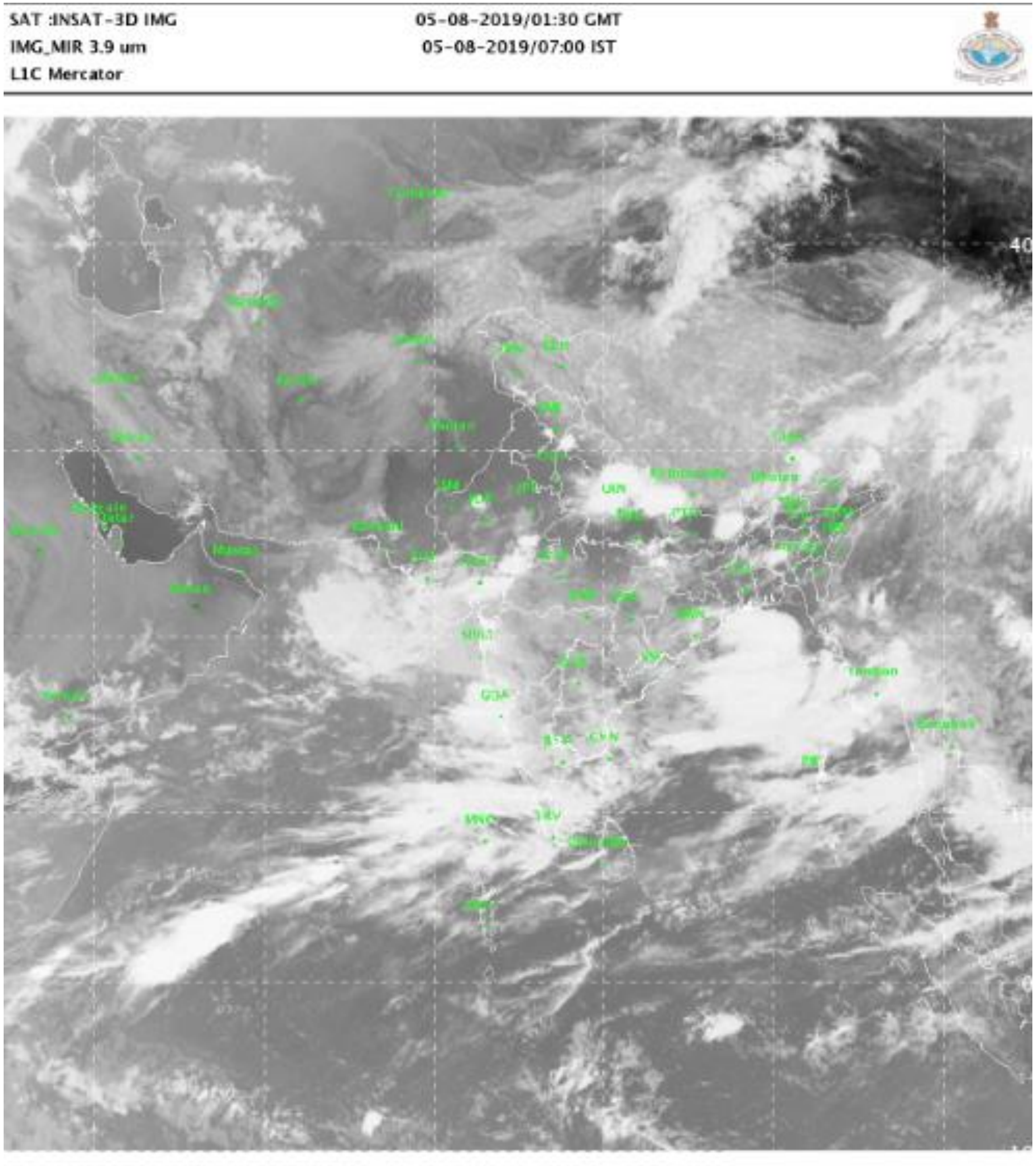


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Satellite images

Band	Name	λ (μm)	uses
1	Vis blue	0.45-0.52	Max water penetration
2	Vis green	0.52-0.60	Measuring planet vigour
3	Vis red	0.63-0.69	Vegetation
4	NIR	0.76-0.90	Biomas & shoreline mapping
5	Middle IR	1.55-1.75	Moisture content
6	Thermal IR	10.4-12.5	Soil moisture & thermal mapping
7	Middle IR	2.08-2.35	Mineral mapping


SAT :INSAT-3D IMG
IMG_MIR 3.9 um
L1C Mercator
05-08-2019/01:30 GMT
05-08-2019/07:00 IST

Satellite images

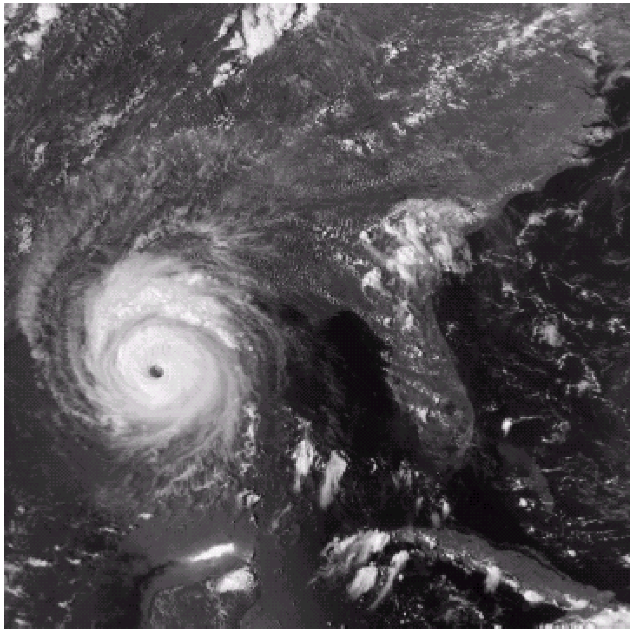
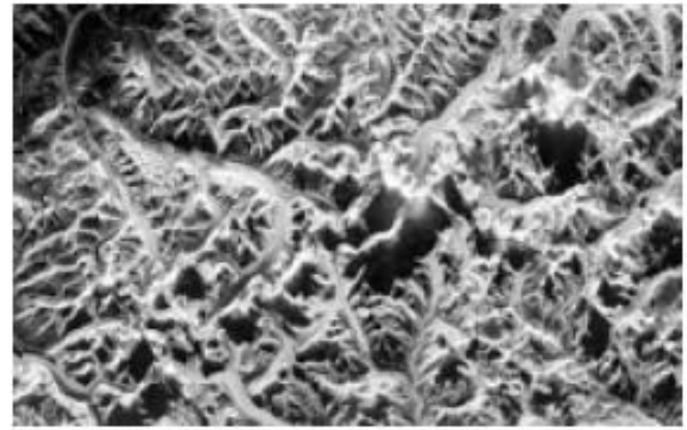


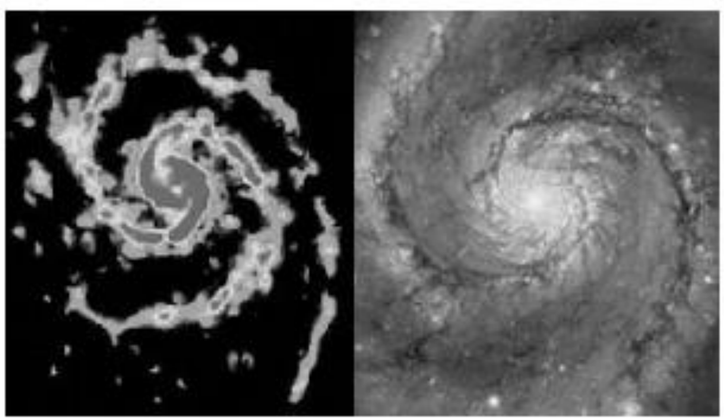
FIGURE 1.11 Multispectral image of Hurricane Andrew taken by NOAA GEOS (Geostationary Environmental Operational Satellite) sensors. (Courtesy of NOAA.)

Microwave

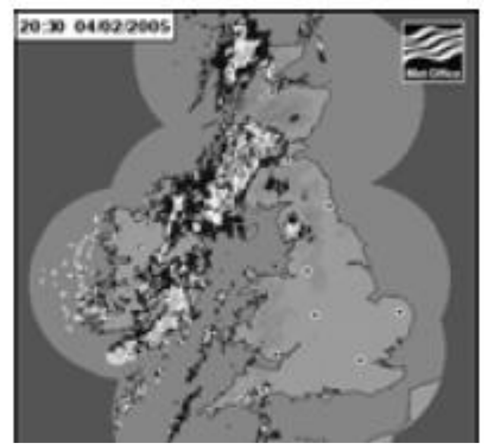
Spaceborne Radar



Astronomy



Weather Radar



Industrial Applications

a b
c d
e f

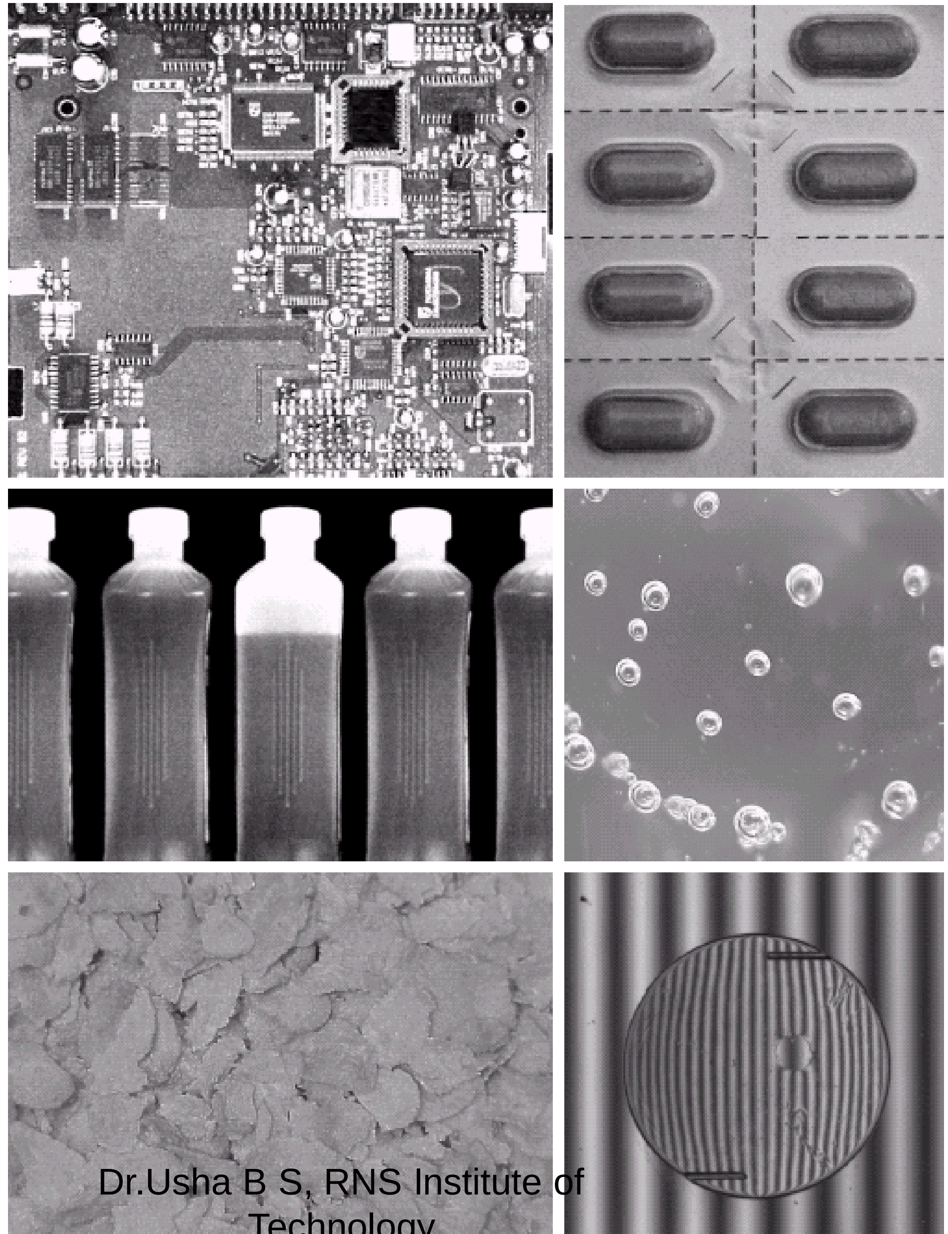


FIGURE 1.14 Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Bubbles in clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)

Law Enforcement Applications

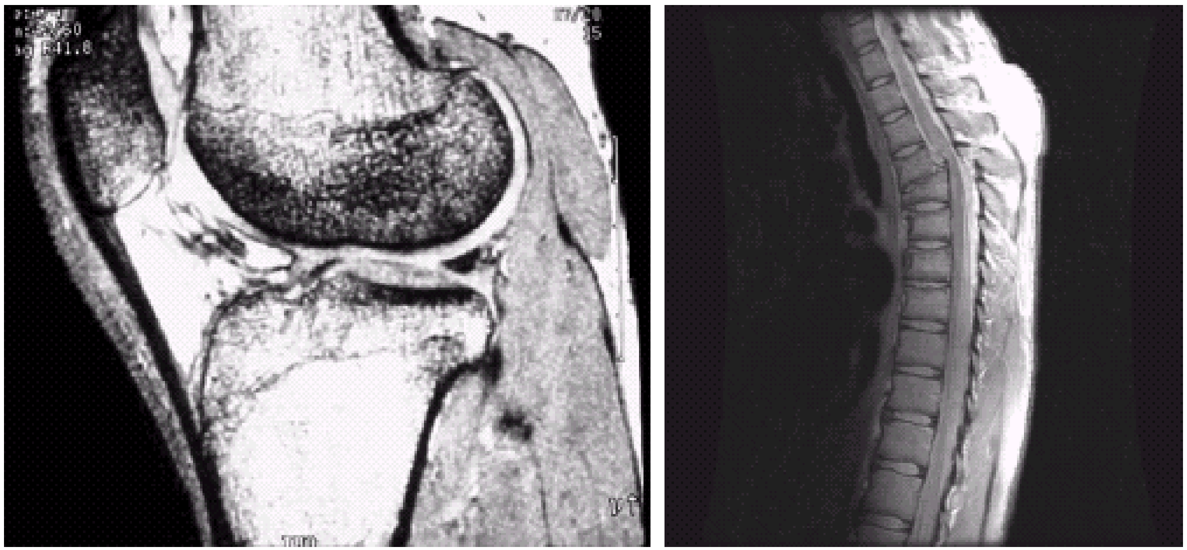
Results of automated reading of the plate content by the system

The area in which the imaging system detected the plate

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.)

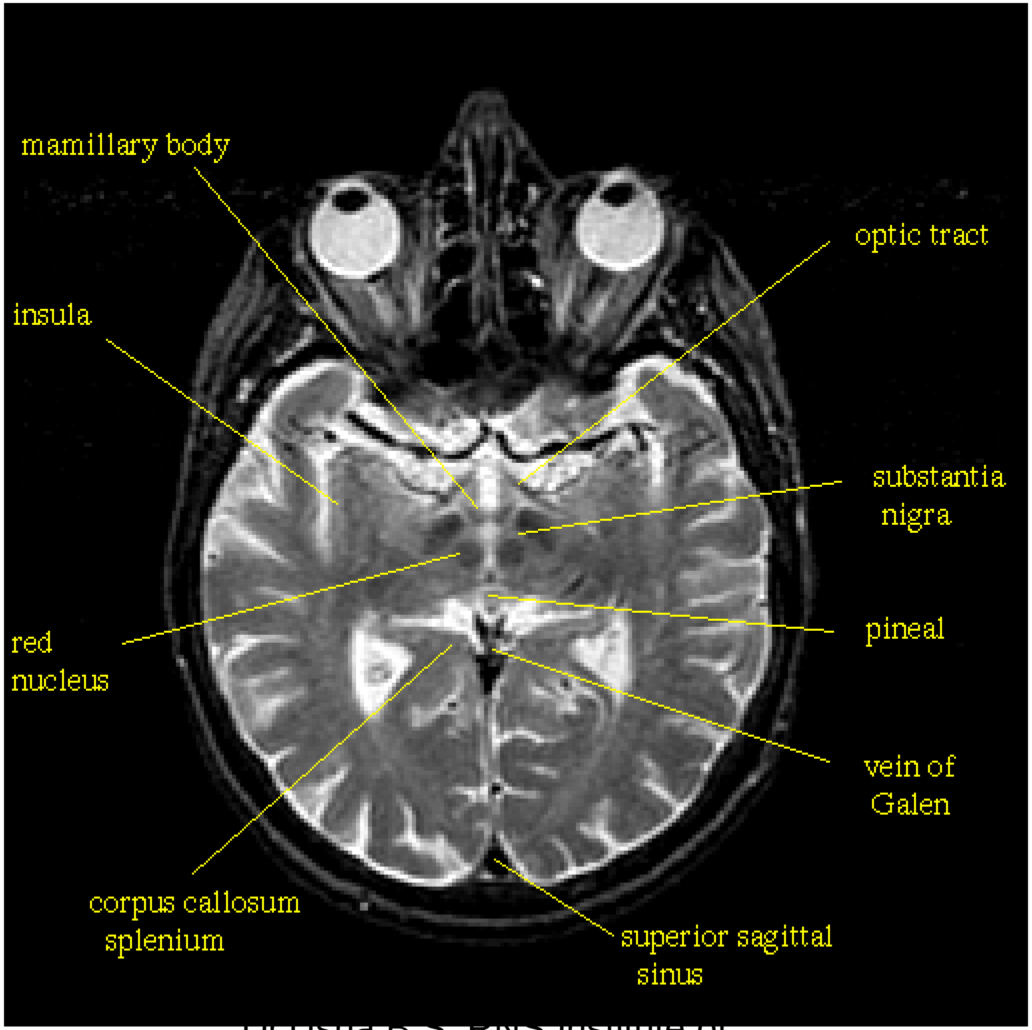
MRI Images



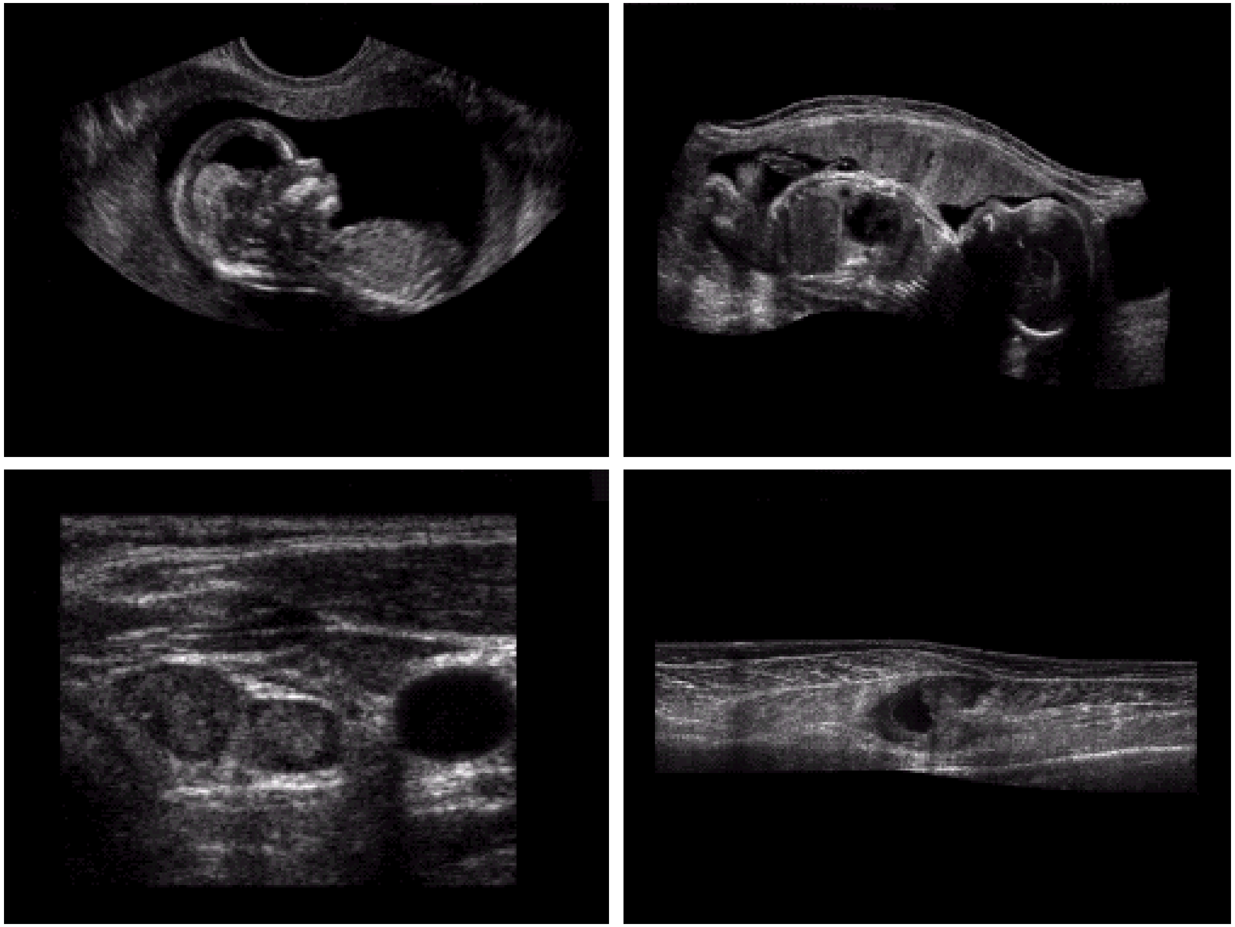
a b

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.)

Medical Images:
MRI of normal brain



Ultrasound Images

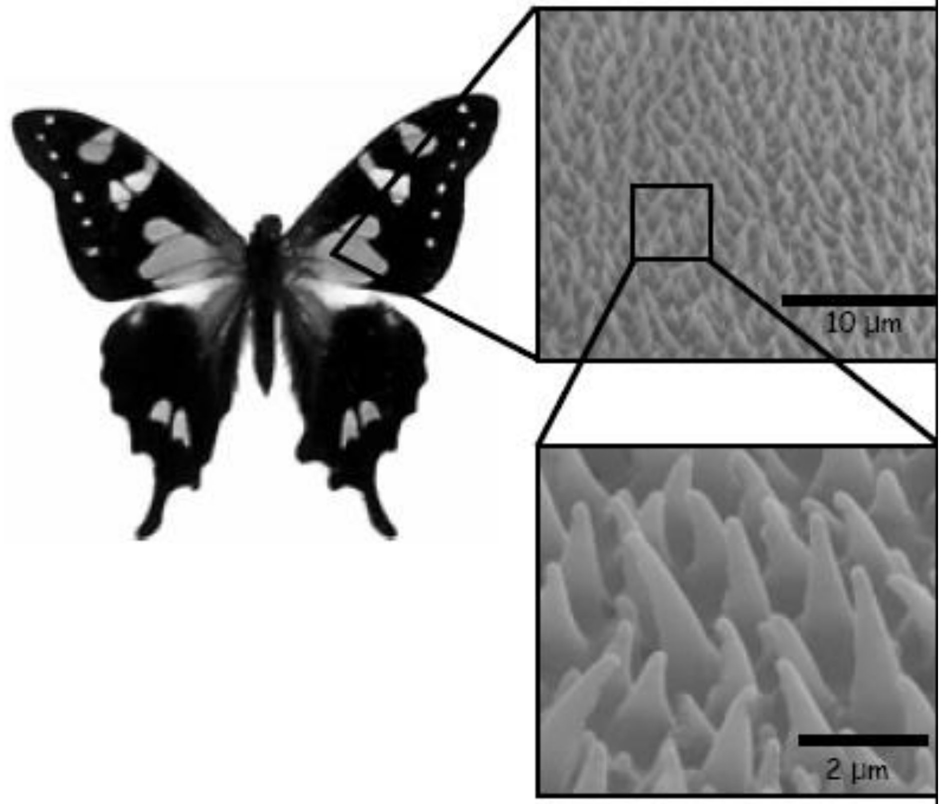


a	b
c	d

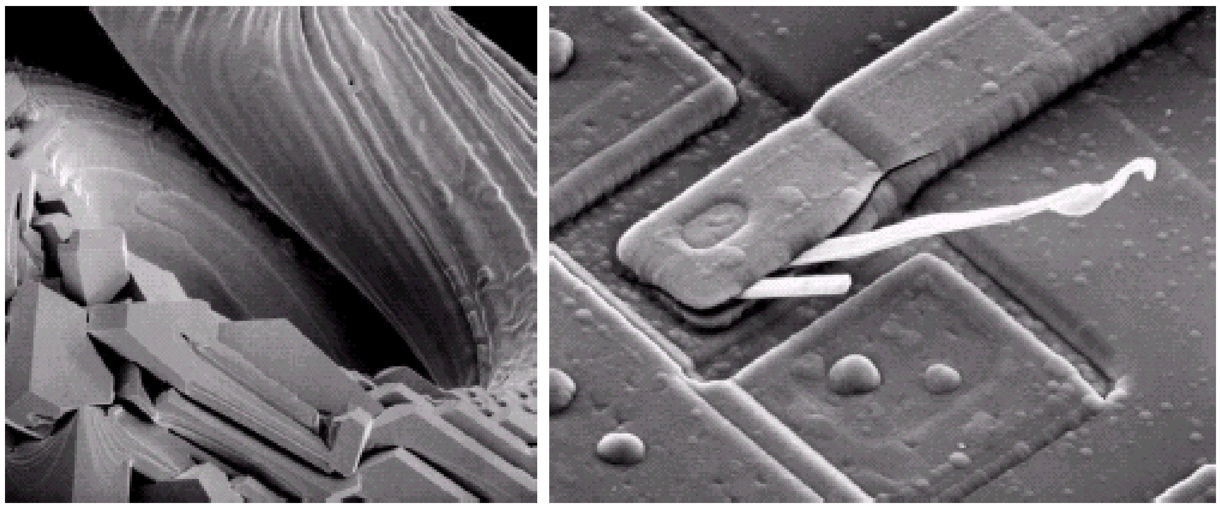
FIGURE 1.20 Examples of ultrasound imaging. (a) Baby. (2) Another view of baby. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

Electrons

- Electron microscopy
- Scanning Electron Microscope (SEM)
- Up to 10,000 X Magnification



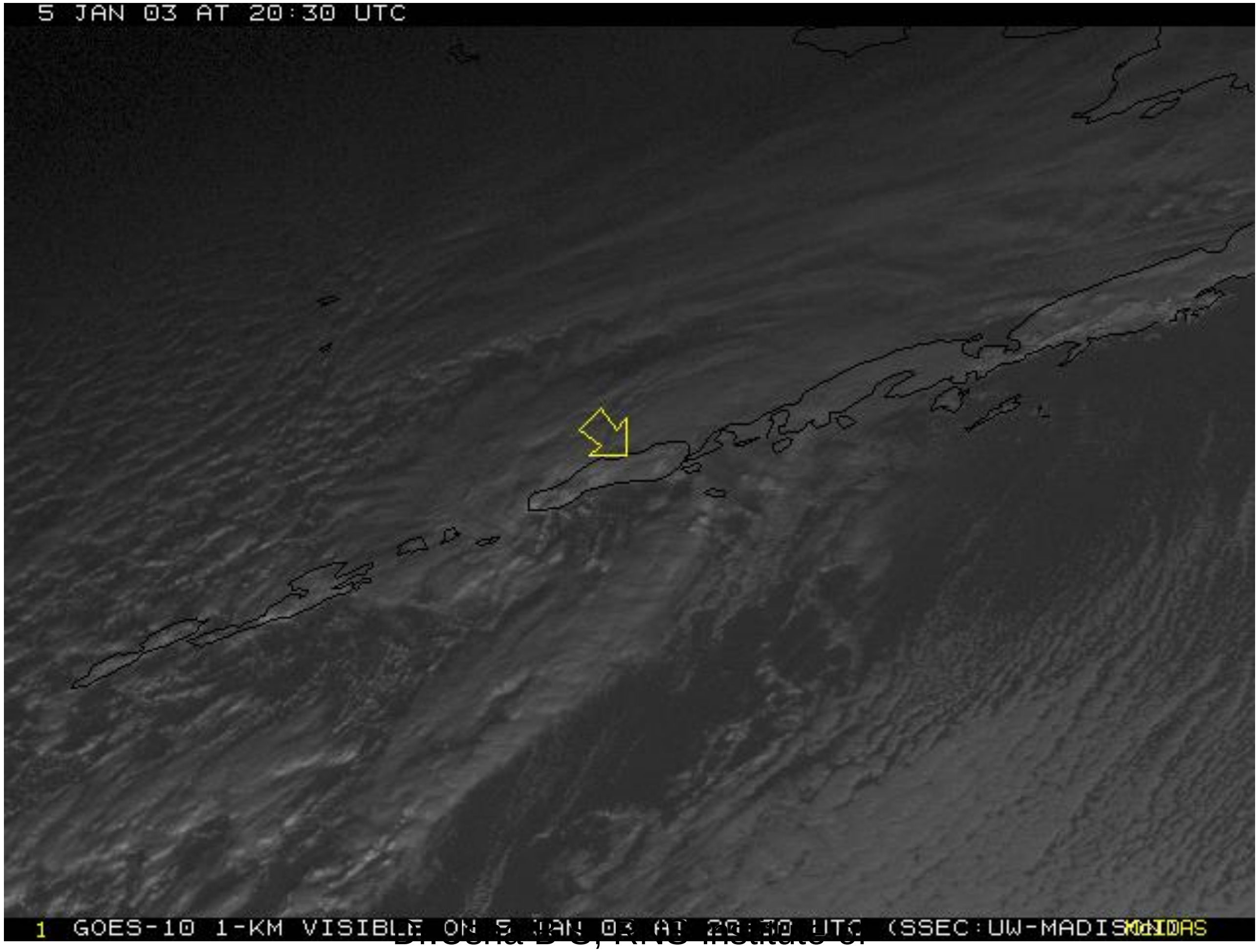
Images from Electron Microscope



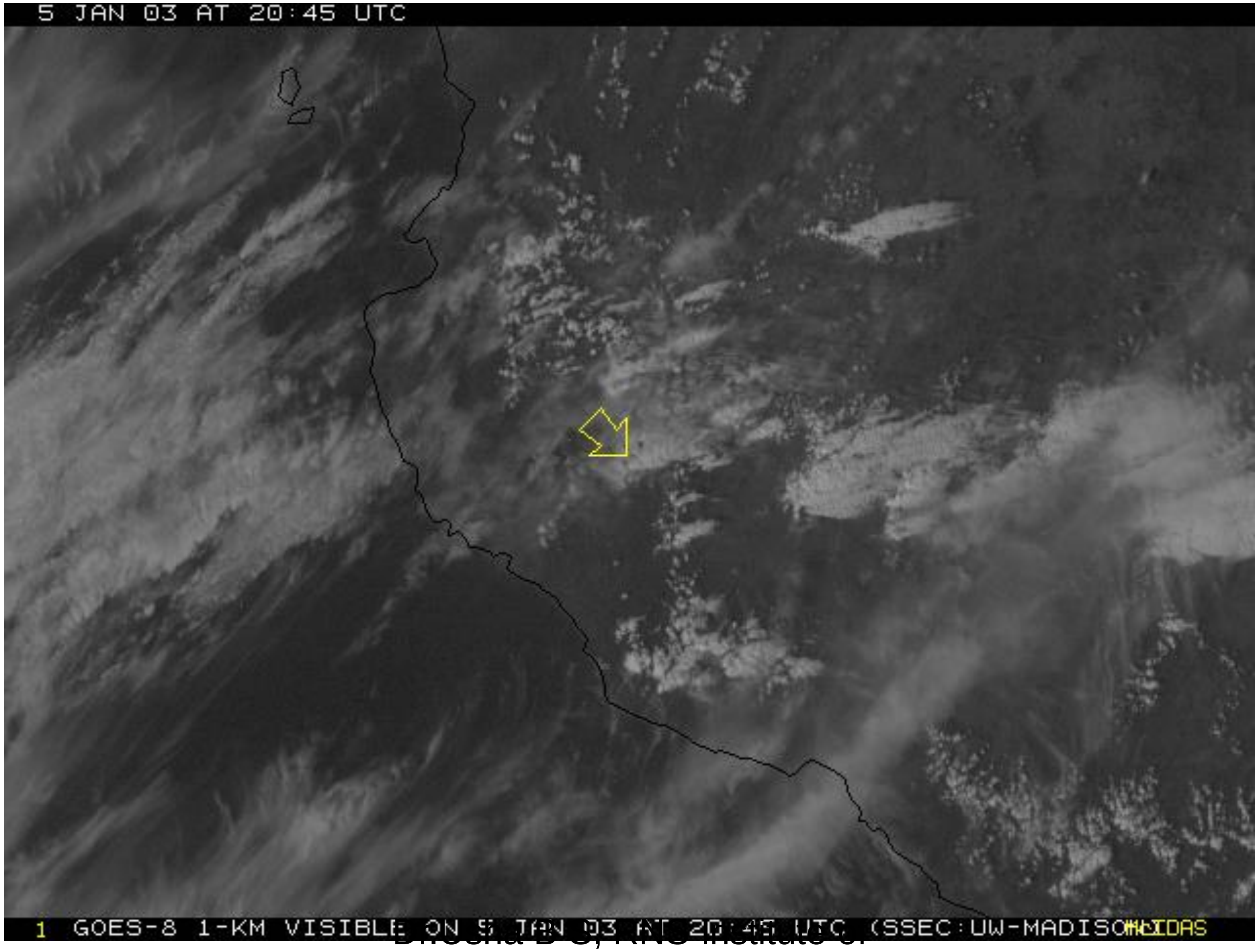
a b

FIGURE 1.21 (a) 250× SEM image of a tungsten filament following thermal failure. (b) 2500× SEM image of damaged integrated circuit. The white fibers are oxides resulting from thermal destruction. (Figure (a) courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene; (b) courtesy of Dr. J. M. Hudak, McMaster University, Hamilton, Ontario, Canada.)

Satellite image
Volcano Kamchatka Peninsula, Russia



Satellite image
Volcano in Alaska

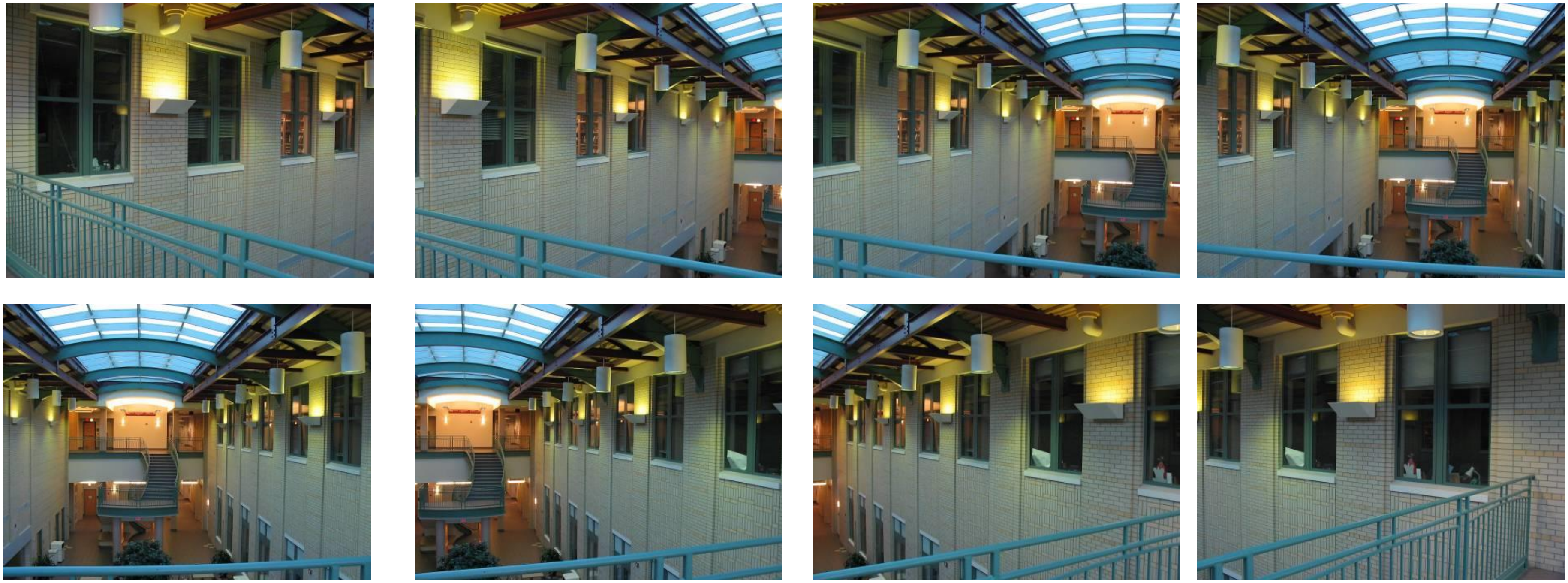


Astronomical images

Spiral Galaxy NGC 1232 - VLT UT 1 + FORS1

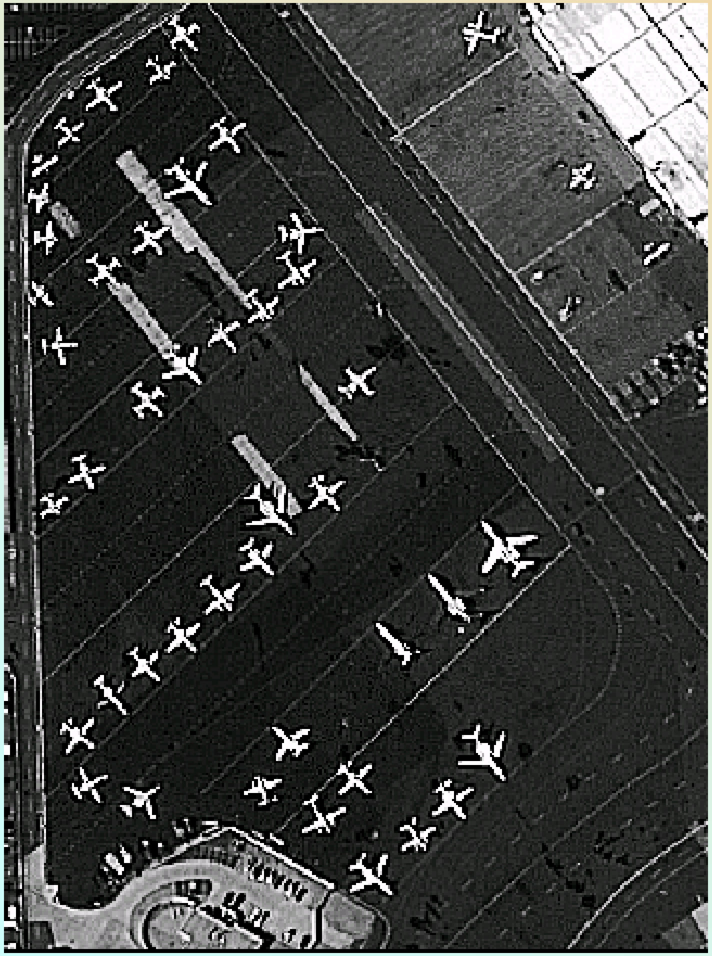
ESO PR Photo 37d/98 (23 September 1998) ©European Southern Observatory

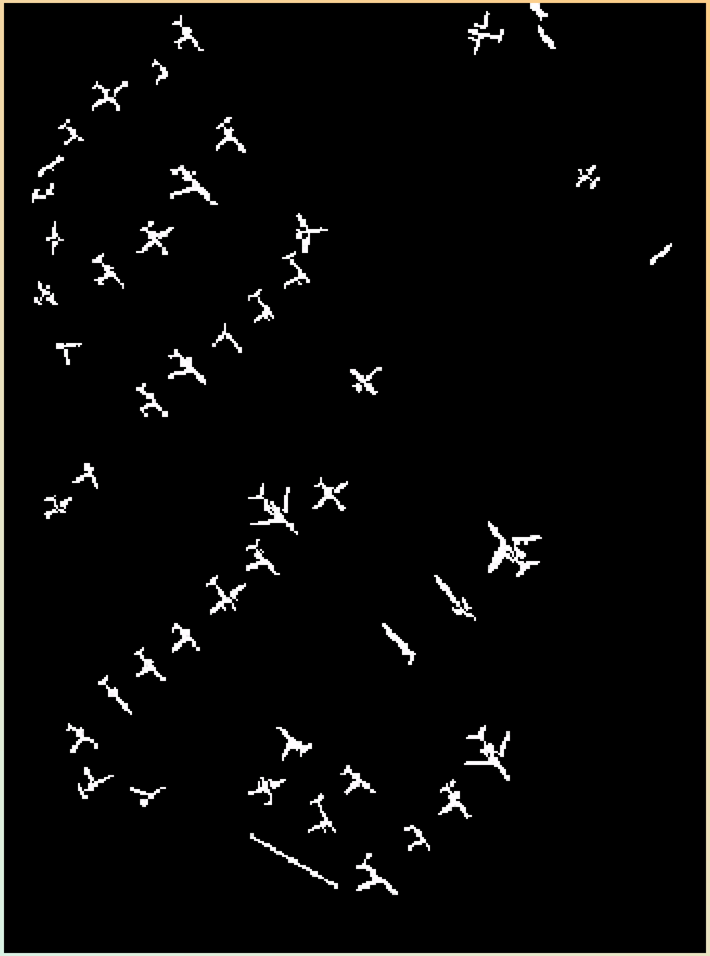
Mosaics: stitching images together

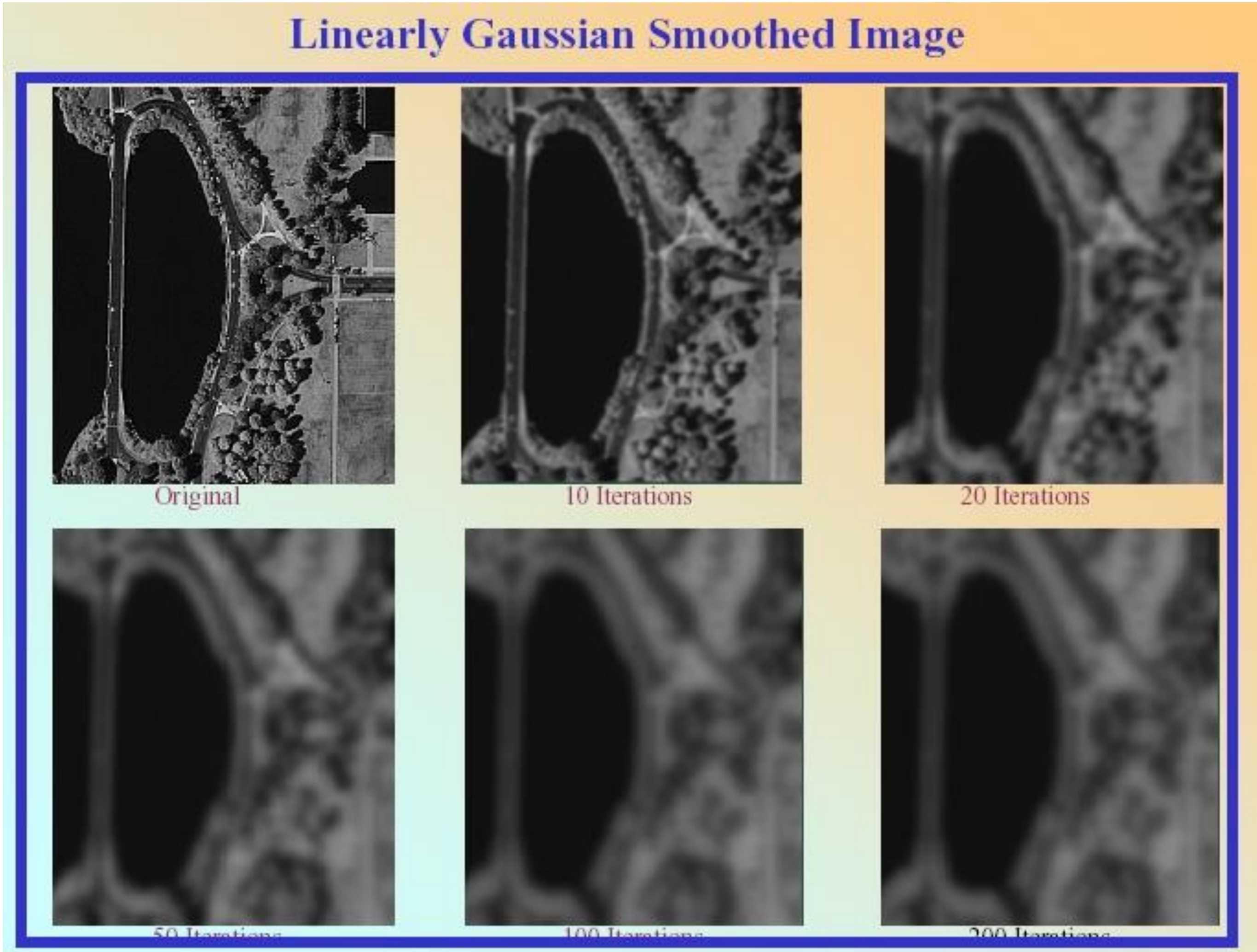


virtual wide-angle camera

Automatic Target Recognition(Aircraft)






Linearly Gaussian Smoothed Image
Original
10 Iterations
20 Iterations

Road Detection using Path Following Algorithm

Image Compositing Example

Needs a better shirt.

This shirt demands a monogram.

He needs some more color.

Nice. Now for the way he'd wear his hair if he had any.

Image Compositing Example

He can't stay in the office like this.

In the studio!

What is DIP? (cont…)

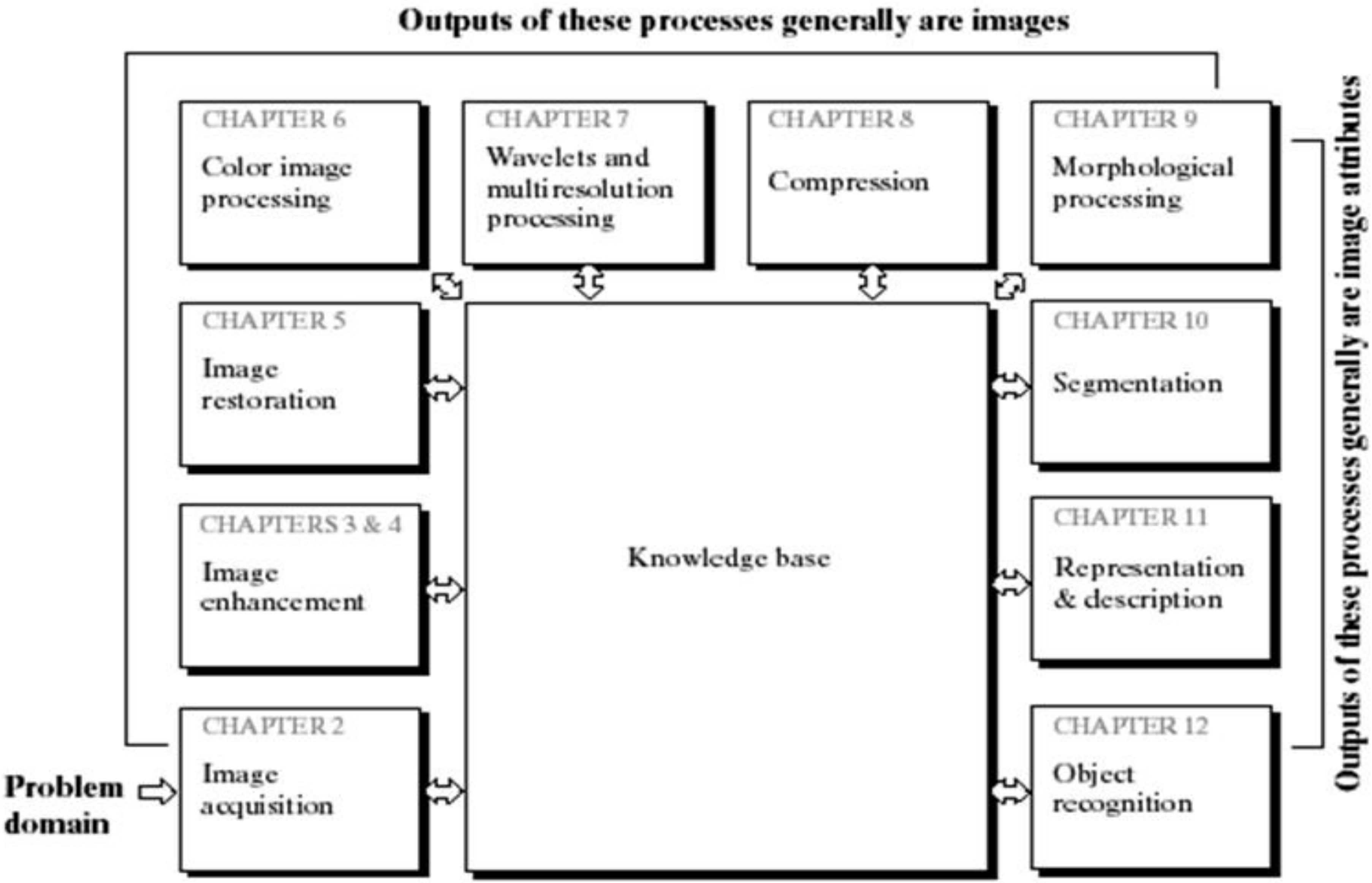
•The continuum from image processing to computer vision can be broken up into low-, mid- and high-level processes

Low Level Process	Mid Level Process	High Level Process
Input: Image **Output: Image** **Examples: Noise removal, image sharpening**	**Input: Image** **Output: Attributes** **Examples: Object recognition, segmentation**	**Input: Attributes** **Output: Understanding** **Examples: Scene understanding, autonomous navigation**

Image Processing

- Enhancement, Restoration, Reconstruction
- Analysis, Detection, Recognition, Understanding
- Segmentation, Visualization
- Coding/Compression

Fundamental Steps in Image Processing



The operations seen above are :

- Image acquisition: involves preprocessing , such as scaling an image.
- Image Enhancement : Manipulating an image so that result is more suitable than original for a specific application. It is used to bring out the detail that is obscured, or simply to highlight certain features of interest in an image.
- Image Restoration: deals with improving the appearance of an image. Restoration techniques are objective and is based on mathematical or probabilistic models of image degradation.
- Color image processing : has become quite important due to increased use of colored image over internet .

Image Enhancement

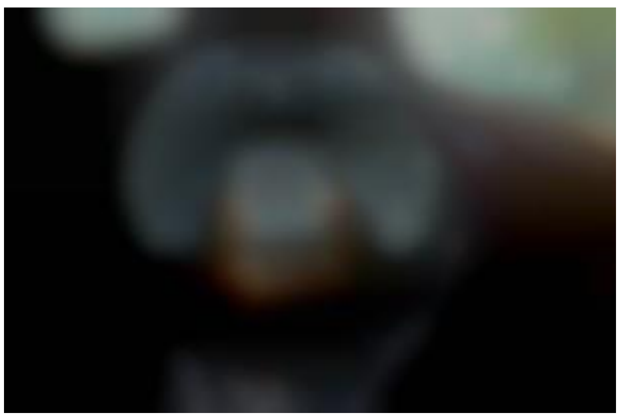
Image Enhancement

Equalization : Image Examples

Original, Equalized (64)
Equalized (256)

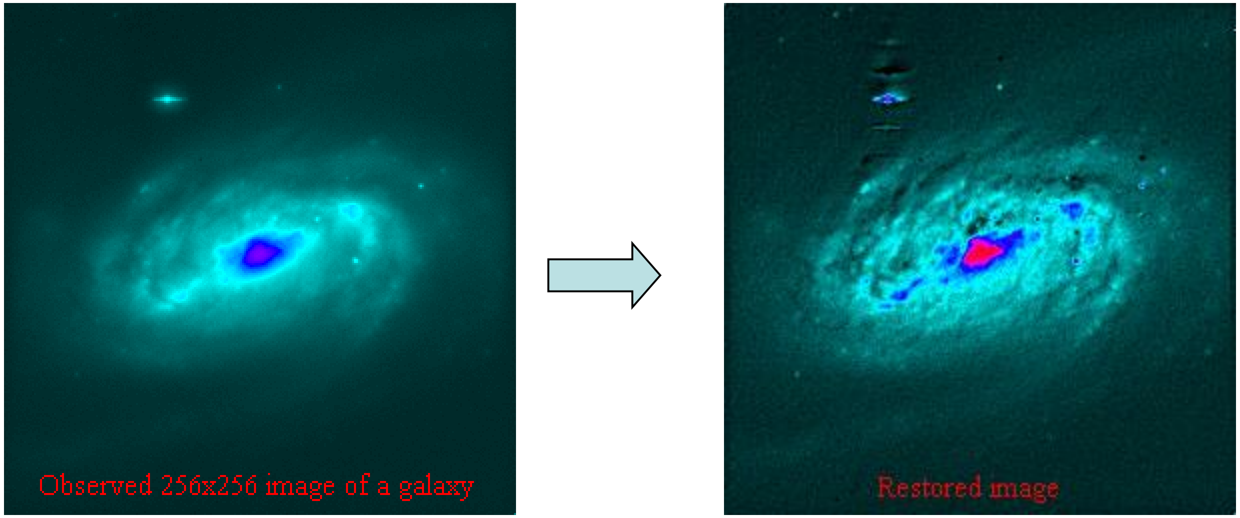
Image Restoration

Distorted Image

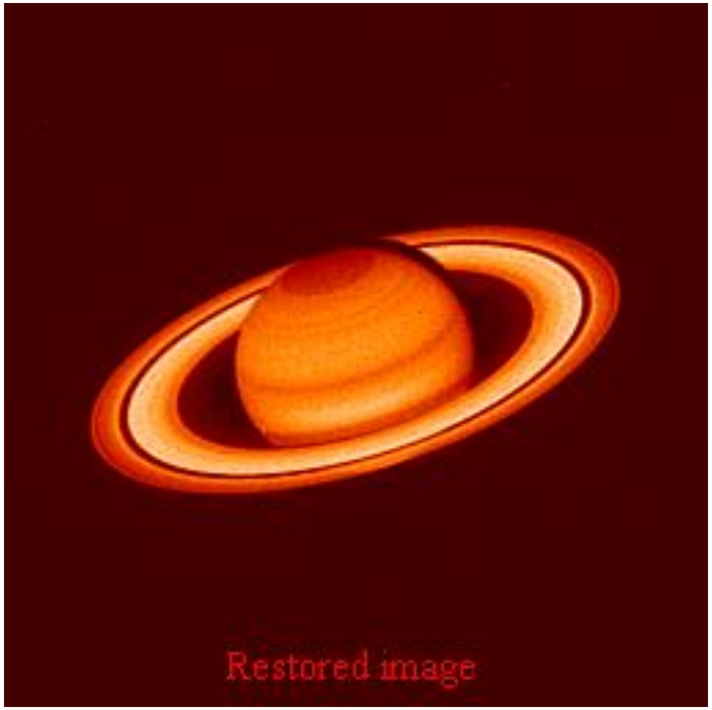


Restored Image

Restoration of HST Images



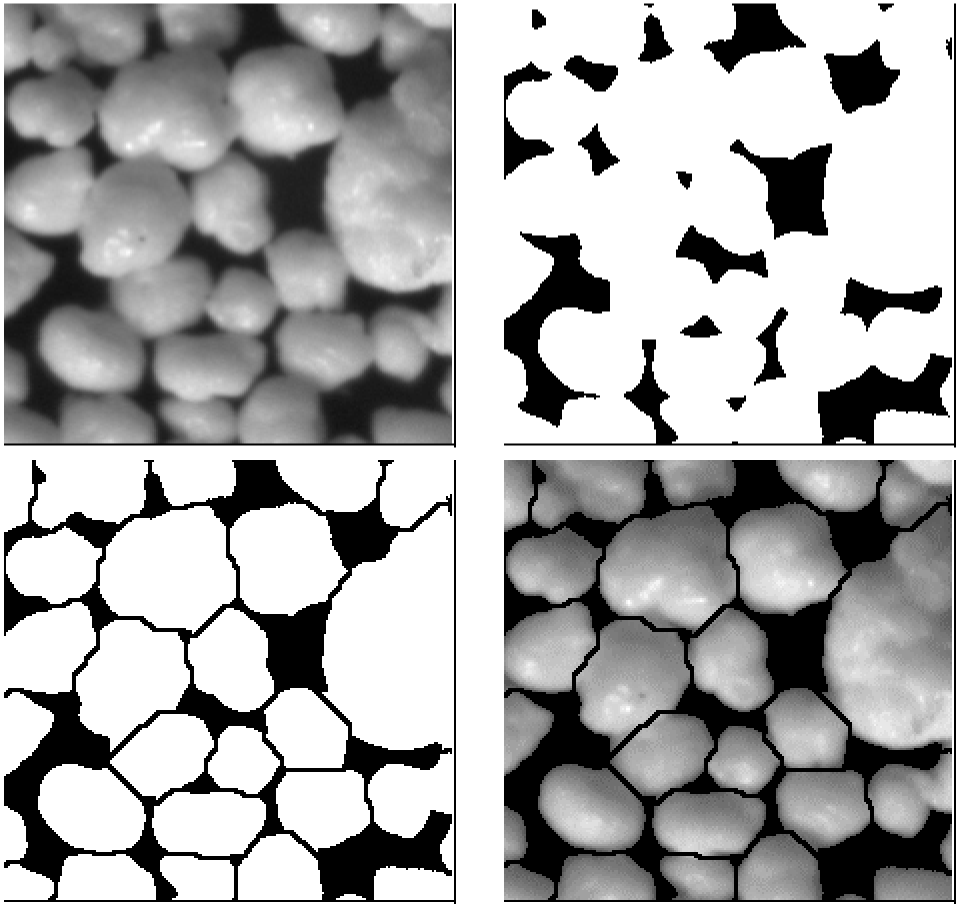
Another Example



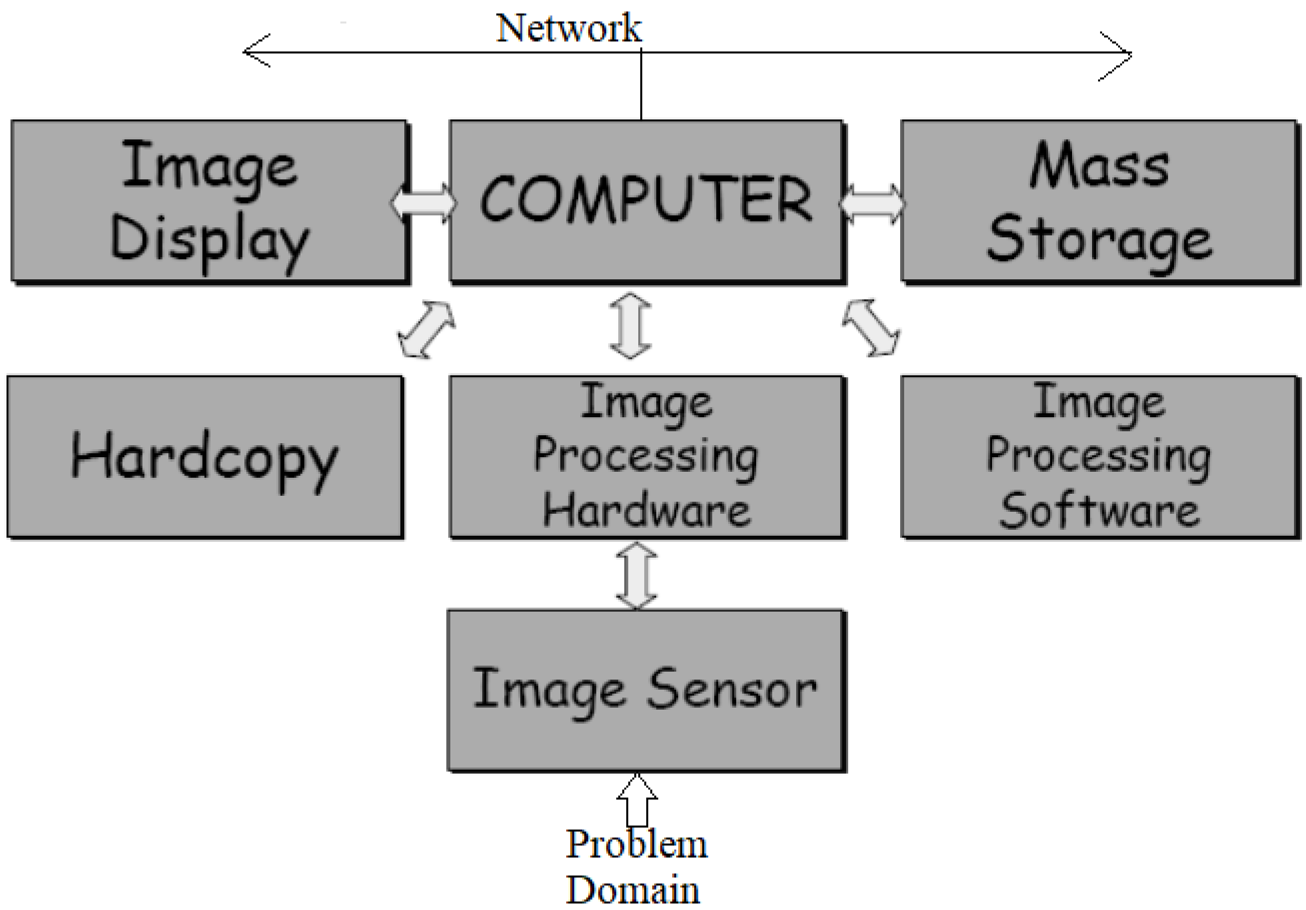
Restoration Example

- Wavelets : are the foundation of representing images in various degrees of resolution .
- Compression: deals with technique for reducing the storage required to save an image and bandwidth to transmit an image.
- Morphological processing: deals with tools for extracting image components that are useful in the representation and description of the shape.
- Segmentation :partitioning an image into its constituent parts or objects.
- Representation and description : is usually raw pixel data for boundary or the internal points of a region. Description extracts the attributes of interest.
- Recognition : assigns labels to the objects based on its descriptors.

Segmentation:Thresholding and Filtering



Components of Image Processing System



Basic components of a general-purpose system used for digital image processing

- **Image sensors** :
  - Physical device that is sensitive to energy radiated by the object that we wish to image is required.
- **Specialized Image Processing Hardware:**
  - It consists of Digitizer which is required to convert the output of the physical sensing device into digital form.
  - Hardware that performs other primitive operations such as an arithmetic logic unit (ALU), which performs arithmetic and logical operations on entire image.

- **Computer** – In an image processing system it is a general-purpose computer.
- **Software** – It consists of specialized modules that does specific tasks (eg. Matlab)
- **Mass storage : is a must for IP as large number of images with high resolutions need large space for storage.**
  - For **short-time storage**, we can use computer memory.
  - Another method is to use a specialized board called frame buffer, that store one or more images and can be accessed rapidly.
- Ex: An image of 1024 X 1024 size, storing the intensity of each pixel in 8 bits, requires one megabyte of storage.

- **Image Displays – portals to view the images at any stage such as TV , monitors … etc**
- **Hardcopy** – These devices include laser printers, film cameras, inkjet units, etc. for physical representation of images.
- **Networking : to transmit and received images.**

Good images

- For human visual
  - The visual evaluation of image quality is a highly subjective process.
  - It is hard to standardize the definition of a good image.
- For machine perception
  - The evaluation task is easier.
  - A good image is one which gives the best machine recognition results.
- A certain amount of trial and error usually is required before a particular image enhancement approach is selected.

Elements of Visual Perception

- Basic understanding of visual perception
- Formation of image and perception by humans
- Physical limitation of human vision
- Limitation

Structure of Human Eye

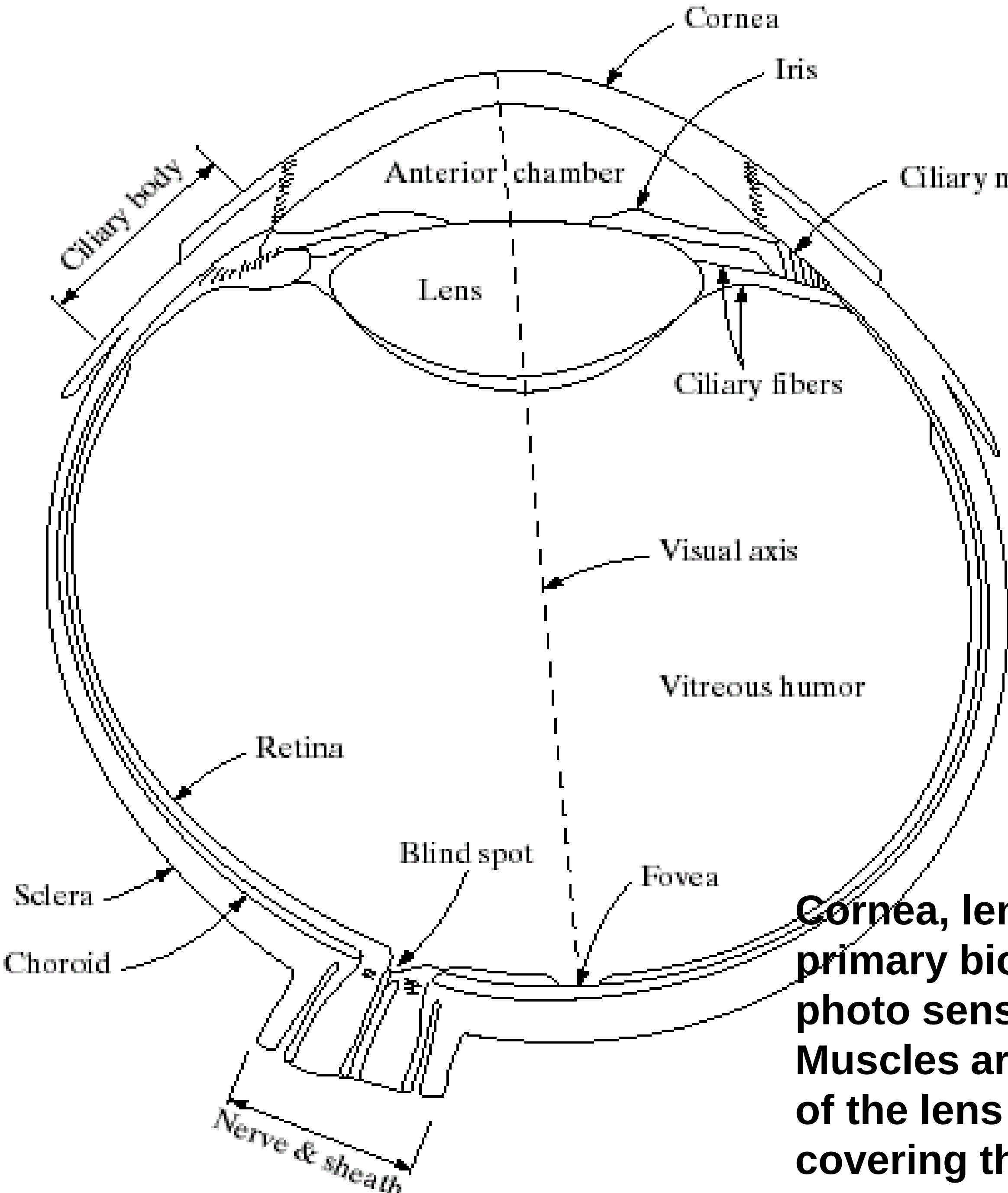


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Cornea, lens and retina form the primary biological components of a photo sensor.
Muscles are used to alter the thickness of the lens and the diameter of the hole covering the lens, called the iris (dia 2 to 8 mm.).

Features of human eye

- Nearly spherical with av. Dia of 20 mm.

Three membranes enclose the eye:

1 The cornea and sclera outer cover

2 The choroids

3 The retina

- Cornea is tough and transparent layer over pupil.
- Sclera is opaque membrane enclosing the remaining part of the eye.
- The choroid is divided into : ciliary body & iris diaphragm

Features of human eye

- The central opening of the iris (the pupil) varies in diameter to control the incident intensity of light.
- The lens is made up of concentric layers of fibrous cells and is suspended by fibers that attach to ciliary body. Lens is made up of 60-70% water, 6% fat and proteins
- The innermost layer of the eye is retina. When focused, the light from an object is imaged onto retina.

Cones and Rods

- There are two types of light receptor cells:
  1. cones(color sensitive) 6-7 million which are concentrated in the region called fovea. Each cone has its own nerve end. Cone vision is called photopic vision

  2. Rods(light perception) 75-150 million distributed over retinal surface. Rod vision is called scotopic vision.
- Blind spot is the region where rods and cones are absent.

Cones and Rods

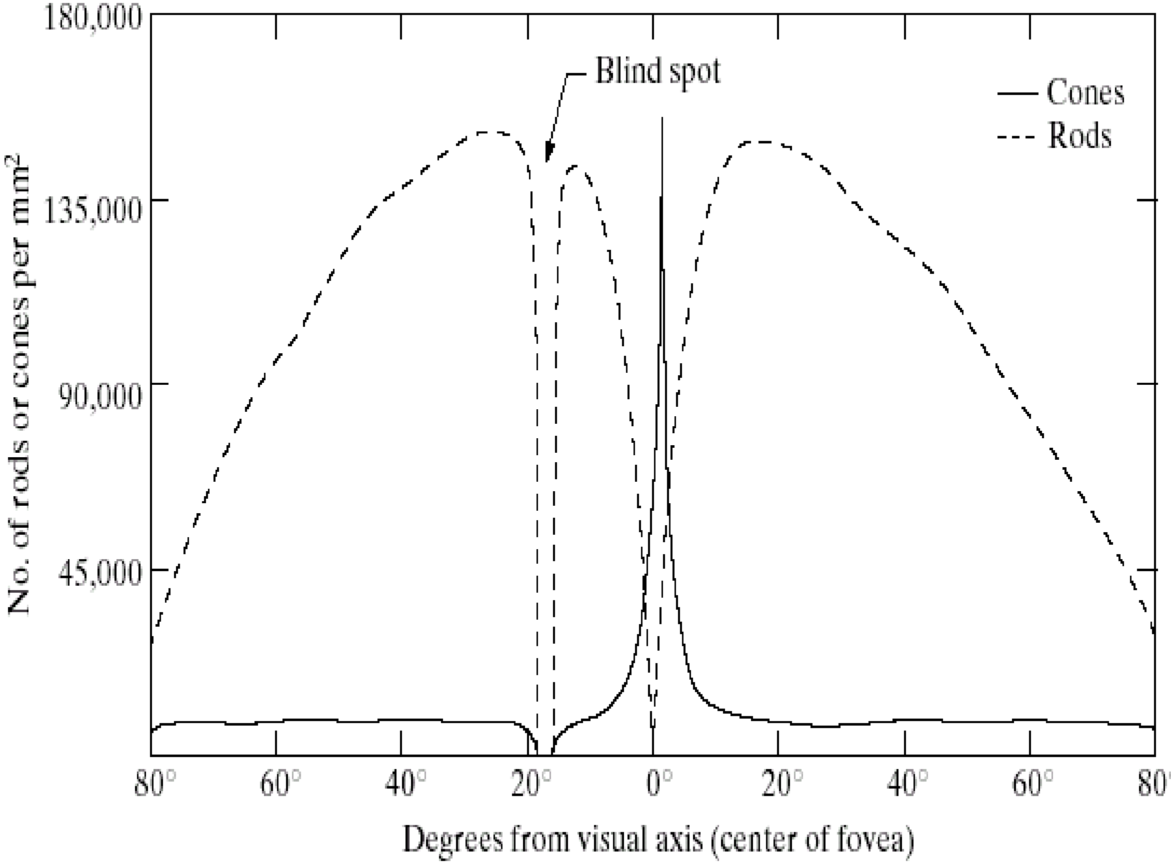
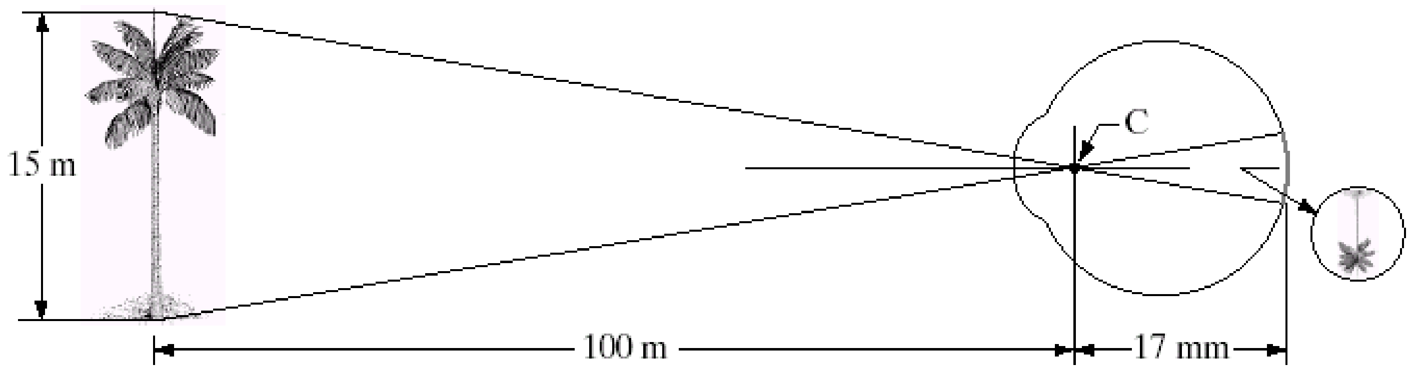


FIGURE 2.2
Distribution of rods and cones in the retina.

Foveated vision: non-uniform resolution of the visual field, highest at the point of fixation and decreasing rapidly

Image formation in the eye

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



15/100=h/17
H=2.55mm

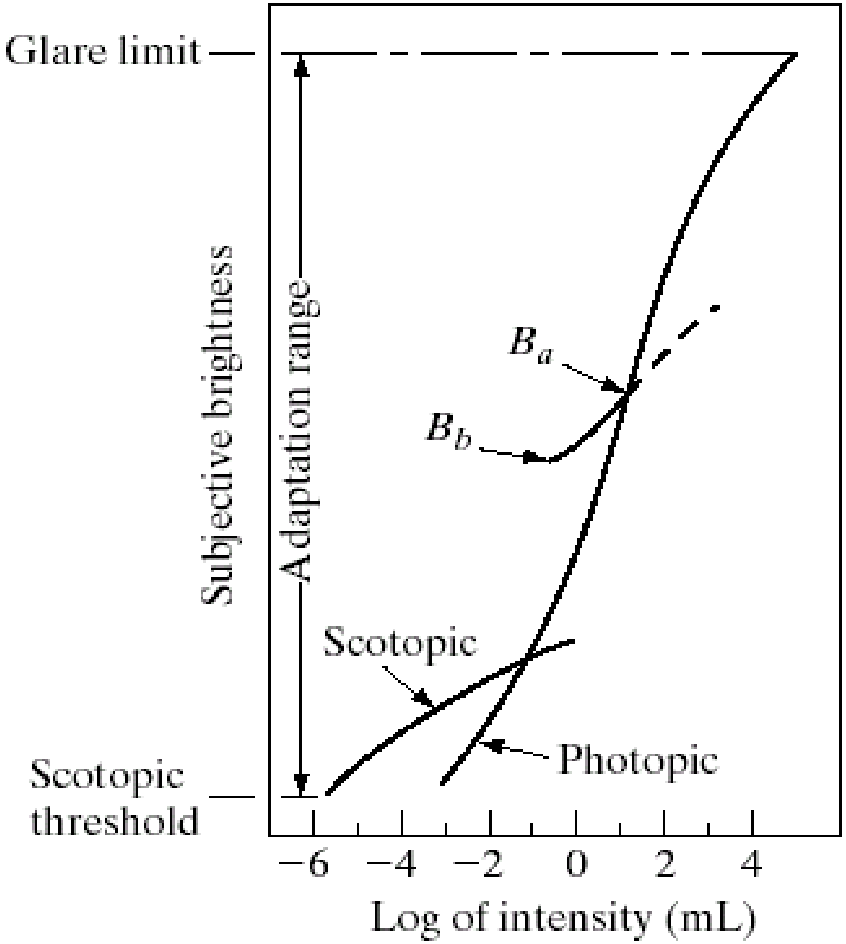
Brightness Adaptaton and Discriminaton

- The range of light intensity levels
to which the human visual system can adapt is enormous—on the order of 10^{10} from the scotopic threshold to the glare limit

FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

For any given set of conditions, the current Sensitivity level of the visual system is called brightness adaptation.

The ability of the eye to discriminate between changes in light intensity at any specific adaptation level is called brightness discrimination



Brightness Adaptation and Discrimination

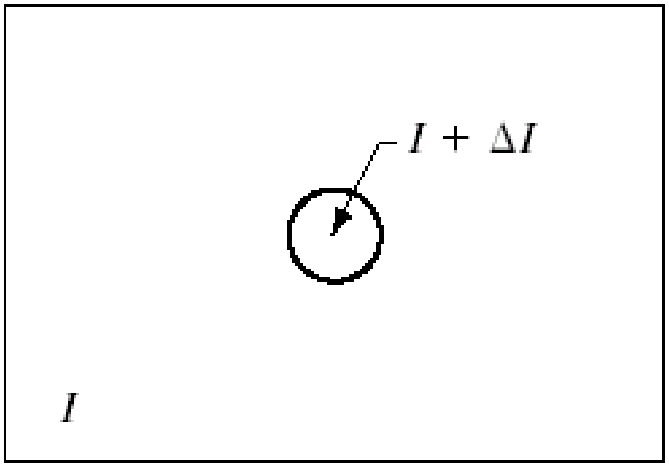


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Weber Ratio = ΔIc/I

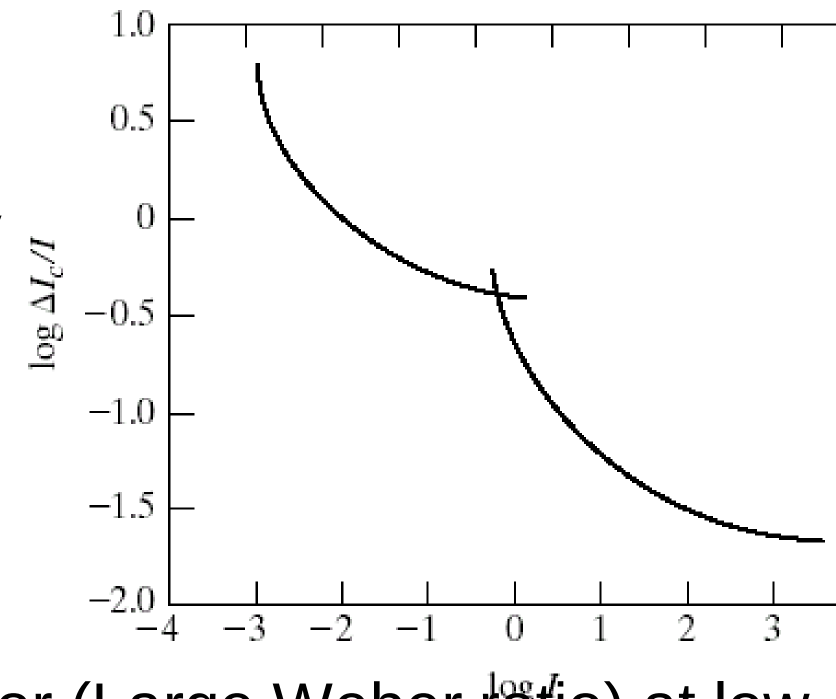
where ΔIc = Increment of illumination.

Weber ratio is high: Poor brightness discrimination

Weber ratio is low: Good brightness discrimination

Weber Ratio Vs I

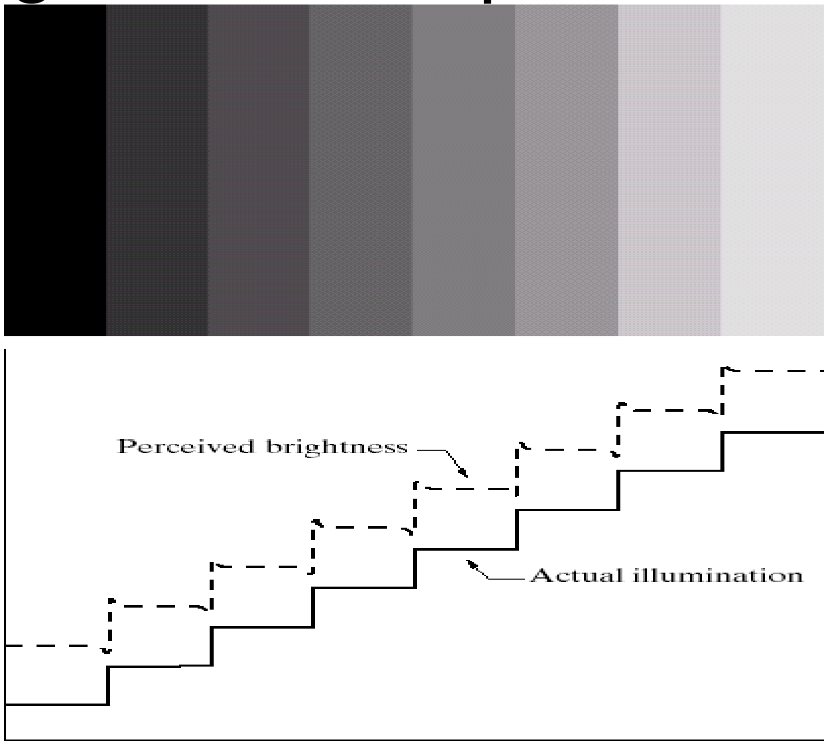
FIGURE 2.6
Typical Weber ratio as a function of intensity.



subjective brightness **(intensity as perceived by human visual system) is a logarithmic function of the light intensity incident on the eye.**

- The brightness discrimination is poor (Large Weber ratio) at low Levels of illumination (vision is carried out by rods).
- It improves Significantly, that is better discrimination(Weber ratio Decreases) as background illumination increases. Here vision is function of cones.

Brightness Adaptation and Discrimination

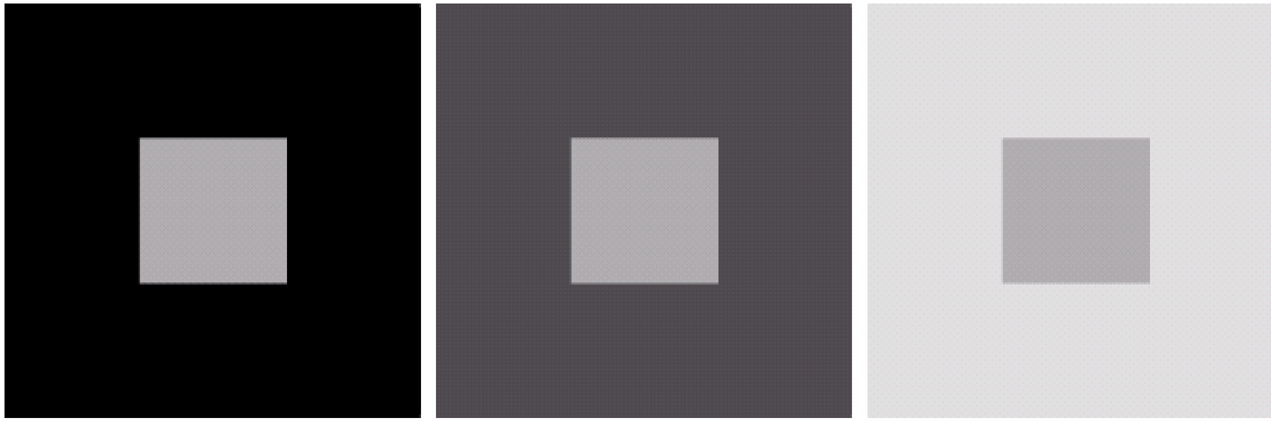


a
b

FIGURE 2.7 (a) An example showing that perceived brightness is not a simple function of intensity. The relative vertical positions between the two profiles in (b) have no special significance; they were chosen for clarity.

Mach band effect: The perceived brightness by the visual System tends to undershoot or overshoot around the boundary of regions of different intensities. The scalloped bands near the boundaries are called Mach bands.

Simultaneous Contrast

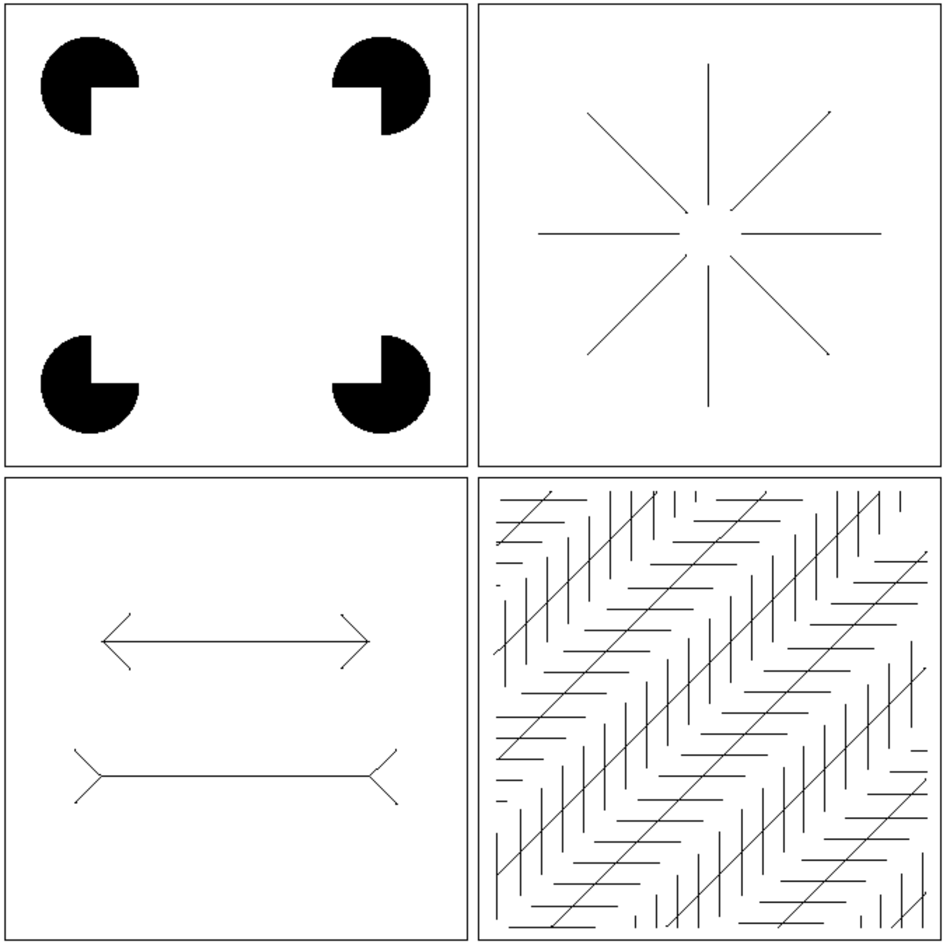


a b c

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

- The simultaneous contrast means a region's perceived brightness does not depend simply on its intensity.
- For example, all squares in the center have exactly same intensity. But they appear to the eye to become darker as the background gets lighter.

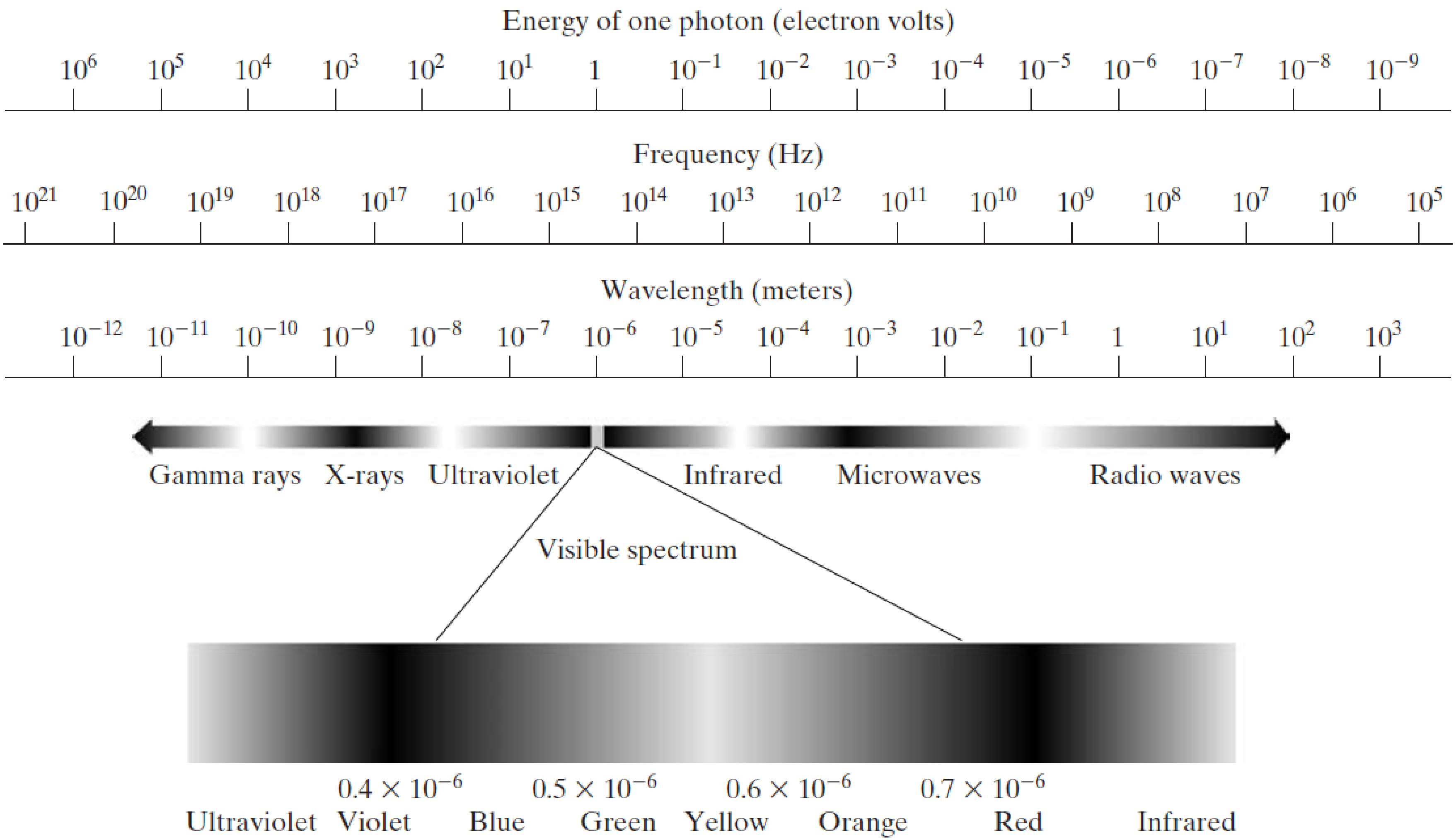
Optical illusions

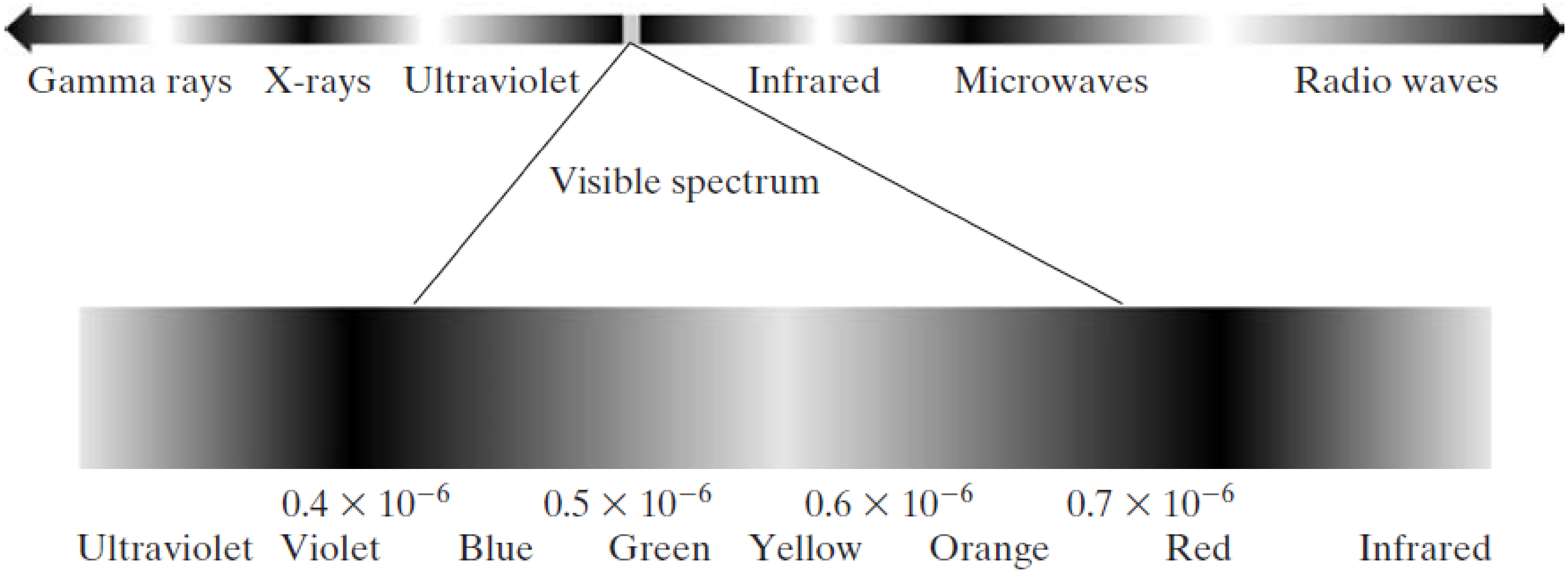


a b
c d

FIGURE 2.9 Some well-known optical illusions.

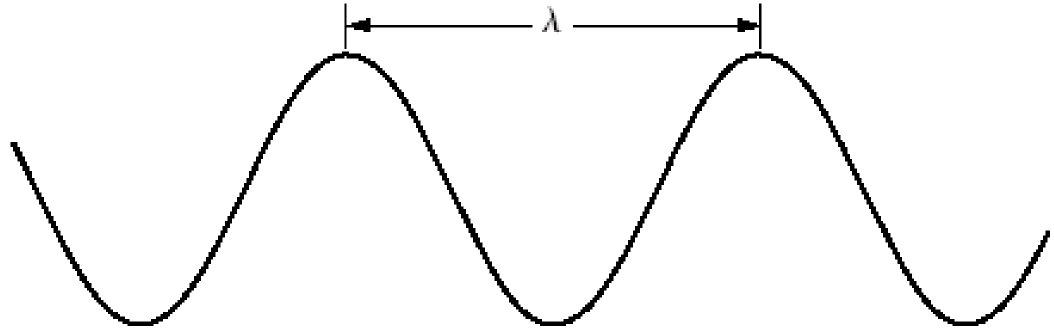
Light and the Electromagnetic Spectrum





The electromagnetic spectrum can be expressed in terms of wavelength, frequency, or energy.

FIGURE 2.11
Graphical representation of one wavelength.



Wavelength (λ) and frequency (*V*) are related by the expression

$$\lambda = c/v$$

***C=speed of light* 2.998 x10⁸ m/s**

Energy E=hv ; h is planck's constant

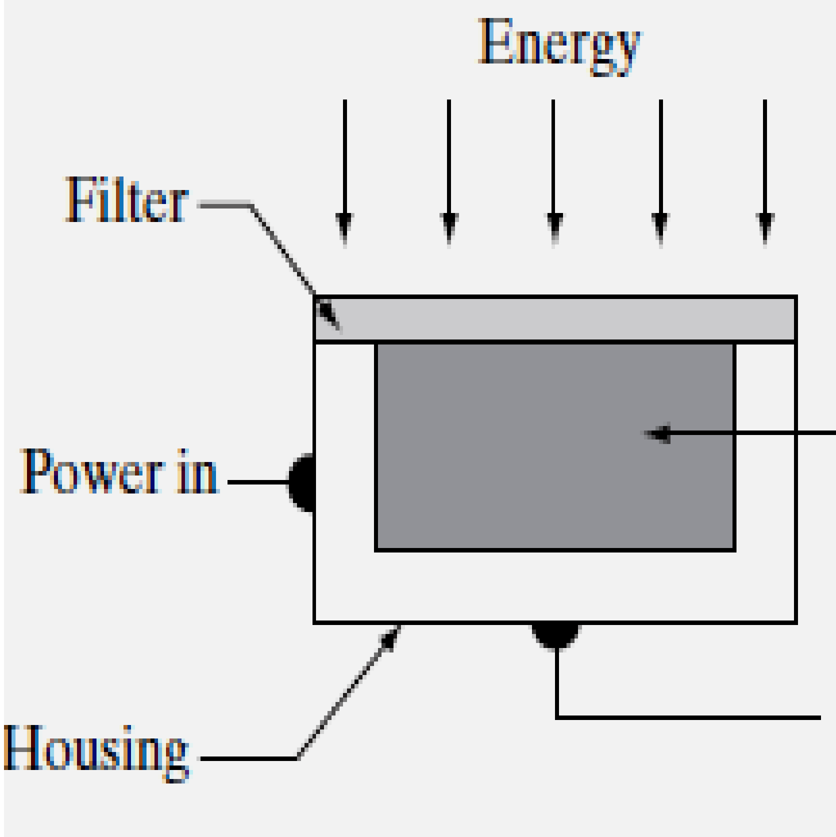
$$E = h\nu = hc/\lambda$$

- Monochromatic light
  - Intensity/ gray level
- Chromatic light
  - *spans the electromagnetic energy spectrum from* approximately 0.43 to 0.79µm {violet to red}

Radiance, Luminance, and Brightness

- *Radiance is the total amount of* energy that flows from the light source (measured in watts (W)).
- *Luminance gives a measure of the amount of* energy an observer *perceives from a light source (measured in lumens (lm))*
- *Brightness is* a subjective descriptor of light perception that is practically impossible to measure.

Image Sensing and Acquisition



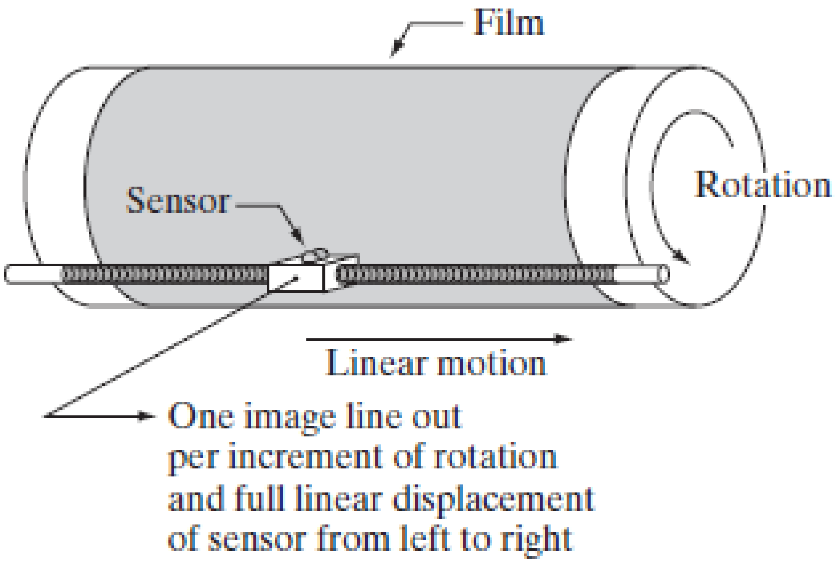
Single imaging sensor.

*The incoming energy is transformed into a voltage by the combination of input electrical power and sensor material.

*Output voltage waveform is response of the sensor(s)

*A digital quantity is obtained from each sensor by digitizing *its response*

Image acquisition using a Single sensor (Microdensitometer)



i)Photodiode is used as sensor
ii) Made up of silicon
iii) Output voltage waveform is proportional to light
iv) Filter in front of sensor is to increase selectivity
This mechanical digitizer is also called as Microdensitometer

Above arrangement is for high precision scanning.

- A film negative is mounted onto a drum whose mechanical rotation provides displacement in one dimension.
- The single sensor is mounted on a lead screw that provides motion in the perpendicular direction.

Line Sensor

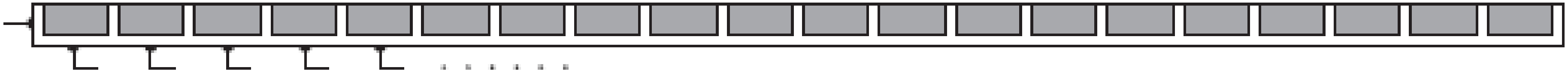


Image Acquisition Using Sensor Strips

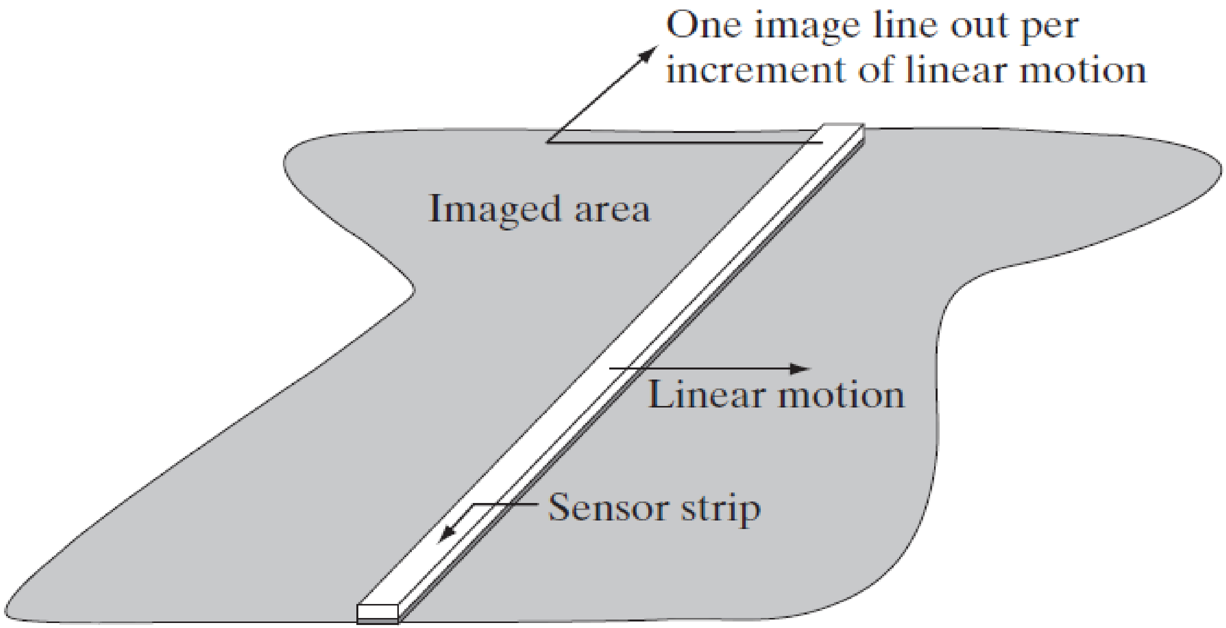
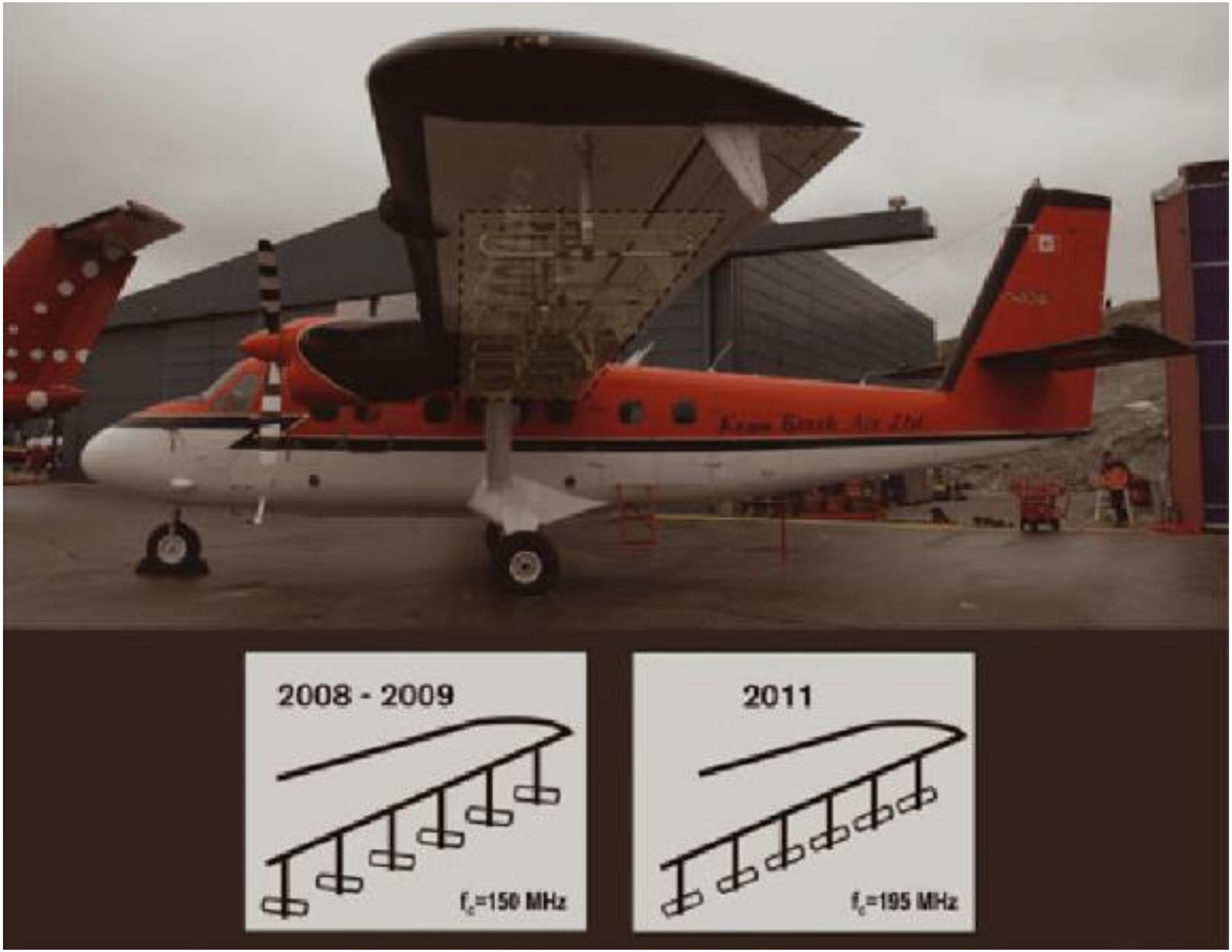


Image acquisition using linear sensor strip. Used in airborne imaging applications The imaging strip gives one line of an image at a time, and the motion of the strip completes the other dimension of a 2-D image

Flat bed scanners

- Used routinely in airborne imaging applications
- Imaging system is mounted on an aircraft flies at a constant altitude and speed over the geographical area to be imaged.
- One-dimensional imaging sensor strips that respond to various bands of the electromagnetic spectrum are mounted perpendicular to the direction of flight.
- The imaging strip gives one line of an image at a time, and the motion of the strip completes the other dimension of a two-dimensional image.


Kenn Borek Air Ltd
2008 - 2009
f_c=150 MHz
2011
f_c=195 MHz

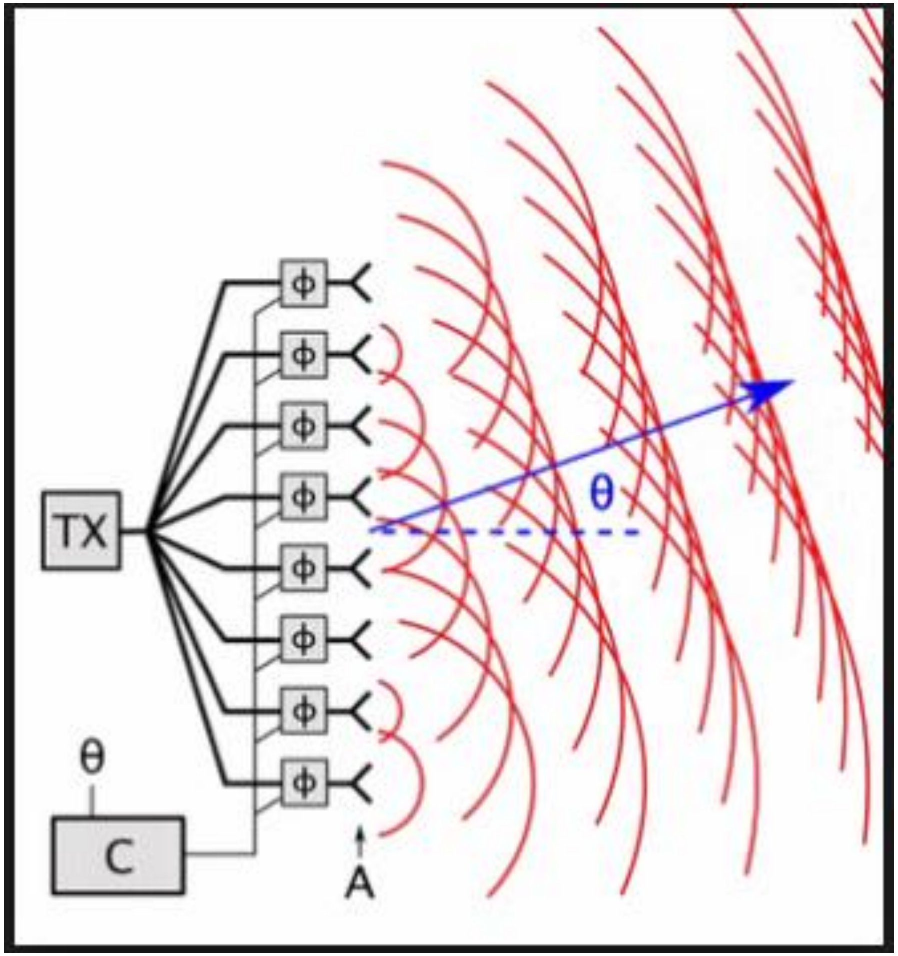
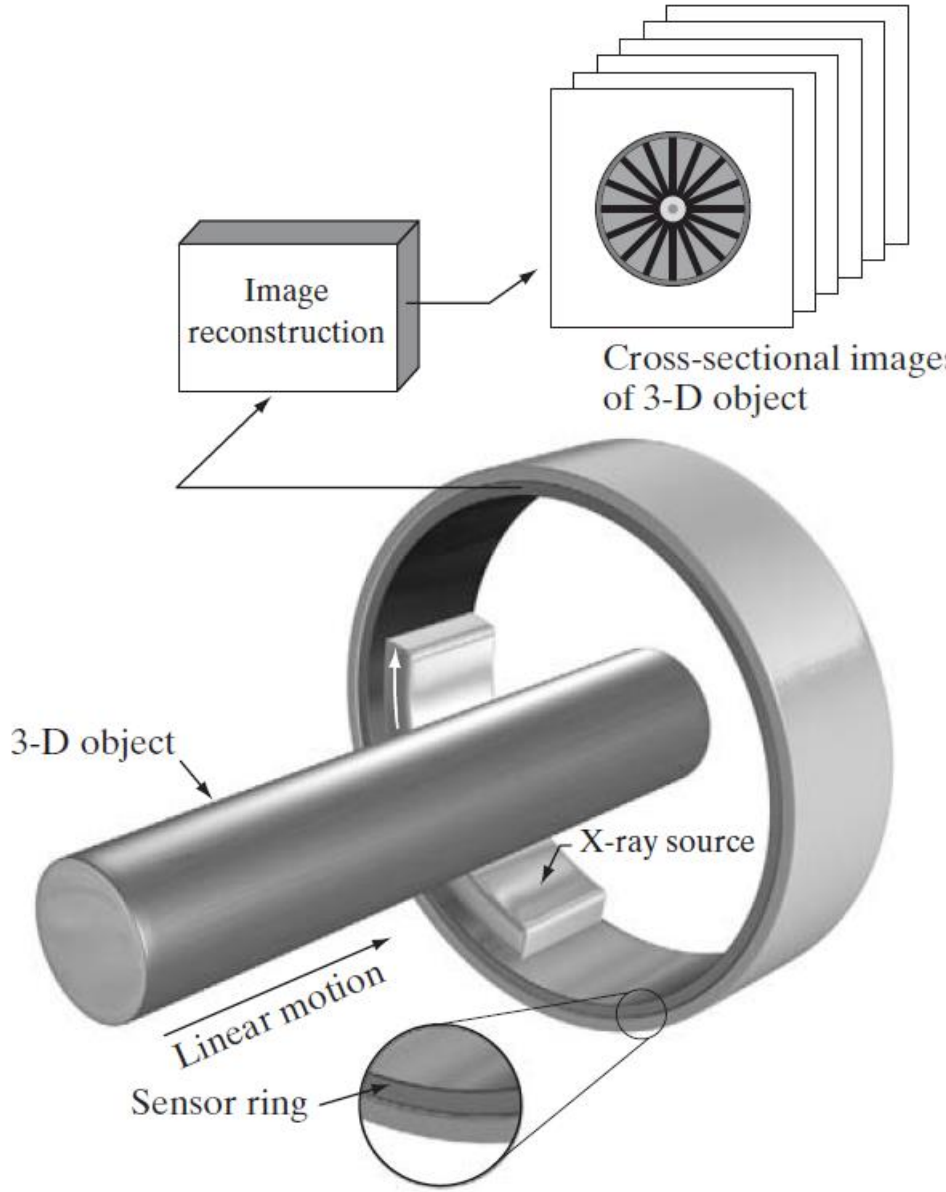

TX
θ
C
A
θ

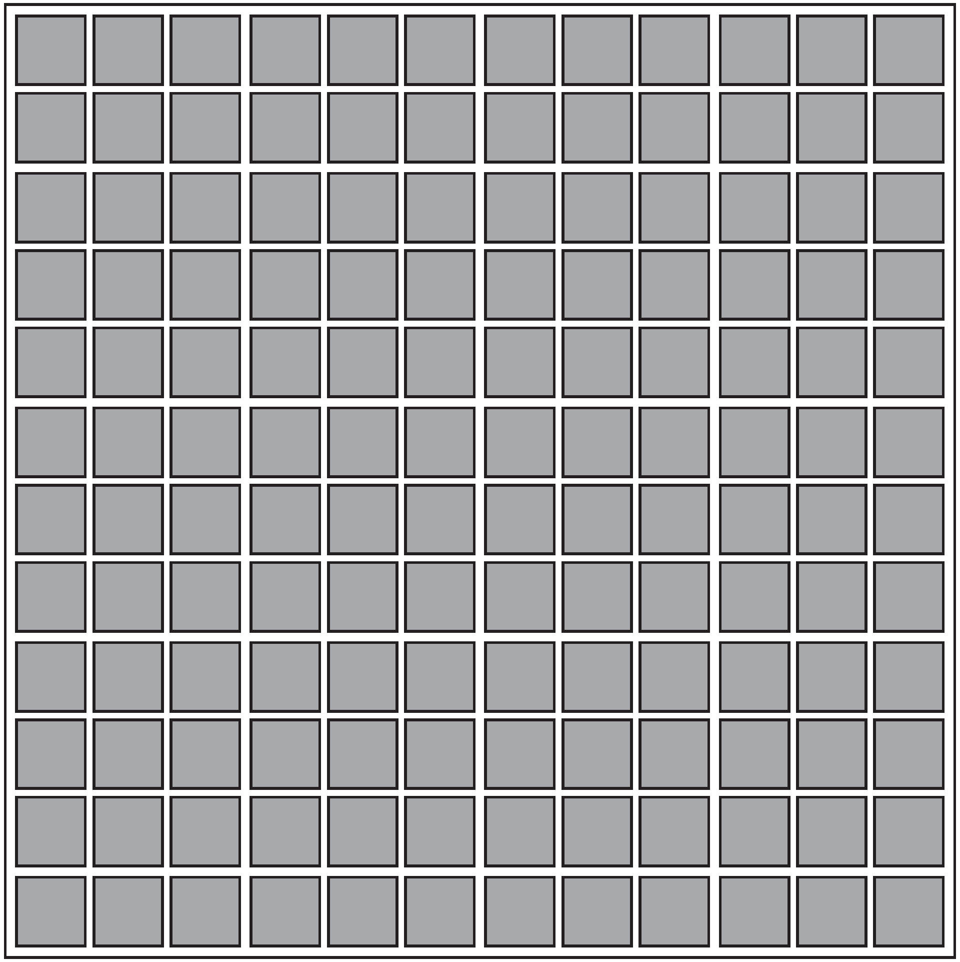
Image acquisition using a circular sensor strip.

Sensor strips mounted in a ring configuration are used in medical and industrial imaging to obtain cross-sectional ("slice") images of 3-D objects

Output of the sensors must be processed by reconstruction algorithms whose objective is to transform the sensed data into meaningful cross-sectional images

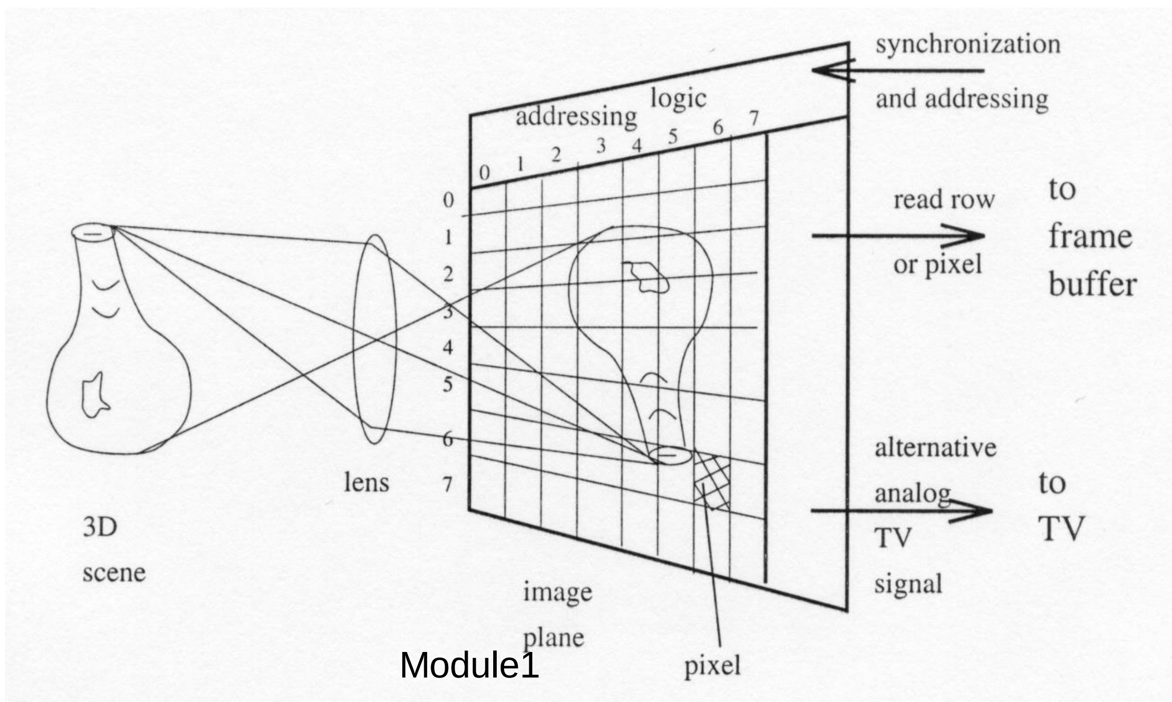


Array Sensor

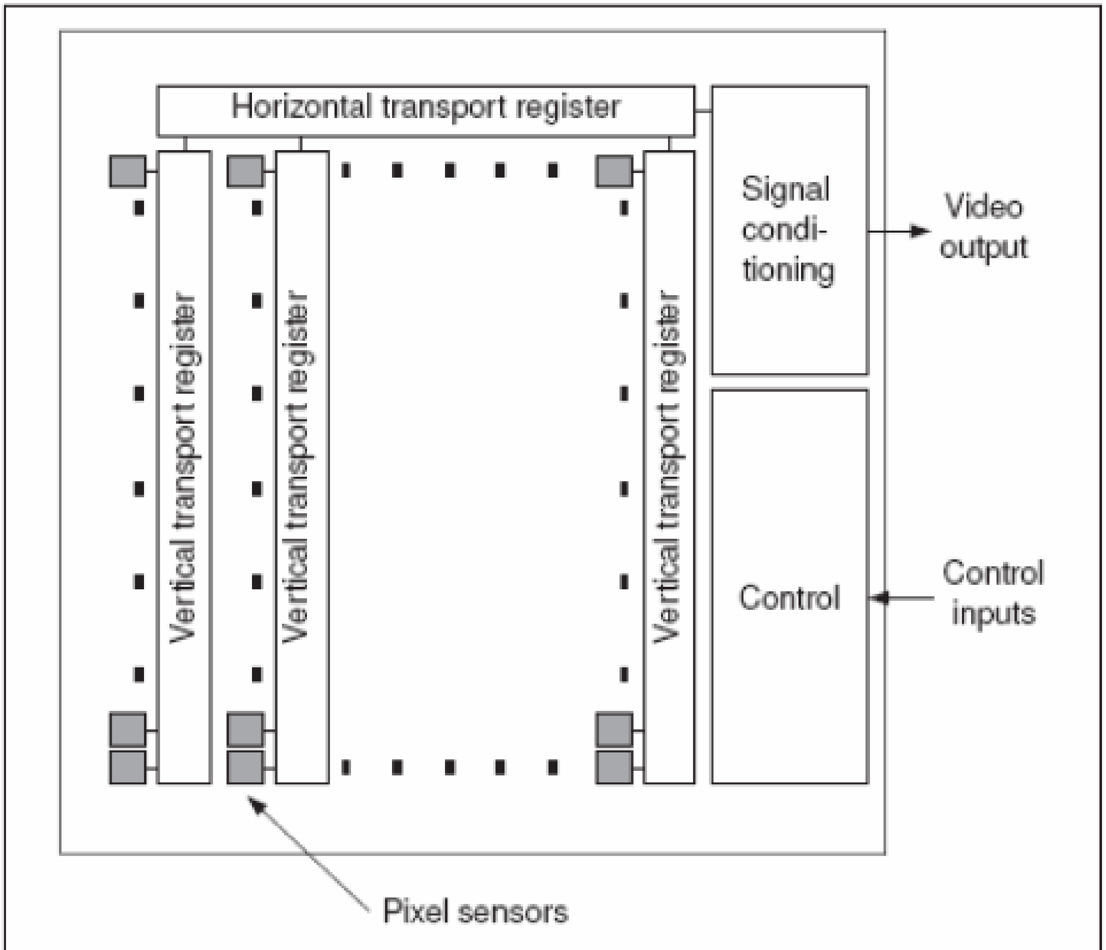


CCD (Charged-Coupled Device) cameras

- Tiny solid state cells convert light energy into electrical charge.
- The image plane acts as a digital memory that can be read row by row by a computer.



CCD sensing element



A Simple Image Formation Model

- **Digital Image — a two-dimensional function f(x,y) where *x* and *y* are spatial coordinates**
- **The amplitude of *f* is called intensity or gray level at the point (x, y)**
- Intensity values are proportional to energy radiated by a physical source
  - Hence f(x, y) must be nonzero and finite

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

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

(1) the amount of source illumination incident on the scene being viewed called *illumination component i(x,y)*

(2) the amount of illumination reflected by the objects in the scene called *reflectance component r(x,y)*

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

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

Where

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

and

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

0 → total absorbtion

1 → total reflectance

Illumination

- On a clear day, the sun may produce in excess of 90,000 lm/m^2 of illumination on the surface of the Earth and decreases to less than 10,000 lm/m^2 on a cloudy day.
- On a clear evening, a full moon yields about 0.1 lm/m^2 of illumination.
- The typical illumination level in a commercial office is about 1,000 lm/m^2

Some Typical Ranges of Reflectance

- Reflectance
  - 0.01 for black velvet
  - 0.65 for stainless steel
  - 0.80 for flat-white wall paint
  - 0.90 for silver-plated metal
  - 0.93 for snow

Image Acquisition Process

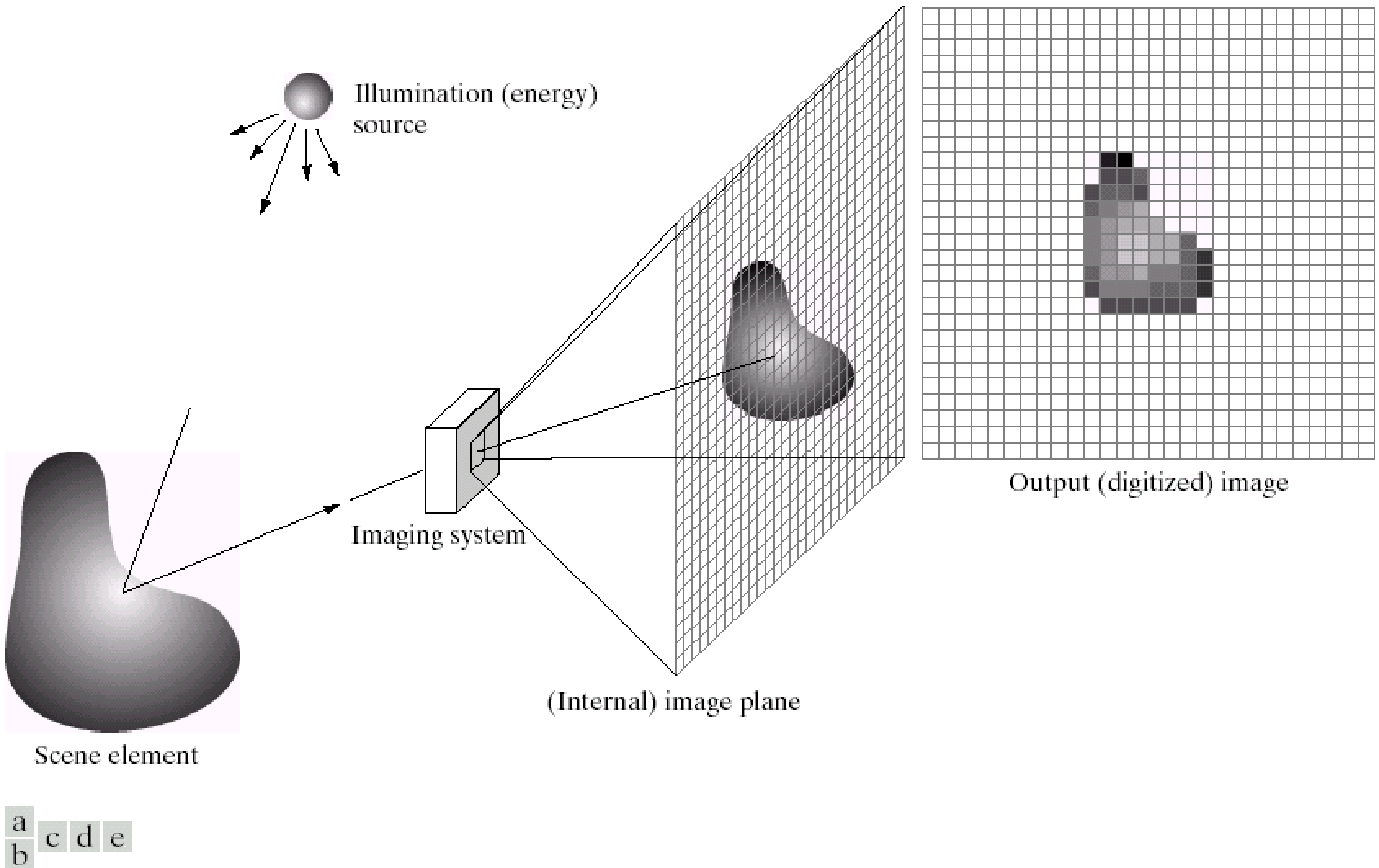
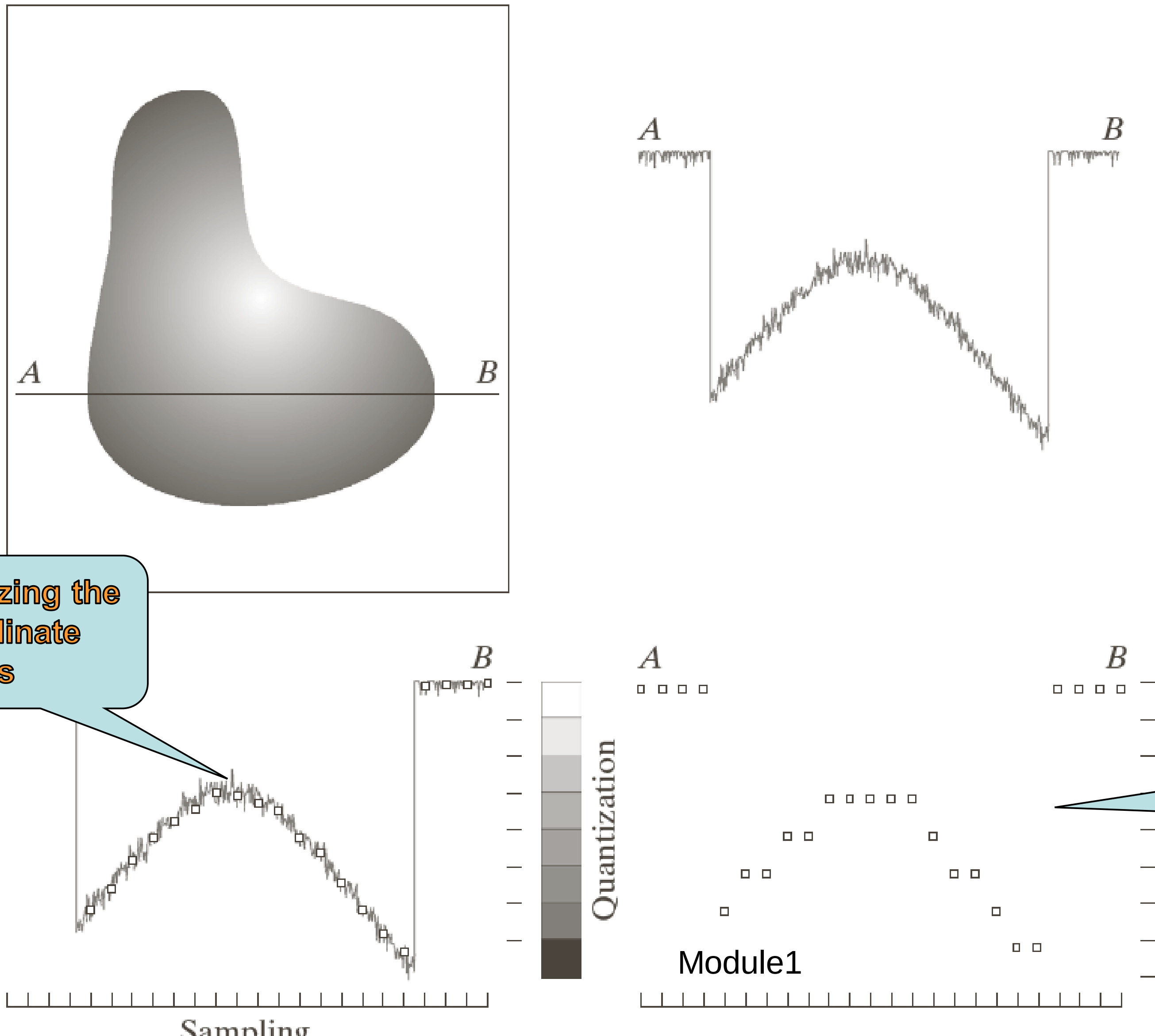


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image Sampling and Quantization



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.

Image Sampling and Quantization

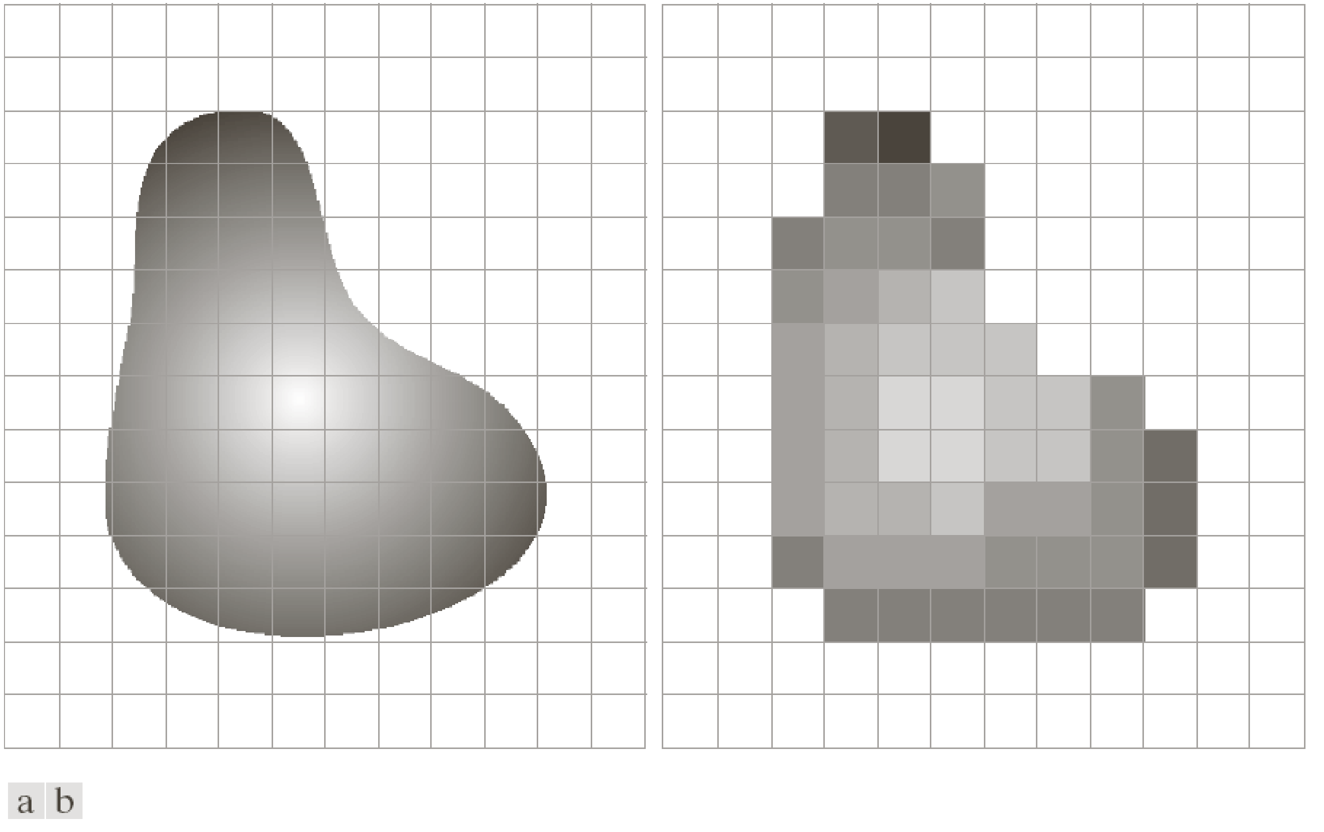
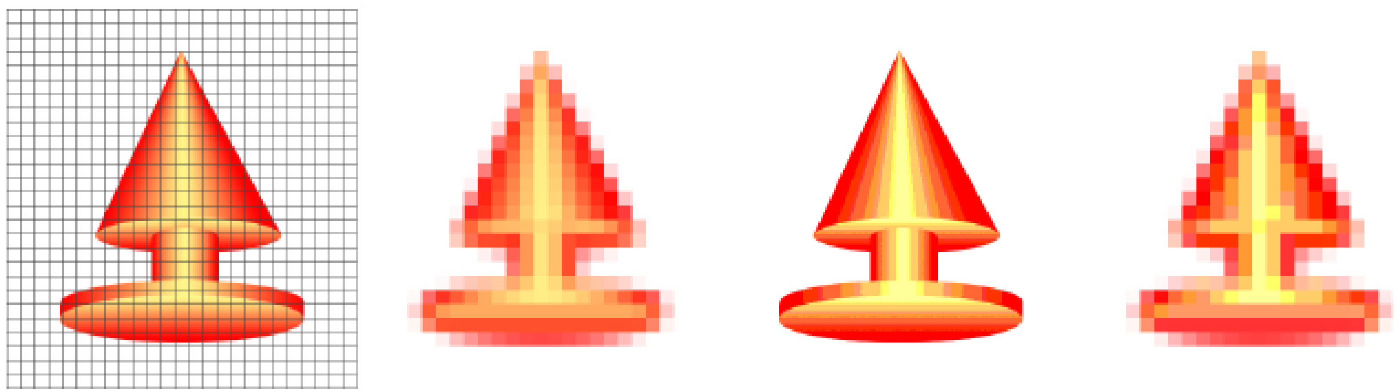


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Sampling and Quantization



real image　　sampled　　quantized　　sampled & quantized

Aliasing

- **Shannon's sampling theorem**
  - If the function is sampled at a rate equal to or greater than twice its highest frequency, it is possible to recover completely the original function from its samples.
- If the function is under sampled, then the phenomenon called **aliasing** corrupts the sampled image.
- **The corruption is in the form of additional frequency components being introduced into the sampled function.**
- **These are called aliased frequencies.**

Aliasing (Cont...)

Note that the sampling rate in image is the number of samples taken (in both spatial direction) per unit distance.

The principle approach for reducing the aliasing effect on an image is to reduce its high frequency components by blurring the image prior to sampling.

However, aliasing is always present in a sampled image.

Representing Digital Images

- The Digital Image f(x,y) is represented as M rows and N columns numerical array as

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

Representing Digital Images

- The representation of an M×N numerical array as

$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \cdots & \cdots & \cdots & \cdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

Representing Digital Images

- The representation of an M×N numerical array in MATLAB

$$f(x,y) = \begin{bmatrix} f(1,1) & f(1,2) & \dots & f(1,N) \\ f(2,1) & f(2,2) & \dots & f(2,N) \\ \dots & \dots & \dots & \dots \\ f(M,1) & f(M,2) & \dots & f(M,N) \end{bmatrix}$$

Representing Digital Images

- Discrete intensity interval [0, L-1], $L=2^k$

$$K=\log_2 L$$

- The number b of bits required to store a $M \times N$ digitized image

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

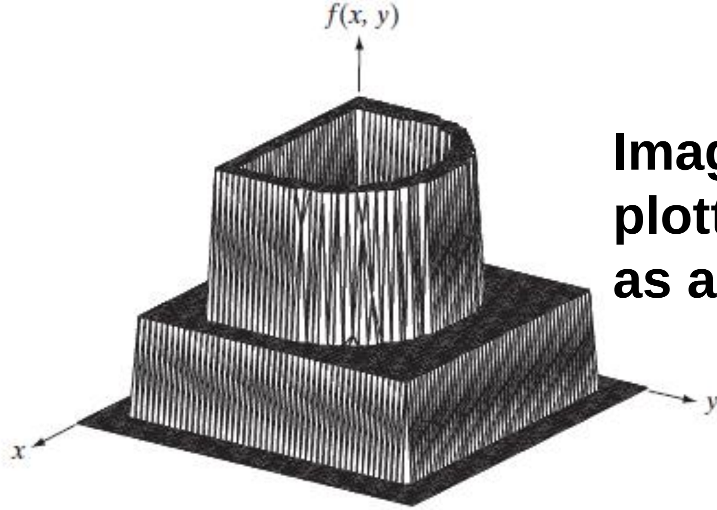
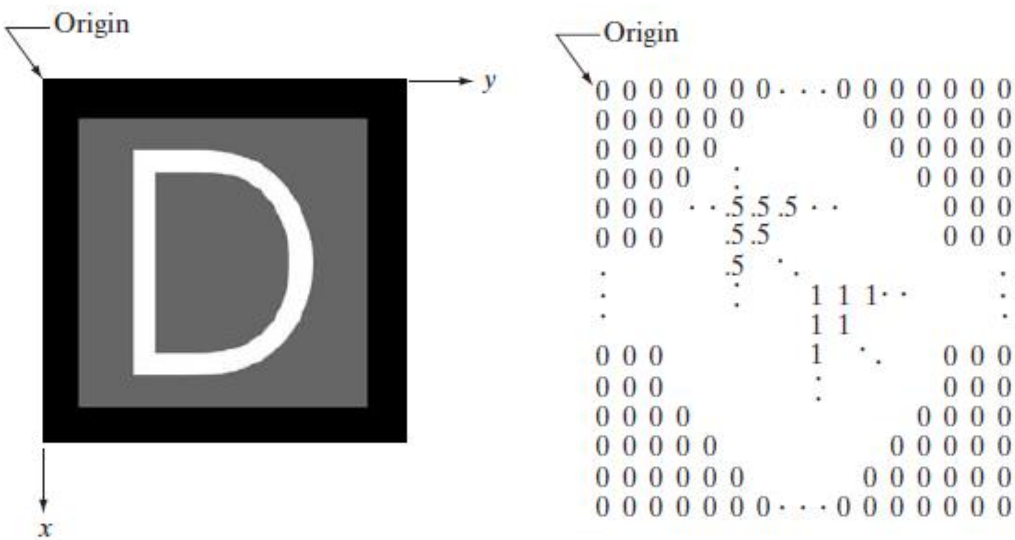


Image plotted as a surface.

Image displayed as a visual intensity array.



Representing Digital Images

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

Intensity resolution

- *Dynamic range of an imaging* system:

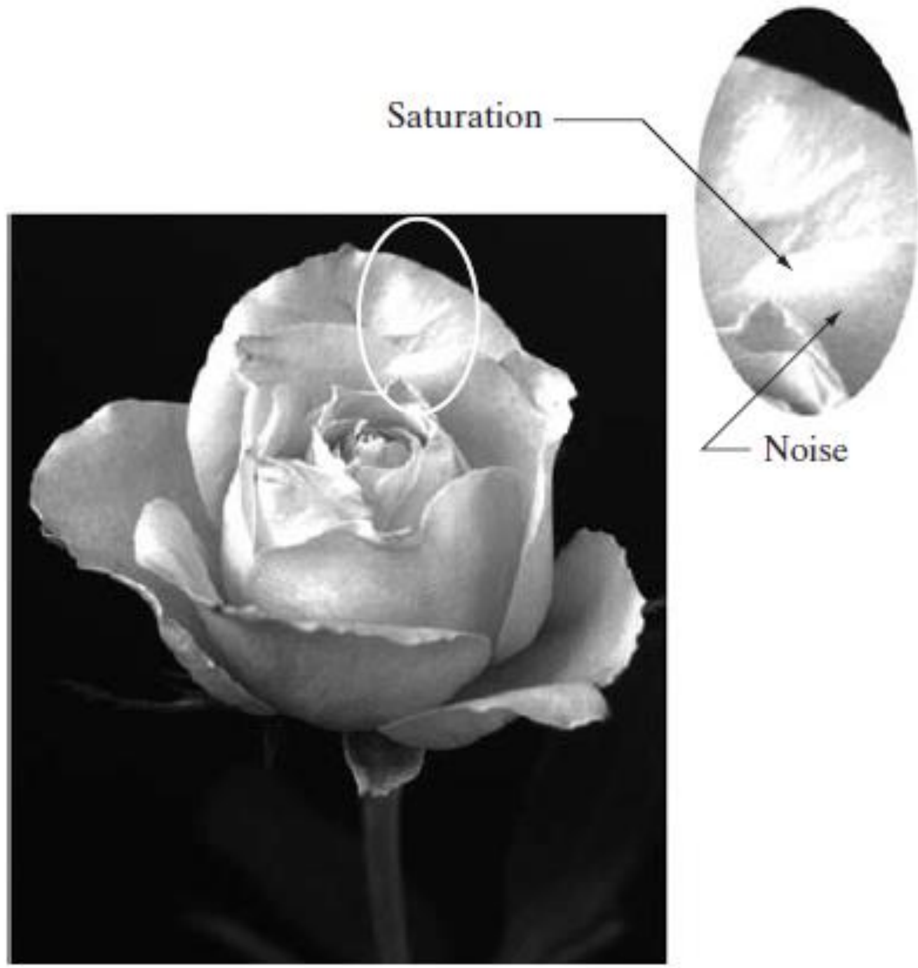
It is the smallest discernible change in intensity level.

Ratio of the maximum measurable intensity to the minimum detectable intensity level in the System

- Upper limit is determined by *saturation*
- Lower limit is determined by *noise*

An 8-bit system quantizes intensity in fixed increments of 1/256 units of intensity amplitude.

Saturation and Noise



L=2^k

Binary, Gray scale and colour image

2,3,4,5,6,7,8 bits to represent intensity

R,G,B plane

Intensity Resolution

The pixel values of the following 5x5 image are represented by 8-bit integers:

$$f = \begin{bmatrix} 123 & 162 & 200 & 147 & 93 \\ 137 & 157 & 165 & 232 & 189 \\ 151 & 155 & 152 & 141 & 130 \\ 205 & 101 & 100 & 193 & 115 \\ 250 & 50 & 75 & 88 & 100 \end{bmatrix}$$

Determine (f) with gray level resolution of 2^k , when

1. K = 5
2. K = 3

Solution 5-bit

Dividing the image by 2 will reduce its gray level resolution by one bit.
Hence to reduce the gray level resolution from 8-bit to 5-bit, we have to reduce 3-bits.
8bits – 5bits = 3 bits will be reduced
Thus, we divide the 8-bit image by 8 (2^3) to get the following 5-bit image:

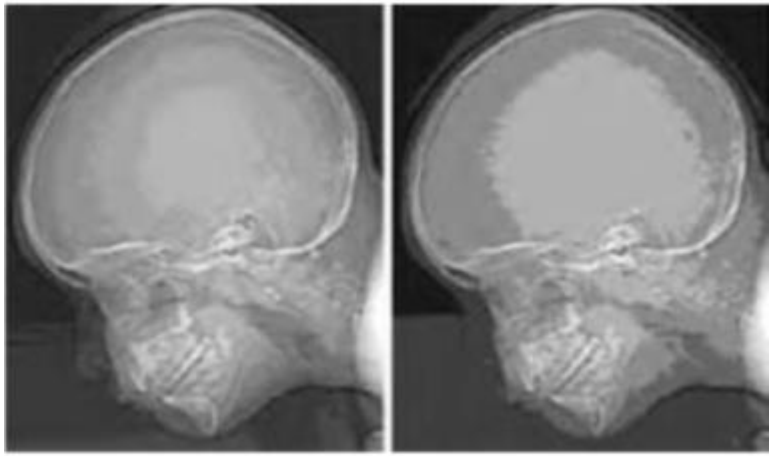
$$f = \begin{bmatrix} 15 & 20 & 25 & 18 & 11 \\ 17 & 19 & 20 & 29 & 23 \\ 18 & 19 & 19 & 17 & 16 \\ 25 & 12 & 12 & 24 & 14 \\ 31 & 6 & 9 & 10 & 12 \end{bmatrix}$$

Solution -3 bit

Similarly, to obtain 3-bit image, we divide the 8-bit image by (32) 2^5

$$f = \begin{bmatrix} 3 & 5 & 6 & 4 & 2 \\ 4 & 4 & 5 & 7 & 5 \\ 4 & 4 & 4 & 4 & 4 \\ 6 & 3 & 3 & 6 & 3 \\ 7 & 1 & 2 & 2 & 3 \end{bmatrix}$$

Intensity Resolution - False contouring



Effect of False Contouring

- Under the low intensity resolution it has an imperceptible set of very fine ridge like structure in areas of smooth gray levels (particularly in the skull).
- This effect cause by the use of an insufficient number of gray levels in smooth areas of a digital image, is called **False Contouring.**
- It happens because the ridges resembles topographic contours in map.
- False contouring is generally is quiet visible in images displayed using 16 or less uniformly spaced gray levels.

DYNAMIC RANGE

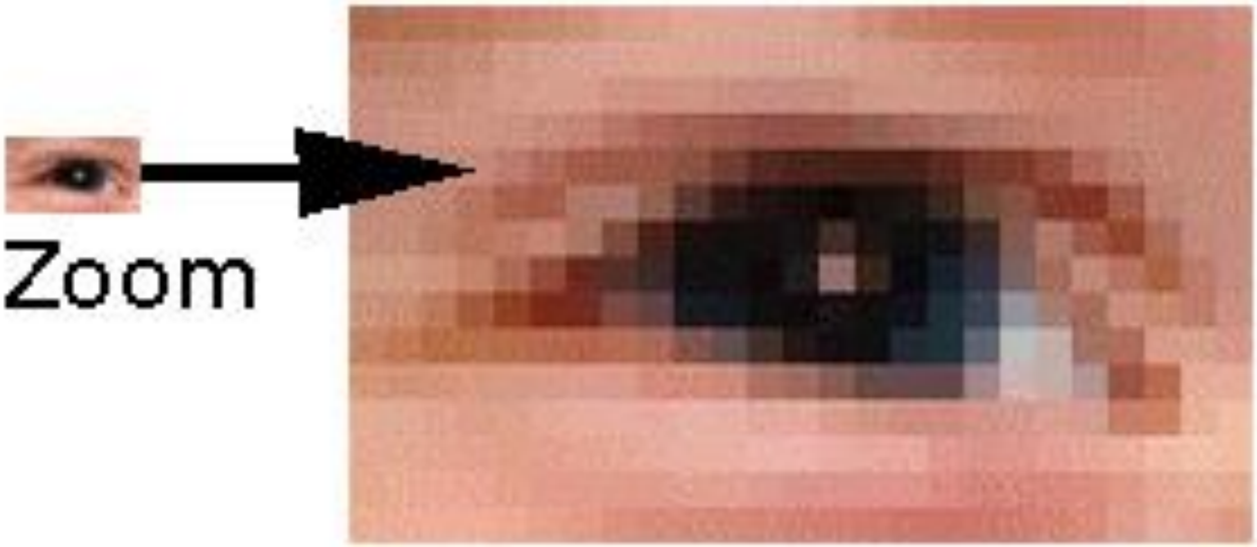
Image Contrast

- When an appreciable number of pixels in an image have a high dynamic range, we can expect the image to have high contrast.

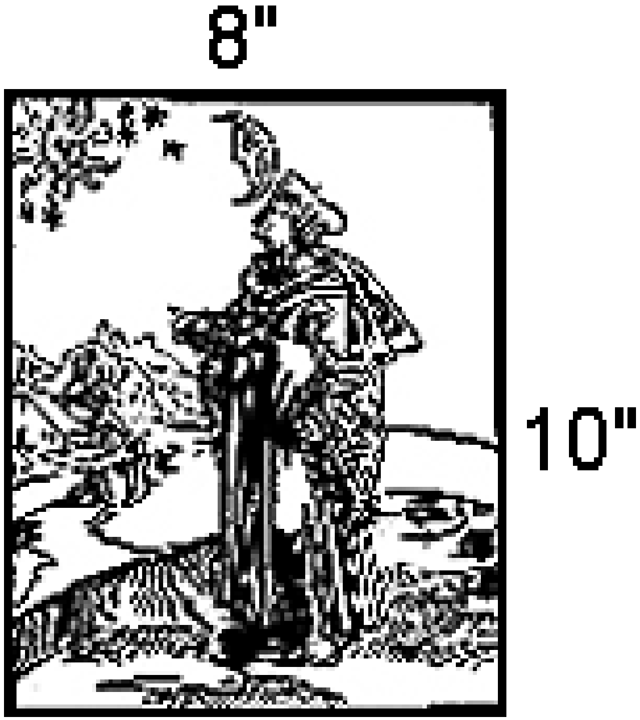
Spatial RESOLUTION:

- Determines smallest noticeable detail in an image. Its an ability to distinguish fine spatial detail. The spatial frequency at which a digital image is sampled (the sampling frequency) is often a good indicator of resolution.
- dots-per-inch (dpi) or pixels-per-inch (ppi) are common and synonymous terms used to express resolution for digital images. Ex: 1.3 Mpixel camera has 1,310,720 pixels generating an image of size 1024X1280
- Generally, but within limits, increasing the sampling frequency also helps to increase resolution.

Resolution



20-megapixel CCD imaging chip can be expected to have a
higher capability to resolve detail than an 8-megapixel camera



- An 8" x 10" document that is scanned at 300 dpi has the pixel dimensions of______
- What are the pixel dimensions of a 5x7-inch photograph scanned at 400 dpi?
- If an 8.5x11-inch page is scanned and has pixel dimensions of 2,550 x 3,300, what is the dpi?

Image Interpolation

- **<u>Interpolation is the process of using known data to estimate values at unknown locations.</u>**
- It happens anytime you resize or remap (distort) your image from one pixel grid to another.
- Image resizing is necessary when you need to increase or decrease the total number of pixels, whereas remapping can occur under a wider variety of scenarios: correcting for lens distortion, changing perspective, and rotating an image.

Image Interpolation (Cont...)

- Even if the same image resize or remap is performed, the results can vary significantly depending on the interpolation algorithm.
- It is only an approximation, therefore an image will always lose some quality each time interpolation is performed.

Image Interpolation (Cont...)

- **Pixel replication** is a special case of nearest neighbor interpolation.
- Pixel replication is applicable when we want to increase the size of an image an integer number of times.
- For instance, to double the size of an image we can duplicate each column (horizontal direction enlargement) or row (vertical direction enlargement).
- Image shrinking is done in similar manner as zooming and the equivalent process of pixel replication is row column deletion.
  - For example, to shrink an image by one half, we delete every other row and column.

Shrinking

B) Shrinking

Shrinking may be viewed as undersampling. Image shrinking is performed by **row-column deletion**. For example, to shrink an image by one-half, we delete every other row and column.

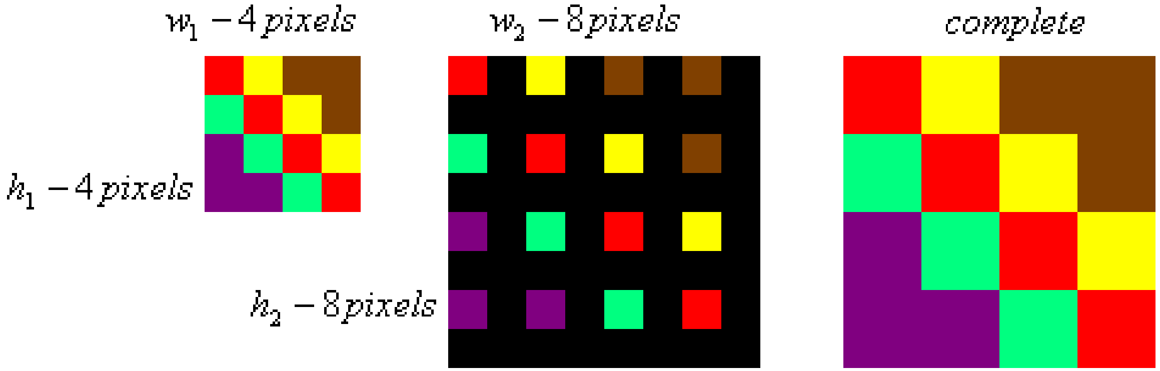
$$\begin{bmatrix} 69 & 69 & 50 & 50 & 80 & 80 \\ 69 & 69 & 50 & 50 & 80 & 80 \\ 45 & 45 & 60 & 60 & 66 & 66 \\ 45 & 45 & 60 & 60 & 66 & 66 \\ 30 & 30 & 55 & 55 & 80 & 80 \\ 30 & 30 & 55 & 55 & 80 & 80 \end{bmatrix} = \begin{bmatrix} 69 & 69 & 50 & 50 & 80 & 80 \\ 45 & 45 & 60 & 60 & 66 & 66 \\ 30 & 30 & 55 & 55 & 80 & 80 \end{bmatrix} = \begin{bmatrix} 69 & 50 & 80 \\ 45 & 60 & 66 \\ 30 & 55 & 80 \end{bmatrix}$$

Original image — image with rows deleted — image with rows and columns deleted

Shrinking, in the other hand involves reduction of pixels and it means loss of irrecoverable information. In this case scaling algorithm is to find the right pixels to throw away.

Zooming

- Zooming may be viewed as oversampling. It is the scaling of an image area A of $w \times h$ pixels by a factor s while maintaining spatial resolution (i.e. output has $sw \times sh$ pixels).
- Zooming: increasing the number of pixels in an image so that the image appears larger Zooming requires two steps:
  - creation of new pixel locations
  - assignment of gray level to those new locations



- **The black pixels represent empty spaces where interpolation is needed, and the complete picture is the result of nearest neighbour interpolation.**
- **Scaling algorithm is to find appropriate spot to put the empty spaces inside the original image, and to fill all those spaces with livelier colors.**

Interpolation Methods

- Image interpolation is used to change the X and Y dimensions of an image

- There are many methods of gray level assignments, for examples:
  - Nearest neighbor interpolation
  - Bilinear interpolation
  - K-Times zooming

Nearest neighbor interpolation (zero order hold)

- Is performed by repeating pixel values, thus creating checkerboard effect. Pixel replication (a special case of nearest neighbored interpolation) is used to increase the size of an image an integer number of times. The example below shows 8-bit image zooming by 2x (2 times) using nearest neighbor interpolation.

$$\begin{bmatrix} 69 & 50 & 80 \\ 45 & 60 & 66 \\ 30 & 55 & 80 \end{bmatrix} = \begin{bmatrix} 69 & 69 & 50 & 50 & 80 & 80 \\ 45 & 45 & 60 & 60 & 66 & 66 \\ 30 & 30 & 55 & 55 & 80 & 80 \end{bmatrix} = \begin{bmatrix} 69 & 69 & 50 & 50 & 80 & 80 \\ 69 & 69 & 50 & 50 & 80 & 80 \\ 45 & 45 & 60 & 60 & 66 & 66 \\ 45 & 45 & 60 & 60 & 66 & 66 \\ 30 & 30 & 55 & 55 & 80 & 80 \\ 30 & 30 & 55 & 55 & 80 & 80 \end{bmatrix}$$

Original image | image with rows expanded | image with rows and columns expanded

Bilinear interpolation (First order hold)

is performed by finding linear interpolation between adjacent pixels, thus creating a blurring effect. This can be done by finding the average gray value between two pixels and use that as the pixel value between those two. We can do this for the rows first, and then we take that result and expand the columns in the same way. The example below shows 8-bit image zooming by 2x (2 times) using bilinear interpolation:

$$\begin{bmatrix} 69 & 50 & 80 \\ 45 & 60 & 66 \\ 30 & 55 & 80 \end{bmatrix} = \begin{bmatrix} 69 & 59 & 50 & 65 & 80 \\ 45 & 52 & 60 & 63 & 66 \\ 30 & 42 & 55 & 67 & 80 \end{bmatrix} = \begin{bmatrix} 69 & 59 & 50 & 65 & 80 \\ 57 & 55 & 55 & 64 & 73 \\ 45 & 52 & 60 & 63 & 66 \\ 37 & 47 & 57 & 65 & 73 \\ 30 & 42 & 55 & 67 & 80 \end{bmatrix}$$

Original image　　image with rows expanded　　image with rows and columns expanded

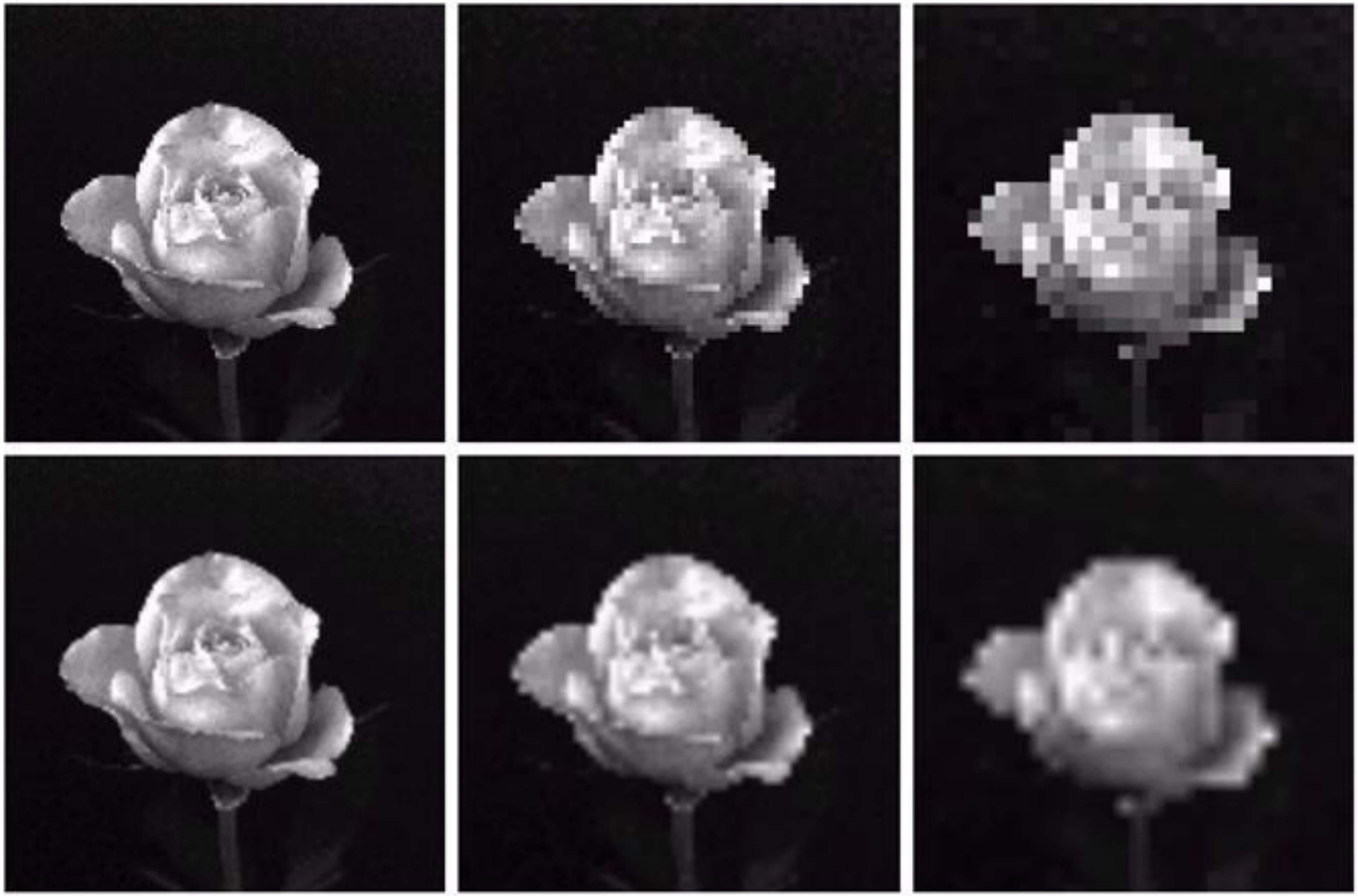
A	B
C	D

Replication

A	A	B	B
A	A	B	B
C	C	D	D
C	C	D	D

Interpolation

A	$\frac{A+B}{2}$	B	$\frac{B}{2}$
$\frac{A+C}{2}$	$\frac{A+B+C+D}{4}$	$\frac{B+D}{2}$	$\frac{B+D}{4}$
C	$\frac{C+D}{2}$	D	$\frac{D}{2}$
$\frac{C}{2}$	$\frac{C+D}{4}$	$\frac{D}{2}$	$\frac{D}{4}$



Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

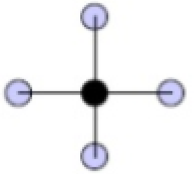
Basic Relationships Between Pixels

- Neighborhood
- Adjacency
- Connectivity
- Paths
- Regions and boundaries

Basic Relationships Between Pixels

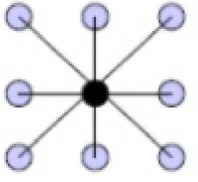
- **Neighbors** of a pixel p at coordinates (x,y)

➢ **4-neighbors of p**, denoted by $\mathbf{N_4(p)}$:
(x-1, y), (x+1, y), (x,y-1), and (x, y+1).



➢ **4 diagonal neighbors of p**, denoted by $\mathbf{N_D(p)}$:
(x-1, y-1), (x+1, y+1), (x+1,y-1), and (x-1, y+1).

➢ **8 neighbors of p**, denoted $\mathbf{N_8(p)}$
$N_8(p) = N_4(p) \cup N_D(p)$



Basic Relationships Between Pixels

- **There are 3 types of Adjacency**

  Let V be the set of intensity values

- **4-adjacency**: Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.
- **8-adjacency**: Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$.
- **m-adjacency:** Two pixels p and q with values from V are m-adjacent if

  (i) q is in the set N4(p), or

  (ii) q is in the set ND(p) and the set N4(p) ∩ N4(q) has no pixels whose values are from V.

Basic Relationships Between Pixels

- **Path**

➢ A (digital) path (or curve) from pixel p with coordinates (x_0, y_0) to pixel q with coordinates (x_n, y_n) is a sequence of distinct pixels with coordinates

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

Where (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent for $1 \le i \le n$.

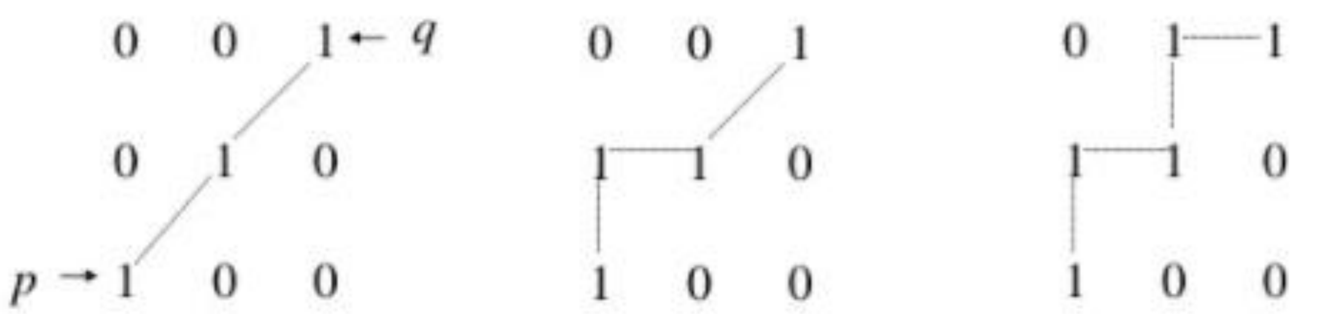
➢ Here *n* is the *length* of the path.

➢ If $(x_0, y_0) = (x_n, y_n)$, the path is ***closed*** path.

➢ We can define 4-, 8-, and m-paths based on the type of adjacency used.

Distance Measure of Path

If distance depend on the path between two pixels such as *m-adjacency* then the D_m distance between two pixels is defined as the shortest *m-path* between the pixels.



$D_m(p, q) = 2$ $\quad$ $D_m(p, q) = 3$ $\quad$ $D_m(p, q) = 4$

Examples: Adjacency and Path

V = {1, 2}

Q

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix}$$

P

Examples: Adjacency and Path

V = {1, 2}

$$\begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array}$$

8-adjacent

Examples: Adjacency and Path

V = {1, 2}

$$\begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array}$$

$$\begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array}$$

8-adjacent

$$\begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array}$$

m-adjacent

Examples: Adjacency and Path

V = {1, 2}

$$\begin{array}{ccc} 0_{1,1} & 1_{1,2} & 1_{1,3} \\ 0_{2,1} & 2_{2,2} & 0_{2,3} \\ 0_{3,1} & 0_{3,2} & 1_{3,3} \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array}$$

8-adjacent **m-adjacent**

The 8-path from (1,3) to (3,3):

(i) (1,3), (1,2), (2,2), (3,3)

(ii) (1,3), (2,2), (3,3)

The m-path from (1,3) to (3,3):

(1,3), (1,2), (2,2), (3,3)

Find 4,8,m adjacency and path

0	1	1	0	1	1	1	1	0
0	1	0	0	2	0	0	1	0
1	0	0	0	1	0	1	0	0

- V={1} V={1,2} V={1}

Basic Relationships Between Pixels

- **Connected in S**

  Let S represent a subset of pixels in an image. Two pixels p with coordinates (x_0, y_0) and q with coordinates (x_n, y_n) are said to be **connected in S** if there exists a path

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

  Where $\forall i, 0 \le i \le n, (x_i, y_i) \in S$

Basic Relationships Between Pixels

Let S represent a subset of pixels in an image

- For every pixel *p* in S, the set of pixels in S that are connected to *p* is called a ***connected component*** of S.
- If S has only one connected component, then S is called ***Connected Set*****.**
- We call R a **region** of the image if R is a connected set
- Two regions, R_i and R_j are said to be ***adjacent*** if their union forms a connected set.
- Regions that are not to be adjacent are said to be ***disjoint.***

Basic Relationships Between Pixels

- **Boundary (or border)**

➢ The ***boundary*** of the region R is the set of pixels in the region that have one or more neighbors that are not in R.

➢ If R happens to be an entire image, then its boundary is defined as the set of pixels in the first and last rows and columns of the image.

- **Foreground and background**

➢ An image contains K disjoint regions, R_k, k = 1, 2, …, K. Let R_u denote the union of all the K regions, and let $(R_u)^c$ denote its complement.

All the points in R_u is called **foreground**;

All the points in $(R_u)^c$ is called **background**.

Question 1

- **In the following arrangement of pixels, are the two regions (of 1s) adjacent? (if 8-adjacency is used)**

1	1	1
1	0	1
0	1	0
0	0	1
1	1	1
1	1	1

Region 1

Region 2

Question 2

- **In the following arrangement of pixels, are the two parts (of 1s) adjacent? (if 4-adjacency is used)**

1	1	1
1	0	1
0	1	0
0	0	1
1	1	1
1	1	1

Part 1

Part 2

- **In the following arrangement of pixels, the two regions (of 1s) are disjoint (if 4-adjacency is used)**

1	1	1	
1	0	1	**Region 1**
0	1	0	
0	0	1	**Region 2**
1	1	1	
1	1	1	

- **In the following arrangement of pixels, the two regions (of 1s) are disjoint (if 4-adjacency is used)**

1	1	1
1	0	1
0	1	0
0	0	1
1	1	1
1	1	1

foreground

background

Question 3

- **In the following arrangement of pixels, the circled point is part of the boundary of the 1-valued pixels if 8-adjacency is used, true or false?**

0	0	0	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	1	0
0	1	1	1	0
0	0	0	0	0

Question 4

- **In the following arrangement of pixels, the circled point is part of the boundary of the 1-valued pixels if 4-adjacency is used, true or false?**

0	0	0	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	1	0
0	1	1	1	0
0	0	0	0	0

Distance Measures

- Given pixels *p, q* and *z* with coordinates (x, y), (s, t), (u, v) respectively, the distance function D has following properties:

a. $D(p, q) \geq 0$ [$D(p, q) = 0$, iff $p = q$]

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

c. $D(p, z) \leq D(p, q) + D(q, z)$

Distance Measures

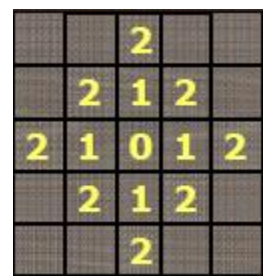
The following are the different Distance measures:

a. Euclidean Distance :

$D_e(p, q) = [(x-s)^2 + (y-t)^2]^{1/2}$

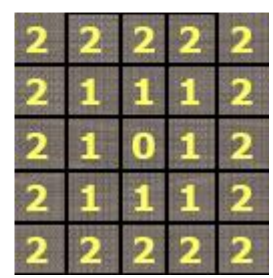
b. City Block Distance:

$D_4(p, q) = |x-s| + |y-t|$



c. Chess Board Distance:

$D_8(p, q) = \max(|x-s|, |y-t|)$



- If P and Q are pixels at coordinates (10,15) and (15,25). Find which distance measure gives minimum distance between pixels?
- If P and Q are pixels at coordinates (5,20) and (25,45). Find which distance measure gives minimum distance between pixels?

Question 5

- **In the following arrangement of pixels, what's the value of the chessboard distance, city-block distance between the circled two points?**

0	0	0	0	0
0	0	1	1	0
0	1	1	0	0
0	1	0	0	0
0	0	0	0	0
0	0	0	0	0

- For v={0,1} find shortest 4,8,m path between p and q. repeat for v={1,2}

$$\begin{array}{rccccl}
 & 3 & 1 & 2 & 1 & \leftarrow q \\
 & 2 & 2 & 0 & 2 & \\
 & 1 & 2 & 1 & 1 & \\
p \rightarrow & 1 & 0 & 1 & 2 &
\end{array}$$

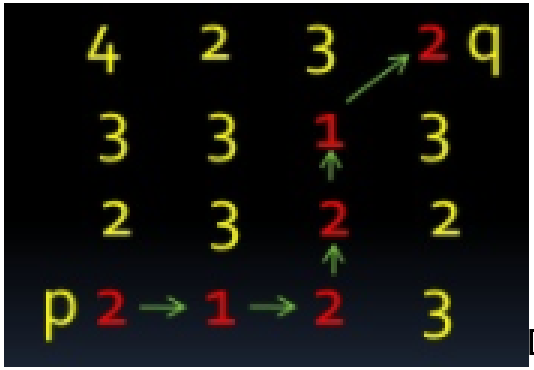
Example # 1: Consider the image segment shown in figure. Compute length of the ***shortest-4, shortest-8 & shortest-m paths*** between pixels p & q where,
V = {1, 2}.

	4	2	3	2	q
	3	3	1	3	
	2	3	2	2	
p	2	1	2	3	

V={1,2}

Path doesn't exist

Shortest 8-path=4



Shortest m-path=5

- For v={0,1} find shortest 4,8,m path between p and q. repeat for v={1,2}

	5	4	3	1	1	← q
	5	4	0	2	0	
	3	2	0	2	4	
	2	1	1	3	5	
p →	1	3	5	1	3	

- Find the time required to transmit a monochrome image of size 2.5”X2” scanned at 150dPI and to be sent at 28Kbps speed?
- Size of image = (2.5”x150)X(2”x150)= 112500 pixels
- For gray scale image, k=8
- #of bits= 112500x8=0.1125 Mbytes
- Time to transmit=(112500x8)/(28x1000)=32.142 secs

Linear versus Nonlinear Operations

- General operator, *H*, that produces an output image, *g*(x, *y*), for a given input image, *f* (x, *y*):

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

- *H* is said to be a *linear operator* if

  $$H[a_i f_i(x,y) + a_j f_j(x,y)] = a_i H[f_i(x,y)] + a_j H[f_j(x,y)]$$
  $$= a_i g_i(x,y) + a_j g_j(x,y) \text{—Eq.(i)}$$

  where, a_i, a_j – arbitrary constants

  $f_i(x,y)$, $f_j(x,y)$ – images of same size.

Max Operation

$$f_1 = \begin{bmatrix} 0 & 2 \\ 2 & 3 \end{bmatrix} \quad \text{and} \quad f_2 = \begin{bmatrix} 6 & 5 \\ 4 & 7 \end{bmatrix}$$

Let a1= 1 and a2 = -1

Check if Max is linear

Max is linear if Max{a1 f1 + a2 f2}= a1 Max {f1} + a2 Max {f2}

Solving LHS

$$\max\left\{(1)\begin{bmatrix}0 & 2\\ 2 & 3\end{bmatrix} + (-1)\begin{bmatrix}6 & 5\\ 4 & 7\end{bmatrix}\right\} = \max\left\{\begin{bmatrix}-6 & -3\\ -2 & -4\end{bmatrix}\right\}$$

$$= -2$$

Solving RHS

$$(1)\max\left\{\begin{bmatrix}0 & 2\\ 2 & 3\end{bmatrix}\right\} + (-1)\max\left\{\begin{bmatrix}6 & 5\\ 4 & 7\end{bmatrix}\right\} = 3 + (-1)7$$

$$= -4$$

LHS noteq to RHS
Max is non-linear